Siberian Fan Reliefs and the Tunguska Cosmic Body

Valery V. Burmakin[1], **Alexander Yastrebov**[2]

[1]Local Historian, Zelenogorsk, Russia; [2]Krypton Ltd., Bryansk, Russia

Correspondence to: Alexander Yastrebov, astrokrypt@mail.ru
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ABSTRACT

Unusual reliefs on the Earth's surface were found in aerial photographs of Eastern Siberia in the late 20th century. The facts justifying the connection are given by Siberian Fan Reliefs and the Tunguska Cosmic Body. It is most natural to assume that we are dealing with the falling of numerous fragments of a collapsed comet. The more likely version is that the comet is captured by the Earth-Moon system and remains in Earth orbit for some time.

1. INTRODUCTION

The previous article presented information about the Siberian Fan Reliefs discovered during the study of satellite images in the 1990s by A. P. Lopatin and L. M. Uskova [1]. The same scientists suggested that the above formations could be linked to the fall of the Tunguska cosmic body.

This article provides the rationale for this thesis and additional material. Considering these phenomena as part of a single event allows a new version of the fall of the Tunguska cosmic body to be constructed.

Unfortunately, the report of the direct authors of the discovery of the Siberian Fan Reliefs went unnoticed by the scientific community. Therefore, the main purpose of the article is to remind that there is a new subject that a wide range of experts may be interested in investigating.

2. SIBERIAN FAN RELIEFS AND THE TUNGUSKA COSMIC BODY

Siberian Fan Reliefs (SFR) may themselves be of great interest to science. But it is the fall of the Tunguska cosmic body (TCB) that is of primary interest.

If SFR were indeed formed by falling cosmic bodies, it is fairly obvious that these falls were almost tangential to the Earth's surface. In such a fall, no crater is formed and the fragments fan out. It is most natural to assume that we are dealing with the falling of numerous fragments of a collapsed comet. Stone and iron asteroids can be excluded as they are not prone to decay and fall as one.

In order to establish a possible link between SFR and TCB, some aspects of the TCB fall need to be considered.

There are several estimates of the power of the Tunguska explosion. Of most interest are estimates of the explosion's power based on the falls and burn marks. This is how A.E. Zlobin reconstructed the shape of the explosion. The power was 13.4 MT in TNT equivalent, or 5.6×10^{16} J [2].

In order to convert kinetic energy into thermal energy, the material of the cosmic body must react with a significant amount of air. Thus it is a series of explosions of varying power along a flight path. The nature of the damage to the body can be very complex and this will give a recorded picture of falls and burns. Calculations show that the kinetic energy of the comet is enough to heat a hundred cubic km of air to over 1500˚C. The ratio of the mass of the comet to the mass of heated air is 5 - 6.

Energy of 5.6×10^{16} J can be obtained at different ratios of mass to velocity of the body. Consider the option at 5000 m/s. The mass of the body will be 4.5×10^{9} kg.

An explosion can occur provided that the frontal pressure $\boldsymbol{P}$ exceeds the compressive strength limit of the material $\boldsymbol{P}_s$

$$P_s \le P = \rho_a \cdot V^2$$

where ρ_a is the density of the atmosphere. At an altitude of 6000 m, it is 0.6601 kg/m^3. The resulting tensile strength is 16.5 MPa. This falls within the ice strength range of 5 - 25 MPa. Little is known about the real strength of the comet's ice. The temperature of the ice is very low and the structure is unknown. Ice of this strength should be quite dense. Let's assume an ice density of 925 kg/m^3. This gives a body diameter of 210 m.

It is possible to simply estimate the trajectory in which the body flew. The pressure at any altitude must not have exceeded the limit. For an altitude of 10,000 m ρ_a amounts to 0.4135 kg/m^3. Critical speed according to the following formula

$$V = \sqrt{\frac{P_s}{\rho_a}}$$

will be 6317 m/s. In order to have a reserve, we will take it as 6200 m/s. The average velocity on the section of the descent trajectory from an altitude of 10,000 m to 6000 m will be 5600 m/s.

The resistance of the body is calculated using the formula

$$F = c_x \frac{\rho_{8000} \cdot V^2}{2} S$$

where c_x is the drag index, for a balloon it is 0.47, ρ_{8000} is the air density at an altitude of 8000 m amounting to 0.5258 kg/m^3. V = 5600 m/s. S is the cross-sectional area.

The drag force is 1.34×10^{11} N. With the mass of 4.5×10^{9} kg, the acceleration (deceleration) will be 29 m/s^2. Descent time from an altitude of 10,000 m to an altitude of 6000 m

$$t = \frac{6200 - 5000}{29} = 41.4 \text{ sec.}$$

During this time, the body will fly 5600 × 41.4 = 231,840 m and decline by 4000 m, which corresponds to an angle of inclination of trajectory of 1˚. For less stable material, the trajectory should be even more gentle. So TCB may well have been a comet which entered the atmosphere at a very slight angle. At re-entry speeds of less than second cosmic, it could penetrate the atmosphere to an altitude of 6 km and there collapse with an explosion. The strength of the ice proves to be sufficient for this.

From this, it follows that the fall pattern of the fragments that formed SFR and the TCB are the same.

Although the study of SFR is at a very early stage, the following circumstances allow us to speak with certainty about their association with TCB.

1) Dendrochronological methods allow us to date fan formation to 1908.

2) At the crash sites, Y. D. Lavbin's expeditions found elevated concentrations of substances characteristic of cosmic bodies.

3) There is evidence from the Irkutsk Observatory that the phenomena occurred on 30 June 1908 and lasted 4 hours. There is evidence of a prolonged soundscape, where explosions ranged from forty-five min.

to an hour and a half. In a single fall, this is not possible.

4) Judging by the shape of the fans, they were formed when the bodies fell at an acute angle to the surface. These calculations show that TCB also entered the atmosphere at an angle of less than one degree.

5) It is absolutely inconceivable that two such unique and homogenous phenomena could have occurred accidentally at the same time and in the same area, and have nothing to do with each other. Nowhere else on Earth are such structures found.

Now it must be established how the break-up into fragments of the original cosmic body occurred.

Theoretically, the comet could simply collapse in the Earth's gravitational field and enter the atmosphere at the right angle and low velocity. But this is highly unlikely, and would give a simpler picture of the fall, as the fragments could not have moved significantly away from each other. The more likely version is that the comet is captured by the Earth-Moon system and remains in Earth orbit for some time. And this is the only way to explain the existence of two groups of falls. There is evidence to support precisely this course of events.

"*Whoever undertakes to solve the mystery of the Tunguska meteorite will need to explain the cause of the glow in the night sky over Central Europe and much of Western Siberia before the meteorite hit, starting a few months before the event. And it is certain that the Tunguska meteorite and the glow of the night sky are related events. Without an explanation of the cause of the glow in the night sky, the mystery of the fall of the Tunguska meteorite cannot be considered solved*".

N. V. Vasiliev

It is necessary to mark that in a number of places the unusual phenomena were observed even before the Tunguska meteorite falling. In **Figure 1**, the distribution of quantity of events, when anomalous optical phenomena were observed, during June-July 1908 is given. It is strange but the majority of places where optical phenomena had been observed before the 30th of June were situated in regions joining to the Baltic Sea [3] (Vasilyev *et al.*, 1965). Several observers even regarded the end of June as the onset of anomalous period of summer 1908, for example, F. de Roi wrote: "Twilights unusual both in their duration and spreading were observed on the whole north of Europe during last days of June and at the beginning of July, 1908. Probably these twilights had started since the 25th of June. Having suddenly increased their intensity in the evening on the 30th of June, they were still visible on the 1st of July and then decreased very quickly" [4, 5].

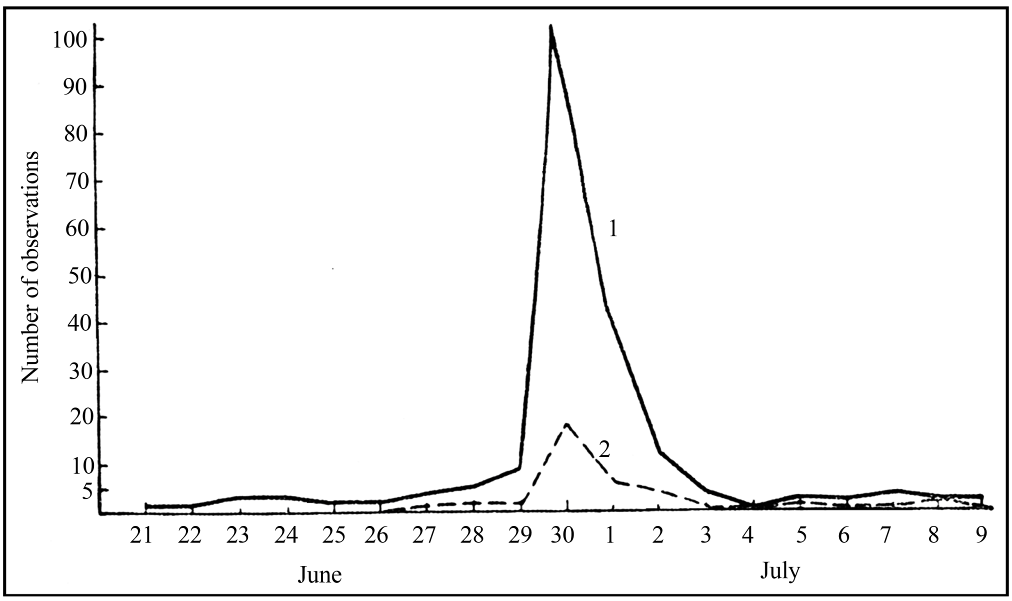

Figure 1. The distribution of quantity observations of anomalous optical phenomena during the June-July of 1908. 1—twilight anomalies; 2—noctilucent clouds.

There is information that these light phenomena began to build up ten days before the fall. There is a report of observations by Professor Weber of Kiel University about unusual regular periodic changes in the direction of the magnetic arrow. This effect began every evening between 27 and 30 June 1908 and lasted over 7 hours each day. After the Tunguska explosion, it disappeared [6].

The mechanism of magnetic perturbations is not clear. But with the version of multiple falls and re-entry of fragments from Earth orbit, this is consistent. If there was an orbit, the fragments could have approached days before impact and caused a disturbance in the substance of the coma. This matter could accumulate in the Earth's vicinity and the effects produced by it are many times greater than the effects of a comet passing through a coma.

According to Weber's observations, the period turns out to be close to 24 hours. The maximum distance of a comet with such a period is about 90,000 km. But the periodic phenomena associated with the comet may not have been due to the comet passing close to Earth at this time, but due to increased dustiness and Earth's diurnal cycles. The question of the period is still open. It can be anywhere from a day to 10 days.

The perigee of the orbit was low, perhaps thousands of km. Tidal forces began to break the comet into fragments and scatter them across its orbit. Orbits with such periods could be unstable under the influence of the Moon. At some point there were falls.

A normal comet could not have entered the Earth orbit. It is probably a small fragment of a comet that has somehow entered an orbit close to that of the Earth. When approaching at less than 2 km/s, the Earth-Moon system capture of the comet becomes possible.

As two groups of falls were identified, TCB could fall either on its own or as part of one of the groups. Fortunately, there is an eyewitness account that allows the trajectory of the TCB to be determined unambiguously with high accuracy.

To the Siberian Branch of the Academy of Sciences, Novosibirsk (Cited in Docs. 48 - 49). From the retired Sivtsov Semyon Rodionovich.

As a 15-year-old teenager I lived in my home village of Khvorostyanka, Samara province, now Kuibyshev oblast. On the day of June 30, 1908 a second sun appeared in the sky above my head, moving from west to east, silently and without a trace, and remained on the visibility horizon for 6 - 7 s, and then fled in a direction roughly north of the city, Kuibyshev. And then in 2 - 3 minutes a strong bang was heard, which was interpreted as a rift in the Earth, and we expected all life to fly into these rifts and the world would end. People went with all their families to the church, where priest Koldushevsky from the pulpit explained that this was God's punishment for the sins of the people who in 1905 confronted God's divine plans. The people prayed tearfully and earnestly, asking for forgiveness. The church bells were jingling hysterically, the worship lasted without interruption. After a long time people were saying about the so-called Tunguska meteorite that had fallen in some taiga.

Archival searches have confirmed the existence of the witness himself and that in the early 20th century Fyodor Stepanovich Kildyshevsky was the priest of the Church of the Intercession in the village of Khvorostyanki.

Above Khvorostyanka, the bolide was calculated to be at an altitude of less than 60 km. According to an eyewitness, the altitude turns out to be about 50 km, which can be considered a complete coincidence. The direction of flight indicated by an eyewitness is also exactly the same.

Initially, from the TCB connection to the SFR west group, the body flight azimuth at the time of detonation was assumed to be 90˚. The trajectory of the bolide passed east of Samara. The observation point over Khvorostyanka allows the trajectory to be determined very precisely. This gives an azimuth at the detonation point of 95˚. At an altitude of 100 km (conditional re-entry), the body was 6000 km away from the explosion site, over the Mediterranean Sea (**Figure 2**). It is possible to reconstruct the orbit and reconstruct the whole picture of the event, right up to the moment when the comet is captured by the Earth-Moon system.

The bolide could probably be seen over Turkey, but rather without sound phenomena. From the Kerch Strait onwards, the sound must have intensified. Beyond the Urals in daytime conditions the bolide

Figure 2. The trajectory of TM.

could be seen more faintly, in the Tyumen region, the bolide was at an altitude of 40 km, at this altitude the descent vehicles leave the plasma formation zone. The surface could not be heated by ice sublimation.

Several powerful aerial explosions were detected by eyewitnesses directly above the TM crash site. These fragments probably broke away from the comet during its fall. For the Tunguska meteorite, the critical ratio of speed of flight to atmospheric density developed at an altitude of about six km. There was an air blast. The drag force is proportional to the square of the linear size of the body, and the deceleration is inversely proportional to the cube. Therefore, small fragments have time to slow down in the thin layers of the atmosphere and penetrate deeper into it. The fragments re-entered the atmosphere independently and dispersed over a wide area south of the TM detonation site.

Some of the fragments broke up into relatively small pieces along their trajectory and they fell over a large area, forming swarming falls. Swarming falls are visible on the Tumanshet River over an area of about 3000 sq·km.

Several dozen fragments have almost reached the Earth's surface. They formed the fan drops. The strength of the fragments need not be the same as that of the main body. Therefore, their explosive destruction is possible over a wide range of speeds. It may be recalled that the kinetic energy of a body at 3000 m/s is roughly equal to TNT equivalent. Fragments forming fan drops are about 10 - 30 m in diameter and 1 - 3 km/s in velocity. The explosion energy of the fragments is 0.5 - 10 Kt. It's a lot, but a thousand times less than the TCB explosion.

What are the Siberian Fan Reliefs? These are footprints on the surface of the Earth with a characteristic fan shape. The resemblance is underlined by the presence of rays resembling spokes.

There are several possible scenarios for the fall.

The first one: it is the fall as a single body. The main events take place after the body has touched down the Earth. The impact causes the single body to shatter into splinters. The velocity of the fragments in the transverse direction is less than the falling velocity; the fragments form a cone with a certain angle. The falls occurred at an acute angle, which can be estimated at no more than 3˚ - 5˚, and at a relatively low velocity, so no crater is formed, but there is a ricochet and a dislocation of part of the ground. In fact, the dispersion is uneven, where the density of fragments is high, bands of more severe damage are formed, up to and including fractures in the rock base.

According to the law of conservation of momentum, part of the energy is transferred to the air, and a hurricane force wind gusts up to 100 m/s within the fan, causing the entire forest to fall out at a distance of up to forty km from the point of impact. In the zone of lanes or spokes the speed reaches up to 200 - 300 m/sec. This can be estimated from the tracks on the ground, in places where these streams cross the field ditches. These flows were probably a mixture of air, ice of various fractions and dislodged material from the surface.

The second variant of a fall is an approach to the surface already in the form of a compact swarm of bodies. Most of the falls appear to have taken place in this scenario. The initial contact traces range in size from a few hundred m to a km and a half.

The third option for a fall is a purely airborne explosion. Such explosions were observed just above Tunguska after the main body exploded. The explosions were at an altitude of at least 3 or 4 km. No trace of such explosions survived on Earth.

The last option is an airburst, but at a low altitude. The main damaging factor is the hurricane gust of air generated by such an airburst. Although individual solid fragments may have survived. These fragments may have flown ahead of the shock wave.

These scenarios can be considered tentative; exactly how the fall took place must be determined at each fall by the traces left behind.

At the time the fans were discovered, they were 80 - 90 years old. The restoration of damaged soil and vegetation follows certain laws. The fans appear on the terrain mainly due to a change in the type of vegetation. Damaged areas are overgrown with deciduous trees. At present, only vast falls of forest are visible. Huge trees lie peaked to the East, covering hundreds and thousands of sq·km (**Figure 3**). Only fallen conifers have survived. If you happen to be in such a place it is easy to mistake everything for the aftermath of a hurricane, and only satellite imagery allows you to assess the bigger picture.

The mechanism for the formation of the bands or spokes is not entirely obvious. They are partly formed by mechanical damage from body fragments. But some of the spokes have a characteristic curved shape. Such bands may have been formed by local whirlwinds. The true mechanism for the formation of the spokes has yet to be established. Chemical exposure cannot be ruled out.

Each fan has its own characteristics. This is due both to the characteristics of each fragment of the comet and to the terrain on which the impact occurred. With a body size of about 30 m, the terrain matters. When hitting a slope, the direction of flight may change.

Figure 3. A typical pattern of falls at fall sites. V. Burmakin Tumanshet 54˚57'31.20"N; 96˚51'53.52"E.

In the light of the proposed hypothesis, it is possible to assess the eyewitness testimony, on the basis of which other hypotheses have been previously constructed, in particular the trajectories of the TCB flight have been proposed. As shown above, for a comet the descent trajectory is rigidly set. Over the surveyed areas, the altitude of the overflight could not exceed 20 km. It is difficult to estimate the brightness of the body and the presence of a trace, but the impact of the ballistic wave must have been very powerful, much more powerful than the bolide over Khvorostyanka, which flew at an altitude of 50 km. There is no indication corresponding to such a flight, especially in terms of ballistic wave impact on Southern and other alternative trajectories. Most of the eyewitnesses were at the sites of the SFR drops and they saw them fly over or the associated light phenomena. The bolides under which SFR were formed were also quite powerful, but considerably inferior to the TCB bolide.

An ice body cannot be heated to high temperatures in the atmosphere due to ice sublimation, so intense glow is excluded. The passage of such a bolide can be relatively unnoticeable. But at the moment of destruction, explosive processes occur, generating bursts and shock waves.

In any case, rough traces on Earth take precedence over not always accurate eyewitness accounts. But overall, there are no clear contradictions between the array of testimonies and the new broader picture of the event. The evidence so far has been considered solely with a willing or unwilling attachment to the only known explosion over Tunguska. They should now be considered and synchronized in view of the fact that there are many falls over a huge area.

Many eyewitnesses have also noted columns of light of different colors, similar to the atmospheric light phenomena associated with large masses of water and dust being carried to different heights. A single body could not have carried water over such a vast area.

There is information about possible falls in other areas, such as Trans-Baikalia. But on some types of terrain, visible tracks do not form or do not persist. For example, on steep rocky slopes, or in wetlands. But it is possible to detect them by space markers.

3. CONCLUSIONS

Thus, we propose our own vision of the mechanism by which the Siberian Fan Reliefs originated. Without refuting the conclusions of many scholars, such as A. P. Lopatin and L. M. Uskova, Y. D. Lavbina, N. V. Vasiljeva and other experts in this field, and emphasizing the importance of research of these scientists and resulting conclusions about the relationship between the occurrence of Siberian Fan Reliefs and the Tunguska meteorite of 1908 we compared the data and formulated the following conclusions.

Events unfolded as follows. A small comet, consisting of a nucleus about 250 m in diameter and several dozen loosely associated fragments, was captured by the Earth and then entered and remained in an elongated elliptical orbit for some time. The perigee of the orbit may have been close enough to the Earth that tidal forces caused the fragments to separate and fall into close orbits, and due to the influence of the Moon, the orbits became unstable and crashes occurred.

The energy of the explosion over Tunguska was 13.4 Mt in TNT equivalent. The height of the blast was six km. The drop azimuth was 95˚. The diameter of the TCB core was 210 m and the velocity at the time of detonation was 5000 m/s. The diameter of fragments that formed fan drops was of the order of 10 - 30 m, velocity was less than 4000 m/s. Explosive energy of fragments was 0.5 - 15 Kt. The falls took place in two groups, the western and the eastern one.

The paper provides material confirming the reality of the crash sites, substantiating the connection with the Tunguska meteorite. At Tunguska, the explosion took place at high altitude and the comet's matter was dispersed over a large area. In SFR, the substance was imprinted in the fan areas. This creates a good prospect for the search, although time is certainly lost.

The study of Siberian Fan Reliefs can provide valuable material for determining the ballistic characteristics of comet ice. This can be important when assessing the comet danger.

In practical terms, we have analyzed eyewitness accounts and justified a specific trajectory for the passage of the Tunguska meteorite, with the possibility of reaching a complete picture of the comet's capture and destruction. Appropriate calculations could confirm or refute the hypothesis put forward. It is particularly interesting to find out how the two groups of falls were formed. It turns out that the Moon did not just change the orbits of the fragments before they crossed the Earth's surface, but also focused them in a relatively small area.

The eyewitness testimony and the SFR indicate that the falls occurred from different directions. This is possible if the orbits of the comet fragments had a common perigee zone, but different planes. This may seem strange, but must find a scientific explanation. This allows simply to explain all the facts related to the TCB without exception.

In conclusion, we would like to draw attention to the following aspect. The Siberian Fan Reliefs make a difference to the so-called mystery of the Tunguska meteorite. There are dozens of hypotheses trying to explain these mysteries. Barely everyone involved in TCB has their own favorite hypothesis. They are all formulated without regard to the fact of the existence of the Siberian Fan Reliefs. New information is therefore unwittingly repulsive. As the discussion in Russia shows, it goes so far as to deny the very existence of Fans, or to suggest non-cosmic mechanisms for their formation. And here it is pertinent to recall that, unlike the other hypotheses, this one can be tested. To do so, they will have to get out of the Tunguska swamps and into the vast expanse of Siberia. Time passes, traces are erased. There is reason to believe that the Siberian Fan Reliefs will reveal many interesting and unexpected things.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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