6. Tracks Too Large to be Seen

The Tunguska space body (TSB) may have been enigmatic, but it did not vanish into thin air. Rather it left three big keys and several smaller ones that can help scientists to unlock the door of this mystery. The first and foremost is a "mechanical" key, namely the gigantic zone of leveled forest occupying an area of some 2,150 km^2. The second, a "thermal" key, provides two items of evidence: the burn on the trees from the light flash of the explosion, which was preserved on trees that had both perished and survived, and the consequences of the forest fire produced by the explosion.

The third key is the magnetic key. Its first component is the record of a local geomagnetic storm that started several minutes after the explosion. But we also have a distinct trace of the influence of a powerful magnetic field that has remained in the soil around the Tunguska epicenter. This is the paleomagnetic anomaly covering an area of about 1,400 km^2. Little is known about this outside the Tunguska research community. Also, at the time of the explosion of the TSB, Professor Weber in Germany recorded a strange disturbance of the geomagnetic field that could be relevant.

It is remarkable that Leonid Kulik 80 years ago was well aware of these mechanical and thermal keys and noted the importance of the "magnetic" aspect of the Tunguska phenomenon. Gigantic trees that were leveled over an enormous area and the unusual burn, covering not only branches and bark of these trees but also moss on the swamps, 20 years after the catastrophe, greatly impressed the pioneer of Tunguska studies. The theoretical speculations of scholars who had never visited the Great Hollow did not convince him. Kulik preferred to ignore their opinions, which were sometimes reasonable. Of course, attributing the leveled forest to an "unusual hurricane" and the burn of the trees to an "unusual forest fire" was absurd, but regarding the "enigmatic craters," the armchair scientists knew better than Kulik. These proved to be just thermokarst holes, as we have seen.

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However, as an empiricist aiming at concrete results, Leonid Kulik was right. By not paying attention to the various nuances and trifles he was bending his every effort to discovering the main thing: the substance of the Tunguska object. The gigantic area of the radially leveled forest was also regarded by Kulik just as another "nuance." When Evgeny Krinov, who looked around more attentively and considered the "strange craters" with more skepticism, suggested exploring the surrounding taiga in detail, he was expelled from the expedition.

Kirill Florensky's approach to the leveled forest did not differ substantially from Kulik's. Florensky said: "Forget about the fallen trees; let's search for the substance of the meteorite. And if there are no large pieces we will look for microscopic particles." Here again, from the point of view of meteoritics, Florensky was completely right. If it was just a big stone or iron meteorite that had leveled millions of trees with its ballistic shock wave, there would be nothing incomprehensible about this. Having measured the directions of some leveled trees, the participants of the expedition of 1958 made sure that the radial character of the fallen forest was perfectly recorded, so that everyone believed no further investigations were needed.

However, later on, some "hard to explain" details began to emerge. Members of the expedition ITEG-2 felt this in 1960 when they started to explore the area of the fallen forest in a systematic way. Although the trees were lying in a radial manner, the shape of the area of leveled forest looked weird. Within this area were three zones: those of standing trees (the "telegraphnik"), mass flattening (the Tunguska explosion felled almost all trees in the territory of 500 km^2), and partially flattened trees laid in a radial direction. And it was far from being elliptical, which would have been usual for a meteoritic fall.

In 1961 the joint expedition of the ITEG and KMET had even more participants than ITEG-2, and the investigation of the leveled forest could have been continued. But Kirill Florensky, the expedition chief, thought this a "senseless waste of time and effort for obtaining quite an obvious answer." Florensky believed that even after determining exact outlines of the area of the flattened forest at Tunguska no new information would be obtained, since the TSB, according to his opinion, had been a usual meteorite. Therefore, the shape of the area of leveled forest could be only elliptical (see Figure 6.1). Reality proved to be somewhat different.

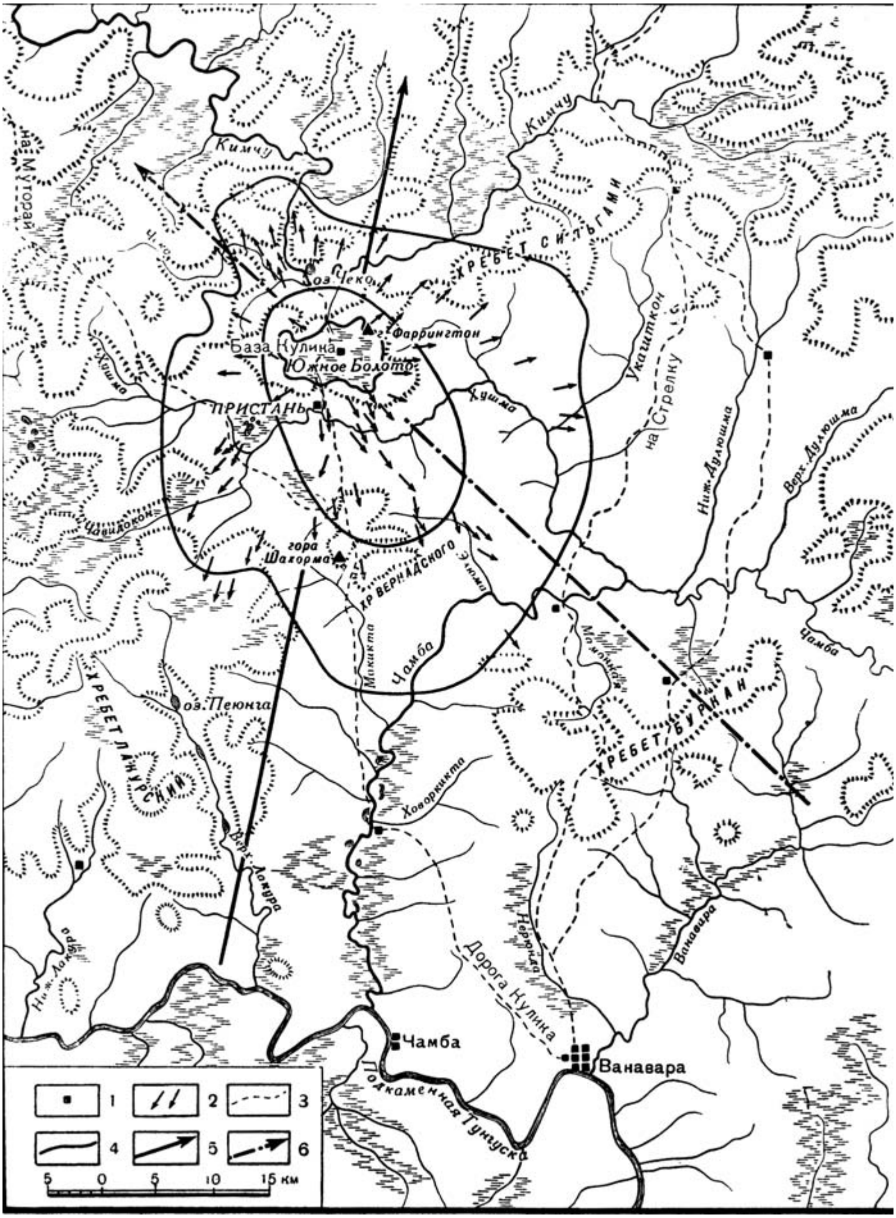

FIGURE 6.1. This is how the Soviet meteor specialists imagined in the early 1960s the general outlines of the area of the leveled forest (the outer closed curve) and those of the area of complete forest destruction (the inner ellipse), judging from theoretical considerations and results of the academic expedition of 1958 (*Source*: Florensky, K. P., et al. Preliminary results of the work of the Tunguska meteoritic expedition of 1958. – *Meteoritika*, Vol. 19, 1960, p. 106.).

His additional argument was, "There are tens of millions of leveled trees and to reach a reliable result it would be necessary to measure each of them. Do you think that is a sound plan?" Wilhelm Fast, a mathematician from Tomsk and an ITEG member, believed there was no need to measure the coordinates and directions of *all* the trees with precise accuracy. It would be sufficient to use small test areas, where the angles (azimuths) of the lying trees would be measured with a simple surveyor's compass accurate to 5°. It would then be possible to determine the average direction of the fallen trees very accurately. Florensky was bewildered: "Do you mean," he asked, "that if I had a hundred faulty watches I could find the exact time with the help of statistical calculations?" "Yes," Fast replied, "just so. If the number of watches is large enough and their erroneous readings are distributed according to a known statistical law, the right time may be determined with very high accuracy." Florensky yielded to this mathematical authority, although it seems he never could believe that that was so.

True, the amount of work, even limited to test areas and 5° accuracy, proved to be enormous. Needless to say, the academic Committee on Meteorites would never have been able to conduct it. The number of researchers who participated in the ITEG program "Flattened Forest" reached 120. Every summer for 20 years (from 1960 to 1979) they regularly performed their somewhat dull but highly important work. And they completed it in the nick of time – while the leveled trees were still relatively fresh. The researchers laid out more than 1,000 test areas, each of them 50 meters by 50 meters, measuring the parameters of all trees in these areas that had fallen in 1908 or perished but were still standing. Usually a test area contained from 100 to 400 or more such trees. The trees that survived the Tunguska catastrophe were also counted. The measuring treks usually lasted about two weeks through the wild sloughy taiga, with its clouds of winged bloodsucking insects – and sometimes bears. But one could not fear going astray, since the strict radial character of the leveled forest made coming back from any point to its center very easy.[1]

The northeastern sector of the leveled wood area proved to be of special interest. Previously, specialists in the Tunguska problem believed that this area did not extend in this direction farther than 4 km from the epicenter. In 1961 a team of "tree measurers," managed by Wilhelm Fast, was traveling to the northeast when they discovered to their astonishment that the forest was leveled in a northeasterly direction for up to 36 km from the epicenter. Other members of the expedition then began to help in measuring the borders. The results were traced on a map, and, step by step, before the eyes of the amazed scientists there appeared the real contour of the area devastated by the Tunguska event. Instead of an ellipse, as had been previously assumed, it resembled a gigantic spread-eagled butterfly with a "wingspan" of 70 km and a body length of 55 km (see Figure 6.2). The whole zone covered some 2,150 km^2.

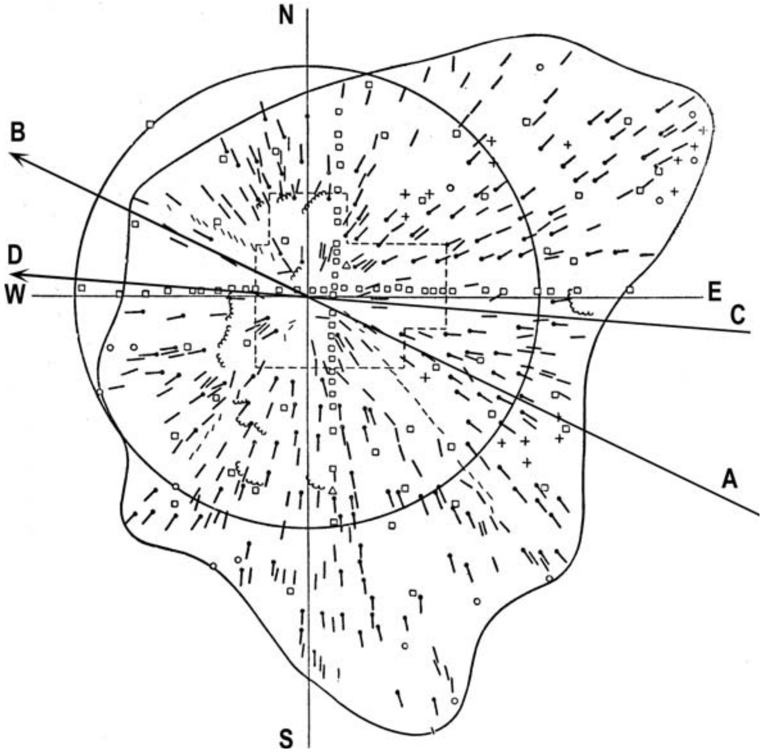

FIGURE 6.2. "Fast's butterfly": the true outlines of the leveled forest at Tunguska, 2,150 km^2 in size, according to the results of the ITEG expeditions. Lines A–B and C–D designate the first and second TSB trajectories determined by Dr. Wilhelm Fast (*Source*: Boyarkina, A. P., Demin, D. V., Zotkin, I. T., Fast, W. G. Estimation of the blast wave of the Tunguska meteorite from the forest destruction. – *Meteoritika*, Vol. 24, 1964, p. 127.).

But the ITEG members did not simply collect empirical data and plot this on maps and graphs. They immediately started to statistically process the data. It was the ITEG member Nikolay Nekrytov who first attempted to analyze the directions in which the trees had fallen, hoping thereby to determine the exact coordinates of the epicenter of the Tunguska explosion and to find a trace of the TSB ballistic shock wave.

In 1963 Wilhelm Fast (see Figure 6.3) took up this work. Fast was born in the Volga German Autonomous Soviet Socialist Republic, which existed from December 1923 to September 1941 in the USSR. In 1939 some 600,000 people lived there, two-thirds of whom were ethnic Germans, mainly descendants of those German settlers who had been invited to Russia in the eighteenth century by the Empress Catherine the Great (1729–1796). After the German invasion of the Soviet Union, the Volga German Republic was abolished and its inhabitants interned and exiled by Soviet authorities to Kazakhstan and Siberia. This is how Wilhelm Fast's family found itself in Siberia.

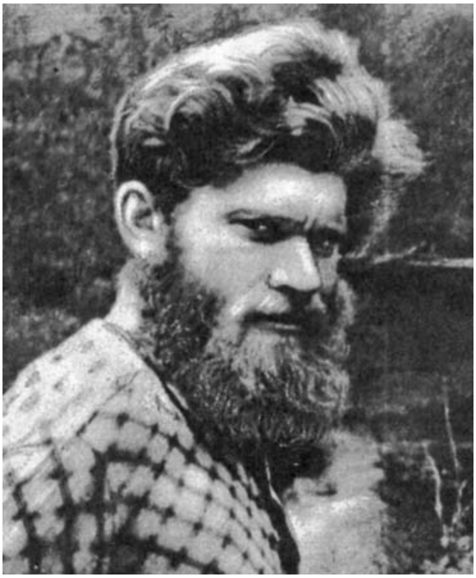

FIGURE 6.3. Dr. Wilhelm Fast (1936–2005), mathematician, the "Newton of Tunguska," who mapped the area of the leveled forest, preserving thereby a precise description of the most important trace of the Tunguska explosion for future generations of researchers (*Source*: Zhuravlev, V. K., Zigel, F. Y. *The Tunguska Miracle: History of Investigations of the Tunguska Meteorite*. Ekaterinburg: Basko, 1998, p. 42.).

Wilhelm had a gift for mathematics, but no real prospect of using it in exile. Luckily, after Stalin's death, he succeeded in entering the mathematical faculty of Tomsk University and, after graduating, began a doctorate course that had nothing to do with the Tunguska problem. His knowledge of the enigma was almost zero.

One day in the spring of 1960, when the ITEG people were preparing their second expedition to Tunguska, Fast accidentally attended their meeting. He listened to the enthusiasts in Tunguska studies and became interested, and subsequently helped them to translate several scholarly papers from German into Russian. After that he decided to go to the Great Hollow himself.

At first, Wilhelm was mainly engaged in measuring magnetic fields on the Southern swamp, but soon he was carried away by the imposing spectacle of the leveled forest. He even applied to his university supervisor to have his dissertation subject changed. The new subject he wanted was "Statistical parameters of the area of leveled forest at Tunguska." At first, his supervisor refused. The proposed subject seemed too far from pure mathematics. But Fast's idea was then supported by Academician Mikhail Lavrentyev (1900–1980), the first Chairman of the Siberian Branch of the USSR's Academy of Sciences. Lavrentyev was a distinguished Soviet mathematician and an outstanding specialist in the computer simulation of nuclear explosions. He had obtained a Lenin Prize for developing nuclear charges for heavy artillery, so Lavrentyev's opinion outweighed that of the supervisor and the dissertation subject was changed.

A detailed map of the leveled forest – the famous "Fast's butterfly," which was based on 650 test areas and 60,000 measured trees – was published in 1964 in KMET's *Meteoritika* annual.[2] In the following two years Wilhelm Fast successfully completed his dissertation. It was the *first* Tunguska dissertation in the world of science. Despite the misgivings of Fast's university supervisor, it turned out purely mathematical. Fast had described the statistical picture of the leveled forest most rigorously, but he believed that a mathematician should not interpret the results obtained in terms of physical models of the Tunguska event or put forward hypotheses about the TSB's nature and origin.

When the directions of the fallen trees were extended on the map toward the center of the Great Hollow they almost intersected at one point, and this looked like the epicenter of the Tunguska explosion. But Fast tried to avoid the term "epicenter." The special point, he insisted, is just a mathematical abstraction, one of the characteristics of the leveled forest area. ITEG colleagues, joking about Fast's super rigor, called this point the "epifast." It is located at a small headland on the northern bank of the Southern swamp, a couple of kilometers from the Stoykovich mountain.[3] Surprisingly, the name itself has taken root, and different variants of the Tunguska epicenter's location – proposed by various researchers – have been called "epi-" plus the first or last name of the researcher.

Fast treated the symmetrical character of the butterfly-shaped area of the leveled forest with equal caution. Its axis of symmetry ran at an angle of 115° to the east from its geographical meridian (see Figure 6.2, line A–B). It seemed quite natural to suppose that along this line – that is, from the east-southeast to the west-northwest – the TSB had been moving in the final stage of its flight. But on this subject Wilhelm Fast also preferred to refrain from any direct interpretation of his discovery. He emphasized again and again that mathematicians should not look for the physical meaning of regularities they reveal. But anyway, his calculations and conclusions could stand even the most demanding criticism.

Fast's main premise was that the trees that were affected by the Tunguska explosion could be considered as measuring instruments, whose readings are governed by certain statistical laws. And these could determine the magnitude of the force that flattened the taiga. Of course, an individual tree might not fall in a strictly radial direction, but the stronger the horizontal component of the blast wave, the smaller would be the deviation of the trees from strict radiality. Near the epicenter, the vertical component of the blast wave was predominant and therefore these deviations were considerable. Going from the epicenter to the border of the leveled forest area, we can see that its radiality becomes increasingly consistent. As we move farther from the epicenter, the vertical component of the blast wave would have become increasingly weaker, which contributes to flattening the trees in a more regular way. But farther still from the epicenter, the blast wave would have become gradually weaker so that the trees began to fall more chaotically.

Fast proved that the dynamic pressure affecting the Tunguska trees was inversely proportional to their deviations from strict radiality. So it now became possible to compose a simple formula connecting these two quantities: the force of the blast wave and the ways in which the trees had fallen. A way to the *physical* modeling of the Tunguska phenomenon was opened.

It was John Anfinogenov (Figure 6.4) who took the first step in this direction. John – a specialist in aerial photography from Tomsk – entered the ITEG in 1965 and attempted to reevaluate results obtained by Fast and to look somewhat differently at the whole picture of the Tunguska event. John's father, Fedor Anfinogenov, was, at the beginning of the 1930s, participating in the construction of the *Dneproges* – the first hydroelectric power station in the USSR. There he made friends with an American engineer and named his own son, born in 1937, after him. That is why Anfinogenov-Jr. received a name very untypical for the Soviet Union and Russia. In the ITEG Anfinogenov began to study those materials that other Tunguska specialists ignored or simply could not examine due to the lack of personnel or time. In particular, the ITEG had aerial

FIGURE 6.4. John Anfinogenov, an eminent Tunguska investigator, who has participated in 18 ITEG expeditions since 1965 and composed the map of the area of complete destruction of the taiga (*Source*: Zhuravlev, V. K., Zigel, F. Y. *The Tunguska Miracle: History of Investigations of the Tunguska Meteorite*. Ekaterinburg: Basko, 1998, p. 135.).

photographs of the Great Hollow, taken in 1949 when the environs of the Podkamennaya Tunguska River were photographed as a part of a large State program. For several years John and his colleagues studied these images and composed a map of the area of complete destruction of the Tunguska forest – 500 km^2 in size. Here almost 100% of all trees had been felled, and the shape of this area was also butterfly-like – similar in some ways to Fast's butterfly, but in other ways different (see Figure 6.5).

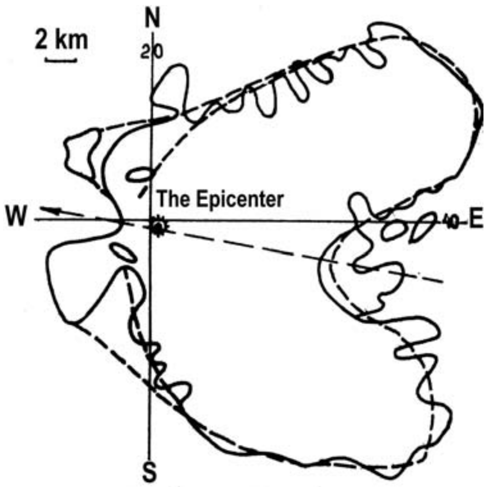

FIGURE 6.5. "Anfinogenov's butterfly" – the area of complete destruction of the Tunguska forest, 500 km^2 in size. This area has shown the most essential characteristics of the Tunguska explosion (*Source*: Zhuravlev, V. K., Zigel, F. Y. *The Tunguska Miracle: History of Investigations of the Tunguska Meteorite*. Ekaterinburg: Basko, 1998, p. 74.).

When depicting Fast's butterfly, researchers usually smoothed out its western contour, supposing that the area of the leveled forest was continuous. In fact, this supposition was wrong. There survived a strip of living trees mixed with the "telegraph poles" and running to the west directly from the epicenter. The "Anfinogenov's butterfly" does show the gap in the contour unequivocally. Its axis of symmetry does not coincide with that of "Fast's butterfly," either. True, several years later Fast himself, having studied additional data on the leveled forest collected in the field and using an improved procedure of finding the axis of symmetry, decided that the axis of symmetry of his "butterfly" must run (and, accordingly, the TSB had to fly) practically from the east to the west (see Figure 6.2, line C–D). This solution was in good accordance with the "Anfinogenov's butterfly." (Of course, it does not mean that the preceding direction of the TSB flight, determined by Fast – from the east-southeast to the west-northwest – is erroneous; rather, it may have to do with another body participating in the Tunguska event.)

The two "butterflies," which show the crucial traits of the forest leveling in the Great Hollow, are the main result from the field investigations conducted by the ITEG. Any hypotheses about the origin of the TSB and the nature of the Tunguska explosion developed without due regard for these "butterflies" would be worthless. What a pity that some scientists wishing to solve the Tunguska problem (not only European and American but Russian as well) had not the foggiest notion of these findings.

Wilhelm Fast remained active in Tunguska studies for the next 20 years, but gradually his attention shifted from science to politics and human rights. As a dissident, in 1982 Fast was expelled from Tomsk University. He met more than once with Alexander Solzhenitsyn and later became one of the founding fathers of the Tomsk branch of the *Memorial* Society.[4] But his scientific achievements cannot be overestimated. Fast's contribution toward understanding the Tunguska problem is quite comparable to that of Kulik and Kazantsev. He had fixed in figures and graphs the largest trace of the Tunguska explosion before it disappeared from the face of the Earth. And his "butterfly" is an outstanding achievement. Like Sir Isaac Newton, Fast liked to repeat: "I am not interested in hypotheses!" and he may safely be called the "Newton of Tunguska." To solve this enigma may need another Einstein, but Wilhelm Fast played his part brilliantly. He left to other specialists the task of interpreting his findings in terms of their own disciplines.

It was geophysicist Alexey Zolotov who went further. As we have seen, he attempted to interpret the structure of the area of leveled forest from a physical point of view. He reasoned that, being a material object, the TSB must have formed a ballistic shock wave, which had in its turn affected the forest before the destruction of the body itself. Somehow, Wilhelm Fast did not notice any deviations from the radial pattern of the leveled trees (neither, probably, did he try to search for them). The leveled forest area looked perfectly radial. Zolotov fully understood, however, that traces of the ballistic shock wave (the "effects of the second order") must have existed, and he set himself the target of finding these and determining from them the magnitude of the wave.

Soviet astronomer Felix Zigel (1920–1988), another contributor to Tunguska studies, illustrated the main difference between blast and ballistic shock waves, a subject of major concern to Tunguska specialists. If you throw a stone into a lake you will see how waves run from it in a concentric way. This is a good model for the blast wave produced by an explosion. Now look at a motorboat rushing across the lake. In its motion it forms a cone-like water wave that is very similar to the ballistic shock wave originating in the atmosphere from a supersonic aircraft or a meteorite.

The general scenario of the Tunguska event shared by almost all Tunguska investigators is very simple: one space body flew over central Siberia, generating in its flight a ballistic shock wave and performing no maneuvers, exploding over the Great Hollow and producing a blast wave. The TSB could, therefore, have been an ordinary meteorite, or a cometary core, or an extraterrestrial spaceship meeting disaster – any one of these would agree with this scenario. And the space body could have flown over the taiga in either a flat or a steep path, and be accompanied by either a strong or weak ballistic shock wave.

Here the term "strong" wave means that it could level trees. "Weak" means that the wave could not level them. Judging from the strict radial character of the leveled forest, we can immediately rule out the combination of a flat path with a strong ballistic shock wave. In this case, the trees would have fallen, forming a herringbone pattern and not a radial one. Therefore, only the following two physical models of the Tunguska phenomenon may be seriously considered:

1. The model with a flat TSB path, in which the magnitude of the blast wave exceeded considerably the magnitude of the ballistic shock wave.
2. The model with a steep TSB path, in which the magnitude of the ballistic shock wave is comparable to or exceeding the magnitude of the blast wave.

In both these cases the trees would have fallen radially. But how can we select from these two options by using other facts less noticeable than the radial pattern? Zolotov attempted to do that by looking at astronomical estimations of the TSB trajectory's slope. Evgeny Krinov, having studied all the evidence, came to the conclusion that it had been in the range of 5–17°. Zolotov accepted Krinov's estimation and selected the model with a flat TSB path and a weak ballistic shock wave.

Researchers believing that the forest destruction had been caused mainly by the ballistic shock wave (even if in combination with a final "thermal explosion") have preferred the model with a steep TSB path and a strong ballistic shock wave. The meteor scientists, even admitting some contribution from the explosion to the destruction of the forest, have constantly tried to minimize its magnitude. Zolotov therefore decided to calculate, from the statistical characteristics of the area of the leveled forest, the parameters of the TSB. First he attempted to find the ratio of magnitudes between the blast and ballistic shock waves. The blast wave leveled millions of trees, so, if their magnitudes were comparable, the ballistic shock wave must have leveled many of them *before* the explosion. There must therefore exist (at least where the TSB approached the Great Hollow) some fallen trees whose deviations from the radial direction are very great – up to 90°. No such deviations were found in the measured trees, however. The mean deviation was just 7.5°. From this it follows that the ballistic shock wave of the TSB *did not level even a single tree*. All trees were leveled by the blast wave only. That is, the magnitude of the ballistic shock wave was much lower than the magnitude of the blast from an explosion – less than 10% of the total energy release during the Tunguska event.

But this was just the start. Zolotov was now faced with a challenging task – to determine the exact parameters of the ballistic shock wave. The altitude of the explosion, he believed, had to be from 6 to 8 km, judging by the diameter of the zone of "telegraphnik" (standing trees). If the TSB path was flat, then its altitude of flight over the area of forest destruction was rather low, and traces of the ballistic shock wave, even if weak, could in principle be found. Although not leveling a single tree, this wave had nevertheless to alter somewhat the directions in which trees fell. That is, along the projection of the TSB trajectory, to the left and to the right of it, there must have formed a band of trees lying not strictly radially. Alexey Zolotov studied the map of the leveled forest area in detail and found two sectors where this was the case (see Figure 6.6). Here in sectors 1, 2, and 3 the blast wave was not affected by the ballistic shock wave and therefore the trees lie strictly radially. However, in sectors 4 and 5 they were deflected, when falling, by the ballistic shock wave, forming an axially symmetric structure. The axis of symmetry ran from the east-southeast to the west-northwest. The herringbone pattern was feeble, but it did exist.

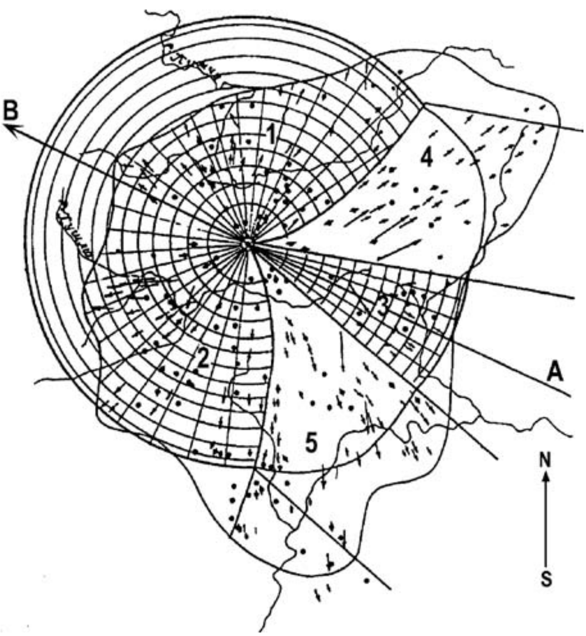

FIGURE 6.6. This shows how Dr. Alexey Zolotov determined the speed of the Tunguska space body and found the trace of its ballistic shock wave in the leveled forest. The line A–B designates the TSB trajectory according to Zolotov (*Source*: Zolotov, A. V. *The Problem of the Tunguska Catastrophe of 1908*. Minsk: Nauka i Tekhnika, 1969, p. 95.).

Because a ballistic shock wave travels symmetrically relative to the flying body's trajectory (let's remember Zigel's motorboat!), this axis is in fact the projection of the trajectory. It attests that the TSB was flying over the area of forest destruction in just this direction. This result of Zolotov's calculations concurred almost perfectly with Fast's first trajectory. What is more, having measured the deviations of the trees from radiality, Zolotov determined the real magnitude of the TSB ballistic shock wave. It approximated 7–20 kt of TNT[5] – not too little after all, but considerably less than the magnitude of the blast wave. Of course, these figures are correct only if the TSB path was flat; otherwise, the estimation has to vary.

The TSB's weak ballistic shock wave made it possible to draw strong conclusions about the dynamic characteristics of this enigmatic body – first of all about its velocity. The ballistic shock wave collided with the blast wave, forming a distinct border between the herringbone pattern and the area of the strictly radial forest leveling. Let's look again at the scheme on Figure 6.6. To find the speed of the TSB, Zolotov used the method of successive approximations. As a first approximation, he took the normal meteoritic velocity of 30 km/s. But this did not explain the location of the border between the herringbone structure and the forest, which was leveled strictly radially. After repeated calculations it was found that the velocity of the TSB was around 1 km/s, which is about the speed of the suborbital spaceplane SpaceShipOne that completed the first privately funded human spaceflight in 2004. At this velocity no "thermal explosion" – or any other type of explosion due to the kinetic energy of a moving body – is conceivable. So the TSB's explosion must have been produced by its inner energy (chemical, nuclear, or other).

It's important to note that all these values were calculated by Alexey Zolotov on the basis of strictly objective data about statistical characteristics of the "main trace" of the Tunguska phenomenon – that is, the leveled forest area. But they do depend on one important parameter of the TSB trajectory: it had to be gently sloping. The alternative model for the TSB allows that it flew "fast" and in a "steep" trajectory. John Anfinogenov decided to investigate this. He even attempted to abandon the idea of the "additional explosion" at the final point of the TSB trajectory and to explain all peculiarities of the Tunguska phenomenon in terms of "pure ballistics." Anfinogenov paid attention to the area of complete destruction of the forest, in which almost all trees had been leveled. In his opinion, this zone of just 500 km^2 contained the most reliable information about the Tunguska explosion, especially data on its magnitude, which must have been, according to his estimation, some 8 Mt of

TNT. In John's view it was not a blast. All the destruction in the taiga, he thought, must have been caused by the energy of motion of a usual (although very big) iron meteorite. Flying at an enormous speed – some 30 km/s – and naturally at a great angle to the surface – 40–50° – the meteorite formed a spindle-like ballistic shock wave, which leveled the forest strictly radially. As for the meteorite itself, it split apart, and its fragments fell down farther to the northwest, at about 5 km from the "epifast." Anfinogenov's friends immediately named this area the "epijohn."

A critic could have said that such a steep slope of the TSB trajectory does not fit the eyewitness testimonies or the well-justified figures of Krinov. But more important is that Anfinogenov's model predicted that within a relatively small zone one should find a great number of fragments of a large iron meteorite. As we know, the ITEG members have combed this zone and its environs without finding one grain of meteoritic iron.

Generally speaking, according to the scientific standards, Anfinogenov's theory should have been refuted and sent to the storehouse of many other Tunguska hypotheses – perhaps witty and sophisticated, but incapable of solving this enigma. However, John did not resign himself to defeat. Trying to explain the failure of the search in the "epijohn," he put forward an interesting idea. According to him, the Tunguska meteorite was not iron at all; instead, it consisted of a sedimentary rock that had been formed on another planet, being little different in its appearance from its terrestrial analogs. The so-called "Deer-stone," found by Anfinogenov himself on Stoykovich mountain (*not* at the epijohn), could be, in his opinion, one of these "anomalous meteorites" (see Figure 6.7). Somehow, meteor specialists do not seem as yet interested in this idea, nor hypersonics specialists in the "purely ballistic" models of the Tunguska event.

The point is that such models have been convincingly refuted – by calculations and modeling experiments. There are strong grounds for believing that the "final explosion" made a considerable contribution to the destruction of Tunguska taiga. Academician Victor Korobeynikov (1929–2003), a noted specialist in the physics of explosion, has developed with his colleagues a mathematical model and techniques to calculate the system of blast waves that are formed when large meteors fly into and explode in the

FIGURE 6.7. The enigmatic "Deer-stone," found in 1972 by John Anfinogenov on the Stoykovich Mountain, near the epicenter of the Tunguska explosion. It measures 2.5 × 1.7 × 1.2 meters and weighs more than 10 tons (*Credit*: Dr. Stanislav Kriviakov, Tomsk, Russia.).

atmosphere. In essence, they managed to deeply mathematize and advance meteoritics as a scientific field of research. During 12 years, these specialists were developing various models of the Tunguska phenomenon, testing them on fast computers and comparing the results with the real structure of the leveled forest area. It is known that the so-called inverse problems in theoretical mechanics (in which we must reconstruct the initial system of acting forces starting from the results of their action) may have more than one mathematically correct solution. For example, as we saw above in the Tunguska problem, an object flying in a flat path and producing a weak ballistic shock wave would have created more or less the same destruction in the taiga (having exploded due to its inner energy) as another object flying in a steep path and producing a strong ballistic shock wave. Academician Korobeynikov and his collaborators came to the conclusion that it was an object flying in a steep path that caused the destruction at Tunguska.

Of course a more powerful explosion occurring at a greater altitude would have produced the same effects as a less powerful one at a lower altitude. The researchers accepted that, judging from the mean diameter of the zone of standing trees, the altitude of the explosion was about 6.5 km. The results of Korobeynikov's computations are as follows: the butterfly-like shape of the leveled forest area and its radial pattern may be reproduced in calculations if the slope of the TSB trajectory was assumed to be 40°. The TSB velocity must have been 25–35 km/s and the magnitude of the *blast* wave one and a half megatons of TNT, with the magnitude of the *ballistic shock* wave three times higher. True, the calculated diameter of the zone of "telegraphnik" turned out only "about 3 km" – whereas in reality it is up to 8 km.[6] And somehow the researchers believed that the 40-degree slope was in agreement with eyewitness accounts.

In fact, both Korobeynikov's and Anfinogenov's 40° sharply contradict these accounts. Krinov's limitation of the slope of the TSB path to 17° is well justified, and this adds strength to Zolotov's model. Of course, as far as pure mathematics is concerned, Korobeynikov's calculations are sound. But astronomer Vitaly Bronshten (1918–2004), who had been studying the Tunguska problem closely for 40 years, once made an apt remark: if we are trying to unveil the real Tunguska mystery, and not just solve an abstract mathematical problem, we must reject those solutions that are inconsistent with observational data.[7]

The simplest scenario for the Tunguska event involves one body, one explosion, and no maneuvers. But strictly speaking this is just one possibility. John Anfinogenov cast doubt on its validity when he proved that the border of the leveled forest area is open in the west, although a closed line had been drawn with certitude on maps for many years. But that line had been obtained by the use of statistics, and as everyone knows there are three kinds of lies – lies, damned lies, and statistics. Individual peculiarities of a phenomenon (in our case, the area of the leveled forest) may be as important as its overall characteristics. It is no mere chance that Wilhelm Fast, when analyzing the general structure of the leveled forest area and smoothing out its contour, at first could not detect the feeble herringbone pattern in its east-southeastern part. Alexey Zolotov found it only because he knew what he was searching for and was attentive to details.

Later, it turned out that another herringbone pattern, though less distinct, existed not only in the east-southeastern part of the Tunguska territory but in the western part as well. The east-southeastern band appeared, in all probability, due to the influence of the ballistic shock wave of the TSB flying over the Tunguska taiga before its explosion. But how was a similar structure formed in the western part of the area? Let's remember that the area of the leveled forest has *two* axes of symmetry – one running from the east-southeast to the west-northwest and the second running practically from the east to the west. So, were there on that summer day of 1908 over the Great Hollow *two* space bodies, and not just one, as the simplest scenario of the Tunguska event presupposes?

Assuming that the TSB was single, we meet with a complicated problem: *what* was the ballistic shock wave reflected in the western part of the leveled forest area? According to the simplest scenario, the TSB path terminated over the Stoykovich Mountain in a powerful explosion. But what if the TSB (or a part of it) could somehow survive its fiery bath and went farther and left traces in the western part of the leveled forest area? For the explosion with a magnitude of at least 40 Mt and a maximum of 50, this assumption looks rather bold, but at least this scheme does not need another space body – which would have complicated the picture of the event too much. For example, couldn't the Tunguska meteorite (a simple iron or stony space body, or the icy core of a comet) have ricocheted from the lower atmosphere?

The "ricochet hypothesis" was originally advanced in 1929 by Ukrainian astronomer Igor Astapovich. Strictly speaking, he meant what might be called a quasi-ricochet. According to his supposition, the TSB flew through the atmosphere at an escape velocity (that is, faster than 11.2 km/s) that allows any material body to overcome Earth's gravitation. Having passed over the Great Hollow at its perigee – the minimal distance from the planet – it did not stop but traveled on into space. The air resistance only slightly distorted the TSB orbit. Astronomers have in fact observed how meteorites enter and leave Earth's atmosphere, though this usually occurs at much greater heights than it did with the TSB. So this idea was not absurd. Surprisingly, four years later Astapovich himself gave up his hypothesis – thinking it unnecessary – and returned to this idea again only in 1963.[8] He believed that there was no explosion at Tunguska; instead, the forest was leveled by the ballistic shock wave of the swiftly moving cosmic body.

Other scientists have put forward similar ideas, usually trying to explain away the lack of any meteoritic substance in the Great

Hollow. It is evident, however, that to leave the atmosphere after flying over the Southern swamp, the TSB must have moved in a *very* flat path, with its slope equal to 0° exactly, so there would have been no radial leveling of the taiga. Instead, the fallen trees would have demonstrated a very distinct herringbone pattern. The idea of a TSB ricocheting off a lower layer in the atmosphere was put forward in 1984 by Dr. Evgeny Iordanishvili. However, he did not reconcile his theory with the leveled forest area in the Great Hollow.[9] Such an analysis was subsequently performed by Gennady Plekhanov.[10] Actually, if a trace of the ballistic shock wave in the leveled forest extended beyond the epicentral zone, it means that the TSB (or a piece of it) survived the explosion and continued its motion forward. Having a sufficiently great speed, it could have flown into space, but most probably it would have fallen somewhere not far from the epicenter. To help explain this, Plekhanov recalled a local earthquake that occurred on June 30, 1908, in the Yenisey taiga at the Greater Pit River, about 460 km to the west-southwest from the explosion site, as well as unpublished reports of some eyewitnesses who saw on the same morning a bolide fly over Baykit (310 km to the west-northwest). He believes that having ricocheted, a piece of the TSB (or the TSB itself) fell in this region, producing the earthquake. However, the chance of it being found there is very low, the region being so vast.

Plekhanov's idea was expressed in "qualitative" terms, without much mathematics, and looked rather attractive. But soon, mathematical calculations revealed weak spots in his considerations. ITEG members Igor Doroshin and Evgenia Shelamova tried to find out if the ricochet effect would have been physically possible – and their results have destroyed this beautiful scheme. It turns out that changing its flight direction from the descending trajectory to an ascending one, the TSB would have endured a g loading (Earth gravitation effect plus accelerative forces) exceeding the normal Earth gravitation by 5,000 times! On the one hand, no "lower layer in the atmosphere" could be dense enough to turn the TSB so sharply. On the other hand, even if this had happened, the g loading would have immediately crushed the space body. In other words, there could have been no real ricochet over the Great Hollow.

Nonetheless, the herringbone pattern extending for 20 km in the western part of the leveled forest area remains a fact, and the simplest explanation for this fact is the survival of all or part of the TSB after the explosion. No ricochet is needed, though. Doroshin and Shelamova believe that the space body (or a swarm of its debris) traveled a distance of some 20 km after the explosion and before falling to Earth relatively close to the Great Hollow, where it might be found today.[11] However, nothing of this sort has so far been discovered in this region.

Now, when the “main trace” of the Tunguska phenomenon – namely, the butterfly-like area of 2,150 km^2 of the leveled forest – is scrutinized, the simplest Tunguska scenario (one space body – one explosion – no maneuvers) proves to be at variance with the facts.

Two axes of symmetry of this area hint at two space bodies; several local epicenters, found using aerial photography, suggest several smaller explosions; and instead of a smooth TSB flight straight to the place of its disintegration there appears a ricochet or another change in the TSB flight direction. Yes, these complications make it more difficult to produce mathematical models of the Tunguska event, whose abstract character was with good reason criticized by experienced meteor specialist Dr. Vitaly Bronshten. But to unravel this mystery without paying serious attention to these facts would not be possible.

The thermal burn of the trees, generated by the light flash, is the second most important trace of this great event. Tunguska researchers are dealing in their studies with many types of thermal injuries to the Tunguska vegetation. Some types look like the normal consequences of a forest fire, but others do not. The forest fire started by the Tunguska explosion could not be called normal, either. Kirill Florensky in the expedition of 1958 came to the conclusion that the fire “originated at the point of meteorite impact and spread in the usual manner,” that is, outward.[12] To say nothing about the lack of any “point of meteorite impact” in the Great Hollow, this is simply not the case. In actual fact, as was proved subsequently, the Tunguska forest fire started simultaneously over a vast territory and did not spread beyond the boundary of the area of the leveled trees. In many places it faded soon, within 24 hours.

Strange fiery injuries to the vegetation attracted the attention of Tunguska investigators from the very beginning of their work in this region. Leonid Kulik, when breaking through the taiga to the center of the Great Hollow for the first time, was astonished by traces of a strange surface burn covering all vegetation in the region. These traces were very different from the consequences of an ordinary forest fire. That is, a forest fire did also take place here, and in the eastern and southeastern directions from the epicenter the forest did burn away, but the "surface burn" was something very different. As Kulik emphasized, the majority of leveled trees were not charred; instead, they were just singed, but traces of this singeing could be seen everywhere to a distance of 10–15 km from the center of the flattened forest area. They remained even on isolated pieces of dry land separated by water, including single trees growing among the swamps.[13] Not only trees and bushes but even marsh moss had kept these fiery marks.

It was the burn and not the subsequent forest fire that destroyed crowns and injured the bark of many trees during the Tunguska explosion. Such heat-sensitive wood species as birch, aspen, alder, and also dark conifers – pine, fir, and cedar – perished almost completely; it was mainly fire-resistant larch that had survived. Igor Doroshin correctly noticed that even in the fiercest forest fires in the taiga, fir and cedar trees never perish completely, and a considerable number of these trees survived in more humid and better shielded zones.[14] But the "fiery factor" at Tunguska acted in an unusually uniform manner. Hardly anything but a light flash could have produced such results.

Of course, Leonid Kulik did not think about any "light flash": in his time such an idea did not exist. It arose only after the first atomic explosions, when a powerful emission of light proved to be one of the most striking factors of nuclear explosions. To explain the peculiar thermal injuries of the taiga vegetation, Kulik applied his favorite hypothesis about a "fiery jet of burning-hot gases and cold bodies," which, he believed, must have struck the Great Hollow when the meteorite had split apart over it. According to his observations, the thermal factor acted downward – sometimes singeing a whole tree, sometimes influencing only its upper part. He did not scrutinize the traces of the surface burn, but at least he described these traces in sufficient detail, and his descriptions are especially valuable since they were then relatively fresh. Fortunately or unfortunately, the taiga was recovering from the consequences of the light burn much faster than from other effects of the catastrophe. To have the fallen trees rot and young growth replace them, many decades were needed; but a tree that survives a forest fire heals its injuries far sooner. The "bird's claws" (broken twigs, charred fractures) that had easily been seen in the taiga to participants of Kulik's expeditions in the late 1920s could not be found by the members of the academic team of 1958 and the ITEG-1 expedition of 1959. These "claws" were accidentally rediscovered only a year later.

Nevertheless, many years of painstaking work by Tunguska investigators made it possible to unravel the situation and to prove that there had in fact been a powerful light flash over the Southern swamp. The specialists continued to argue not about this fact but only about the magnitude of the flash. What share of the whole energy of the Tunguska explosion was emitted as visible and infrared light?

To answer this question, it was necessary, first of all, to find the lost traces of the thermal burn, which had so surprised Leonid Kulik. Of course, there was no reason to mistrust him (especially as Evgeny Krinov had also seen these strange marks). But where were they now? As it turned out, many years after the Tunguska explosion the burn traces resembled fissures filled with resin, up to half a meter in length, running along the branches. When studying living larches in 1961 that had survived the Tunguska catastrophe, two ITEG members – physicist Igor Zenkin and radio engineer Anatoly Ilyin – paid attention to the unusual damage of their branches. Through their upper parts stretched long ribbon-like cracks filled with wood resin. Judging from the number of tree rings, the cambium was damaged in 1908, after which the "wounds" began to heal, forming "resin scars." It is noteworthy that all these scars faced the center of the Great Hollow.

But finding the burn traces was just the first step in this investigation. Now the researchers had to study them in detail. This was difficult and dangerous work, perhaps the most dangerous in all Tunguska research. "Burn-hunters" selected a larch some 100–200 years old facing the center of the Great Hollow and growing in open terrain: in the middle of a swamp or at the edge of the forest. Having put on homemade foot climbers, a researcher climbed up the tree some 20 meters in height, trying to reach the top. There he examined its branches, searching for those having "resin scars." After finding such a branch, its coordinates were measured, namely, the height of its location, direction, the angle between the branch and the vertical; all data being marked on the branch itself. Then the branch was cut off and thrown down. And this process was repeated many times – at 20 meters above the ground, on the treetops of larches that swayed even in a weak wind. The selected branches were sawed up into separate pieces and examined again to eliminate any possibility of a fault.

Having finally established that it was a burn injury, the samples were sent to Tomsk, Novosibirsk, and Moscow to be investigated in well-equipped laboratories. Under a microscope, the age of the branch itself and that of the injury were verified and some additional parameters measured. In this way the Tunguska "burn-hunters" have processed more than 400 larches and collected some 1,800 samples!

Experienced specialists in forestry determined that the strange injuries were due to local heating of cambium to temperatures of 65°C or more. The results obtained are in a lengthy "Catalog of Thermal Injuries of Larch Branches."[15] This research produced some interesting results. In particular, it was found that the zone of the light burn was considerably less than the zone of the leveled forest; its length is some 18 and 12 km wide. In shape it resembles an egg, the axis of symmetry being directed almost exactly from the east to the west. Also, having discovered traces of the light burn of the trees, Igor Zenkin and Anatoly Ilyin immediately realized that this data could be used both to determine the coordinates of the source of the light flash and to estimate its energy.[16] For this purpose, they selected branches with the most distinct burn injuries. Thus the position of the source of the light flash was determined by the parallactic method (cross-bearing from different points). It was located over the southern bank of the Southern swamp, at a distance of more than 2 km southeast from the "epifast," the epicenter determined by Wilhelm Fast.[17] We can therefore conclude that the center of the explosion did not coincide with the center of the light flash. Strange indeed! But at least, these two centers lie practically along the first TSB trajectory determined by Wilhelm Fast. Dmitry Demin, a founding father of the ITEG, commenting on these facts said: "The discrepancy between the centers of the explosion and light flash may testify to their spatial disconnection."[18] That is, the center of explosion was *not* the center of the light flash! Well, it appears again that the true picture of the Tunguska phenomenon goes far beyond its simplest models...

Incidentally, Demin did not restrict his consideration to this short remark. Together with his friend Vladimir Vorobyov, he attempted to check the result obtained by Zenkin and Ilyin. After all, a tree is a living body, constantly growing and changing. A "resin scar" today may not face the same direction as it did in 1908 after the light flash. So could there be another, more precise way to find the coordinates of the flash? Vorobyov and Demin looked for the thickest tree branch to have been burnt and measured its diameter. Evidently, the higher the heat in the Great Hollow during the Tunguska explosion, the thicker the branches that would have been affected. Therefore, diameters of the thickest burned branches are good indicators of the intensity of the thermal flow in different places of the area of light burn. Gathering these figures and placing them on a map we can encircle the point from which the light had been emitted. Having processed the collected data, the researchers found that the center of the light flash had been at an altitude of 7 kilometers and 2.5 kilometers to the east from the "epifast."[19]

Now, it seems that the calculations, performed by Ilyin and Zenkin, confirm the *first* TSB trajectory determined by Fast (according to which the TSB flew to the west-northwest). At the same time, the calculations performed by Demin and Vorobyov confirm the *second* Fast trajectory (the TSB flew practically to the west)! In both cases the center of the explosion is separated from the center of the light flash by a considerable distance. Again and again, the specter of a second TSB appears on the map of the Great Hollow...

By the way, the lost and found "bird's claw" proved to be very informative. As Valery Nesvetaylo, a biologist from Tomsk, found out, all of them appeared only on those broken branches that had been dead – and therefore dry – at the moment of the catastrophe. What is more, these burns formed due to a thermal stream directed upward, not downward. It looks as if the light flash first ignited dry moss, fallen pine needles, and other flammable material covering Earth's surface in the taiga, and only after that did the fire burn the ends of dry branches that had been broken by the blast wave of the explosion. This finding made it possible to understand how the forest fire had originated simultaneously over such a large territory.

The forest fire, resulting from the powerful light flash, did not go beyond the boundary of the leveled forest area. It did not even reach its boundary. However, it covered a territory that was considerably (about five times) larger than the area of the light burn (see Figure 6.8). A very strong wind blowing immediately behind the front of the blast wave scattered the burning branches and pine needles up to a distance of some 30 km from the epicenter, but after that a "reverse" mechanism came into effect. Both the fiery

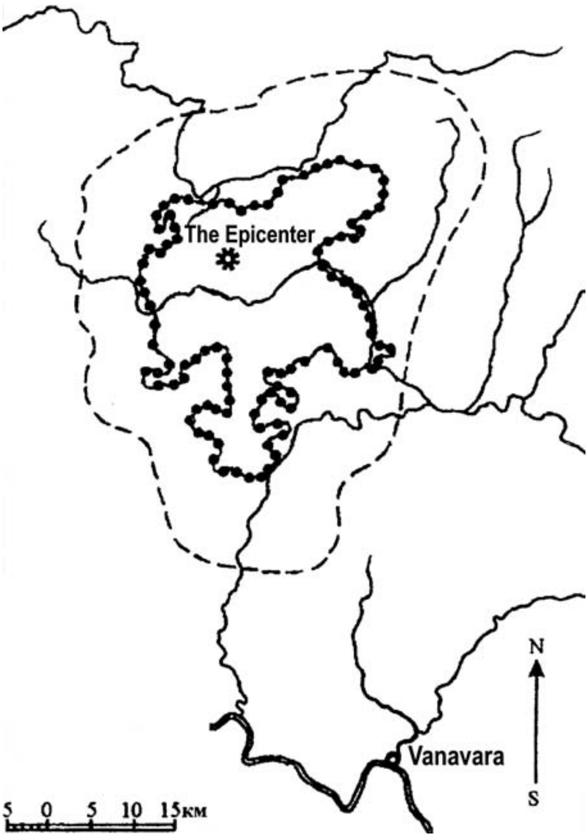

FIGURE 6.8. The zone that was occupied by the post-catastrophic Tunguska forest fire on the background of the "Fast's butterfly" (*Source*: Vasilyev, N. V. *The Tunguska Meteorite: a Space Phenomenon of the Summer of 1908.* Moscow: Russkaya Panorama, 2004, p. 137.).

ball of the Tunguska explosion and the intense forest fire near the epicenter formed a powerful pillar of hot air. The result: the strong wind changed its direction, blowing to the center of the leveled forest area. It fanned the flames of the forest fire, preventing it at the same time from spreading beyond the boundary of this area. A "fiery storm" developed, something like that which occurs when nuclear bombs are tested in the atmosphere.

As Figure 6.8 illustrates, the shape of the forest fire area is very irregular. This is understandable: the flame was spreading in this or that direction, following the terrain. Contrary to that, the burnt area from the light flash looks more regular. It may be described as

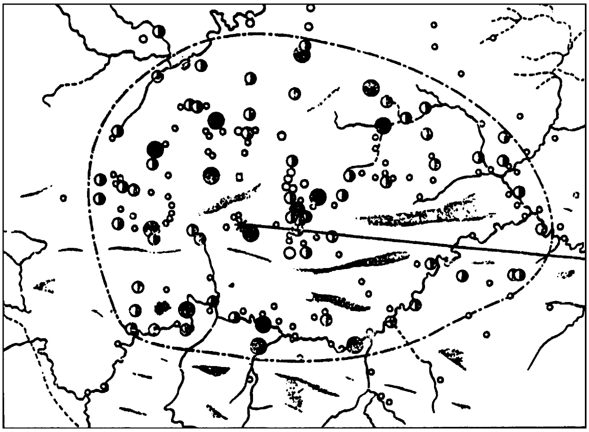

FIGURE 6.9. Smoothed outlines of the area in the Great Hollow where the vegetation was burned by the light flash of the Tunguska explosion (*Source*: Vasilyev, N. V. *The Tunguska Meteorite: A Space Phenomenon of the Summer of 1908.* Moscow: Russkaya Panorama, 2004, p. 131.).

egg-shaped, its butt-end pointing east and its pointed end toward the west (see Figure 6.9). But if we take into consideration the distribution of the intensity of the light-burn damage, a much more complicated figure arises (see Figure 6.10). It extends up to 16 km to the east from

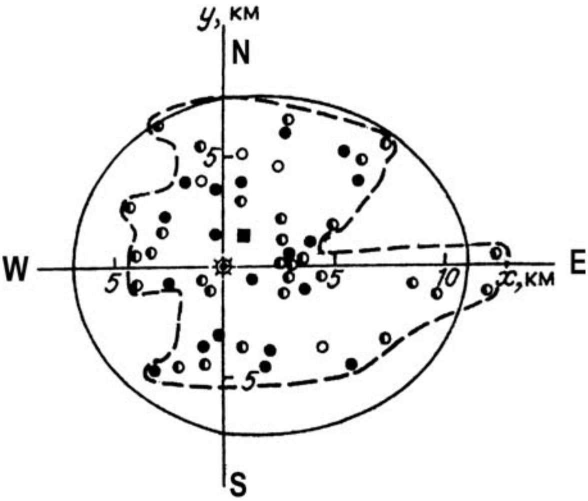

FIGURE 6.10. True (not smoothed) outlines of the Tunguska burned area from the light flash (*Source*: Zhuravlev, V. K., Zigel, F. Y. *The Tunguska Miracle: History of Investigations of the Tunguska Meteorite*. Ekaterinburg: Basko, 1998, p. 103.).

the epicenter, with two separate zones being well noticeable within it – the zone of intense burns and the zone of weak burns. Theoretically, traces of severe burning must have remained at the center of this figure and those of weak burning at its periphery. In reality the picture looks much stranger: the zone of weak burning cuts from the east into the zone of severe burning; and directly under the TSB trajectory the burning is considerably weaker than that at a distance from it. But at the very center of the figure there is evidence of the maximum level of the light flash: on a larch were found the thickest burnt branches of all.[20]

If the source of the light flash had had a regular spherical shape (as, by the way, usually happens in nuclear explosions), nothing of this sort could have taken place. Starting from the shape of the thermal burn area on the ground and using methods of computer tomography, some ITEG researchers attempted to determine the shape of the source of light emission. The result obtained by the ITEG member Stepan Razin was very peculiar: it was neither a ball, nor an egg, nor even a cylinder. The source of the light flash looked like the cap of a mushroom: a convex surface at the top and concave at the bottom.

It is worth noting that initially the idea of the light flash as the main source of the catastrophic forest fire got a hostile reception from the meteorite specialists. For them it looked too much like the "atomic heresy" – especially as the pioneer investigator of this question was the chief proponent of the nuclear hypothesis, Alexey Zolotov. However, in time all the participants in the Tunguska investigations and discussions unanimously agreed that the share of light in the total energy of the Tunguska explosion could not be less than one-tenth. But problems with the light flash were still far from being resolved. New difficulties emerged when researchers realized that the structure of the thermal burn zone was more irregular than previously thought. Near severely damaged larches, one could see other trees whose branches were quite healthy and devoid of any sign of thermal burn. In 1929, Evgeny Krinov had a similar problem when he found several groups of living trees, practically undamaged and standing not far from the epicenter. "It is incomprehensible how these small groves survived," he wrote, "since there are around them no shields against the blast wave."[21]

For the light flash this picture looked no less strange than for the blast. Mutual shielding could not explain away all cases, even taking into account that decades had passed since the catastrophe and that many traces of the thermal burn would have vanished. (Recall that Kulik saw these traces in the leveled forest area practically everywhere.) There therefore seems no escape from the conclusion that the light flash was very uneven. The intricate inner structure of the zone of thermal burn also testifies to this supposition. And last but not least, even at the epicenter of the Tunguska explosion some trees belonging to species highly sensitive to overheating – such as cedar and birch – somehow survived.

Dr. Nikolay Kurbatsky, a scientific worker of the Krasnoyarsk Institute of Forestry and a specialist in forest fires, noted that there was an evident contradiction between the severity of thermal injuries to tree branches and their final survival. To leave such scars as are still seen on Tunguska trees, the light flash must have been *very* powerful. But needles of pines, cedars, and firs die when heated to 60°C or more for several seconds. The "resin scars" testify that the Tunguska light flash was powerful enough to heat a branch one centimeter across to 65°C, at which point the cambium will die and a burn trace will appear. But in this case all the needles of the tree – and therefore the tree itself – should have perished. No living cedars, firs, and pines would have been left in the epicentral zone. In actual fact, there have remained some cedars, firs, and pines bearing no traces of the thermal burn at all. Therefore, the light emitted somehow bypassed them.[22] Two absolutely undamaged cedars grow at the western edge of the Southern swamp – practically at the epicenter. How could that happen?

Zolotov supposed that individual trees and small groves could have been shielded from the light flash by lumps of dense fog, typical in the Tunguska taiga, whose dimensions may reach tens and hundreds of meters. Hardly so. First, the undamaged trees stand, more often than not, side by side with the burnt ones. And second, the undamaged trees, as a rule, carry no noticeable structural injuries, either. The fog could probably protect the trees from the light emission – but definitely not from the blast wave. So, the "paradox of the Tunguska forest fire," formulated by Igor Doroshin, is most probably valid: a light flash with energy sufficient to ignite dry moss would inevitably have destroyed the Tunguska pines, cedars, and firs within the boundary of the light burn area. Since this is not the case, the flash must have resembled a host of powerful "thermal rays," rather than a simple fireball.

There exists, by the way, one more puzzling but little-known feature of the Tunguska forest fire that defies explanation. Leonid Kulik, emphasizing its dissimilarity from ordinary forest fires, wrote: "We do not know any other case where, after a forest fire had almost completely devastated the taiga, the dried-up trees would have been standing for 22 years, remaining so well-preserved, not darkened, but with amber-colored wood. We have been successfully using this wood as a construction material and as superb firewood."[23]

Igor Doroshin, having paid special attention to this note of the pioneer of Tunguska studies, consulted specialists in forestry and forest fires, asking them if this could have taken place? The specialists answered in unison: never! So Doroshin had to organize an excursion for them to the Great Hollow to show them the wood. Having checked that the trees did in fact perish in 1908, these specialists had to acknowledge that the Tunguska forest fire had led to the conservation of the wood and bark of the "telegraph trees." But the mechanism of this conservation still remains a mystery.[24]

Admittedly, having scrutinized the two largest traces of the Tunguska phenomenon – the areas of the leveled forest and the thermal burns – researchers did obtain a lot of valuable information, but they could not develop that information into keys to unlock the Tunguska enigma. Or rather, the keys were made but proved ineffective. They turn, so to speak, equally well in two opposite directions. Parameters of the leveled forest area correspond both to a space body of unknown nature that flew slowly in a flat path and exploded over Stoykovich mountain, and to a normal stone meteorite or to the core of a comet that flew with enormous speed in a steep path and broke apart, rather than exploded, over the same mountain. In the first case, the forest was leveled by the blast wave, in the second case by the ballistic shock wave – perhaps with a small additional blast at the very end of the TSB flight. Similarly, the powerful light flash might have been generated either by a thermonuclear explosion or by the radiance of a "super-bolide" that had been scorched hot when moving through the atmosphere. Effects of the second order (such as two axes of symmetry of the area of leveled forest or peculiarities of the zone of light burns) are certainly interesting and hint at a more intricate picture of the event, but they alone give no way of deciding between different models of the Tunguska phenomenon. So it only remains to try other locks – and other keys. Let's now turn to the magnetic key – also large, definitely important, and probably deserving more attention than was accorded to it in the past. A separate chapter will be the minimal mark of respect we can pay to this underestimated trace of the Tunguska explosion.

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3. Its coordinates proved to be $60°53' \, 09'' \pm 6''$N and $101°53' \, 40'' \pm 13''$E.
4. *Memorial* is a community of several human rights organizations in post-Soviet countries – Russia, Ukraine, Kazakhstan, Latvia, and Georgia. Its main task is the awakening and preservation of the societal memory of the severe political persecution in the recent past of the Soviet Union.
5. More exactly $(6 \pm 3) \times 10^{20}$ ergs.
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15. The program "Thermal Burn" was performed under the supervision of Anatoly Ilyin. Such noted scientists participated as mathematicians Boris Shkuta (Novosibirsk) and Vladimir Vorobyov (now professor and chief of the Department of Applied Mathematics of Arkhangelsk University), Evgeny Gordon (now professor and a member of the European Academy of Sciences), Vladimir Schnitke (now chief of the St. Petersburg branch of the *Memorial* Society), and many other ITEG members.
16. Zenkin, G. M., Ilyin, A. G. About the light burn of trees in the region of the Tunguska meteorite explosion. – *Meteoritika*, Vol. 24, 1964 (in Russian).
17. Geographical coordinates of the center of the light flash are as follows: 60°52′48″N, 101°55′18″E, its altitude 4,800 m.
18. Vorobyov, V. A., Demin, D. V. New results of investigation of thermal injuries of larches in the region of the Tunguska meteorite fall. – *Problems of Meteoritics*. Tomsk: University Publishing House, 1976, p. 60 (in Russian).
19. Ibid., p. 62.
20. Zhuravlev, V. K., Zigel, F. Y. op cit, p. 103.
21. Krinov, E. L. *The Tunguska Meteorite*. Moscow: Academy of Sciences of the USSR, 1949, p. 160 (in Russian).
22. See Doroshin, I. K. op cit.
23. Kulik, L. A. op cit., pp. 15–16.
24. Doroshin, I. K. op cit.