PRISMA Day 2022, Torino 25-26 Nov 2022

Computation of a possible Tunguska's strewn field

Albino Carbognani, Mario Di Martino, Giovanna Stirpe

INAF – Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Italy

INAF – Osservatorio di Astrofisica di Pino Torinese, Torino, Italy

Tunguska event

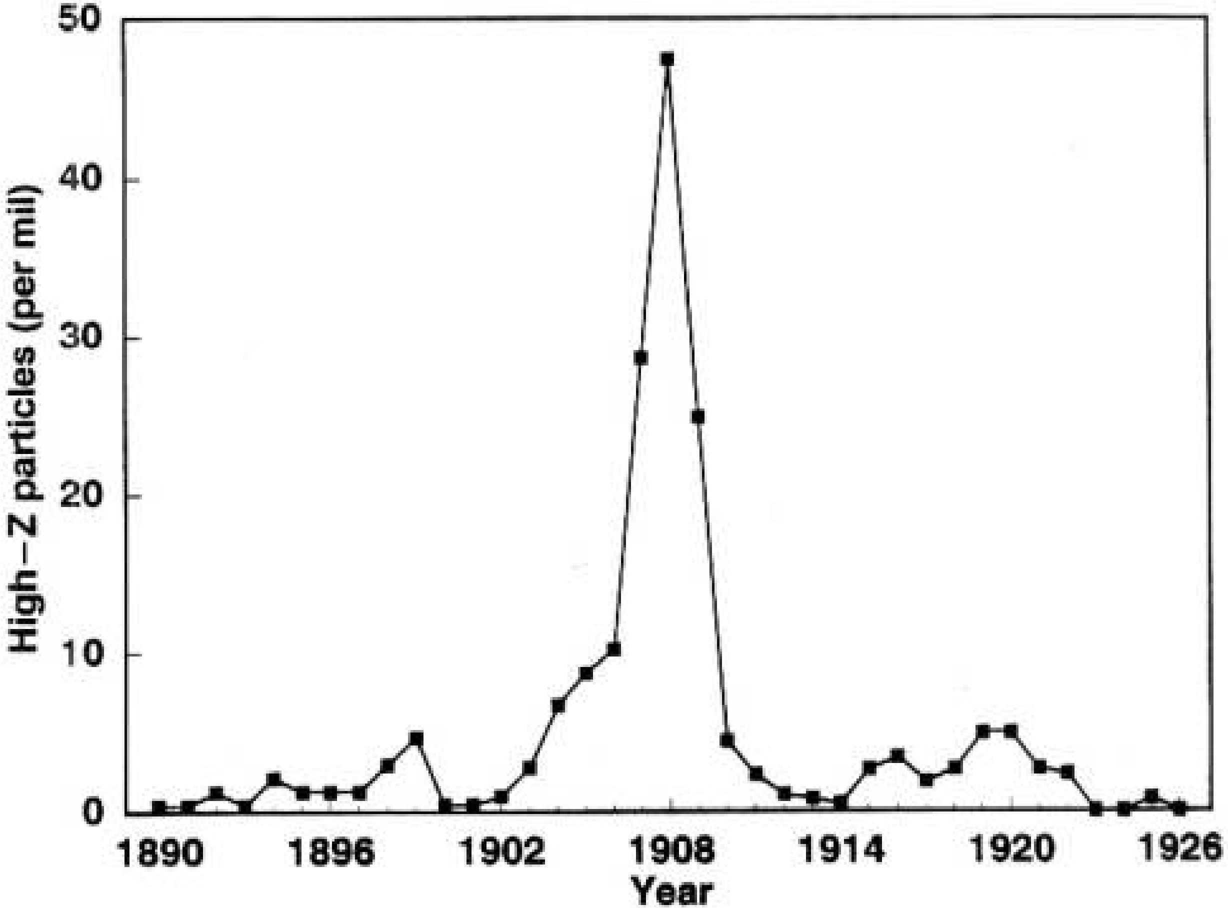
On **Jun 30, 1908** at 07:14:28 local time (**00:14:28 UT**), a small cosmic body of 50-60 meters in diameter **exploded into the atmosphere about 8.5 km above the ground**. In the explosion an energy around **15 Mt** was developed which, in the form of a thermal wave and shock wave, **destroyed an area of 2150 km^2 of Siberian taiga**.

The first on-site scientific expedition was conducted in **1927** only - 19 years after the event - and is due to the Russian geologist **Leonid Kulik**.

Despite the careful research conducted over the years by several expeditions around the catastrophe epicenter, **no macroscopic meteorite has ever been found** despite the fierce excavation research conducted by Kulik in the epicenter area.


tunguska.ru
Arctic Ocean
RUSSIA
SIBERIA
Tunguska Event
30.06.1908
KAZAKHSTAN
MONGOLIA
CHINA
JAPAN
IRAN
Moscow
Stockholm
Helsinki
Oslo
Krasnoyarsk
Novosibirsk
Astana
Ulaanbaatar
Beijing
Seoul
Tokyo
Sea of Okhotsk
Bering Sea

Microrenmants of the The TCB (Tunguska91)



Longo et al., Planetary and Space Science 42, n.2, p. 163-177; 1994

A new method is here used to obtain experimental data on the nature and composition of the TCB.

The leading hypothesis of the method is that in the **forest conifers** which have survived the Tunguska catastrophe, the **fluid resin** present at the moment of the event could have **acted as a trap** for airborne particles, as happens in amber.

The growth rings of trees can give information on the age of the resin and therefore on the time when the particulate was trapped in them.

The time distributions of the particles in the years 1885-1930 show clear **abundance peaks centered on 1908**. This makes it possible to conclude that the presence of **Fe, Ca, Al, Si, Au, Cu, S, Zn, Cr, Ba, Ti, Ni, C and O** in the particles observed is **related to the Tunguska event** and that these elements are probable **constituents of the TCB**.

John’s Stone

Size: 2.0 m x 1.5 m x 1.0 m; Mass: 10.000 kg; composed of sedimentary metamorphic quartz-rich conglomerate gravelite sandstone with grain size of 0.5–1.5 cm, rarely up to 5 cm. The rock consists 98.5% of SiO_2.

An exotic meter-size **quartzitic boulder** known as **John’s Stone** was found by **John Anfinogenov in 1972** buried in permafrost close to the epicenter of the 1908 Tunguska event.

That the boulder might be a **glacial erratic** is unlikely, one reason being that no major source areas for quartziferous rocks are known in the region. Disturbances in the permafrost suggest the **boulder impacted the ground from above**.

Quartz is exceedingly rare in meteorites, and an extraterrestrial quartzite is unheard of; however, quartz and silica-rich rocks appear to be present on Mars.

Triple oxygen isotope ratios determined on two samples of the quartzite reveal a **terrestrial rather than a meteorites composition** (Bonatti et al., Icarus, 2015).

Meteorites or non-Meteorites?

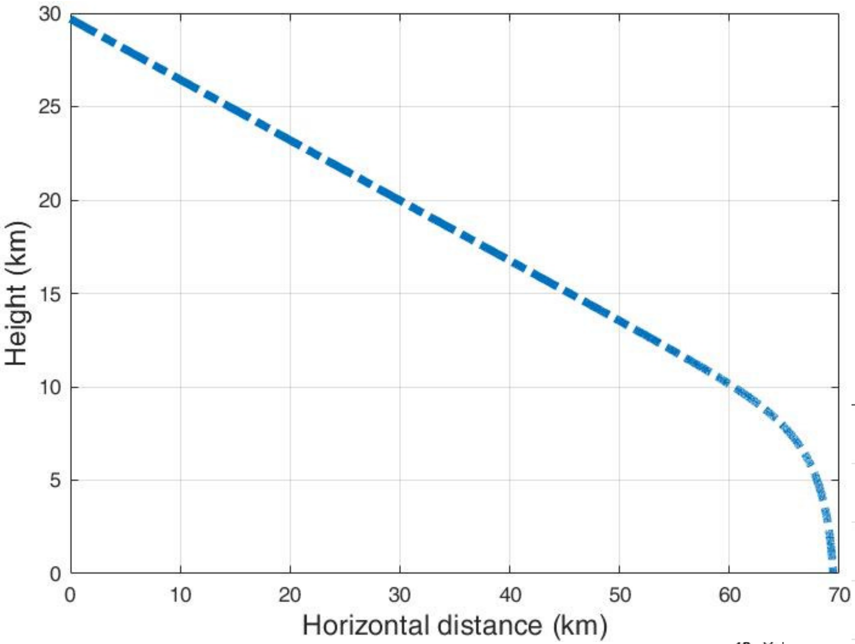
1. The **absence of macroscopic meteorites** is **not a proof of the** complete disintegration **of the TCB**: the **time elapsed** from the fall to the first Kulik expedition was 19 years, enough time for any little craters and meteorites to be buried by **mud and vegetation**.
2. In the scientific literature a reference regarding the **existence of possible macroscopic fragments** from the TE is in **Artemieva and Shuvalov** (2007, 2016), which mentions this possibility for cm-m sized fragments after simulating the TE using a **hydrodynamic model with a strengthless falling body**.
3. Other authors point out that the **dynamic strength** of decimetric rock objects entering the atmosphere is of the order of **1 MPa**, therefore **the arrival of large rocks on the ground in an energetic event such as that of Tunguska is very unlikely because they would completely disintegrate during the airburst** (Collins et al., 2008).
4. **Eyewitnesses** observed a stone that **appeared "from nowhere" in the destroyed forest**, far from any rock outcroppings after the catastrophe. A Tungus (Evenkis) named Daunov saw a **large shiny stone of tin color**. Vitaliy Voronov reported about a **gray stone with sharp edges** that was removed from a tree trunk after the catastrophe of 1908. Nastya Dzhonkoul told about seeing a rock falling from the sky: "**A large stone, as large as a deerskin tent, bounced off the ground twice or thrice and then swamped in the bog**" (Suslov, 1967; Vasiliev et al., 1981; Anfinogenov et al., Icarus 243, 2014).

Chelyabinsk Event

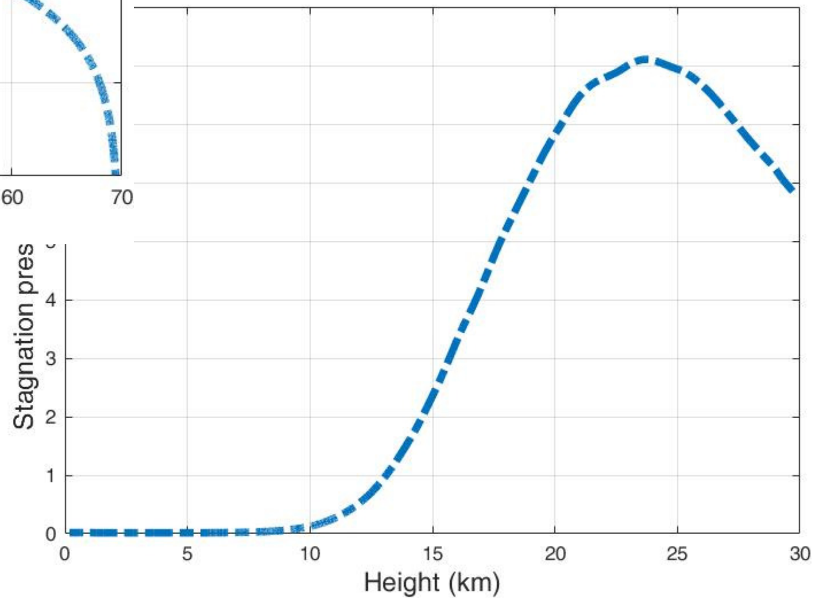
On **Feb 15, 2013 at 03:20:20.8 UT** a small asteroid with an estimated **diameter of about 20 m** begins the entry in the atmosphere toward the Russian city of Chelyabinsk (Lat. 55°03’ N , Long. 61°08’ E), located just East of the Ural mountains.

About **11 s** after entering into the atmosphere, at about **29.7 km** altitude and **40 km South of Chelyabinsk**, the pressure of the atmospheric shock wave becomes very strong and the asteroid explodes (main airburst), fragmenting into several pieces.

The Fragment F1



Single body model
V start=19.2 km/s
h start = 29.7 km
D = 0.73 m
Γ = 0.6



After the main airburst around 29.7 km, about **20 fragments emerged from the disruption clouds**.

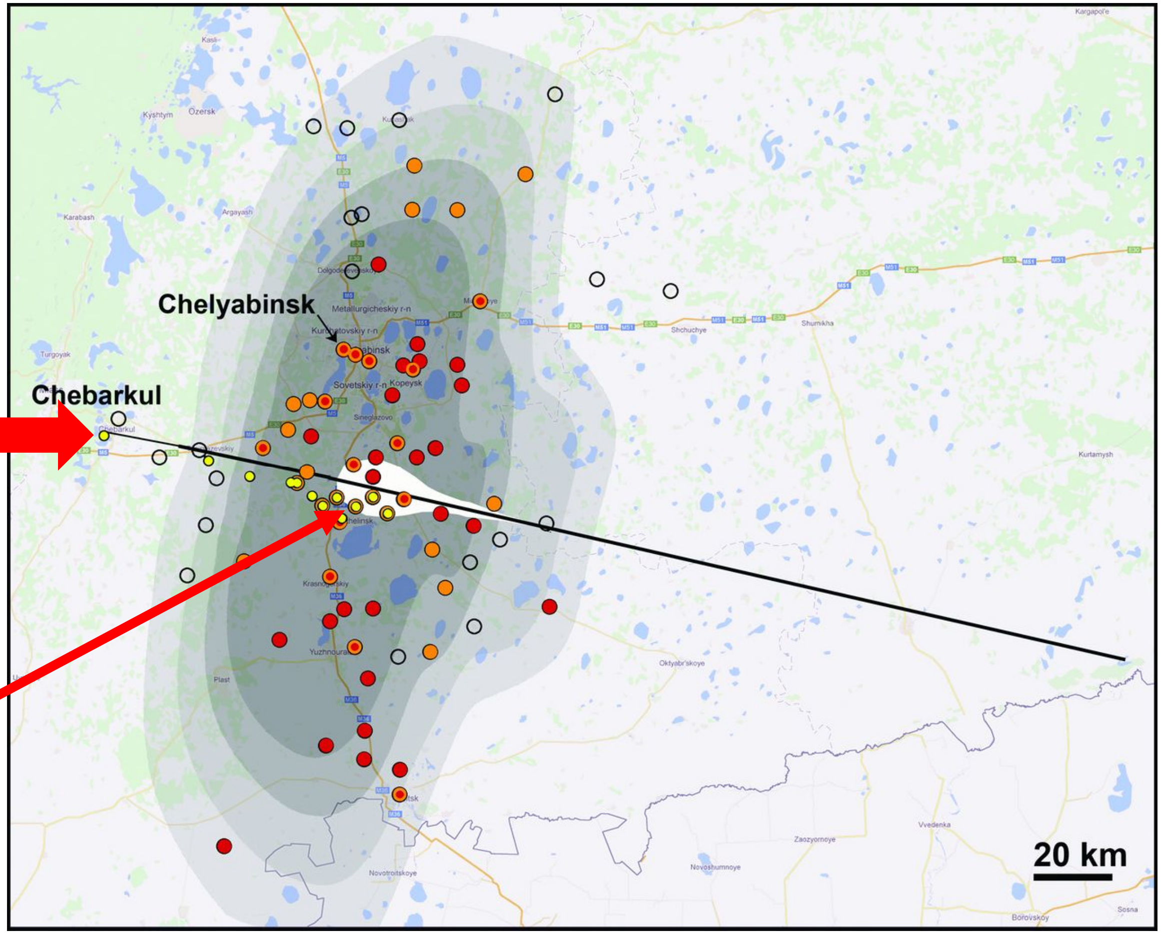
The main boulder was destroyed at an altitude of 22 km, while another fragment - **F1** in the scientific literature - survived the fall in the densest layers of the atmosphere, survived a maximal **dynamic pressure of about 15 MPa** at an altitude of about 20 km, and began the **dark flight phase** at about 12.6 km height with a speed of 3.2 km/s.

The atmospheric path ended on the frozen surface of the **Lake Chebarkul**.

F1 (650 kg)

$$S = \bar{k}\Gamma(1+\alpha)\rho_{fr}V^2$$

Strength ≈ 1 MPa



$$\frac{dV}{dt} \propto -\frac{V^2}{M/A} + g\sin(\theta)$$

Smaller the meteoroid and greater the negative acceleration will be. This caused smaller fragments to fall much earlier than the fragment F1.

Weibull's Law

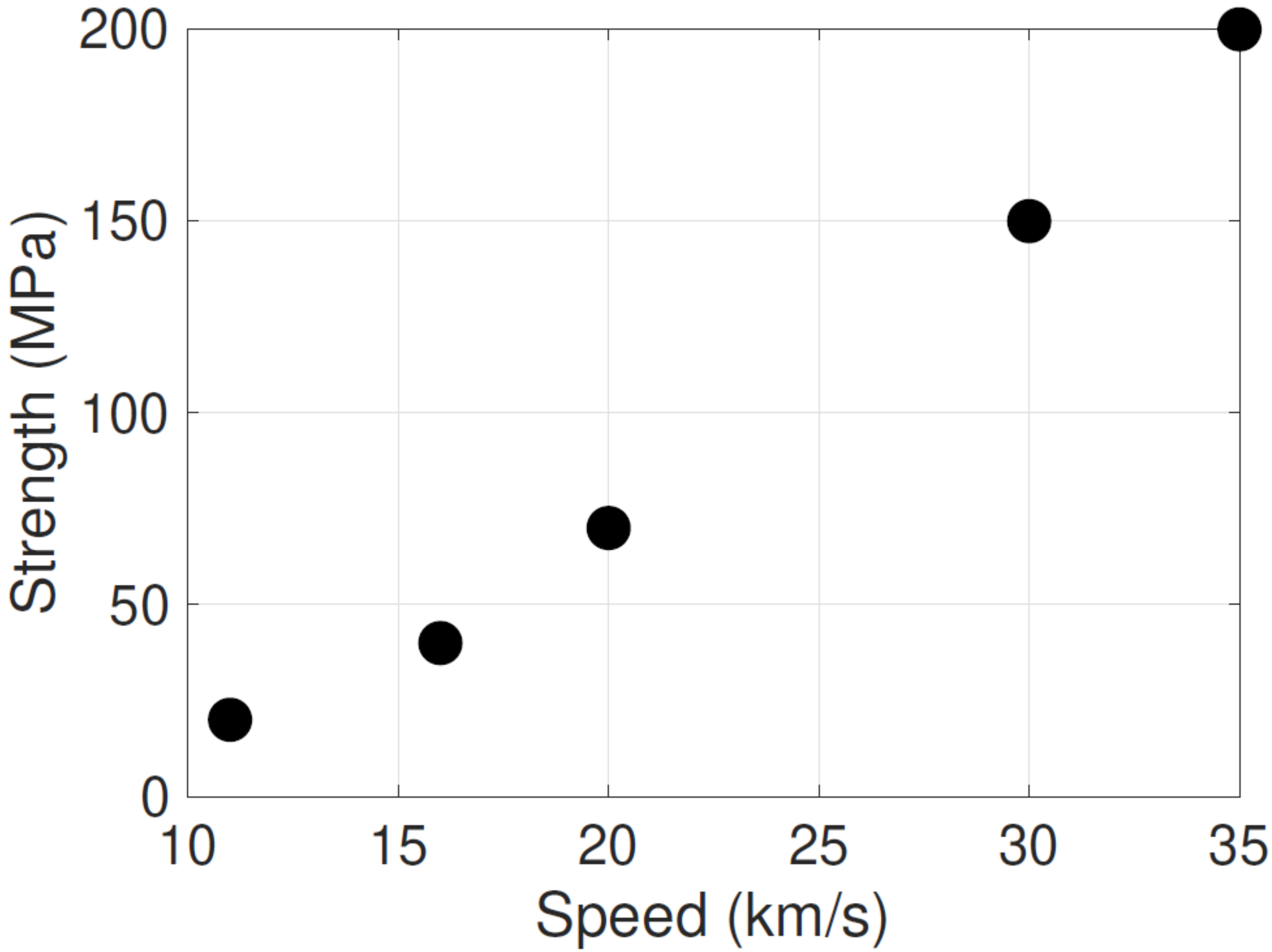
The **strength of the original body** is the **lower limit of the strength of the blocks** into which it can separate as it crosses the atmosphere. If the mechanical destruction of a body occurs along the **fracture lines**, then it is reasonable to expect that the **strength depends on the volume or mass** and that the following **scale relation** holds (Weibull, 1951; Svetsov et al., 1995):

$$S_{main} = S_{fr} \left(\frac{m_{fr}}{m_{main}} \right)^{\alpha}$$

The α **value increases as the inhomogeneity of the material increases** and a value between **0.1 and 0.5** is expected.

In the case of Chelyabinsk, the value can be directly estimated from the **mechanical strength** and **mass values** measured on **meteorites**. Mechanical properties of the Chelyabinsk meteorite were determined at NASA Ames and compression strength is determined to be 330 MPa (C3: 4.46 g), 327 MPa (C4: 4.84 g) and 408 MPa (C5: 1.58 g), similar to other ordinary chondrites. **With these data we found $\alpha \approx$ 0.2**.

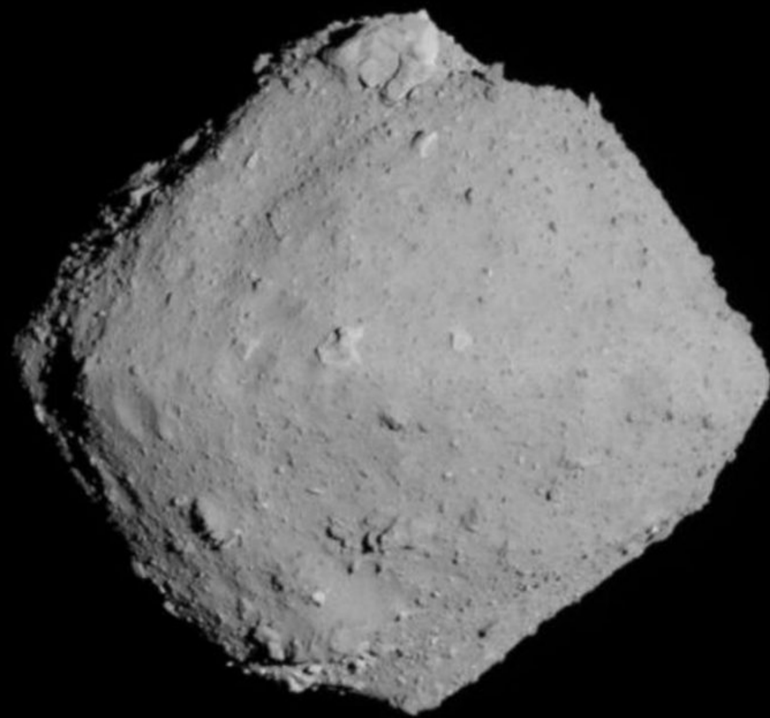
Tunguska's Strength



Despite the falling velocity into the atmosphere remains the most difficult parameter to estimate, for reasonable values in the range 11-35 km/s we can estimate that the mechanical strength of TCB was superior to that of Chelyabinsk and in the **range 20 – 200 MPa**.

With $\alpha \approx$ **0.2**, **$m_{main} \approx$ 4x 10^8 kg** and **$S_{main} \geq$ 20 MPa**, we found **$S_{fr} \geq$ 200 MPa** for a fragment with a diameter of about **1 m**, and **$S_{fr} \geq$ 100 MPa** for a fragment of about **4 m**, i.e. the macroscopic fragments small enough to escape the shock wave appear potentially able to resist the airburst phase.

Bennu & Ryugu



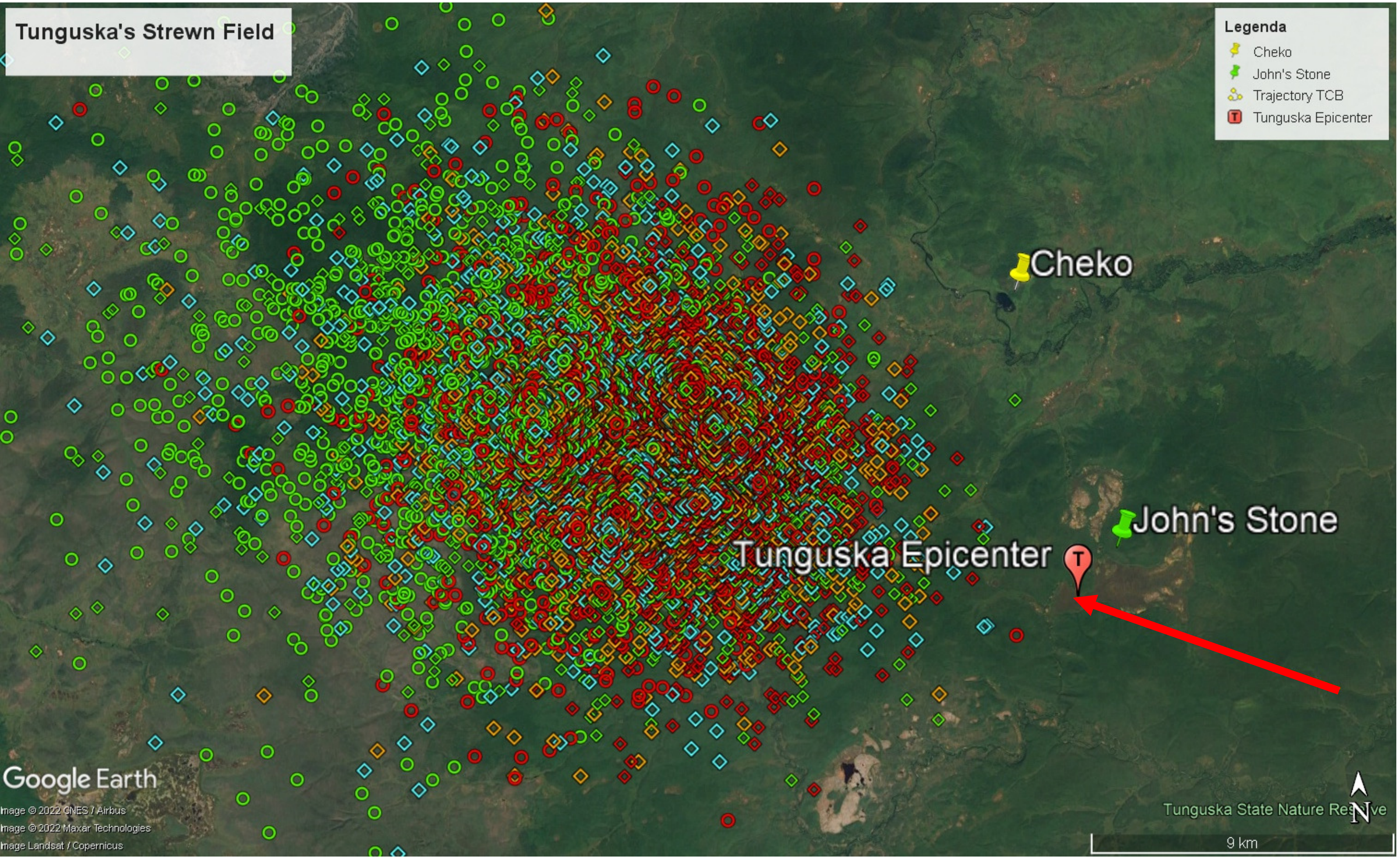
The measurements of thermal inertia conducted by the OSIRS-REX mission on the Bennu boulders have shown that there are two rock types: **low and high tensile strength, with a factor about 8 between the two categories** (from 0.1 MPa to 0.8 MPa), see Rozitis et al. (2020). **This shows how variable the strength of a monolithic boulder on asteroid surface can be**.

Carancas

The fall of Carancas, which took place in Peru on **September 15, 2007**, is emblematic: in this case there was no fragmentation and the rocky meteoroid arrived intact on the ground, generating a crater 13 m in diameter near **Lake Titicaca**.

The estimated starting speed for this monolithic body, with dimension in the range 0.9-1.7 m, is under 23 km/s and the dynamic **strength ranges from 20 to 40 MPa**, values much **higher than 0.4-12 MPa valid for small meteoroids**.

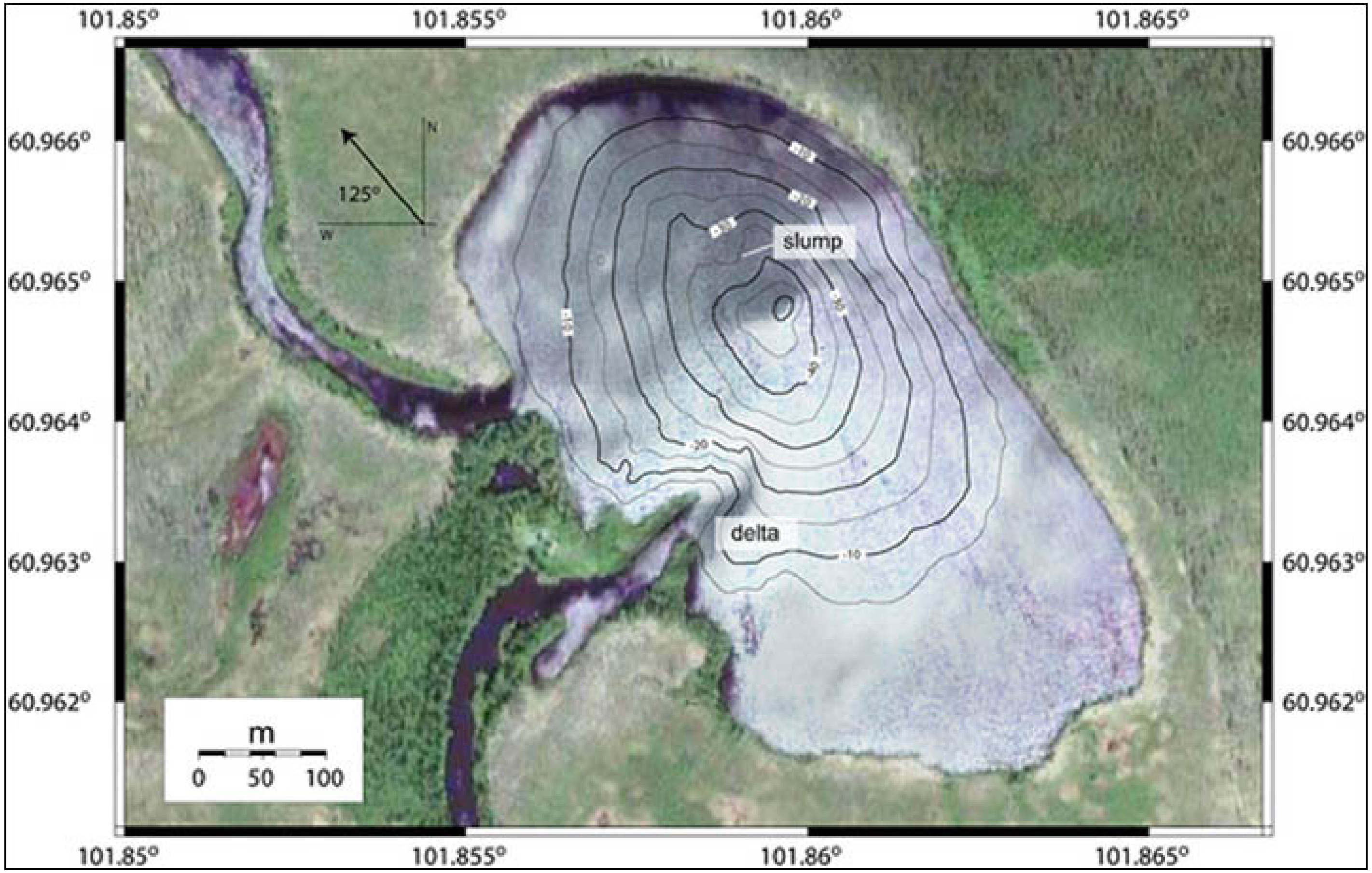
Tunguska's Strewn Field (?)



Quantity	Best Value
Entry elevation angle (°)	15 ± 5
Entry azimuth[a] (°)	110 ± 10
RA apparent radiant (°)	89 ± 10
DEC apparent radiant (°)	4 ± 6
Time of explosion (UT)	0h 14m 28s
Height of explosion (km)	8.5 ± 2
Energy of explosion (Mt)	~ 15
Epicenter Latitude (°)	60.886 ± 0.02 N
Epicenter Longitude (°)	101.894 ± 0.02 E
Speed range (km/s)	$15 - 21(18 \pm 3)$

[a] Clockwise from North

Lake Cheko



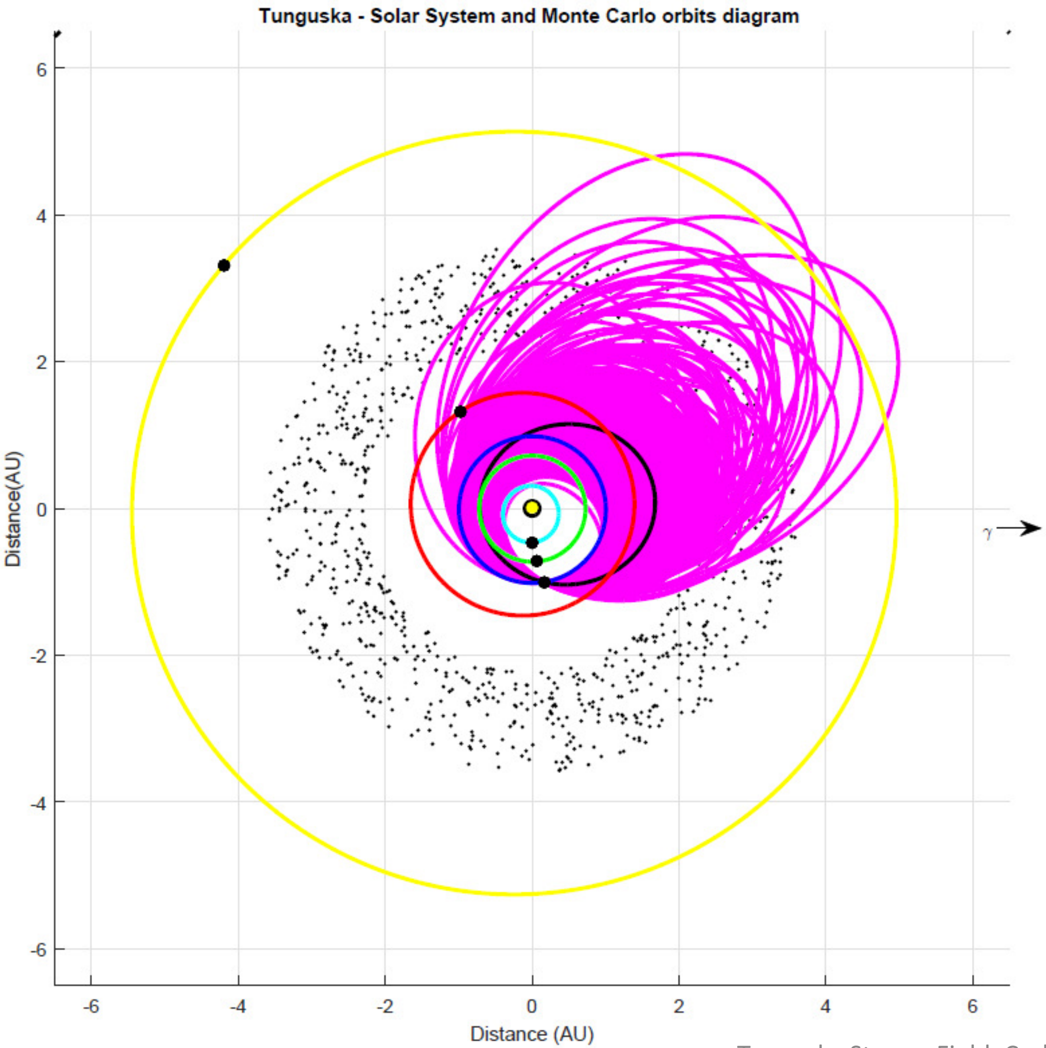
These results about a possible strewn field give us the opportunity to make some comments about the Cheko lake, a small lake elliptical in shape with axes equal to **500 x 350 m** elongated in NW-SE direction, located about **9 km** in a direction with azimuth of 348° from the epicenter.

Cheko lake is considered by some authors as a **possible impact crater** (Gasperini et al., 2007, 2008, 2009, 2014).

Making computations of the strewn field by varying the trajectory's azimuth we find that the **lake could be an impact crater** if the azimuth of the trajectory traveled by the TCB were between **160 and 170 degrees**.

However, **these values are distant from the most common azimuth** value adopted here (**110° ± 10°**).

Tunguska's Origin



Taking into account the possible parameters of the ground trajectory we explored different speed ranges: 16 ± 5, 20 ± 5, 30 ± 5 and 35 ± 5 km/s to compute the **possible heliocentric orbits**. For higher speeds the TCB no longer belongs to the solar system, because the heliocentric speed is higher than escape velocity from the Sun at the Earth's distance.

The result tell us that about 70% of the orbits are of asteroidal origin, while the remaining 30% are of cometary origin.

Thanks for the attention

Albino Carbognani, Mario Di Martino, Giovanna Stirpe