氏　　　　名	石　原　吉　明
生　年　月　日	
本　　　　籍	愛知県
学 位 の 種 類	博士（理学）
学 位 記 番 号	博甲第609号
学位授与の日付	平成16年3月25日
学位授与の要件	課程博士（学位規則第4条第1項）
学位授与の題目	Analyses of Bolide Shockwaves（火球衝撃波の解析）
論文審査委員(主査)	古本　宗充（自然科学研究科・教授）
論文審査委員(副査)	寅丸　敦志（自然科学研究科・助教授）木原　國昭（理学部・教授） 奥野　正幸（理学部・教授）深尾　良夫（東京大学・教授）

学位論文要旨

Abstract

A high velocity passage of a meteoroid through the atmosphere generates a shock wave with a conical front. When the shock front arrives at the surface, it causes high frequency ground motions that are registered on the seismograms. I use seismological data to determine the trajectory of the meteoroid in the atmosphere. Strong shockwaves from the 1998 Miyako fireball, the 1999 Kobe meteorite fall and the 2003 Kanto large bolide are recorded by dense arrays array of seismographs installed in the Honshu Island, Japan. I determine the velocities and the trajectories of the three fireballs in the upper atmosphere using the arrival times of the shock waves at the stations. The seismological data have not only arrival time data, but also have amplitude data. The amplitude data are ground displacement records generated by shockwave and depend on a meteoroid size. I investigate the ablation process of the 1999 Kobe meteorite using the seismological records. The results show that the diameter of the Kobe meteorite has changed from ~ 0.6 m at 70 km to ~ 0.3 m at 30 km and that at 30 ~ 25 km the size has rapidly decreased. This rapid size change is caused by a fragmentation of the meteoroid.

Introduction

Fireballs, which are caused by high velocity passages of meteorites through the atmosphere, generate shockwaves. It has been known that such shock waves are often recorded on seismograms. It is possible to determine the trajectories and the sizes of fireballs by using the seismological records. The determination of the fireball trajectory is very important to study "How did the Solar System and the Earth was made up?". The determination of a meteoroid (fireball) is also very important to study "The ablation process of meteorite and fall dynamics".

Trajectory Determination

I have searched shockwave signals from many bright fireballs observed in two periods Sep. 1996 to Nov. 1998 and May 2000 to Dec. 2003 and at a time of 1999 Kobe meteorite fall. It is indicated that shockwaves from fireballs that are darker than brightness magnitude-10 are too weak to be recognized on seismograms of ordinary seismic stations in Japan.

The shockwaves from three two large fireballs, which are called Miyako fireball, Kanto large bolide, and Kobe meteorite, are clearly recorded on many seismograms. I determine their trajectories and velocities from the arrival times of seismic signals. I assume that the shock wave velocity in the atmosphere is 0.32 or 0.31 km/s and that, the fireball motion is a linear motion with a constant velocity, generating a cone of shock front shape. Following Nagasawa and Miura [1987], arrival times of a shock front are expressed by a non-linear equation with six parameters of the trajectory, velocity, azimuth, angle of incidence, and reference coordinates of space (x_0, y_0, 0) and the time t_0. The optimum parameters are calculated by a grid search method. The five parameters of trajectory excepting the velocity are estimated with high accuracy. For the 1998 Miyako fireball, the optimum values of the trajectory parameters are the meteoroid velocity of 18 km/s, the azimuth of the trajectory of 287 °, the incident angle of trajectory of 18.5 °. For the 1999 Kobe meteorite, the optimum values of the trajectory parameters are the meteoroid velocity of 18 km/s, the azimuth of the trajectory of 249 °, the incident angle of trajectory of 30 °. For the 2003 Kanto large bolide, the optimum values of the trajectory parameters are the meteoroid velocity of 14 km/s, the azimuth of the trajectory of 229.5 °, the incident angle of trajectory of 15.5 °.

Meteoroid Size Estimation

The 1999 Kobe meteorite was recovered and its shockwaves were clearly recorded by seismographs. I investigate the ablation process of the 1999 Kobe meteorite using the seismological records. The amplitudes of the ground motions are converted to the amplitudes of the atmospheric shockwaves using a conversion formula given by an experiment [Takahashi *et al.* 2004] and a theoretical consideration [Ben Menahem and Singh, 1981]. The obtained amplitudes of the shockwaves on the ground are in a pressure range from 0.1 to 10 Pa. The shockwave amplitudes and representative source dimensions at the sources in the upper atmosphere, whose locations have been determined by the analysis of the arrival times of the shockwaves, are calculated by a formula of ReVelle [1976]. Then I estimate the radius of the meteorite, adopting a relation R=Md, where R is the representative dimension, d is the radius, and M is the Mach number of the meteorite motion. The results show that the diameter of the Kobe meteorite has changed from ~ 0.6 m at a height of 70 km to ~ 0.3 m at 30 km and that at 30 ~ 25 km the size has rapidly decreased [Fig.1]. This rapid size change is caused by a fragmentation of the meteoroid.

References

Ben-Menahem. A., and S. J. Singh, Seismic Waves and Sources. Springer-Verlag New York Heidelberg Berlin, 1981.

Nagasawa, K. and K, Miura, Aerial Path Determination of a Great Fireball from Sonic Boom Records on Seismographs, *Bull. Earthq. Res. Inst. Univ. Tokyo*, **62**, 579-588, 1987 (in Japanese with English abstract).

ReVelle, D. O., On Meteor-Generated Infrasound, *J. Geophys. Res.*, **81**, 1217-1230, 1976.

Takahashi, Y., Y. Ishihara, Y. Hiramatsu, and M. Furumoto, Ground motions generated by shock waves from firework, *zishin*, submitted.

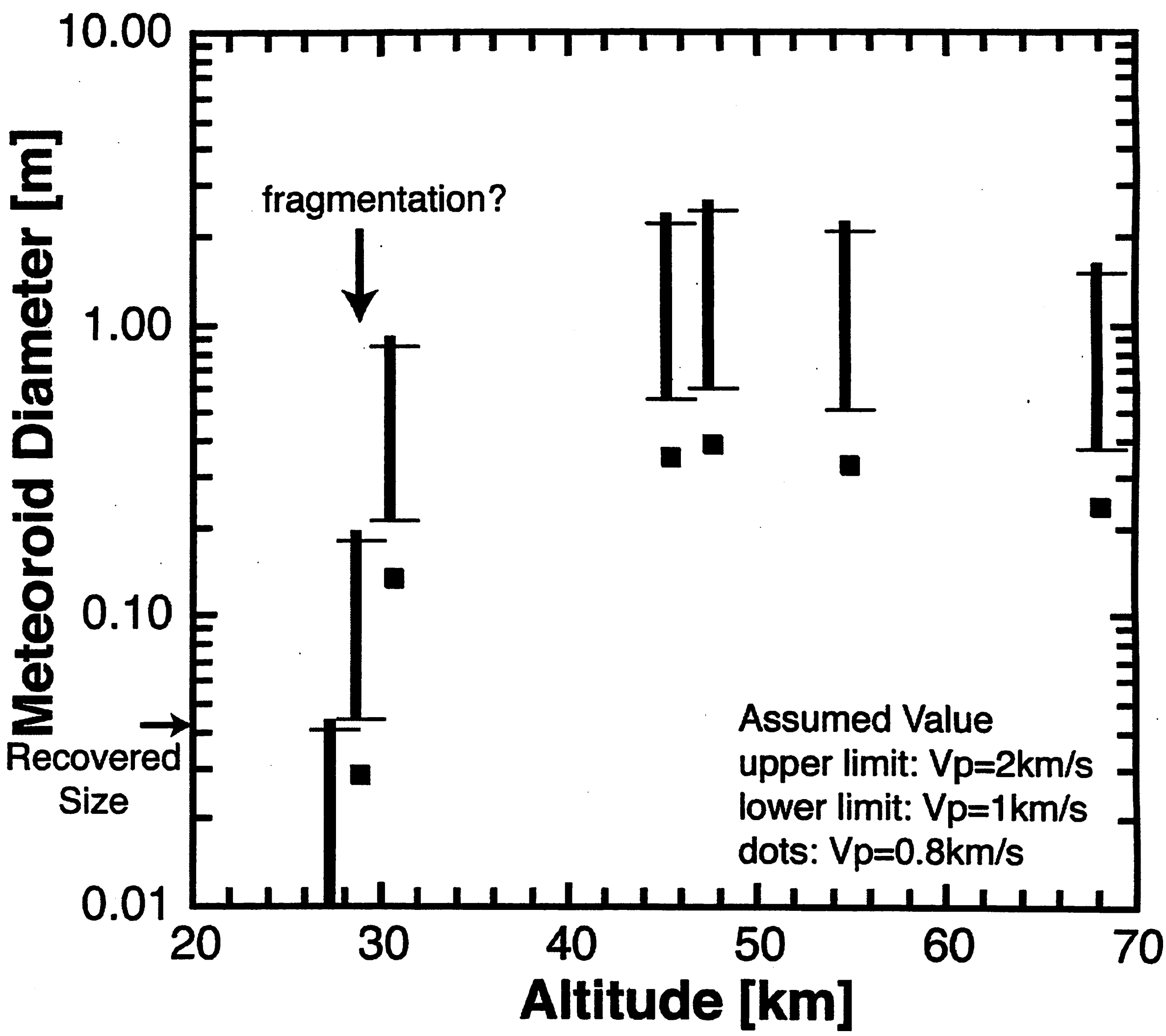

Fig. 1 The graph shows an estimated meteoroid diameter at each altitude. The diameter of meteoroid has change from about 0.6 m at 70km to ~ 0.3 m at 30km. Rapid size changed has occurred at 30 ~ 25km. An ablation process has continued until at ~ 25 km.

学位論文審査結果の要旨

太陽系内を公転する微小天体が、地球と衝突し大気中を高速で通過する際に、強い衝撃波を発生する。この衝撃波が十分に強いと、その衝撃波の圧力で地面が揺すられ、地震計に記録される。石原吉明君は地震計の記録を精密に解析することで、微小天体の大気中での軌跡および摩滅によるサイズ変化の様子を明らかにすることを目指している。

石原君は、現在日本列島に展開されている高性能微小地震観測網の観測点の記録を丹念に調べ、火球の光度が -10 等よりも明るい場合、地震計に記録されるほどの強さの衝撃波が発生することを明らかにした。そして地震計による衝撃波記録が充分大きく、軌跡等の解析に利用出来る 3 個の大火球の例を選び出した。そしてこれらの火球から発生した衝撃波が地震観測点に達した時間と観測点の位置の関係から、大気中での衝撃波発生経路つまり火球の速度や軌跡を決定した。さらに、1999 年に神戸市に落下した隕石については、地震計に記録された地動振幅からまず大気中の衝撃波の振幅を求め、さらに地震記録から決定した経路の情報を使って小天体のサイズ変化を推定した。この解析の結果、地球突入前のサイズのみならず、大気中での分裂に対応すると考えられる急激なサイズ変化も得ている。これまで経路決定などは、主に写真やビデオ観測によって行われてきたが、本研究により地震観測網が小天体の衝突現象の研究に有効な観測装置であること示している。本研究は微小天体衝突の研究方法として新しい可能性を示したものであり、よって博士の学位に値するものと判断した。