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SIMULATION OF THE TUNGUSSKA METEORITE EXPLOSION

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SUMMARY

By simulation of the Tungusska meteorite explosion it was ascertained that the forest fall may be explained by an axial explosion wave (ballistic wave); at the same time, the projection of the axis is clearly defined by the shape of fall's field, that is, the heap. The explosion's linear energy increase (ballistic wave) in the latter part of the trajectory is comparatively small. It corresponds to area increase of moving body's cross section only by several times. It is natural to interpret this as its fragmentation.

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* *

As a result of cumbersome expeditionary operations between 1958 and 1965, a map of the area of fallen forest in the region of the Tungusska meteorite fall was drawn and the contour of the dislocation region and the direction of fallen trees at various points was established [1 — 3]. By way of field investigations there were measured over an area of 2200 km^2 the azimuths of nearly 40 000 trunks having fallen on 30 June 1908. The compilation of the presently available results is represented in Fig. 1, where each arrow represents the average of 10 — 150 azimuth measurements. The character of the Tungusska fall leaves no doubt that it was the result of action by a powerful aerial wave with energy of the order of $4 \cdot 10^{23}$ erg [4 — 7], of which the seat was situated at a certain height above ground.

The field of directions (Fig. 1) evidently characterizes the motion of the shock wave front near the ground. Contrary to what can be expected at a point aerial explosion, the eccentric position of the epicenter and the presence of wings-lobes, in which a deflection of several degrees from centrality is noticeable, is characteristic for it. These peculiarities

* MODELIROVANIYE VZRYVA TUNGUSSKOGO METEORITA.

may be explained by assuming that the shock wave is a ballistic wave by its very origin, induced by supersonic motion of a meteoric body in the atmosphere, and still reinforced at the end as a result of its disintegration or stormy fragmentation [4, 8, 9].

In model experiments the ballistic wave was produced by explosion of a blasting fuse having a linear explosion energy (per unit of length) $e_l = 6.3 \cdot 10^9$ erg/cm and a denotation velocity of $7 - 8$ km/sec. The linear

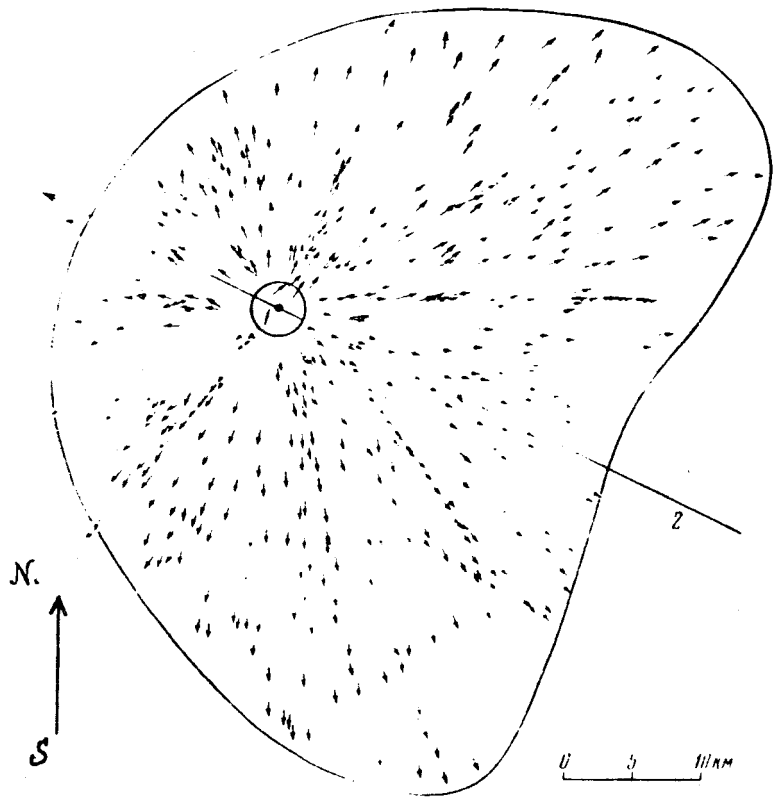

Fig. 1. - Field of the directions of forest dumping. 1 — epicenter by on-the-spot determination and the zone of standing forest; 2 — trajectory projection according to astronomical data.

energy of fuse explosion was increased at the end several times by an additional charge of explosive matter. The cord was disposed in inclined manner and ended at certain height **h** above the model of the forest. The trees were simulated by flexible nonelastic wires of 3 cm height; they were provided with a cylindrical "crown" made of plastic (Fig. 2). The wires bended under the effect of the wave, thereby marking the field of directions, orthogonal to wave front.

The closest resemblance of the simulated fall field with that of Tungusska was attained at inclination $\alpha = 30^{\circ}$ to the horizon (Fig. 3), at height of the end $h = 24$ cm and increase of e_l at the end by four times.

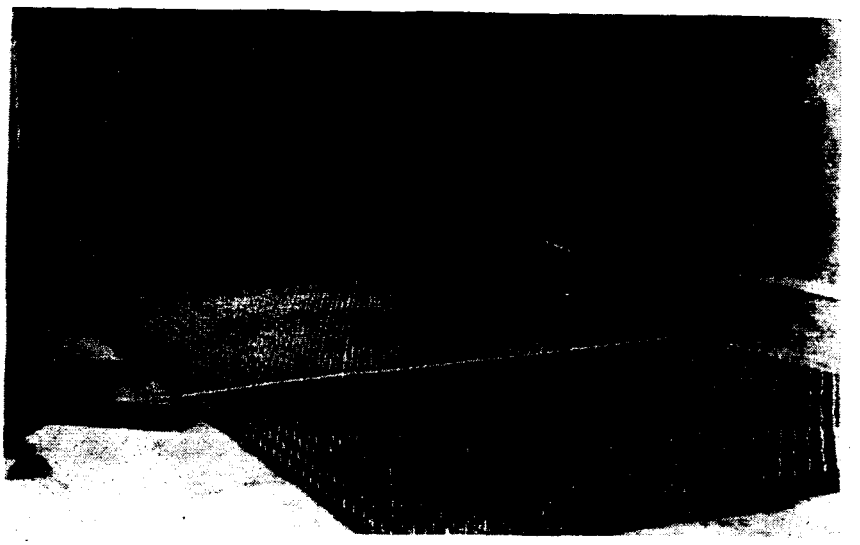

Fig. 2. - Disposition of the cord and of the field prior to explosion; the denotation takes place downward. The distance between the series of model trees is 5 cm.

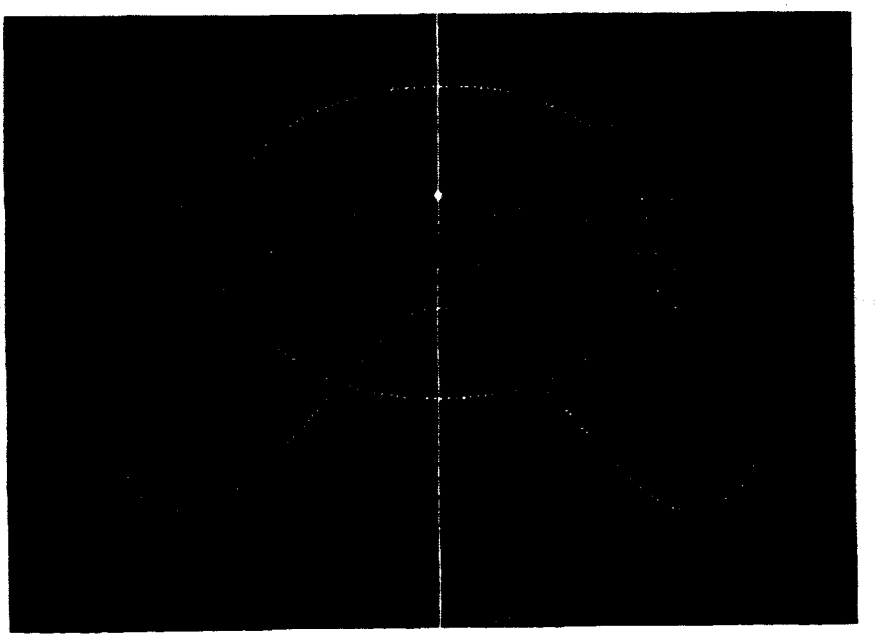

Fig. 3. - Plane photo of the fall field at 30° inclination and a fourfold increase at the end. The boundaries indicated are those of the concentrated and axial explosions made separately.

The explosions of the concentrated final charge and of the uniform fuse, made separately, show that this pattern is generally formed by simple superimposition of the respective fields. The point charge gives a circular central field of the heap with an epicentral zone where the heap is absent. The elongated terminal blasting charge (1 : 10) also forms a practically central field, but only slightly elongated perpendicularly to the length. The heap from the axial explosion has a shape of characteristic wings sidewise from the trajectory projection and is not central. Its shape is sufficiently steady when inclinations vary. Sharp distinctions (from that conveyed in Fig. 3) take place only at $\alpha \leqslant 10^{\circ}$ and $\alpha \geqslant 60^{\circ}$. This heap forms the rear part of the field.

The consideration of experimental fields allows us to conclude that the isochrones of the wave front on model plane are satisfactorily represented by cross sections of a cone, widening from the explosion axis and closed from beneath by a hemisphere (Fig. 2).

In the part of the field where the ballistic wave is acting (Fig. 4) the current lines are orthogonal trajectories to a family of elliptical isochrones, which precisely explains the noncentrality of that part of the field. In its forward part the current lines degenerate into straight lines emerging from the epicenter.

The pattern indicated is somewhat disrupted near the epicenter, which is expressed in its blurring backward along the trajectory projection. This is caused by the character of diffraction at the end of the cord, and also by the fact that the real wave has, contrary to the cone, a certain convexity of generatrices, for its velocity decreases at the outset and approaches the speed of sound only at a certain distance from the source.

The mechanism of lobe (wing) formation is explained by the following. In the model plane the incident and reflected waves act on the vertical tiny rods, whereas in the region of irregular reflection, the leading wave, having formed as a result of their interaction, is acting. As is well known, when the shock wave acts upon "thin" objects (trees, rods) the principal blowing factor is the kinetic head $q = \rho u^2$ behind the wave front [10]. At present there are experimental determinations of the value of the horizontal component of the kinetic head at above-ground explosions [10] as functions of

the excess pressure of the incident wave, p, and of the incidence angle θ. The function

$$q = q(p, \theta)$$

is characterized by a sharp maximum at $\theta \approx 45 - 55^{\circ}$, that is, with the beginning of irregular reflection.

Shown in Fig. 4 are the isolines of the angle θ, formed by the front of the incident conical wave with the model plane. The lines of equal excess pressures p obviously coincide with the front's isochrones. Utilizing the curvilinear coordinates p and θ, it is possible to construct the isolines of the horizontal kinetic head on the model plane (Fig. 4). Their system corresponds to the experimentally observed heap contour. In the experiment its boundary passes at about $q \approx 0.35$ kg/cm^2.

The preferential propagation of the ballistic wave toward the sides of trajectory projections was also suspected earlier when considering the acoustical phenomena induced by low-flying bolide [11]. But in the experiment the axial symmetry of the corresponding field is exposed in the sharpest manner. It is interesting that the azimuth of the trajectory projection of the Tungusska meteorite, defined as the axis of symmetry of Fig. 1 and equal to 295°, coincides with a precision to a degree with the recently determined meteorite radiants by astronomical methods [9].

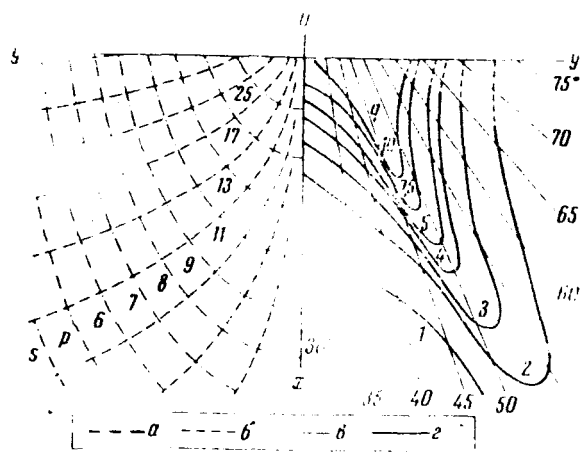

Fig. 4. Scheme of the heap's field for $\alpha = 30^{\circ}$, xO - projection of the cord, O - end of the cord; yy — geometrical boundary of the conical w. a — isochrones of the front; б — current lines; в - lines of equal θ; г — isolines q.

The pattern of ballistic wave upon the surface, represented in Fig. 4, admits such a transformation with the change of explosion energy. The formula

$$p = f\left(\frac{\sqrt{e_l}}{r}\right),$$

where r is the distance to the axis, stands for both the cylindrical explosion and the ballistic wave. This is why for natural values of q and α the linear dimensions of x and y increase by the number of times $\sqrt{e_l}$ increases. In case of variation of α a similar transformation is possible in the coordinates p and θ.

Therefore, the forest heap at the place of Tungusska meteorite fall may be explained by an axial explosion wave (ballistic wave); at the same time, the axis' projection is clearly defined by the shape of the fall field. The explosion's linear energy increase (of the ballistic wave) in the terminal part of the trajectory is comparatively small. It corresponds to area increase of moving body's cross section only be a few times, w ich can naturally be interpreted as its fragmentation.

**** THE END ****

Committee on Meteors of the
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&
Institute of Physics of the Earth
in the name of O.Yu.Schmidt

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