

# Substantiation of the Western Trajectory of the Tunguska Cosmic Body

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## ABSTRACT

Although more than 100 years have passed since the Tunguska event, no hypothesis has yet been proposed that would be consistent with the entire set of available facts and observations. A hypothesis has been put forward that the Tunguska Cosmic Body was an ice comet and its fall was accompanied by the fall of smaller fragments, whereas the TCB and fragments fell from intermediate Earth orbits. This explains all the observed phenomena without exception, including those that occurred long before the catastrophe. In this paper, we present eyewitnesses' reports and objective materials obtained in the event area and confirming the TCB passage in the direction from West to East. The western trajectory has been traced for 3500 km from the Volga to the Lower Tunguska. We have carried out a detailed analysis of the eyewitnesses' reports revealing the circumstances of passage of a huge fireball. We provide criticism of trajectories constructed without taking new information into account. We have estimated the energy released during this event and determined the mechanical properties of the comet matter. Science may obtain with new objects to study the direct impact of the comet matter on the Earth's surface. This may be useful for evaluating the comet-related hazard.

## 1. INTRODUCTION

The Tunguska meteorite (TM) problem has been solved for more than 100 years now. Numerous groups of researchers and individual enthusiasts have suggested many hypotheses and solutions to this problem, which are proven in the researcher's opinion. However, no one could put forward the only true and indisputable final solution that would suit everyone. Disagreements concern both identifying the type of the Tunguska celestial body itself (meteorite, asteroid, comet, or fireball) and its movement direction and trajectory.

The discovery made through interpretation of satellite images in 1996 allowed us to look at the prob-

lem in a new way [1]. These are images of objects on the Earth's surface, which are traces of tangential impacts with trails of fan-shaped dispersion of scratches and furrows, named later "Siberian Fan Reliefs" (SFR) [2, 3]. Siberian Fan Reliefs are scattered across a large area in the taiga on the right bank of the Yenisey river from west to east; similar objects were also found and confirmed by Tunguska event eyewitnesses' reports in the interfluvium of the Angara and Podkamennaya Tunguska rivers, the Kan, Biryusa, and Lena rivers.

According to our hypothesis, TCB was a small comet that was captured by the Earth-Moon system and remained in the Earth orbit for some time. Under the effect of the Moon, the orbit was unstable, which caused the fall. Based on the assumption that TCB was related to the Western group of Siberian Fan Reliefs, we have considered the fall trajectory in the direction from West to East (the Western trajectory). Later, we found geographically-referenced evidence of TCB flying towards Siberia from the lower reaches of the Volga, which made it possible to refine the TCB flight trajectory.

In [3], some parameters of the event are substantiated. The energy of the explosion over the Tunguska river was 13.4 Mt in TNT equivalent. The explosion altitude was 6 kilometers. The TCB nucleus diameter was 210 m; the body weight,  $4.5 \times 10^9$  kg. The main matter was ice with a density of  $925 \text{ kg/m}^3$ ; the ice tensile strength being equal to 16.5 MPa. The velocity at the time of explosion was 5000 m/sec. The trajectory inclination angle in the dense atmosphere was less than one degree. These parameters do not contradict the available facts, but may be refined after obtaining other data.

This paper presents additional information on the Western trajectory of TCB, which makes it possible to reveal interesting and even unexpected circumstances of the TCB flight in the atmosphere.

## 2. WESTERN TRAJECTORY

There are numerous hypotheses of the space catastrophe in Siberia. Currently, the air explosion of a comet in the Tunguska region is considered the most probable. This best explains the absence of a crater. However, researchers have not yet been able to come to a consensus on all the circumstances of this event. The main disagreement is related to the TCB fall direction. Several possible trajectories for the TCB approach to the explosion site have been suggested. All hypotheses are put forward within the paradigm of a single body's fall. Since eyewitness reports are often vague, there is room for such discussions.

The Western trajectory had long been considered as possible, but it had few supporters. First of all, this can be explained by the virtually complete absence of evidence from this direction.

Discovering Siberian Fan Reliefs testifies to several falls that occurred within a limited time and from different directions. We can explain such a pattern of falls by assuming that the comet was captured by the Earth-Moon system and stayed in near-Earth orbit.

It was suggested that numerous comet fragments were in orbits similar to that of TCB, but, prior to the fall, they were distributed over different azimuths. They passed the perigee point at about the same time, but approached it from different sides. These orbits formed something similar to the shell of a rugby ball. If you imagine the Earth as a tennis ball inside a rugby ball, you can easily imagine how the fragments fell from different directions. This hypothesis explains all the facts related to the cosmic catastrophe.

As shown by the experience of discussions in Russia, it is the SFRs that raise the greatest objections. They are insufficiently studied and have not yet been introduced in the scientific circulation. Therefore, it is advisable to substantiate the Western trajectory using the traditional approach based on the witnesses' reports and objective data.

Elementary calculations presented in [3] show that, for a comet made of ice to reach an altitude of six kilometers, it must fly on a very flat trajectory. In dense atmosphere, the trajectory angle to the surface should be less than one degree.

Initially, the TCB flight path was traced based on the assumption of its relationship with the Western group of SFRs, which had an approximate direction of fall from west to east. To confirm and adjust the flight direction, we should find eyewitness reports from locations close to the proposed path. The search for such reports has been carried out taking into account the very flat flight path. From the entire corpus

of reports, we have found only two ones that meet the necessary requirements.

At a short distance from the proposed path, there is the village of Khvorostyanka. A witness from this village described the flight of a formidable fireball [4], p. 226.

*“To the Siberian Branch of the Academy of Sciences, Novosibirsk (quoted from doc. No. 48-49). From senior citizen Semen Rodionovich Sivtsov.*

*When I was a 15-year-old teenager, I lived in my home village of Khvorostyanka, Samara Government, now, the Kubyshev Region. On June 30, 1908, a second sun appeared in the sky above my head, which moved from west to east, silently and without a trace. It remained on the visibility horizon for 6 or 7 seconds, and then it disappeared in a direction approximately north of Kuybyshev. After 2 or 3 minutes, we heard a strong sound of explosion, which was perceived by us as a break in the Earth. We expected that all living things would fall into these breaks and the end of the world would come. People with all their families went to church, where priest Koldyushevsky explained from the church pulpit that this was the God's punishment for the sins of people, who raised their hands to the Lord's foundations in 1905. People prayed tearfully and earnestly, asking to forgive them. The church bells rang desperately, the church service continued without interruption and later, after a long time, people began to say that a meteorite called Tunguska meteorite fell somewhere in the taiga.”*

Archival searches have confirmed the existence of the witness himself and the fact that, in early 20<sup>th</sup> century, Fedor Stepanovich Kildyushevsky was a priest of the Intercession Church in the village of Khvorostyanka.

According to calculations, the fireball was at an altitude of less than 60 km above Khvorostyanka. According to the eyewitness, the height was within the range of 40 to 60 kilometers, which is a complete coincidence. The flight direction indicated by the eyewitness also coincides exactly.

This made it possible to adjust the flight path. Along the path, near the confluence of Podkamennaya Tunguska and Yenisey, the village of Sulomay is located. A witness from Sulomay allowed us to identify one more point on the path.

### 3. TCB FLIGHT CIRCUMSTANCES

A detailed examination of the story told by the witness from the village of Sulomay allows us to discover many interesting and even unexpected things.

The report of the witness from Sulomay is quoted from the book by A. Olkhovatov *The Tunguska Phenomenon of 1908* [5], pp. 187-188. The report was recorded by S.I. Weinstein. It should be noted that we present the original version of the witness's report based on the manuscript. Later, Weinstein corrected his testimony for reasons that are not entirely clear. Perhaps, he was influenced by alternative hypotheses, according to which a gas explosion occurred above Tunguska.

*“There is evidence from Sulomay reported to the author of these lines (A. Olkhovatov) by the famous Russian ethnographer S.I. Weinstein. It had been collected by Weinstein in 1948, during his ethnographic expedition near the village of Sulomay, where the Kets live. Those interested can review this text in the archive of the Institute of Ethnology and Anthropology of the Russian Academy of Sciences (collection by S.I. Weinstein, manuscript The Kets of Podkamennaya Tunguska, 1950, pp. 105-106). Let us retell it.*

*Ilya Tyganov (born in 1889) reported that one or even two nights before the Tunguska phenomenon (TPh) (he did not remember it exactly), the sky was unusually bright at night, as at dawn. When asked by Weinstein if it was the northern lights, Tyganov replied no, it was not, since he had seen the northern lights many times. The northern lights cover only part of the sky, whereas at that time, the whole sky was bright.*

*That bright night, his brother (a shaman) performed a ritual to ‘avert the disaster’, saying that the evil spirits of the underworld were to blame for this. Ilya Tyganov himself did not sleep that bright night, and other people did not sleep, but dogs barked and howled. In the morning, he saw with horror that, from the left bank of Podkamennaya Tunguska, a ‘second Sun’ was flying—brighter than the real one (it was painful for the eyes to look at it). It was accompanied by a loud roar, stronger than thunderstorms. The ‘second*

*Sun' moved very quickly across the sky. Soon, from the side of Vanovara, a column of bright fire without smoke rose to the sky, and they heard a deafening explosion, such as had never been heard before or since. The earth trembled, a strong upper wind rose and uprooted tall trees from the ground along with their roots in the taiga. It knocked down all the tents, scattered belongings, women and children cried and screamed. Then, everything calmed down, but, for one or two nights (he cannot remember it exactly), it was still light at night, and dogs continued to bark and howl almost continuously.*

*The taiga has thinned out strongly, but low trees and bushes have remained in place. That summer, there were almost no animals in the taiga: they had gone away somewhere, and for unknown reason, the fish were not caught: probably, they also had gone away somewhere."*

The Kets led a nomadic life, but due to the help of A. Olkhovatov, the author of the quoted book, we could find out that the evidence was related to namely to the village of Sulomay.

According to calculations, in Sulomay, the fireball flew at an altitude of 16 km. The ballistic wave was very strong: "...they heard a deafening explosion, such as had never been heard before or since. The earth trembled..." It was precisely a ballistic wave, as the distance to the epicenter was too great.

The flare from the explosion in the epicenter and the time of the ballistic wave arrival to the observer coincided. The fireball velocity in the Sulomay area was about 8.4 km/sec. The time of flight to the epicenter, taking into account the deceleration, was approximately 83 seconds. Therefore, the ballistic wave arrived in the same time. The direct distance to the trajectory can be estimated at 26 km. It means the flight of a body with a diameter of 210 meters at a distance of 20 kilometers to the south at an altitude of 16 km at a speed of 8.4 km/sec.

We can estimate the "flight power". If we calculate that kinetic energy lost the body when its speed changed from 8.4 km/sec. to 5 km/sec. along a section of 600 kilometers from Sulomay to Tunguska, it turns out that 30 kilotons in TNT equivalent were released per kilometer. Two Hiroshima per kilometer! During the passage, the comet matter could be shed. With an instant slowdown, this was accompanied by an explosion and, accordingly, a bright glow. But the observer did not see any trace behind the comet. The weight loss during the flight was probably insignificant.

*"...from the left bank of Podkamennaya Tunguska, a 'second Sun' was flying—brighter than the real one (it was painful for the eyes to look at it). It was accompanied by a loud roar, stronger than thunderstorms".*

This is a very interesting fact: immediately during the flight, there was "a loud roar, stronger than thunderstorms". Even if the fireball was flying above the witness, the sound could not arrive earlier than in 45 seconds. Therefore, it was the so-called electrophonic effect. Electrophonic fireballs have been known for a long time, but this case is unprecedented.

With such power released during the flight, it is quite natural to make a comparison with an atomic explosion. One of the damaging factors during an atomic explosion is an electromagnetic pulse. The electrophonic effect can be described as something close to an electromagnetic pulse. Its instantaneous power is lower, but the action is continuous. So far, science does not give an unambiguous answer about how electrophonic sounds are generated. Based on the above description, we can assume that electromagnetic waves generated during the flight at a high speed had an impact directly on the air and generated shock waves therein at a considerable distance from the trajectory.

In the areas where the secondary fireballs were flying, many witnesses also heard the sound during the flight. However, secondary fireballs could fly by and explode somewhere in the neighborhood, so the sound pattern becomes more complicated. An eyewitness hears sounds from the flight or explosion of one fireball, looks at the sky, and see another one.

*"...a strong upper wind rose".* You can observe a similar effect while standing on a roadside when a large vehicle passes by at high speed. The witness said that the wind uprooted trees, but the ballistic wave could also be involved therein, for example, peeling the trees to bare trunks along the flight path, forming the so-called "telegraph poles". The wind was generally expected to blow from west and to fall the trees towards east. Local whirlwinds and even tornadoes were possible. The width of the damage area in the taiga was up to forty kilometers. According to Weinstein, he saw the moss-covered remains of these fallen

trees near Sulomay.

*“Soon, from the side of Vanovara, a column of bright fire without smoke rose to the sky, and they heard a deafening explosion.”* The fact of observing a column of fire is very interesting. In the epicenter near Vanovara, the witness’s horizon line passes at an altitude of 28 km. He could not directly see a flare at an altitude of 6 to 10 km. So that we could talk about a column, something had to glow at a height of 28 kilometers and above, being visible even during the day. The light of the explosion with a power of more than 50 Mt on Novaya Zemlya was visible at a distance of more than 1000 km. The explosion power over Tunguska was lower, but comparable. An eyewitness from the village of Podkamennaya Tunguska, fifty kilometers west of Sulomay, reported: *“A red glow was visible in the east for a long time”*.

Tyganov noted glow phenomena both before and after the catastrophe. The sentence *“one or even two nights before the Tunguska phenomenon (he did not remember it exactly), the sky was unusually bright at night, as at dawn”* is not quite clear, as there could be either one or two or even three bright nights before the fall. This was followed by a bright night before the fall and another night or two nights after the fall.

Light phenomena before and after the fall were observed in a limited area in Europe and part of Siberia. If the comet and its fragments were in orbit with a period multiple of 24 hours and with a perigee at a latitude of 60°, they could throw dust into the relevant region. When passing the perigee, dust separation processes could be more intense. Dust in the atmosphere could gradually dissipate, but the comet maintained the concentration necessary for the glow during its periodic flybys.

Observations by Professor Weber [6], who noted regular periodic changes in the magnetic needle direction on June 27 to 30, 1908, allow us to opt for a 24-hour period. Penetration of significant masses of gas and dust into the atmosphere could have generated a magnetic storm that caused abnormalities. Light phenomena could occur every day, even with a period of 2 to 3 days, if dust was kept in the right area and at the right altitude.

Before the fall, the glow phenomena began to intensify, which indicates a change in the orbit. All the circumstances of this change in the orbit have yet to be established. It cannot be a coincidence that there was a new moon on June 28. Moreover, there was a solar eclipse on this day. This was the time of super-tides.

Tyganov noted the anxious behavior of dogs. It is difficult to image that such a reaction to the upcoming cosmic event was recorded in their genetic memory. Most likely, the dogs heard something. Animals are known to behave in a similar way before earthquakes. Dust ingress into the atmosphere in large amounts and at high speed can be accompanied by ultra or infrasound. If the sound has a tendency to increase, the animals begin to worry; perhaps they find this a sign of an approaching earthquake.

#### **4. CHUVAR (WESTERN) FOREST FALL**

If the hypothesis of the Western direction is true, there should be forest falls in the immediate vicinity of the epicenter, where the fireball was flying at a lower altitude, whereas its velocity was already significantly lower, about 5 km/s. And such a forest fall does exist: this is the so-called Chuvar or Western Forest Fall. Evidences of these forest falls are collected in [5], pp. 293-298. The same source cites eyewitness reports who associate this forest fall with the year of 1908. The total area of the forest fall is estimated at 30 to 40 sq.km.

The forest fall is located on the slopes of a mountain, 23 kilometers from the epicenter, and was discovered in 1959 by N. Vasiliev. Here is a quote from N. Vasiliev’s documentary records:

*“...Suddenly, the landscape has changed dramatically. The eastern slope of the 593<sup>rd</sup> height was rather steep, and here, on this slope, the group stepped into the forest fall area, and what a striking one! None of us had seen such a picture either on Makikta, or south of Khushma, or on the Kulik’s trail. The landscape seemed fantastic. huge trees, up to a meter across, were uprooted, thrown at each other, split like matches. At first, the forest fall was completely chaotic, then, closer to the hill top, the trunks were arranged in a familiar way with crowns in one direction and roots in the opposite one. However, the direction of trunks*



*was exactly the opposite of that observed in the area explored by Kulik: here, the crowns pointed to the east, and the roots to the west. It seemed that our group had stumbled upon a new center of disaster...* And further on: *"...the measurements of the fallen trees azimuths on the Western slope of the 593<sup>rd</sup> mountain gave the same result: most (90 percent) of trunks were turned with their tops in the east and their roots in the west direction. The general pattern was quite clear: some kind of air impact (maybe a hurricane, or maybe a shock wave), moving here from west to east, hit the Western slope of the hill and uprooted the forest which covered it".*

L.I. Popov, a member of the Tunguska expeditions of the early 1960s, not only visited the Southern Forest Fall, but also flew around it [7].

*"I flew in a two-seat plane. The pilot on my left, a flock of spiders hushed on the wind glass in front of my nose, and my ears unprotected from the engine roar. When approaching the southern end of the Chuvar Ridge, I asked the pilot to deviate from the route to the right in order to examine the strip-shaped forest fall where I later had to work.*

*Below, I could see a swampy area, the northern edge of which was bordered by forest that grew on a high ground in the form of hilly islands. The end of the Chuvar Ridge wedged into the swamp and, slightly north of this cape, I could clearly see a strip of forest fall on the Western slope of the ridge, which ended along the left bank of the Khushmo river in its upper reaches, almost merging with the blurred boundary of the Kulik's (radial) forest fall. It was almost no more than half a kilometer.*

*From this Eastern boundary, the strip of forest fall about a kilometer wide (more or less) stretched across the ridge, the Eastern slope of which looked as a more dead zone, as the horizontal hurricane flow was damped by the Western slope, and the reflected shock wave only slightly left its traces, more clearly visible near the Khushmo river, whereas, further to the east, there were no traces. To the west of Chuvar, the strip manifested itself as bald spots on elevated grounds; it stretched, perhaps, for 5 or 6 kilometers. The width of this strip was visible for about half a kilometer. The plane flew over the forest fall and returned to its route."*

The above information is enough to plot the Southern Forest Fall on the map. The calculated path of the Western fireball passed exactly over the 593<sup>rd</sup> mountain. To the south of the Chuvar Ridge, there is another strip-shaped forest fall. The length of this forest fall is 7 km and the width, up to one and a half kilometers. The forest fall orientation toward the epicenter indicates a high probability of its connection with the TPh. The forest fall is located six kilometers from the path. In Sulomay, tents flew twenty kilometers from the path.

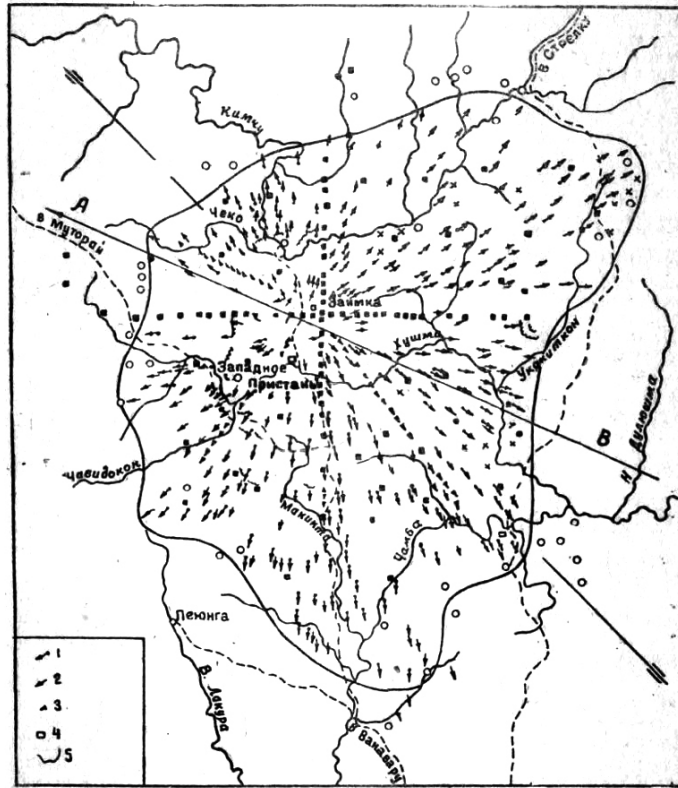
The hurricane wind raised by the passage of a huge fireball produced forest falls from Sulomay to the epicenter. And since forest falls were already significant in Sulomay, the trail should go beyond Yenisey to the west. The total length of the trail could exceed 1000 kilometers.

## 5. OBJECTIVE DATA ON THE TCB TRAJECTORY

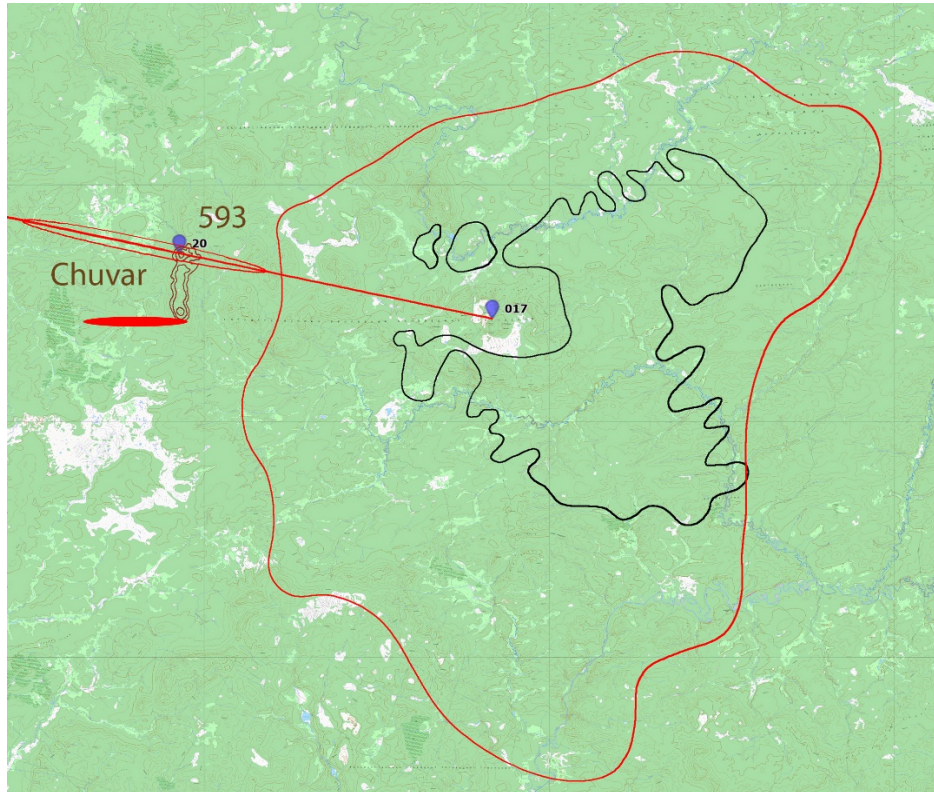
Attempts have been made to determine the trajectory azimuth based on objective data. The position of the TM trajectory projection in the epicenter area was determined by the axis of symmetry of the forest fall zone—the so-called "Fast Butterfly" [8] (Figure 1) created by the air explosion of the TM. This gives us the direction of 99° from the true meridian. The calculated trajectory gives an angle of 101° to 102°.

The diagram (Figure 2) shows the "butterfly" contour in red and the continuous forest fall contour in black with the plotted estimated trajectory and location of the Chuvar (Western) Forest Fall. The TCB path passes through the 593<sup>rd</sup> height to the Fast epicenter; it correlates well with the butterfly shape and the areas of continuous forest fall.

As for the "butterfly" itself, the entry to it from the west is better founded. The fireball matter could not explode instantly like dynamite, but should have reacted with a significant amount of air. It is natural to assume that, at some point, the destruction started, which should have been growing like a chain reaction. Therefore, the "butterfly head" should be on the entry side (a fan-shaped pattern). However, the destruction process is not ideal; so that the formation of several epicenters was possible. In general, the explosion was voluminous and elongated, but having a complex structure.



**Figure 1.** Fast butterfly.



**Figure 2.** The trajectory of TCB and Chuvar Forest Fall.

Another quote from A. Olkhovatov's book:

*"Within a radius of 3 to 4 kilometers around the epicenter, there is the area of so-called telegraph poles: trees which have survived during the explosion, but, as a rule, have been badly damaged (broken off, with tops damaged, etc.) and dead trees... Another remarkable fact: the strip of poles can be traced from the epicenter to the west along the Tunguska meteorite trajectory extension towards the Chuvar Forest Fall for a couple of tens of kilometers!"* (P. 281)

These poles were formed by the ballistic wave of the fireball approaching the explosion site. This is another evidence in favor of the Western trajectory. The researchers tried to explain the "butterfly" shape by the combined effect of the ballistic wave and the main explosion at the epicenter. The ballistic wave trace was found in the form of telegraph poles and an extension on the Chuvar Forest Fall, but it was rejected as not related to the disaster, since it contradicted the hypotheses of the flight direction that existed at that time.

The approach to explaining the features of the butterfly structure should now be revised. We should proceed from an almost horizontal trajectory and the explosion development direction from west to east.

## 6. CRITIQUE OF ALTERNATIVE TRAJECTORIES

There are a large number of hypotheses explaining this event, but none of them can connect the entire set of available facts with eyewitnesses' reports. The situation was so bad that there were even hypotheses not related to the fall of a cosmic body. We can mention a spacecraft explosion, plasmoids of unknown origin, a volcanic eruption, a gas explosion, and Nikola Tesla's activities.

In the light of new information, these hypotheses seem redundant, since the fall of a cosmic body is the most natural explanation for the event. However, there are hypotheses based on the fall of a cosmic body, but suggesting other directions of the TCB pathway. They are based on facts and, therefore, they are quite scientific in nature; but the facts themselves were not chosen very well due to a number of circumstances.

From the south and southeast directions, there are many evidences of fireballs' flight; many people believe that the TM flew through these areas. The logic is simple: there is an explosion epicenter and reports by witnesses pointing approximately in the right direction. If we analyze these evidences, we will find out that some reports exclude others. For example, if the fireball was visible in one place, this excludes its visibility in another one. We can assume that there were several fireballs, but only one of them was related to the TM.

We should consider how this fireball flight should look like for an observer located, for example, on Angara at a distance of 300 km from the epicenter. First, the observer could see the fireball. If the fireball is electrophonic, its flight might be accompanied by sounds, and one could hear the fireball at first. Then, after several minutes, a ballistic shock wave should arrive to the observer. It must be much more powerful than electrophonic sounds. After that, the fireball flew to the epicenter on Tunguska. After 2 or 3 minutes, seismic waves from the epicenter might reach (or may not reach) the observer. For 10 to 12 minutes after this, nothing should happen; then, the sounds of the explosion over Tunguska should be heard, if the sound reached the observer at all.

The report from Sulomay describes a flight that matches the scale of catastrophe. Moreover, the sequence of events corresponds to the suggested passage scenario; therefore, on the southern paths, there must be at least no less powerful ballistic shock wave. We could assume that the TM flew over the witnesses at a very high altitude and the ballistic wave was weak. But this is contradicted by the short time between the flight and the explosion or explosions noted by the witnesses.

The short time between the passage and the arrival of sounds of explosion or explosions, a weak ballistic wave, the absence of hurricane-force winds and forest falls along the flight trajectory indicate that it was not the TM passage that was observed in the southern and eastern directions, but the passage of numerous secondary fireballs. This is also evidenced by the sound pattern noted by many observers. They heard many explosions, many of them being heard for a long time, up to an hour and a half.

G.K. Kulesh, the Head of the Kirensk Meteorological Station, wrote in his letter dated June 23, 1908:



*“On June 17 (by the Julian Calendar), in the northwest of KIRENSK, a phenomenon was observed that lasted approximately from 7:15 a.m. to 8 a.m. I did not have a chance to observe it, since, after taking records of meteorological instruments, I sat down to work. I heard muffled sounds, but I mistook them for gun shots on the military field across the Kirenga river. Having finished the work, I looked at the barograph tape and, to my surprise, saw a line next to the line made at 7 o'clock in the morning. This surprised me, because I did not get up from my seat during the work, the whole family was sleeping, and no one entered the room. That is what happened (I retell the essence of eyewitness' reports). At 7:15 a.m., a fire column four fathoms in diameter, in the form of a spear, appeared in the northwest. When the column disappeared, five strong jerky blows were heard, as from a cannon, quickly and distinctly following one after another; then, a thick cloud appeared there. After 15 minutes, the same blows were heard again; after another 15 minutes, the same thing repeated. The ferryman, a former soldier and a generally experienced and developed man, counted 14 blows. As part his service duties, he was at the riverside and observed the phenomenon from the very beginning to the end.”*

This evidence was recorded no later than six days after the disaster. Obviously, we are talking about three or even four different events. First, a fire column appeared, and soon, blows were heard. The fire column in the northwest was probably the explosion on Tunguska: the explosion direction and time coincide (the explosion occurred at 07:00  $14.5 \pm 0.8$  minutes local time). However, the distance from the epicenter to Kirensk is 500 km, so the sound could reach there only after 25 minutes. Consequently, the observer could hear the sound of the explosion on Tunguska mixed with the sounds of secondary fireballs, but he also could not hear it at all. We cannot explain such a duration of explosions as part of the fall of a single body. The first explosions were from the fall of other fireballs.

Some of the secondary fireballs gave rise to Siberian Fan Reliefs. The fragments had a wide range of sizes; the total number of fireballs, each of which was capable of producing the phenomena observed in the southern direction, was several tens. But the power of these fireballs was at least two or three orders of magnitude lower.

Supporters of the southern and eastern trajectories have to resort to many tricks to explain the forest fall pattern at the catastrophe site. This includes the body's crushing before the explosion with fragments spreading over several kilometers, a diving trajectory, a fall at an angle obviously unsuitable for an icy body. They constantly have to divide witnesses into right and wrong or forgetful ones. In general, the southern and eastern trajectories can be compared with the search for keys not where they were lost, but where it is light. The fireballs really flew over there; the evidences were recorded and, from the very beginning, they were in the circulation of data related to the Tunguska meteorite.

Attempts were made to find evidence of the fireball flight over the section from Khvorostyanka to Sulomay, but so far without success, although the trajectory passed for some time over a rather populated area. It was early in the morning, and few people could watch the flight. A single blow might not make a strong impression.

Sound can be generated by two factors: a ballistic wave and explosions due to an intense release of the looser shell. Perhaps, it was over Khvorostyanka that such a release took place, and the further flight was quieter. This is supported by the fact that the flight made, perhaps, a stronger impression on Sivtsov than on Tyganov, although the fireball flew much higher in a very rarefied atmosphere. When a fighter jet flies at supersonic speed, a receding sound is always heard after the passage of the shock wave. The witness did not mention this.

But the main thing is that no one has ever collected eyewitness evidences in this area. Another factor could be the terrible famine in the Volga region and the Southern Urals in 1921-1922, where the TM flew. Especially large was the number of dead children; therefore, in the 1960s and 1970s, when interest in the Tunguska catastrophe revived again, there were almost no eyewitnesses left. The only witness found from Khvorostyanka wrote that he had lost his entire family, nine people.

## **7. EASTERN (SHISHKOV'S FOREST FALL)**

We can continue the path to the east, up to the so-called Eastern Forest Fall. This a forest fall discov-

ered back in 1911 by a geodetic expedition of the Omsk Department of Waterways and Highways, led by engineer and writer V.Ya. Shishkov, author of the famous novel *Gloomy River*, and rediscovered in 1990 by geologist and taiga hunter V. Voronov.

Here is what P.N. Lipaya, a member of this expedition, wrote about this: “*We walked two or three days through a windfall area, having dismounted from reindeer, at a speed of 10 to 12 kilometers a day. Having entered a section of a continuous windfall, we found that all the trees had been fallen there. What was in the low places is unknown, because we walked on top. I can no longer remember the orientation of trunks. In a permafrost area, the roots of larches and other trees spread out horizontally, and a fallen tree creates a large network of its root system, which was typical for that landscape. We observed very young shoots of two or three years. On the fallen trees, there were very few branches, which caught my eye. All the trees were quite unusually heavily charred, but their root system did not seem to have been charred. The trunks did not cross each other, but lay parallel. It is difficult to say now whether the branches were broken off only on one side and whether the burn was uneven. We walked 20 to 30 kilometers through the windfall, but it was obvious that it extended in width, maybe, up to hundreds of kilometers.*”

The contours of the forest fall are not outlined; as coordinates, Voronov indicated the upper reaches of the Khuga and Kulinda rivers. This lies just on the extension of the Sulomay—Chuvar Forest Fall line—the epicenter of the Kulik’s Forest Fall.

The expedition crossed the forest fall from north to south, their path was 25 to 30 kilometers. The length along the east-west line is estimated at 100 kilometers. Broken branches and burn marks indicate a powerful air explosion. The possibility of forest falls by an ordinary hurricane can be excluded. If a part of the TCB matter survived the explosion above the Kulik’s Forest Fall, the air explosion in the area of the Eastern Forest Fall occurred at a height of about 2.5 to 4 km.

The forest fall surface area, with the forest fall dimensions of  $30 \times 100$  km, is 2356 sq.km. Let us recall the Kulik’s Forest Fall surface area is estimated at 2150 sq.km.

The length of the forest of one hundred kilometers, as indicated by P.N. Lipaya, may seem overestimated. He measured it visually; their route passed, as he wrote, “on top”, along watersheds. Height differences were up to fifty meters; under such conditions, it is theoretically possible to see forest falls over fifty kilometers with field glasses. Lipaya was a land surveyor with an experience in measuring distances. Why did he need to exaggerate? So, it would be wrong to deny the possible forest fall length of a hundred kilometers. We should have a valid reason for this.

The forest fall length of 100 kilometers with a one-time explosion is impossible. There must be a constant release of the body shell matter during the entire flight over the extended forest fall. Was there a complete destruction of the TCB in this case? Theoretically, part of the matter could fly 300 to 400 kilometers from the Kulik’s epicenter and reach the Earth’s surface. The supposed path of such a residual fireball crosses the Podkamennaya Tunguska river near the village of Preobrazhenka.

There are several evidences from this village. Another fireball flew from east to west over this location. Witnesses did not note anything related to the fall of the TCB remnants.

I.M. Volozhin from Preobrazhenka told: “*In June, I worked in the field. I saw a meteorite fall over the horizon (azimuth:  $285^\circ$ ). From the side where the meteorite fell, a flame column shot to the height of at least two trees; then, smoke appeared which rose even higher than the flames. About 5 or 6 minutes after that, I heard a strong roar, even my horse fell to its knees. The earth shook, window glasses rattled, dishes clinked in cupboards.*” [9].

Several other witnesses confirmed the explosion azimuth of  $285^\circ$ . The sound travel time was 5 to 10 minutes. Perhaps, the explosion was produced by a flying fireball, but there is every reason to believe that the eyewitnesses saw the explosion that gave rise to the Eastern Forest Fall. The fireball observed over Preobrazhenka either flew by silently, or no one paid attention to the sound; it was probably one of the minor secondary fireballs.

The flare azimuth corresponds to the Eastern Forest Fall. The time indicated by the eyewitness confirms the possible forest fall length of 100 km. Five or six minutes mean the nearest point of the Eastern Forest Fall at a distance of 100 to 120 kilometers from Preobrazhenka. The far point should be at least 220

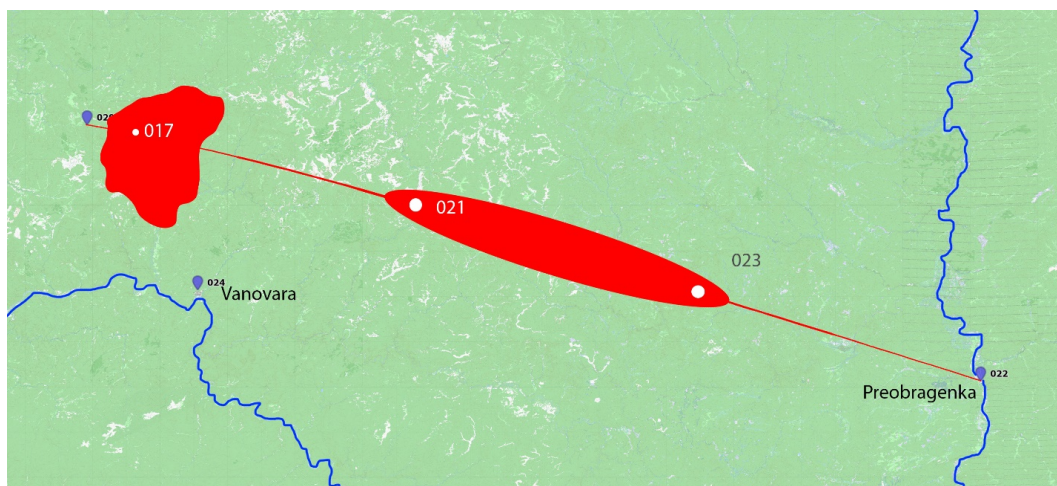
to 230 kilometers away. This confirms the significant length of the forest fall. The earthquake in Preobrazhenka at a distance of 150 kilometers from the Eastern Forest Fall center corresponds to the scale of this event. **Figure 3** shows the supposed shape of the forest fall. Point 021 corresponds to the evidence by Voronov, point 023 has been restored based on the report from Preobrazhenka.

There is an opportunity of researching and clarifying the dimensions of the Eastern Forest Fall, but this opportunity is rather theoretical: these regions are difficult to access, and for the forest fall boundaries to be determined, we need to use the archeological methods, since time has been lost. Point 023 may be of the greatest interest; there, we can expect to find cosmic markers, e.g., iridium. In the paradigm of a single event and the fireball flight direction from east to west, this forest fall did not fit into the hypotheses put forward and, therefore, it was ignored, just like the Western Forest Fall. Since there is the evidence provided by a qualified witness, a member of the expedition, being confirmed by witnesses from Preobrazhenka and by Voronov's report, the forest fall length can be estimated at about 100 km for the time being, with a width of up to 30 km.

## 8. EVALUATION OF THE EVENT PARAMETERS

The release of power in the Eastern Forest Fall could be 15 Mt, if compared with the Kulik's Forest Fall and considered to be proportional to the forest fall surface area. However, its power could probably be much lower. The forest fall could have been produced not only by a shock wave, as at the Kulik's Forest Fall, but also by induced hurricane winds. The efficiency of such an action is much higher; therefore, it requires less power. Voronov noted that the trees lay mainly with their tops to the east, which confirms the likelihood of just such an action. In permafrost conditions, it is difficult for trees to take root; so, it is not difficult to make them fall. But there was also a thermal burn, which requires a lot of power. Thus, 3 to 5 Mt could be required to produce the Eastern Forest Fall. It is difficult to judge about this without additional special studies.

The explosion power at the Kulik's Forest Fall is estimated at 13.4 Mt. The fireball weight and velocity have been estimated based on this power. The Eastern Forest Fall would require additional power; therefore, we should "increase" the fireball weight or "reduce" the flight altitude; to do so, we should increase the available ice strength. The author prefers the second option: it is supported the extended shape of the Eastern Forest Fall and the lack of forest falls between the forest fall end and Preobrazhenka. Perhaps, the trajectory ended up on the Earth a hundred kilometers from Preobrazhenka. With a trajectory angle of  $1^\circ$ , this means an explosion altitude of 4.5 km in the Kulik's epicenter. The explosion power for producing similar damage and burns could be reduced to 8 Mt, and the remaining 5.4 Mt would be used to produce the Eastern Forest Fall.



**Figure 3.** Eastern forest fall.

The entire flight of the fireball was accompanied by a huge release of energy. Along the section from Sulomay to the epicenter, a power of 23 Mt was released. In this area, there was forest damage with varying intensity within a strip up to forty kilometers wide over 600 km.

The TCB kinetic energy at the entrance to the earth's atmosphere can be estimated at 60 to 70 Mt, without taking into account the possible separation of matter from its surface during passage through the atmosphere, as in this case, the energy could exceed 100 Mt.

## 9. TCB STRUCTURE: PROBABILITY OF A NEW SIMILAR EVENT

The comet threat definitely exists, and we can extract useful information from this catastrophe to assess it. The comet caused serious damage; fortunately, it occurred in sparsely populated areas.

In the case under consideration, the comet's matter reached the Earth surface. The ice from which the comet was composed turned out to be quite strong. We assume that the comet's nucleus was homogeneous, without any structural failures. No nucleus fragmentation was recorded until the last kilometers above the Earth; there was only its outer layers separation. According to calculations, the ice strength was 16.5 MPa, but the actual value might be higher or lower.

Ice is a complex substance; there are many modifications of it with different strengths. The comet ice formation processes can only be assumed. Over the billions of years of the comet's existence, its nucleus had become solid. Processes could be slow, but the time was unlimited. Inclusions, if any, did not affect the ice strength.

TCB can be classified as a micro-comet. Maybe, this was a fragment of a much larger comet destroyed and scattered, for example, by Jupiter. After such an impact, the TCB nucleus either had been preserved or restored to a fixed stable state.

On its approach to the Earth and in an intermediate orbit, under the influence of tidal forces, significant fragments were separated. These fragments were held together by the comet's nucleus due to gravity and adhesion forces. These fragments, because of their small dimensions, passed through the atmosphere with less aerodynamic loads and could approach the Earth surface with a lower strength. Some fragments disintegrated as they approached the Earth's surface and produced swarm-like falls over a wide area.

There were several tens of large fragments, perhaps up to one hundred. The comet surface was covered with smaller and less durable fractions, up to dust. At each approach of the comet, being in an intermediate orbit, dust and gases fell into the atmosphere and caused glow phenomena. Probably, it would be more correct to speak not about abstract dust, but about water in various aggregate states, from gaseous one to microcrystals.

Therefore, when assessing the cometary threat, we should proceed from the fact that comets are not loose snowballs, but solid ice, at least their nuclei.

A fall from an intermediate orbit may seem an unlikely event, but this is not quite true. The beginning of the last century was marked by an increased meteorite activity. There are hypotheses that there exists a swarm of cosmic bodies periodically approaching the Earth. The range of velocities of such approaches can be wide. If the approach velocity is insignificant, bodies can be captured by the Earth-Moon system with subsequent fall. For this range of speeds, the above scenario is many orders of magnitude more likely than an accidental entry of a body in the Earth projection.

Probably, a similar event was the so-called meteor procession in 1913. On the evening of February 9, 1913, residents of the southeastern regions of Canada and neighboring US states observed a real parade of dozens of luminous bodies that slowly moved across the sky in a southeastern direction. Their trajectory length was estimated at 9000 km. The TCB trajectory was 5 to 6 thousand kilometers at altitudes less than 100 km.

## 10. CONCLUSIONS

Therefore, the Western trajectory has been traced along 3500 km from the Volga to Lower Tunguska (Figure 4). The Western and Eastern Forest Falls, which for long years puzzled and even upset many re-



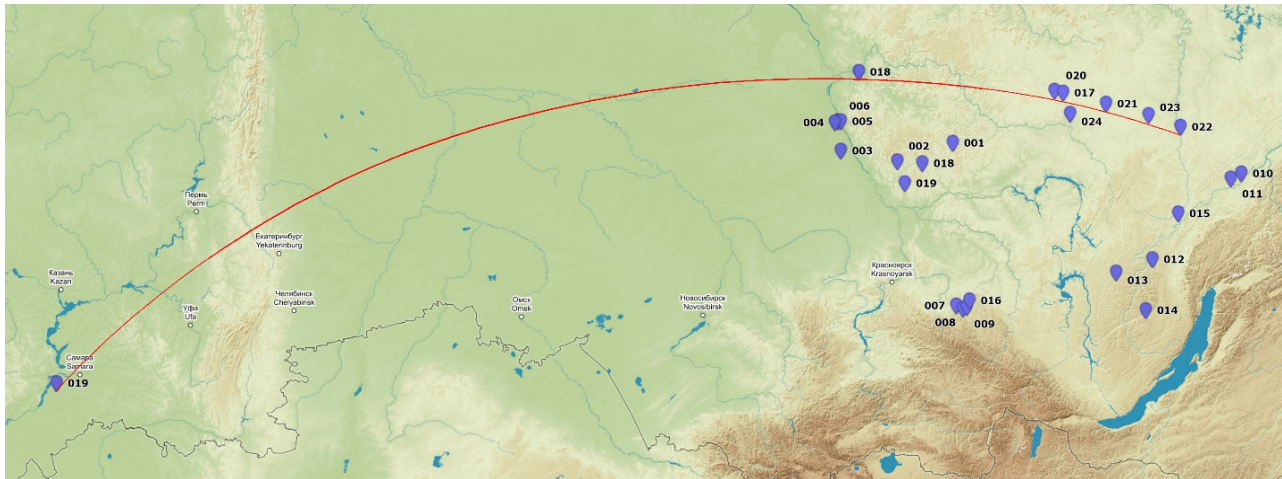
searchers, lay well on the TCB path. It is in good agreement with the objective data obtained on the Kulik's Forest Fall. We have identified the consequences of the passage of a huge fireball in the atmosphere: an unusually strong electrophonic effect, a powerful shock wave, and a hurricane wind. The estimated length of the destruction strip of varying degrees of intensity along the Western trajectory is more than a thousand kilometers with a width of up to 40 km. The total power of the event is estimated at 60 to 70 Mt.

Without the display of Siberian Fan Reliefs, the event's picture would be incomplete. **Table 1** provides coordinates of some fan reliefs and main points on the TCB Western trajectory.

**Table 1.** TCB trajectory and Siberian Fan Reliefs.

No	Formation	Coordinates	Azimuth*
001	Kazhma	N 59°36'48.96"; E 96°05'30.90"	69° ± 20°
002	Lendakha-Big Pit	N 59°05'42.94"; E 93°10'52.91"	113° ± 7°
003	Kasskoye	N 59°23'30.68"; E 90°12'49.37"	116° ± 5°
004	Sym2	N 60°07'29.92"; E 89°53'08.12"	92° ± 8°
005	Sym3	N 60°09'40.18"; E 90°12'41.82"	86° ± 4°
006	Sym	N 60°09'19.29"; E 90°03'32.77"	80° ± 7°
007	Sedelochny	N 55°00'03.56"; E 96°19'03.08"	85° ± 5°
008	Tumanshet	N 54°54'16.52"; E 96°40'50.78"	90° ± 15°
009	Agul-Chukhlaikha	N 54°57'31.20"; E 96°51'53.52"	70° ± 15°
010	Right bank of the Lena river	N 58°46'09.96"; E 111°20'00.67"	37° ± 5°
011	Lena river1	N 58°39'00.54"; E 110°47'45.66"	15° ± 20°
012	Lena river2	N 56°27'02.25"; E 106°42'40.99"	4° ± 10°
013	B. Vereya-Ilim	N 55°59'00.11"; E 104°44'41.86"	12° ± 5°
014	Gorely-Kelora-Lena	N 54°51'04.75"; E 106°19'40.78"	100° ± 7°
015	Kulebyachikha-Lena River	N 57°41'26.48"; E 108°01'24.31"	55° ± 10°
016	Tumanshet swarm	N 55°09'05.08"; E 96°58'34.74"	90° ± 5°
017	Epicenter	N 60°59'01.56"; E 101°57'11.25"	
018	Sulomay	N 52°44'58.53"; E 48°41'29.06"	
019	Khvororostyanka	N 52°51'21.11"; E 48°57'18.28"	
020	Chuvar	N 60°58'42.37" E 101°28'11.01"	
21	Eastern windfall	N 60°37'48.36" E 104°10'20.50"	
22	Preobrazhenka	N 60°01'54.94" E 108°06'19.68"	
23	End of track	N 60°20'35.73" E 106°25'28.41"	
24	Vanovara	N 60°22'13.54" E 102°16'57.77"	

\*The last column is the angle between the direction of the central axis of the structure and the direction to the north.



**Figure 4.** The trajectory of TCB.

Supporters of other possible directions can put forward their arguments and counterarguments, but, to date, there is not a single alternative trajectory with such a degree of detail.

We can even leave out which side the TCB flew from, but it is impossible to deny the fact that a powerful fireball flew from the west. Taking into account the fireballs recorded from other directions, we can draw an unambiguous conclusion: on the day of the catastrophe, fireballs flew at the same time, but from different directions. This was clearly manifested in Preobrazhenka, where two fireballs flew towards each other at the same time. This makes the intermediate orbit hypothesis the only one possible. This makes no sense to deny the connection between Siberian Fan Reliefs and TCB.

The intermediate orbit with the fragment distribution by different azimuths, no matter how fantastic it may look, is actually a proven fact. Celestial mechanics must provide an explanation for this fact. We can restore the intermediate orbit parameters with great accuracy.

The version with the intermediate orbit and multiple falls explains almost all the available facts, including the glow phenomena long before June 30.

We could discuss the fall directions endlessly, but I would like to once again draw your attention to Siberian Fan Reliefs. Their study can reveal many interesting things to us. Of particular importance may be the study of the ballistic parameters of comet ice based on traces left on the Earth surface. The comet threat does exist, and it is easier to study fan reliefs than to send spacecraft to comets. But not by much, since the terrain is difficult and harsh. Only a few traces have survived to this day, and after a while, only archaeologists will be able to deal with this problem.

## CONFLICTS OF INTEREST

The author declares no conflicts of interest regarding the publication of this paper.

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