Finding a piece of the elusive cosmic body that devastated a Siberian forest a century ago could help save the earth in the centuries to come

By Luca Gasperini, Enrico Bonatti and Giuseppe Longo

June 30, 1908, 7:14 a.m., central Siberia—Semen Semenov, a local farmer, saw "the sky split in two. Fire appeared high and wide over the forest.... From ... where the fire was, came strong heat.... Then the sky shut closed, and a strong thump sounded, and I was thrown a few yards.... After that such noise came, as if . . . cannons were firing, the earth shook ..."

Such is the harrowing testimony of one of the closest eyewitnesses to what scientists call the Tunguska event, the largest impact of a cosmic body to occur on the earth during modern human history. Semenov experienced a raging conflagration some 65 kilometers (40 miles) from ground zero, but the effects of the blast rippled out far into northern Europe and Central Asia as well. Some people saw massive, silvery clouds and brilliant, colored sunsets on the horizon, whereas others witnessed luminescent skies at night—Londoners, for instance, could plainly read newsprint at midnight without artificial lights. Geophysical observatories placed the source of the anomalous seismic and pressure waves they had recorded in a remote section of Siberia. The epicenter lay close to the river Podkamennaya Tunguska, an uninhabited area of swampy taiga forest that stays frozen for eight or nine months of the year.

JAMES PORTO

GIANT FIREBALL in the sky was the first indication that an unknown celestial object had exploded over Siberia. In this artist's conception, Semen Semenov, who witnessed the blast at a distant trading post, starts to feel the heat.

[THE AUTHORS]

Luca Gasperini, Enrico Bonatti and Giuseppe Longo have studied the Tunguska mystery for many years. Gasperini is a research scientist at the Institute of Marine Science in Bologna, Italy. Bonatti is professor of geodynamics at the University of Rome "La Sapienza" and special scientist at Columbia University's Lamont-Doherty Earth Observatory. Longo is professor of physics at the University of Bologna (www-th.bo.infn.it/tunguska).

Ever since the Tunguska event, scientists and lay enthusiasts alike have wondered what caused it. Although most observers generally accept that some kind of cosmic body, either an asteroid or a comet, exploded in the sky above Siberia, no one has yet found fragments of the object or any impact craters in the affected region. The mystery remains unsolved, but our research team, only the latest of a steady stream of investigators who have scoured the area, may be closing in on a discovery that will change our understanding of what happened that fateful morning.

The study of the Tunguska event is important because past collisions with extraterrestrial bodies have had major effects on the evolution of the earth. Some 4.4 billion years ago, for example, a Mars-size planetoid seems to have struck our young planet, throwing out enough debris to create our moon. And a large impact may have caused the extinction of the dinosaurs 65 million years ago. Even today cosmic impacts are evident. In July 1994 several astronomical observatories recorded the spectacular crash of a comet on Jupiter. And only last September, Peruvian villagers watched in awe and fright as a heavenly object streaked across the sky and landed not too far away with a loud boom, leaving a gaping pit 4.5 meters deep and 13 meters wide.

Using satellite observations of meteoric "flares" in the atmosphere ("shooting stars") and acoustical data that record cosmic impacts on the surface of the earth, Peter Brown and his co-workers at the University of Western Ontario and Los Alamos National Laboratory estimated the rate of smaller impacts. The researchers have also extrapolated their findings to larger but rarer incidents such as the Tunguska event. The average frequency of Tunguska-like asteroidal collisions ranges from one in 200 years to one in 1,000 years. Thus, it is not unlikely that a similar strike could occur during our lifetimes. Luckily, the Tunguska impact took place in an unpopulated corner of the globe. Should something like it explode above New York City, the entire metropolitan area would be razed. Understanding the Tunguska event could help us prepare for such an eventuality and maybe even take steps to avoid its occurrence altogether.

The first step in preparing ourselves would be to decide whether the cosmic object that affected Siberia was an asteroid or a comet. Although the consequences are roughly comparable in either case, an important difference is that objects in the solar system that circle far away from the sun on long-period orbits before returning, such as comets, would hit the earth at much greater velocities than close-orbiting (short-period) bodies, such as asteroids. A comet that is significantly smaller than an asteroid thus could release the same kinetic energy in such a collision. And observers have much more difficulty detecting long-period objects before they enter the inner solar system. In addition, the probability that such objects will cross the earth's orbit is low relative to the probability that asteroids will. For these reasons, confirmed comet impacts on the earth are so far unknown. Therefore, if the Tunguska event was in fact caused by a comet, it would be a unique occurrence rather than an important case study of a known class of phenomena. On the other hand, if an asteroid did explode in the Siberian skies that June morning, why has no one yet found fragments?

First Expedition

Part of the enduring mystery of the Tunguska event harks back to the stark physical isolation of central Siberia and the political turmoil that raged in Russia during the early 20th century, a time when the czarist empire fell and the Soviet Union emerged. These two factors delayed scientific field studies for nearly 20 years. Only in 1927 did an expedition led by Leonid Kulik, a meteorite specialist from the Russian Academy of Sciences, reach the Tunguska site. When Kulik got to the site, he was confronted with some

KEY CONCEPTS

- Exactly 100 years ago a comet or an asteroid exploded a few kilometers above the Tunguska region of central Siberia, leaving a huge zone of destruction.
- Despite many searches, no one has found any remnant of the impact body. Such evidence could help scientists gauge the danger posed today by medium-size comets or asteroids.
- A team of Italian scientists has found evidence of a possible impact crater about 10 kilometers from ground zero. They will soon return to recover what may be a fragment of the cosmic object.

—The Editors

[IMPACT ZONE]

The Tunguska Event

Many scientists believe that an asteroid or comet entered the earth's atmosphere over central Siberia (*map inset*) and exploded between five and 10 kilometers above the ground. The airburst flattened about 80 million trees over 2,000 square kilometers, which is about four times the area of Lake Tahoe. If the impactor was an asteroid, investigators estimate its diameter would have ranged from 50 to 80 meters. Searchers have so far found no remains of the object, which seems to have disintegrated.

FELLED FOREST

BLAST ZONE

GROUND ZERO

almost unbelievable scenery. Amazingly, the blast had flattened millions of trees in a broad, butterfly-shaped swath covering more than 2,000 square kilometers (775 square miles). Furthermore, the tree trunks had fallen in a radial pattern extending out for kilometers from a central area where "telegraph poles," a lone stand of partially burned tree stumps, still remained. Kulik interpreted this ravaged landscape as the aftermath of an impact of an iron meteorite. He then began to search for the resulting crater or meteorite fragments.

Kulik led three additional expeditions to the Tunguska region in the late 1920s and 1930s, and several others followed, but no one found clear-cut impact craters or pieces of whatever had hit the area. The dearth of evidence on-site gave rise to various explanatory hypotheses. In 1946, for instance, science-fiction writer Alexander Kazantsev explained the puzzling scene by positing a scenario in which an alien spacecraft had exploded in the atmosphere. Within a few years, the airburst theory gained scientific support and thereafter limited further speculation. Disintegration of a cosmic object in the atmosphere, between five and 10 kilometers above the surface, would explain most of the features investigators observed on the ground. Seismic observatory records, together with the dimensions of the devastation, allowed researchers to estimate the energy and altitude of the blast.

The lack of an impact crater also suggested that the object could not have been a sturdy iron meteorite but a more fragile object, such as a relatively rare, stony asteroid or a small comet. Russian scientists favored the latter hypothesis because a comet is composed of dust particles and ice, which would fail to produce an impact crater. Another explanation for the tumult in the Tunguska region claimed that the destruction resulted from the rapid combustion of methane gas released from the swampy ground into the air.

Laboratory Models

In 1975 Ari Ben-Menahem, a seismologist at the Weizmann Institute of Science in Rehovot, Israel, analyzed the seismic waves triggered by the Tunguska event and estimated that the energy released by the explosion was between 10 and 15 megatons in magnitude, the equivalent of 1,000 Hiroshima atomic bombs.

Astrophysicists have since created numerical simulations of the Tunguska event to try to decide among the competing hypotheses. The airburst of a stony asteroid is the leading interpretation. Models by Christopher F. Chyba, then at the NASA Ames Research Center, and his colleagues proposed in 1993 that the asteroid was a few tens of meters in diameter and that it exploded several kilometers above the ground. Comparison of the effects of nuclear test airbursts with the flattened pattern of the Tunguska forest seems to confirm this suggestion.

More recent simulations by N. A. Artemieva and V. V. Shuvalov, both at the Institute for Dynamics of Geospheres in Moscow, have envisioned an asteroid of similar size vaporizing five to 10 kilometers above Tunguska. In their model, the resulting fine debris and a downward-propagating gaseous jet then dispersed over wide areas in the atmosphere. These simulations do not, however, exclude the possibility that

MARY EVANS *Photo Researchers, Inc. (ground zero)*; AP PHOTO *(felled forest)*; KEVIN HAND *(map illustrations)* meter-size fragments may have survived the explosion and could have struck the ground not far from the blast.

Late last year Mark Boslough and his team at Sandia National Laboratories concluded that the Tunguska event may have been precipitated by a much smaller object than earlier estimates had suggested. Their supercomputer simulation showed that the mass of the falling cosmic body turned into an expanding jet of high-temperature gas traveling at supersonic speeds. The model also indicated that the impactor was first compressed by the increasing resistance of the earth's atmosphere. As the descending body penetrated deeper, air resistance probably caused it to explode in an airburst with a strong flow of heated gas that was carried downward by its tremendous momentum. Because the fireball would have transported additional energy toward the surface, what scientists had thought to be an explosion between 10 and 20 megatons was more likely only three to five megatons, according to Boslough. All this simulation work only strengthened (and continues to strengthen) our desire to conduct fieldwork at the Tunguska site.

Trip to Siberia

Our involvement with the Tunguska event began in 1991, when one of us (Longo) took part in the first Italian expedition to the site, during which he searched for microparticles from the explosion that might have become trapped in tree resin. Later, we stumbled on two obscure papers by Russian scientists, V. A. Koshelev and K. P. Florensky, that reported their discovery of a small body of water, Lake Cheko, roughly eight kilometers from the suspected epicenter of the phenomenon. In 1960 Koshelev speculated that Lake Cheko might be an impact crater, but Florensky rejected that idea. Florensky instead believed the lake was older than the Tunguska event, based on having found loose sediments as thick as seven meters below the bottom of the lake.

Word that a lake sat close to ground zero piqued our interest in mounting a field trip there because lake-bottom sediments can store a detailed record of events that occurred in the surrounding region, the basis of paleolimnological studies. Although our team knew little of Lake Cheko, we thought that we could perhaps apply paleolimnological techniques and find in the lake's sediments clues to unravel the Tunguska mystery, as if the lake were the black box from a crashed airliner.

A few years later we found ourselves journeying to Russia in the cargo hold of an Ilyushin Il 20M propeller plane, a onetime aerial spy from the cold war era. Having found the necessary funds and having organized our venture in cooperation with research groups at Moscow State University and Tomsk State University in Russia (with the assistance of former cosmonaut Georgi M. Grechko), we were finally on our way to the Tunguska region. After the transport carried most of our Italian team and its equipment to a military base near Moscow, we flew overnight to Krasnojarsk, in central Siberia. We then transferred our equipment and ourselves, plus several researchers from Tomsk State, into the belly of a

SKY VIEW OF TUNGUSKA

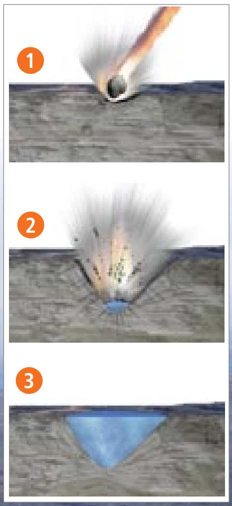
If you have access to Google Earth or Microsoft Virtual Earth on your computer, you can view Lake Cheko (*above*), which may have been formed by the Tunguska event, at these map coordinates: 60° 57′ 50.40″ North, 100° 51′ 36.01″ East.

Find the Tunguska impact zone at coordinates 60° 54′ 59.98″ North, 101° 56′ 59.98″ East.

GIUSEPPE LONGO (*Lake Cheko*); KEVIN HAND (*impact illustrations*)

[HYPOTHETICAL SCENARIO]

Was Lake Cheko Created by the Tunguska Event?



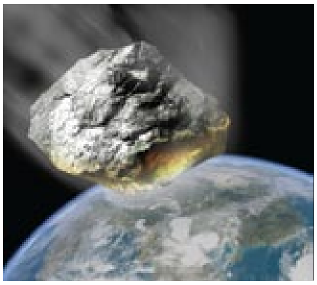
The authors speculate that debris from the posited Tunguska airburst hit the surface, forming Lake Cheko in the following series of events:

1. A meter-size fragment survived the explosion and streaked to the ground some eight kilometers from ground zero, close to the Kimchu River. The slight ellipticity of today's Lake Cheko and its location relative to the blast epicenter suggest that the fragment flew in at a 45-degree angle, hitting the land at a speed slower than one kilometer per second.

2. Energy generated by the fragment's impact melted the permafrost, and the subsequent release of gas and water enlarged the crater to the present size of Lake Cheko—about 350 by 500 meters.

3. Sediments laid down during the intervening years by the inflow of the Kimchu River formed a thin layer on the bottom of the lake.

TRACKING A DEATH STAR



Apophis is a 300-meter-long asteroid that scientists estimate to have a one-in-45,000 chance of hitting the earth in the year 2036. Although such an impact is unlikely, it could obliterate part of our planet, so the Planetary Society, a nonprofit space-advocacy group, wants to send a probe to observe the trajectory of Apophis. Such information should allow scientists to assess the threat it poses and, if needed, determine how best to alter its path. The society offered a $25,000 prize for the best design of a mission to track Apophis. SpaceWorks Engineering in Atlanta won the competition with a simple spacecraft concept dubbed Foresight, a $140-million probe that would orbit the asteroid and report back. The society hopes to find funds for Foresight.

huge Mi 26 heavy-lift helicopter (formerly used by the military). For six hours we squatted among our equipment, deafened by the chopper's twin turboshaft engines, until we finally reached our distant goal in the middle of the endless taiga.

After circling the lake's dark waters warily, the helicopter hovered precariously above the swampy lakeside (which was too soft for a landing) as we jumped down amid a torrential rainstorm. With eight blades rotating furiously above our heads, the resulting hurricane of air and water seemed set to sweep us away when at last we managed to unload our heavy cargo. With a roar, the craft lifted upward, and we were left drenched and exhausted near the edge of the lake, suddenly immersed in the deep silence of the Siberian wilderness. Any small relief we felt when the rain stopped was immediately forgotten as clouds of voracious mosquitoes descended on us like massed squadrons of tiny dive-bombers.

On-Site Studies

We spent the next two days organizing the camp, assembling our survey boat (a catamaran) and testing our equipment. Our studies would require a range of technologies, such as acoustic echo sounders, a magnetometer, subbottom acoustic profilers, a ground-penetrating radar, devices to recover sediment cores, an underwater television camera and a set of GPS receivers to enable study teams to track their position with a resolution of less than a meter.

For two weeks after that, our group surveyed the lake from the catamaran, tormented the entire time by hordes of mosquitoes and horseflies. These efforts focused on exploring the sedimentation and structure of the lake's subbottom. Other team members, in the meantime, busied themselves with their own tasks. With his ground-penetrating radar, Michele Pipan, a geophysicist at the University of Trieste, gradually mapped the subsurface structures (some three to four meters deep) below the 500-meter shore perimeter. Eugene Kolesnikov, a geochemist at Moscow State, and his colleagues excavated trenches in peat deposits near the lake, a tough job given the resistance of the hard permafrost layer below the surface. Kolesnikov's team searched the peat layers for chemical markers of the Tunguska event. At the same time, Romano Serra of Bologna University and Valery Nesvetailo of Tomsk State collected core samples from nearby tree trunks to study possible anomalies in the tree-ring patterns. Meanwhile, high above us, the aircraft that brought us to Krasnojarsk returned and circled the region to take aerial photographs so that we could compare them with those Kulik made some 60 years before.

We had assumed that the lake-bottom sediments might contain markers of the Tunguska event. After completing just a few runs across Lake Cheko with our high-resolution acoustic profiler, it became clear that the sediments blanketing the lake's bottom were more than 10 meters thick. Some sediment particles had been transported to the lake by winds, but most of them came by way of the inflow of the little Kimchu River that fed Lake Cheko. We estimated that sediment deposition in a small body of water that stays frozen for most of the year would probably not exceed a few centimeters a year, so such a thick sediment layer might imply that the lake existed before 1908.

On the other hand, the more we profiled the lake bottom, the more perplexed we became. It appeared that the lake, which is about 50 meters (165 feet) deep in the middle and has steep slopes, is shaped like a funnel or an inverted cone, a structure that is difficult to explain. If the lake were thousands of years old, it would probably have a flat bottom, the result of fine sediments gradually filling it up. We also found it hard to account for the funnel shape using typical erosion-deposition processes that occur when a small river meanders across a relatively flat landscape. Our entire team discussed these questions during the evenings as we sat under rain tarps, dining on delicious Russian kasha seasoned liberally with the bodies of dead mosquitoes.

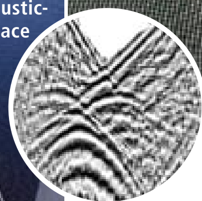
Soon our time in Tunguska was nearly over. The expedition members spent the last day frantically disassembling the boat, packing the equipment and dismantling the camp. When the helicopter arrived at noon the next day, we rushed to load all our stuff and ourselves into the hovering chopper amid the storm of human-made turbulence and finally began our return.

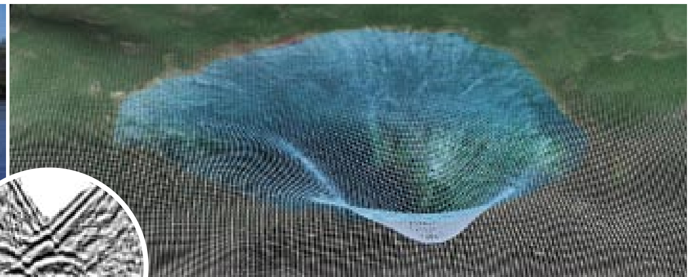
Titillating Evidence

Back in our laboratories in Italy, the three of us completed processing our bathymetric data, which confirmed that the shape of Lake Cheko's bottom differs significantly from those of other Siberian lakes, which typically feature flat bottoms. Most lakes in the region form when water fills the depressions left after the ubiquitous permafrost layer melts. The funnellike shape of Lake Cheko, in contrast, resembles those of known impact craters of similar size—for instance, the so-called Odessa crater, which was

KEVIN HAND

Lake Survey Turns Up Anomalies





After arriving at the Tunguska site, the authors surveyed Lake Cheko using acoustic-echo sounders that they installed on a catamaran (*photograph, left*). The data they obtained revealed that the profile of the lake bottom under its layer of sediment resembles the shape of an impact crater (*digital image, top*). The probe also located an acoustic-echo trace of a dense, meter-size object buried below the crater. The authors are returning this year to determine whether the object is a fragment of the body that exploded overhead in 1908.

created 25,000 years ago by the impact of a small asteroid in what is now Odessa, Tex.

The idea that Lake Cheko might fill an impact crater became more attractive to us. But if the lake is indeed a crater excavated by a fragment of the Tunguska cosmic body, it cannot have been formed earlier than 1908. We sought evidence that the little lake existed before the event. Reliable, pre-1908 maps of this uninhabited region of Siberia are not easy to come by, but we found a czarist military map from 1883 that fails to show the lake. Testimony by local Evenk natives also asserts that a lake was produced by the 1908 explosion. But if the lake was not formed before 1908, how can one explain the thickness of the deposits carpeting its floor? Our seismic-reflection data revealed two distinct zones in the lake's deposits: a thin, roughly meter-thick upper level of laminated, fine sediments typical of quiet deposition overlying a lower region of nonstratified, chaotic deposits.

A recent study by two Italian paleobotanists, Carla Alberta Accorsi of the University of Modena and Luisa Forlani of the University of Bologna, however, has shown that whereas the upper sediment layers contain abundant evidence of aquatic plants, these signs are totally absent in the lower chaotic deposits, which hold plentiful quantities of pollen from forest trees. So it looks as if the lake's true deposits are only about a meter thick, a feature that is compatible with a hypothesis that posits a young age for the lake. A forest seems to have grown on wet ground there before the lake formed.

Our survey team also observed the half-buried remains of tree trunks in the deeper part of the lake via underwater video. And high-frequency acoustic waves reflected back from the same zone showed a characteristic "hairy" pattern that could have resulted from the presence of the remains of trunks and branches. Perhaps these results are a trace of the forest obliterated by the impact.

Suspect Lake Shape

To explain the lower chaotic deposits, we can imagine a cosmic body hitting soggy ground overlying a layer of permafrost several tens of meters thick. The impactor's kinetic energy is transformed into heat, which melts the permafrost, releasing methane and water vapor and expanding the size of the resulting crater by as much as a quarter. At the same time, the impact would have plastered preexisting river and swamp deposits onto the flanks of the impact crater, where they would later be imaged as the chaotic deposits in our acoustic-echo profiles.

Most intriguing, a careful analysis of the seismic-reflection profiles we obtained across the lake has revealed several meters below the deepest point at the center a strong acoustic reflector, probably the echo of a dense, meter-size rocky object. This result is supported by the finding of a small magnetic anomaly above the same spot during our magnetometer survey. Are these indications of a fragment of the Tunguska body?

We are anxious to find out. Our team is now preparing to return later this year to attempt to drill the center of the lake to reach the dense seismic reflector. The year 2008 is the centennial of the Tunguska event. We hope it will also be the year the Tunguska mystery is solved. ■

➡ MORE TO EXPLORE

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GIUSEPPE LONGO (*boat with equipment*); SOURCE: "A POSSIBLE IMPACT CRATER FOR THE 1908 TUNGUSKA EVENT," BY L. GASPERINI ET AL., IN *TERRA NOVA*, AUGUST 2007 (*acoustic-echo trace*); KEVIN HAND (*wire frame illustration*)