THE

TUNGUSKA

EVENT

Compiled by

Campbell M Gold

(2012)

CMG Archives
http://campbellmgold.com

(This material was compiled from various unverified sources)

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Introduction

The Tunguska event was a powerful explosion that occurred at 60 degrees 55'N-101 degrees 57'E, near the Podkamennaya ("Under Rock") Tunguska River, in what is now Evenk Autonomous Okrug, at 07:17 AM (local time) on 30 June 1908.

Something exploded 5 to 10 kilometres (3 to 6 miles) above the Stony Tunguska River; and approximately 2,150 square kilometres of Siberian taiga were devastated and some 80 millions trees were overthrown.

Even now (2012), it is still not clear what was the source of the explosion - was it the result of an exploding comet fragment, meteoroid, or something else?

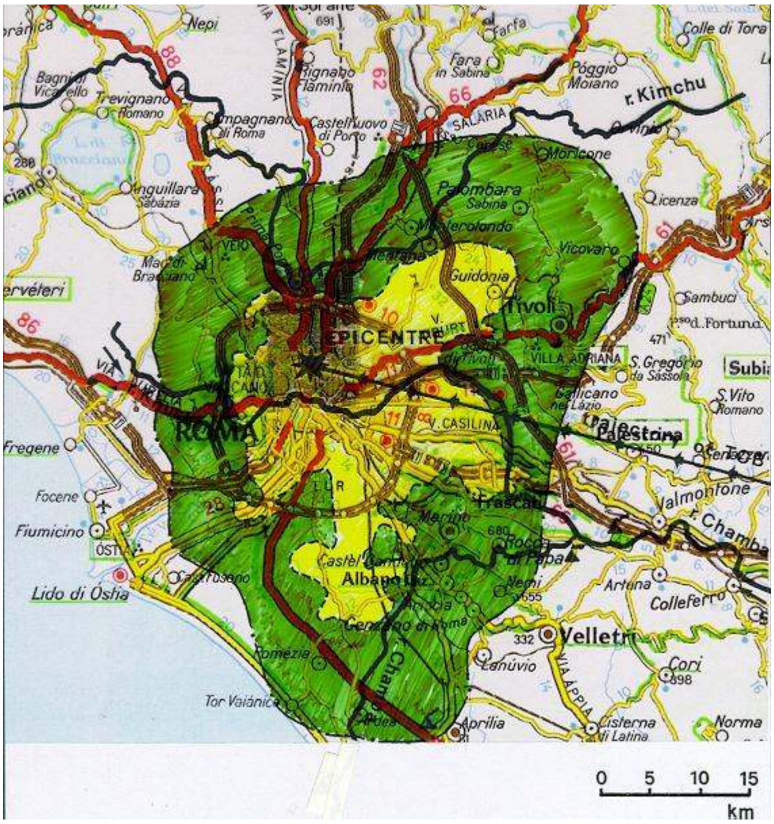
Above - Location of the Tunguska Event

The explosion was 1,000 times more powerful than the atomic bomb dropped (06 Aug 1945) on Hiroshima, Japan; and it flattened an estimated 80+ million trees over a 2,150 square kilometre (830 square mile) area.

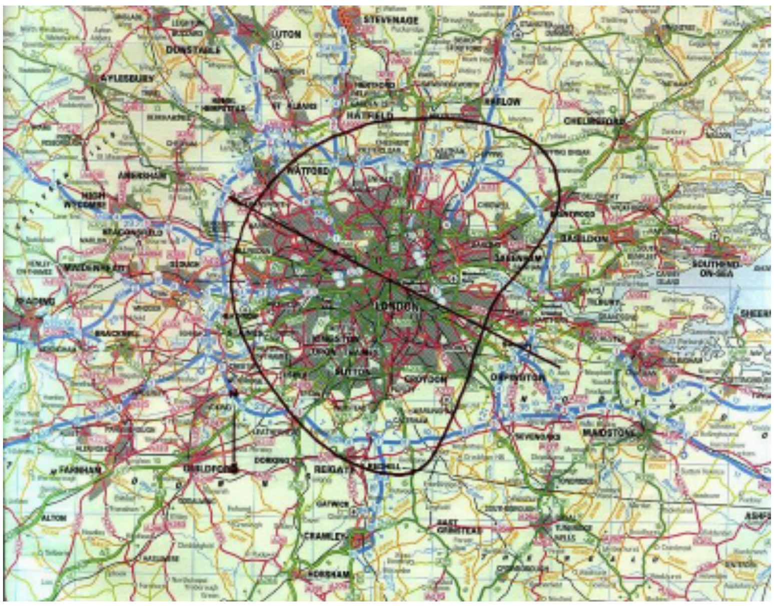
The estimated level of the shockwave from the blast would have measured 5.0 on the Richter scale.

The Tunguska incident is the largest impact event in recorded history; and despite many expeditions and careful searches neither craters nor meteoric debris have been discovered.

An explosion of this magnitude would have the power to destroy a large metropolitan area.



Above - Rome area compared with that of the Tunguska devastation.
Yellow: area of charred trees. Green: area of felled trees



Above - London area compared with that of the Tunguska devastation.

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The Object's Size

Different studies have suggested varying estimates of the object's size, with general agreement being that it was some 30 or so meters across.

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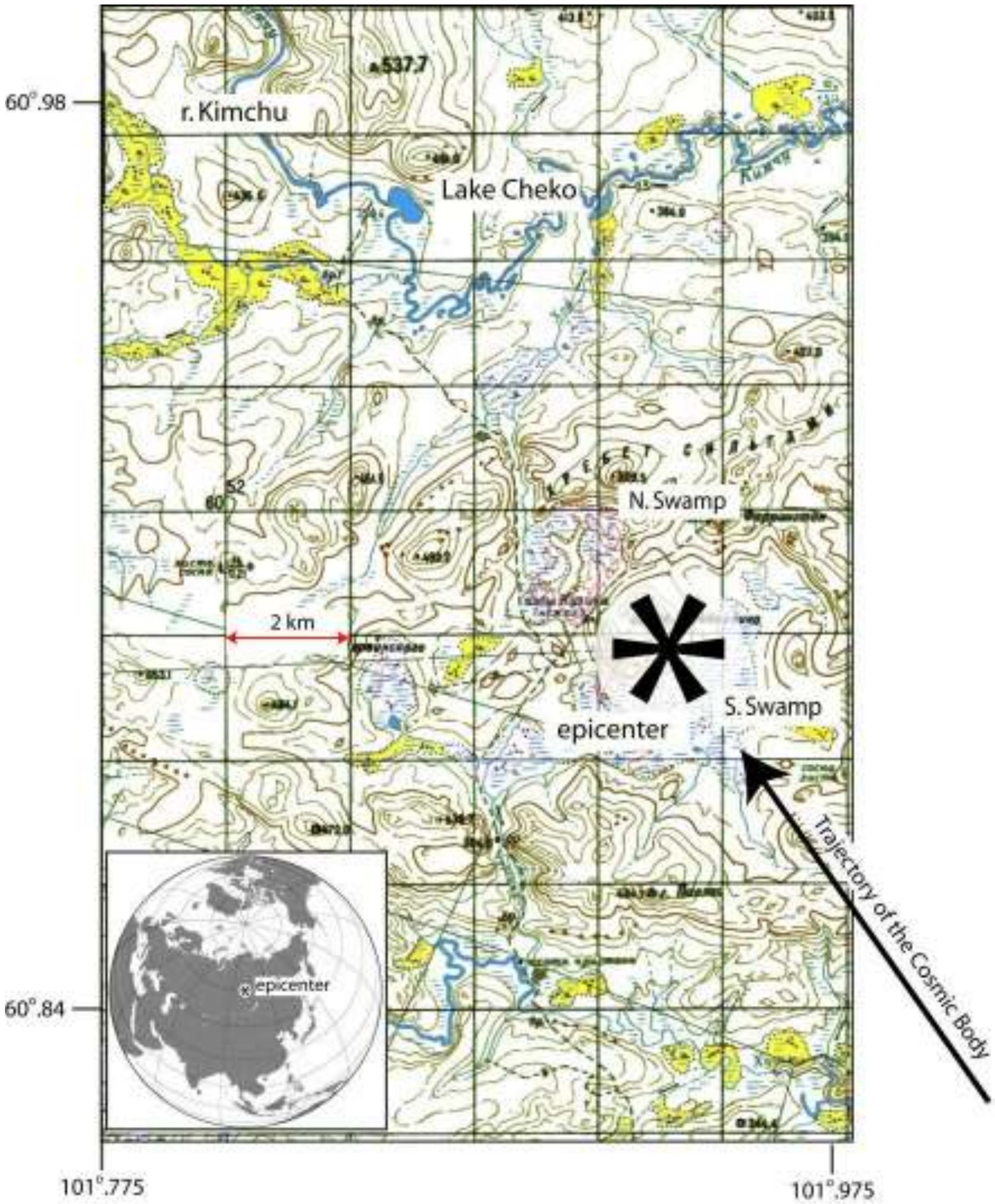
The Event Site



Above - The Event Site
From: Terra Nova, Vol. 19, n. 4 (2007) © Blackwell Publishing Ltd
Topographic map of the Tunguska Event region.
Lake Cheko and the site of the inferred epicentre are indicated, as well as the probable trajectories for the cosmic body.

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The 1883 Map


КАРТА
АЗІЯТСКОЙ РОССІИ
СЪ ПРИЛЕГАЮЩИМИ КЪ НЕЙ ВЛАДѢНІЯМИ
СОСТАВЛЕНА
ПРИ ВОЕННО ТОПОГРАФИЧЕСКОМЪ ОТДѢЛѢ
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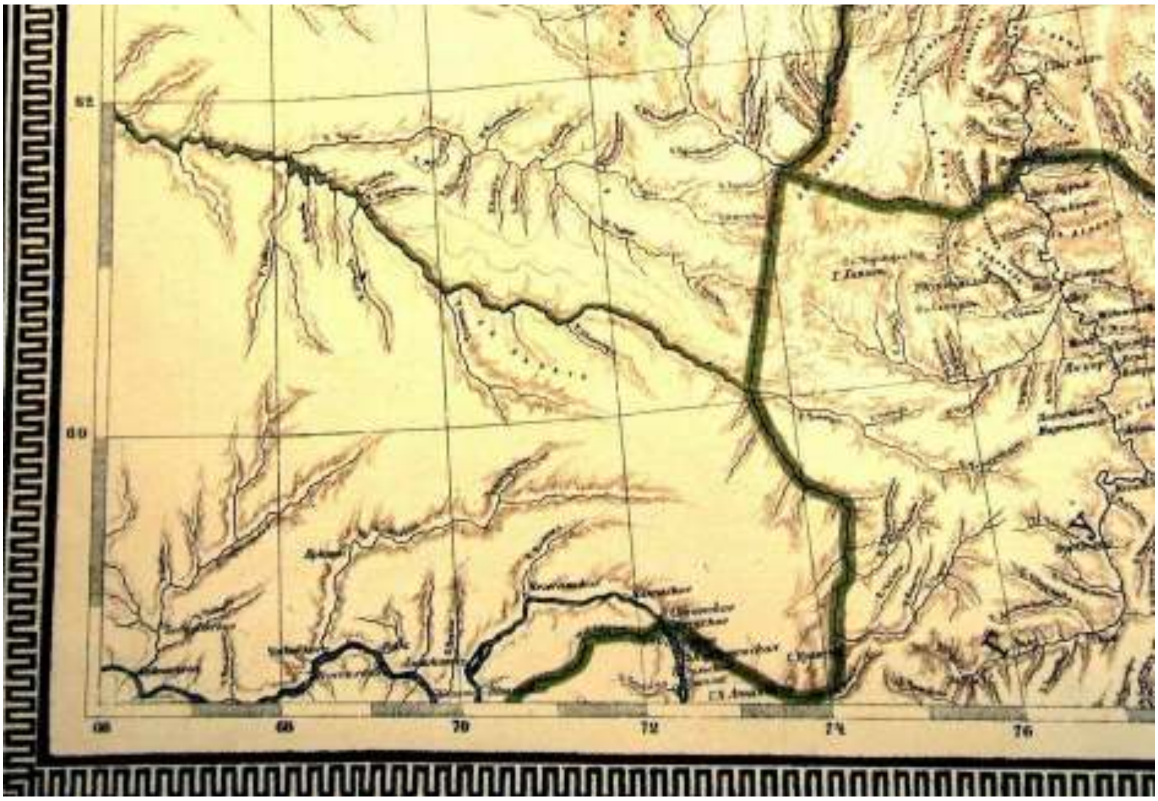
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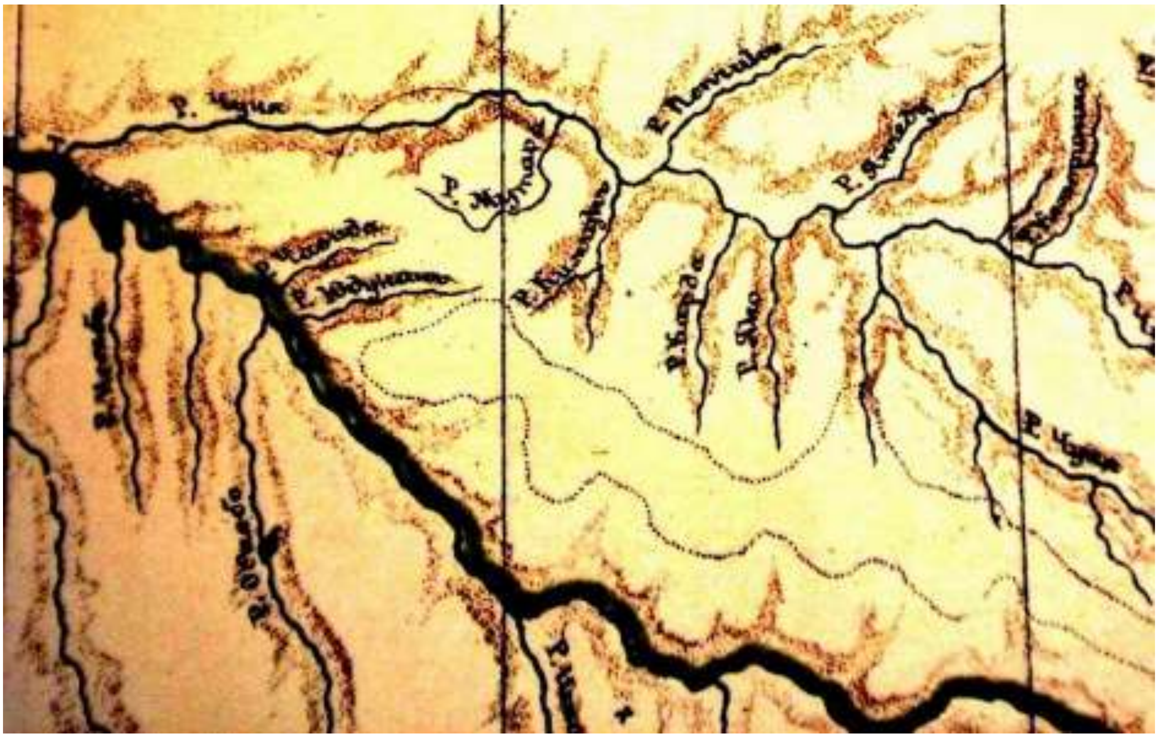

Above - The only map of the site available before 1908
was the map elaborated in 1883 by the Russian Army Headquarters.

The longitude is here given in degrees from the "Pulkovo Meridian", near S. Petersburg, at 30° 19' 34''E from Greenwich.

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Kulik Expeditions

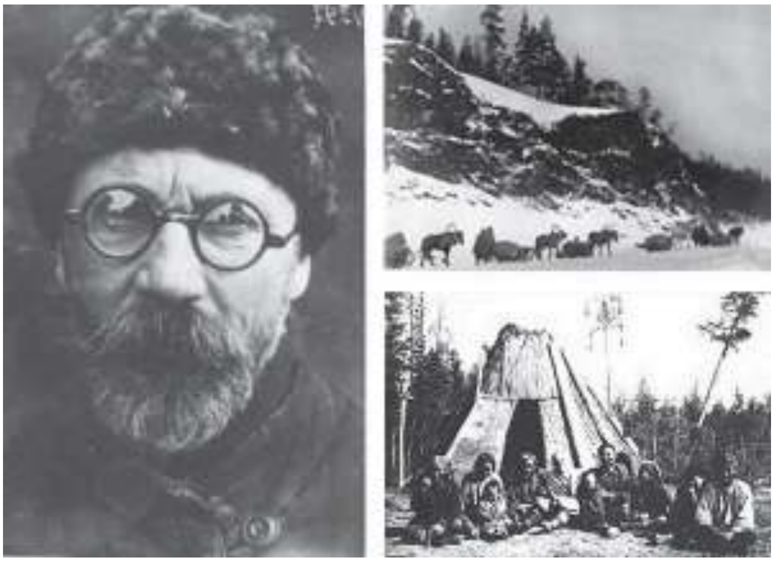
In 1921 Professor Leonid A. Kulik was charged with the task of locating and examining meteorites that had fallen within the Soviet Union. While preparing for this expedition, he came across an account of an explosion in Tunguska, Siberia, reprinted from an old newspaper:

> *...a huge meteorite is said to have fallen in Tomsk several sagenes from the railway line near Filimonovo junction and less then 11 versts from Kansk. Its fall was accompanied by a frightful roar and a deafening crash, which was heard more then 40 versts away. The passengers of a train approaching the junction at the time were struck by the unusual noise. The driver stopped the train and the passengers poured out to examine the fallen object, but they were unable to study the meteorite closely because it was red hot...*

Strangely enough the story turned out to be wrong in almost every detail, but even so, Kulik had never heard of this impact before and it caused him to go searching for additional old newspaper accounts. By piecing these stories together he determined that the event, which he felt sure was the result of a meteorite fall, must have been enormous. Kulik decided to see if he could find the site during his trip.

During his first expedition(1921) Kulik only managed to establish the general location of the blast area, and he did not actually visit it. Subsequently, Kulik continued to collect reports and stories about the event.

Kulik returned to the Academy with enough photographs and documentation to convince even his most skeptical colleagues that something unusual had happened along the Tunguska river. He led two more expeditions back to Siberia, one in 1929 and another in 1938; however, he was never able to establish that the cause of the blast, and even today the exact cause of the explosion remains unknown.



Above - Professor Leonid A. Kulik and his expedition (1927?)

Above - Trees felled by the Tunguska explosion.
Credit: the Leonid Kulik 1927 Expedition.

The parallel fallen trees indicate the direction of the blast wave.

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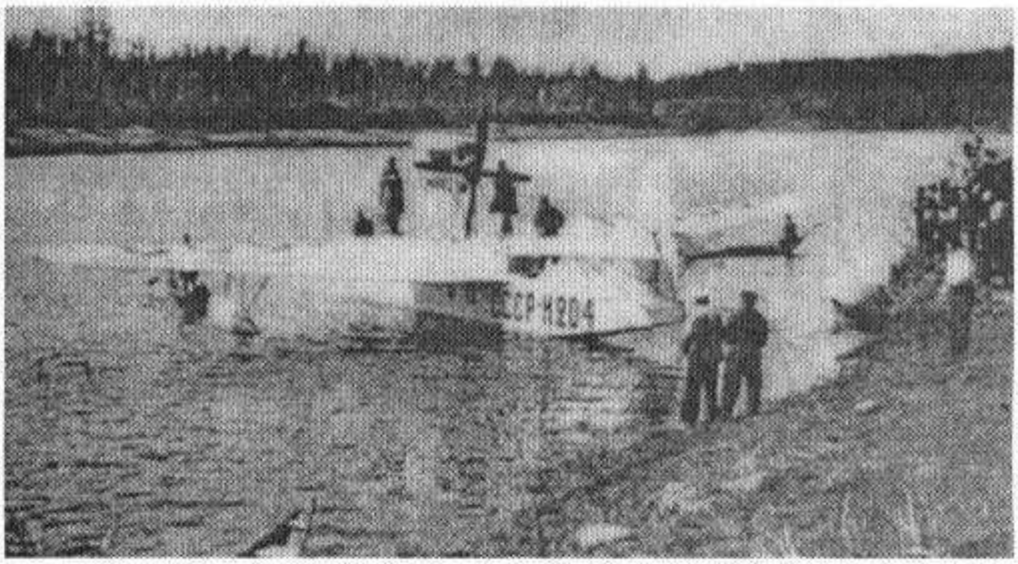
The 1938 Aerial Photographic Survey

The 12 July 1937, a first attempt to begin the aerial survey was made with an hydroplane N-31 of the Polar Aviation. Unfortunately, the hydroplane crashed near Vanavara, as it landed in the Podkamennaya Tunguska river. L. A. Kulik, the photographer S. V. Petrov, and the pilot Khudonogov were unhurt, but the survey had to be postponed till the spring of 1938.



Гидросамолет Н-204 на Подкаменной Тунгуске у фактории Вановара

Above - The hydroplane N-204 of the Polar Aviation,
on the Podkamennaya Tunguska River near Vanavara factory
(Acknowledgement - Tunguska Page of Bologna University:
http://www-th.bo.infn.it/tunguska/)

On 23 May 1938, the newspaper "*Aviatsionnaya gazeta*" reported that the survey was planned for June 1938.

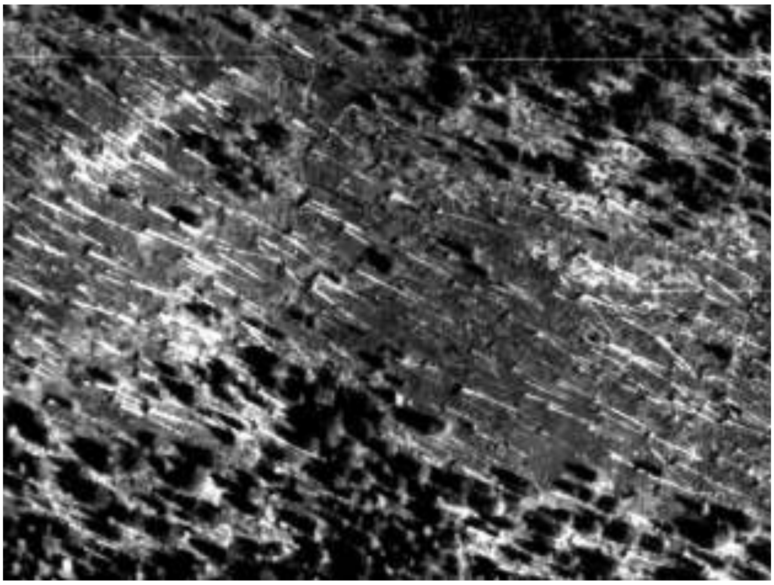
The aerial photo survey was carried out from 27 June 1938 to the beginning of August 1938 by Petrov and Kalmykov with the pilot Charnetskiy ("Aviatsionnaya gazeta", 47 (169) 27 Aug 1938).

The delay meant that the survey was made when all the vegetation was covered with leaves, thus significantly masking the trees overthrown by the explosion.

In 50 flight hours, 1500 aerial photographs were taken - the survey covered (on a scale of 1:4700) an area of devastated forest roughly equal to 250 km^2, i.e. with a mean radius of 12 km from the epicentre.

Kulik's Aerial Photographic Survey - July-August 1938

Above - Portion of one of the photos from Kulik's aerial photographic survey (1938) of the Tunguska region.
(Acknowledgement - Tunguska Page of Bologna University: http://www-th.bo.infn.it/tunguska/)



Above - Portion of one of the photos from Kulik's aerial photographic survey (1938) of the Tunguska region.
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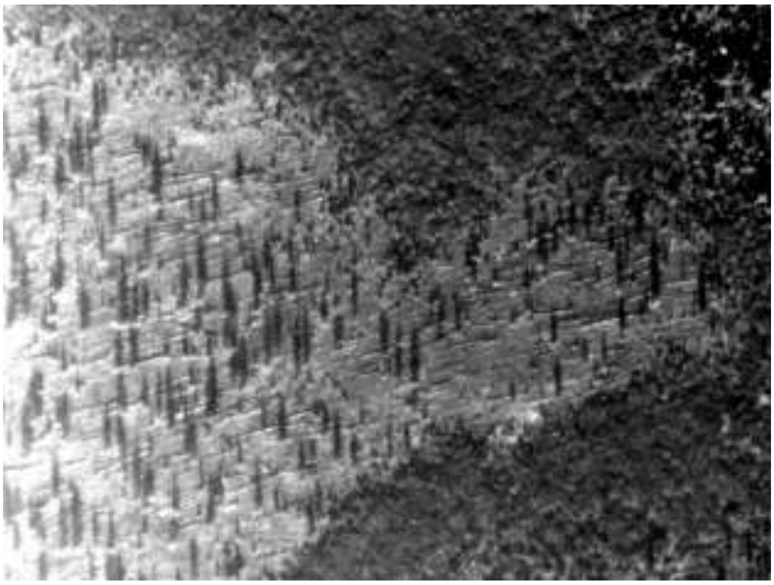

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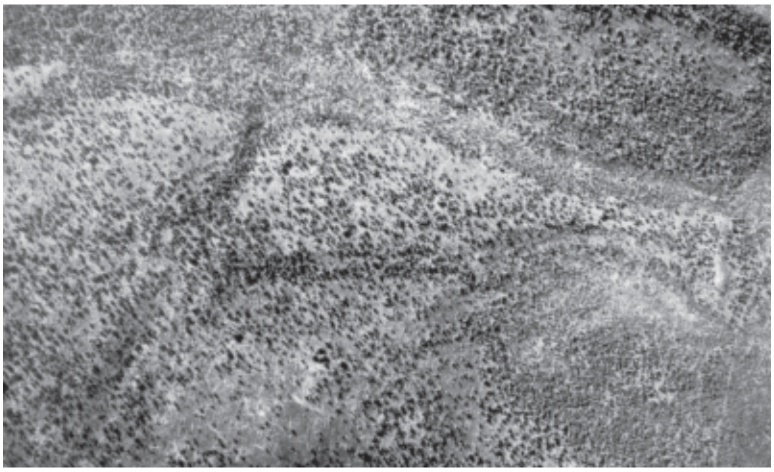

Above - Portion of one of the photos from Kulik's aerial photographic survey (1938) of the Tunguska region.
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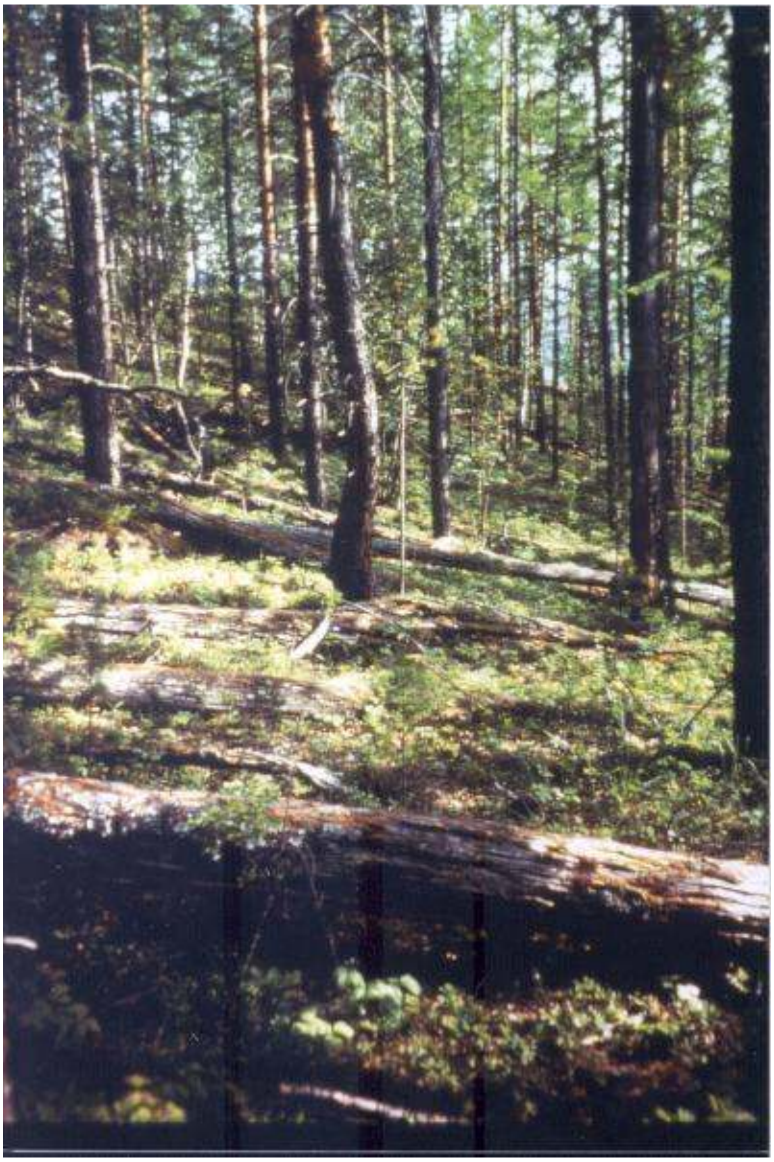

Above - Evgeniy Kolesnikov photographed Tunguska
60 years later (c. 1987).

The fallen trunks are still there, with the taiga growing in between them.
Credit: Photo: Evgeniy M. Kolesnikov,
Lomonosov Moscow State University

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1999 Expedition - University of Bologna

Above - Tunguska 1999

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Tunguska Today

The actual dates of the following Photos have not been established; however, they are supposed to be of "recent origin":

Above - Photo from 1927 (1908 was the year of the Event) compared with one purported to be from 2008

Above - Tunguska Today

Above - Tunguska "Telegraph Pole Tree"

Above - Tunguska "Telegraph Pole Trees"

Above - Tunguska Hut

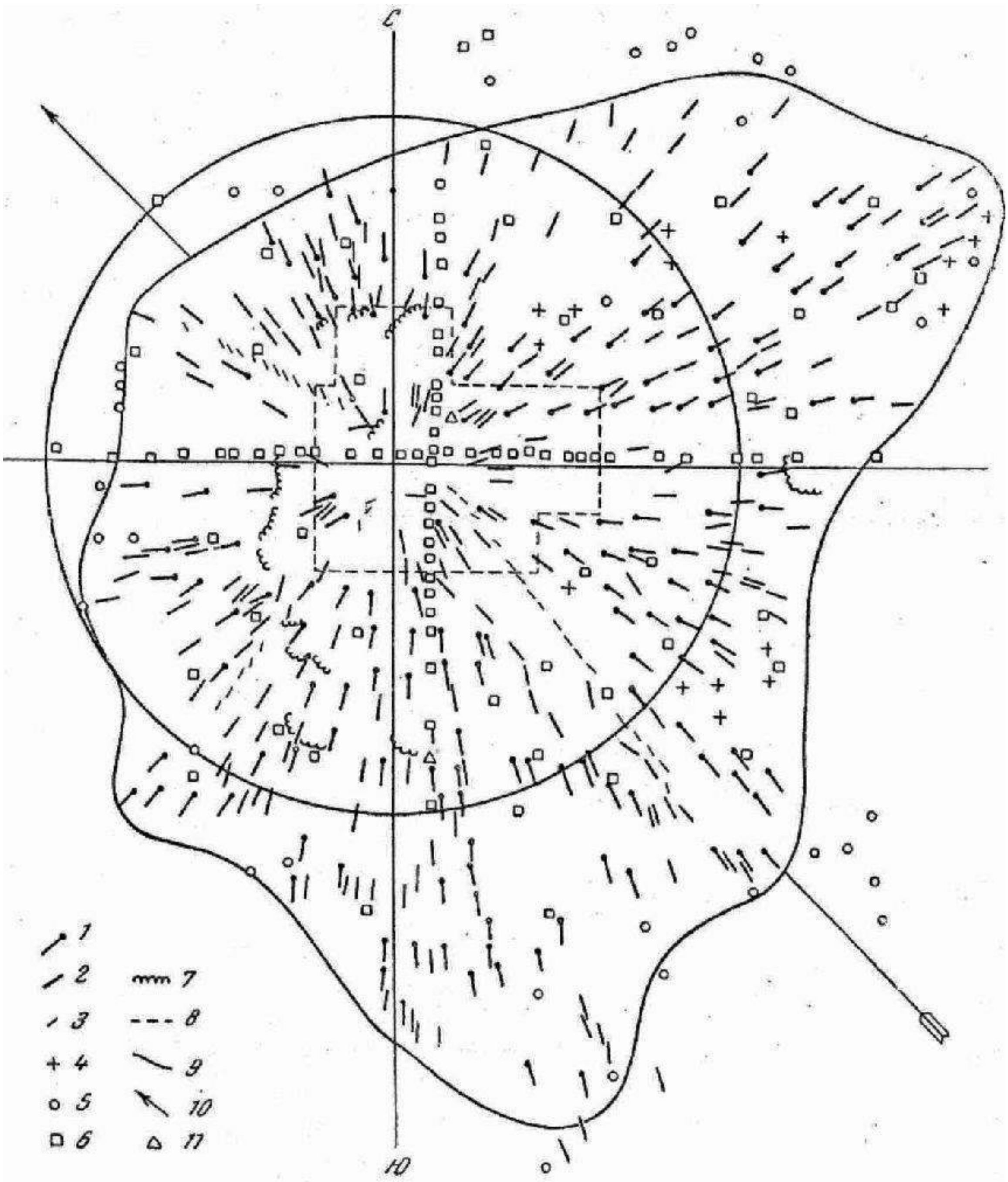
Above - Tunguska Today

Above - Tunguska Hut

Above - Tunguska Idol

Above - Tunguska Hut

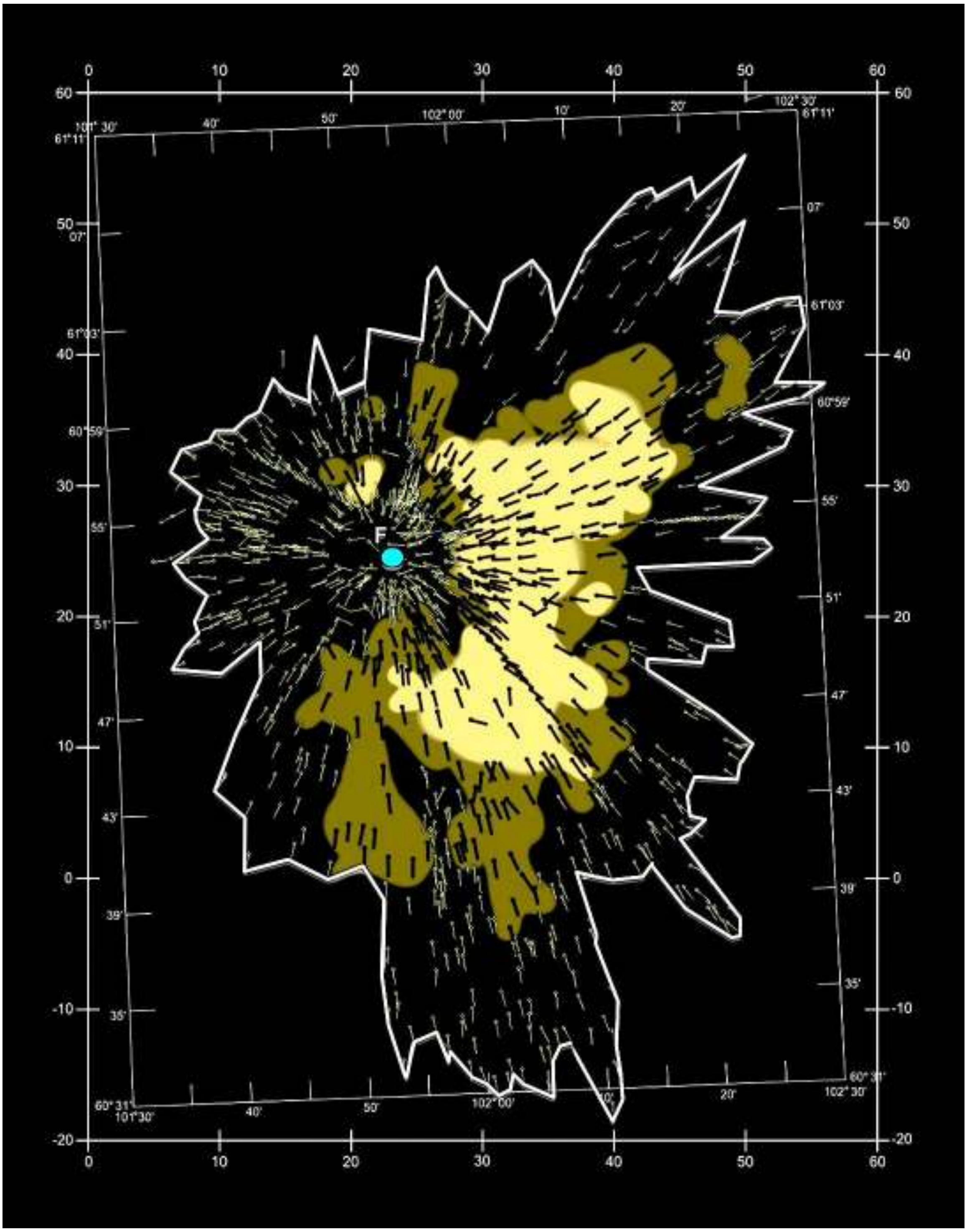
Fallen Tree Distribution



Fast map of fallen tree distribution, as it appeared in 1961 on the basis of azimuth data measured in 1958-1961.

This map showing a butterfly distribution was used in the last 40 years for comparison with theoretical models.

Now an updated map is available - See Below.



Above - The new map of fallen tree directions

In the last 40 years, the map of fallen tree azimuths used for comparison with theoretical models was the one constructed on the basis of of azimuth data measured in 1958-1961 (See image).

The new map of fallen tree directions has been obtained from:

1) revised Fast data
2) data from the 1938 and 1999 aerophotosurveys

3) Anfinogenov 1967 data. A reliability degree for each trial area averaged azimuth has been introduced. In the figure, the yellow, sepia and black areas correspond to a high, medium and low reliability, respectively.

The external frame represents Fast "kilometer" coordinates, while the inner - the geographical ones.

On the basis of the tree fall data and earlier eyewitness testimonies we consider that the Tunguska Cosmic Body was a multiple bolide formed by at least two bodies of similar mass (see "APPENDIX ONE", and "APPENDIX TWO").

They likely entered the atmosphere very close to each other following parallel trajectories with azimuths ~135° and an inclination of the total combined shock wave axis between 30° and 50°.

The first body, with a greater mass, emitted the maximal energy at a height of about 6-8 km.

The second, of minor mass, flew a little higher, on the right side and behind the first body, following the azimuth ~135° in the direction of the lake Cheko.

To download a higher resolution image click here: 267 kb *or here* 229 kb.
This image can be copied and published only with a full reference to:

Longo G., Di Martino M., Andreev G., Anfinogenov J., Budaeva L., Kovrigin E.: "A new unified catalogue and a new map of the 1908 tree fall in the site of the Tunguska Cosmic Body explosion." In: Asteroid-comet Hazard-2005, pp. 222-225, Institute of Applied Astronomy of the Russian Academy of Sciences, St. Petersburg, Russia, 2005. (**pdf**, 211 kb)

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Tunguska Eyewitness Reports

S. Semenov

Testimony of S. Semenov, as recorded by Leonid Kulik's expedition in 1930.

> *At breakfast time I was sitting by the house at Vanavara Trading Post [65 kilometres/40 miles south of the explosion], facing north. [...]*
>
> *I suddenly saw that directly to the north, over Onkoul's Tunguska Road, the sky split in two and fire appeared high and wide over the forest [as Semenov showed, about 50 degrees up--expedition note].*
>
> *The split in the sky grew larger, and the entire northern side was covered with fire. At that moment I became so hot that I couldn't bear it, as if my shirt was on fire; from the northern side, where the fire was, came strong heat. I wanted to tear off my shirt and throw it down, but then the sky shut closed, and a strong thump sounded, and I was thrown a few metres. I lost my senses for a moment, but then my wife ran out and led me to the house.*
>
> *After that such noise came, as if rocks were falling or cannons were firing, the earth shook, and when I was on the ground, I pressed my head down, fearing rocks would smash it. When the sky opened up, hot wind raced between the houses, like from cannons, which left traces in the ground like pathways, and it damaged some crops.*
>
> *Later we saw that many windows were shattered, and in the barn a part of the iron lock snapped.*

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Chuchan of Shanyagir tribe

Testimony of Chuchan of Shanyagir tribe, as recorded by I. M. Suslov in 1926.

> *We had a hut by the river with my brother Chekaren. We were sleeping. Suddenly we both woke up at the same time. Somebody shoved us. We heard whistling and felt strong wind.*
>
> *Chekaren said, "Can you hear all those birds flying overhead?"*
>
> *We were both in the hut, couldn't see what was going on outside. Suddenly, I got shoved again, this time so hard I fell into the fire. I got scared. Chekaren got scared too. We started crying out for father, mother, brother, but no one answered.*
>
> *There was noise beyond the hut, we could hear trees falling down. Chekaren and I got out of our sleeping bags and wanted to run out, but then the thunder struck. This was the first thunder. The Earth began to move and rock, wind hit our hut and knocked it over. My body was pushed down by sticks, but my head was in the clear.*
>
> *Then I saw a wonder: trees were falling, the branches were on fire, it became mighty bright, how can I say this, as if there was a second sun, my eyes were hurting, I even closed them.*
>
> *It was like what the Russians call lightning. And immediately there was a loud thunderclap. This was the second thunder.*
>
> *The morning was sunny, there were no clouds, our Sun was shining brightly as usual, and suddenly there came a second one!*
>
> *Chekaren and I had some difficulty getting out from under the remains of our hut. Then we saw that above, but in a different place, there was another flash, and loud thunder came. This was the third thunder strike. Wind came again, knocked us off our feet, struck against the fallen trees.*
>
> *We looked at the fallen trees, watched the tree tops get snapped off, watched the fires. Suddenly Chekaren yelled "Look up" and pointed with his hand. I looked there and saw another flash, and it made another thunder. But the noise was less than before. This was the fourth strike, like normal thunder.*
>
> *Now I remember well there was also one more thunder strike, but it was small, and somewhere far away, where the Sun goes to sleep.*

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Sibir newspaper, 02 July 1908

> *On the 17th of June, around 9 a.m. in the morning, we observed an unusual natural occurrence. In the north Karelinski village [200 verst, or about 130 miles, north of Kirensk] the peasants saw to the north west, rather high above the horizon, some strangely bright (impossible to look at) bluish-white heavenly body, which for 10 minutes moved downwards.*
>
> *The body appeared as a "pipe", i.e. a cylinder. The sky was cloudless, only a small dark cloud was observed in the general direction of the bright body. It was hot and dry.*
>
> *As the body neared the ground (forest), the bright body seemed to smudge, and then turned into a giant billow of black smoke, and a loud knocking (not thunder) was heard, as if large stones were falling, or artillery was fired. All buildings shook. At the same time the cloud began emitting flames of uncertain shapes. All villagers were stricken with panic and took to the streets, women cried, thinking it was the end of the world.*

The author of these lines was meantime in the forest about 6 verst (about four miles) north of Kirensk, and heard to the north east some kind of artillery barrage, that repeated in intervals of 15 minutes at least 10 times.

In Kirensk in a few buildings in the walls facing north east window glass shook.

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Siberian Life newspaper, 27 July 1908

When the meteorite fell, strong tremors in the ground were observed, and near the Lovat village of the Kansk uezd two strong explosions were heard, as if from large-caliber artillery.

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Krasnoyaretz newspaper, 13 July 1908

Kezhemskoe village. On the 17th an unusual atmospheric event was observed. At 7:43 the noise akin to a strong wind was heard. Immediately afterwards a horrific thump sounded, followed by an earthquake that literally shook the buildings, as if they were hit by a large log or a heavy rock.

The first thump was followed by a second, and then a third. Then the interval between the first and the third thumps were accompanied by an unusual underground rattle, similar to a railway upon which dozens of trains are travelling at the same time.

Afterwards for 5 to 6 minutes an exact likeness of artillery fire was heard: 50 to 60 salvoes in short, equal intervals, which got progressively weaker.

After 1.5-2 minutes after one of the "barrages" six more thumps were heard, like cannon firing, but individual, loud and accompanied by tremors.

The sky, at the first sight, appeared to be clear. There was no wind and no clouds. However upon closer inspection to the north, i.e. where most of the thumps were heard, a kind of an ashen cloud was seen near the horizon, which kept getting smaller and more transparent and possibly by around 2-3 p.m. completely disappeared.

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The 1908 Fallout

The Tunguska catastrophe in 1908 evidently led to high levels of acid rain, according to Russian, Italian and German researchers based on the results of analyses of peat profiles taken from the disaster region.

In peat samples corresponded to 1908 permafrost boundary they found significantly higher levels of the heavy nitrogen and carbon isotopes 15N and 13C. The highest accumulation levels were measured in the areas at the epicentre of the explosion and along the trajectory of the cosmic body. Increased concentrations of iridium and nitrogen in the relevant peat layers support the theory that the isotope effects discovered are a consequence of the Tunguska catastrophe and are partly of cosmic origin.

It is estimated that around 200,000 tons of nitrogen rained down on the Tunguska region in Siberia at that time.

"Extremely high temperatures occurred as the meteorite entered the atmosphere, during which the oxygen in the atmosphere reacted with nitrogen causing a build up of nitrogen oxides," Natalia Kolesnikova told the Russian news agency RIA Novosti on last Monday. Mrs. Kolesnolova is one of the authors of a study by Lomonosov Moscow State University, the University of Bologna and the

Helmholtz Centre for Environmental Research (UFZ), which was published in the journal Icarus in 2003.

In two expeditions in 1998 and 1999, Russian and Italian researchers took peat profiles from various locations within the Siberian disaster area. The type of moss studied, Sphagnum fuscum, is very common in the peat material and obtains its mineral nutrients exclusively from atmospheric aerosols, which means that it can store terrestrial and extraterrestrial dust.

Afterwards, the samples were analysed in laboratories at the University of Bologna and the Helmholtz Centre for Environmental Research (UFZ) in Halle/Saale. Among other things, the UFZ specialises in isotope analyses of sediments, plants, soil and water and it was asked to help by the team of Moscow researchers led by Dr Evgeniy M. Kolesnikov.

Kolesnikov, who has been investigating the Tunguska event for 20 years, has been to Leipzig University and UFZ twice as a guest researcher with the help of the German Research Foundation (DFG) to consult with the isotope experts.

"The levels of accumulation of the heavy carbon isotope 13C measured right on the 1908 permafrost boundary in several peat profiles from the disaster area cannot be explained by any terrestrial process. This suggests that the Tunguska catastrophe had a cosmic explanation and that we have found evidence of this material," explains Dr Tatjana Böttger of the UFZ. Possible causes would be a C-type asteroid like 253 Mathilde, or a comet like Borelly.

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Lake Cheko

During a 1999 scientific expedition by the University of Bologna, Italy, they discovered evidence suggesting that Lake Cheko, a small lake (500 m diameter; 50 m maximum depth) located 8 km NW of the inferred epicentre of the Tunguska explosion, may be a crater left by a m-sized fragment of the cosmic body that survived disintegration. The results were published in Terra Nova: http://www-th.bo.infn.it/tunguska/terranova.html.

During the 1999 expedition, Longo's team didn't plan to investigate Lake Cheko as an impact crater, but rather to look for meteoroid dust in its submerged sediments. However, while sonar-scanning the lake's topography, the team were struck by its "cone-like" features.

"Expeditions in the 1960s concluded the lake was not an impact crater, but their technologies were limited," Longo said. However, with the advent of better sonar and computer technologies, he explained, the lake took shape.

In June of 2007 it was further announced that scientists from the University of Bologna had identified a lake in the Tunguska region as a possible impact crater from the event. Lake Cheko is a small bowl shaped lake approximately 8 kilometres north-north-west of the epicentre.

"When we looked at the bottom of the lake, we measured seismic waves reflecting off of something," said Giuseppe Longo, a physicist at the University of Bologna in Italy and co-author of the study. "Nobody has found this before. We can only explain that and the shape of the lake as a low-velocity impact crater."

Going a step further, Longo's team had dived to the bottom and had taken 6-foot core samples. This revealed fresh mud-like sediment on top of "chaotic deposits" beneath. However, as Longo explained, the samples are inconclusive of a meteorite impact.

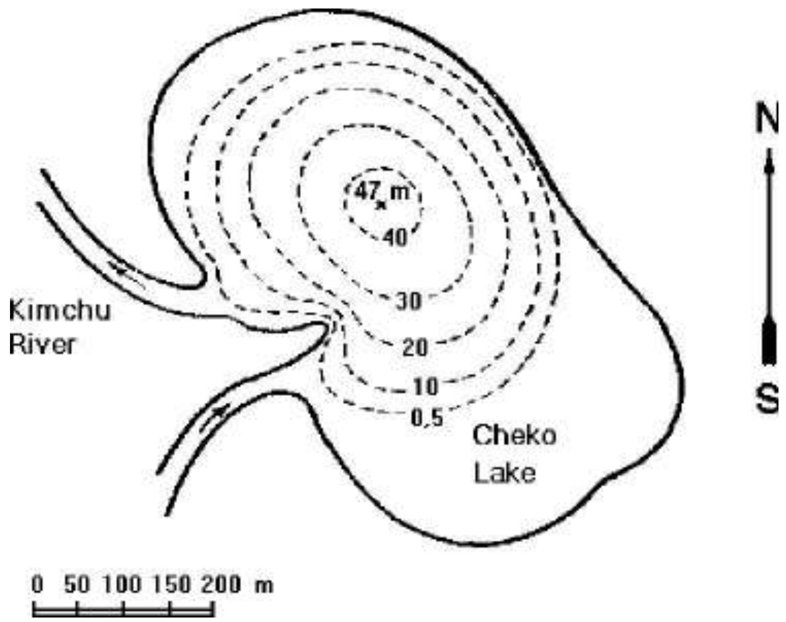
"To really find out if this is an impact crater," Longo said, "we need a core sample 10 meters (33 feet) into the bottom" in order to investigate a spot where the team detected a "reflecting" anomaly with their seismic instruments. They have postulated that this could be where the surface was compacted by an impact or where part of a meteorite lies. The object, if exists, could be more than 30 feet in diameter and weigh almost 1,700 tons.

However, this hypothesis has been challenged by other impact crater specialists - a 1961 investigation had dismissed a modern origin of Lake Cheko, saying that the presence of meters thick silt deposits at the lake's bed suggests an age of at least 5000 years.

"We know from the entry physics that the largest and most energetic objects penetrate deepest," said David Morrison, an astronomer with NASA's Ames Research Centre. That only a fragment of the main explosion reached the ground and made a relatively small crater, without creating a larger main crater, seems contradictory to Morrison.

Harris agreed that physics could work against Longo's explanation, but did note that similar events - with impact craters - have been documented all over the world.

"In 1947, the Russian Sikhote-Alin meteorite created 100 small craters. Some were 20 meters (66 feet) across," Harris said. A site in Poland also exists, he explained, where a large meteor exploded and created a series of small lakes. "If the fragment was traveling slowly enough, there's actually a good chance (Longo's team) will unearth some meteorite material," Harris said.



Above - The first bathymetry of the lake Cheko done in 1960
by the team guided by V. A. Koshelev.

Using more powerful instrumentation, a second bathymetric map
was constructed in 1999 by researchers of the Tunguska99 Expedition (See below).

Some of the evidence in favour of an impact is:

1) The unusual, funnel-like morphology of the lake, different from that of common thermokarst Siberian lakes, but compatible with a “soft" low-velocity (<1 km/s) impact crater of a m-size projectile in a swampy ground with permafrost.

2) The lake appears to be not older than 1908, as suggested by radiometric dating of the lacustrine sediments and by the absence of aquatic plant pollens in sediments older than 1908.

3) A clear magnetic/density anomaly is present at the lake centre, about 10m below the bottom.

Above - 3-D reconstruction of the morphology of the Lake Cheko
based on real topographic /bathymetric data

These data suggest that Lake Cheko formed in 1908 as a consequence of an impact, and that below its bottom there could be markers of the “impactor" that could indicate whether the Tunguska cosmic object was an asteroid or a comet.

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TUNGUSKA

SUMMARY

This excellent summary of information (author unknown) regarding the Tunguska event was sourced from:

http://geology.mines.edu/faculty/Klee/Tunguska.pdf

and is included with grateful thanks and appreciation

[2012]

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OVERVIEW

Date:	30 June 1908; 0714 local
Location:	Central Siberia near the Podkamennaya [Stony] Tunguska River 101° 53' 40" E; 60° 53' 09" N
Crater Diameter:	0 - that is, *there is no crater*
Detonation:	15 Mt [Megaton] atmospheric explosion at 7 km [5-10 km] [from seismic, barographs, and tree blowdown]
Eyewitnesses:	Fireball from 110° - 15° atmospheric entry - steepened to 40° - may have veered - indigenous Evenki were nomadic reindeer herders, hunters and trappers

PRE-IMPACT GEOLOGY

Triassic traps of Siberia - mostly basalts and fine-grained gabbros; south of glaciated terrain

Geology not really important; surface conditions more relevant:

> Taiga, or boreal forest, of larch, pine, and birch w/ abundant lichens, incl. reindeer moss, discontinuous permafrost zone, but appears continuous at hypocenter, p-frost table about 30 cm

IMPACTOR

Hypothesized:

> Iron meteorite, cometary nucleus, carbonaceous chondrite, stony asteroid
>
> Comet exploded 850 m 0.002 g/cm^3 at 40 km/s 30° Turco ao 1982
>
> Asteroid disintegrated - 30 m 3.5 g/cm^3 at 15 km/s 45° Chyba ao 1993
>
> Asteroid disintegrated - 58 m ablates by EMR [Electromagnetic radiation] after fragmentation Svetsov 1996
>
> Asteroid disintegrated - 80 m deceleration and explosion Hills and Goda 1993
>
> Ricocheted out of atmosphere - Plekhanov and Plekhanova 1998

Vasilyev - probably a small asteroid, density about 3, about 10^5 tonnes, 15 kps

Also suggested: antimatter, micro black hole, permafrost gas hydrate eruption, nuclear-powered spaceship accident

IMPACT EFFECTS

Tremendous explosion - heard hundreds of kilometers away

Pressure wave registered on microbaragraphs around the world

Seismic records from stations around Russia, as far as Germany

Geomagnetic disturbance recorded at Irkutsk - similar to nuclear blast

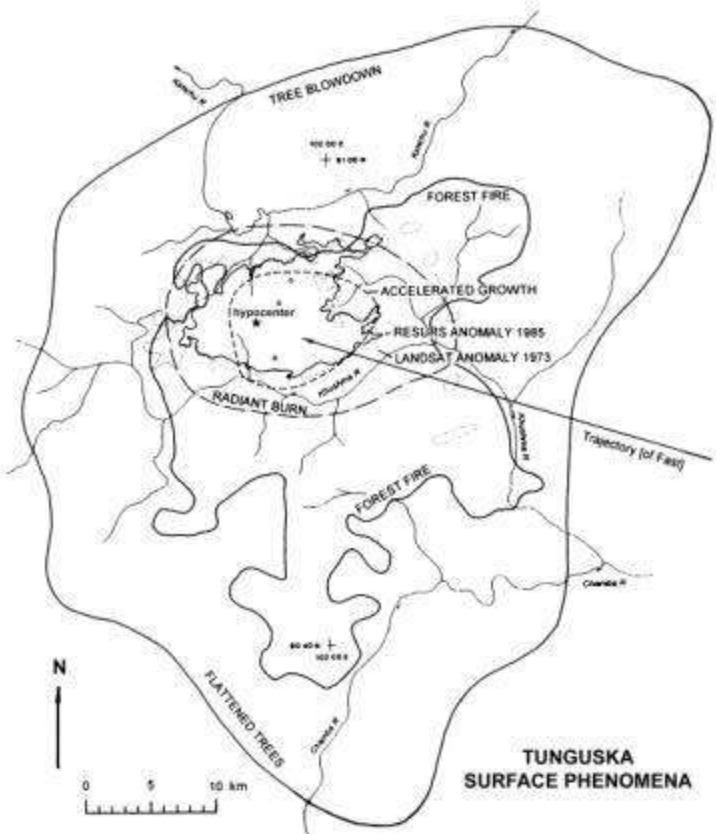
Light night and noctilucent clouds [mesospheric ice from cosmic dust] seen throughout Europe

30% kinetic energy as EMR [Electromagnetic radiation] caused radiant burn and flash ignition of green forest over 200 km^2 area

Radial tree blowdown over 2150 km^2 in butterfly pattern; hypocentral trees [3 km] are 'telegraph poles' from vertically directed pressure wave

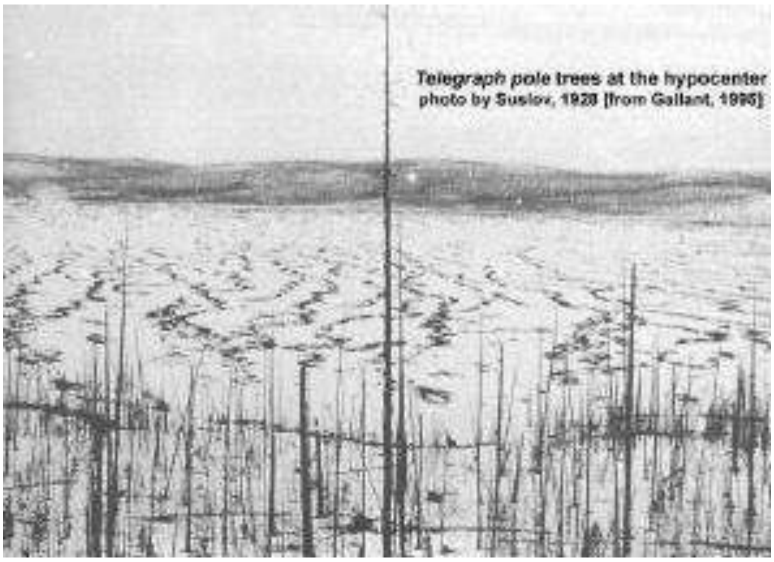
Physically modeled with primacord - inclined string at 30^o with larger charge at end

Temperature of explosion - estimated to be 10 000 K - 30 000 K



Above - TUNGUSKA
SURFACE PHENOMENA

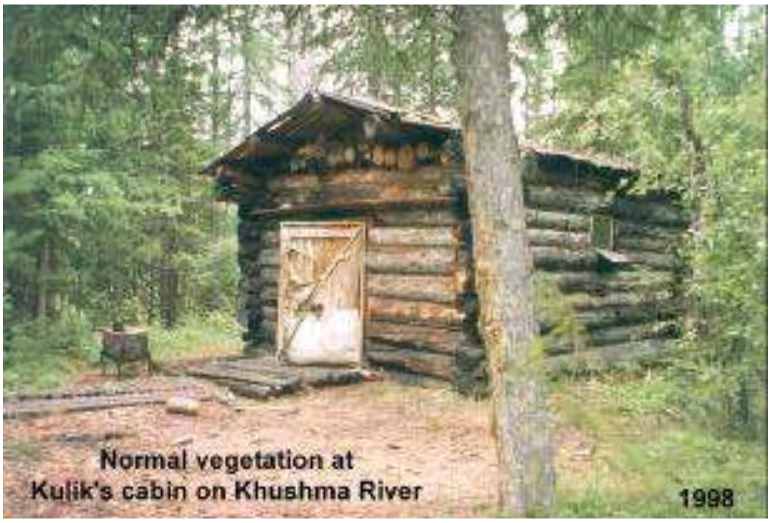
Above - Tunguska tree blowdown 20 years later
photo by Suslov [from Gallant, 1996]



Above - Telegraph pole trees at the hypocenter
photo by Suslov [from Gallant, 1996]

Physical Evidence Almost None

Above - View of ground zero from helicopter - 1998
note lack of evidence of tree blowdown



Above - Normal vegetation at
Kulil's cabin on Khushma River - 1998

The taiga has healed itself.

In 1998, very few felled trees remained, and only a few stumps of ‘telegraph pole’ trees.

Scientists flying in to the site by helicopter saw no evidence whatsoever from low altitude.

If one were not aware of the co-ordinates, there would be no way of knowing that anything at all unusual had happened at this site.

Above - TUNGUSKA HYPOCENTER (STAR)
modern vegetation anomaly
Resurs-F Satellite Image

Above - Larch tree that survived the
Tunguska explosion; radiant
burn scar faced hypocenter

Environmental	accelerated plant growth few years afterward [N_2 -> N + O -> NO_3] - sharp increase in plant mutations
Geochemical	elemental enrichment of 1908 peat layer *suggests* carbonaceous chondrite
Ir [iridium]	[20 ppt ave crustal rock] anomaly 240-540 ppt in ashed *Sphagnum fescue* core [neutron activation analysis, but only found in one peat core of four cores taken, and anomaly only about 2x upper peat layers [Hou ao 1998];

Kolesnikov ao [1995] show anomaly below 1908 layer, but values are only 5-20 ppt

HISTORY OF INVESTIGATIONS

I. 1908 - WWII

Scientists were unable to find source of explosion because shamanistic Evenki considered the site taboo and diverted attempts to penetrate the taiga.

Meteoriticist Leonid Kulik eventually found site after 19 years had elapsed, led expeditions 1927, 1928, 1929-30, 1933, 1937, 1938, 1939

Kulik fought in WWII, captured by Germans, died in POW camp

Kulik's Conclusion: originally thought iron meteorite, final thought cometary impact

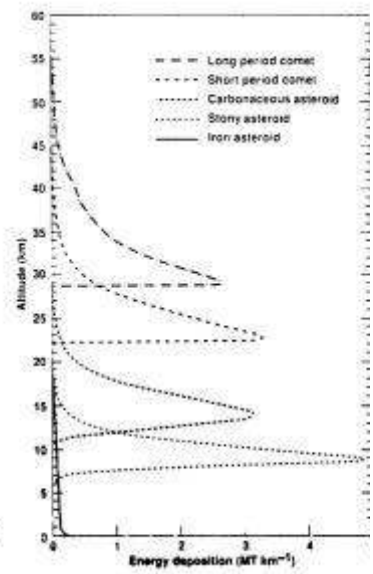
II. 1949 - 1992

multidisciplinary research by Soviet scientists Conclusion: comet or stony asteroid

III. c1992

Opened to international scientists
1992 1st International Expedition
1996 Bologna Conference
1998 90th Anniversary Krasnoyarsk Conference
1999 Italian Expedition Lake Cheko
Conclusion: stony asteroid or comet

FIG 1 Airburst altitudes for five 15-Mton candidate Tunguska bolides incident at 45°. Comets and carbonaceous asteroids deposit their energy too high in the atmosphere to account for the Tunguska explosion, whereas iron objects reach and crater the surface. Typical stony asteroids, however, deliver the bulk of their energy near an altitude of 9 km, and this is consistent with observations.



From Chyba and others, 1993

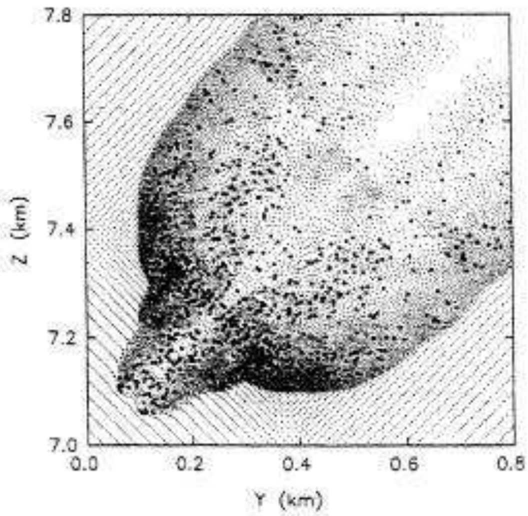


Fig. 1. A swarm of debris at a stage of full disintegration of the meteoroid. The coordinates start at the epicenter of the explosion on the ground. The solid circles represent meteoroid particles, the points are particles of the air

From Svetsov, 1996

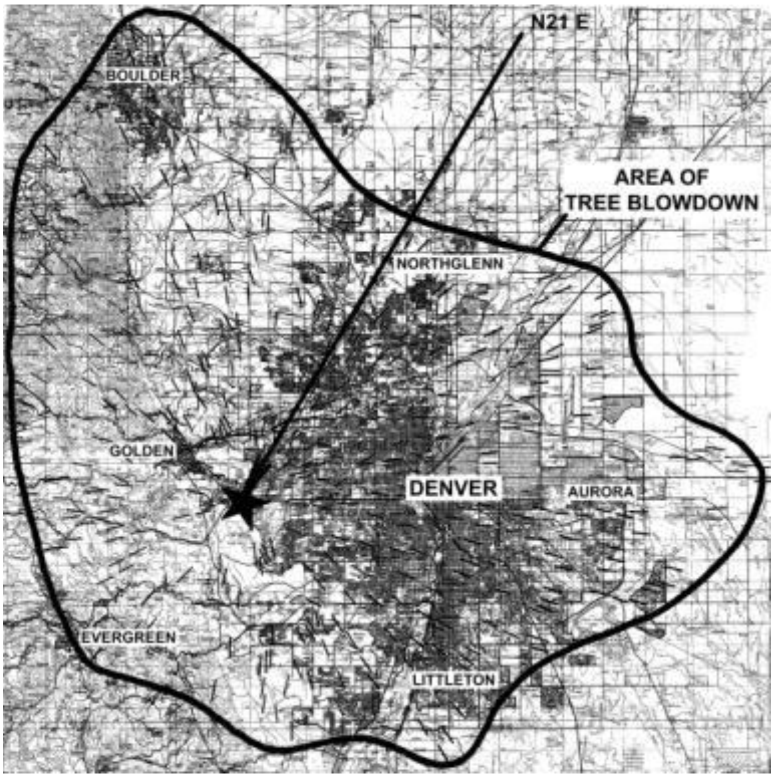
Above - *THE origin of the explosion over Tunguska, central Siberia, in 1908 has long been an enigma. Models of the disruption of solid objects entering the atmosphere indicate that the Tunguska explosion occurred at an altitude of 6--10 km, and that the source object was probably a stony asteroid. But important questions concerning the nature of the object remain, particularly as no fragments have been identified in the area of the explosion. Unlike smaller objects (such as meteorites), which decelerate high in the atmosphere and can thus escape complete ablation and/or pulverization, a Tunguska-sized object penetrates deeper into the atmosphere, where it will experience a greater aerodynamic load: the object should be disrupted into a vast number of fragments, each no larger than about 10 cm (ref. 2), which are then widely dispersed. Here I calculate the flux of radiation both inside and outside the fireball associated with the fragmenting object, and show that this is sufficient to totally ablate the dispersing fragments. The apparent absence of solid debris is therefore to be expected following the atmospheric fragmentation of a large stony asteroid. [Abstract - Total ablation of* *the debris from the 1908 Tunguska explosion, V. V. Svetsov, Institute for Dynamics of Geospheres, Russian Academy of Sciences, 38 Leninskii Prospect, Moscow 117979, Russia]* *http://www.nature.com/nature/journal/v383/n6602/abs/383697a0.html*

SIGNIFICANCE

Tunguska represents a category of impactors for which we have no cratering record

Energy at Tunguska is about the same as Meteor Crater, and may be considerably less than other meteoroids that have lower strength - carbonaceous chondrites [Revelstoke], comets - and therefore explode higher in the atmosphere

If the Tunguska bolide had arrived four hours later, it would have destroyed St. Petersburg.



Above - Overlaying the map of tree blowdown onto a map of the Denver metro area shows destruction in the entire city of Denver, as well as all the outlying municipalities of Boulder, Golden, Evergreen, Littleton, and Aurora.

The recurrence interval for such an event has been estimated to be as frequent as every 100 years.

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http://geology.mines.edu/faculty/Klee/Tunguska.pdf

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Conclusion

So, after all the dust of hypontesos and speculation settles, what is the conclusion?

Currently, the leading scientific explanation for the Tunguska explosion is the airburst of a meteoroid/comet fragment 6-10 kilometres (4--6 miles) above Earth's surface.

However, astrophysicist Wolfgang Kundt has suggests the Tunguska event was caused by the sudden release and subsequent explosion of 10 million tons of natural gas from within the Earth's crust. The similar "verneshot hypothesis" has also been suggested as a possible cause of the event.

Finally, is there any evidence to suggest a UFO crash or other Alien activity? No.

Postscript

Recently, a St.-Petersburg group of Tunguska researchers (Dr. Heinrich Nikolsky, Edward Schultz, Dr. Vladimir Schnitke, Dr. Maxim Tsynbal, and Professor Yury Medvedev) put forward a new hypothesis, according to which the Tunguska space body was after all a comet. Having touched the Earth’s upper atmosphere, it was captured by the gravitational field of our planet and settled into an elliptical orbit, its perigee being over Antarctica. This comet made four revolutions around Earth, during the last of them moving along the 101st eastern meridian and gradually losing altitude. Somewhere over the Angara river the space body divided into several fragments, whose explosions devastated the taiga.

Whether or not this model fits well all circumstances of the Tunguska event - say, the powerful light flash, the local geomagnetic storm and especially the Weber effect - remains an open question, but the model itself is certainly interesting and worthy of further development. (http://www.tunguskamystery.info/Tunguska_Event)

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APPENDIX ONE

A NEW UNIFIED CATALOGUE AND A NEW MAP OF THE 1908 TREE FALL IN THE SITE OF THE TUNGUSKA COSMIC BODY EXPLOSION

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John Anfinogenov 4, Larissa Budaeva 3, Evgeny Kovrigin 3

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http://www-th.bo.infn.it/tunguska/Abstract-AKO-2005.pdf

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Introduction

The 1908 tree fall is the principal source of information on the Tunguska Cosmic Body (TCB) explosion. The data on forest devastation give information on the energy emitted and on the height of the explosion. The directions of flattened trees make it possible to calculate the coordinates of the wave propagation centre(s) and to obtain information on the so-called epicentre(s) of the explosion. From the azimuth distribution of flattened trees, the final trajectory of the TCB, defined by its azimuth *(a)*, the trajectory inclination *(h)* over the horizon and the height *(H)* of the explosion, can be obtained.

Fast map and catalogues

Though Kulik discovered the radial orientation of fallen trees since 1927, systematic measurements of fallen tree azimuths were begun only during the two great post-war expeditions organized by the Academy of Sciences in 1958 and 1961, and during the Tomsk 1959-1960 expeditions. Under the direction of Fast, with the help of Boyarkina, this work was continued for two decades during ten different expeditions from 1961 up to 1979. A total of 122 people, mainly from Tomsk University, participated in these on site measurements. The data collected have been published in a catalogue in two parts [1-2]:

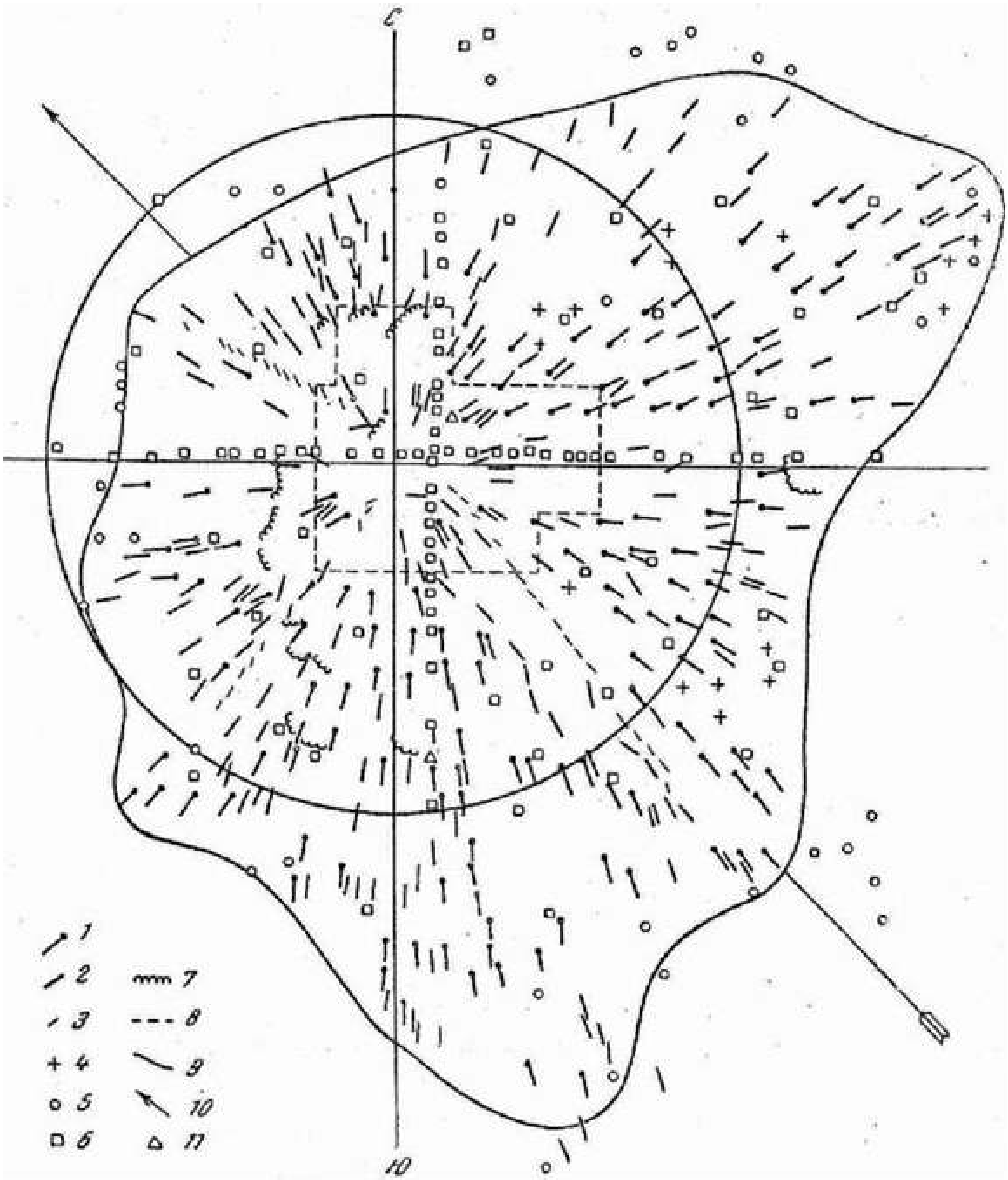

Fig. 1 - Fallen tree distribution (1961) [3-4].

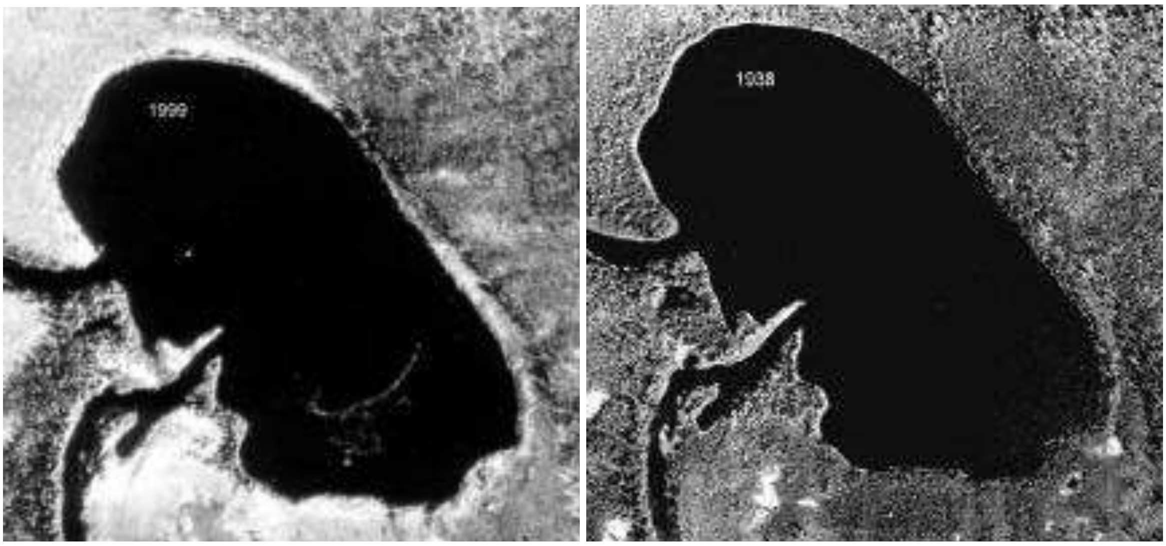

Fig. 2 - The lake Cheko in Kulik's APS *(left)* and in Tunguska99 APS *(right).*

the first one contains the data obtained by six expeditions (1958-1965), which include the fallen tree azimuth averaged on trial areas equal to 2500 or 5000 m^2, chosen throughout the whole devastated forest. In the second part, the data collected by the six subsequent expeditions (1968-1976) were given. Unfortunately, a map containing all the data [1-2] has never been published. In the last 40 years, the map of fallen tree azimuths used for comparison with theoretical models [e.g. 5-6] was the one constructed by A. Boyarkina, V. Fast and co-workers [3-4]. This map, reproduced in Fig. 1 contains only the data on the azimuths measured in 1958-1961.

Analysing the data on flattened tree directions from the first part of his catalogue [1], Fast obtained the epicentre coordinates 60°53'09'' ± 06'' N, 101°53'40'' ± 13'' E (single explosion). Subsequently [2], Fast found a trajectory azimuth *a* = 99° and Bronshten analyses gave a height of the explosion *H* = 7.5 ± 2.5 km and a trajectory inclination *h* = 15°.

The new map and catalogue

We have used three datasets to construct the new map of fallen tree directions: 1) revised Fast data [1-2], 2) data from Kulik 1938 aerophotosurvey, 3) the data collected in 1967 by Anfinogenov group. To analyse the 1938 aerophotosurvey (APS) and to link its photos to the ground, the Tunguska99 expedition carried out a new APS. The 1999 APS [7-8] covered a ~300 km^2 surface between the latitudes 60° 50' 00" N and 60° 58' 30" N and between the longitudes 101°45' 00" E and 102° 05' 00" E, corresponding to an area a little larger than that of the 1938 APS (dashed line in Fig.1). Finally, we carried complementary on-site measurements in July 1999 and 2002 to obtain the coordinates of different reference points in the same area. These data allowed us to recognise ground elements on the aerial pictures and to connect them to the regional topographic net. Photos of the lake Cheko shot in 1938 and in 1999 are shown in Fig. 2. Minor changes can be seen on the shores near the ingoing/outgoing Kimchu river.

The correspondence between the "kilometre coordinate system" used by Fast and the standard geographical coordinates has never been published. In the new unified catalogue, for each Fast azimuth we give its kilometre and geographical coordinates. The last ones have been obtained by using reference points recognised on the ground. Though part of Fast trial areas data was not used due to the rather

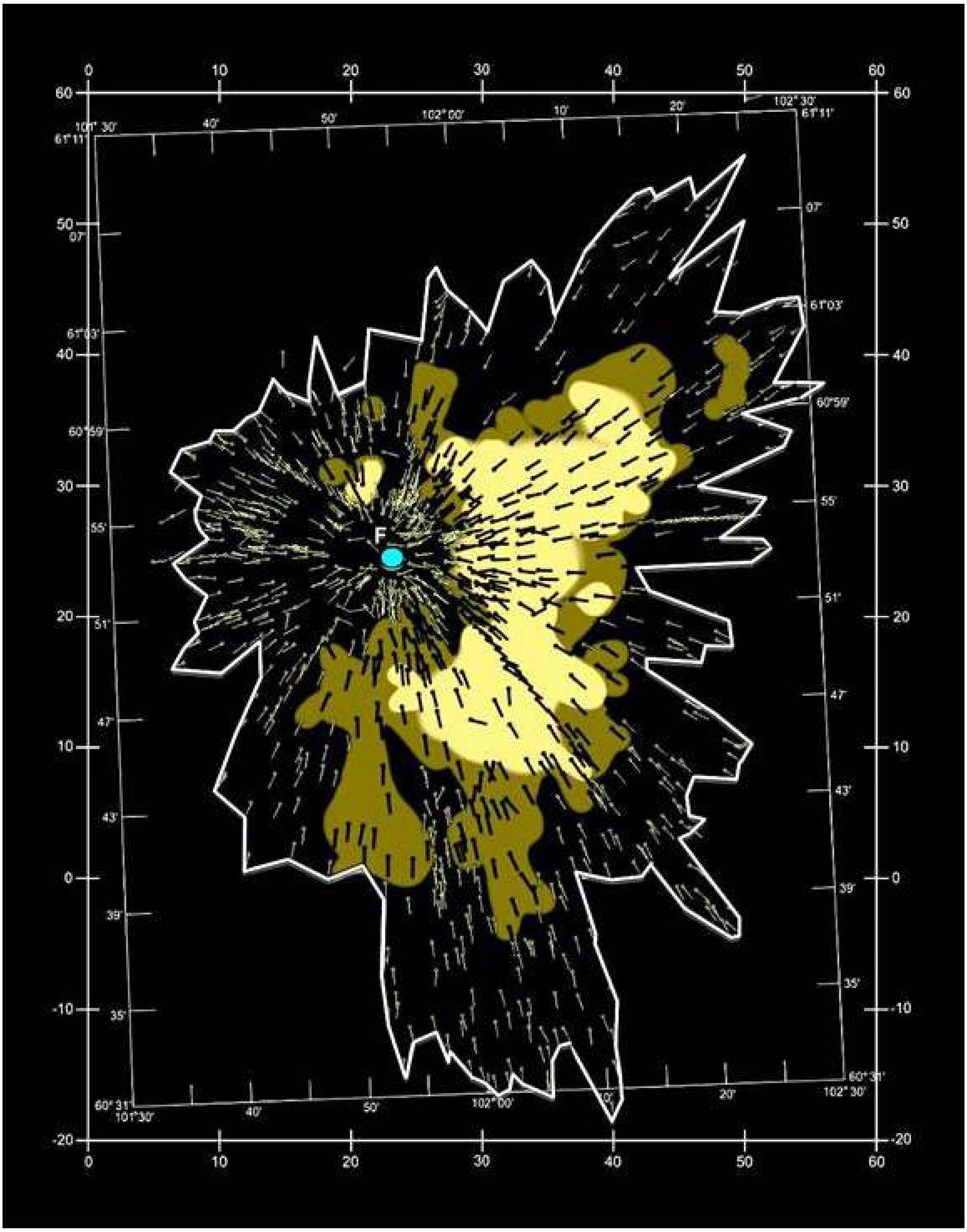

Fig. 3 - The unified map of fallen tree azimuths.

poor statistics, the new catalogue includes 1165 azimuths extracted from Fast data [1-2] and published here after the introduction of the necessary corrections. To these data, 80 Anfinogenov azimuths and other 350 obtained from the digitalized photos of the 1938 APS have been added. Thus, the data we used are several times larger than those in Fig. 1 or those considered by Fast to obtain the mentioned TCB trajectory parameters. We have introduced a reliability degree for each trial area averaged azimuth. In Fig. 3, the white, gray and black areas correspond to a high, medium and low reliability, respectively. In the figure, the external frame represents the kilometer coordinates, while the inner - the geographical ones.

From the data on fallen tree directions in our new unified catalogue, we obtain a single body trajectory azimuth *a* = 110° ± 5°. The same data are compatible with the hypothesis that the cosmic body was composed by at least two bodies, falling independently but very close one to the other, with a trajectory azimuth ~135 ° and an inclination of the total combined shock wave axis between 30° and 50°. The first body, with a greater mass, emitted the maximal energy at a height of about 6-8 km. The second, of minor mass, flew a little higher, on the right side and behind the first body, following the azimuth ~135° in the direction of the lake Cheko.

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http://www-th.bo.infn.it/tunguska/Abstract-AKO-2005.pdf

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APPENDIX TWO

CHAPTER 18

THE TUNGUSKA EVENT

by

G. Longo

Longo G.: The Tunguska event. In the book:
"Comet/Asteroid Impacts and Human Society,
An Interdisciplinary Approach,
Bobrowsky, Peter T.; Rickman, Hans (Eds.).",
546 p., © Springer-Verlag, Berlin Heidelberg New York,
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http://www-th.bo.infn.it/tunguska/Tenerife.htm

http://www-th.bo.infn.it/tunguska/Asteroids-Chapter-18.pdf

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18.1
Introduction

In the early morning of 30th June 1908, a powerful explosion over the basin of the Podkamennaya Tunguska River (Central Siberia), devastated 2 150 ± 50 km^2 of Siberian taiga. Eighty millions trees were flattened, a great number of trees and bushes were burnt in a large part of the explosion area. Eyewitnesses described the flight of a “fire ball, bright as the sun". Seismic and pressure waves were recorded in many observatories throughout the world. Bright nights were observed over much of Eurasia. These different phenomena, initially considered non-correlated, were subsequently linked together as different aspects of the “Tunguska event" (TE).

Almost one century has elapsed and scientists are still searching for a commonly accepted explanation of this event. Several reviews and books summarize the results acquired by the intensive investigations of the last century, e.g. Kulik (1922, 1939, 1940), Landsberg (1924), Krinov (1949, 1966), Gallant (1995), Trayner (1997), Riccobono (2000), Bronshten (2000), Vasilyev (1998, 2004) and Verma (2005).

Despite great efforts, the TE remains a conundrum.

18.2
The Hypotheses

The most plausible explanation of the event considers the explosion in the atmosphere of a “Tunguska Cosmic Body" (TCB), probably a comet or an asteroid-like meteorite.

18.2.1
Comet or Asteroid?

From his first determination of the basin of the Podkamennaya Tunguska River as the explosion site, Kulik (1922 and 1923) used the term “Tunguska meteorite", for the TCB, and continued searching for an iron body, similar to one found in Arizona (Kulik 1939, 1940; Krinov 1949, 1966). Voznesenskij (1925) hypothesized an equal probability for a stony or an iron body composition. Shapley (1930) was the first to suggest that the Tunguska event was caused by the impact of a comet and Kresák (1978) indicated the comet Encke as the origin of the TCB. Fesenkov (1949), for many years, supported the stony object hypothesis. Later, Fesenkov (1961) worked out a definite model of an impact between a comet and the Earth’s atmosphere. From that time onward, the majority of Russian scientists followed the cometary hypothesis (see for example Grigorian 1998), whereas many western scientists preferred an asteroidal model (e.g. Sekanina 1983, 1998; Chyba et al. 1993).

For many reasons, these two “schools" practically ignored each other until the international workshop Tunguska96, held in Bologna (Italy) from 15th to 17th July 1996 (Di Martino et al. 1998). In the recent past the cometary hypothesis has been favored on the basis that a low-density object was needed to explain the Tunguska catastrophe (Petrov and Stulov 1975; Turco et al. 1982). Subsequently, to account for the concentration of energy release of the explosion, two sub-versions of this hypothesis have been developed, one introducing chemical reactions (Tsymbal and Shnitke 1986), the other nuclear-fusion reactions (D’Alessio and Harms 1989). On the other hand, it has been shown (Grigorian 1976; Grigorian 1979; Passey and Melosh 1980; Levin and Bronshten 1986) that the fragmentation of a normal density object can greatly increase the rate of energy deposition in a small region near the end of the trajectory, thus appearing as an atmospheric explosion. Detailed calculations which include the effect of aerodynamic forces that can fracture the object, and the heating of the bolide due to friction with the atmosphere, have recently been performed, showing that the TE is fully compatible with the catastrophic disruption of a 60-100 m diameter asteroid of the common stony class (Chyba et al. 1993; Hills and Goda 1993). However, due to the uncertainty of such input parameters as the energy and height of the explosion or the inclination angle and the encounter velocity of the impactor, the same calculations do not exclude the possibility that the TCB was a high velocity iron object, nor rule out a carbonaceous asteroid as an explanation of the event. Considering a “plume-forming" atmospheric explosion, Boslough and Crawford (1997) have suggested that the commonly accepted energy-yield is an overestimate and that a 3 megaton event could generate the observed devastation. Many of the phenomena associated with the TE can be related to the formation and collapse of an atmosphere plume, caused either by a comet or by an asteroid. For example, the predicted ejection at altitudes of some hundreds of kilometers of the impactor mass can explain the “bright nights" associated with the TE.

It is difficult to definitely support one or the other hypothesis. Therefore, one way to achieve certainty about the nature and composition of the TCB remains the search for some of its remnants. Numerous radiocarbon analyses of Tunguska wood samples (Nesvetajlo and Kovaliukh 1983), chemical analyses of soil and plants (Kovalevskij et al. 1963; Emeljanov et al. 1963; Kirichenko and Grechushkina 1963; Iljina et al. 1971), bed-by-bed chemical analyses of the peat formed by *Sphagnum fuscum* in 1850-1950 (Vasilyev et al. 1973; Golenetskij et al. 1977a; Golenetskij et al. 1977b; Kolesnikov et al. 1977), isotopic analyses of many different soil, peat and wood samples (Kolesnikov et al. 1979), as well as analyses of the spherules from Tunguska soil samples collected in a radius of several tens of kilometers from the epicenter (Florenskij et al. 1968; Jéhanno et al. 1989; Nazarov et al. 1990) have been completed. Nevertheless, many conclusions of this intensive work are still uncertain, so that further investigations are needed. Although almost every year there is an expedition to Tunguska, so far no typical material has permitted a certain discrimination to be made between an asteroidal or cometary nature of the TCB. Some papers report that hydrogen, carbon and nitrogen isotopic compositions with signatures similar to those of CI and CM carbonaceous chondrites were found in Tunguska peat layers dating from the TE (Kolesnikov et al. 1999, 2003) and that iridium anomalies were also observed (Hou et al. 1998, 2004). Measurements performed in other laboratories have not confirmed these results (Rocchia et al. 1990; Tositti et al. 2006). Moreover, a concentration of microparticles of inferred cosmic origin was found in tree resins dating from the TE (Longo et al. 1994; Serra et al. 1994). Although these data are compatible with the hypothesis of the impact of a cosmic body, they are by no means conclusive and are not sufficient to prove the nature of the TCB. The same can be said about the lacustrine sediments of Cheko Lake (Sacchetti 2001) studied in the framework of the multidisciplinary investigation as carried out by the Italian scientific expedition Tunguska99 (see *http://www-th.bo.infn.it/tunguska/)* (Amaroli et al. 2000; Pipan et al. 2000; Gasperini et al. 2001; Longo et al. 2001; Longo and Di Martino 2002 and 2003; Longo et al. 2005). This field research has been strengthened by theoretical studies and modeling. In a recent paper (Farinella et al. 2001), a sample of possible TCB orbits has been constructed and a dynamic model was used to compute the most probable source of a TCB placed on each of these orbits. The results of calculations gave a greater probability for a TCB coming from an asteroidal source (83%), than from a cometary source (17%).

18.2.2
“Non-traditional" Hypotheses

Vasilyev (2004) states, “We should not exclude the possibility that the Tunguska phenomenon is a qualitatively new phenomenon for the science, that should be analyzed from non-traditional positions". These “non-traditional" approaches still consider an impact with the atmosphere of “something" coming from external space. Several of them, though published in scientific journals, were found to be technically groundless, e.g. the hypotheses involving near critical fissionable material (Zigel’ 1983; Hunt et al. 1960), antimatter meteors (Cowan et al. 1965), and tiny black holes (Jackson and Ryan 1973). Others consider alien spacecrafts (Kazantsev 1946; Baxter and Atkins 1976). Kazantsev was the first who explained the lack of fragments or impact craters in Tunguska by an explosion in the atmosphere. Nevertheless, I think that here we can ignore such extremely “non-traditional" hypotheses.

18.2.3
Alternative Approaches

Recently, some “alternative" approaches were presented to explain the TE. Different from the above-mentioned traditional or non-traditional explanations, these alternative approaches deny an impact of an external body with Earth. They claim that the event was triggered by a terrestrial cause. I mention here two of the more discussed alternative interpretations.

The first is a tectonic interpretation (e.g. Ol’khovatov 2002), which considers the coupling between tectonic and atmospheric processes in a “very rare combination of favorable geophysical factors." Another recent work that should be mentioned is the “kimberlite interpretation" (Kundt 2001), which considers the TE as caused by the tectonic outburst of some 10 megaton of natural gas. For the volcanic (outflow) inter pretation, Kundt presents the estimates of the involved mass and kinetic energy of the vented natural gas, of its outflow timescale, supersonic and subsonic ranges, and buoyant escape towards the exosphere.

The main idea of this latter work is contradicted by at least two facts. The first and more obvious point against the hypothesis of an explosion from the ground is that the eyewitness testimonies describe the trajectory of a *bolide crossing the sky* (see Sect. 18.3.2). Among these testimonies, the earliest, given a few days after the event by educated people, have a high trustworthiness. On that basis, the first Kulik expedition (1921-1922) gathered sufficient information to conclude, that “the meteorite fall in the neighborhood of the Ogniya river, a left tributary of the Vanavara river, which is a right tributary of the Podkamennaya Tunguska (Hatanga) river" (Kulik 1922, 1923, 1927; Landsberg 1924). The first expedition could not go farther than Kansk, about 600 km from the Tunguska explosion site. Five years later, Kulik discovered the site about 50 km from the mentioned tributary of the Vanavara River.

A second objection comes from the absence of debris clearly referred to the explosion in the epicenter area. If we assume that the anomalous optical phenomena observed after the TE, were due to particles released in the atmosphere by the explosion, we should find an increasing concentration of those particles (with grain-size progressively decreasing) toward the explosion epicenter. As also pointed out by Kundt, we do not observe a carpet of dust in the vicinity of the epicenter as we should observe for the explosion of a meteorite, but also (and more markedly) for the explosion of a diatreme or any volcanic emission. How could an explosion “from below" disperse dust in the atmosphere to an extent comparable to that of the Krakatau without leaving significant traces close to the epicenter? It seems more probable that an explosion “from above" could explain this occurrence.

Moreover, geological maps of the region (Sapronov 1986) and our own observations during the Tunguska99 expedition do not report the presence of mantle rocks, such as peridotites or eclogites, which are usually associated with kimberlites. Though the area is centerd on the roots of the lower Triassic Kulikovsky paleovolcanic complex (see Fig. 18.1), which extends over an area 25 × 20 km wide, displaying numerous, various sized craters, it is presently a tectonically stable cratonic region, as testified by the low intraplate seismicity. The map from the USGS catalog, which reports significant worldwide earthquakes during historical times, confirms this stability.

Finally, the “radonic storm" registered at our base camp (see Fig. 18.2) during the Tunguska99 expedition (Longo et al. 2000; Cecchini et al. 2003) has nothing to do with a “kimberlite" phenomenon, as suggested by Kundt. Indeed, we registered an intensity enhancement of gamma radiation during a thunderstorm (see Fig. 18.3) due to radon daughters, as observed in other parts of the world, where no “kimberlite interpretation" is possible. Though we cannot accept the main ideas of Kundt, the outflow theory can help us to understand some aspects of the TE. It is plausible, and even probable, that gas releases took place from the permafrost dissolution (caused by the impact of the TCB and not by a kimberlite outflow). For example, part of the multiple explosions heard for more than half an hour by many earlier trustworthy witnesses (Kulik 1922, 1927; Obruchev 1925; Voznesenskij 1925) might probably be due to a rapid release of gas (methane) from the permafrost layer as a consequence of the thermal burst related to

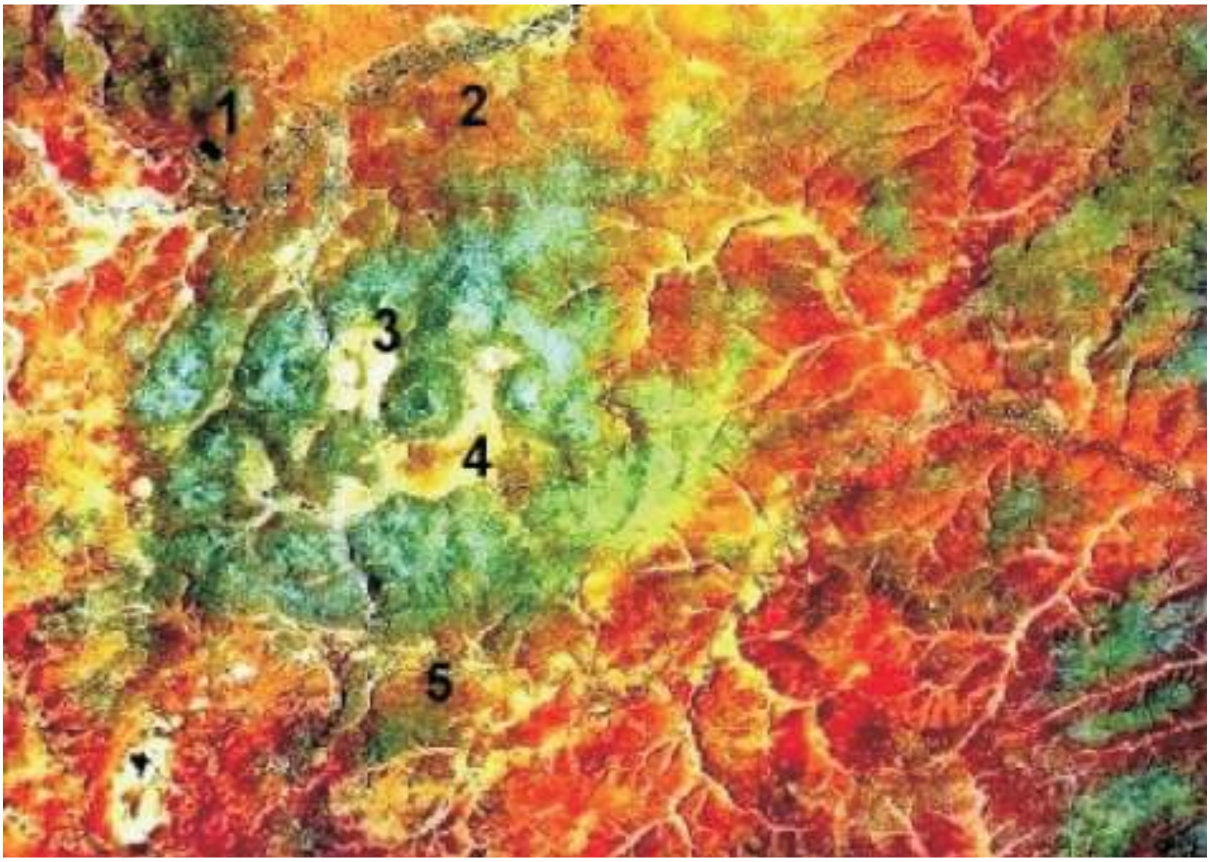

Fig. 18.1. Satellite view of the Kulikovsky paleovolcanic complex (*1* - lake Cheko, *2* - river Kimchu, *3* - Northern swamp, *4* - Southern swamp, *5* - river Khusma)

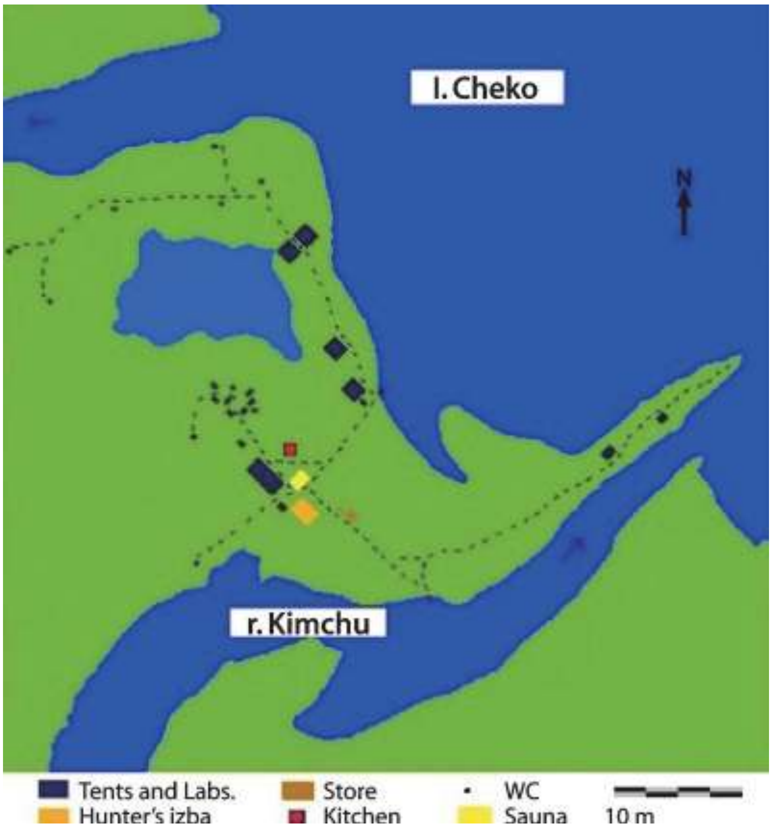

Fig. 18.2. The base camp of the Tunguska99 expedition on the shore of the lake Cheko (drawing by Andrey Chernikov)

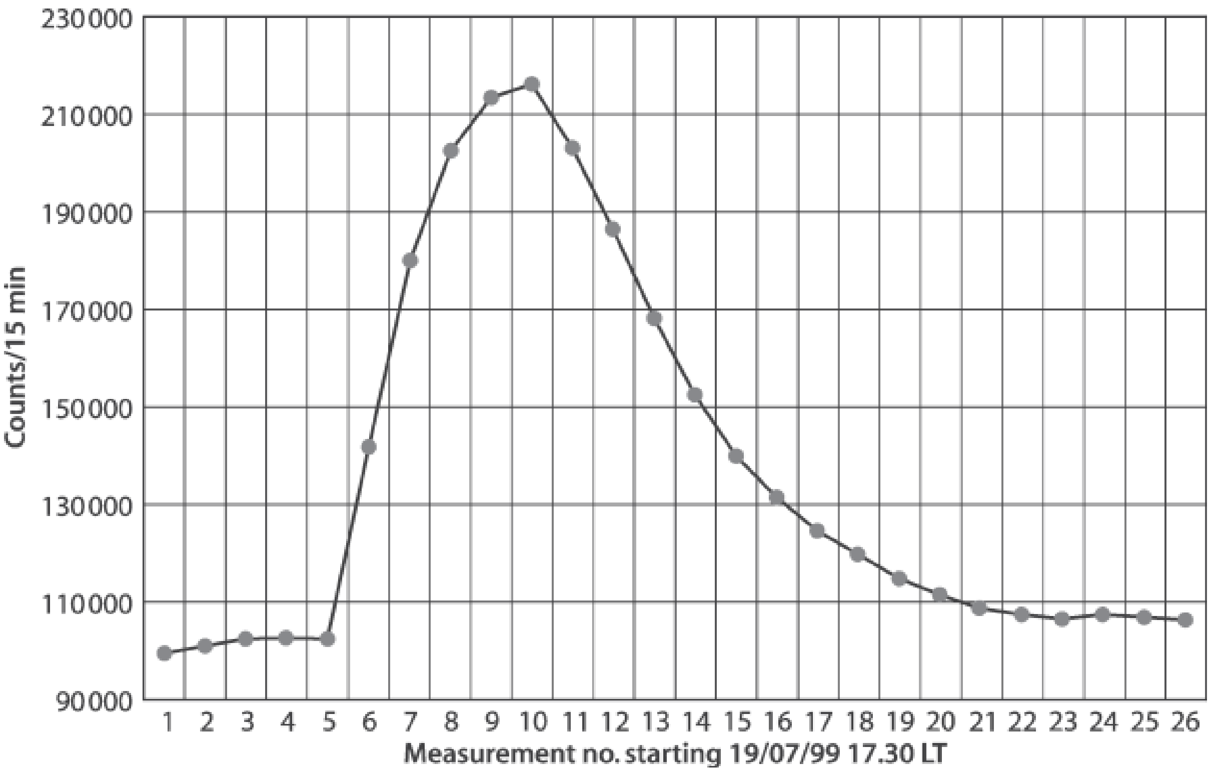

Fig. 18.3. Gamma-ray (25 keV-3 MeV) intensity enhancement registered at the base camp of the lake Cheko during the thunderstorm of July 19, 1999. Note the steep rise of counting rate, while it is raining. It corresponds to gammas emitted by radon daughters

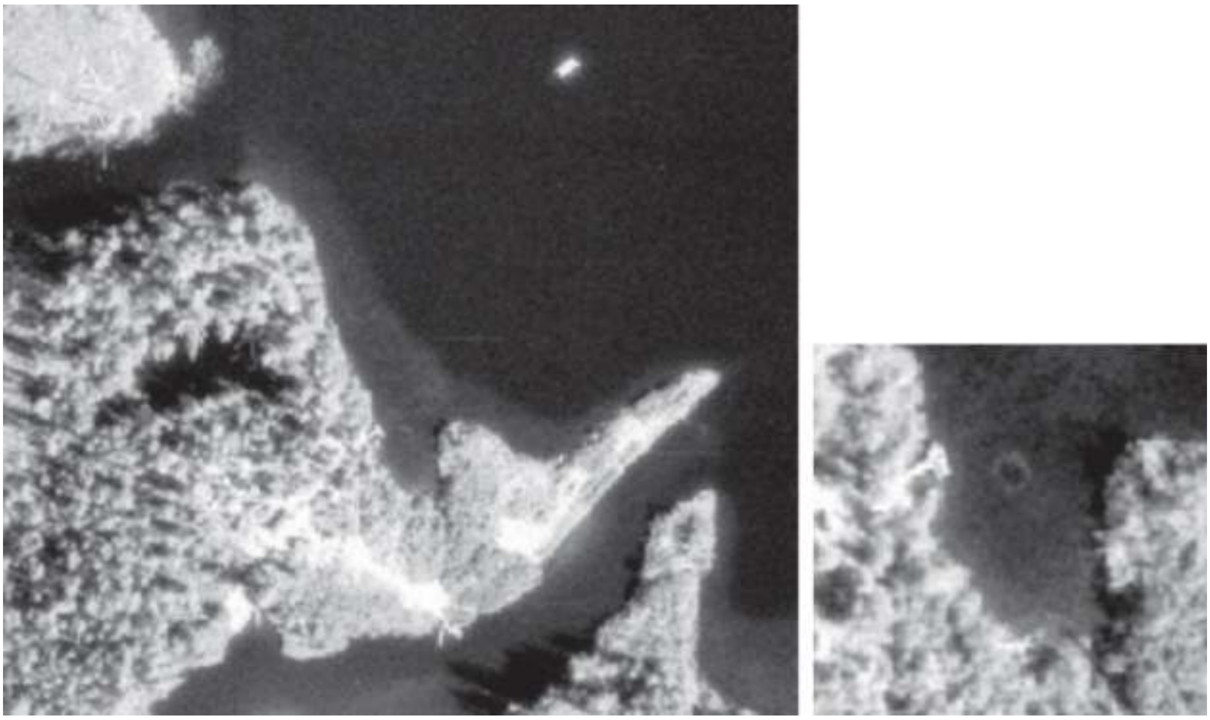

Fig. 18.4. Aerial view of the camp of the Tunguska99 expedition (23 July 1999). Near the shore, a hole with a few meters diameter resulting from a gas outflow can be seen on the lake bottom the main event. Indeed, in July 1999, we observed a small “crater" originated “from below" on the Cheko Lake bottom (see Fig. 18.4). It could be due to methane emission from decaying organic matter in the *surface* layer of some tens of meters. Obviously, this does not contradict the known *tectonic stability* of the region.

18.3
Known Data

18.3.1
Objective Data

Three main kinds of objective data on the Tunguska explosion are available: seismic and barometric registrations, recorded immediately after the event, information on the bright nights, observed in Eurasia in July 1908, and data on forest devastation, systematically collected 50-70 years later and recently integrated with the data of the 1938 and 1999 aerial photographic surveys.

Seismic and Barometric Registrations

Seismic records from Irkutsk, Tashkent, and Tiflis were published together, two years after the event (Levitskij 1910), those from Jena, three years later. However, the first paper that connected to the TE the origin of these seismic waves was published only in 1925 (Voznesenskij 1925). Similarly, the barograms recorded in 1908 in a great number of observatories throughout the world, were associated with the TE some twenty years later (Whipple 1930; Astapovich 1933). From the analysis of the available seismograms and barograms, the time that the seismic and aerial waves started was calculated. The main results obtained are listed in Sect. 18.4.

Bright Nights Observed

In 1908, the attention of astronomers and geophysicists in Europe and Asia was drawn to some unusual phenomena, such as bright nights, noctilucent clouds, brilliant colorful sunsets and other observations. It is difficult to conclude that some of these phenomena are really “anomalous". For example, in June-July, the appearance of noctilucent clouds reaches its maximum and it is difficult to distinguish between “usual" and “unusual" noctilucent clouds. Therefore, I shall consider here only the bright nights phenomenon.

Bright nights ("at midnight, it was possible to read the newspaper without artificial lights"; see Figs. 18.5 and 18.6) were described in many papers (e.g., De Roy 1908; Shenrock 1908; Süring 1908; Svyatskij 1908). At that time, many explanations for the bright-nights phenomenon were proposed. Up to 1921, meager information about a great 1908 bolide was published only in some local Siberian newspapers. Nobody considered a link between these phenomena, although on 4 July 1908, the Danish astronomer Torwald Kohl wrote: "It would be advisable to learn whether in recent times some great meteorite has been seen in Denmark or elsewhere" (Kohl 1908). It was only in 1922, after his first recognition in Siberia that Kulik wrote about a probable link between the bright nights in Eurasia and the explosion in Central Siberia (Kulik 1922). From that time onward, such phenomena have been considered as two parts of the Tunguska event.

The phenomenon and its correlation to the TE, was thoroughly studied in the 1960s (Zotkin 1961; Vasilyev et al. 1965). The 4 March 1960 issue of *Science* published a letter from the Committee on Meteorites of the Academy of Science of the USSR addressed to foreign scientists and asking them to send all the information available on the optical phenomena of 1908 (Fesenkov and Krinov 1960).

Zotkin (1961) studied the bright nights, observed in 114 points of the globe. He distinguished observations following the 30 June from those preceding that date. He considers the latter poorly reliable and of "local character", whereas the events observed from the 30 June did not have a "local" character and were observed in more than a hundred points of Europe and Asia.

Vasilyev (1965) considered a more complete data set and referred to 86 communications and articles dated to 1908. He lists 14 cases of bright nights from 21 to 29 June 1908 and 159 cases from 30 June up to 3 July (in subsequent papers, he indicates about twenty other cases from 4 to 28 July). He considers *all* these cases related to the Tunguska event and this is not easy to explain.

It seems to me that Zotkin's approach is more acceptable. Only the bright nights following the 30 June should be related to the Tunguska event. This is confirmed by the *global* character of the phenomenon and by *polarization* measurements. The "global" character of the phenomenon, observed in the nights beginning on 30 June and 1 July 1908 are illustrated in Fig. 18.5 (Vasilyev and Fast 1976). As can be seen, the bright nights were observed on an area of about 12 million km^2, from the longitude 6.5°W (Armagh, Ireland; see Fig. 18.6) up to 92.9° E (Krasnoyarsk) and from the latitude 41° N (Tashkent) up to 60° N (Petersburg). If the bright nights are due to dust in the atmosphere, the light reflected should be polarized. Busch (1908a,b) measured the daylight polarization in Arnsberg (Germany). His results indicate an absence of the effect in the first half of 1908 up to 28 June, a strong effect the 1 July that gradually disappears up to 25 July. The conclusions of Zotkin were that it is difficult to accept that dust particles could reach Great Britain from Tunguska in 22 hours. Therefore, they were ice particles from the comet tail and the comet nucleus exploded in Tunguska. Bronshten (1991) hypothesized that the particles were transported from Tunguska by gravitational forces. In Boslough and Crawford model (1997), the mass of the impactor, as well as water from the humid lower atmosphere, are ejected above the top of the atmosphere and within 15 minutes can extend more than 2000 km from the impact site.

Data on Forest Devastation

The data on forest devastation are a second kind of objective information source about the event. The main part of these data refers to the tree fall and the direction of flattened trees. From these data we can obtain information on the coordinates of the wave propagation centers (often called "epicenter(s)") and on the final TCB trajectory.

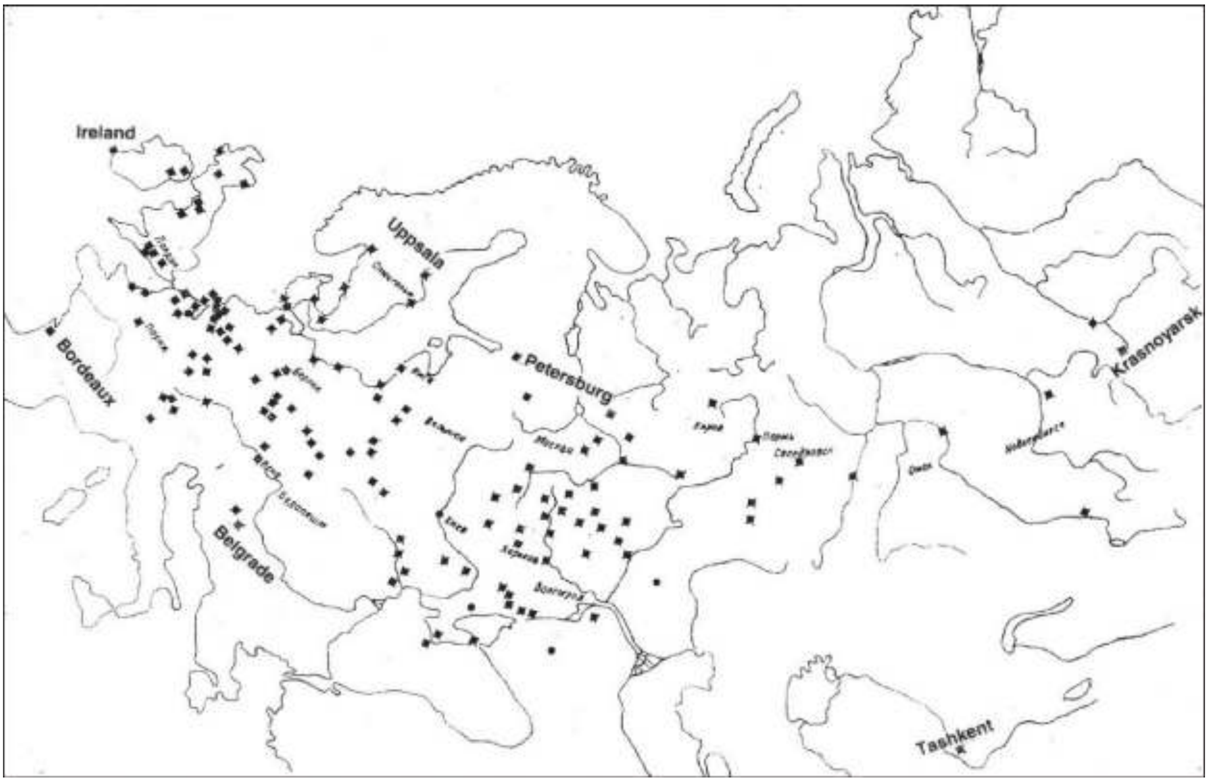

Fig. 18.5. Stations where anomalous bright nights were observed the 30 June/1 July 1908

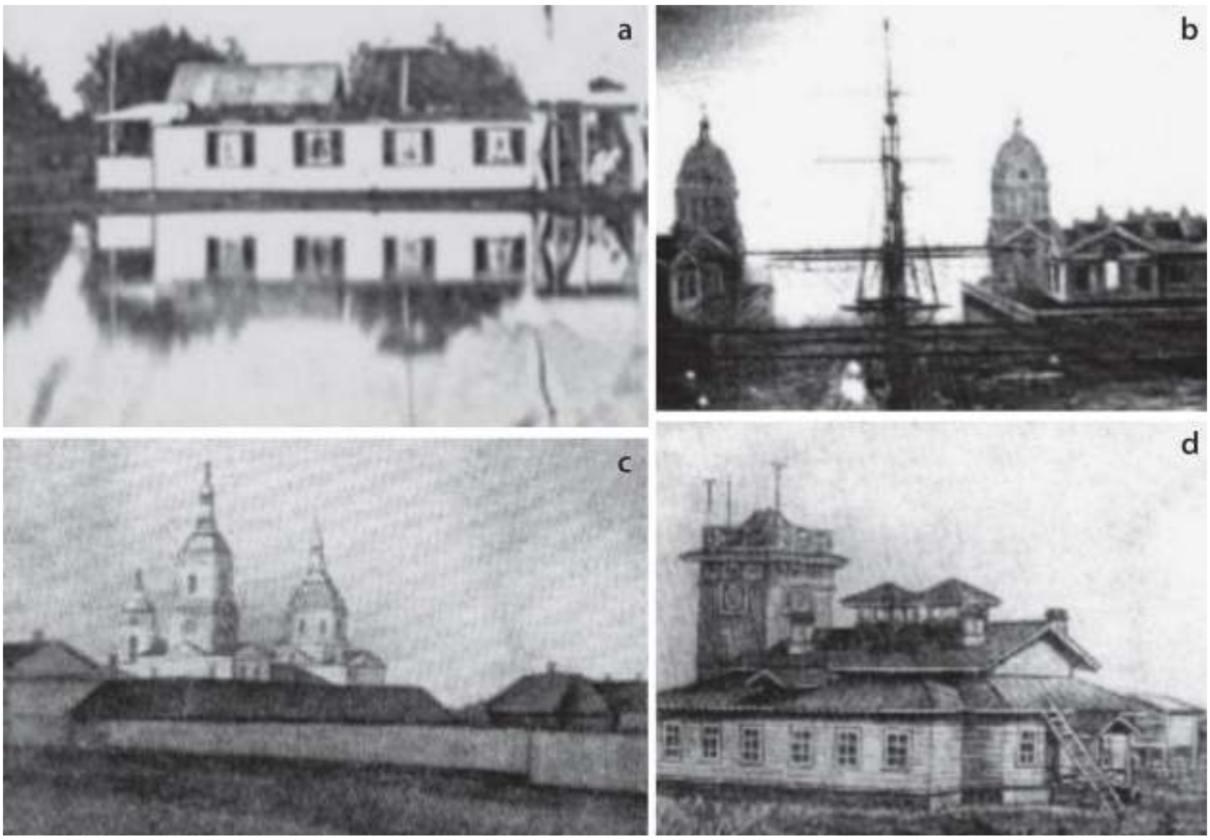

Fig. 18.6. Photos taken during the bright night of 30 June 1908 in (a) Armagh, (b) Greenwich, and (c) Tambov. (d) The Irkutsk observatory at the beginning of the 20th century

Though Kulik discovered the radial orientation of fallen trees as early as 1927, systematic measurements of fallen tree azimuths were started only during the two great post-war expeditions organized by the Academy of Sciences in 1958 and 1961 (Florenskij et al. 1960; Florenskij 1963), and during the Tomsk 1959-1960 expeditions. Under the direction of Fast, with the help of Boyarkina, this work was continued for two decades during ten different expeditions from 1961 up to 1979. A total of 122 people, mainly from Tomsk University, participated in these on site measurements. The data collected have been published in a catalog in two parts: the first one contains the data obtained by six expeditions (1958-1965), which include the whole set of single-tree azimuths and the azimuths averaged on trial areas equal to 2500 m^2 or 5000 m^2, chosen throughout the whole devastated forest (Fast et al. 1967). In the second part, the data collected by the six subsequent expeditions (1968-1976) were given (Fast et al. 1983).

The data on forest devastation also give information on the energy emitted and on the height of the explosion. Indeed, these data include, not only fallen tree directions, but also the distances that different kinds of trees were thrown, the pressure necessary to do this, information on forest fires and charred trees, data on traumas observed in the wood of surviving trees and so on (e.g. Florenskij 1963; Vorobjev et al. 1967; Longo and Serra 1995; Longo 1996, 2005).

In order to correct, update and enlarge the fallen tree distribution data, we performed a new aero-photographic survey during the Tunguska99 expedition (Longo and Di Martino 2002, 2003) (see map on Fig. 18.7). This survey was needed to obtain a new unified catalog, which includes:

(*1*) corrected Fast data (Fast et al. 1967, 1983),

(*2*) data from Kulik's 1938 aerial photosurvey never previously analyzed, (*3*) never published data collected in 1967 by the Anfinogenov group in the central region of the site. These three datasets have been checked and completed with our on-site measurements carried out in July 1999 and 2002 to obtain the coordinates of different reference points in the same area. These data allowed us to recognize ground elements on the aerial pictures and to connect them to the regional topographic net.

Unfortunately, a map containing all the data from Fast's catalogs (Fast et al. 1967, Fast et al. 1983) has never been published. In the last 40 years, the map of fallen tree azimuths used for comparison with theoretical models (e.g. Korobeinikov et al. 1990; Boslough and Crawford 1997) was the one constructed by A. Boyarkina, V. Fast and coworkers (Florenskij 1963; Boyarkina et al. 1964). This map contains only the data on the azimuths measured in 1958-1961. The new unified catalog and the new map (Longo et al. 2005) have been constructed using a number of tree azimuths and trial areas several times larger than those considered in Fast's analyses. Moreover, we have introduced a reliability degree for each trial area averaged azimuth. The reliability degree has been assigned on the basis of the percentage of singletree azimuths that lay in a sector of 15° centered on the averaged azimuth. A good agreement between the new map and the horizontal aerodynamic pressure calculated on the basis of Korobeinikov et al. (1990) model has been obtained.

No Impact Craters or Meteorite Fragments

Data on forest devastation and records of the atmospheric and seismic waves have made it possible to deduce the main characteristics of the Tunguska explosion, i.e. its

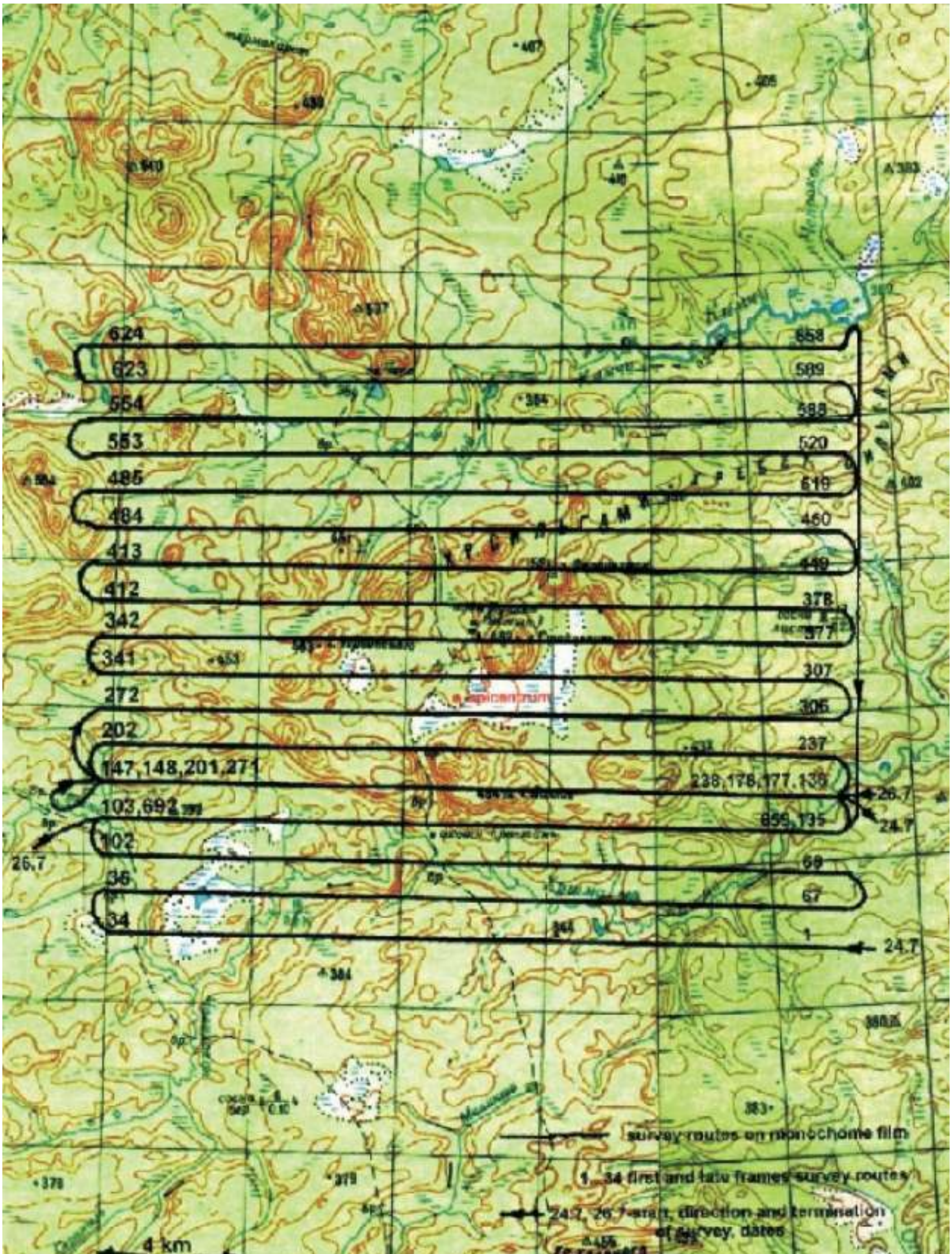

Fig. 18.7. Flight routes of the 1999 aero-photosurvey

exact time, 00h 14m28s UT (Ben-Menahem 1975), the coordinates of the point usually called epicenter, 60° 53' 09" N, 101° 53' 40" E (Fast 1967), the energy release, equivalent to 10-15 million tons of TNT (Megaton) that corresponds to about one thousand times the Hiroshima bomb energy, and height of the explosion (5-10 km), though the values for the last two parameters are estimated with great uncertainty. However, neither macroscopic fragments of the cosmic body, nor a typical signature of an impact, like a crater, have ever been found in an area of 15 000 km^2, so that the nature and composition of the TCB and the dynamic of the event have not yet been clarified.

18.3.2
Eyewitnesses Testimonies

There is a great number of eyewitness testimonies. The more complete collection of these testimonies is provided by Vasilyev et al. (1981). It contains direct observations of the Tunguska explosion from 386 different points and a list of the geographical coordinates of these points. To these observations, the authors have added news published in newspapers, reports and communications from many official employees for a total of 708 testimonies. It is easy to find contradictions in this material collected for more than 60 years by very different people. Sometime these contradictions are more apparent than real. As an example I can remember the contradiction recently removed by Fast VG[1] and Fast NP (2005). As is well known, two centuries before the TE, the czar Peter I introduced a reform in the Orthodox Church. Entire villages of people that did not recognize the reform were sent to Siberia. Therefore many Siberian regions and villages in 1908 were populated by people following the “old faith". For them, the daily timetable was regulated starting from the morning prayers at “*obied"*, i.e. 8 o’clock in the morning. When asked about the explosion time, they answered that the explosion took place some time before the *obied*, which really corresponds to the seismic wave registrations after 7 o’clock local time. For the secular people that collected the testimonies, the word *obied* means lunch, i.e. about 12-14 o’clock. Therefore, they completed the forms by noting that the eyewitness stated that the explosion took place at noon, or even in the afternoon. These testimonies were considered not trustworthy due to the clear contradiction with instrumental registrations. A thorough statistical analysis performed by the Fasts (2005) has shown that the distribution of “midday eyewitnesses" correctly reproduces the distribution of the population following the “old faith".

To use them properly, it is important to take into account the different trustworthiness of the testimonies. I think that we can distinguish the following groups of testimonies in decreasing order of trustworthiness:

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[1] It was the last contribution to the Tunguska studies given by the great researcher Vilgem Genrikovich Fast (1936-2005).

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1. The testimonies collected *in the days immediately following the Tunguska explosion* by the director of the Irkutsk magnetic and meteorological observatory Voznesenskij (1925). Unfortunately, Voznesenskij published them only 17 years later due to an excess of scientific prudence. Immediately after the registration of the earthquake N° 1 536, in the morning of 30 June 1908, Voznesenskij sent to all his correspondents a request to report what they or other people had observed on that morning. In his paper he gives a table with the results received from 61 correspondents and a map

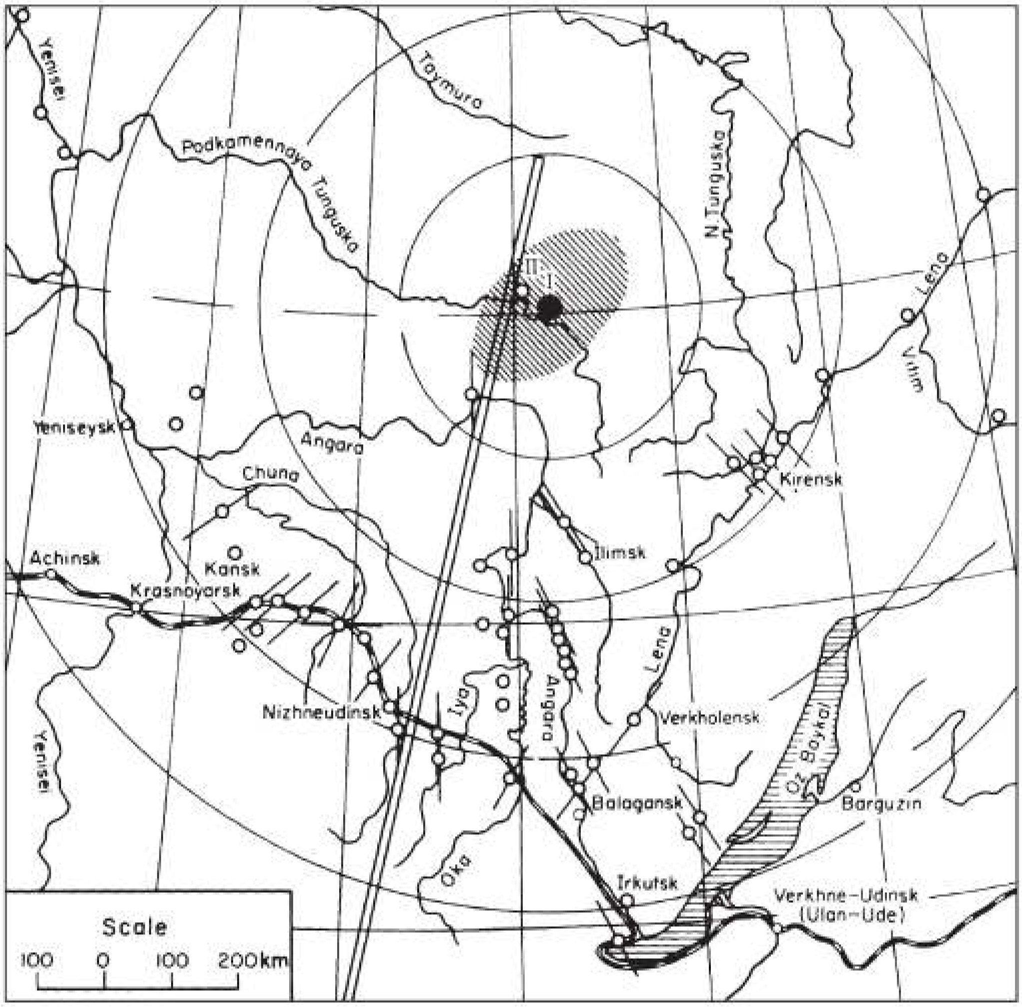


Fig. 18.8. A map with the dislocation of the correspondents that sent in July 1908 their reports to the Irkutsk Observatory. The map was published by Voznesenskij (1925) and reproduced by Krinov (1949, 1966)

showing their location on a very great territory (Fig. 18.8). Moreover, he refers to many individual testimonies from "cultured" people (chief of town post office, employees of meteorological observatories, agronomist and so on).

2. The testimonies collected before, during and immediately after (up to 1933) the expeditions of Kulik. They were collected mainly by Obruchev (1925), Suslov (1927) and Kulik (1922, 1923, 1927). I have mentioned in Sect. 18.2.3 that this primary information was sufficient to understand in 1922 that research had to be directed to the north of the Podkamennaya Tunguska River, in the neighborhood of the Vanavara River.

3. In the period from about 1933 up to 1958 practically no new eyewitness was questioned and, finally, in the 1960s, a massive material with hundreds of new testimonies from old people was collected in many regions. A thorough examination of these records can still be useful as Fasts's work shows.

No doubt that the more valuable testimonies are those written immediately after the fall by the correspondents of the Irkutsk observatory. They are not influenced by Voznesenskij who asks only about observations related to the *earthquake N° 1536*, without any reference to a flying body. Many of these reports are written before the publication in local newspapers of the first information on the event. These genuine reports, synthesized by Voznesenskij in 1925, are now stored in the Archives of the Meteorite Committee of the Russian Academy of Sciences hereafter referred as "Archive RAS". In the following paragraph, I give in brackets the page of the document N° 57 of Archive RAS in which these testimonies are gathered.

To describe what seen in the morning of 30 June 1908, no one of these reports testify something different from a flying object. Many reports are written after questioning a great number of persons. For example, the director of the meteorological station of Maritui states that his report is written after the interrogation of about 500 persons on a great territory around his station (19). I quote here some descriptions of the correspondents:

“a large group of local inhabitants noticed a ball of fire in the north west coming down obliquely" (3); “the workmen saw a fiery block flying, it seemed, from south east to north west" (4); “in the north west a pillar of fire appeared about 8 meters in diameter…it was accurately established that a meteorite of very large dimensions had fallen" (5); “the local peasants told me that they saw some sort of fiery ball flying in the north" (6); “a loud noise was heard…probably from a passing meteor (aerolith)" (9); “some of local inhabitants had seen an elongated body narrowing towards one end, about one meter in length, torn as it were from the Sun…this body flew across the sky and fell in the north east" (16); “the fall of an aerolith was observed…a fiery streamer was seen" (26); “a ball of fire appeared in the sky and moved from south east to north west. As the ball approached the ground…it had the appearance of two pillars of fire" (36).

The testimony of page 16 was written the 30 June 1908 (the day of the event), that of page 6 - the 1 July 1908 (the day after the event), the others - from a few days up to six weeks after the event. Many correspondents could not understand what they have seen or heard. For example, in the letter referred to on page 6, the correspondent wrote to the Irkutsk observatory: “I have the honor to ask submissively the observatory to communicate and clarify what this means and could it be dangerous for human life".

These testimonies, and many others, contradict the “alternative" approaches (see Sect. 18.2.3) that deny the impact of an external body with Earth.

18.4 Parameters Deduced

18.4.1 Explosion Time

Studying the available seismic data, a first determination of the explosion time as 0h 17m 12s UT was obtained by Voznesenskij (1925). This value was used up to the 1960s. The explosion time deduced from the barograms of 6 British meteorological stations, was equal to 0 h 15 m UT (Whipple 1930). The independent analysis of the barograms from 13 Siberian stations, gave an explosion time equal to 0h 16m 36s UT (Astapovich 1933). These two sets of data were subsequently analyzed more carefully taking into account the exact distances and the properties of seismic and atmospheric waves. Pasechnik (1971) obtained a first result (0h 14m 23s UT), based solely on Jena and Irkutsk’s seismic data. Two additional and more complete analyses were independently performed by Ben-Menahem (1975) and Pasechnik (1976). They found practically the same value for the time the seismic and aerial waves started (see Table 18.1, updated from Farinella et al. 2001).

Pasechnik (1976) calculated that the time of the explosion in the atmosphere was 7-30 seconds earlier depending on the height and energy of the explosion; this interval was subsequently reduced to 2-20 seconds (Pasechnik 1986). In the 1986 paper, however, Pasechnik revised his previous results obtaining a value equal to 0h 13m 35s ± 5s UT. The commonly accepted explosion time is the time given by Ben-Menahem for the instant the seismic waves started, i.e. 0h 14m 28s UT.

18.4.2 Coordinates of the Epicenter

The first contact point between the Earth surface and the shock wave from the airburst is commonly called “epicenter," though this term is not proper. From the data collected during the first three expeditions, Fast (1963) obtained the epicenter coordinates 60° 53' 42" N, and 101° 53' 30" E. These values are very close to the final ones 60° 53' 09" ± 06" N, 101° 53' 40" ± 13" E, calculated by Fast (1967) analyzing the whole set of data from the first part of the catalog (Fast et al. 1967). At about the same time, Zolotov (1969) performed an independent mathematical analysis of the same data and obtained the second values quoted in Table 18.1. The coordinates of Fast's epicenter with the uncertainties quoted, corresponding to about 200 m on the ground, were subsequently confirmed in all Fast's papers.

Examining the direction of fallen trees seen on the aerial photographic survey performed in 1938, Kulik suggested (1939, 1940) the presence of 2-4 secondary centers of wave propagation. This hypothesis was not confirmed, although neither was it definitely ruled out, by Fast's analyses and by seismic data investigation (Pasechnik 1971, 1976, 1986). Some hints of its likelihood were given by Serra et al. (1994) and Goldine (1998). This hypothesis is compatible with the recent reanalysis of the direction of fallen trees made on the basis of Fast's data integrated by those obtained from the 1938 and 1999 aerial photosurveys (Longo et al. 2005). The high trustworthiness of earlier eyewitnesses is also in favor of the multicenter hypothesis (Voznesenskij 1925, Archive RAS).

18.4.3
Trajectory Parameters, Height of the Explosion and Energy Emitted

The final TCB trajectory can be defined by its azimuth (α), here given from North to East starting from the meridian, the trajectory inclination (*h*) over the horizon and the height (*H*) of the explosion. These parameters can be estimated from the data on forest devastation, seismic records and eyewitness' testimonies. The height of the explosion is closely related to the value of the energy emitted, usually estimated to be equal to about 10-15 MT (Hunt 1960; Ben-Menahem 1975), although some authors consider the energy value to be higher, up to 30-50 megaton

Table 18.1. Parameters deduced for the Tunguska explosion. In the last column, the sources used to find the given values are indicated: SM: seism,ic; BM: barograph measurements; FT: fallen tree directions; FD: forest devastation data; EW: eyewitness

Source	Parameter	Remarks
	Time of the explosion (UT)	
Ben-Menahem (1975)	$0^h 14^m 28^s$	SM
Pasechnik (1976)	$0^h 14^m 30^s$	SM, BM
Pasechnik (1986)	$0^h 13^m 35^s$	SM
	Geographic coordinates of the epicentre	
Fast (1967)	60°53'09" N, 101°53'40" E	FT
Zolotov (1969)	60°53'11" N, 101°55'11" E	FT
	Height of the explosion, *H* (km)	
Fast (1963)	10.5	FD
Ben-Menahem (1975)	8.5	SM
Bronshten and Boyarkina (1975)	7.5	FD
Korotkov and Kozin (2000)	6 – 10	FD
	Trajectory azimuth, α (deg)	
Krinov (1949)	137	EW
Fast (1967)	115	FT
Zolotov (1969)	114	FT
Fast et al. (1976)	99	FT
Yavnel' (1988)	114 – 138	EW
Andreev (1990)	123	EW
Zotkin and Chigorin (1991)	126	EW
Koval' (2000)	127	FT, FD
Bronshten (2000)	122	EW
Bronshten (2000)	103	FT, FD
Longo et al. (2005) (single body)	110	FT
Longo et al. (2005) (multiple bodies)	135	FT
	Trajectory inclination, *h* (deg)	
Krinov (1949)	17	EW
Sekanina (1983)	< 5	EW
Zigel (1983)	5 – 14	EW
Yavnel' (1988)	8 – 32	EW
Andreev (1990)	17	EW
Zotkin and Chigorin (1991)	20	EW
Koval' (2000)	15	FT, FD
Bronshten (2000)	15	EW, FT
Longo et al. (2005) (single body)	30	FT
Longo et al. (2005) (multiple bodies)	30 – 50	FT

(Pasechnik 1971, 1976, 1986). In agreement with the first energy range, which seems to have more solid grounds, the height of the explosion was found equal to 6-14 km. A height of 10.5 ± 3.5 km was obtained by Fast (1963) from data on forest devastation. Using more complete data on forest devastation, Bronshten and Boyarkina (1975) subsequently obtained a height equal to 7.5 ± 2.5 km. From seismic data, Ben-Menahem deduced an explosion height of 8.5 km. Data on the forest devastation examined, taking into account the wind velocity gradient during the TCB flight (Korotkov and Kozin 2000), gave an explosion height in the range 6-10 km.

A close inspection of seismograms of Irkutsk station, made by Ben-Menahem (1975), showed that the ratio between East-West and North-South components is about 8 : 1, even though the response of the two seismometers is the same. Since the Irkutsk station is South of the epicenter, Ben-Menahem (1975) inferred that this was due to the ballistic wave and therefore the azimuth should be between 90° and 180°, mostly eastward. However, it is not possible to obtain more stringent constraints on the azimuth from seismic data.

It is not clear how Voznesenskij (1925) determined the direction of the bolide's flight given in Fig. 18.8. Using only the eyewitness data collected in 1908, Yavnel' (1988) obtained α = 114°-138° and h = 8°-32°. A critical analysis of the eyewitness reports written in 1908 together with those collected in the nineteen-twenties, made by Krinov (1949) gave an azimuth α = 137° with h = 17°.

Analysing the data on flattened tree directions from the first part of his catalog (Fast et al. 1967), Fast found a trajectory azimuth α = 115° ± 2° as the symmetry axis of the "butterfly" shaped region (Boyarkina et al. 1964; Fast 1967). The independent mathematical analysis of the same data gave α = 114° ± 1° (Zolotov 1969). Having made another set of measurements, Fast subsequently suggested a value of α = 99° (Fast et al. 1976). In this second work, the differences between the mean measured azimuths of fallen trees and a strictly radial orientation were taken into account. He gave no error for this new value, but a close examination of Fast's writings suggests that he considered an error of 2°. Koval' subsequently collected complementary data on forest devastation and critically re-examined Fast's work. He obtained a trajectory azimuth α = 127° ± 3° and an inclination angle h = 15° ± 3° (Koval' 2000).

From a critical analysis of all the eyewitness testimonies collected in the catalog of Vasilyev et al. (1981), Andreev (1990) deduced α = 123° ± 4° and an inclination angle h = 17° ± 4°. Zotkin and Chigorin (1991) using the data in the same catalog obtained: α = 126° ± 12° and h = 20° ± 12°, whereas from partial data, Zigel' (1983) deduced h = 5° ± 14°. A different analysis of the eyewitness data (Bronshten 2000), gave α = 122° ± 3° and h = 15°. In the same book a mean value α = 103° ± 4° is given obtained from forest devastation data. Sekanina (1983, 1998) studied the TE on the basis of superbolide theories and the analysis of the data available and eyewitness testimonies. He suggested an inclination over the horizon h < 5° and an azimuth α = 110°.

From the data on fallen tree directions in our new unified catalog (Longo et al. 2005), we obtain a single-body trajectory azimuth α = 110° ± 5° and h = 30°. The same data are compatible with the hypothesis that the cosmic body was composed by at least two bodies, falling independently but very close one to the other, with a trajectory azimuth ~135° and an inclination of the total combined shock wave axis between 30° and 50°. The first body, with a greater mass, emitted the maximal energy at a height of about 6-8 km. The second, of minor mass, flew a little higher, on the right side and behind the first body, following the azimuth ~135° in the direction of the Lake Cheko. The last azimuth is in agreement with what found by Krinov (1949) and Yavnel' (1988) analyzing earlier eyewitness testimonies.

18.5 Tunguska-like Impacts

The Tunguska event is the only phenomenon of this kind that has occurred in historical time. The consequences of the event can be directly studied in situ. From such a study we can obtain a great amount of information useful to better understand and predict the characteristics of future Tunguska-like impacts, i.e. due to bodies with diameters equal to a few tens of meters. Many different models have been proposed to describe the impact with our planet by bodies having these dimensions. I mention here only some recent models, which imply a greater impact frequency and, therefore, a greater hazard.

18.5.1 Recent Models and Impact Frequency

The frequency of Tunguska-like impacts is highly dependent on the emitted energy, the explosion height and the entry angle.

Most of the published models for Tunguska have assumed that the explosion was essentially from a point source. Recent models consider that such events are more analogous to explosive line charges, with the bolide's kinetic energy deposited along the entry column.

Plume-forming Impacts

Boslough and Crawford (1997) explain the TE as due to a "plume-forming" atmospheric explosion, i.e. as associated with the ejection and collapse of a high plume. I report here a brief description of the three overlapping phases of the plume formation, as summarized by Stokes et al. (2003):

1. *Entry phase.* When a bolide penetrates a planet atmosphere, it encounters gases at high speed that both slow it down and heat it up. A "bow shock" develops in front of the bolide where atmospheric gases are compressed and heated. Some of this energy is radiated to the bolide, causing ablation (i.e., melting and vaporization that remove material of the bolide's surface) and deformation. The rest of the energy is deposited along the long column created by the bolide's passage; much of the bolide's kinetic energy is lost in this manner. In some cases, aerodynamic stresses may overcome the bolide's tensile strengths and cause it to catastrophically disrupt within seconds of entering the atmosphere. Airblast shock waves produced by this sequence of events may reflect off the surface causing great devastation.

2. *Fireball phase.* The events taking place during the entry phase produce a hot mixture of bolide material and atmospheric gas called a fireball that is ballistically shot upward by the impact. Since it is incandescent, it radiates energy away in visible and near infrared wavelengths. Buoyant forces cause the fireball to rise because it is less dense than the surrounding atmosphere. The fireball's energy expands most easily along the low-density high sound speed entry column that was created by the bolide' passage.

3. *Plume phase.* The expanding fireball (and associated debris) rushes back out the entry column, ultimately reaching altitudes of many hundreds kilometers above the top of the atmosphere. After ~10 minutes of cooling and contracting at these heights, however, the plume splashes back onto the upper atmosphere, releasing additional energy as it collapses and impacts.

Boslough and Crawford (1997) re-examined the phenomena associated with the TE in the context of their model. They found that a 3 megaton plume-forming event could generate the seismic waves that were actually observed, whereas Ben-Menahem (1975) considering the waves generated by a point explosion has obtained the generally accepted value of about 12.5 megaton. Boslough and Crawford (1997) obtained a qualitative agreement between the calculated wind speed at different distances and the treefall shown on the map (Boyarkina et al. 1964) used for almost 40 years. This agreement would be improved using our new unified catalog and the corresponding map (Longo et al. 2005). The most convincing aspect of the plume-forming model is that it not only account for forest devastation and seismic and pressure waves but, for the first time, it gives a simple and reasonable explanation of the magnetic field disturbance and of the "bright nights" associated with the Tunguska event. The resulting plume, 100 seconds after the impact, is given in Fig. 18.9. As shown, a mixture of dust, water and tropospheric air is ejected above the top of the atmosphere. It is this material, transported westward rapidly enough, that caused the bright nights within 12 hours at distances up to 6000 km.

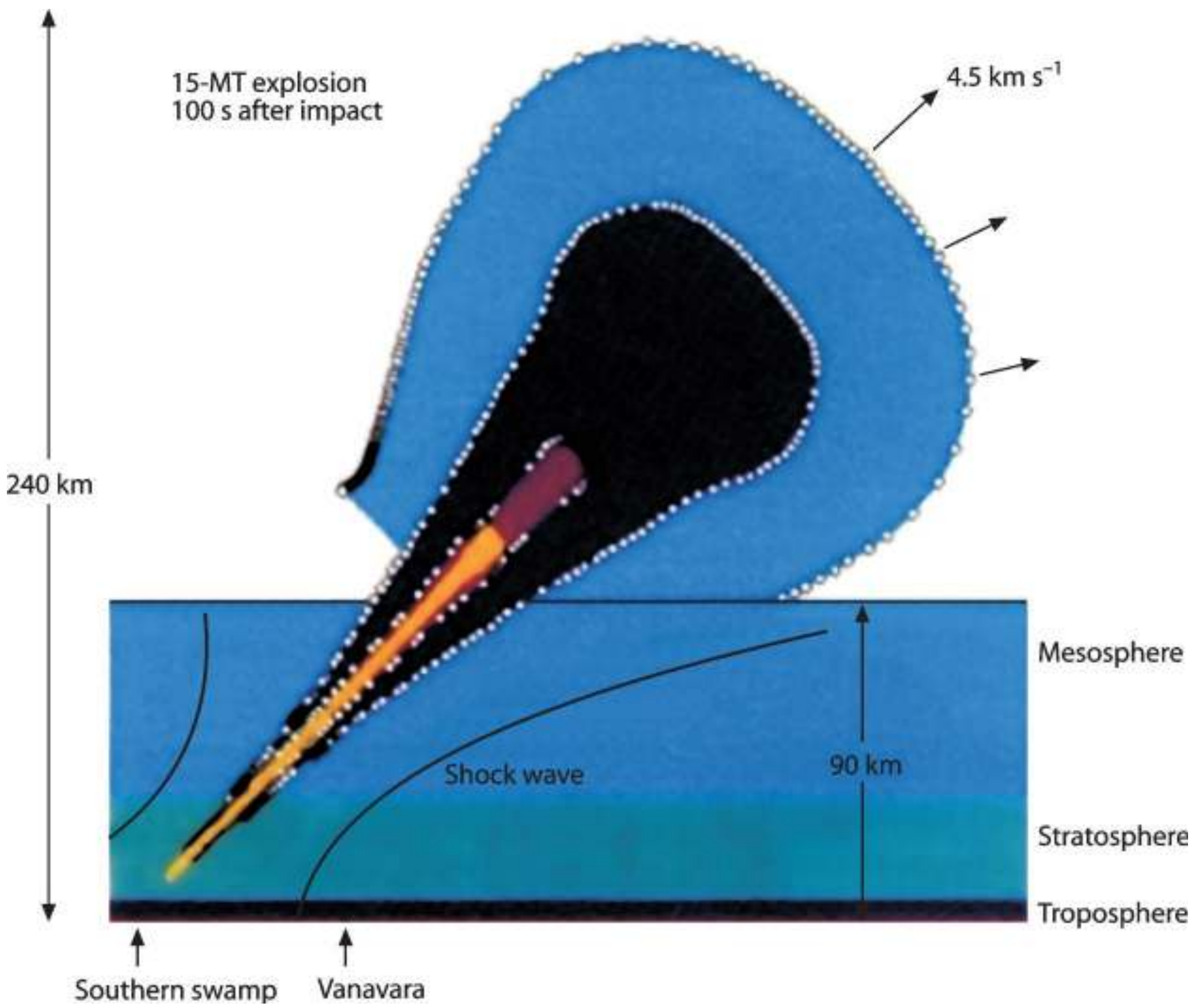
Shuvalov (1999) developed a similar plume-forming model. Firstly, he considered a volumetric absorption in the projectile of the radiation emitted by shock compressed atmospheric gas. Subsequently, Shuvalov and Artem'eva (2002) improved the model considering a surface absorption of the radiation. They elaborated a 2D numerical model with radiation and ablation for the impact of Tunguska-like bodies and obtained results similar to those of Boslough and Crawford (1997) for the plume formation and the ejection in the upper atmosphere of hot vapor and air.

All the authors of plume-forming simulations consider their calculations as preliminary and underline the necessity of developing a totally self-consistent 3D numerical model using realistic topography and including simultaneously radiation and ablation, disruption of the bolide, formation and evolution of a fireball and of a plume.

Foschini Hypersonic Flow

Let me mention two other representations of impacts that consider the bolide energy deposited along an entry column. Foschini (1999, 2001) developed a model studying the hypersonic flow around a small asteroid entering the Earth's atmosphere. This model is compatible with fragmentation data from superbolides. Foschini considers a bow shock in the front of the cosmic body that envelops the body. As the air flows toward the rear of the body, it is re-attracted to the axis. Therefore, there is a rotation of the

Fig. 18.9. A plume due to a total energy deposition of 15 megaton, 100 seconds after the impact of a stony asteroid (Boslough and Crawford 1977). Material within all but the outermost shell has been ejected from within the troposphere, and contains the mass of the impactor, as well as water from the humid lower atmosphere



stream in the sense opposite to that of the motion and this creates an oblique shock wave (wake shock). Since the pressure rise across the bow shock is huge when compared to the pressure behind the body, it can be assumed that there is a vacuum behind the cosmic body. According to the model, the condition for fragmentation depends on two regimes: steady state, when the Mach number does not change, and unsteady state, when the Mach number undergoes strong changes (Foschini et al. 2001). In the latter case, the distortion of shock waves causes the amplification of turbulent kinetic energy. So, a sudden outburst of pressure that can overcome the mechanical strength of the body, starting the fragmentation process is expected. On the other hand, in the first case - the steady state - the effect of compressibility suppresses the turbulence, and then the viscous heat transfer becomes negligible. The cosmic body is subjected to a combined thermal and mechanical stress.

The key point in fragmentation is how the ablation changes the hypersonic flow. The existence of asteroids with an extremely low density, such as Mathilde (~1300 kg m-3), suggests that such a body could have an increased efficiency in deceleration. A possible process by means internal cavities could increase the deceleration and airburst effi-

Fig. 18.10. In the Foschini model, as the cosmic body enters the Earth atmosphere, the ablation removes the surface, discovering the internal cavities, which act as something similar to a parachute, thereby increasing the deceleration

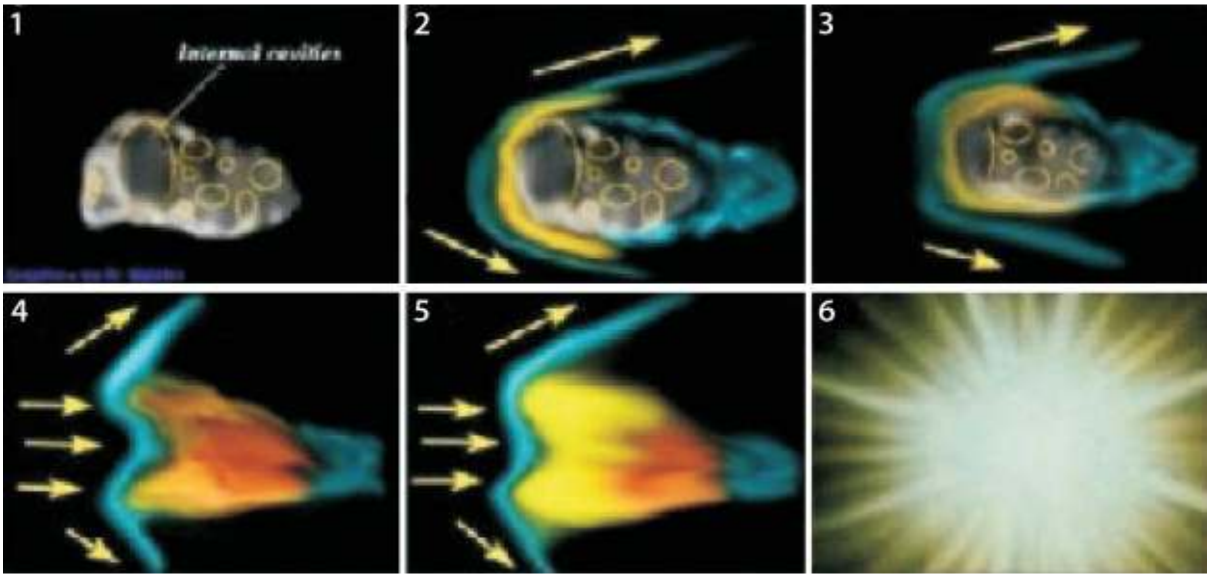
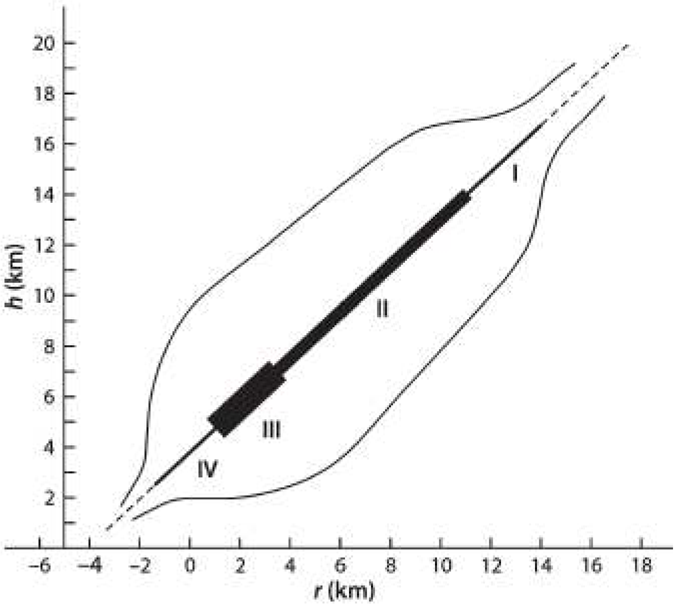


Fig. 18.11. The energy emission in the “Anfinogenov spindle".
h - height from the Earth surface;
r - distance from Fast epicentre



ciency is shown on Fig. 18.10. Following these lines Farinella et al. (2001) concluded that an object like asteroid Mathilde could explain the TE.

Anfinogenov Spindle

Anfinogenov (1966) and Anfinogenov and Budaeva (1998) proposed a qualitative model of the energy emitted by a “semi-infinite" linear source. The bolide begins disrupting and vaporizing when it enters the stratosphere and releases an increasing energy as it moves down. The energy emission is schematically described by the four cylinders shown in Fig. 18.11. In region I some 20% of mass and energy is lost, about 80% is emitted in regions II and III and less than 1% in region IV. The maximal energy emission is reached at a height of 6-8 km. The resulting shock wave has the form of the so-called “Anfinogenov spindle".

On the basis of the tree fall data and earlier eyewitness testimonies we consider that the TCB was a multiple bolide formed by at least two bodies of similar mass (Longo et al. 2005). They likely entered the atmosphere very close to each other following parallel trajectories with azimuths ~135°. The second body flew slightly higher, behind the first, and was decelerated by the shock wave. The resulting summary shock wave from the different spindles had an inclination angle of it symmetry axis ~45°.

18.5.2
Global and Local Damages

No doubt that a KT impact causes global damages, but the local character of damages from Tunguska-like events is questionable. It depends on the target. For the majority of the Earth’s surface, which is water, there would be no damage (the lower limit for tsunami generation is about 10 times the Tunguska energy). Also, most of the land surface is still sparsely populated. The situation is quite different for a Megaton explosion in a large city or a populated region. Apart from the direct damages and casualties, we cannot exclude that some country could interpret that it had suffered a nuclear attack. Even at the time of the real Tunguska explosion, its consequences would have been very different, *if* the cosmic body would have reached the Earth about four hours later. Instead of hitting a non-populated forest at about 60° N, it could have impacted the Russian capital of St. Petersburg at the same latitude. Under these conditions, the Russian participation to World War I and the Russian Revolution would not have been possible. The whole history of humanity in the 20th century would be different. In short, the consequences, even of a “modest" impact are highly dependent on the target.

18.6
Concluding Remark

From the models mentioned in Sect. 18.5, it was deduced that the Tunguska explosive yield has been overestimated by a factor 3-4. This means that the interval between Tunguska-like events can be about three times less than usually expected. The expected frequency for such events, from the present value of about twice in a millennium can approach the century timescale. Therefore, the Tunguska-like impacts may present a more serious hazard than previously estimated. The real Tunguska event is the only phenomenon of this kind that happened during relatively recent time and that can be studied directly. The analyses of the data and samples collected during recent in situ expeditions have made it possible to check some characteristics of the Tunguska event. Many of its aspects are still unclear. Therefore, it is important to further both theoretical and experimental research on this phenomenon. For example, most of the scientists consider that the Tunguska event was due to the impact with the atmosphere of an asteroid or a comet. A clear choice between these two hypotheses has important practical consequences. The knowledge of the nature of the object, which explosion caused the devastation observed, will make it possible to verify and develop the models of the explosion mechanisms and fragmentation of cosmic bodies in the atmosphere. Broadening the study to the known impacts, will allow obtaining better estimates of the impact probability for cosmic bodies with different composition and dimensions.

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http://www-th.bo.infn.it/tunguska/Tenerife.htm

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APPENDIX THREE

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TUNGUSKA GENETIC ANOMALY AND ELECTROPHONIC METEORS

by

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One of great mysteries of the Tunguska event is its genetic impact. Some genetic anomalies were reported in the plants, insects and people of the Tunguska region. Remarkably, the increased rate of biological mutations was found not only within the epicenter area, but also along the trajectory of the Tunguska Space Body (TSB). At that no traces of radioactivity were found, which could be reliably associated with the Tunguska event. The main hypotheses about the nature of the TSB, a stony asteroid, a comet nucleus or a carbonaceous chondrite, readily explain the absence of radioactivity but give no clues how to deal with the genetic anomaly. A choice between these hypotheses, as far as the genetic anomaly is concerned, is like to the choice between “blue devil, green devil and speckled devil", to quote late Academician N.V. Vasilyev. However, if another mysterious phenomenon, electrophonic meteors, is evoked, the origin of the Tunguska genetic anomaly becomes less obscure.

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1. Introduction

Tunguska -- the scent of mystery and adventure, all over the ninety five years. Many theories to what happened many years ago in remote region of the Sleeping Land -- this is the meaning of the Tartar word Siberia (Gallant 2002). And none of them can explain all the facts. Not very surprising -- the systematic research had begun with significant delay and the facts found are indeed perplexing (Vasilyev 1998, Bronshten 2000a, Zolotov 1969, Zhuravlev and Zigel 1998, Ol’khovatov 2003). What is really surprising is that this at first glance purely scientific problem raised so much interest. It seems the irrational roots of this phenomenon are not always recognized and appreciated. We are tempted to give some thought to this side of the Tunguska problem before we embark on the more conventional scientific track.

The truth is that both the public interest in the Tunguska catastrophe and its scientific exploration were spurred by Kazantsev’s (Kazantsev 1946) fantastic suggestion that a nuclear-powered alien spacecraft catastrophe caused the Tunguska event (Plekhanov 2000, Baxter and Atkins 1977). Another truth is that the scientific community is rather reluctant about alien spacecrafts and other UFOs unlike their wordly fellows. But doing so the scientific community misses one important point: the birth and rise of the modern age UFO myths as well as their apparent impact on the popular culture are awesome phenomena begging for scientific explanation. To our knowledge, Jung (Jung 1959) was the first to realize scientific importance behind seemingly absurd UFO accounts.

According to Jung these accounts are just a projection of the inner psychic state of modern man into the heavens and represent his longing for wholeness and unity in this divided, hostile and alien new world. Therefore an important message behind of such UFO myths is that they signal an increasing psychological stress in the society, changes of the archetypes, or psychic dominants, and possibly indicate the end of an era in history and the beginning of a new one (Fraim 1998).

In this respect the mythological impact of the Tunguska explosion on the native Evenk people, representatives of the different culture, is of great interest. Therefore it is not surprising that Floyd Favel, one of Canada's most acclaimed playwrights and theater directors, decided to develop his next play, The Sleeping Land, on the base of great spiritual significance of the Tunguska event for the Evenk people (Gordon and Monkman 1997). He has really a good story for the play. It starts "with the battle between two Tunguska Evenk clans. Over the years, their feud escalated, both clans using their powerful shamans to curse to the other, with evil spirits, misfortune and disease. The hostility between them grew until one shaman called upon the Agdy to destroy the hated enemy forever. These fearsome iron birds fly above the earth in huge clouds, flapping their terrible wings to cause thunder, flashing lightening from their fiery eyes. On that sunny morning in June, the sky became black as a never ending legion of the fearsome birds swooped low over the unfortunate Shanyagir clan. Their devastating blasts of fire blew the Shanyagir's tents up into the air over the tree tops. The clan's belongings were destroyed, two hundred and fifty of their reindeer vanished without a trace, the ancient forest was flattened in every direction, and those who still could, fled in panic. To this day, the Evenk believe that only the Agdy can live in the area where explosion took place. Only a few will risk visiting. And none will live there" (Gordon and Monkman 1997).

Although the cultures are different, this Evenk myth has some resemblance with the Sodom and Gomorrah Biblical story of miraculous destruction of these cities by the raining down of fire from heaven. One can even think that this ancient myth was also born due to real cosmic event (Clube and Napier 1982). In Koran, the holy book of Islam, one finds a similar story (Wynn and Shoemaker 1998) "about an idolatrous king named Aad who scoffed at a prophet of God. For his impiety, the city of Ubar and all its inhabitants were destroyed by a dark cloud brought on the wings of a great wind." This last story has an unexpected and adventurous continuation. In 1932 an eccentric British explorer John Philby (Monroe 1998), obsessed by the idea to find Ubar, made an arduous trip into the Empty Quarter of southern Saudi Arabia, which is one of the most inaccessible and formidable deserts of our planet (Wynn and Shoemaker 1997). He really found something interesting, the place he dubbed Wabar -- fortunate misspelling because it was not the Lost City of Koran, but the place of the fierce meteorite impact (Wynn and Shoemaker 1997, 1998). The real Ubar city was allegedly found much later and this is another breathtaking adventure (Clapp 1999). Radar images from the Landsat and SPOT remote sensing satellites, which uncovered old caravan routes, played the crucial role in this discovery (El-Baz 1997). Evidence indicates that Ubar was not destroyed from heaven, instead it fell into sinkhole created by the underground limestone cavern collapse. But the Wabar meteorite was certainly capable to destroy Ubar or any other ancient city, because the 12 kilotons blast was comparable to the Hiroshima bomb (Wynn and Shoemaker 1998). The Tunguska explosion was thousand times more powerful, capable to destroy any modern city. Therefore we come to the conclusion that the unconscious fears of modern man about hazards from the outer space are not completely groundless, although not aliens but minor space bodies cause the peril. It is clear that to reliable estimate this danger it would be helpful to understand the nature of the Tunguska Space Body (TSB). And this is the point we embark on the more conventional scientific track, as promised.

There are two main hypotheses on this track about the nature of the TSB: cometary (Shapley 1930, Zotkin 1969, Kresak 1978, Fesenkov 1966) and asteroidal (Kulik 1940, Fesenkov 1949, Sekanina 1983, Chyba et al. 1993). Unfortunately for the science the proponents of these two hypotheses practically ignored each other for a long time (Farinella et al. 2001) assuming the question was settled down once for all by their own solution -- an interesting example of the Planck's principle (Hull et al. 1978), according to which "a new scientific truth does not triumph because its supporters enlighten its opponents, but because its opponents eventually die, and a new generation grows up that is familiar with it." There is still no consensus among scientists about the choice between a comet and an asteroid. Some recent research supports the asteroidal origin of the TSB (Foschini 1999, Farinella et al. 2001) while Bronshten (2000b) advocates the cometary hypothesis indicating that despite an extensive and scrupulous search no stony fragments of alleged asteroid were found. He gives arguments that neither fireball radiation nor air friction can eliminate completely such fragments from the stony asteroid.

But there are facts which are hard to reconcile with either of these hypotheses (Vasilyev 2000, Ol'khovatov 2003). Below we discuss genetic impact of the Tunguska event, which is one of such facts.

2. Biological consequences of the Tunguska event

Ecological consequences of the Tunguska event have been comprehensively discussed by Vasilyev (Vasilyev 1999, 2000). They constitute another conundrum of this intricate phenomenon. There were two main types of effects observed. The first type includes accelerated growth of young and survived trees on a vast territory, as well as quick revival of the taiga after the explosion. The second type of effects is related to the genetic impact of the Tunguska explosion.

Already participants of Kulik's first expeditions made some observations about forest recovery in the catastrophe area. In various years the impressions were different (Vasilyev 1999): in 1929--1930 the taiga seemed depressed in this area, while in 1953 no signs of growth deceleration were seen in comparison with neighboring regions. The first systematic pilot study of growth of the tree vegetation in the catastrophe region was performed during 1958 expedition (Vasilyev 1999). Anomalously large tree ring widths up to 9 mm were found in young specimens which were germinated after the catastrophe, while the average width of the growth rings before the catastrophe was only 0.2--1.0 mm. Besides the young trees, the accelerated growth was observed also for the survived old trees.

Stimulated by these first findings, a large scale study of the forest recovery in the Tunguska area was performed in series of following expeditions after 1960. In 1968 expedition, for example, morphometric data for more than six thousand pine specimens were collected. This vast material establishes the reality of the accelerated growth without any doubt (Vasilyev 1999). More recent study of Longo and Serra (Longo and Serra 1995) confirms this spectacular phenomenon and indicates that the growth has weakened only recently for trees of the respectable age of more than 150 years.

The cause of the anomalous growth remains controversial. The most natural and simple explanation, suggested already in sixties (Vasilyev 1999), assumes that the explosion led to the improved environmental conditions due to ash fertilization and decreased competition for light and minerals because of the increased distance between trees. Longo and Serra (Longo and Serra 1995) found an interesting correlation between the anomalous tree growth and the dimensions of the growth rings before the catastrophe. The growth acceleration was more prominent for trees that grew more slowly before the catastrophe. But their conclusion that this finding seems to favour the above described simple hypothesis should be considered as too premature in light of Vasilyev's (1999, 2000) more detailed and broad perspective analysis of the problem.

According to Vasilyev (1999), an averaging influence of the Tunguska event on the final tree dimensions is just a manifestation of the Wilder's Law of initial values (Wilder 1953), which states that the higher the initial level of some physiological function, the smaller the response of the living organism to function-raising agents and the greater the response to function- depressing agents, irrespective to the stimuli nature. Naturally, the change of the environmental conditions played a significant role in the taiga recovery. But there are some features of the accelerated growth phenomenon which are hard to explain solely on the grounds of this obvious factor.

The areas where the accelerated growth is observed have different shapes for the young, after-catastrophe trees and for the old ones that have somehow survived the catastrophe (Vasilyev 1999). For the young trees the effect is maximal within the epicenter area. But the region where the accelerated growth is observed differs significantly both from the area of the forest fall and from the area affected by forest fire. This interesting fact hints that the change in the environmental conditions due to the forest devastation is not the leading factor of the accelerated growth in this case. Instead, one can suggest that the leading role was played by proximity of the ancient volcano and the resulting contamination of the soil by volcanic material (Vasilyev 1999). An interesting fact is that the Tunguska epicenter almost exactly coincides with the muzzle of a Triassic volcano. Therefore, if the quick growth of the young trees in the Tunguska area is indeed related to the soil enrichment by some rare earth and other elements of volcanic origin, it is not surprising that the effect is maximal in the epicenter area, where the volcano muzzle is also situated. What is surprising was found by observing later generation trees. It turned out that the younger the trees, the higher the concentration of the accelerated growth effect towards the projection of the TSB trajectory (Vasilyev and Batishcheva 1979, Vasilyev 1999). Therefore there should be one more factor, directly related to the TSB and possibly of mutagenic nature.

For the old survived trees the effect of the accelerated growth is more scattered and patchy character. One can find such trees in the forest fall area, as well as outside of it. Again, the effect is more prominent in regions nearby to the TSB trajectory. Besides, the contours of the areas, where the effect is observed have oval shapes stretched along the direction of the TSB trajectory (Emelyanov et al. 1979, Vasilyev 1999). It is also interesting that there are regions, as for example in the area between Kichmu and Moleshko rivers, with considerable forest fall but without any signs of the accelerated growth among survived trees (Vasilyev 1999). Moreover, the effect of the accelerated growth does not reach its maximum in the investigated area. Instead its extrapolated maximum is expected far away from the epicenter, at some 20-25 km distance (Emelyanov et al. 1979, Vasilyev 1999). One has an impression that the flight of the TSB was accompanied by some unknown agent capable to induce remote ecological and maybe even genetic changes.

Genetic consequences of the Tunguska event is the most controversial subject. In sixties some experiments were performed in Novosibirsk to find genetic effects of ionizing radiation on pines. Among various changes, the most prominent effect was an increased occurrence of 3-needle cluster pines, while usually the pine used in experiments had 2-needle clusters. Stimulated by this finding, G.F. Plekhanov organized special expeditions to study young pines in the catastrophe area. It turned out that the frequency of 3-needle cluster trees was really increased in the epicenter area, having the maximum near the Mount Chirvinskii -- the special point where the TSB trajectory “pierces" the Earth’s surface and where the effect of accelerated growth also reaches its maximum for after-catastrophe trees (Vasilyev 1999). However, as was found later, it is rather common that 3-needle cluster pines occur with high frequency in areas with intense forest recovery (after forest fires, for example), when pines have large linear increments. Therefore, unfortunately, this interesting phenomenon can not be undoubtedly associated with the primary factors of the Tunguska explosion and might be a secondary effect.

In seventies V.A. Dragavtsev elaborated a special algorithm to separate genotypic and phenotypic variations. Tunguska pine trees linear increments were processed with this algorithm. It was found that the genotypic dispersion has sharply increased in the Tunguska trees. The effect is prominent, has a patchy character and concentrates toward the epicenter area, as well as toward of the TSB trajectory projection (Vasilyev 1999, 2000, 1998). At maximums the genotypic dispersion shows about 12-fold increment (Vasilyev 2000). One of the maximums coincides again with the Mount Chirvinskii, another -- with the calculated center of the light flash (Vasilyev 1999).

No indications of increased mutageneses was found in the area, however, in later study of pine isozyme systems polymorphysm by electrophoresis method. Unfortunately only 11 trees were studied from different locations and the results were averaged because of sample smallness. Therefore, although this result does not strengthen Dragavtsev’s findings, it is inconclusive to reject them either (Vasilyev 1999).

Some population-genetic studies were performed in the catastrophe area by using a pea Vicia cracca. All studied phenogenetic characteristics were found considerably higher in the epicenter area than in the reference point near the Vanavara settlement (at about 70 km from the epicenter). At that two special points with maximal effect were clearly seen in the data. Remarkably, one of them is again the Mount Chirvinskii and the another one (the Chugrim canyon) is only at 1--1.5 km distance from the light flash center (Vasilyev 1999).

The same researchers studied fluctuating asymmetry of birch leaves in the broader region. It is believed that the fluctuating asymmetry arises as a result of stress the organism experiences during its development and is a good measure of its ability to compensate for stress. It was found that the asymmetry is significantly increased not only in the epicenter area but also in remote regions not affected by the Tunguska explosion (Vasilyev 1999). This is not surprising because the climatic conditions are severe in the Siberian taiga and recent studies indicate that fluctuating asymmetry in leaves of birch seems to be a robust indicator of ambient climatic stress (Hagen and Ims 2003). Interestingly, in the epicenter area one of the sites where the highest asymmetry is observed is noted Mount Chirvinski (Vasilyev 1999).

In 1969 morphometric peculiarities of ants Formica fusca were searched in the epicenter area by inspecting 47 anthills. No noticeable differences were found at several locations, but ants from the Mount Chirvinskii and from the Chugrim canyon were significantly different (Vasilyev 1999). Unfortunately no reference studies were performed outside the epicenter area. Analogous studies were continued in 1974--1975 by using ants Formica exsecta. No peculiarities were found in ants inhabited in the central and peripheral parts of the catastrophe area (Vasilyev 1999).

A very interesting genetic mutation, possibly related to the Tunguska event, was discovered by Rychkov (Rychkov 2000). Rhesus negative persons among the Mongoloid inhabitants of Siberia are exceptionally rare. During 1959 field studies, Rychkov discovered an Evenk woman lacking the Rh-D antigen. Genetic examinations of her family enabled to conclude that a very rare mutation of the Rh-D gene happened in 1912. This mutation may have affected the women's parents, who in 1908 lived at some 100 km distance from the epicenter and were eyewitnesses of the Tunguska explosion. The women remembered her parents' impressions of the event: a very bright flash, a clap of thunder, a droning sound, and a burning wind (Rychkov 2000).

All these facts indicate that the Tunguska event had left a very peculiar ecological and genetic traces. The hard question, however, is to separate the primary and secondary factors leading to the observed phenomena, which may have complex origins. A recurrent appearance of the TSB trajectory and some special points related to it in the above given stories suggests nevertheless that the flight and explosion of the TSB was accompanied by some unknown stress factor. A great challenge for the conventional Tunguska theories is when to find and explain the nature of this factor. We think that such a factor might be electromagnetic radiation. Interestingly, a powerful electromagnetic radiation is suspected to accompany electrophonic meteors -- an interesting class of enigmatic meteoritic events.

3. Electrophonic meteors and Tunguska bolide

The history of the electrophonic meteors research presents another good example of the Planck's principle in action. In 1719 eminent astronomer Edmund Halley collected eyewitnesses accounts on a huge meteor fireball seen over much of England. He was perplexed by the fact that many reports declared the bolide was hissing as if it had been very near from the observer. Being aware that the sounds can not be transmitted so quickly over distances in excess of 100 km, he dismissed the effect as purely psychological, as "the effect of pure fantasy". This conclusion and Halley's authority hindered any progress in the field for two and a half centuries (Keay 1997).

At present eyewitnesses accounts on the unusual sounds which accompany some rare meteoritic events are quite numerous (Vinković et al. 2002, Keay 1994a) and almost no more doubts are left about reality of the effect. Electrophonic sounds can be divided into two classes according to their duration. About 10% of the observed events have short duration, about one second, and are of burster type. They produce sharp sounds which are reported as "clicks" and "pops". Other electrophonic events are of the long duration sustained type and the corresponding sounds are described as being "rushing" or "crackling" (Keay 1992a, Kaznev 1994). Interestingly, similar "clicks" have been reported to be heard by soldiers during nuclear explosions and it is assumed that they are caused by an intense burst of very low frequency (VLF) electromagnetic radiation, which is peaked at 12 khz (Johler and Monganstern 1965, Keay 1997).

The mechanism of how VLF radiation can be generated by a meteoroid was proposed by Keay (Keay 1980). It is suggested that the geomagnetic field becomes trapped and "twisted" in the turbulent wake of a meteoroid. Afterwords the plasma cools and the strain energy of the field is released as VLF electromagnetic radiation. The theory was further elaborated by Bronshten (Bronshten 1983) who showed that as much as megawatt VLF power can be easily generated by bright enough bolids.

Extra low frequency (ELF) and VLF electromagnetic fields can be generated also by other possible mechanisms. For example, explosive disruption of a large meteoroid will generate electromagnetic pulses similar to what happens in nuclear explosions. An electrostatic mechanism of perturbing geoelectric field, operating for bolids with steep trajectories, was considered by Ivanov and Medvedev (Ivanov and Medvedev 1965). Beech and Foschini developed a space charge model for electrophonic bursters (Beech and Foschini 1999, 2001). They suggest that during meteoroid catastrophic breakup a shock wave is produced which propagates in the plasma around the meteoroid and leads to a significant space charge due to different mobility of ions and electrons. In this case no significant VLF signal is generated, instead we have a brief transient in the geoelectric field.

Suitable transducer is required to transform the VLF energy into audible form and this is that makes the electrophonic meteor observation such a rare and capricious phenomenon (Keay 1997). From a group of even closely placed observers one or two may hear the sounds and the others do not. In a series of experiments Keay and Ostwald demonstrated (Keay and Ostwald 1991, Keay 1997) that for audible frequency electric fields various common objects can serve as a transducer. For example, volunteers were able to detect as low as 160 volts peak-to-peak variations of the electric field at 4 kHz frequency, with their hair or eyeglass frames acting as a transducer.

Therefore at last we have a clever and scientifically sound explanation of these mysterious sounds which baffled scholars for centuries. But any theory needs experimental confirmation. Unfortunately instrumentally recorded electrophonic meteor data are very scarce due to extreme rareness of the phenomenon: by an optimistic prediction a person which would spend every night outdoors may expect to hear an electrophonic sound once in a lifetime (Keay and Ceplecha 1994b, Keay 1997).

In 1993 Beech, Brown and Jones (Beech, Brown and Jones 1995) detected 1--10 kHz broad band VLF transient concomitant to the fireball from the Perseid meteor. However no electrophonic sounds were reported. Still earlier a meteor VLF signal was detected by Japanese observers (Keay 1992b). Garaj et al. (Garaj et al. 1999), as well as Price and Blum (Price and Blum 1998) reported detection of the ELF/VLF radiation associated with the Leonid meteor storm. A very interesting observation was made during reentry of the Russian communications satellite Molniya 1--67 (Verveer et al. 2000). An observer reported an electrophonic sound near the end path of the satellite, which produced a large orange fireball during its entry in the atmosphere. At the same time several geophysical stations in Australia detected a distinct ELF (about 1 Hz) magnetic pulse. Unfortunately no instrumentation was available to detect electromagnetic radiation above 10 Hz to check Keay-- Bronshten's theory. Interestingly, ELF electromagnetic transients may effect the human brain directly and therefore may require lower energy levels to produce electrophonic effects (Verveer et al. 2000). These sparse experimental data are clearly insufficient to draw definite conclusions about the physics of the radio emissions from meteors (Andreić and Vinković 1999). On the other hand, the existing theoretical models are also too simplified to be able to give a detailed description of the phenomenon (Bronshten 1991).

A remarkable benchmark in the research of electrophonic meteors was the first instrumental detection of electrophonic sounds during the 1998 Leonid meteor shower (Zgrablić et al. 2002). Ironically Leonid meteors are least suitable devices for production of the VLF radiation via the Keay--Bronshten mechanism which demands the Reynolds number in the meteor plasma flow to exceed 106. In the case of Leonids, which are mostly dust grains, this leads to unreasonably large initial size D0 > 3 m and mass _ 3000 kg (Zgrablić et al. 2002). Nevertheless two clear electrophonic signals were instrumentally recorded during the expedition. The first originated from the meteor at the altitude of _ 110 km. The second -- at altitude of 85--115 km. In both cases the sounds preceded the meteors' light maximum. These features are hard to explain also in other models suggested for electrophonic bursters. No ELF/VLF signal was detected in these two events. But the receiver apparatus was insensitive for frequencies below 500 Hz, while the frequency range of the observed electrophonic sounds was 37--44 Hz. If one assumes that these sounds originated from the transduction of the ELF/VLF transient, the observed sound intensities will imply unreasonably high ELF/VLF radiation power, impossible to explain by any theoretical mechanism starting from meteor alone (Zgrablić et al. 2002). Therefore this remarkable observations show that the existing theories are at least incomplete and the electrophonic meteor mystery remains still largely unsolved.

Zgrablić et al. (Zgrablić et al. 2002) suggested that the Leonids acquire large enough space charge and can trigger an yet unidentified geophysical phenomenon upon entering the E-layer of ionosphere at _ 110 km. It is assumed that such phenomena in its turn will generate a powerful EM radiation burst. Note that this possibility was advocated by Ol'khovatov (Ol'khovatov 1993) much earlier.

But Keay--Bronshten mechanism is expected to operate well for slow and bright bolids (brighter than the full Moon), which penetrate deep into the atmosphere. The Tunguska meteorite was clearly of this type. Therefore we can not exclude that its flight was accompanied by a powerful ELF/VLF radiation. Are there any eyewitness accounts which support the electrophonic nature of the Tunguska bolide?

Already in 1949 Krinov (Krinov 1949) draw his attention to the strange circumstance that many independent observers described sounds which preceded the appearance of the bolide. He notes that similar phenomena were reported many times by spectators of electrophonic meteors. But there was a significant difference: in the Tunguska bolide case the sounds were extraordinary strong, more like to powerful strikes than to the feeble electrophonic cracks and rustles. Krinov notes further that this difference might be a consequence of the exceptional magnitude of the Tunguska event. However more likely to him appears the explanation that all these reports were purely psychological in nature, that the observers have a unconscious tendency to change the succession of light and sound effects, or unify them in time by neglecting the time lag due to low velocity of the sound. Here is one such witness account (Krinov 1949) from K.A. Kokorin, resident of Kezhma village:

“... at hours 8--9 in the morning, not later, the sky was completely clear, without any clouds. I entered the bath (in the yard) and just succeeded in taking my shirt out when suddenly heard sounds, resembling a cannonade. At once I run out in the yard, which had an opened perspective towards the south-west and west. The sounds still continued at that time, and I saw in the south-west direction, at an altitude about the half between the zenith and the horizon, a flying red sphere with rainbow stripes at its sides and behind it. The sphere remained flying for some 3--4 seconds and then disappeared in the north-east direction. The sounds were heard all the time the sphere flew, but they ceased at once as the sphere disappeared behind the forest."

Krinov’s reaction to this report is very characteristic for the history of the electrophonic sounds research. He considers it clearly impossible the sounds to precede the bolide flight and concludes that Kokorin just forget the right succession of the events because of remoteness of the event, as the inquiry took place in 1930. Of course, in this particular case Krinov might be right, but the fact that similar assertions can be found in many other witness accounts forces us to believe just the opposite.

E.E. Sarychev, inquired in 1921 (Vasilyev et al. 1981) remembers: “I was a leather master. In summer (near the spring) at about 8 AM tanners and I washed wool on the bank of Kana river, when suddenly a noise emerged, as from wings of a frightened bird, in the direction from south to east, towards Anzyr village, and a wave went upward the river like ripples. After this a piercing strike followed, and then dull other strikes, as if from the underground thunder. The strike was so powerful that one of workers, Egor Stepanovich Vlasov (who died now), fell into the water. With the emergence of noise, a radiance appeared in the air, of spherical shape, the size of half Moon and with a bluish tinge, quickly flying in the direction from Filimonov to Irkutsk. Behind the radiance a trail was being left in the form of sky-bluish stripe, stretching along almost all the track and gradually decaying from the end point. The radiance disappeared behind the mountain without any explosion. I can’t notice how long it lasted, but it appeared only very briefly. The weather was absolutely clear and there was the still around."

Ya.S. Kudrin, who was a nine years old child at that time, gives the following description of the sounds heard (Vasilyev et al. 1981): “The sound was like a thunder, it ceased after the bolide flight. The sound was not very strong, just like ordinary thunder. The sound was moving together with the object toward the north. The sound was heard before the object became visible and it stopped as the object disappeared."

I.K. Stupin was also 8--10 years old boy in 1908 and also remembers that the appearance of the sound preceded the appearance of the object. According to him the sound was cavernous and of low tone. At that he did not notice any air wave or vibration of the Earth (Vasilyev et al. 1981).

The eyewitness report from V.I. Yarygin is also interesting in this respect (Konenkin 1967): “In 1908 I lived in village Oloncovo, at some 35 km from the town Kirensk upstream to Lena river. At that day we rode horses in a field. At first we heard a loud roar, so that the horses had stopped. We saw a blackness on the sky, behind of this blackness there were blazing tails and then a fog of the black color. The sun vanished and darkness came down. From this blackness a flame of fire darted from south to north."

One can easily find witness reports where the character of sounds resembles very close the electrophonic ones. For example E.K. Gimmer describes the sounds from the meteorite as of sizzling type, as if a red-hot iron was put into water (Vasilyev et al. 1981). S.D. Permyakov remembers that there was no roar when the bolide fled above him, instead he heard some noise and boom (Konenkin 1967).

Note that the electrophonic nature of the Tunguska bolide was argued earlier by Khazanovitch (Khazanovitch 2001), who gives some other examples of eyewitness accounts to support this suggestion. Even more earlier Vasilyev (Vasilyev 1992) had discussed an unsolved conundrum that thunderlike sounds were heard not only during and after the bolide flight, but also before it. He dismissed the psychological explanation of this strange fact by subjective errors, as the peculiarity had been reported by too many independent observers, some of them being at several tens of kilometers from the bolide-trajectory projection, and therefore the sounds heard by them can not be caused by the ballistic wave. He came to the conclusion that the only real explanation could be achieved by suggesting a link with powerful electromagnetic phenomena, induced by the bolide.

It is interesting that a terrific roar of presumably electrophonic nature was reported by eyewitnesses to accompany overhead passing of a Tunguska- like bolide in the British Guyana in 1935 (Steel 1996). Other known evidence of electromagnetic disturbances from bolids indirectly supports a possibility that the similar phenomena is not excluded also in the Tunguska event case. The most recent one is related to the Vitim meteorite which fell in Siberia 25th September 2002. The witness report from G.K. Kaurtsev, a Mama airport employee, clearly indicates that a strong alternate electromagnetic field was induced by the bolide during its flight which led to the induction phenomenon and to the appearance of St. Elmo’s fires (Yazev et al. 2003):

“At night there was no electricity, the settlement was disconnected. I woken up and saw a flash in the street. The switched off filament lamps of the chandelier lighted dimly, to half their normal intensity. After 15--20 seconds an underground boom came. Next morning I went to the dispatcher office of the airport. Security guards Semenova Vera Ivanovna and Berezan Lydia Nikolaevna have told the following story. They were on the beat and have seen that “bulbs were burning" on the wooden poles of the fence surrounding the airport’s meteorological station. They were scared very much. Fires glowed during 1--2 seconds on the perimeter of the protection fence. The height of the wooden poles is approximately 1.5 meters."

Note that the Mama settlement was at several tens of kilometers distance from the bolide’s flight path. Besides, the scale of the Vitim event is incomparable with the scale of the Tunguska explosion: the latter was by about three orders of magnitude more energetic. Therefore it seems very plausible that the Tunguska bolide flight might be accompanied by very strong alternate electromagnetic fields. The next question is whether these fields could lead to the observed ecological and genetic consequences.

4. Biological effects of ELF/VLF electromagnetic radiation

It is not excluded that one should apply to a magical herb mugwort (Artemisia Vulgaris), the foremost sacred plant among Anglo-Saxon tribes, to resolve the enigma of the Tunguska genetic impact. It is said that mugwort can invoke prophetic dreams if used in a dream pillow (Cunningham 1985). So a solution of the riddle could be dreamed up in this way. But jokes aside, what is really magical about mugwort, it is the suspected ability of Artemisia Vulgaris to use Earth’s magnetic field for adaptation purposes. Mugwort is not the only plant with such ability. For example, compass- plant (Silphium Laciniatum) uses the same adaptation strategy, which is even more pronounced in this case. Its deeply cut basal leaves are placed vertically and they align themselves in a north-south direction. This allows them to avoid excessive heat of the overhead midday sun and so minimize the moisture loss, but nevertheless have a maximum exposure to the morning and evening sun.

Some animals, including fish, amphibians, reptiles, birds and mammals, are also using geomagnetic field for orientation (Wiltschko and Wiltschko 1995). The sensory basis of magnetoreception is not completely clear yet. Two types of magnetoreception mechanisms are suspected in vertebrates. The evidence for a light-dependent, photoreceptor-based mechanism is reviewed by Deutschlander et al. (Deutschlander et al. 1999) along with the proposed biophysical models. It is supposed, for example, that magnetic field can alter the population of excited states of photosensitive molecules, like rhodopsin, which might lead to chemical effects. But some experiments have shown that light is not necessary for magnetoreception (Wiltschko and Wiltschko 1995). Therefore a mechanism for a direct sensing of the magnetic field should also exist. This mechanism possibly is based on chains of single-domain crystals of magnetite in a receptor cell (Walker et al. 2002). As the chain rotates in the magnetic field, it will open some mechanically gated ion channels in the cell membrane by pulling on the microtubule-like strands which connect the channels to the chain.

Above given examples indicate that Earth-strength magnetic fields can affect biological systems. Moreover, this interaction provides evolutionary important tools for adaptation. Therefore one can expect that the magnetic sense in the biological systems is as perfect as any other known sensory systems and has evolved down to the thermal noise limit in sensitivity (Kirschvink et al. 2001).

Thus it is not surprising that various biological effects of the low frequency nonionizing electromagnetic radiation have been found, although the underlying mechanisms responsible for these effects are still not completely understood (Marino and Becker 1977, Binhi and Savin 2001, Becker and Marino 1982, Binhi 2002). The potentially hazardous effects of the ELF electromagnetic fields were especially scrutinized during last decades, because the power frequencies of most nations are in the ELF range. Let us mention some most impressive facts from Marino and Becker's review (Marino and Becker 1977).

Even relatively brief exposures to high intensity ELF electric fields were shown to be fatal to mice, Drosophila and bees. For example, above 500 v/cm, bees sting each other to death. And 30--500 v/cm at 50 Hz is sufficient to change metabolic rate and motor activity.

ELF electric field exposure affects central nervous system. For example, a significant increase in hypothalamic activity was recorded from the microelectrodes implanted in anesthetized rats during the 1 h exposure period to the inhomogeneous electric field of 0.4 v/cm maximum at 640 Hz. Some in vitro studies indicate effects on the calcium release and biochemical function. For example, 1.55 v/cm electric field at 60 Hz caused complete loss of biochemical function in brain mitochondria after 40 min exposure.

Exposure to the ELF electric or magnetic field produces a physiological stress response. For example, rats exhibited depressed body weights, decreased levels of brain choline acetyltransferase activity, and elevated levels of liver tryptophan pyrrolase after 30--40 days exposure to 0.005--1.0 v/cm electric field at 45 Hz.

It was found that an asymmetrically pulsed magnetic field repeating at 65 Hz with a peak value of several G accelerates the healing of a bone fracture in dogs. Some studies indicated a slight enhancement of growth in plants near high-voltage transmission lines. The growth rate of beans was significantly (about 40%) effected by 64 days exposure to 0.1 v/cm electric field at 45 Hz, when the been seeds were planted in soil. But no significant effect was observed when the soil was replaced with a nutrient solution.

Of course, possible genetic effects of VLF/ELF radiation are most interesting in the context of our goals. Some early work suggested that weak electric and magnetic fields produced genetic aberrations in Drosophila, however these observations were not confirmed by subsequent experiments (Marino and Becker 1977). Epidemiological evidence of possible carcinogenic effects of electromagnetic field exposure is reviewed by Heath (Heath 1996) and Davydov et al. (Davydov et al. 2003). It seems this field is subject to continuous controversy. Some studies suggest that exposure to power frequency electromagnetic fields may lead to increased risks of cancer, especially for leukemia and brain cancer. But other epidemiological studies did not reveal any increased risk. For example, eight of the eleven studies conducted in 1991--1995 found statistically significant elevation of risk for leukemia. And four of the eight investigations that studied brain cancer also found some increase in risk (Heath 1996). Nevertheless Heath considers the overall evidence as "weak, inconsistent, and inconclusive".

For energetic reasons, VLF/ELF radiation of not thermal intensity can not damage DNA or other cellular macromolecules directly. On this basis, the possibility that such weak electromagnetic fields can induce any biological effects was even denied for a long time (Binhi and Savin 2001), until a plethora of experimental evidence proved that "Nature's imagination is richer than ours" (Dyson 1996). Let us mention one such recent experiment of Tokalov et al. (Tokalov et al. 2003).

Cells have very effective emergency programs to cope adverse environmental conditions. Remarkably, cellular stress response is rather uniform irrespective to the stress factor nature. Some cellular functions that are not essential for survival, for example cell division, are temporarily suspended. Besides special kind of genes, the so called heat shock proteins (HSP), will be activated. Their major function is the proper refolding of the damaged proteins. Heat shock proteins, notably the HSP70, were first discovered while investigating cellular responses to a heat shock, hence the name. Tokalov et al. (Tokalov et al. 2003) studied effects of three different stressors on the induction of several heat shock proteins and on the cell division dynamics. The stress was produced by 200 keV X-ray irradiation, by exposure to a weak ELF electromagnetic field (50 Hz, 60±0.2 μT), or by a thermal shock (41◦ C for 30 min).

The pattern of induction of the most prominent members of the heat shock multigene family was found similar for all three stressors and HSP70 was the most strongly induced gene. But no effect on cell division was detected in the case of ELF electromagnetic field exposure, in contrast with other two stressors. Interestingly, when combined with the heat shock, ELF electromagnetic field shows cell protective effect: the number of proliferating cells strongly increases in comparison with the case when only the heat shock stress is present. One might think that this protection property is related to the induction of HSP70 genes by the electromagnetic field which helps to cope the thermal stress. But no protective effect was found when ELF electromagnetic field exposure was combined with ionizing X-ray irradiation. The reason of this difference is unknown, as are the molecular targets of ELF electromagnetic field. It was suggested that electromagnetic fields can act directly on DNA by influencing electron transfer within the DNA double helix (Goodman and Blank 2002).

The fact that weak electromagnetic fields can induce the stress proteins indicates that cells consider electromagnetic fields as potentially hazardous (Goodman and Blank 2002). This is surprising enough, because the magnitude of an effective magnetic stimulus is very small. Electromagnetic fields can induce the synthesis of HSP70 at an energy densities fourteen orders of magnitude lower than heat shock (Goodman and Blank 2002). Such extra sensitivity to the magnetic field must have good evolutionary grounds. Interesting thermo-protective effect of the ELF electromagnetic field exposure mentioned above, and the absence of any effects of weak electromagnetic fields on the cell proliferation, may indicate that cells are not really expecting any damage from the weak electromagnetic impulse, but instead they are using this impulse as some kind of early warning system to prepare for the really hazardous other stress factors which often follow the electromagnetic impulse. There is another aspect of this problem also: some recent findings in evolutionary biology suggest that heat shock proteins play important role in evolution.

HSP90 guides the folding process of signal transduction proteins which play a key role in developmental pathways. When HSP90 functions normally, a large amount of genetic variation, usually present in genotype, is masked and does not reveal itself in phenotype. However, under the stress Hsp90 is recruited to help chaperon a large number of other cellular proteins. Its normal role is impaired and it can no longer buffer variation. Therefore some mutations will become unmasked and individuals with abnormal phenotype will appear in the population. If a mutation proves to be beneficial in the new environmental conditions, the related traits will be preserved even after the HSP90 resumes its normal function. Therefore HSP90 acts as a capacitor of evolution. If environmental conditions are stable, the buffering role of HSP90 ensures the stability of phenotype despite increased accumulation of hidden mutations in genotype. When the environmental conditions suddenly change, as for example after the asteroid impact, which is believed to cause the dinosaur extinction 65 million years ago, this great potential of genetic variation is released in phenotype and the natural selection quickly finds the new forms of life with greater fitness. The Drosophila experiments of Rutherford and Lindquist (Rutherford and Lindquist 1998) demonstrated this beautiful mechanism, which may constitute the molecular basis of evolution.

Further studies have shown that the HSP70 and HSP60 protein families also buffer phenotypic variation (Rutherford 2003). As was mentioned above, experiments demonstrated that ELF electromagnetic fields can induce various heat shock proteins and in particular HSP70. Therefore we can speculate that ecological and genetic consequences of the Tunguska event are possibly not related to mutations which happened during the event, but are manifestations of the latent mutations, already present in the Tunguska biota, which were unmasked due to the stress response. ELF/VLF radiation from the Tunguska bolide might act as a stressor thereby explaining why the effect is concentrated towards the trajectory projection.

Note that direct mutagenic effect of the TSB flight and explosion is not also excluded. Because the Tunguska bolide was electrophonic bolide of the exceptional magnitude, very strong induced electric and magnetic fields are expected, and therefore they could induce significant Joule heating in biological tissues. One can even find a witness accounts which can be interpreted as supporting this supposition, for example P.P. Kosolapov’s report (Krinov 1949):

“In June 1908, at about 8 in the morning I was in Vanavara settlement preparing myself for a hay harvest and I needed a nail. As I could not find it in the hut, I went out in the yard and began to drag out the nail by pliers from the window frame. Suddenly something as if burned my ears. Seizing them and thinking that the roof was under fire, I raised my head and asked to S.B. Semenov who was sitting on the porch of his house: “Did you see something?" -- “How not to see, answered he, I also felt as if I was embraced with heat." After that I immediately went to the hut, but as I just entered it and wanted to sit down on the floor to start work, a heavy blow followed, soil began to drop from the ceiling, the door of the Russian stove was thrown out on the bed which stand in front of the stove and one window glass was broken. After that a sound like thunderclap appeared which receded in the north direction. When there was quiet again, I rushed out in the yard, but noticed nothing any more."

Krinov notes that the eyewitness did not mention any light phenomena and explains this by the fact that he was near the south wall of the hut and thus shielded from the north half of the sky were the explosion took place. Krinov further speculates that the heat sensation was caused by the bolide glow as it fled overhead towards the explosion point. In our opinion more realistic explanation is provided by the Joule heating due to extraordinary strong electromagnetic pulse.

Many survived trees in the epicenter area have characteristic damages as if originated from the lightning strikes. Therefore one can expect that the explosion was accompanied by thousands of lightning strikes (Ol’khovatov 2003). It was proposed long ago that strong electric fields associated with thunderstorms could accelerate electrons to relativistic energies and lead to X-ray radiation. But all past attempts to register such radiation from lightnings have produced inconclusive results. At last, recent rocket-triggered lightning experiments unambiguously demonstrated that lightnings are accompanied by short intense bursts of ionizing radiation (Dwyer et al. 2003).

The detector used in these experiments (a NaI(Tl) scintillation counter) cannot distinguish between X-rays, gamma-rays and energetic electrons. So the actual composition of the radiation burst is unknown, but the fact that the radiation was not significantly attenuated by the 0.32 cm aluminum window on the top of the detector ensures that the particle energies were much more than 10 keV. The form of the observed signal indicates that the signal was produced by multiple energetic particles. The bursts had typical durations of less than 100 microseconds and the total deposited energy was typically many tens of MeV per stroke. The energetic radiation seems to be associated with the dart leader phase of the lightning and precedes the return stroke by about 160 μs.

Similar observations were made earlier by Moore et al. (Moore et al. 2001), who observed energetic radiation from natural lightning. In this case the radiation burst was associated with much more slower stepped leader phase and preceded the onset of the return stroke current by several milliseconds.

As we see, at present one has solid experimental evidence that lightnings are sources of short bursts of ionizing radiation. Note that this experimental fact cannot be explained by the conventional theories of high-voltage breakdown at high pressures and therefore they need to be revisited (Krider 2003).

We do not know whether the TSB flight was also accompanied by ionizing radiation. This is not excluded as well because the strong electric fields associated with the alleged space charge separation could produce energetic enough runaway electrons. Even if present, this radiation maybe will be too attenuated before reaching the ground to produce significant biological effects. However, it seems very plausible that at least the explosion was accompanied by intense bursts of ionizing radiation from lightnings with possible biological consequences.

5. The riddle of the sands

We tried to argue in the previous sections that the genetic and ecological impact of the Tunguska event is possibly related to the powerful ELF/VLF electromagnetic radiation from the bolide and to the ionizing radiation due to lightnings which accompany the explosion. Note that ionizing radiation from the bolide and electromagnetic pulse as possible causes of genetic mutations were considered earlier by Andreev and Vasilyev (Trayner 1997) from different perspective. Turbulent wake behind the large enough bolide can produce required energetics of ELF/VLF radiation, for example by Keay--Bronshten mechanism. The TSB was indeed very large, with the estimated prior to explosion mass between 105 and 106 tonnes (Trayner 1997). The fact that no single milligram of this vast material was reliably identified in the epicenter region possibly tells against the asteroidal nature of the TSB (Bronshten 2000b). But cometary theory may also fail to explain the low altitude of the explosion, as well as some specific features of the forest devastation in the epicenter. These features indicate that besides the main explosion there were a number of lower altitude (maybe even right above the surface) less severe explosions (Vasilyev 1998). The most striking fact is that the impression of the ballistic wave on the forest seems to extend beyond the epicenter of the explosion, as if some part of the Tunguska object survived the huge explosion and continued its flight (Vasilyev 1998). Of course, it is a great enigma how an icy comet nucleus can lead to such strange effects. Maybe the key to this riddle is buried in the Libyan desert sands.

In 1932 an incredibly clear, gem-like green-yellow glass chunks were discovered in the remote and inhospitable Libyan desert in western Egypt. Geologists dated the glass at 28.5 million years old and it is the purest natural silica glass ever found on Earth, with a silica content of 98%. About 1400 tonnes of this strange material are scattered in a strewn field between sand dunes of the Great Sand Sea (Wright 1999).

The origin of Libyan Desert Glass (LDG) is not completely clear. LDG seems to be chunks of layered tektite glass, the so called Muong Nong type of tektite (Muehle 1998). Tektites are “probably the most frustrating stones ever found on Earth." (Faul 1966). The prevailing theory about their origin is that they are formed from the rocks melted in large meteorite impacts. But secrets of glass making in such impacts are still unknown and some scientists even refuse that such high quality glasses, as one has, for example, in the LDG case, could ever originate as a result of a fierce impact. The main argument against the terrestrial impact origin of tektites is the following (O’keefe 1994). Tektites are unusually free from the volatiles, like water and CO2, which are always present in terrestrial rocks. Glassmakers need several hours to remove bubbles from the melted material to produce the high quality glass in industrial glass-making process. But the impact is very brief phenomenon, so there is not enough time to remove the volatiles.

O’keefe himself preferred lunar volcanism as an alternative explanation of tektite origin (Cameron and Lowrey 1975). In this approach tektites are considered as “Teardrops from the Moon", in perfect agreement with ancient legends (Kadorienne 1997). Very romantic theory of course, but it encounters even more severe difficulties (Taylor and Koeberl 1994). As a result the impact theory reigns at present.

But the glassmaker objection should be answered, and usually one refers to shock compression (Melosh 1998), the trick not used by glassmakers but expected in impact events. Due to shock compression at 100 Gpa, silicates almost instantaneously reach temperatures as high as 50000 ◦C (Melosh 1998). Of course, nothing even remotely similar to such extreme conditions ever happens in industrial glass production. Therefore the comparison is not justified.

In the case of the Libyan Desert Glass, however, no impact crater have been found. Therefore Wasson and Moore (Wasson and Moore 1998) suggested that an atmospheric Tunguska-like explosion, 104 times more powerful, was responsible for LDG formation. Tremendous explosion heated a 100km×100km portion of the entire atmosphere to temperatures high enough to melt small desert sand grains, which were elevated by generated turbulence. As a result a thin melt sheet of silicate was formed and a radiation background have kept it hot enough for some time to flow and produce Muong Nong type tektites after solidification. Maybe multiple impacts produced by a fragmented comet, like Shoemaker--Levy-9 crash with Jupiter, is needed to ensure the appropriate scale of the event (Wasson 1995).

But the question about the high quality glass making reappears in this scenario, because now there are no extreme pressures associated with the impact cratering, and therefore no extreme compressive heating. Besides, evidence for shock metamorphism was revealed in some sandstones from the LDG strewn field by microscopic analysis (Kleinmann et al. 2001). This indicates to an impact, not to an atmospheric explosion. But then where is the crater? The situation is further involved by the recent strontium and neodymium isotopic study of these very sandstones and of some LDG samples (Schaaf and Muller-Sohnius 2002). Isotopic evidence indicates the difference between the sandstones and LDG, therefore the former cannot properly be regarded as possible source materials for LDG (Schaaf and Muller-Sohnius 2002).

As we see, Libyan Desert Glass, much like to the Tunguska event, suggests very strange and peculiar impact. Maybe the required explanation should be also very unusual and queer, like an impact of the mirror space body. Surely you will have a lot of glass after such an impact, won't you?

More seriously, the mirror matter idea is completely sound and attractive scientific idea, which dates back to the Lee and Yang's (Lee and Yang 1956) seminal paper. This hypothetical form of matter is necessary to restore the symmetry between left and right. At the fundamental level the notions of left and right (left-handed and right-handed spinors) originate because the Lorentz group is locally identical to the SU(2)×SU(2) group (see, for example, Silagadze 2002). Therefore one expects that the difference between these two factors of the Lorentz group, the difference between left and right, should be completely conventional and the Nature to be left-right symmetric. But P and CP discrete symmetries are broken by the weak interactions, so they can not be used to represent the symmetry between left and right, if we want a symmetric universe. One needs a new discrete symmetry M, instead of charge conjugation C, so that MP remains unbroken and interchanges left and right.

Lee and Yang (Lee and Yang 1956) supposed that this new symmetry can be arranged if for any ordinary particle the existence of the corresponding "mirror" particle is postulated. These new mirror particles are hard to detect because they are sterile (or almost sterile) to the ordinary gauge interactions. Instead they have their own set of mirror gauge particles, which we are blind to. The only guaranteed common interaction is the gravity (for a review and references on mirror matter idea see Foot 2001a, 2002, Silagadze 2001, 1997). Therefore big chunks of mirror matter can be detected by their gravitational influence. This means that in the solar system we do not have very much mirror matter, if any. But some amount is certainly allowed. Even a planetary or stellar mass distant companion to the sun is not excluded and represents a fascinating possibility (Foot and Silagadze 2001).

Mirror matter is a natural dark matter candidate. It may even happen that the mirror matter constitutes the dominant component of the dark matter (Berezhiani et al. 2001, Foot and Volkas 2003). We know that there is a lot of dark matter in our galaxy and even in the solar neighborhood its density can reach roughly 15% of the total mass density (Olling and Merrifield 2001). Therefore small asteroid size mirror objects occasionally colliding with the Earth is a possibility which can not be excluded.

What will happen during such collision depends on the details how the mirror matter interacts with the ordinary matter. If the predominant interaction is gravity, nothing interesting will happen, as the mirror asteroid will pass through the Earth unnoticed. But things will change if mirror and ordinary matters interact via sizable photon-mirror photon mixing (Foot 2001b, Foot and Yoon 2002). In this case mirror charged particles require small ordinary electric charge, they lose their sterility with respect to the ordinary electromagnetic interactions and the mirror and ordinary nuclei will undergo Rutherford scattering, causing the drag force upon entry of a mirror space body into the atmosphere.

In a number of detailed studies (Foot 2001b, Foot and Yoon 2002, Foot and Mitra 2002) the entry of a mirror body into the Earth's atmosphere was analyzed. The outcome depends on several factors, such as the magnitude of the photon-mirror photon mixing, the size of the mirror space body, its chemical composition and initial velocity. As concerned to the Tunguska problem, the most interesting conclusion was that a large (R _ 40 m) chunk of mirror ice, impacting the Earth with initial velocity of about 12 km/s, will not be slowed down much by the drag force in the atmosphere, but it will melt at a hight 5-10 km. Once it melts, the atmospheric drag force will increase dramatically, due to the body's expected dispersion, causing the body to release its kinetic energy into the atmosphere. Therefore an atmospheric explosion is expected.

If the TSB was indeed a mirror asteroid or comet, as suggested by Foot (Foot 2001b), the absence of the ordinary fragments is nicely explained. Of course, mirror fragments are still expected, if the body had significant non- volatile component. Maybe these fragments are still buried at the impact site, but nobody bothers to dig them out.

Some other exotic meteoritic phenomena also appear less puzzling if one accepts that they were caused by mirror impactors (Foot and Yoon 2002). And not only on the Earth. Looking at asteroid Eros and at its impact craters, Foot and Mitra (2002) came to a strange conclusion that the small mirror space bodies in the solar system can actually outnumber the ordinary ones. The reasoning is the following (Foot and Mitra 2002). When a mirror space body collides with an asteroid, it will release its kinetic energy at or below the asteroid's surface, depending on its size, velocity and the magnitude of the photon-mirror photon mixing. For Small mirror bodies the energy is released too slowly and over too large a volume to expect any crater formation. Therefore a crater hiatus is expected at some critical crater size, if the craters are caused by mirror impactors. And this is exactly what is observed for Eros: a sharp decrease in rate was found for craters with diameter less than about 70 m.

Foot and Mitra (2002) was able to infer some estimation of the photon- mirror photon mixing magnitude from these observations. The result fits nicely in the range which is expected if the anomalous meteoritic phenomena, and the Tunguska event in particular, was indeed caused by the mirror matter space bodies. There are some other interesting experimental implications of the mirror matter which also involve the same range of the mixing parameter (for a review, see Foot 2003).

Eros reveals still another footprint of the mirror world. Puzzling flat- flaw crater “ponds" were unexpectedly discovered on its surface. The mirror impact theory provides a ready explanation (Foot and Mitra 2002): a large enough mirror space body while releasing its energy underground will melt surrounding rocks. If the photon-mirror photon parameter is negative, some extra heat is expected besides the kinetic energy. In this case mirror and ordinary atoms attract each other, so for the mirror matter chunk it is energetically favorable to be completely embedded within ordinary matter, releasing energy in the process (Foot and Yoon 2002).

Interestingly, an enigmatic flat-flaw crater can be found even on Earth. It is the nearly circular 38 km wide Richat structure in Mauritania, the western end of the Sahara desert. Nowadays this structure is no more considered as an impact structure, despite its uniqueness in the region, reported presence of coesite, and its round “bull's-eye" shape. The reason is flat-lying strata at the center of the structure with no signs of the disrupted and contorted beds, lack of evidence for the shock-metamorphic effects, and the suspicion that the reported coesite is in fact misidentified barite (Everett et al., 1986). The Richat structure is believed to be a dome of endogenic origin sculpted by erosion. However why it is nearly circular remains a mystery.

Maybe Eros ponds hint the similar mirror matter explanation for this mysterious formation. Note that 50 km west-southwest of the Richat structure one finds similar but much smaller (of about 5 km diameter) formation -- the Semsiyat dome. If the “soft" impact of the main mirror body created the Richat structure, one can thought that its large fragment may caused the Semsiyat dome.

One expects numerous lightnings during a mirror impact event, because the mirror space body will accumulate an ordinary electric charge while flying in the atmosphere. The charge builds up because the ionized air molecules can be trapped within the mirror body, while the much more mobile electrons will escape (Foot and Mitra 2002). Interestingly, there were some speculations that the coesite-bearing quartzite breccias of the Richat structure were produced by lightning strikes (Master and Karfunkel 2001). As already was mentioned above, there is an evidence that the Tunguska event was accompanied by thousands of lightning strikes. More recently, one can mention January 14, 1993 anomalous low altitude fireball event in Poland, a candidate for a mirror meteorite strike, with enormous electrical discharge at the impact site, which destroyed most of the electrical appliances in nearby houses (Foot and Yoon 2002).

There is something similar to the Libyan Desert Glass in south Australia, the so called Edeowie glass field (Haines et al. 2001). Unlike to the LDG, this enigmatic fused crustal material is quite clast-rich and inhomogeneous. The enigma in this case consists in the fact that no impact crater has been found nearby, despite clear evidence that some rocks were melted in situ. Haines et al. (Haines et al. 2001) concluded that lightning and impact-related phenomena are the only reasonable possibilities capable to produce the observed fusion. But in fact maybe there is one more reasonable alternative, a large mirror body hitting the ground at cosmic velocity (Foot and Mitra 2003), capable to provide both the impact and spatially and temporally confined intense lightnings.

6. Concluding remarks

We have mentioned some riddles in this article, such as the Tunguska genetic anomaly and electrophonic meteors, magnetoreception in biological systems and molecular basis of evolution, Libyan desert Glass and Edeowie glass field, flat-flaw Eros craters and the Richat structure, parity violation and the hypothetical mirror matter, and tried to argue that all these puzzles maybe are just different pieces of the same one big jigsaw puzzle. The picture that was assembled can be hardly considered as completely satisfactory, as in many cases we rely on hypothesis instead of firmly established scientific facts. Therefore we can not guarantee that the suggested picture is really the one created by the jigsaw puzzle author (the Nature). Nevertheless it seems to us interesting enough to offer to your attention.

As to the Tunguska genetic anomaly, we see the following picture as a reasonable explanation. The Tunguska bolide was of electrophonic nature. That means its flight was accompanied by a powerful ELF/VLF electromagnetic radiation. This radiation acted as a stress factor on the local biota and triggered subtle mechanisms to release the hidden genetic variations into the phenotype. Some direct mutagenic factors, related to the ionizing radiation associated with lightnings during the explosion, are also not excluded.

Interestingly, if the above given explanation is correct, the Tunguska genetic anomaly represents in miniature the action of the molecular basis of evolution. On much more grater scale, global catastrophic events, like the asteroid crash 65 million years ago which ended the dinosaur era, boost the evolution by the same mechanism. We are left to admire the Grand Design of Nature and try to survive its next evolutionary turn.

Therefore, finally let us return to outer space fears of sinful modern man. For a long time the ancient belief that the cosmos can influence mundane affairs was considered by scientists as a mere superstition. “Modern astronomers generally scoff at such superstitious beliefs, so it is somewhat ironic that science has in the past few decades uncovered compelling evidence for celestial interference in terrestrial matters" (Jewitt 2000). It is now widely accepted that near Earth objects larger than 1 km in diameter represent considerable hazard and in the past Earth witnessed a number of withering impacts, which maybe shaped the biological evolution. There are attempts to convince governments and society to fund ambitious projects to completely identify potentially threatening near Earth objects and develop adequate defense systems (Jewitt 2000).

But the Tunguska event and some other mysterious events of probably impact origin indicate the enigmatic type of soft impacts which do not leave any crater, as well as impactor fragments, despite their tremendous magnitude. In this article we mentioned one possible explanation that these impact events are caused by mirror space bodies. Of course, this explanation looks exotic, but in fact it is the only one falsifiable in near future.

For mirror matter explanation of anomalous impact events the crucial ingredient is the presence and magnitude of the photon-mirror photon mixing. And this can be experimentally tested! In fact the crucial experiment is already planned. This is ETH-Moscow positronium experiment (Badertscher et al. 2003, Foot 2003). The photon-mirror photon mixing leads to the orthopositronium-mirror orthopositronium oscillations. As a result in some tiny fraction of events the orthopositronium will decay into mirror photons and this will be detected as an event with missing energy. It is expected that the experiment will reach the needed sensitivity to prove or disprove the presence of the photon-mirror photon mixing of relevant magnitude (Badertscher et al. 2003, Foot 2003).

If the ETH-Moscow positronium experiment outcome turns out to be positive, it will mean bad news for fearful modern man, except the mirror matter theory proponents maybe. The peculiarities of the Eros craters, if really caused by mirror impactors, indicate significant population of small mirror bodies in the inner solar system. So the potential hazard for Earth is bigger than estimated. More importantly, it is very hard, if not impossible at all, to timely discover Earth approaching mirror space body and avert its impact. Therefore sinful modern man will be bound to face outer space hazards with eyes wide shut.

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APPENDIX FOUR

KULIK'S SECOND EXPEDITION (1928)

Above - From the Archive of the Meteorite Committee of the Russian Academy of Sciences

Fourth and fifth from the left: the shaman Bur with Strukov,
cameraman of Kulik's second expedition (1928).

The shaman Bur (woman) lived on the border of Vanavara
in a "chum", the traditional Evenk hut.

http://www-th.bo.infn.it/tunguska/Ev-1928-Shaman-Bur-with-Strukov.htm

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Above - The god Ogdy

http://www-th.bo.infn.it/tunguska/Ev-Ogdy1991.htm

End

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APPENDIX FIVE

TUNGUSKA MEDIA REPORTS

For interest the following Media Reports regarding Tunguska have been provided:

(The following material has been compiled from various unverified sources)

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THE TUNGUSKA IMPACT -- 100 YEARS LATER

NASA Science - Science News

(30 June 2008)

Editor:

Dr. Tony Phillips

Source:

http://science.nasa.gov/science-news/science-at-nasa/2008/30jun_tunguska/

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June 30, 2008: The year is 1908, and it's just after seven in the morning. A man is sitting on the front porch of a trading post at Vanavara in Siberia. Little does he know, in a few moments, he will be hurled from his chair and the heat will be so intense he will feel as though his shirt is on fire. That's how the Tunguska event felt *40 miles* from ground zero.

Today, June 30, 2008, is the 100th anniversary of that ferocious impact near the Podkamennaya Tunguska River in remote Siberia--and after 100 years, scientists are still talking about it.

"If you want to start a conversation with anyone in the asteroid business all you have to say is Tunguska," says Don Yeomans, manager of the Near-Earth Object Office at NASA's Jet Propulsion Laboratory. "It is the only entry of a large meteoroid we have in the modern era with first-hand accounts."

Above - Trees felled by the Tunguska explosion.
Credit: the Leonid Kulik Expedition.

While the impact occurred in '08, the first scientific expedition to the area would have to wait for 19 years. In 1921, Leonid Kulik, the chief curator for the meteorite collection of the St. Petersburg museum led an expedition to Tunguska. But the harsh conditions of the Siberian outback thwarted his team's attempt to reach the area of the blast. In 1927, a new expedition, again lead by Kulik, reached its goal.

"At first, the locals were reluctant to tell Kulik about the event," said Yeomans. "They believed the blast was a visitation by the god Ogdy, who had cursed the area by smashing trees and killing animals."

While testimonials may have at first been difficult to obtain, there was plenty of evidence lying around. Eight hundred square miles of remote forest had been ripped asunder. Eighty million trees were on their sides, lying in a radial pattern.

Those trees acted as markers, pointing directly away from the blast's epicenter," said Yeomans. "Later, when the team arrived at ground zero, they found the trees there standing upright - but their limbs and bark had been stripped away. They looked like a forest of telephone poles."

Such debranching requires fast moving shock waves that break off a tree's branches before the branches can transfer the impact momentum to the tree's stem. Thirty seven years after the Tunguska blast, branchless trees would be found at the site of another massive explosion - Hiroshima, Japan. Kulik's expeditions (he traveled to Tunguska on three separate occasions) did finally get some of the locals to talk. One was the man based at the Vanara trading post who witnessed the heat blast as he was launched from his chair. His account:

Suddenly in the north sky… the sky was split in two, and high above the forest the whole northern part of the sky appeared covered with fire… At that moment there was a bang in the sky and a mighty crash… The crash was followed by a noise like stones falling from the sky, or of guns firing. The earth trembled.

The massive explosion packed a wallop. The resulting seismic shockwave registered with sensitive barometers as far away as England. Dense clouds formed over the region at high altitudes which reflected sunlight from beyond the horizon. Night skies glowed, and reports came in that people who lived as far away as Asia could read newspapers outdoors as late as midnight. Locally, hundreds of reindeer, the livelihood of local herders, were killed, but there was no direct evidence that any person perished in the blast.

Above - The location of the Tunguska impact.

"A century later some still debate the cause and come up with different scenarios that could have caused the explosion," said Yeomans. "But the generally agreed upon theory is that on the morning of

June 30, 1908, a large space rock, about 120 feet across, entered the atmosphere of Siberia and then detonated in the sky."

It is estimated the asteroid entered Earth's atmosphere traveling at a speed of about 33,500 miles per hour. During its quick plunge, the 220-million-pound space rock heated the air surrounding it to 44,500 degrees Fahrenheit. At 7:17 a.m. (local Siberia time), at a height of about 28,000 feet, the combination of pressure and heat caused the asteroid to fragment and annihilate itself, producing a fireball and releasing energy equivalent to about 185 Hiroshima bombs.
"That is why there is no impact crater," said Yeomans. "The great majority of the asteroid is consumed in the explosion."

Yeomans and his colleagues at JPL's Near-Earth Object Office are tasked with plotting the orbits of present-day comets and asteroids that cross Earth's path, and could be potentially hazardous to our planet. Yeomans estimates that, on average, a Tunguska-sized asteroid will enter Earth's atmosphere once every 300 years.

"From a scientific point of view, I think about Tunguska all the time," he admits. Putting it all in perspective, however, "the thought of another Tunguska does not keep me up at night."

http://science.nasa.gov/science-news/science-at-nasa/2008/30jun_tunguska/

End

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SPACE SHUTTLE SCIENCE SHOWS HOW

1908 TUNGUSKA EXPLOSION

WAS CAUSED BY A COMET

ScienceDaily

(June 24, 2009)

http://www.sciencedaily.com/releases/2009/06/090624152941.htm

The mysterious 1908 Tunguska explosion that leveled 830 square miles of Siberian forest was almost certainly caused by a comet entering the Earth's atmosphere, says new Cornell University research. The conclusion is supported by an unlikely source: the exhaust plume from the NASA space shuttle launched a century

The research, accepted for publication (June 24, 2009) by the journal *Geophysical Research Letters*, published by the American Geophysical Union, connects the two events by what followed each about a day later: brilliant, night-visible clouds, or noctilucent clouds, that are made up of ice particles and only form at very high altitudes and in extremely cold temperatures.

"It's almost like putting together a 100-year-old murder mystery," said Michael Kelley, the James A. Friend Family Distinguished Professor of Engineering at Cornell who led the research team. "The evidence is pretty strong that the Earth was hit by a comet in 1908." Previous speculation had ranged from comets to meteors.

The researchers contend that the massive amount of water vapor spewed into the atmosphere by the comet's icy nucleus was caught up in swirling eddies with tremendous energy by a process called two-dimensional turbulence, which explains why the noctilucent clouds formed a day later many thousands of miles away.

Noctilucent clouds are the Earth's highest clouds, forming naturally in the mesosphere at about 55 miles over the polar regions during the summer months when the mesosphere is around minus 180 degrees Fahrenheit (minus 117 degrees Celsius).

The space shuttle exhaust plume, the researchers say, resembled the comet's action.
A single space shuttle flight injects 300 metric tons of water vapor into the Earth's thermosphere, and the water particles have been found to travel to the Arctic and Antarctic regions, where they form the clouds after settling into the mesosphere.

Kelley and collaborators saw the noctilucent cloud phenomenon days after the space shuttle Endeavour (STS-118) launched on Aug. 8, 2007. Similar cloud formations had been observed following launches in 1997 and 2003.

Following the 1908 explosion, known as the Tunguska Event, the night skies shone brightly for several days across Europe, particularly Great Britain -- more than 3,000 miles away.

Kelley said he became intrigued by the historical eyewitness accounts of the aftermath, and concluded that the bright skies must have been the result of noctilucent clouds. The comet would have started to break up at about the same altitude as the release of the exhaust plume from the space shuttle following launch. In both cases, water vapor was injected into the atmosphere.

The scientists have attempted to answer how this water vapor traveled so far without scattering and diffusing, as conventional physics would predict.

"There is a mean transport of this material for tens of thousands of kilometers in a very short time, and there is no model that predicts that," Kelley said. "It's totally new and unexpected physics."

This "new" physics, the researchers contend, is tied up in counter-rotating eddies with extreme energy. Once the water vapor got caught up in these eddies, the water traveled very quickly -- close to 300 feet per second.

Scientists have long tried to study the wind structure in these upper regions of the atmosphere, which is difficult to do by such traditional means as sounding rockets, balloon launches and satellites, explained Charlie Seyler, Cornell professor of electrical engineering and paper co-author.

"Our observations show that current understanding of the mesosphere-lower thermosphere region is quite poor," Seyler said. The thermosphere is the layer of the atmosphere above the mesosphere.

The paper is also co-authored by physicist Miguel Larsen, Ph.D. '79, of Clemson University, and former student of Kelley. The work performed at Cornell was funded by the Atmospheric Science Section of the National Science Foundation.

On July 1, Kelley will give a lecture, "Two-dimensional Turbulence, Space Shuttle Plume Transport in the Thermosphere, and a Possible Relation to the Great Siberian Impact Event," at a plenary session of the annual meeting of Coupling, Energetics and Dynamics of Atmospheric Regions in Sante Fe, N.M.

Journal Reference:

Kelley, M. C., C. E. Seyler, and M. F. Larsen. (2009), Two-dimensional Turbulence, Space Shuttle Plume Transport in the Thermosphere, and a Possible Relation to the Great Siberian Impact Event. *Geophys. Res. Lett*, (in press) DOI: 10.1029/2009GL038362

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http://www.sciencedaily.com/releases/2009/06/090624152941.htm

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SPACE SHUTTLE LINKS

1908 TUNGUSKA EXPLOSION

TO COMET

by

Staff Writers

Ithaca NY (SPX)

(25 Jun 2009)

http://www.spacedaily.com/reports/Space_Shuttle_Links_1908_Tunguska_Explosion_To_Comet_999.html

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The mysterious 1908 Tunguska explosion that leveled 830 square miles of Siberian forest was almost certainly caused by a comet entering the Earth's atmosphere, says new Cornell University research. The conclusion is supported by an unlikely source: the exhaust plume from the NASA space shuttle launched a century later.

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Above - Noctilucent clouds are the Earth's highest clouds, forming naturally in the mesosphere at about 55 miles over the polar regions during the summer months when the mesosphere is around minus 180 degrees Fahrenheit (minus 117 degrees Celsius). The space shuttle exhaust plume, the researchers say, resembled the comet's action. A single space shuttle flight injects 300 metric tons of water vapor into the Earth's thermosphere, and the water particles have been found to travel to the Arctic and Antarctic regions, where they form the clouds after settling into the mesosphere.

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http://www.spacedaily.com/reports/Space_Shuttle_Links_1908_Tunguska_Explosion_To_Comet_999.html

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CRATER COULD SOLVE 1908

TUNGUSKA METEOR MYSTERY

by

Dave Mosher

Staff Writer

Space.com

(26 June 2007)

http://www.space.com/3996-crater-solve-1908-tunguska-meteor-mystery.html

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Above - A three-dimensional rendering of Lake Cheko in Tunguska, Siberia.
The level of the lake is lowered 40 meters (131 feet) to emphasize its cone-like shape.
CREDIT: www-th.bo.infn.it/Tunguska / University of Bologna

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In late June of 1908, a fireball exploded above the remote Russian forests of Tunguska, Siberia, flattening more than 800 square miles of trees. Researchers think a meteor was responsible for the devastation, but neither its fragments nor any impact craters have been discovered.

Astronomers have been left to guess whether the object was an asteroid or a comet, and figuring out what it was would allow better modeling of potential future calamities.

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Italian researchers now think they've found a smoking gun: The 164-foot-deep Lake Cheko, located just 5 miles northwest of the epicenter of destruction.

"When we looked at the bottom of the lake, we measured seismic waves reflecting off of something," said Giuseppe Longo, a physicist at the University of Bologna in Italy and co-author of the study. "Nobody has found this before. We can only explain that and the shape of the lake as a low-velocity impact crater."

Should the team turn up conclusive evidence of an asteroid or comet on a later expedition, when they obtain a deeper core sample beneath the lake, remaining mysteries surrounding the Tunguska event may be solved.

The findings are detailed in this month's online version of the journal *Terra Nova*.

Submerged evidence

During a 1999 expedition, Longo's team didn't plan to investigate Lake Cheko as an impact crater, but rather to look for meteoroid dust in its submerged sediments. While sonar-scanning the lake's topography, they were struck by its cone-like features.

"Expeditions in the 1960s concluded the lake was not an impact crater, but their technologies were limited," Longo said. With the advent of better sonar and computer technologies, he explained, the lake took shape.

Going a step further, Longo's team dove to the bottom and took 6-foot core samples, revealing fresh mud-like sediment on top of "chaotic deposits" beneath. Still, Longo explained the samples are inconclusive of a meteorite impact.

"To really find out if this is an impact crater," Longo said, "we need a core sample 10 meters (33 feet) into the bottom" in order to investigate a spot where the team detected a "reflecting" anomaly with their seismic instruments. They think this could be where the ground was compacted by an impact or where part of the meteorite itself lies: The object, if found, could be more than 30 feet in diameter and weigh almost 1,700 tons — the weight of about 42 fully-loaded semi-trailers.

Caution for now

From a UFO crash to a wandering black hole, wild (and wildly unsupported) explanations for the Tunguska event have been proposed. Alan Harris, a planetary scientist at the Space Science Institute in Boulder, Colorado, said the proposal by Longo's team isn't one of them.

"I was impressed by their work and I don't think it's something you can wave off," said Harris, who was not involved in the research.

Longo and his team "are among the recognized authorities on Tunguska" in the world, Harris told *SPACE.com*. "It would be thrilling to dig up chunks of the meteor body, if they can manage to. It would lay the question to rest whether or not Tunguska was a comet or asteroid."

Some researchers, however, are less confident in the team's conclusions.

"We know from the entry physics that the largest and most energetic objects penetrate deepest," said David Morrison, an astronomer with NASA's Ames Research Center. That only a fragment of the main explosion reached the ground and made a relatively small crater, without creating a larger main crater, seems contradictory to Morrison.

Harris agreed that physics could work against Longo's explanation, but did note that similar events -- with impact craters -- have been documented all over the world.

"In 1947, the Russian Sikhote-Alin meteorite created 100 small craters. Some were 20 meters (66 feet) across," Harris said. A site in Poland also exists, he explained, where a large meteor exploded and created a series of small lakes. ?If the fragment was traveling slowly enough, there's actually a good chance (Longo's team) will unearth some meteorite material,? Harris said.

Longo's team plans to return to Lake Cheko next summer, close to the 100th anniversary of the Tunguska Event. "This is important work because we can make better conclusions about how cosmic bodies impact the Earth, and what they're made of," Longo said. "And it could help us find ways to protect our planet from future impacts of this kind."

End

http://www.space.com/3996-crater-solve-1908-tunguska-meteor-mystery.html

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THE 1908 TUNGUSKA EXPLOSION:

ATMOSPHERIC DISRUPTION OF A STONY ASTEROID

***Nature* 361, 40 - 44**

(07 January 1993)

DOI: 10.1038/361040a0

by

Christopher F. Chyba[*†], Paul J. Thomas[‡] & Kevin J. Zahnle[*]

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http://www.nature.com/nature/journal/v361/n6407/abs/361040a0.html

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Abstract

The explosion over Tunguska, Central Siberia, in 1908 released 10 to 20 megatons (high explosive equivalent) of energy at an altitude of about 10 km. This event represents a typical fate for stony asteroids tens of metres in radius entering the Earth's atmosphere at common hypersonic velocities. Comets and carbonaceous asteroids of the appropriate energy disrupt too high, whereas typical iron objects reach and crater the terrestrial surface.

End

http://www.nature.com/nature/journal/v361/n6407/abs/361040a0.html

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APPENDIX SIX

RECENT

TUNGUSKA

PHOTOS

(c. Mid 1990 Onwards)

(When known, credit is given in parenthesis)

http://olkhov.narod.ru/pictures.htm

Introduction - Taiga

"Taiga" is the Russian word for forest and is the world's largest land biome, making up 29% of the world's forest cover - the largest areas are located in Russia and Canada.

In North America the Taiga covers most of inland Canada and Alaska as well as parts of the extreme northern continental United States and is known as the "Northwoods". It also covers most of Sweden, Finland, much of Norway, much of Russia (especially Siberia), northern Kazakhstan, northern Mongolia, and northern Japan (on the island of Hokkaido).

Above - Tunguska taiga

The taiga is the terrestrial biome with the lowest annual average temperatures after the tundra and permanent ice caps.

Extreme winter minimums in the northern taiga are typically lower than those of the tundra. The lowest reliably recorded temperatures in the Northern Hemisphere were recorded in the taiga of north-eastern Russia.

The taiga or "boreal forest" has a sub-arctic climate with large temperature range between seasons; however, the long and cold winter is the dominant feature.

The soil in the taiga is thin and poor in nutrients, and this contributes to the fact that most trees grow close to the ground and their roots don't go too far into the soil. Even though the taiga is mostly coniferous - dominated by larch, spruce, fir, and pine, some broadleaf trees can also been seen here. Birch, aspen, willow, and rowan are examples. Additionally, many of the trees found in the taiga change their biochemistry throughout the year, so they have the strength and resilience to better resist freezing. The Taiga also has moss and bogs.

Above - Tunguska taiga

Flora and Fauna

Nowhere else in the world is there such a large number of furry animals than in the taiga. Large herbivorous animals and small rodents live in these forests - bears, weasels, raccoons, wolves, lynxes, rabbits, and squirrels; and they are well adapted to the harsh weather.

Often, the larger animals eat copiously during the warmer months and gain a lot of weight They then sleep through the colder months when they hibernate. The animals that do not hibernate generally become less active.

Brown bears are among the largest and most widespread across taiga.

About 300 species of birds summer in the taiga, and only about 30 species remain through the winter - these are the ones with more feathers to keep them warm.

The taiga produces an enormous amount of oxygen, and it is said that the taiga generates enough oxygen on its own to re-generate enough oxygen for the entire planet.

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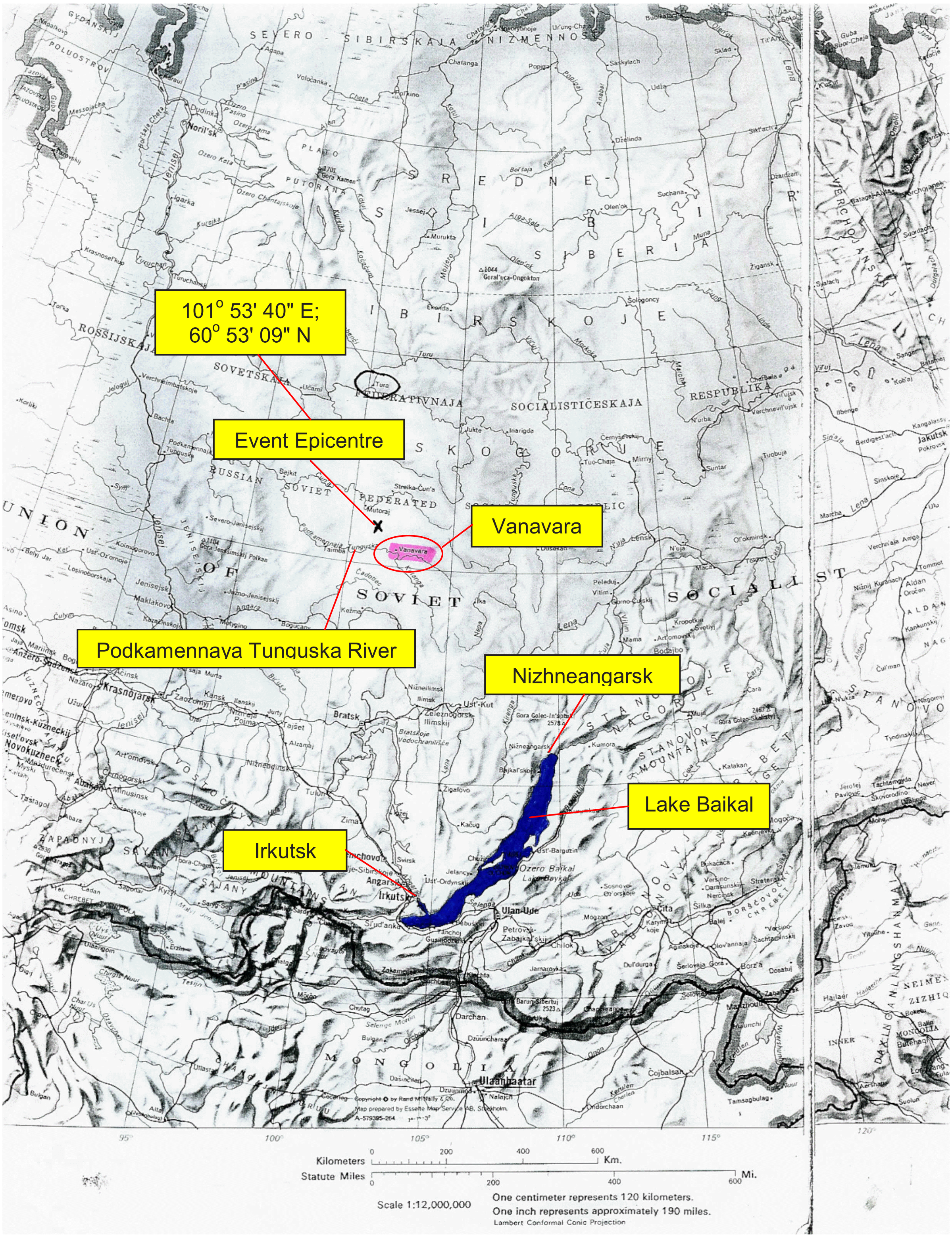
Tunguska Event Location

The Tunguska event took place in Central Siberia near the Podkamennaya [Stony] Tunguska River
101^{o} 53' 40" E; 60^{o} 53' 09" N



Tunguska is located in the Central Siberian Plateau, a sparsely populated, desolate region of peat bogs, and pine forests. North of Irkutsk and the northern most tip of Mongolia, the region is highly representative of the Tartar word for Siberia, "the sleeping land". Tunguska is also North-North-West of the "Mysterious Lake Baika" (which curves down from Nizhneangarsk towards Irkutsk).

Vanavara

Above - Vanavara Airport

Above - Vanavara Airport

Vanavara is the closest settlement to the Tungusta event area, and is approx. 40 miles south east of the epicentre.

The Tunguska event area can be reached by boat from Vanavara to Kordon Pristan along the rivers Podkamennaya Tunguska, Chamba, and Khushma.

Above - Vanavara seen from the Stony Tunguska River

Above - The river Podkamennaya Tunguska by the mouth of the Vanavara River

Above - Vanavara today, 2007

Above - The Vanavara Museum

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The "Deer Stone", also known as the "John Stone"

Above - The "Deer Stone"/"John Stone"

Date Unknown - This stone (also know as the the "Deer-stone" or the "John Stone") was discovered in 1972 by John F. Anfinogenov on Stoykovich Mountain, near the epicenter

It is a terrestrial stone, but there are some problems with its appearance in the Tunguska epicentre (V. Romeiko)

The stone is a quarz-disseminated conglomerate-gravelite sand-stone belonging to highly strong sedimentationrock consisting by 98.5% of SiO_2

John Anfinogenov is an eminent Tunguska investigator, who has participated in eighteen ITEG expeditions since 1965, and who has composed a map of the area of taiga complete destruction.

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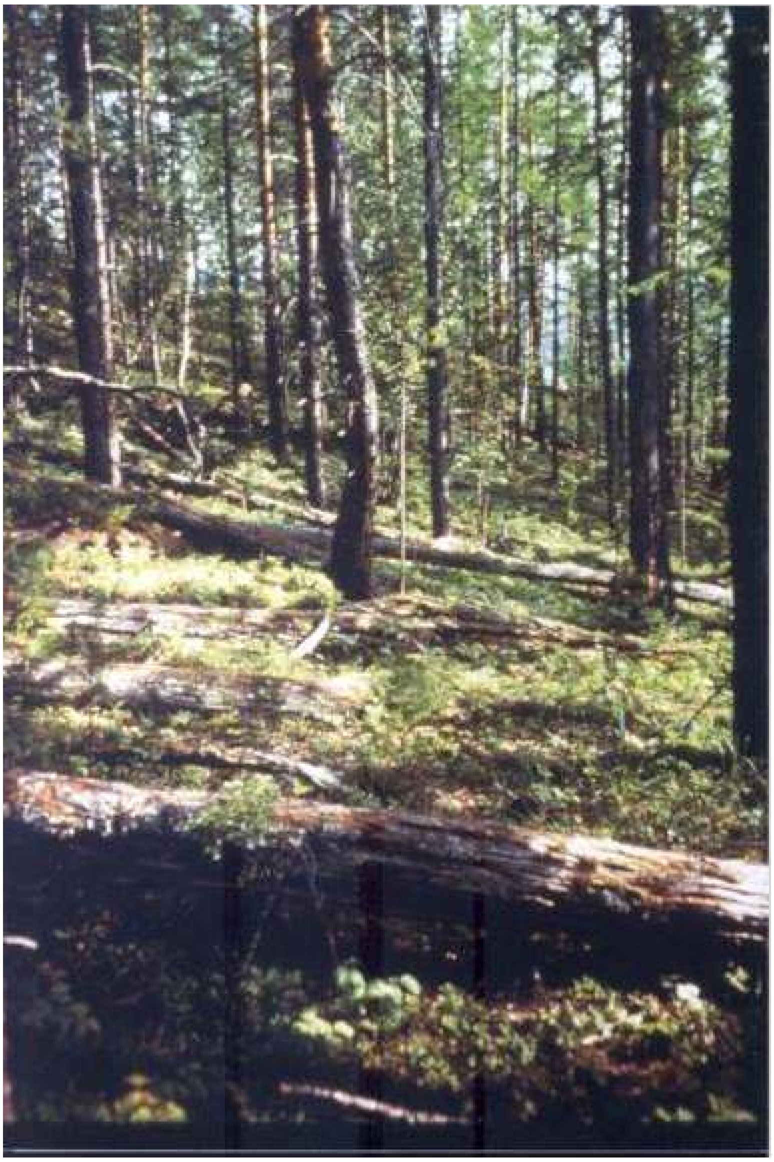

60 years later (c. 1987)
The fallen trunks are still visible, and the taiga re-establishing itself between them
(Evgeniy M. Kolesnikov - Lomonosov Moscow State University)

Date Unknown - View of the Tunguska epicentre
Note that there are no visible traces of the 1908 event - just a vigorous growing taiga
(V. Romeiko)

1995 - Taiga at the Tunguska epicentre
(Sergei Ipatov)

1995 - A little way from the Tunguska epicenter
Kulik's huts in the taiga
(Sergei Ipatov)

1999 - Tunguska
(unverified)

2002 - *Kulik's* huts in the Tunguska epicentre
(Canadian-British-Russian group)

2002, Late May - *Pristan'* (Quay) area
(approx. 7 km to the south of the Tunguska epicentre)
(Canadian-British-Russian group)

2003 - There are a lot of bogs in the Tunguska area
(L. Pelekhan')

2004 - A *zimov'e* (a winter house for hunters, trappers, etc.)
Area of the *Tetere* River
(A. Chernikov)

2007, Summer - *Pristan'* (Quay) area (approx. 7 km to the south of the Tunguska epicentre)
Pristan' can be reached by a river
(N. Lebedeva)

2007, Summer - Southern swamp,
epicenter of the Tunguska event
(L. Pelekhan')

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Photos of the Tunguska event area during the 100th anniversary c. 30 June 2008

2008, June - swampy area near the Tunguska epicentre
(V. Bidyukova)

2008, June - local swamp near the Tunguska epicentre
(V. Bidyukova)

2008, June - huts in the *Pristan'* (Quay) area
(approx. 7 km to the south of the Tunguska epicenter)
(V. Bidyukova)

2008, June - *labaz* for preserving food
(as during Kulik's expeditions)
(V. Bidyukova)

2008, June - remnants of a tree fallen in the 1908
Tunguska event
(V. Bidyukova)

2008, June - remnants of a tree fallen in the 1908
Tunguska event
(V. Bidyukova)

2008, June - sunset in the Tunguska epicenter area
(V. Bidyukova

2008, June - a new hut in *Pristan'* (Quay) area
(V. Bidyukova)

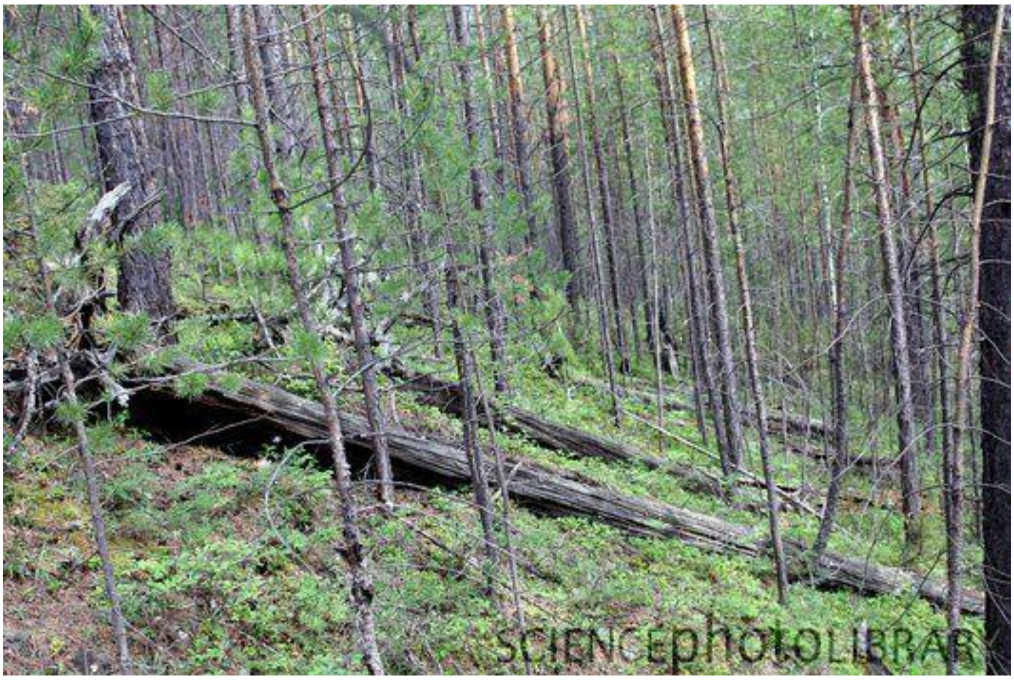
2008, June - area near to Zaimka Kulika
(Approx. 1 km from the Tunguska epicenter- the white square is a helicopter landing area)
(V. Bidyukova)

2008, June - area near to Zaimka Kulika
(Approx. 1 km from the Tunguska epicentre - the white square is a helicopter landing area)
(V. Bidyukova)

2008, June - A monument to the *'originator of the Tunguska event'*
near the Tunguska epicenter
(V. Bidyukov).

2008, June - Fog, and a mountain near the Tunguska epicenter
(V. Bidyukova).

2008, June - Fog in taiga
(V. Bidyukov)



c.2008 - "*Fallen trees at Tunguska, 100 years after the famous explosion*"
(Unverified)

Above - Tunguska, 2009
(Unverified)

Above - Tunguskak, 2009
(Unverified - Trees from 1908)

Above - Tunguska, 2009
(Unverified - Trees from 1908)

End

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