Original paper

The bolide of February 10, 2010: Observations in Hidalgo and Puebla, Mexico

Guadalupe Cordero*, Karina Cervantes-de la Cruz and Eduardo Gómez

Received: May 8, 2010 ; accepted: September 28,2010; published on line: December 17, 2010

Resumen

El 10 de febrero de 2010 los habitantes de algunas poblaciones cercanas a los límites entre los estados de Puebla e Hidalgo, México, escucharon un fuerte estallido sobre sus cabezas acompañado de tremores sísmicos y vibración en techos de lámina y vidrios. Algunas personas en Tulancingo, Hidalgo, localizado a unos 25 km de distancia de la zona, vieron un bólido y escucharon una explosión asociada a él aunque de mucho menor intensidad que el escuchado cerca del lugar de la explosión. Una de las posibles explicaciones dadas al evento fue que el fenómeno auditivo y visual se debió a la entrada de la basura espacial número 33006 proveniente del satélite COSMOS 2421. En este trabajo se analiza dicha posibilidad, se reportan los resultados de las entrevistas hechas a testigos y se evalúa la hipótesis alternativa de que el bólido pudo ser producido por la caída de un meteoroide.

Palabras clave: bólido, meteoro, escombros espaciales, México.

Abstract

On February 10th, 2010, the inhabitant population of some towns near the border between the States of Hidalgo and Puebla, Mexico, heard a strong blast overhead and felt seismic tremors and roof and windows vibration. At Tulancingo, Hidalgo, 25 km from the explosion zone, visual reports of a bolide and thunder-like sounds were described. A possible explanation may be related with re-entry of spatial debris number 33006 from satellite COSMOS 2421. We describe interviews with witnesses. An alternative hypothesis is a meteoritic origin of the bolide.

Key words: bolide, meteoroid, spatial debris, Mexico.

G. Cordero
Departamento de Ciencias Espaciales
Instituto de Geofísica
Universidad Nacional Autónoma de México
Ciudad Universitaria
Delegación Coyoacán, 04510
México, D.F.
Fax: +52 (55) 55 50 24 86
Tel. +52 (55) 56 22 41 13 (ext. 20)
**Corresponding author: gcordero@geofisica.unam.mx*

K. Cervantes-de la Cruz
Seminario Mexicano de Meteorítica
Instituto de Geología
Universidad Nacional Autónoma de México
Ciudad Universitaria
Delegación Coyoacán, 04510
México, D.F.
Tel. +52 (55) 56 22 43 00 (ext. 105)
e-mail: *kecervan@yahoo.com.mx*

E. Gómez
Seminario Mexicano de Meteorítica
Instituto de Geología
Universidad Nacional Autónoma de México
Ciudad Universitaria
Delegación Coyoacán, 04510
México, D.F.
Tel. +52 (55) 56 22 43 00

Introduction

Approximately 40,000 tons of interplanetary material falls to the Earth each year (Brownlee, 2001). The effect of these objects depends on their size, velocity, angle of entry, and strength. Meteoroids between 0.05 mm and 20 cm diameter may produce meteors (Ceplecha *et al*., 1998), whereas meteoroids between 1 m and 10 m can produce bolides (Shumilov *et al*., 2003) with energies of explosion of ~5 kt (Brown *et al*., 2002). Small asteroids, ~50-100 m of diameter, also produce bolides and usually explode in the air (Brown *et al*., 2002). Their energy may be ≥ 10 Mt as in the Tunguska event (Ben-Menahem, 1975; Martin, 1966).

The estimated frequency of collision of meteoroids with diameters greater than 1 m is between 35 and 159 per year, depending on the assessment method (Brown *et al*., 2002; Poveda *et al*., 1999). This means that we would expect that one bolide occurs every 2 to 10 days on some place on Earth; however, they are not always observed because they fall near inhabited sites or weather conditions do not enable sightings.

When a bolide explodes in the atmosphere, the atmospheric shock wave generated by the explosion may produce seismic waves that can be detected at seismic stations, as for the events of Hawera, New Zealand in 1999 (Manville *et al*., 2004), and Bala, UK in 1974 (Musson, 2006). Occasionally, the explosion produces infrasonic signals recorded by microbarographs, as in the case of Vitim in 2002 (Shumilov *et al*., 2003).

The sound of the explosion may cause panic, as for the Curuça River event on August 13th, 1930 (L'Osservatore Romano, 1931; Bailey, 1995). The October 8th, 2009 fireball in Indonesia was attributed to an object 10 meters in diameter with an energy of about 50 kt (http://neo.jpl.nasa.gov/news/news165.html).

Observations

On February 10th, 2010, around the 15:50 local time, a strong explosion was heard in the municipality's counties of Tulancingo (Hidalgo) and Ahuazotepec (Puebla). Most reports came from the localities of El Durazno, and Las Puentes (Hidalgo) and Ahuazotepec (Puebla), in east central Mexico (Fig. 1). The sound was related to a sudden strong burst, but no sightings were reported because of the fog. However, witnesses reported a rumble similar to that of a heavy truck. No objects did fall but the windows vibrated. Many people thought that an explosion had taken place in the nearby gas pipeline or in the petrochemical plant.

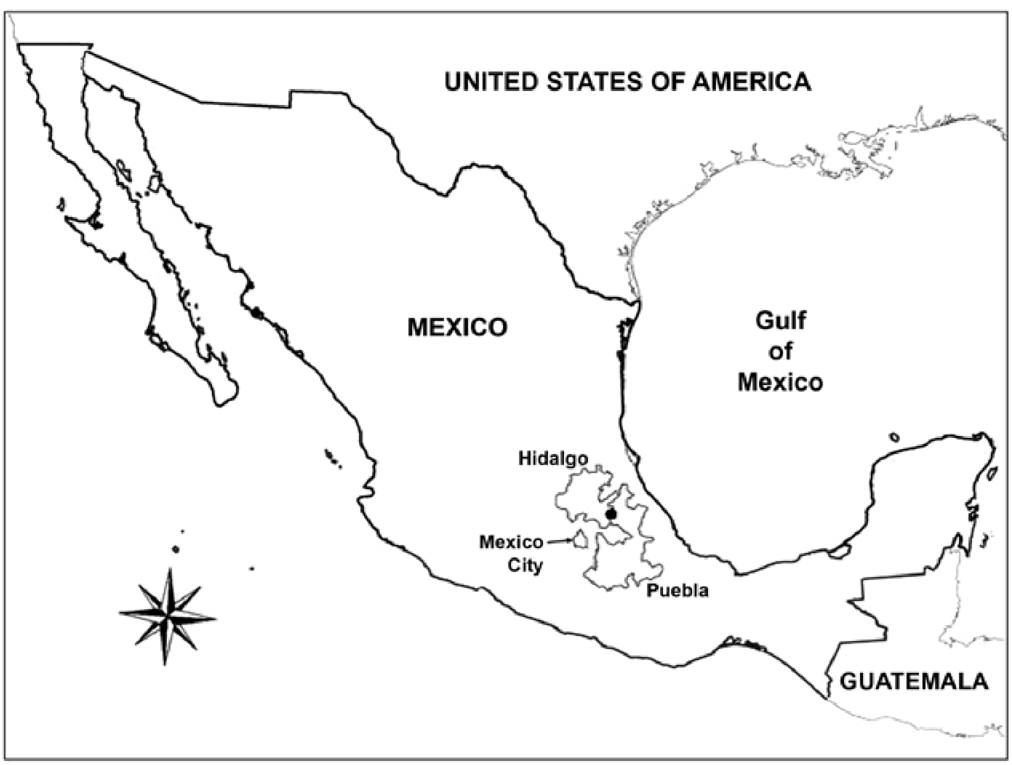

Figure 1. Location of the States of Hidalgo and Puebla. The black point between both States shows the area where the explosion was heard.

In Tulancingo, Hidalgo, some 25 km west from the estimated place of the explosion, a bolide was seen and a dull sound was heard. Witnesses thought that an airplane had crashed.

Civil protection offices at Tulancingo and Ahuazotepec received many phone calls from people who thought that a serious accident had occurred. Staff of the civil defense and fire departments of both municipality's counties and the army spent two days looking for the accident without success.

Several other versions of the event emerged. Rumors included an impact of a meteorite causing a bridge to collapse, or producing a 30 m impact crater. UFO sightings were also reported.

The media in the area compiled several testimonies from the inhabitants. Many people went to the area looking for remains of an air crash, the explosion of pipeline, spatial debris, a meteorite or an extraterrestrial spaceship.

Spatial Debris

The Mexican Space Agency AEXA suggested that the bolide might have been produced by the reentry of a fragment of COSMOS 2421, debris numbered 33006 (Herrera-Cortés, 2010).

We performed an information search about this debris or any other that could have fallen in Mexico on February 10th, 2010. Celestrak (http://celestrak.com/) and Space Track (http://www.space-track.org/perl/decay_query.pl) reported that debris 33006 from COSMOS 2421 had fallen on February 12th, 2010 not February 10th. On the other hand, Space Track listed two events in February from COSMOS 2421, the 33755 on February 6th and the 33006 on February 12th. On this last date there was also debris 30808 from the Chinese satellite Fengyun 1C, and debris 29455 from satellite SL-12 of the Commonwealth of Independent States. On February 10th only one fall was found, debris number 34251 from the tank Breeze-M. No location was reported for this event.

The Orbital Debris Quarterly News (http://www.orbitaldebris.jsc.nasa.gov/newsletter.html), a publication of the NASA Orbital Debris Program Office, publishes news, statistics, and valuable material on spatial debris. In issue 2, volume 14 published in April 2010, no mention is made of an event on February 10th in Mexico. As debris 34251 was not expected to fall in Mexico, the bolide of 10 February may have been caused by a meteoroid.

Methodology

Two weeks after the event, we went to the area of the explosion to interview possible witnesses of the event. Over a period of 4 months, after the event we returned to the area 12 times. Even though more than 80% of the interviewed people heard the sonic boom and/or perceived windows or roof vibration, very few saw the bolide. We required eyewitnesses to return to the location where they observed the fireball and asked them to point at the initial and final points of the trajectory that they saw. With some object in the horizon as reference, we measured the azimuth and angle over the local horizon for each point using a BRUNTON compass (Trigo-Rodríguez, *et al*., 2006). Geographic coordinates were obtained with GPS.

To obtain the trajectory of the bolide, we did a stereographic analysis as used by structural geologists to represent lines or planes in space. For each eyewitness we obtained two lines described by an azimuth and an angle over the horizon, defining a plane in space. The path of the bolide was obtained as the intersection of the planes defined by the data reported by the eyewitnesses (Leyshon and Lisle, 1995).

To find the intersection, we used a Wulff (equal-angle) stereo net and we plotted the pair of lines for every eyewitness as a pair of points on the stereo net. Then we rotated the stereo net until both points fell on a great circle. This was the plane containing both lines. For each eyewitness, individual planes and poles of each plane were obtained. The poles of the planes were plotted using the Dips 5.041 program (Fig. 3). The poles were located in four regions of the stereo net (I to IV on Fig. 3); to obtain average planes whose intersections yielded the possible trajectory of the bolide. The solution was not unique because of measurement errors and because witnesses failed to remember the exact points where they saw the bolide.

Assessment of the Trajectory

It is important to know the path of a bolide in the atmosphere as it allows one to determine the orbit and associate it with NEOs or Main Belt asteroids. It also helps delimiting the area where a meteorite search can be performed. A good way to carry out this search is by means of meteor networks, such as the Spanish Meteor Network (Madiedo *et al*., 2009), which has been successful in determining the orbits of some bolides and the area where meteorites have been recovered (Trigo-Rodríguez *et al*., 2006). For the event of 10 February 2010, nor videos nor photographs or sound records are available.

Data

Over one hundred people were interviewed in thirteen towns (Table 1), but only twelve saw the event. The twelve witnesses showed us the place where the fireball was sighted. We required them to return to the place where they observed the fireball and to point out the initial and final points of the segment of the trajectory that they saw. With some object in the horizon as a reference, we took the azimuth and the angle over the local horizon for each point. The result is shown in Table 2 and the Fig. 2. Fourth column in Table 2 gives the azimuth (from the North through East) and the fifth column shows the angular elevation of the object as referred to the local horizon. There are two rows for each witness, the first for the initial point of the observed path and the second for the final point.

Table 1. Geographical coordinates of the towns where it was possible to obtain information.

Town	Latitude	Longitude
Acaxochitlán	20° 09′ 24.4″	98° 12′ 21.1″
Ahuazotepec	20° 02′ 41.6″	98° 09′ 50.6″
Camotepec	20° 01′ 35.7″	98° 04′ 51.7″
Cuautepec	20° 03′ 54.2″	98° 16′ 55.1″
El Durazno	20° 04′ 21.2″	98° 10′ 51.3″
Huayapita	20° 04′ 19.3″	98° 14′ 0.8″
La Mesa	20° 05′ 14.9″	98° 13′ 33.9″
Las puentes	20° 03′ 21.3″	98° 12′ 6.6″
Ojo de agua	20° 05′ 23.9″	98° 11′ 43.8″
Pachuca	20° 01′ 56.1″	98° 47′ 32.9″
Piedras encimadas	20° 02′ 10.4″	98° 02′ 51.1″
San Marcos	20° 06′ 4.8″	98° 13′ 35.7″
Tulancingo	20° 05′ 2.3″	98° 21′ 58.3″

Table 2. Data obtained from the twelve eyewitnesses. We obtained only one point from de fourth eyewitness because she only saw something similar to a cloud.

Eyewitness	Latitude	Longitude (Degrees) ± 2º	Azimuth (Degrees) ± 6º	Angle
1	20° 04′ 45.6″	98° 25′ 10.8″	46.5 34.5	28 15
2	20° 04′ 58.9″	98° 24′ 58.4″	54.5 56.5	39 17
3	20° 04′ 58.3″	98° 24′ 56.7″	89.5 64.5	52 39
4	20° 03′ 32.2″	98° 04′ 35.0″	272.5	<2>
5	20° 01′ 56.1″	98° 47′ 32.9″	234.5 149.5	59 49
6	20º 08′ 37.8″	98º 17′ 08.4″	225.5 63.5	40 25
7	20º 08′ 37.2″	98º 17′ 09.1″	216.5 63.5	20 16
8	20º 08′ 37.3″	98º 17′ 08.5″	264.5 54.5	45 15
9	20º 08′ 37.6″	98º 17′ 08.0″	213.5 58.5	14 14
10	20º 08′ 38.2″	98º 17′ 09.1″	219.5 59.5	22 9
11	20º 08′ 19.4″	98º 17′ 05.0″	197.5 57.5	21 12
12	19º 48′ 25.0″	98º 40′ 21.5″	146.5 34.5	61 12

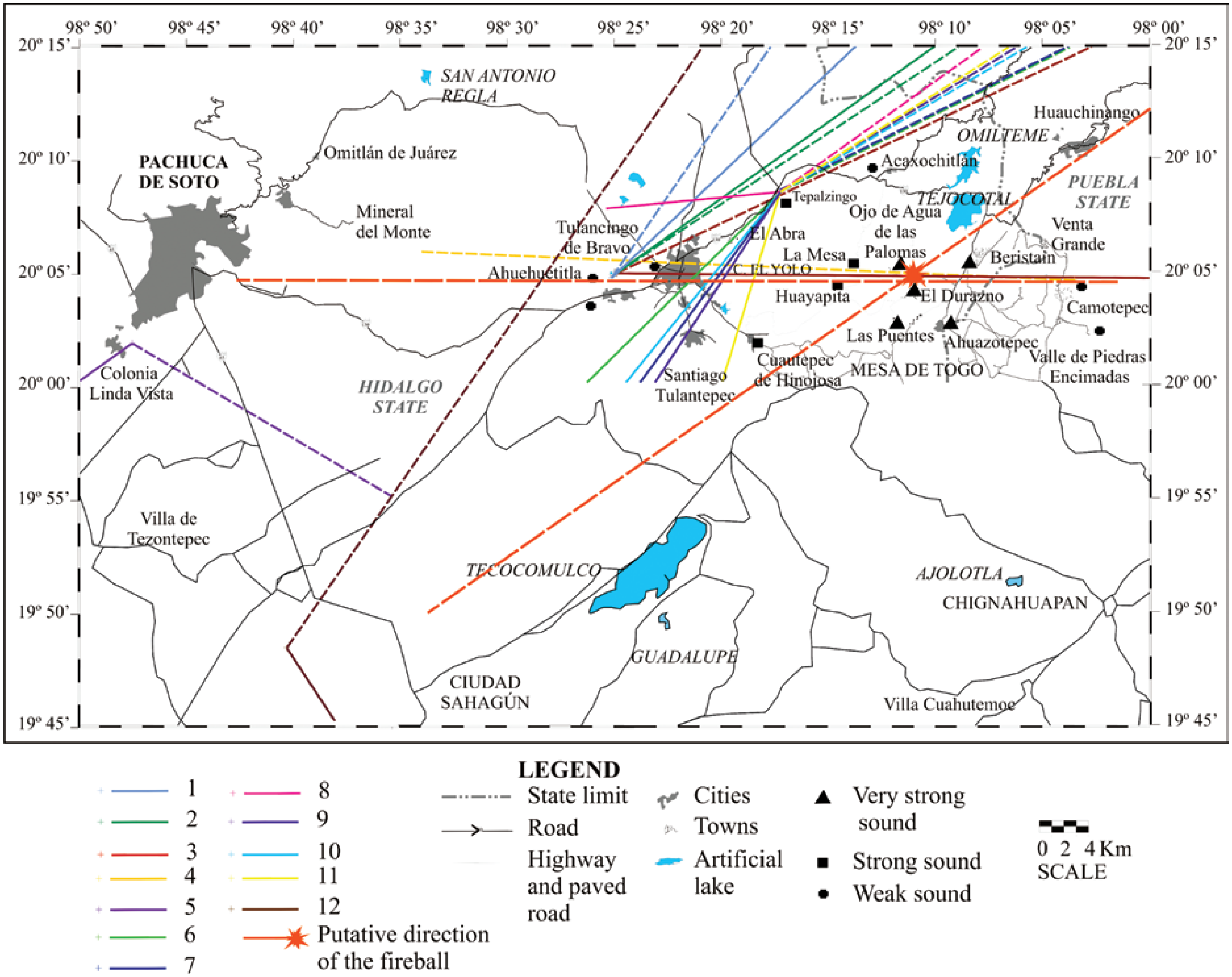

Figure 2. Location of the towns listed in Table 1 and the location of eyewitnesses in Table 2. (●) pointed at places where the sound of the explosion was weak. (■) pointed at places where the sound was strong, (▲) pointed at places where the sound was very strong. The classification of the last two is subjective. Colors of the lines are related to each witness according to the label inside this figure and Table 2. For each eyewitness, solid lines indicate the beginning of the observed path and dotted lines indicate the end of the observed path of the bolide.

The luminosity of a bolide depends on the mass loss rate of the meteoroid (Ceplecha *et al*., 1998; Hills and Goda, 1993). Extinction occurs when the ablation is over, that is, when the bolide slows down to ~3 km s^{-1} (Passey and Melosh, 1980; Ceplecha *et al*., 1998; Trigo-Rodríguez *et al*., 2006). Thus the observed path corresponds to the luminous part of the trajectory in the atmosphere.

According to witness 3, the bolide flared up two or three times during the time of observation (~3). Each flare-up represents a discrete fragmentation event (Ceplecha and ReVelle, 2005; Trigo-Rodríguez *et al*., 2006). Thus the bolide had two or three minor fragmentations before it was extinguished. Finally, the meteoroid exploded and the report was heard by the inhabitants of localities around El Durazno.

Witnesses 2 and 4 (Table 2) only saw the trail of the bolide or a kind of cloud. The eyewitnesses near Tulancingo (1 and 3), reported that they saw the bolide for ~7 seconds and ~3 seconds, respectively. Witness 3 claimed that the bolide was brighter than the full Moon. Both mentioned that they heard a sound, but not a very loud one. The witness near Pachuca reported that he did not hear any sound, but only saw the bolide.

Witnesses 6 to 11 were in a football field in Tepaltzingo (Fig 2) when they saw the bolide. They describe the bolide as a fire ball whose apparent magnitude range was between 6 and the full Moon (-12). They commented that the object sparkled like burning wood and looked blue in front, red in the middle part and yellow-orange at the tail. They heard a sound like a sonic boom approximately 7 seconds after they lost sight of the bolide behind a nearby hill.

Witness 12 was in a prickly pear field in San Felipe. He described the bolide as an object similar to the size of a compact car.

Trajectory

Using the stereographic method described in methodology section 4, we obtained the planes and the poles of these planes from the data provided by each eyewitness. Plotting the poles, we found that they could be grouped into four sets of points labeled with roman numerals in Fig. 3. For each set of points we obtained an average pole and plotted the perpendicular plane to it (curves I to IV in Fig. 3). The resulted planes are defined by a deep (inclination with respect horizontal) and a strike (direction perpendicular to deep) (Table 3). The intersection of these planes must be the trajectory of the bolide.

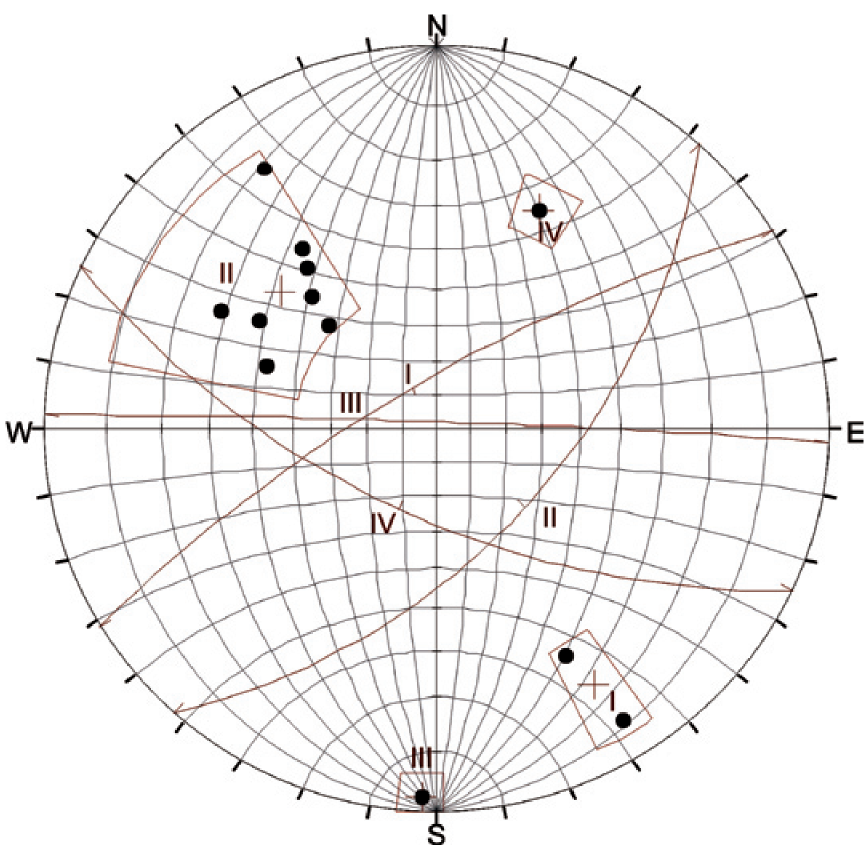

Figure 3. Wulff stereonet projection of the data. Points are the poles of the planes of each eyewitness. On it, planes are represented by curves, lines are represented as points. Roman numerals represent sets of poles, enclosed points are used to obtain a mean plane. The intersections between planes represent the bolide trajectory.

Table 3. Mean planes obtained from the data provided by the twelve eyewitnesses. Inside the parenthesis, the data from Table 2 that were used to determine the plane are identified.

Mean Plane **Set number** (Eyewitness)	Strike	Deep	95.44% Confidence limit
I (2, 8)	239	76	14.4 °
II (1, 3, 6, 7, 9, 10, 11, 12)	42	569.7°	
III (5)	115	64	-
IV (4)	272	88	-

Considering the points of intersection between the most confident data (curves I, II and III), we obtained several possible trajectories (Table 4). The intersection between planes I and III was rejected, because the bolide would have traveled in a direction opposite to the one which was actually seen. The intersection between planes II and III yielded an East-West direction to the trajectory; this result is more reasonable but a West-East direction does not represent all the data. The trajectory obtained from the intersection between planes I and II defines better the flight of the bolide. The azimuth of the trajectory is between 55º and 90º, represented by two lines through the orange star in Fig. 2. This star points to the location where the sound of the sonic boom was the strongest within the area enclosed by triangles where the sound was very strong.

Table 4. Trajectories obtained from the intersection of three pairs of the planes described in Table 3.

Line from mean plane intersection	Azimut	Angle
I and II	55°	16°
II and III	90°	47°
I and III	277°	78°

Earthquake

According to witnesses in Ahuazotepec, El Durazno and Las Puentes (Table 1), a tremor, similar to the one produced by the passing of a heavy truck was associated with the explosion. In El Durazno, water in ponds overflowed, as in an earthquake. According to this, people felt a seism of intensity I to IV on the Mercalli scale (Lowrie, 1997). No earthquake was recorded at the seismological stations near the area. There were no microbarographs in the area.

Future Work

More field work in needed to constrain the trajectory of the bolide in order to constrain the area where to look for meteorites. Meanwhile, it is probable that a meteorite or meteorites could be found in the mountains around El Durazno, though this is not an easy task.

A meteor network in Mexico will require documenting the incidence of meteoroids and small bodies.

Conclusions

This event caused fear among the inhabitants of Hidalgo and Puebla and was reported in the media. Civil protection and military agencies were involved in the search. It is important to study this kind of events in order to inform and to calm people. The civil protection departments of both states gave us all the information that they compiled.

Unfortunately, there were no seismic, barographic, photographic or sonic records that we could use to define the trajectory of the bolide. It is important to have a bolide network.

From the data of twelve eyewitnesses, we obtained a rough estimation of the trajectory of the bolide. The azimuth falls between 55º and 90º with an angle to the horizontal of between 16º and 47º.

Acknowledgments

The authors would like to acknowledge Jesús García Avila and José Luis Lastiri García, heads of the civil protection and fire departments of Tulancingo (Hidalgo) and Zacatlán, (Puebla) and their staffs. The assistance of Lic. Jorge Márquez Alvarado and C. Raymundo Olvera Muñóz, municipal presidents of these localities, and inhabitants of these sites, is much appreciated. Without their cooperation, interest, and kindness, it would not have been possible to do this work. We thank the support of the Institute of Geophysics, UNAM. We thank Jose Luis García Martínez and Gilberto Arreguín Molina for their useful comments to this work.

Bibliography

Bailey M.E., Markham D.J., Massai S., Scriven J.E., 1995, The 1930 "Brazilian Tunguska" Event. *The Observatory,* 115, 250-253.

Ben-Menahem A., 1975, Source Parameters of the Siberian Explosion of June 30, 1908, from Analysis and Synthesis of Seismic Signals at Four Stations. *Phys. Earth Planet. Int.,* 11, 1-35.

Brown P., Spalding R.E., ReVelle D.O., Tagliaferri E., Worden S.P., 2002, The flux of small near-Earth objects colliding with Earth. *Nature,* 420, 294-296.

Brownlee D.E., 2001, The Origin and Properties of Dust Impacting the Earth in Accretion of Extraterrestrial Matter Throughout Earth's History. In B. Peucker-Ehrenbrink and B. Schmitz (eds.), Kluwer Academic-Plenum Publishers, Accretion of Extraterrestrial Matter Throughout Earth's History, New York, pp. 1-12.

Ceplecha Z., Borovička J., Elford W.G., Revelle D.O., Hawkes R.L., Porubčan V., Šimek M., 1998, Meteor Phenomena and Bodies. *Spa. Sci. Rev.,* 84, 327-471.

Ceplecha Z., ReVelle D.O., 2005, Ffragmentation model of meteoroid motion, mass loss, and radiation in the atmosphere. *Met. & Plan. Sci.,* 40, 35-54.

Herrera Cortés J.J., AEXA (Agencia Espacial Mexicana). [27 April, 2010] <http://www.aexa.tv/index.php?option=com_content&task=view&id=277&Itemid=2>.

Hills J.G., Goda M.P., 1993, The Fragmentation of Small Asteroids in the Atmosphere. *The Astron. J.,* 105, 1114-1144.

Kelso T.S., Celestrak. [25 April, 2010] <http://celestrak.com>.

Leyshon P.R., Lisle R.J., 1995, Stereographic Projection Techniques in Structural Geology. Oxford, Butterworth-Heinemann, 112 pp.

L'Osservatore Romano (Informazioni Fides), 1931, La Caduta di Tre Bolidi alle Amazzoni, Nr. 50, 1, March, 5.

Lowrie W., 1997, Fundamentals of Geophysics. Cambridge University Press. UK, p. 127.

Madiedo J.M., Trigo-Rodríguez J.M., Alonso J., Zamorano J., Ocaña F., Docobo J.A., Pujols P., Lacruz J., 2009, The Spanish Meteor Network (SPMN): Full Coverage of the Iberian Peninsula by means of High-sensitivity CCD Video Devices. EPSC Abtracts, 4, EPSC2009-560.

Manville V., Sherburn S., Webb T., 2004, Seismic detection of the 7 July 1999 Hawera Fireball. *New Zea. J. of Geol. & Geophy.,* 47, 269-274.

Martin Von H., 1966, Die Tunguska-katastrophe in geophysikalischer Sicht. *Die Sterne,* 42, 3/4, 45-51.

Musson R.M.W., 2006, The enigmatic Bala Earthquake of 1974. *Astron. & Geophy.,* 47, 5, 11-5, 15.

NASA. NASA Orbital Debris Program Office. [25 April, 2010] <http://www.orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html>.

Passey Q.R., Melosh H.J., 1980, Effects of Atmospheric Breakup on Crater Field Formation. *Icarus,* 42, 211-233.

Poveda A., Herrera M.A., García J.L., Curioca K., 1999, The Diameter Distribution of Earth-crossing Asteroids. *Plan. Spa. Sci.,* 47, 679-685.

Shumilov O.I., Kasatkina E.A., Tereshchenko E. D., Kulichkov S. N., Vasil'ev A. N., 2003, Detection of Infrasound from the Vitim Bolide on September 24, 2002. *JETP Letters,* 77, 2, 115-117.

Space Track. The Source for Surveillance Data. [26 April, 2010] <http://space-track.org/perl/decay_query.pl>.

Trigo-Rodríguez J.M., Borovička J., Spurný P., Ortiz J.L., Docobo J.A., Castro-Tirado A.J., Llorca J., 2006, The Villalbeto de la Peña Meteorite Fall: II. Determination of Atmospheric Trajectory and Orbit. *Met. & Plan. Sci.,* 41, 505-517.

Yeomans D., NASA. Near Earth Object Program. [27 April, 2010]. <http://neo.jpl.nasa.gov/news/news165.html>.