THE INFLUENCE OF PLANETARY ATMOSPHERES ON INCOMING BODIES

E. Illés-Almár
Konkoly Observatory, 1525. Box 67. Budapest, Hungary

Abstract

An overview is given on the examples of recent and past events concerning the influence of planetary atmospheres on incoming bodies.

Introduction

There are many traces of impacts on Earth and other planetary bodies in the form of impact craters, but the event itself is observed only in a few cases. Here we mention three of them that have some connection to the issue mentioned in the title:

- the series of impacts of comet Shoemaker-Levy 9 on Jupiter,
- the fall of the Peekskill meteorite in the USA and
- the Tunguska Event.

As regards the traces, a crater field on Earth and the radar images of Venus obtained by the Magellan space probe give some idea about the atmospheric effect on impacts. It is understandable that atmospheric effect was observed only on Venus among the Solar System bodies because of its massive atmosphere and the very low level of erosion. Besides Venus principially one could await atmospheric effects only on two other planetary bodies because of their sufficiently dense atmosphere, namely on Earth and on Titan. But on Earth the very strong erosion generally covers up the traces very quickly. On Titan, on the contrary, we could not observe any trace on the surface because of its non-transparent atmosphere.

On the basis of the Magellan imagery on Venus several kinds of atmospheric effects can be separated:

- lobate ejecta blanket, and/or missing of some sectors of the ejecta blanket,
- synchronous impacts of chunks of exploding bodies.
- cut off of crater diameters.
- traces of "tunguska events"

Impact of Comet Shoemaker-Levy 9 (SL-9) on Jupiter

The only impact event of a natural body that was forecasted and consequently observed so far in the history of mankind is the impact of comet Shoemaker-Levy 9 into Jupiter [1]. The comet was fragmented at least into 22 pieces beforehand because of Jupiter's tidal effect. The series of impacts spread over 6 days between 16-22 July 1994. In spite of the fact, that some people doubted that any effect could be observed from the Earth, many telescopes – almost every in orbit – followed the events. The effect in some cases was extremely violent. The scenario observed was as follows:

- The meteor flash phase: when the body arrived into the atmosphere it was heated up and glared because of the air drag. The temperature reached 10,000 K at this first flash.
- Breaking apart: after a long path in the atmosphere the incoming body was heated up to such a degree that it exploded.
- The explosion was followed by the fireball phase: the material of the impactor was launched (Fig. 1) as high as 3000 km above the cloud deck into the upper atmosphere and the temperature reached 30,000 K.
- Some 5-10 minutes later a splash down of the launched material occured, it fell back on the lower layers of the atmosphere with a velocity of 5-12 km/sec, that caused a heating of the atmosphere by cca 2000 K.
- After 90 minutes a dark spot appeared on the impact site (Fig. 2) the material of which is unknown. Around a central dark spot that spread out with smaller velocity, another almost concentric dark egg shaped ring appeared and spread out with the sound velocity of the minimum temperature layer like a wavelike phenomenon. It reached about 20,000 km size in some cases.

The molecules that were detected: in the first 2 minutes strong emission of NH_3 and strong absorption of CH_4, in the 4th minute strong emission of CO (2000-3000 K is needed), in the 6th minute ultraviolet emission of H_3^+ (1400 K is needed), in the 12th minute H_2O was detected. In the 16th minute H_2, in the 30th minute Li, Na, K, Ca, Fe, $H\alpha$, after the 45th minute S and neutral and ionized metal (MgI, MgII, FeI, FeII, SiI) emerged. After 8 days SiO_2, C_2H, H_2O then, CO, HCN, CS appeared in emission that went into absorption by September. CS_2 could be detected even in April 1995.

On the basis of the observations (with 10^{15} g mass coming in) a thermochemical model indicates that everything has been vaporized, the material of the impactor and the neighbouring atmospheric envelop as well. Then photolysis, chemical reactions, condensation took place as well as interaction among participants. Consequently, there is no chance for the original molecules of the impactor to be observed.

The Peekskill meteorite

The fall of a larger chunk of meteoroid occured on 9 Oct. 1992 at 23 hour 48±1 min UT over the Eastern part of USA [2, 3]. The 700 km path of the falling body between 46.4-33.6 km altitudes was recorded by 14 videocameras. This is the first case when moving pictures stay at disposal on a bolide. The orbit could have been reconstructed. This is only the fourth case when the orbit of a meteorit is known up till now. The inclination was 3.4° to horizontal. At 41.5 km height break up occured and afterwards more than 70 pieces could be observed (Fig. 3). The bolide's velocity outside the atmosphere was 14.72±0.05 km/sec, and 12.4 kg ordinary chondrite has been found.

The "Tunguska Event"

The so called Tunguska meteoroid earlier was thought to be a comet that blew up at about 6-9 km height over the Tunguska River in Siberia on 30. June 1908, $0^h 14^m$ UT with energy about 20-50 Mtn TNT [4]. The site of the event was visited only later. No fallen material was found, the trees of the forest were hurled down and they are lying radially.

Computer simulation [5] for a comet with relative velocity not more than 72 km/sec and with a 5×10^{13} g mass could describe the observations – with fusion energy release in the gas cap only 5×10^{-3} Joule. The arising inclined cilindrical shock front caused the trees to fall away from the centrum (Fig. 4). The pressure reached 25,000 atm. Between the body and the shock wave the temperature could reach 400,000 K. But another computer simulation [6] exclude the possibility of a comet, because it should have been exploded 2-3 times higher. The body could be rather a stony asteroid, because of its 6-9 km explosion height (an iron asteroid, on the contrary, would explode even lower).

The traces of a grazing impact in Argentina

The crater field at Rio Cuarto city, Argentina [7, 8] (Fig. 5, 6), counts at least 10 long elliptical features the largest of which being 4.5×1.1 km. It is a remnant of a grazing impact of an asteroid that also exploded coming through the atmosphere. The identification happened recently, in spite of the fact that geophysicists recognized it already earlier, but they thought it was created by water or winds. Such elliptical craters are known on other planetary bodies as well, for example many on Mars, some on Venus and on the Moon, but on Earth, besides the above mentioned, only one has been discovered in Campo del Ciclo, Argentina.

Traces of the atmospheric effects on impacts on Venus

Among the impact craters found on Venus [9] one can easily observe the effect of the atmosphere because of its massive nature. (The surface pressure is about 100 atm.)

The craters with a diameter of more than 15 km are similar to those found on other bodies in the Solar System but their ejecta blanket differ very much. The inner part of the ejecta blanket – between 0.5 and 0.8 crater diameter – is ballistic and similar to those found on other bodies. But there is an outer part of the ejecta until 2.5 (instead of 1.4) crater diameter, that is superballistic. Here only smoother material can be found. The outermost part (until 3-4 crater diameter and even beyond) is very smooth i.e. radar dark (Fig. 7). This smooth ejecta blanket is obviously overlain by the strong winds that blew radially from the impact site at the time of the impact. The flower shape outer feature of the superballistic ejecta blanket can also be caused by the turbulence of the atmosphere after the impact, that was throwing down the picked up matter cauliflower-like at the edges of the ejecta blanket (Fig. 8). The turbulent movement of the atmosphere can be the cause of the lack of the ejecta blanket in some directions as well. The direction of the lack indicates the direction of the approach of the incoming body, if it was coming in obliquely.

If the crater diameter is smaller than about 15 km, than 50%, if smaller than 12 km than almost all of the craters are irregular (Fig. 9) indicating the synchronous impact of several chunks – or the craters are in clusters (Fig. 10) referring to the explosion of the impactor close to the surface. Smaller than 3 km diameter craters do not exist indicating that bodies smaller than about 100 m can not survive the transit through the atmosphere. But there are a lot of radar-dark (that is smooth) areas without craters (Fig. 11). These are very probably the traces of so called "tunguska events" when the incoming body exploded in the atmosphere, and the arising shock wave was strong enough to smooth the boulders and the soil out.

Conclusion

The events reported in this paper – the SL-9 impact in particular – indicate that the breaking apart and the explosion of a relatively large interplanetary body during the transit of a dense atmosphere seems to be inevitable. If this happens at least partially, then evolving temperatures are high enough to modify principially both the physics and chemical composition of the entering body and its surroundings. Therefore one should not expect to find the original molecular composition in the remnants of such an impact: neither H_2O in the traces of comet SL-9 after its impact on Jupiter, nor chemically intact traces of interplanetary matter in spherules previously modified by an explosion in the terrestrial atmosphere.

Aknowledgement: The author is indebted to Mr. P. Decsy for his able help in the preparation of the paper.

References

1. *Science*, Vol. **267**, pp. 1282-1317, 3. March 1995.
2. P. Brown, Z. Ceplecha, R.L. Hawkes, G. Wetherill, M. Beech, K. Mossmann: The orbit and atmospheric trajectory of the Peekskill meteorite from video records *Nature*, **367**, pp. 624-626, 17. Feb. 1994.
3. Z. Ceplecha, P. Brown, R.L. Hawkes, G. Wetherill, M. Beech, K. Mossmann: Video observations, atmospheric path, orbit and fragmentation record of the fall of the Peekskill meteorite. *Earth, Moon, and Planets*, **72**, Nos.1-3, pp. 395-404, 1996.
4. G.V. Andreev, N.V. Vasilyev: The Tunguska 1908 explosion's region as an international park of studies of the ecological consequences of collisions of the Earth with the Solar System small bodies. *Earth, Moon, and Planets*, **72**, Nos 1-3, pp. 467-468, 1996.
5. S.J.D. D'Alesso, A.A. Harms: The nuclear and aerial dynamics of the Tunguska Event *Planetary & Space Sci* **37**, No.3, pp. 329-340, 1989.
6. P.J. Thomas, C.F. Chyba, K. Zahn: The Tunguska explosion and airbursting of comets and asteroids Paper 17.10 DPS Munich 1992, Book of Abstracts p. 965.
7. P.H. Schultz, R.E. Lianza: Recent grazing impacts on the Earth recorded in the Rio Cuarto crater field, Argentina *Nature*, **355**, pp. 234-237, 16. Jan. 1992.
8. P.H. Schultz, J.K. Beatty: Teardrops on the Pampas *Sky and Telescope*, April 1992, pp. 387-392.
9. *Science*, Vol. **252**, pp. 213-312, 12. April 1991.

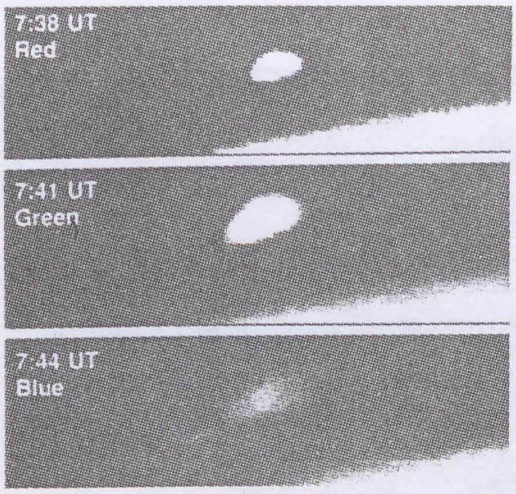

Fig. 1. Above the disk of Jupiter the fireball glares after the impact of the first fragment (designated by A) of comet Shoemaker-Levy 9 as observed in different wavelengths by the Hubble Space Telescope.

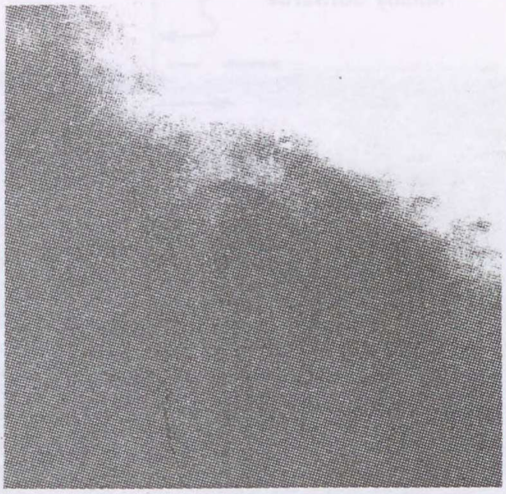

Fig. 2. The dark spot and the egg-shaped ring after the impact of fragment G of comet Shoemaker-Levy 9 as observed by the Hubble Space Telescope. The smaller dark spot to the left is the aftermath of fragment D.

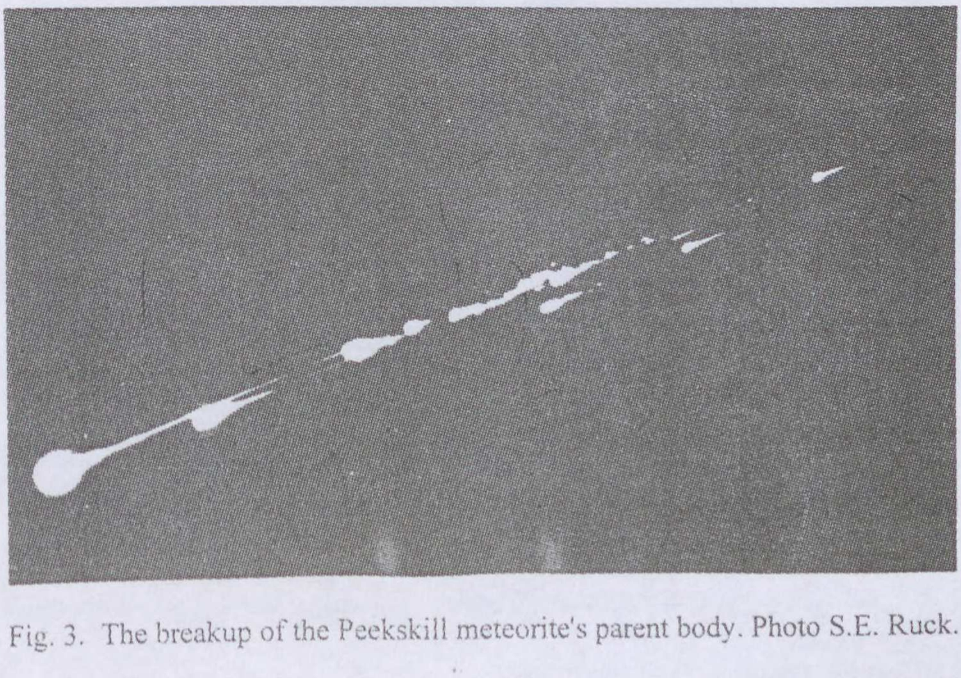

Fig. 3. The breakup of the Peekskill meteorite's parent body. Photo S.E. Ruck.

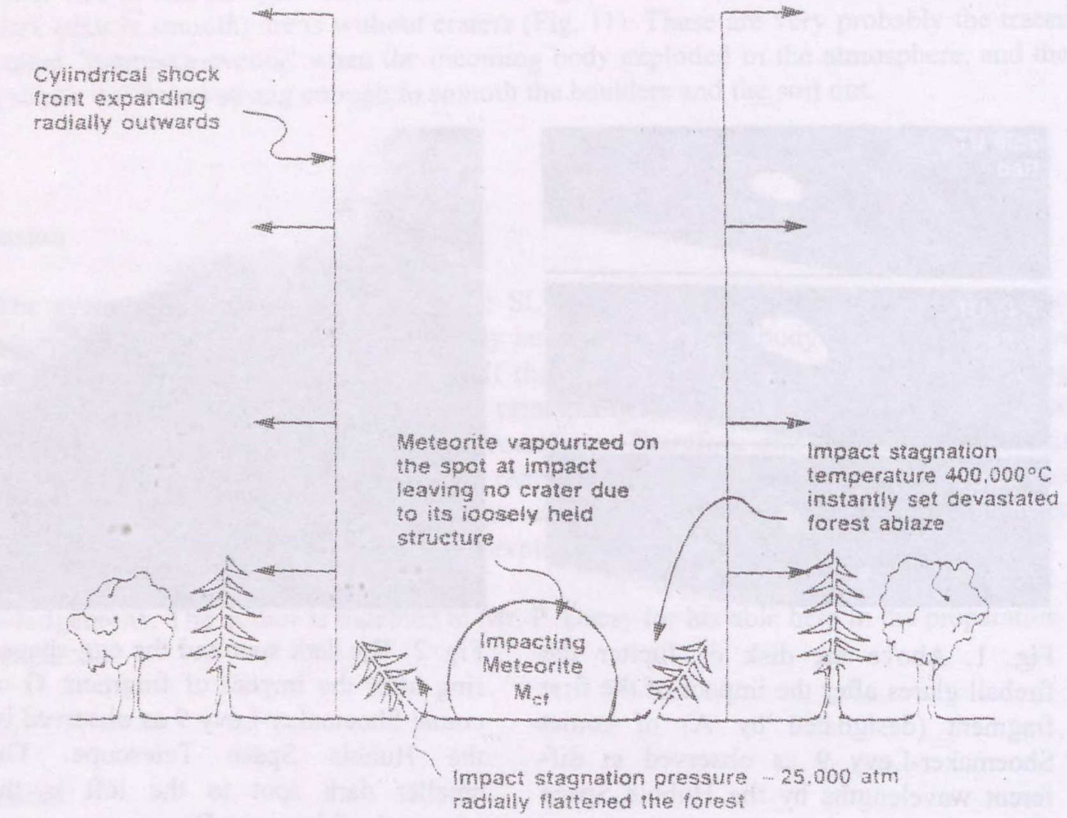

Fig. 4. A Conception how the Tunguska Event has flattened the forest radially [3].

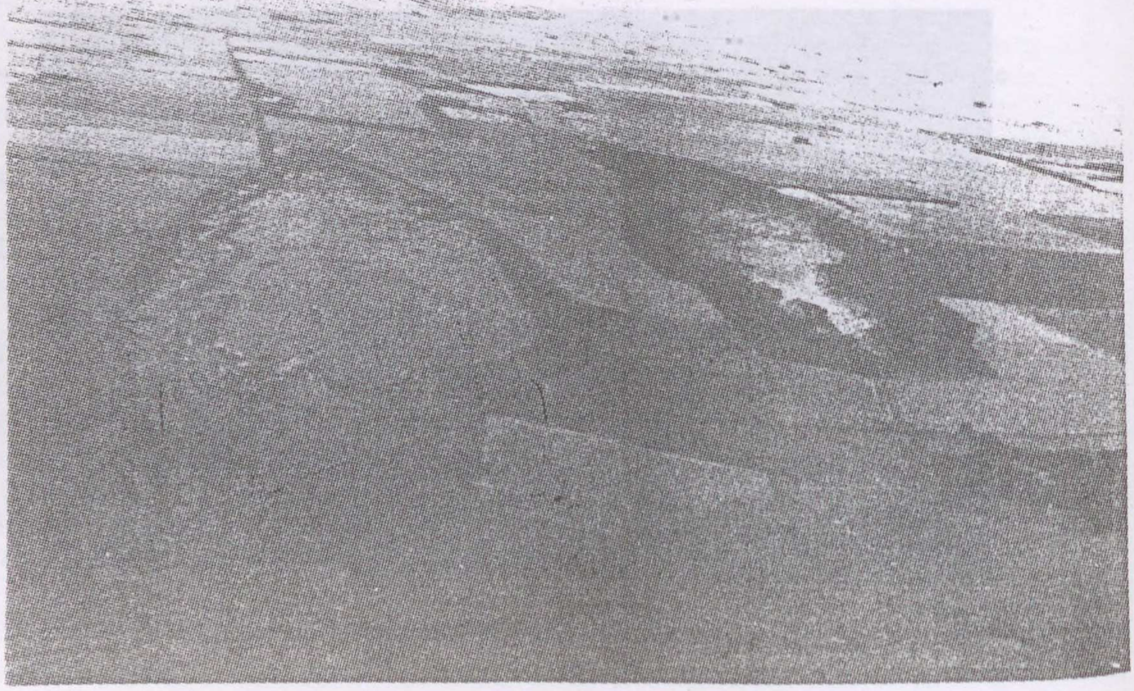

Fig. 5. Aerial view of two elliptical features
on the crater field at Rio Cuarto city, Argentina [6].

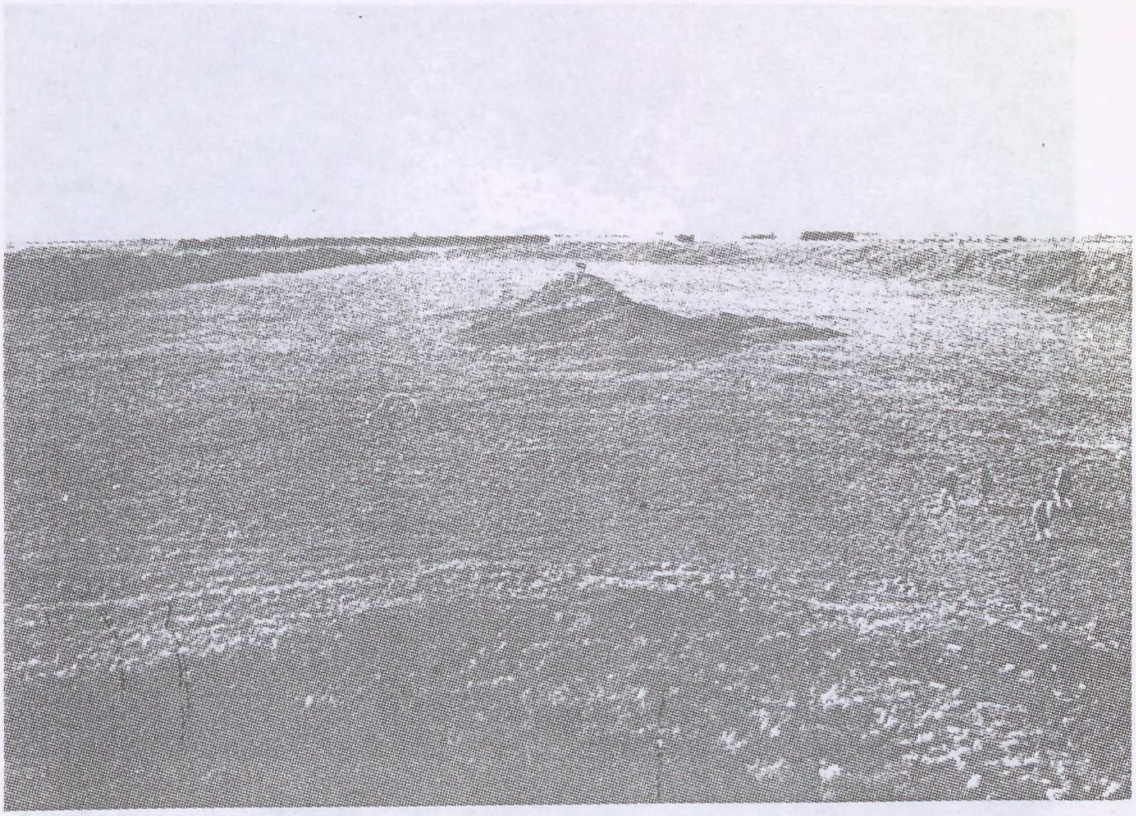

Fig. 6. Inside panorama of one of the craters within the craterfield at Rio Cuarto city, Argentina [6].

Fig.7. A typical larger impact crater on Venus. Its inner part is ballistic, its outer part is superballistic and the outermost ejécta blanket is radar-dark. Magellan radar image.

Fig. 8. A typical larger impact crater on Venus with couliflower-like edges and a missing sector of the ejecta blanket in one direction. Aglaonice crater. Magellan radar image.

Fig. 9. A typical irregular impact crater on Venus suggesting the synchronous impact of several fragments of a body that exploded just before the impact. Magellan radar image.

Fig. 10. A typical crater cluster on Venus suggesting the explosion of the impactor close to the surface. Magellan radar image.

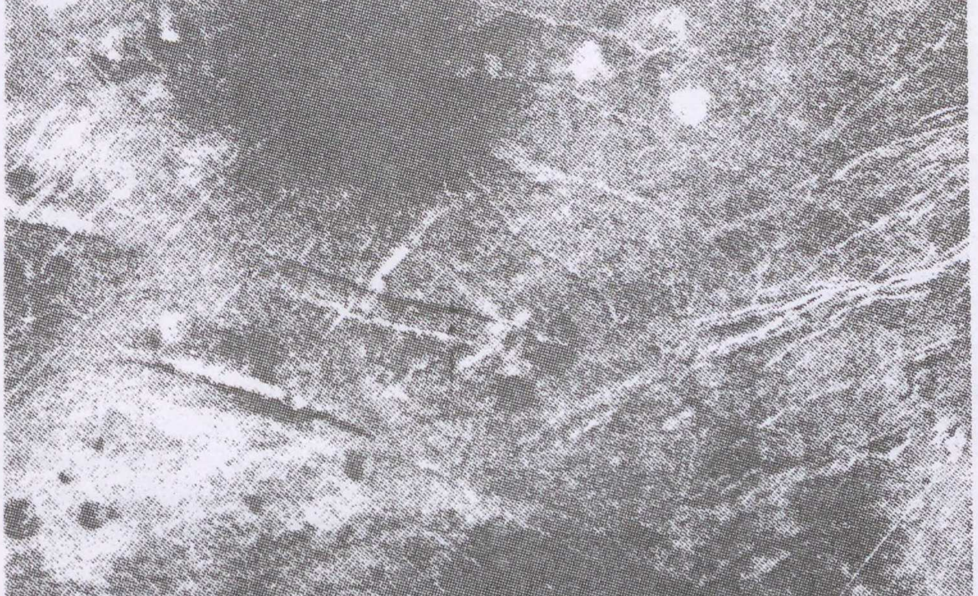

Fig. 11. Typical traces of "tunguska events" on Venus with radar-dark, i.e. smooth areas – some of them without any crater (upper part), some with a small impact crater inside (lower part). Magellan radar image.