LETTERS TO THE EDITOR

GEOPHYSICS

Axis Changes in the Earth from Large Meteorite Collisions

GALLANT[1] has evaluated axis change in the Earth caused by collisions of large meteorites. The displacements he estimates, however, are larger than those I published ten years ago[2] and more recently with slight modification[3]. He calculates that a Juno-sized meteorite (about 190 km diam.) colliding at 20 km/sec would cause an axis displacement of 0° 45 . However, by using the correct criterion of interaction of the Earth's angular momentum with the moment of momentum of the colliding body, the actual displacement would be only about 0° 02′. In fact, a bigger body, say 320 km in diameter, colliding at a maximum possible velocity of 72 km/sec would produce only 0° 32′ axis shift despite an energy 75 times the Juno example.

Table 1 gives examples of maximum effects of collisions with the Earth and the Moon. The assumptions made are that the collision path is tangential to a great circle perpendicular to the equator, density of 3·5, velocity 72 km/sec, and a complete rebound caused by a reverse directed jet of explosion products to approximate as a maximum a two-fold momentum exchange. For these decidedly optimum conditions the axis displacement is the arc tan ($2mVR$: angular momentum of Earth), where mV is momentum of meteorite and R is the radius of the Earth or Moon. When assuming a collision tangential to the equator the axis change is zero but the two momenta give the change in rotational velocity. The equivalent changes are much greater for the Moon and they suggest that with patience and in time man might get to see the full surface without satellites and landings on the Moon. They also have bearing on considerations of the figure of the Moon[3].

Table 1

Spheroids Diameter (km)	$2mVR$ (g cm^2 sec^{-1})	Axis change*	Rotational velocity change† (%)
		Earth	
3·2	$5·5 \times 10^{32}$	—	0·000001
32·0	$5·5 \times 10^{35}$	0° 00′ 02″	0·001
320·0	$5·5 \times 10^{38}$	0° 32′	0·9
640·0	$4·4 \times 10^{39}$	4° 15′	7·5
		Moon	
3·2	$1·5 \times 10^{31}$	0° 2′	0·0006
32·0	$1·5 \times 10^{34}$	0° 22′	0·65
320·0	$1·5 \times 10^{37}$	81° 20′	650·0

Angular momentum, Earth $5·89 \times 10^{40}$ g cm^2 sec^{-1}
Angular momentum, Moon $2·3 \times 10^{36}$ g cm^2 sec^{-1}

* Axis change only of the longitudinally tangent type collisions, the corresponding velocity change not shown.
† Velocity change for equatorially tangent collisions.
Note that for the more average conditions of collision the changes indicated here would be about half those shown.

The disparity in our results arises from the fact that generally one cannot use energies vectorially to determine changes in rotation. Gallant attempts to solve this by estimating the fraction (x) of the collision energy going toward axis change and then has the further complication of estimating the fraction (y) of the same energy going towards formation of the crater. Such collision is an explosive process with the energy dispersed almost hemispherically into the Earth and also into the atmosphere, oceans and beyond. Rotational change has a strict directional requirement which is met by conservation of momentum but not by the dispersed energy of a collision. A crater is the structure in which takes place the total conversion of the kinetic energy of a simple body into a great variety of thermal, mechanical, potential, electromagnetic and chemical energies plus the kinetic energy of a great mass of ejecta. Such crater should manifest in its formation most if not all the energy converted.

From this I would agree that his working hypothesis $x=y=30$ used in the equation sin $\alpha/2$ proportional to $\sqrt{\frac{x}{y}D^3}$ needs revision. To be consistent with the results of the momenta calculations the more likely values would be about $x=0·1$, $y=50$, unless some drastic change is found necessary in Innes'[4] correlation of crater-forming energy and diameter. If one does use $x=30$ in Gallant's equation 1 for the Juno example the calculated axis displacement is 2°, considerably higher than the value derived through the method of momenta.

Nevertheless, it is stressed that recognition of axis change through large meteorite impacts agrees with our conclusion[2] that such processes can provide valuable insight to world-wide tectonic patterns and fluctuations of continental shorelines through the agency of re-establishing the equilibrium figure of rotation. Another important aspect is that of the concomitant change of the total or planetary climate which is so strongly dependent on the inclination of the axis to the ecliptic. As pointed out by Gallant the possibility of slip increases the magnitude of geographical shifts. This mechanism could be of great significance in favouring the growth of the core of the Earth where inertial slip might be expected at surfaces of great density and moment of inertia discontinuities[5]. These subjects and others are considered in more detail in refs. 2 and 3.

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2 Kelly, A. O., and Dachille, Frank, *Target: Earth—(The Role of Large Meteors in Earth Science)*, 175 (published by the authors, 1953).
3 Dachille, Frank, *Bull. South Carolina Acad. Sci.*, **24** (1962). Also contributed discussion *VPI–NASA Lunar Conf.* (1962).
4 Innes, M. J., *J. Geophys. Res.*, **66**, 2225 (1961).
5 Dachille, Frank, *Earthquake Notes, Eastern Section Seis. Soc. Amer.*, **27**, 22 (1956); *J. Ala. Acad. Sci.*, **27** (1955); **26** (1954).

Lunar Dust and Terrestrial Ice Nucleus Concentration

BIGG[1] demonstrated a relation between summer ice nucleus concentration and lunar phase. If one assumes that increase of ice nuclei causes increase in precipitation, relations between precipitation and lunar phase can be accounted for. The effect is global and it occurs in lower latitudes with a delay of a few days. When Bigg's curves are reduced to 34° S. latitude, they show two equal maxima of ice nuclei concentration, the first occurring 6 days, the second 18 days after new Moon. The maxima are 12 days apart (synodic month = 29·53 days).

It is well known that the meteor flux near the Earth is strongly anisotropic. For meteors moving in the plane of ecliptic, there are two strong maxima, connected with meteor streams moving in elliptical orbits of the Jupiter family away and toward the Sun. One would expect that meteors falling on the Moon produce copious amounts of dust. They would also produce narrow rebound jets of tektite-like particles, directed in opposite direction to the direction of the incoming meteorite. Such jets may have velocities of the order 10 km/sec, so that they can leave the lunar surface without difficulty, whereas the crater-forming material is thrown out more or less horizontally with velocities too low for it to leave the Moon. Such high-velocity jets have been postulated by Dachille[2] in connex-