GEOMORPHOLOGICAL FEATURES POTENTIALLY ASSOCIATED WITH THE 1908 TUNGUSKA CATASTROPHE

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Introduction: Eyewitnesses who personally visited the region of the 1908 Tunguska catastrophe soon after the event reported the presence of the following *de novo* geomorphological features in the impact area (without specifying their precise location): (i) fountain-like ejecta of boggy deposits associated with the fall of the Tunguska cosmic body (TCB); (ii) flowing of water well from under the ground for several days after the event; (iii) funnel-like hole in the ground at the end of the *de novo* dry groove conventionally named "dry river"; (iv) ground disturbance in the form of a groove with rocks in the walls; and (v) one or several boulders of unusual color and texture that appeared "out of thin air" in the forest after the event.

Aim: The aim of the study was to find these geomorphological features associated with the 1908 Tunguska catastrophe.

Methods: The methods comprised decoding of the aerial survey photographs taken in 1938 and 1949 and the field studies performed from 1965 to 2015. Aerial photography scales were 1 *cm* to 50 *m* (1:5,000) for the 1938 survey and 1 *cm* to 500 *m* (1:50,000) for the 1949 survey. Decoding consisted in viewing the stereoscopic pairs of aerial photographs with aim to identify fresh geomorphological formations. Field studies were done within the areas of interest identified based on the analysis of the first eyewitness' reports and decoding of aerial survey photographs.

Results: Based on the aerial photography analysis, the following fresh geomorphological formations were identified as potentially associated with the 1908 Tunguska catastrophe: Lake Cheko (1) fed by the river Kimchu and Peyunga Lake (2) fed by the river Verkhnyaya Lakura. These lakes had slightly eroded fresh signs of the massive disturbances in their floors with a total area of 25,000 m^2. Two massive rock slides were found on the south-east brow of the Lakura ridge (3) and on the left bank of the river Chamba just downstream of the Iceland spar mine Khrustalniy (4); a total area of these rock slides exceeded 10,000 m^2. Large impact holes (5) were identified in the South Bog initially carpeted with continuous peat-forming vegetation. The location of these holes corresponded to the "epicenter 1" estimated by the first explorer of the 1908 Tunguska event, Leonid Kulik, based on the analysis of directions of the fallen trees within the continuous forest fall area surrounding the South Bog. Diameter of the largest impact hole in the South Bog was 45 *m*; a total size of the group of other holes was about 50 *m*. Studies showed the presence of the ground disturbances (6) in the form of dolines north of the Lakura ridge near the valleys of the river Khushma and of the creek Chavidokon. Dried up intermountain lake (7) with a hole in its east part was found east of the Lakura ridge near the valley of the upstream portion of the river Makikta. The aerial photographs revealed the lake (8) at the bottom of the basin on the right bank terrace of the river Chamba downstream of the massive rock-slide (4). Field studies in the epicenter area of the TCB explosion showed the presence of over 30 funnel-like structures (9) of 1.0 to 2.5 *m* in diameter with typical raised rims; these funnels were located 2 to 4 *km* west of the epicenter estimated by Wilhelm Fast based on the forest fall analysis. The exotic boulder (John's Stone) (10) was discovered at the top of the Stoykovich Mountain in the epicenter of the Tunguska catastrophe [1]: the boulder had fresh signs of high energy impact and was associated with the groove- and pipe-like disruptions of the permafrost. The walls of these groove- and pipe-like impact structures contained splinters of this boulder consistent with the reports of eyewitnesses.

Discussion and Conclusions: The fall of the TCB fragments caused the formation of impact structures such as the funnels, grooves, and the pipe-like disturbances in the ground (9, 10); the fall also produced powerful surface seismic waves triggering massive rock-slides (3, 4) and disturbances in surface and subsurface hydrogeological structures (1, 2, 5, 7, 8) over the area of the Tunguska catastrophe. The groove- and pipe-like disturbances (10) in the ground, associated with the exotic boulder called John's Stone, represented the impact structures with morphology distinct from that of classical impact craters. Similar pipe-like impact morphology was described for several large fragments of the 1947 Sikhote-Alin iron meteorite [2] fallen in the waterlogged deposits. In the epicenter area of the 1908 Tunguska catastrophe, other pipe-like impact structures containing large boulder-sized meteorite rocks may be present.

References: [1] Anfinogenov J. et al. 2014. *Icarus* 243:139–147. [2] Krinov E. L. and Fonton S. S. 1959. In: The Sikhote-Alin iron meteorite shower. Part I. Ed.: V. G. Fesenkov and E. L. Krinov. Moscow. Publishing House of the USSR Academy of Sciences. Pp 157–303.