# 5.5 Cause of Explosion

**5.5-1** **What caused the explosion?**

**5.5-2** **Lightning: Linkage to the explosion**

**5.5-3** **How lightning may have entered the mine**

## 5.5-1 What caused the explosion?

A variety of possible causes were considered and evaluated as part of the investigation into the January 2, 2006 explosion at the Sago mine. Ignitions caused by open flame, spontaneous combustion, roof falls, faults in the mine electrical systems, and lightning were suspected and considered. The following summarizes the findings of each. Lightning is the probable cause of the explosion.

### 5.5-1a Open Flame

The seals had been completed for a period of 22 days when the mine explosion occurred, making it unlikely that an open flame of man-made origin could have been the source of the ignition which is known to have originated within the sealed area itself. No evidence was found of any batteries, smoking materials, or other potential ignition sources in or around any area that could have been the source of the ignition.

### 5.5-1b Spontaneous Combustion

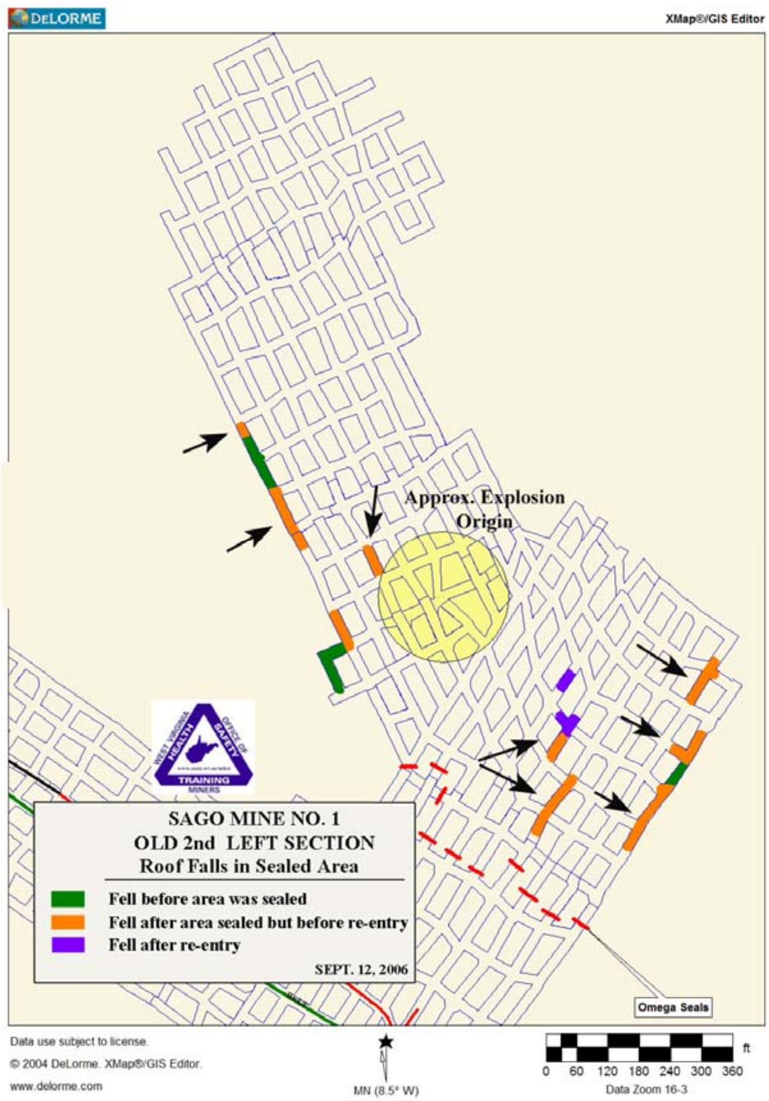
Spontaneous combustion is a potential problem with coals that have chemical properties that enable endothermic reactions to heat the coal to the point that it can smolder and eventually catch fire without an outside ignition source. Western coals that have a high moisture content and a low fixed carbon-to-volatile ratio are susceptible to spontaneous combustion. This phenomenon is not without precedent in the Eastern U.S. but it is much less common. Documented cases exist where oxidation of reactive constituents in the coal such as iron sulfides[1] can lead to self-heating. Typically, however coals that are susceptible to spontaneous combustion generally show signs that are recognized early in mining, i.e. the coal has an established history of spontaneous heating in open stockpiles or gob piles. Further, spontaneous combustion would not go away after the explosion. It would continue to smolder and would

[1] Pyrite and marcasite are the most common

likely be very difficult to extinguish. There has been no known history or evidence of spontaneous combustion at the Sago Mine either before or after the explosion.

### 5.5-1c Roof falls

There are several roof falls that have been identified and mapped within the sealed-off area of the mine. **Map 1** illustrates the location of known roof falls. Rocks of certain types[2] are capable of creating sparks if they strike metal objects such as roof bolts.




**Map 1**.—The location of known roof falls in the area behind the seals. Arrows indicate those falls which occurred after the seals were built but before mine re-entry.

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2 Quartzose sandstone or chert are two such rock types that have sparking potential characteristics.

Several of these falls are known to have occurred either before the explosion or after the explosion, and so have been discounted. Of the remaining falls (indicated with arrows), only one (1) is in the region where the balance of the evidence indicates the explosion originated.

**Photo 1.** Roof fall in Old 2$^{nd}$ Left Section. In some cases, a determination of whether the fall occurred before or after the explosion could be made by the relative abundance of soot covering it. A heavy soot typically covered falls that occurred before (or possibly during) the explosion.

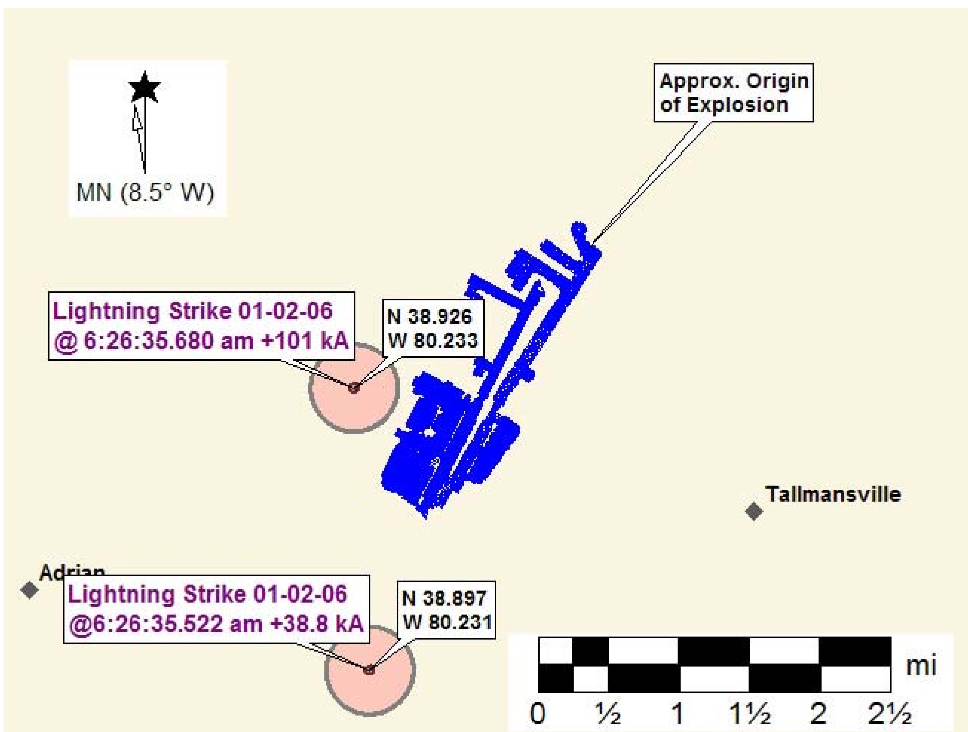
The domed top of the fall contains inter-bedded layers of sandstone that, under the right conditions, could have produced the necessary spark. However, after examining this area several times since the explosion, no evidence has been found that would indicate that the ignition started there. The balance of the inferred propagation directions of the blast favors a point-of-origin farther to the southeast.

### 5.5-1d Mine electrical system

No evidence was found of any electrical equipment malfunction or failure of electrical circuits that could have caused ignition of the explosive mixture of methane and oxygen behind the seals. No apparent lightning damage was found in any electrical equipment or in the electrical installations on the surface or underground[3]. Testing is still ongoing in several different areas trying to determine the cause of the explosion. Deficiencies were found, both on the surface and underground, resulting in 33 non-contributing violations being issued by the West Virginia Office of Miners' Health, Safety & Training. (**Appendix 5.1:** *Statistics and Fact Finding).*

### 5.5-1e Lightning

A severe winter electrical storm passed through the Sago region the morning of January 2, 2006. Shortly before 6:30 AM EST, the storm produced several intense lightning discharges near the mine, and mine personnel and nearby residents heard loud thunder which they described as being "extremely violent."




**Map 2.** Two (2) of the lightning strikes reported by Vaisala between 5:00 AM and 7:00 AM EST on January 2, 2006 within a 5- mile radius of the top end of Sago Mine. The closest strike to the mine was also the strongest (101,000 amperes).

3 Except for damage to the 12kV powerline, as noted and described in Section 5.5-3d.

On January 5, 2006, the OMHS&T ordered a report of lightning strikes in the Sago area at about the time of the explosion from Vaisala-Thunderstorm[4] in Tucson, Arizona Vaisala provided strike locations in latitude and longitude coordinates, together with estimates of the peak current in the discharges and the polarity (see **Appendix 5.5-2**: *STRIKEnet Report LA105304).*

Two large and nearly simultaneous positive cloud-to-ground strokes were recorded within 2 – 2.5 miles of the Omega seals across Old Second Left Section at the time of the explosion. One strike was located approximately 1 mile NW of the mine portal and the other approximately 1 mile to the SW.

Testimony by mine personnel on the surface described the wind picking up and a strong lightning flash illuminating the general area accompanied by ground shaking near the time of the explosion. Immediately afterward alarms began to sound on the CO monitoring system on the #4 Belt near the mouth of 2 Left Section. The CO monitor located at the 2 Left Section Belt tailpiece lost communications within 14 seconds. The underground power tripped at a splitter box near the #2 Belt Power Center within 23 seconds of the initial CO monitor alarm at #57 block on #4 Belt sounded. Later corroborating evidence included:

- Precise time correlation of the CO alarms with the lightning strikes
- Correlations with a subtle seismic event recorded by a seismograph in Morgantown, West Virginia
- Physical evidence at one of the lightning strike locations
- The accounts of nearby residents

How lightning actually entered the mine has been the subject of intense examination. The actual means by which this happened has at this writing not been determined with certainty. Additional research continues and resources are being used to gain more answers to this question than currently are available.

More details on the apparent linkage of lightning to the explosion are given **Section 5.5-2** of this report.

[4] Vaisala (pronounced *Vi' sa-la'*) is an Arizona-based commercial lightning service that provides reports of lightning strikes detected by the National Lightning Detection Network

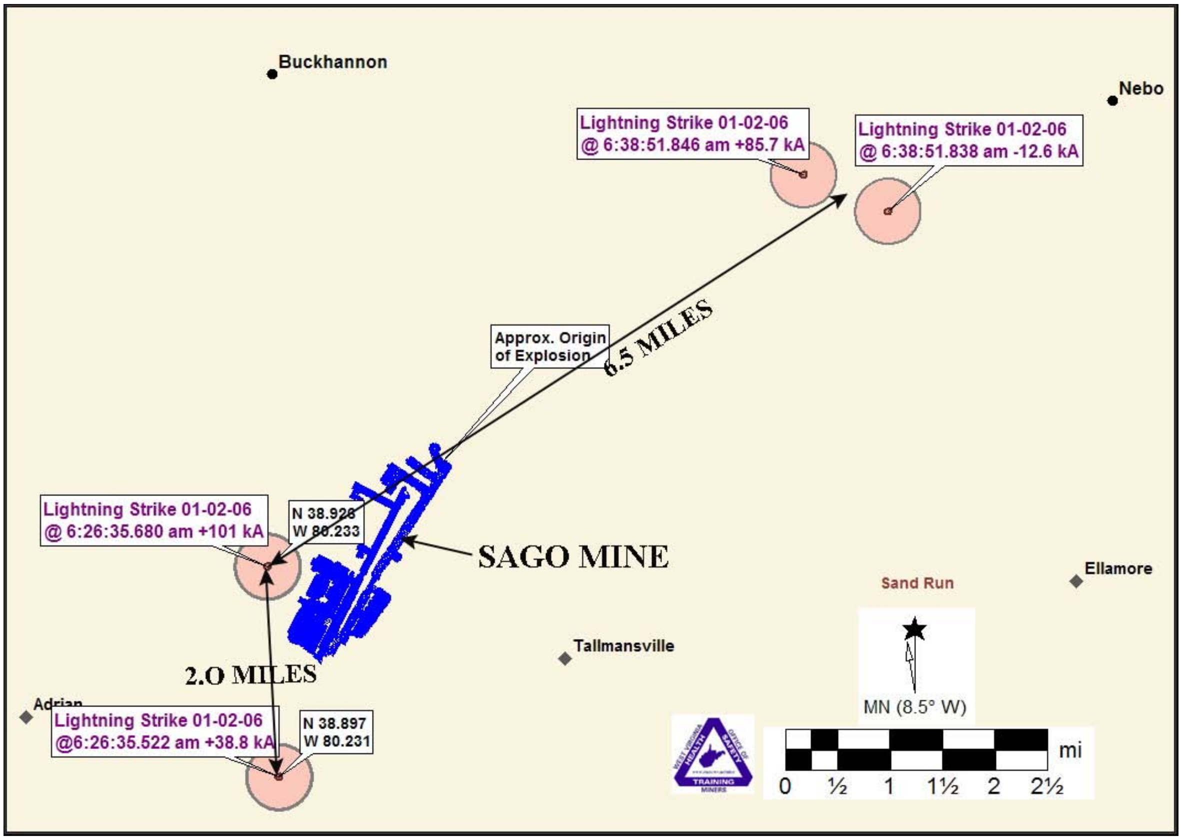
# 5.5-2 Lightning: Linkage to the explosion

### 5.5-2a Lightning Strikes recorded by Vaisala

Evidence for a lightning-related cause for the January 2, 2006 explosion began to emerge early in the investigation. There were reports of a severe strike close to the Sago Mine just prior to the belt alarms going off and the loss of power systems underground. As investigators waited for mine recovery efforts to allow the underground examinations to begin, the initial focus of the investigation began with the exploration of leads and collection of evidence which could be performed on the surface. Because of the strong electrical storms that were ongoing that day, the issue of lightning was addressed.

Several commercial lightning detection networks provide lightning data for almost any location in the country and requests for reports of these events can be made online. On January 5, 2006 OMHS&T obtained a report of four (4) lightning strikes within a 5-mile radius of a point on a map centered at the Old 2$^{nd}$ Left section of Sago Mine (**Appendix 5.5-2:** *STRIKEnet Report LA105304*) for the time period between 5:00 AM and 7:00 AM EST on 1-2-06. This report was provided by StrikeNet, a division of Vaisala, based in Tucson, Arizona. A summary of the results are shown below.

| Date / Time | Latitude | Longitude | Amperes (000's) |
|---|---|---|---|
| 01/02/06 06:26:35.522 EST | 38.897 | -80.231 | +38.8 |
| 01/02/06 06:26:35.680 EST | 38.926 | -80.233 | +101.0 |
| 01/02/06 06:38:51.838 EST | 38.975 | -80.123 | -12.6 |
| 01/02/06 06:38:51.846 EST | 38.980 | -80.138 | +85.7 |




**Map 1.** Location of lightning strikes within a 5 mile radius of the center of the Sago Old 2nd Left sealed area between the hours of 5:00 AM and 7:00 AM on the morning of January 2, 2006. Strike coordinates, magnitudes, and polarities were provided by Vaisala-Thunderstorm Unit in Tuscon, Arizona-- owned and operated by the National Lightning Detection Network (NLDN).

### 5.5-2b Physical evidence of lightning

On Friday, January 6, 2006 a representative of OMHS&T accompanied by an engineer from Anker Mining West Virginia Mining Company, Inc.[1] traveled to the closest (and strongest) of the reported lightning strikes using a GPS unit and the coordinates provided by Vaisala—a drive of approximately three minutes from Sago Mine. There, a large poplar tree was spotted with conspicuously fresh damage in its top. Closer inspection confirmed it to be the result of a very recent lightning strike. A wide gash extending from the top to the bottom of the 50-ft. tree spiraled 360-degrees (**Photo 1**). The force of the lightning produced a small gouge in the ground at the base of the tree. The poplar tree is located approximately 197 ft. from the coordinates provided by Vaisala.

[1] Anker Mining, WV provided GPS tracking and coordination with landowners

Wood debris from the lightning strike was found around the tree and this was documented in a survey performed on January 13, 2006 by Allegheny Surveys, Inc., based out of Birch River, WV[2] (see **Appendix 5.5-2**: *Forensic Survey of Poplar Tree*). Disintegration of the top portion of the tree left splintered wood fragments ranging from several feet to just inches in length, scattered symmetrically within a radius of approximately 150-feet.

**Photo 1.** A poplar tree recently stuck by lightning was located on 1-6-06 near the location where Vaisala recorded a +101kA lightning strike on 1-2-06 at 6:26:35AM. Photo by Kermit Melvin

On the afternoon of January 6, 2006 an attempt was made to locate similar physical evidence at each of the other three (3) locations. A +38.8 kA stroke that was approximately simultaneous with the poplar tree strike was reported approximately two (2) miles to the south. The other two strikes were both time-wise and geographically next to one another and located approximately six and one-half (6.5) miles to the northeast (see **Map 1**). The two lightning

[2] Allegheny Surveys. Inc. also assisted in establishing ground control to site the boreholes the night of January 2, 2006.

strikes to the northeast occurred 12 minutes and 16 seconds after the +101 kA and +38.8 kA strokes. Despite efforts on this day and on subsequent days, and despite repeat efforts by others, no other physical evidence of lightning from that day has been found at these remaining locations.

### 5.5-2c CO Monitor Correlation

The underground belt conveyor haulage system at Sago Mine is equipped with a Pyott Boone Model 1703 gas monitoring system (**Photo 2**) which continuously monitors carbon monoxide (CO) concentrations at strategic locations along its length. This information is analyzed and recorded on a desktop computer located at the mine dispatcher's office at the surface. A computer log for the period December 25, 2005 to January 11, 2006 is contained in **Appendix 5.5-2:** *Pyott Boone Data*.

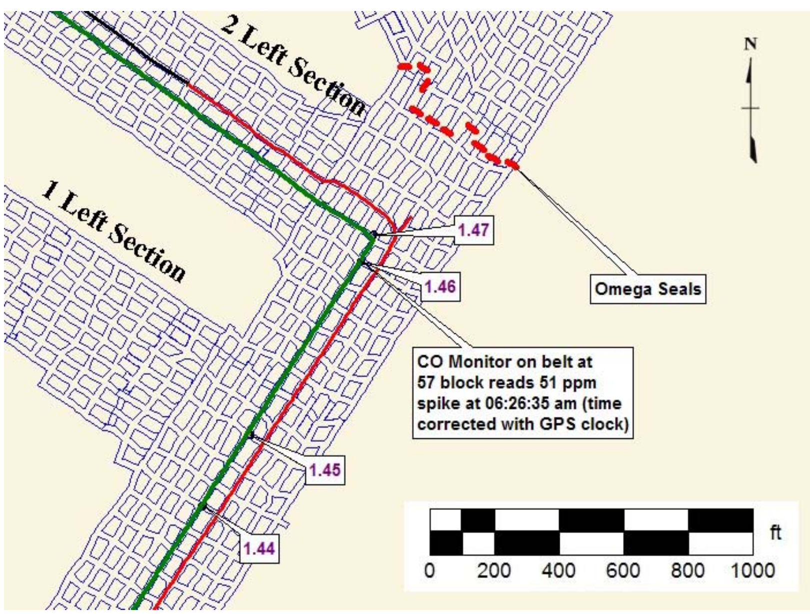

**Photo 2.** An example of the CO (carbon monoxide) monitors used to monitor the conveyor belt for mine gases underground at the Sago mine.

**Map 2** (below) shows the location underground of CO monitors 1.46 and 1.47 on #4 Belt at or near where it adjoins #6 Belt. Unit 1.46 was located at #57 Break on #4 Belt—a distance of approximately 500 ft. from the front of the Omega seals and in-line with the explosion forces. The system is set up to signal trouble as follows:

| CO Concentration | Status |
|---|---|
| < 5 ppm | Normal |
| 5 ppm | Warning |
| 10 ppm | Alarm |
| 107 ppm | Max reading (sensor overload) |

According to the computer log at 31 seconds after 6:31 AM sensor unit 1.46 on #4 Belt sent an alarm for 51 ppm[3] CO concentrations, and it was never heard from again. Seconds later the two monitoring units downstream on #4 Belt reported 107 ppm just before they too disappeared from the system. CO monitors and belt systems suddenly began reporting trouble, reporting CO, power loss, and dead communications along #4 Belt and also along # 5 Belt and #6 Belt[4]. These events document the timing of the explosion which, according to the computer clock apparently began with the 51 ppm alarm at 6:31:31 AM.

The Pyott Boone CO monitoring system sends its information to the surface through a communication line to a standard PC desktop computer running Windows 2000. The time assigned to recorded events is based on the time kept by the internal clock in the computer, which was set close to the correct time, but not exactly.




**Map 2**. Location of some of the CO monitors on the mine conveyor belt at the time of the explosion.

3 ppm-- parts per million
4 located in 1 Left Section and 2 Left Section, respectively

On January 11, 2006 an accuracy check was performed on the computer clock and it was found to have been set 4 minutes and 56 seconds ahead of the actual time[5]. This determination was made by comparing the time that had been set manually with a GPS receiver that reported Universal Time[6] -- the same time that Vaisala and other lightning detection networks use to report lightning strikes.

After correcting the log of the CO monitor by subtracting 4 minutes and 56 seconds from the recorded times the actual time of the 51 ppm CO alarm at 6:31:31 AM was determined to be 6:26:35 AM. This is only a few fractions of a second different from the time of the +101 kA and +38.8 kA lightning strikes that were recorded by Vaisala: 6:26.35.680 AM and 6:26:35.522 AM, respectively. The estimated accuracy of this time correlation is +/- 1 second. A compelling connection with lightning was thus established.

### 5.5-2d Seismic event correlation

The timing of the explosion as indicated by the CO monitor log (using the corrected time) has been corroborated by at least four (4) seismographs in West Virginia and Virginia that recorded a subtle ground disturbance very close to Sago Mine at that time. The location of the epicenter of this subtle seismic event is in the region of Sago Mine.

Seismographs residing at the West Virginia Geological Survey located near Mont Chateau, and at least three (3) other locations recorded a subtle seismic event that was analyzed by a seismologist[7] at Virginia Polytechnic Institute in Blacksburg, Virginia. Seismograph recordings from stations located in Blacksburg, Virginia; Prospectville, Virginia; and Forest Hill, West Virginia were also used. The Sago seismic event correlated closely with the (corrected) timing of the Sago mine explosion as signaled by the 51 ppm CO spike on the Pyott Boone computer log. A brief report was written about the analysis of the seismic data and provided to investigators. A copy of this report is given in **Appendix 5.5-2**: *Results from Analysis of Seismic*

[5] Memorandum to Doug Conaway from Monte Hieb dated January 12, 2006 (see **Appendix 5.5-2**)
[6] Time correlation provided by Allegheny Land Surveying and documented later in a letter dated January 14, 2006 (see **Appendix 5.5-2:** *Time Differential of CO Monitors computer at Sago*)
[7] Martin Chapman, Director, Department of Geosciences, VPI&SU; Results from the Analysis of Seismic Data for the January 2, 2006 event near Sago, WV, 8pp.

*Data for the January 2, 2006 event near Sago, WV.* Three (3) different methods were used to calculate the timing[8] of the seismic event.

| | | |
|---|---|---|
| Method 1: | Depth constrained | 06:26 AM 36.6 sec. to 06:26 am 39.9 sec. |
| Method 2: | Depth unconstrained | 06:26 AM 35.4 sec. to 06:26 am 41.2 sec. |
| Method 3: | Depth and loc. unconstrained | 06:26 AM 36.5 sec. to 06:26 am 40.0 sec. |
| | Average: | 06:26 AM 38.2 seconds +/- 2 seconds. |

The report concludes that it is possible the exact time of the event could be a bit earlier due to the fact that the signal was so close to the noise level that the exact arrival times of the P-wave (the "primary" or "compression" wave) and the S-wave (the "secondary" or "shear" wave) are not precise.

Summary and conclusions:

The very close time correlation of two near-simultaneous lightning strikes with the first signals from the CO monitor indicating that there had been an explosion, together with corroboration of the time by analysis of a subtle seismic that originated near Sago Mine, provides strong circumstantial evidence that has led investigators to conclude that lightning was associated with the mine explosion of January 2, 2006, and most probably was the direct cause.

| | |
|---|---|
| • Time of +38.8 kA lightning strike | 6:26 AM 35.522 sec. +/- .0005 sec. |
| • Time of +101 kA lightning strike | 6:26 AM 35.680 sec. +/- .0005 sec |
| • 51 ppm CO spike (first detection of explosion) | 6:26 AM 35 sec. +/- 1 sec. |
| • Seismic event recorded by MCWV, et.al. | 6:26 AM 38.2 sec. +/- 2sec. |

[8] Seismographs are also based on GPS clock time

### 5.5-2e Residents interviews

Information provided by lightning detection networks gives only part of the story about the lightning activity in the Tallmansville Road area above Sago Mine that morning. Residents' descriptions about what they saw and felt that morning provides an account of the electrical storms that is not recorded elsewhere. Although this testimony varies, there is a sense that the storm was remarkable in several ways:

- There was considerable lightning and thunder that morning, but one particular discharge stood out from the rest.
- That flash was accompanied by what many describe as an explosion or long crash that shook the ground.
- The ground shaking was described primarily by people living on the ridge above the Sago Mine. Shaking on Bailey Ridge[9] was described as exceptionally strong, lasting for many seconds.
- While hardly anyone describes a lightning bolt striking the ridge, many describe a flash that momentarily lit up the sky like day. Some describe a strong flash to the east—one so strong it left one resident's ears ringing.
- Rolling thunder following the flash was described by some. One resident on Bailey Ridge described it as rolling from east to west.
- Remarkably, no one lost power that morning. Lights may have flickered, but if there were outages due to lightning, they were few in number.

It is unlikely that the explosion caused the ground shaking that residents on the ridge describe. The men at 1 Left Switch did not hear an explosion. They felt the blast and were pelted with debris, but did not hear an explosion. Strong ground shaking was not mentioned.

Residents that live between the location of the +101 kA lightning strike and the vicinity of the communication towers to the northeast on Bailey Ridge were interviewed and summaries of those interviews are given below. Also, **Appendix: 5.5-2:** *Sago Mine Resident Interviews* gives a map showing the locations of those interviewed and selected comments of the residents.

[9] A high ridge situated approximately one (1) mile east of the area where the underground methane explosion occurred.

3-8-06 Resident 1

Residence on the surface above Old 2nd Left Section

This resident was up at 4:00AM on January 2, 2006 (normal waking time). Thunder and lightning were occurring in the area for most of the morning. He could not be specific on the location or distance away. There were no electrical power or telephone interruptions.

- Lightning was identified in the area. Recalls lightning from 5:00 AM to late morning.
- Thunder was identified in the area but no relation to timing with lightning strikes.
- Proximity of lightning not distinguished.
- No ground strikes noted.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

3-14-06 Resident 2

Plant manager for the potable water for the area south of Buckhannon River.

This water supply system provides mine supply water and potable water for Sago Mine. The treatment plant is near the second Vaisala, lightning strike location. Plans and drawings indicate that the line construction to the mine is PVC – not - metal pipe. The only exception is 140 ft. of metal pipe crossing the Buckhannon River. The potable water supply line is 4 in. and the mine water supply line is 6 in. Lab analysis shows that the specific conductance of both samples are 110.

3-15-06 Resident 3

Residence above explosion area of Sago.

This resident's house sets directly over the sealed area of Sago Mine (between 7 & 8 entry – next to the last cross cut of mains). Between 6:00 and 6:30 AM he was awakened by the storm. Lightning in the area illuminated the sky and the sound of thunder was instantaneous with the lightning. It was so violent that it shook the windows and pictures in the house. Everything outside was as bright as mid day when the lightning would strike. He was at the doorway on the east side of the house trying to retrieve his pets. Did not specifically see lightning – only the illumination. When it thundered, the cats in the house scattered-- the fur raised on the animals. When asked about the electrical power and telephone, he stated there were no disruptions, but thunderstorms usually knock the power out.

- Lightning was identified in the area and was very strong. Timing of lightning was between 6:00 and 6:30AM.
- Thunder was identified in the area and was intense.
- Proximity of lightning was very close (flash-boom).
- No ground strikes physically observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

3-16-06 Resident 4

Resident above explosion area of Sago

This resident was awaken approximately 5:00AM from the lightning and thunder, she checked on the children sleeping over with her daughter. She stated, clearly lightning and thunder was in the area. Did not know the location of the lightning, but it illuminated the house when she checked the time. She went back to bed and at 6:30 AM she was awakened by thunder / explosion. This was so extreme that it frightened her. It shook the pictures on the wall. She feels it was the explosion and not thunder. She stated that there was no electrical power and, to her knowledge, telephone loss, which seemed unusual to her because electrical storms usually disrupt the power in the area.

- Lightning was identified in the area and was very strong.

- Thunder was identified in the area and was intense. Was awakened by thunder at 6:30 AM.
- Proximity of lightning was close.
- No ground strikes observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

3-20-06 Resident 5

Resident above explosion area of Sago

This resident is elderly and her house is on the southern edge of "Old 2nd Left Section", 3 breaks inby the mains. She was up around 6:00 AM and did not see any lightning or hear thunder. She did hear a BOOM around 6:30 AM and feels it was the explosion. She stated that she doesn't believe that lightning caused the Sago explosion. There were no power problems – not even flickering, which usually happens when a storm is in the area. To her recall, the telephone service was not interrupted. She stated there are two wells and one cistern on her property. On April 19th samples and location of two wells and two springs were taken. These water sources were sampled and sent to a laboratory for analysis.

- Lightning was not identified in the area.
- Thunder was not identified in the area, but did hear a boom (She feels it was an explosion.).
- Proximity of lightning was not identified.
- No ground strikes observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

3-22-06 Resident 6

Resident above explosion area of Sago

This resident was up at 4:30 AM and her husband left for work at 5:15 AM. There was a storm in the area (bushes along house were blown by wind / rubbing house). Did not hear any thunder or see lightning. Between 5:45 & 6:30 AM she was awakened by a loud noise that seemed to come from the ground. She thought it was an earthquake and ran to the bathroom for protection. The noise also woke the children. There was no power outage and to her knowledge the telephones were okay.

- Lightning was not physically identified in the area.
- Thunder was not identified in the area (Thought loud noise came from the ground and felt it was an earthquake. Timing was between 5:45 and 6:30 AM).
- Proximity of lightning was not identified.
- No ground strikes observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

3-28-06 Resident 7

This resident was awake at 5:00 AM. There was a storm in the area with thunder and lightning. Around 6:30 AM a strike of lightning was so strong he actually thought a bomb went off. There was no loss of power, and between 10:00 to 10:30 he used his telephone.

- Strong lightning was identified in the area and, the time was around 6:30 AM.
- Thunder was identified in the area and intense.
- Proximity of lightning was very close, but not measurable.
- No ground strikes were observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

3-28-06 Resident 8

This resident was awake at approximately 6:00 AM. Stated the thunder was different and rumbled for a long time. There was no power interruption, and, as far as she knows, no problem with the telephone. She did not use the telephone until the afternoon that day.

- Lightning was identified in the area, but not severe.
- Thunder was identified in the area, but seemed normal.
- Proximity of lightning was not identified.
- No ground strikes were observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

3-30-06 Resident 9

This resident was up around 6:00 AM. A storm was in the area around 6:30 AM. The thunder was the strongest he had ever heard. There was an instant "flash – boom". The power flickered but stayed on. The telephone service, to his knowledge, also stayed on.

- Lightning was identified in the area and very strong. The time was identified around 6:30 AM.
- Intense thunder was identified in the area.
- Proximity of lightning was very close (flash-boom). (Location was to the south of his home.)
- No ground strikes were specifically located.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

3-30-06 Resident 10

This resident let her pet dog out of the house around 6:00 AM. She stated the storm was very bad with multiple strikes of lightning – mostly to the northeast of their home. The electricity and telephone service never did go out.

- Strong lightning was identified in the area. The storm occurred all morning, but was the strongest around 6:30 AM.
- Intense thunder was identified in the area.
- Proximity of lightning was not identifiable.
- No ground strikes were observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

4-3-06 Resident 11

This resident stated he was awakened at 6:30 AM by the loudest thunder he had ever heard. He could not identify the location or direction of the lightning. There were multiple lightning strikes in the area. He had no telephone or electricity outage.

- Lightning was identified in the area and woke him around 6:30 AM.
- Intense thunder was identified in the area.
- Proximity of lightning was not notable.
- No ground strikes were observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

4-3-06 Resident 12 & 13

The two stated that they were awakened by thunder around 6:30 AM. The thunder and lightning were fairly strong, but they never noticed any specific direction. They had no telephone and electricity outage.

- Fairly strong lightning was identified in the area. Woke him around 6:30 AM.
- Intense thunder was identified in the area.
- Proximity of lightning was not notable.
- No ground strikes were observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

4-3-06 Resident 14

This resident stated there was very severe lightning to the south of his residence. The storm around his house was not as severe. He stated that there was definitely lightning in the area, but he could not be specific on the location of any strikes. His wife is very afraid of lightning, and the two spent the morning in their basement. Both the telephone and electricity stayed on that day.

- Very strong lightning was identified in the area to the south, but was not as strong around the house. No specific time was identified.
- Thunder was identified in the area.
- Proximity of lightning was widely dispersed.
- No ground strikes were observed.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

4-3-06 Resident 15

The storm was fairly strong with lightning and thunder. He did not notice any specifics on the location of the lightning.

- Lightning was identified in the area.

- Thunder was identified in the area.
- Proximity of lightning was dispersed.
- No ground strikes were observed.
- Electrical service was not noted.
- Telephone service was not noted.

4-3-06 Resident 16

The lightning and thunder were very strong. Shortly after 6:00 AM the thunder occured almost immediately after the lightning strikes. One very strong lightning strike was directly in front of his house (east of his house). This strike made the sharpest thunder of all, and the resonance actually caused his ears to ring. He feels that this was the strongest lightning he had ever seen. He had no power or telephone outage, but thinks the lights did flicker on occasions.

- Lightning was identified in the area. It was very strong and close.
- Intense thunder was identified in the area. The strongest thunder was shortly after 6:00 AM.
- Proximity of lightning was very close and to the east.
- No ground strikes were observed.
- Electrical service was not interrupted but flickered a little.
- Telephone service was not interrupted.

4-19-06 Resident 17

Resident 17 was up early that morning. Lightning with instant thunder occurred just before 6:30 AM. The thunder was long lasting with a rumble of several seconds. The electrical and telephone service stayed on.

- Lightning was identified in the area around 6:30 AM. It was very strong and close.
- Thunder occurred instantly after lightning strikes.

- Electrical service was not interrupted.
- Telephone service was not interrupted.

4-19-06 <u>Resident 18</u>

This resident and family were up early. The thunder was very strong and occurred shortly after 6:00 AM. The lightning <u>was primarily to the southwest</u>. They said it actually sounded like two strikes two to three minutes apart. They had no electrical or telephone interruptions.

- Lightning was identified in the area shortly after 6:00 AM. It was very strong and close.
- Thunder was strongest to the southwest and sounded like two reports of thunder.
- Electrical service was not interrupted.
- Telephone service was not interrupted.

11-22-06 <u>Resident 19</u>

These residents describe a very bright flash sometime after 6:00 am that lit up everything like daylight on both sides of the house. The thunder rolled from east to west. The husband who describes himself as a sound sleeper was awakened by a huge shudder of thunder. It was compared to the sound of a train going over a trestle. And again, "It was just rolling-- like an airplane crash that just keeps going." The jolt shook the house so badly the house was shuddering as he arose and pulled on his trousers, and he describes continued shaking after he walked over to the living room. He checked his foundation for damage. "It just felt strange."

## 5.5-2f Examination of Data from Lightning Detection Networks

Introduction

The U.S. National Lightning Detection Network (NLDN) detected a large, 2-stroke, positive cloud-to-ground lightning flash in the region of the Sago mine on the morning of January 2, 2006. At about the same time, a methane explosion occurred in a sealed area of the mine. In this report, we will first summarize the lightning information that was obtained by the NLDN, and then we will examine the data that were obtained by three other lightning detection networks. We will discuss the possibility of upward or "triggered" lightning in the region of the Sago mine that may not have been reported by the NLDN or the other networks.

NLDN Data

The NLDN contains about 200 gated, wideband lightning sensors that cover the U.S. and Canada, and it is owned and operated by the Vaisala-Thunderstorm Unit in Tucson, AZ. The sensors are precisely time-synchronized using GPS receivers, and the NLDN computes the locations and amplitudes of the coincident electromagnetic signals using an optimum combination of the times-of-arrival, magnetic directions, and source amplitudes of all pulses that are characteristic of cloud-to-ground lightning strokes.

On the morning of January 2, 2006, the NLDN detected 69 CG strokes within 30 km of the mine entrance in the interval from 06:00 to 06:30 EST. A map showing the locations of these strokes is given in **Figure 1**, and a detailed listing of the stroke parameters is given in **Appendix 5.5-2**: *Attachment A*. It should be noted that the NLDN reported two, large positive events within 6 km of the mine at about the time of the explosion. The times of the first and second strokes were 11:26:35.523 UT (06:26:35.523 EST) and 11:26:35.680 UT (06:26:35.680 EST), respectively, and the interval between them was 157 milliseconds. The first stroke had an estimated peak current (Ip) of about +39 kiloamperes (kA), and the second had an Ip of +101 kA. A map showing the locations of all strokes that occurred in the 4-hour interval from 04:30 to 8:30 AM EST within 5 miles of the mine entrance is given in **Figure 2**, and the locations of all strokes detected in the 2-hour interval from 05:00 to 07:00 EST within 5 miles of the point-of-origin of the methane explosion is given in **Figure 3**. The elliptical regions shown in red around the stroke locations in **Figures 1, 2**, and **3** are the boundaries of the 99% confidence regions[10].

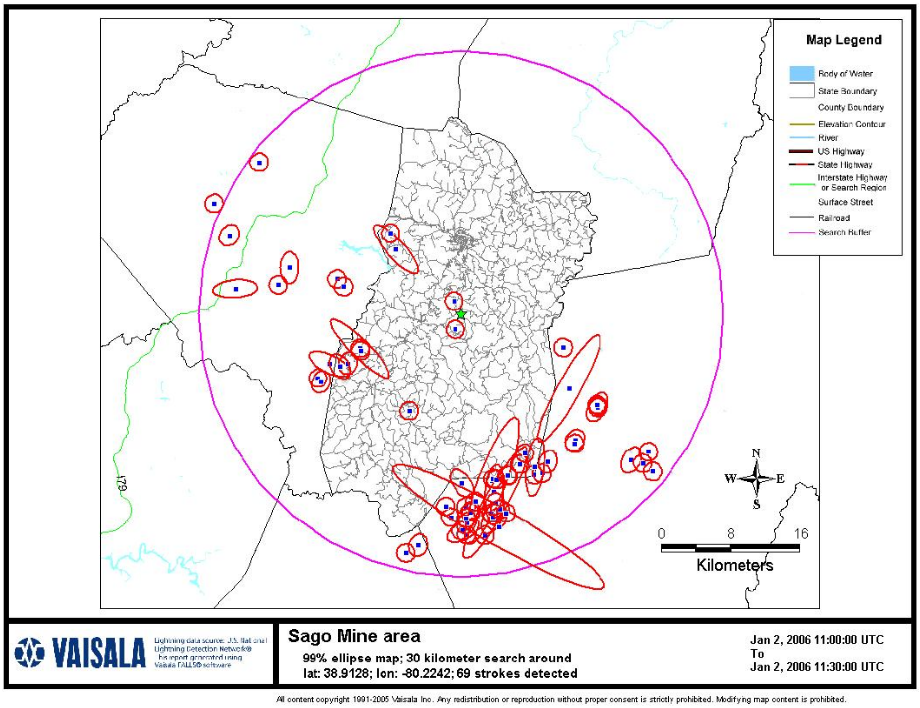



**Figure 1**. Cloud-to-ground lightning strokes detected by the NLDN within 30 km of the entrance to the Sago mine between 06:00 AM and 06:30 AM EST on January 2, 2006. The red circles and ellipses show the boundaries of the 99% confidence regions.

[10] Cummins, K. L., M. J. Murphy, E. A. Bardo, W. L. Hiscox, R. B. Pyle, and A. E. Pifer (1998), A combined TOA/MDF technology upgrade of the U.S. National Lightning Detection Network, *J. Geophys. Res., 103,* 9038-9044, 1998a

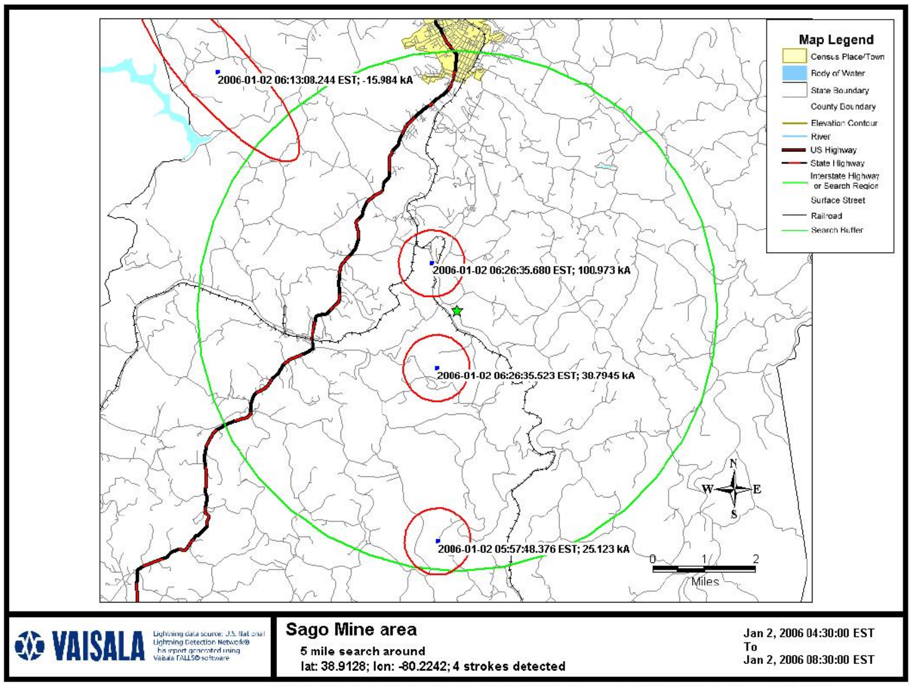





**Figure 2.** Cloud-to-ground lightning located within 5 miles of the entrance to the Sago mine between 04:30 AM and 08:30 AM EST on January 2, 2006.

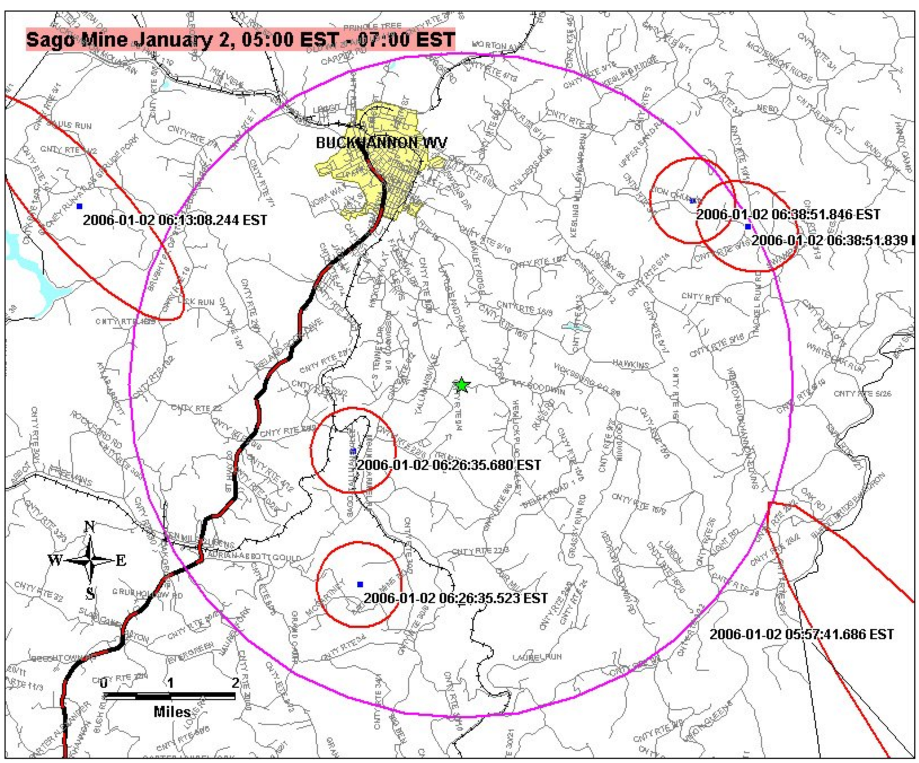



**Figure 3.** Cloud-to-ground lightning located within 5 miles of the point-of-origin of the explosion at the Sago mine between the hours of 05:00 AM and 07:00 AM EST on January 2, 2006.

NLDN Location Accuracy

A Vaisala Report dated January 26, 2006, summarizes the parameters of the two strokes that were detected near the Sago mine on January 2 (see **Appendix 5.5-2:** *Attachment B*). The second stroke at 06:26:35.680 EST had an estimated peak current of +101 kA and was located about 3 km (1.9 mi) from the point-of-origin of the explosion. A lightning struck tree was found within 200 feet of this location shortly after the explosion (see **Photo 1**), and the presence of this tree shows that the NLDN location accuracy was quite good in the region of the Sago mine (see also **Appendix 5.5-2**: *Attachment C*).

An evaluation of the overall NLDN detection efficiency and other performance parameters on January 2, 2006, is given in **Appendix 5.5-2:** *Attachment D.*

Lightning Detected by the USPLN

The United States Precision Lightning Network (USPLN) detected lightning in the region of the Sago mine near the time of the explosion, and a complete report summarizing the USPLN measurements is given in **Appendix 5.5-2:** *Attachment E.* The salient information on the two strokes that were located is given in Appendix 1 (below). It should be noted that the strike at 06:26:35 EST was undoubtedly the same as the first NLDN stroke, and the peak amplitudes of both were similar, +35 kA in the USPLN report and +39 KA in the NLDN dataset. The USPLN did not report the +101 kA stroke at 06:26:35.680 EST.

Appendix 1. Cloud-to-ground lightning strikes for the period of 5:00 AM EST January 2, 2006 to 7:00 AM EST January 2, 2006 within the 10 mile view shown above. Time is in 24-hour Eastern Standard Time (EST) format. Heading is relative to due north from the location of interest. For example, 90 degrees = east, 180 degrees = south, 270 degrees = west, 0 degrees = north. (Lightning data source: USPLN)

| Date (mm/dd/yy) | Time (hhmmss) | Latitude (Degrees) | Longitude (Degrees) | Magnitude (Amps) | Heading (Degrees) | Range (Miles) |
|---|---|---|---|---|---|---|
| 01/02/06 | 62635 | 38.907 | -80.221 | 35000 | 203 | 2.5 |
| 01/02/06 | 63851 | 39.007 | -80.288 | -35800 | 315 | 6.5 |

Lightning Detected by the WWLLN

The World Wide Lightning Location Network (WWLLN)[11] detected a lightning discharge in the region of the Sago mine at the same time as the first NLDN stroke, and Prof. Robert Holzworth at the University of Washington kindly provided the following event parameters:

| Year | Mo | Day | Hr | Min | Sec | .fract | Lat | Long | el | #sta (UTC or Z) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2006 | 1 | 2 | 11 | 26 | 35 | .522888 | 38.85 | -80.21 | 3 | 5 |

The uncertainty in time was about 3 microseconds, and this report is clearly the same (first) stroke that was detected by the NLDN and the USPLN. The WWLLN did not report the +101 kA stroke at 06:26:35.680 EST.

Lightning Waveforms Recorded by the LASA

The Los Alamos Sferics Array (LASA)[12,13] recorded broadband lightning waveforms at 3 sensor sites on January 2, 2006, at times that were consistent with the first and second strokes detected by the NLDN, after the times for electromagnetic propagation were subtracted from the times that the signals were received. **Figures 4, 5**, and **6** (courtesy of Dr. X-M Shao) show the electric field waveforms recorded at Daytona Beach, FL; Lincoln, NE; and Garden City, KS, respectively, at the times of the first (top) and second (bottom) NLDN strokes near the Sago mine. Note in **Figures 4 to 6** that all pulses begin with a positive excursion that is characteristic of a positive lightning impulse propagating over the ground, and then there is a large, negative excursion that is caused by the first ionospheric reflection at the distances involved.

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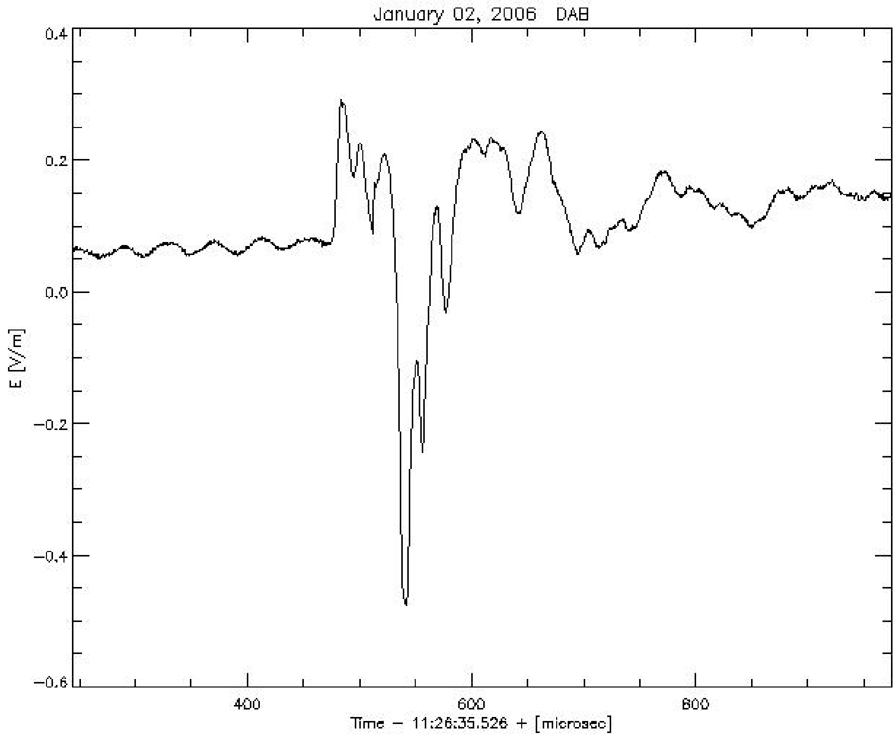
11 Jacobson, A. R., R. Holzworth, J. Harlin, R. Dowden, and E. Lay, Performance Assessment of the World Wide Lightning Location Network (WWLLN), using the Los Alamos Sferics Array (LASA) as Ground Truth, *J. Atmos. Oceanic Tech*., *23*, 1082-1092, August 2006.

12 Ibid.

13 Shao, X-M, M. Stanley, A. Regan, J. Harlin, M. Pongratz, and M. Stock, Total Lightning Observations with the New and Improved Los Alamos Sferics Array (LASA), J. Atmos. Oceanic Tech., 23, 1273-1288, October 2006.



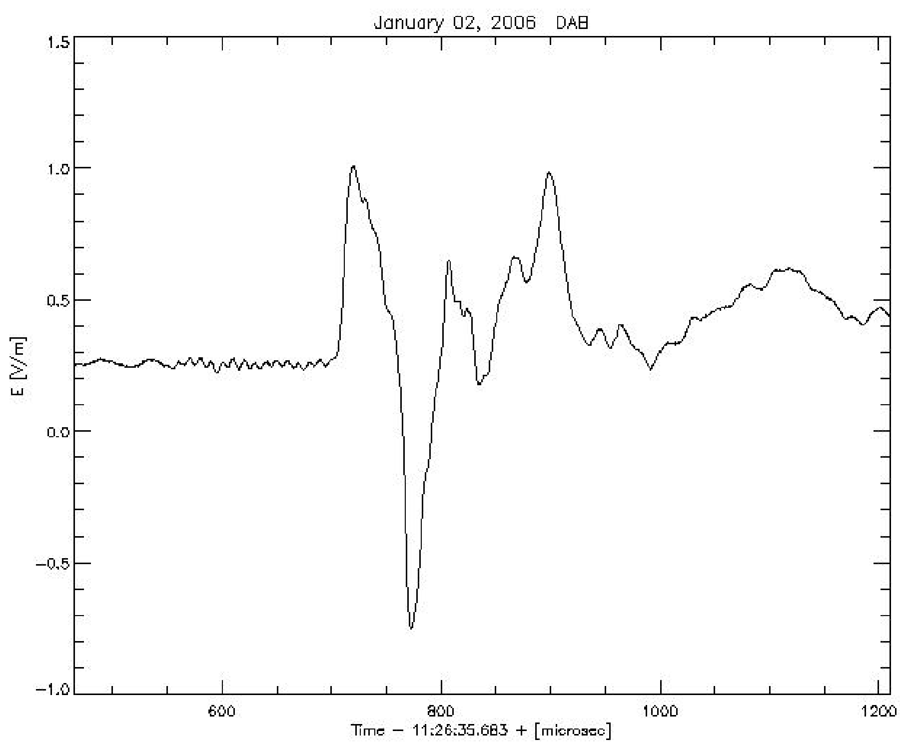
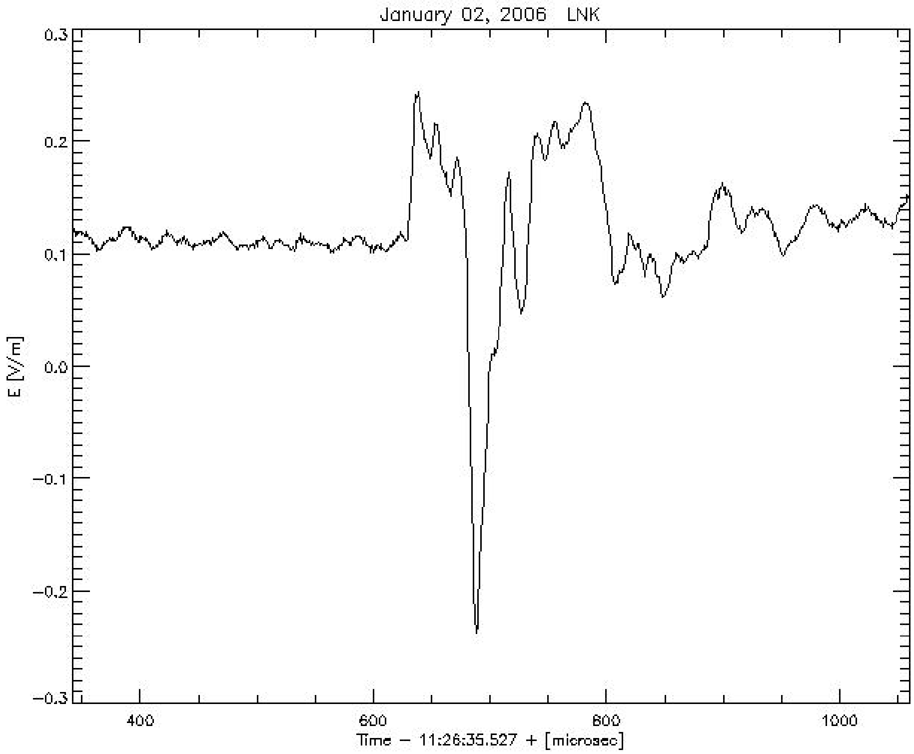




**Figure 4.** Electromagnetic pulses recorded by the LASA sensor at Daytona Beach, FL.



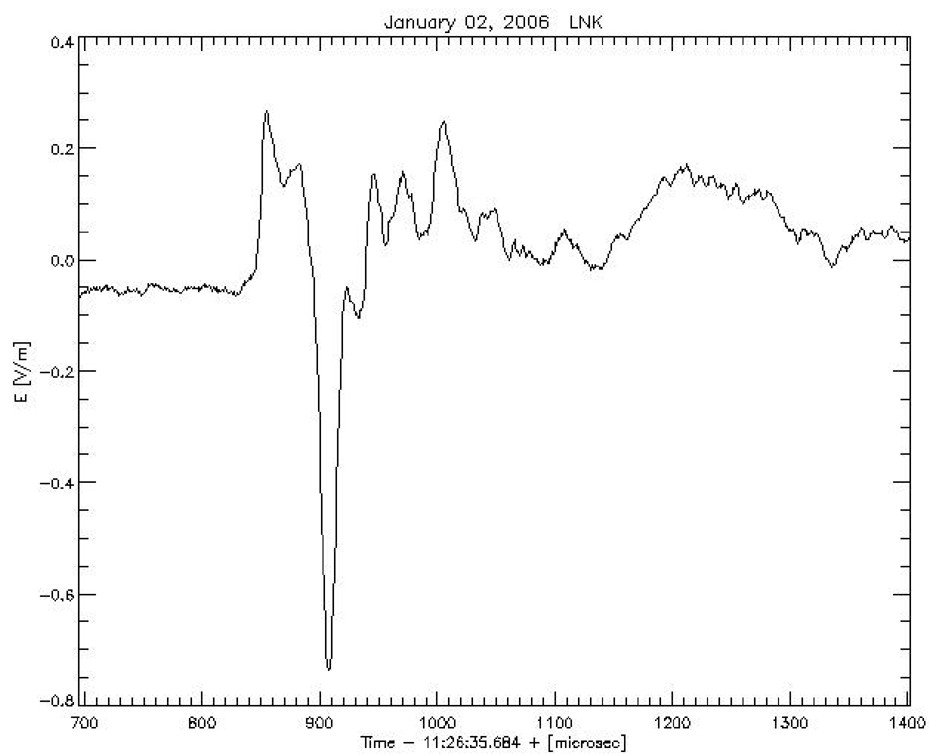




**Figure 5.** Electromagnetic pulses recorded by the LASA sensor at Lincoln, NE.

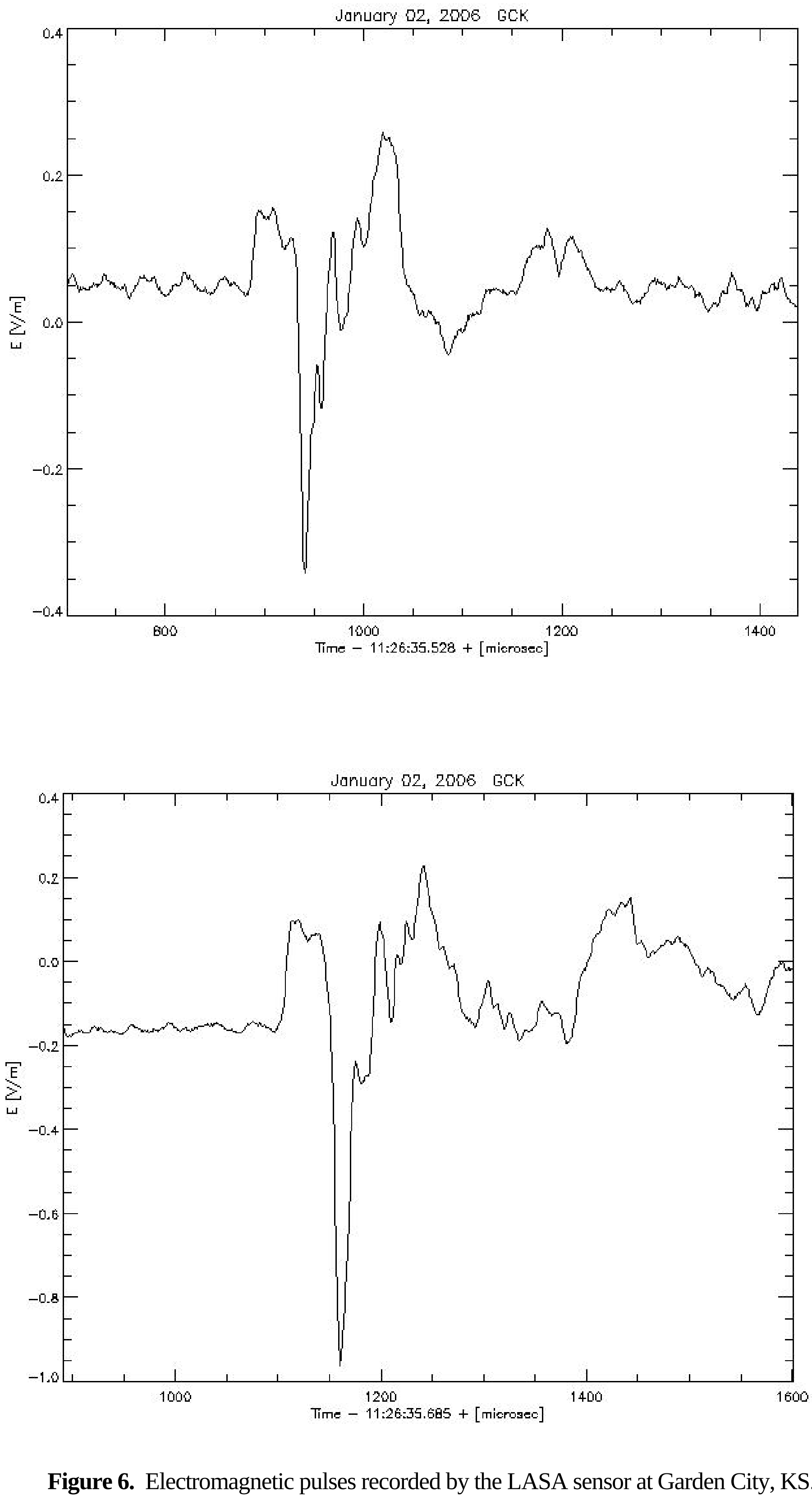



**Figure 6.** Electromagnetic pulses recorded by the LASA sensor at Garden City, KS.

Search for Missed Lightning Strokes

In an effort to find evidence of any small lightning strokes that may have been detected by individual sensors but not reported by the NLDN, we searched the NLDN database for all uncorrelated reports from individual sensors that were within 500 km of the Sago mine where the lightning direction-of-arrival was from the Sago mine at about the time of the explosion. The results are summarized in **Appendix 5.5-2:** *Attachment F*. The key point in Attachment F is that there is no evidence of any small ground strokes or cloud discharges in the region in a 10 second interval prior to the first positive stroke that was reported by the NLDN. The two small reports (highlighted in red) from the sensor at Spencer, WV, at 11:26:35.512345 UT and 11:26:35.518452 UT were undoubtedly due to cloud or leader pulses that preceded the first positive stroke at 06:26:35.523 EST (11:26:35.523 UT).

Summary and conclusions

Information from multiple time-synchronized sensors indicates that there were two (2) large cloud-to-ground lightning strikes near the Sago Mine at the same time that the mine explosion occurred. This information is regarded as strong circumstantial evidence contributing to the conclusion that lightning caused the January 2, 2006 mine explosion at the Sago Mine.

Residents confirm that there was electrical storm activity on the morning of January 2, 2006. Residents on Tallmansville Road reported a loud crash or explosion, followed by ground shaking. Several residents thought that this was the mine explosion. This is unlikely, however, as the crew of First Left Section who were approximately one-thousand (1000) feet from the explosion did not report hearing it, or feeling the earth shake,-- they felt only the wind and the effects of flying debris.

A review of the raw lightning data from the NLDN did not produce any other evidence of cloud-to-ground lightning strikes in the region of the Sago mine in the several seconds prior to the time of the explosion. The network is designed to detect and report cloud-to-ground discharges. However, strokes that have less than 3 kA peak current, cloud discharges, or upward lightning are not normally reported by the present lightning detection systems.

# 5.5-3 How lightning may have entered the mine

There are many possible pathways or mechanisms whereby the electromagnetic energy from lightning could have entered the Sago Mine, and which mechanisms were actually involved are still being studied. Before solutions and precautions can be developed to prevent future accidents like Sago it is first necessary to understand the possible modes by which lightning energy could have entered the mine.

## 5.5-3a Possible modes of entry

Lightning produces very large voltages and currents at the ground strike point and the resulting paths of current are often unpredictable and capricious in their behavior. The only thing we can say for sure is that if there is a direct transfer of electrical energy, the current will tend to follow the path of lowest impedance. But lightning can also create current and voltage surges in conductors that are in close proximity to the strike point without actually contacting them. At this time, investigators generally believe that there are at least three (3) ways the electrical energy from lightning can propagate into an underground mine and cause an explosion:

Possible means by which lightning could enter the mine:

1) **Electrical Conduction –**

   a) the lightning current can travel into mines on metallic conductors like the electric power wires, communication cables, the belt structure, deep well casings, rail, wire roof mesh, etc.

   b) lightning current can travel directly through the earth or be guided by low-resistivity layers and geological structures that trap water underground

2) **Magnetic Induction**—the large, time-varying magnetic field from lightning can cause electric current to flow in a wire loop, without actually touching it. If there is a gap in the loop, large voltages can appear across the gap.

3) **Electric Field Coupling** – if the skin depth of the overlayer is large, low frequency electromagnetic fields from lightning can propagate into the earth and cause transient voltages to appear on large conductors, like vertical gas wells or the metallic roof mesh.

Various networks of gas lines, utility lines, power lines, wire roof mesh (underground), and an abandoned pump cable (underground) were examined. Also, various methods of direct coupling through the earth were explored both analytically and through experimentation.

As of this writing, there is no clear proof of the precise mechanism by which the electricity from lightning entered the Sago mine. The body of evidence gathered during the investigation, however, allows the following points to be made with some degree of confidence.

- The timing of the two nearby lightning strikes at 6:26:35 AM EST coincides to within 1 second with the mine explosion [1] (see **Section 5.5-2**)
- There are no known continuous metallic conductors extending from the surface of the ground into the sealed area of the mine void at the time of the explosion—nor underground from the outby side of the seals to the inby side.[2]
- Each of the coupling scenarios that remain under consideration today involve transmission of lightning-related energy into the sealed area, ***at least in part***, through or along solid rock and/or fractured earth strata without the presence of a continuous metallic conductor to the surface

### 5.5-3b The possibility of Upward or Triggered Lightning

Upward or triggered lightning discharges are often initiated by tall structures when such a structure is in close proximity to natural lightning[3] This type of event is frequently missed by the NLDN[4]. either because there are no return strokes in the discharge or because the stroke waveforms do not

[1] Based on the 51 ppm CO spike at block 57 at 6:26:35 +/- 1 second.
[2] A steel sample tube approximately 40 feet long was installed as required in the Omega seal #10 (seal located farthest east) for purposes of sampling mine gases. It is equipped with a valve and installed near the roof. No wire roof mesh was used in this location.
[3] Rakov, V.A. and M.A. Uman, Lightning: Physics and effects, Cambridge University Press, 687 pp., 2003, Chapter 6.

have an amplitude or shape that corresponds to natural strokes. An example of a flash that was triggered by a radio tower in Rapid City, SD, is given in **Photo 1**. In this case, the discharge was also recorded by a video camera that had precise timing, and analysis showed that it occurred approximately 120 milliseconds ***after*** the NLDN located a positive ground stroke about 7 km (4.4 miles) from the tower.

Significantly, the upward flash in **Photo 1** was ***not reported*** by the NLDN, either because it did not contain return strokes, or if such strokes did occur, their peak currents were below the NLDN trigger detection threshold[5] and/or they had improper waveforms.

Upward lightning is also known to strike power lines, especially in the winter months, and an example of this phenomenon is shown in **Photo 2**. The exposure for the image in Photo 2 was ¼ second or 250 milliseconds.

**Photo 1.** An upward, ground-to-cloud lightning flash in Rapid City, SD, on 26 March 2004. [Photo © 2004 by Tom Warner]

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[4] National Lightning Detection Network (Vaisala)
[5] That threshold is reported by NLDN to be 3 to 5 kA.

The locations of tall towers in the region above the Sago mine, and that are located close to pipelines or other ground conductors, are shown on **Map 1**. The two positive cloud-to-ground strokes that were located by the NLDN had very large amplitudes, and it is possible that one or both of these strokes initiated one or more upward discharges from tall, nearby structures.


**Photo 2.** Upward discharges to a power line in Japan (courtesy of N. Honma)

### 5.5-3c Coupling of electromagnetic energy into the Sago mine

In **Section 5.5-2** we have seen that there were two, very large, positive cloud-to-ground strokes in the vicinity of the Sago mine at about the time of the explosion, and that there may have been one or more undetected upward lightning discharges that were not detected by the NLDN. Professor Thomas Novak and co-workers have recently discussed the possibility that lightning can cause methane explosions in underground mines during thunderstorms, and they have shown that low-level, corona discharges are one possible cause of ignition[6, 7]. The peak impulse power in a typical

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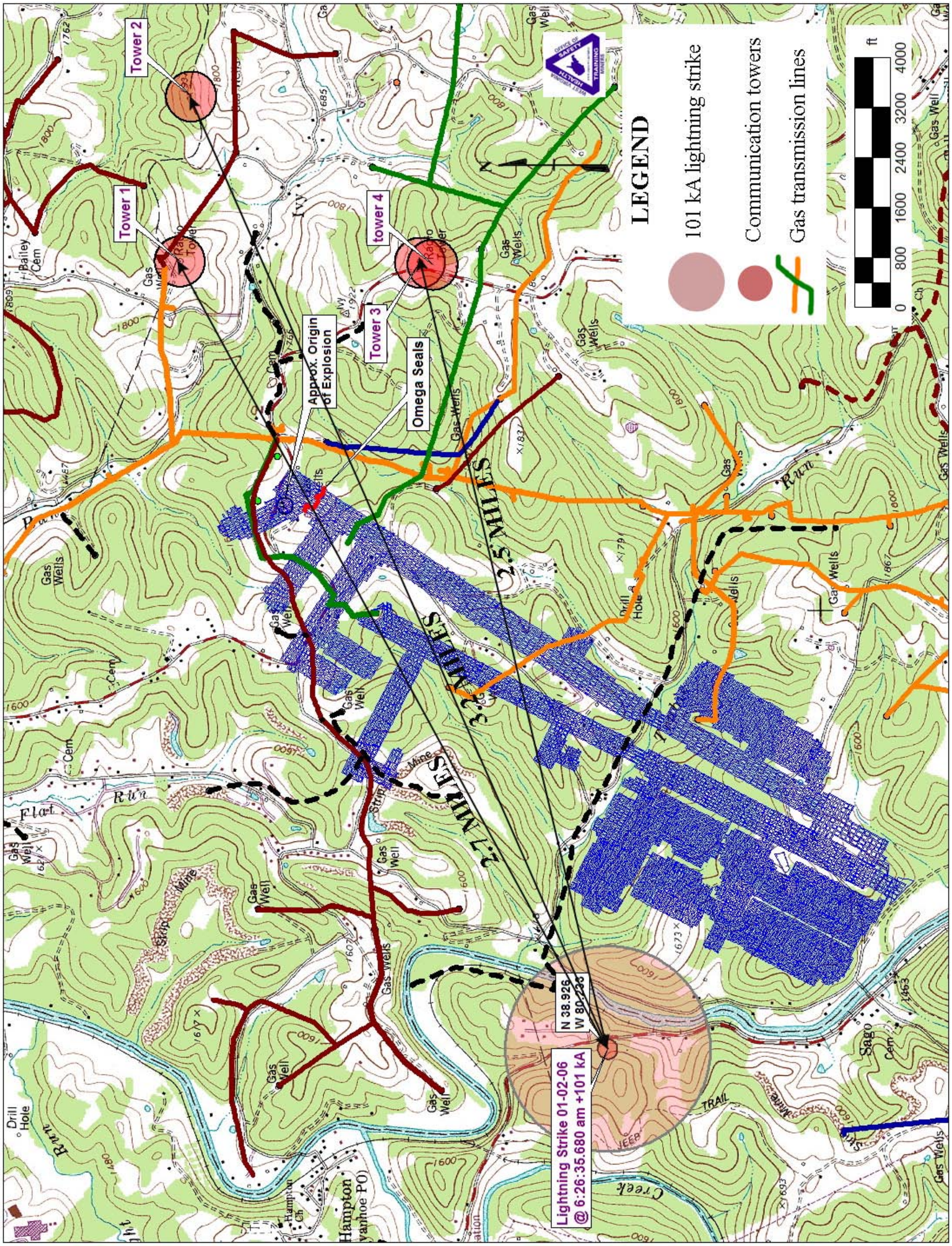
6 Novak, T. and T. J. Fisher, Lightning Propagation Through the Earth and Its Potential for Methane Ignitions in Abandoned Areas of Underground Coal Mines, *IEEE Trans. on Industry Applications, 37* (6), 1555-1562, 2001.

7 Sachs, H. K. and T. Novak, Corona-Discharge-Initiated Mine Explosions, *IEEE Trans. on Industry Applications, 41* (5), 1316-1322, 2005.




**Map 1.** Location of high antennas east of Sago Mine. Upward lighting from such structures can be initiated from cloud-to-ground strikes that occur several miles away.

lightning stroke is of the order of 10,000 megawatts[8], and the impulse current is about a billion times larger than the current in typical corona. A key question in this investigation is “How did the electromagnetic energy from lightning couple into the Sago mine?” We do not have a definitive answer yet, but there are many possibilities. Lightning current could have been conducted directly into the mine on the electric power or other wiring at the mine entrance. A dispatcher at the time of the incident received a painful crackling from the telephone[9], and this in turn is evidence that a high voltage transient was present on the communications wires. The large lightning currents could also have caused transient voltages to appear on the extensive network of gas pipelines and wells near the Sago mine, and a portion of that current could have been conducted into the region of the explosion. Any large loops in metallic conductors, either inside or outside the mine, could have acted as magnetic antennas and created large potential differences (voltages) across any gaps in those loops in response to the time-varying lightning magnetic field. The metallic roof mesh, or any other large masses of metal (like vertical well casings), could also have acted as electric field antennas and caused large voltages to appear on the extremities of those antennas in response to the low frequency electric field in the ground.

There are reports by residents who live on the ridge between the +101 kA stroke location just west of the Sago mine and the towers shown in **Map 1** who describe phenomena associated with an unusually large flash sometime after 6:00 AM. These accounts could be due to an upward or triggered lightning discharge that was initiated by a nearby tower.

The degree to which external electromagnetic fields can propagate into the earth and couple onto structures depends on the thickness of the overlayer, its resistivity, and the frequency of the source. **Figure 1** shows the “skin depth” of a homogeneous material as a function of its resistivity and frequency.

Lightning strokes are a broadband source of electromagnetic energy, and the peak in the power spectrum is typically in the range of a few to a few tens of kilohertz. Positive cloud-to-ground strokes usually contain long, continuing currents and the spectrum of those strokes extends down to

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8 Krider, E. P., On the electromagnetic fields, Poynting vector, and peak power radiated by lightning return strokes, *J. Geophys. Res.*, *97* (D14), 15,913–15,917, 1992.

9 Page 33, starting on line 11 of Statement by William (Bill) Chisolm, February 15, 2006.

frequencies of the order of one kilohertz or less. It should be noted in **Figure 1** that a material with an average resistivity of 100 ohm-meters has a skin depth of 100 meters at frequencies of 3 kilohertz or less.

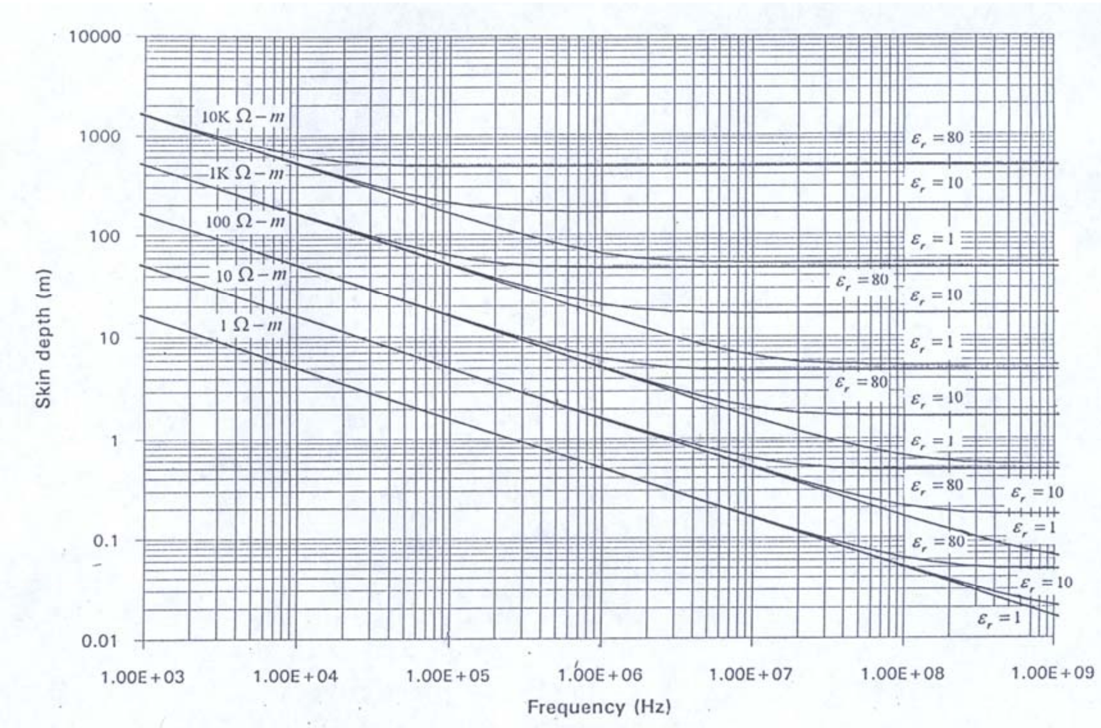



**Figure 1.** Skin depth as a function of soil resistivity and frequency.

More work is planned on the question of how lightning energy coupled into the Sago mine. In order to clarify which of the many possible mechanisms dominates the coupling, it would be good to measure the voltage transients that appear on various conductors inside the mine when there is natural lightning in the region.

### 5.5-3d Examination of the surface electrical systems

The poplar tree that was struck by lightning (see **Section 5.5-2**) is approximately three-hundred thirty (330) feet away from the private power distribution line that services the Sago Mine. At the time of the explosion this line serviced only the Sago Mine and the facilities at the Sawmill Run Prep Plant. Because it was in close proximity to such a powerful lightning strike (+101 kA) the line seemed a prime candidate as the path by which lightning could have entered the Sago Mine. (See **Map 2**)

Surface electrical systems were examined by coordinated efforts of MSHA, OMHS&T and representatives of ICG [10] This included an examination of the following:

1) the 12kV power distribution line extends from the Allegheny Power substation on French Creek, southwesterly approximately 2.6 miles to the Sawmill Run Sub-station (**see Map 2**).

2) a 12kV branch line to the Sago Mine that begins just south of the community of Sago and crosses the Buckhannon River north to the Sago Mine

3) a split at the Sago mine where power passes to a separate transformer that powers the stacker belt, mine offices, and pit sump pump, and another split that runs to the Sago Mine substation which steps down the power from 12470 volts to 7200 volts..

4) electric highline feed from the Sago Mine Sub-station underground into Sago mine

French Creek Sub-station

The French Creek sub-station (**see Photo 3**) receives 138,000 volts 3 phase AC from Allegheny Power Company[11] and steps down to 12,470 volts 3 phase AC thru a Delta-Wye Transformer. This power then feeds a substation located behind the Sawmill Run Preparation Plant, (**Photo 4**) on approximately 2.6 miles of privately-owned and maintained power lines (**Photo 5**). It is located near the community of Hampton, West Virginia, where French Creek empties into the Buckhannon River.

**Photo 3**. French Creek Substation

The 12kV line branches off of this line (**Photo 6**) and feeds the sub-station located at the Sago Mine. (**Photo 7**)

All three sub-stations were checked for possible lightning damage or equipment malfunction. No apparent damage or malfunction was found. Two areas, one on the main line (**Photo 8**)

[10] ICG provided transportation to structures and historical background on the 12kV system

and the other on the branch line (feeding Sago) (**Photo 9**) had possible lightning damage. The location of this damage on the powerline system is shown on **Map 2**. Because no power outages were reported at either the Sago mine or the Sawmill Run Preparation Plant on the morning of January 2, 2006, it could not be determined when this damage occurred. Only eight (8) of the mainline pole structures were not butt-grounded (see **Photo 10**). However three (3) of the eight (8) pole structures that were located closest to the poplar tree that was struck by lightning were not butt-grounded.

The butt-grounds are tied to the overhead ground wire. None of the guy wires were grounded or insulated at the time of the explosion. This was not a requirement when the pole structures were installed, however guy wires located above phase conductors and have a potential of becoming energized are now required to be grounded or insulated. All of the affected guy wires are now either grounded to the system ground or insulated. There are at least two more sets of lightning arrestors between this area and where the high voltage cable enters underground so required lightning protection was being provided. The lightning arrestors are rated at a phase-to-ground voltage (10kV). The damaged center phase insulators (**Photo 8**) have two (2) prominent chips in the lower two bells and this damage could have been caused by lightning. It is unknown when this damage occurred but the insulators are used for insulation purposes—not lightning protection. The displaced earth at the base of the pole and the discolored ground wire could be indications of lightning (**Photo 11**).

**Photo 4.** Sawmill Run Preparation Plant Sub-station

**Photo 5.** Section of 2.6 mile 12KV power line

[11] Allegheny Power owns, operates, and maintains this substation.

**Photo 6.** The 12KV branch line is approximately 1 mile in length line feeding the Sago Sub-station.


**Photo 7.** Sago Sub-station

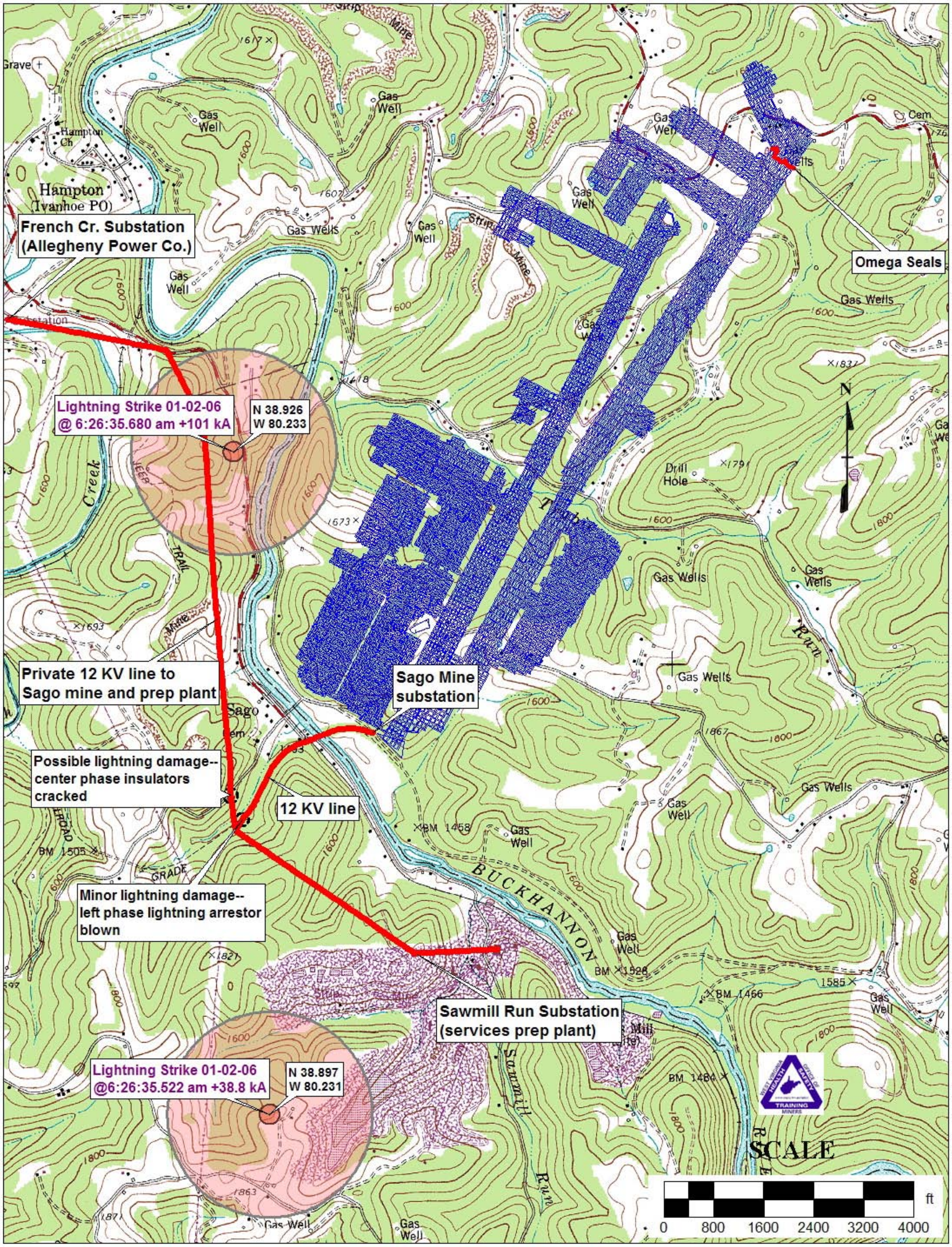
**Photo 8.** Damaged insulators on the middle phase wire on the main 12KV line

**Photo 9**. Damaged lightning arrestor on the outside phase of the branch line feeding the Sago sub-station

**Photo 10**. This two pole structure is butt-grounded at each pole. Note "antenna" atop each pole.

**Photo 11**. Disturbance at base of pole with the damaged insulators

The main 12kV line has 795mcm ACSR phase conductors and two 336mcm ACSR neutral/ ground conductors located above the phase conductors. The main 12kV line was installed sometime in the mid 1970's. The branch line was installed in 1999. The phase conductors of the branch line are 336 mcm ACSR.




**Map 2.** Location map showing Sago Mine No. 1, the Sawmill Run and Sago substations, the 12 kV power distribution line, minor damage found on those lines, and the lightning strikes recorded at 6:26:35 AM EST.

### 5.5-3e Examination of the underground electrical systems

Two electrical investigation teams, each consisting of OMHS&T, MSHA, ICG, and UMWA personnel inspected and/or tested the electrical equipment and electrical installations for possible lightning damage or malfunction.

The two investigation teams split up and worked in different areas of the mine. Two sections of high voltage cable were physically damaged during the explosion, one inby the one-left switch and another section inby the two-left switch. This condition tripped a high voltage circuit breaker at a splitter box located near the # 2 Belt Drive. There was no interruption of power on the surface. No evidence was found of any electrical equipment malfunction or failure of electrical circuits that may have triggered the methane explosion behind the seals. No apparent lightning damage was found on any of the mine-site equipment or electrical installations on the surface or underground, although some damage to the 12kV distribution line leading to the mine was found, as previously noted. Thirty-three (33) non-contributing violations were issued by OMHS&T (see **Appendix 5.1:** *Statistics and Fact-finding).*

Conductivity testing

Because no continuous metallic conductors were found across the seals that could have provided an electrical path from one side of the seals to the other, and because several significant gaps exist in the wire roof mesh leading back to the approximate origin of the explosion, a series of resistivity tests were performed to determine if electricity could have found a path of low resistance directly through roof rock strata and/or floor strata. Four tests were performed in this regard along various locations between the tailpiece of #4 Belt and up to the approximate origin of the explosion.

Test 1

Resistivity testing of the roof bolts, wire mesh screen, and mine floor was conducted on February 14, 2006; (**Figure 3)** to determine if a low-resistance electrical path exists from outside the sealed area to an area behind the seals where the explosion is believed to have originated. Testing was first conducted from the end of the track and continued back to this area.

Four pole resistivity tests (**Figure 2**) were conducted using a NGI Unilap GEO x resistance tester. Four metal rods were driven in the mine floor at 20 foot intervals, starting at the end of the track and continuing up into the region where the explosion is believed to have originated. Measurements were taken every 60 feet for a total distance of approximately 1250 feet. Readings were also taken between roof bolts and/or wire mesh screen in the same areas.

Resistance measurements between roof bolts and/or wire mesh screen for the first 1130 feet averaged 3 ohms. Resistance measurements between the rods in the mine floor averaged 7.5 ohms. Resistance measurements across the next 120 feet ranged from 3000 ohms to infinity.

These resistance measurements were suspect due to roof with possible carbon traces on the roof bolt plates and/or wire mesh screen. For this reason additional tests were conducted on April 3 and 4, 2006, where 5/8 diameter holes were drilled into the mine roof and steel nails were installed with a Hilti nail gun. This was done to isolate the nails from the carbon on the roof surface.

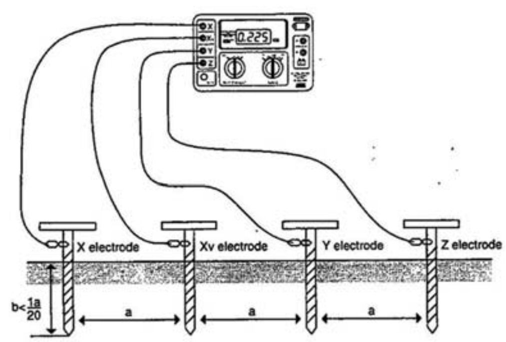



**Figure 2** Four Pole Resistivity Test

Test 2

A four pole resistivity test was conducted on April 3, 2006, (**Figure 4**) across the area where the seals had been installed prior to January 2, 2006.

- The resistance between the installed **roof nails** ranged from 2.3 ohms to 17000 ohms.
- The resistance between the installed **floor nails** ranged from 7 ohms to 12.8 ohms.
- The resistance between the **roof bolts** ranged from 0 ohms to 3.5 ohms.

The same four pole resistivity tests were conducted from the number 4 belt conveyor tailpiece structure up to the area of the blown out seal in the number 5 entry.

- The resistance between the installed **roof nails** ranged from 3,300 ohms to 61,000 ohms.
- The resistance between the installed **floor nails** ranged from 5.4 ohms to 14.9 ohms.
- The resistance between the **roof bolts** ranged from 0 ohms to .004 ohms.

The same four pole resistivity tests were conducted in the number 6 track entry.

- The resistivity between the installed **roof nails** ranged from 3.9 ohms to 6,200 ohms.
- The resistance between the **floor nails** ranged from 11.7 ohms to 12.7 ohms.
- The resistance between the **roof bolts** ranged from .003 ohms to 8.3 ohms.

Test 3

Four pole resistivity tests were conducted on April 4, 2006, (**Figure 5**) across the gaps in the wire mesh roof screen in several locations in the formerly sealed area. 5/8 diameter holes were drilled into the mine roof and steel nails were installed with a Hilti nail gun. The nails were installed at different intervals (depending on the length of the gap in the roof screen) and measurements were taken with a NGI Unilap GEO x resistance tester in locations # 1 thru 4. Measurements at location #5 were taken with a Fluke Model # 27 Volt-Ohm meter.

- In location #1 the roof nails were installed on 12 foot centers and the measured resistance ranged from 0.02 ohms to 3 ohms.
- Location #2 (3 foot centers) measurements ranged from 1 to 4.7 ohms of resistance.
- Location #3 (4 foot centers) measurements ranged from 1 to 51 ohms of resistance.
- Location #4 (10 foot centers) measurements ranged from 0.004 ohms to 2.1 ohms of resistance.
- Location #5 measurements were taken with a Volt-Ohm meter and were 4 ohms between roof bolts and 4 ohms between wire mesh screen.

Test 4

Tests were conducted using a megger and a Volt-Ohm meter at several locations including using approximately 1200 feet of 12/2 AWG solid copper wire to measure the resistance between the number 4 Belt conveyor tailpiece and roof bolts and/or wire mesh screen located in the approximate origin of the explosion. (see **Figure 6**). Resistance measurements were also taken between the track and wire mesh screen (Location #1) 2 ohms, between the track and the number 4 Belt tailpiece (Location #2) 100 ohms. Also at Location #2 the measured resistance between the #4 Belt tailpiece and the wire mesh screen was 0.439 ohms. A Volt-Ohm meter was used for the resistance measurements between the #6 Belt Power Center and the track (Location #3) and showed 1.2 ohms and between the Power Center and a roof bolt (Location #3) it showed 600 Ohms. Testing at Location #4 utilized the 1200 feet of solid copper wire stretched from the #4 Belt tailpiece to the approximate area of the explosion. Measured resistance between the #4 Belt tailpiece and roof bolts in this area ranged from 100 to 175 ohms when using a megger and 40 ohms when using Volt-Ohm meter. Measured resistance between the tailpiece and wire mesh screen in this area was 100 ohm when using a megger and from 50-52 ohms when using a Volt-ohm meter. The resistance of the 12/2 solid copper wire is 1.6 ohms of resistance per 1000 foot.

In addition to these tests a geophysical log for corehole SF 52-06 shows that the upper ½ of the interval between a rider[12] seam that is present approximately 60 feet above the coal seam had the lowest average resistivity in the overburden column; averaging around 100 ohms. The bottom ½ of the interval was not logged.

Summary of findings

No evidence has been found of damage to the 12 kV power distribution system, to the substations, surface power systems, or underground power systems that can be attributed to the lightning strike at 6:26:35 AM on January 2, 2006.[13] If stray current or induced currents made their way through these systems, it would not have found an uninterrupted connection over metallic conductors the entire way to the region of the explosion origin. The only metallic conductors extending past the mainline track and belt are the mats of wire roof mesh installed in the track entry, belt entry, and primary escapeway. There are numerous gaps in the wire roof mesh.

The shale roof in the mine is high in clay content, and from the results of the electrical tests conducted in the roof it appears to have low resistivity. This by itself is not necessarily evidence this was the path the electricity from lightning traveled. Testing of the ability of mine infrastructure to deliver a sufficient amount of current that deep into the mine has been recently performed by Sandia National Laboratories for MSHA. At the time of this writing the data are preliminary and has not been made available to OMHS&T.

[12] Also called the Upper Kittanning seam.

[13] The damaged lightning arrestor on the branch line to Sago Mine was likely caused by lightning and could have occurred that day. The cracked insulator and ground disturbance shown in Photos 8 and 11 may or may not be lightning-related.

DELORME XMap®/GIS Editor

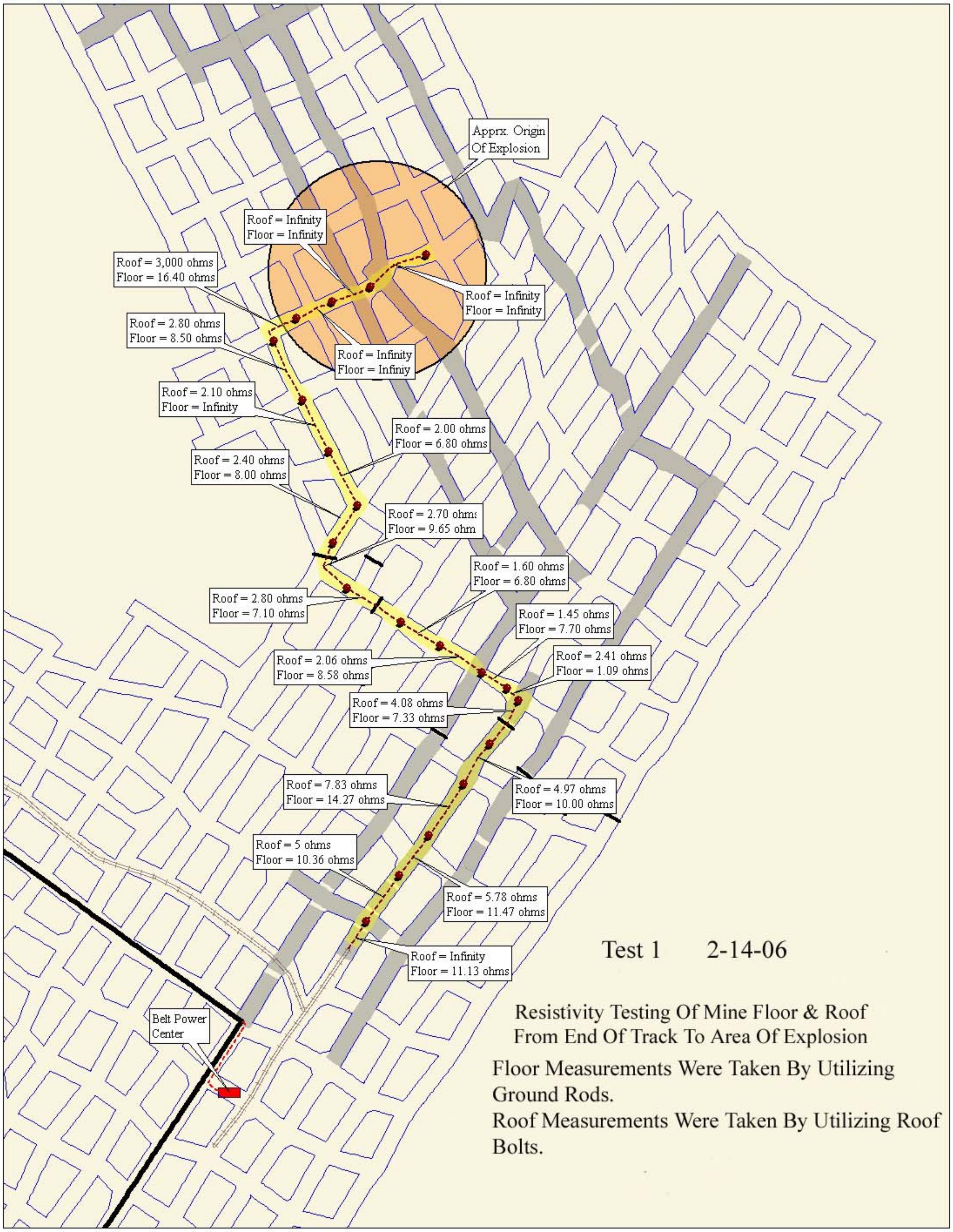





**Figure 3**

MN (8.5° W)

0 40 80 120 160 200 240 280 ft

Data Zoom 17-0

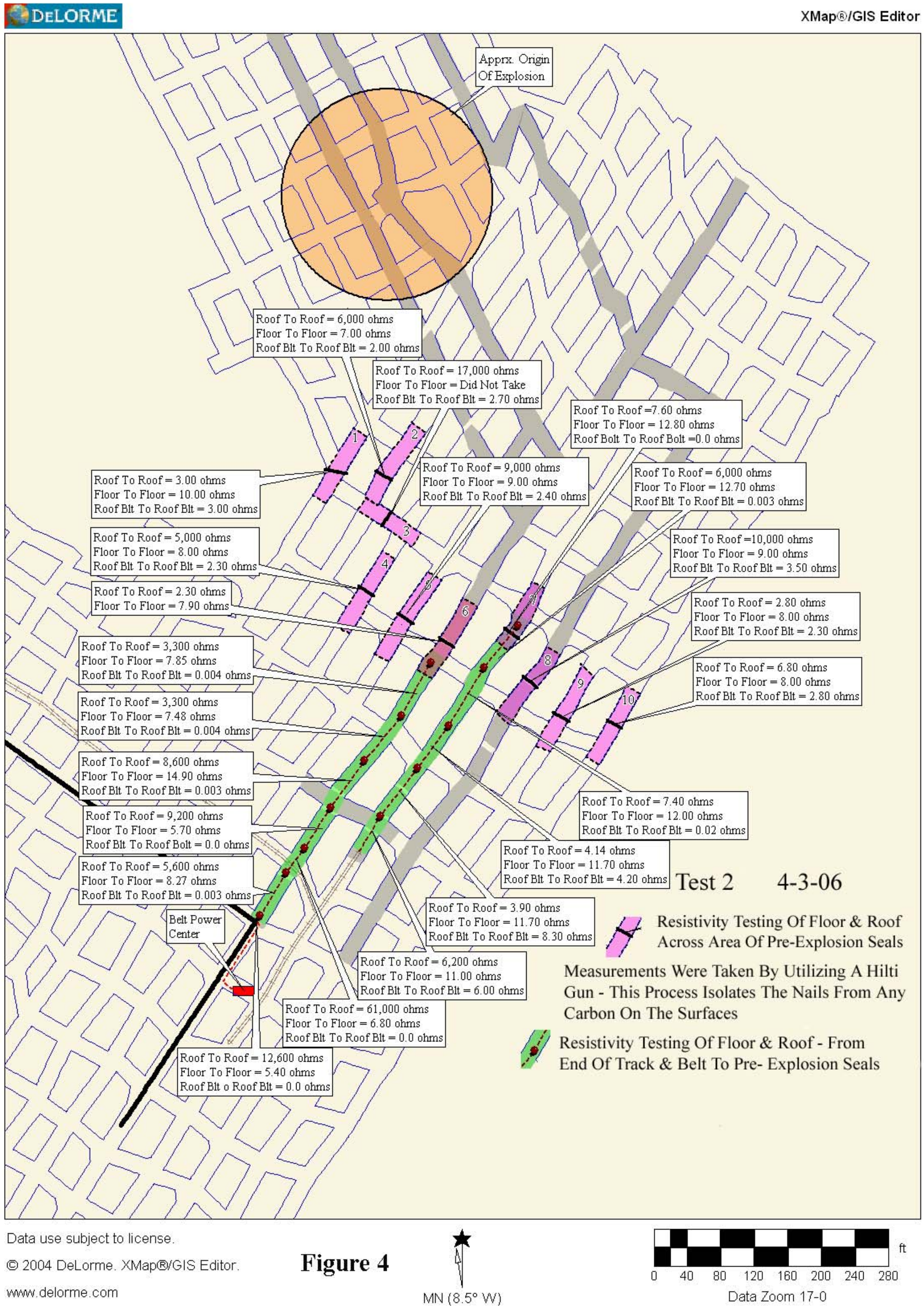

DELORME
XMap®/GIS Editor
Apprx. Origin Of Explosion
Roof To Roof = 6,000 ohms
Floor To Floor = 7.00 ohms
Roof Blt To Roof Blt = 2.00 ohms
Roof To Roof = 17,000 ohms
Floor To Floor = Did Not Take
Roof Blt To Roof Blt = 2.70 ohms
Roof To Roof =7.60 ohms
Floor To Floor = 12.80 ohms
Roof Bolt To Roof Bolt =0.0 ohms
Roof To Roof = 3.00 ohms
Floor To Floor = 10.00 ohms
Roof Blt To Roof Blt = 3.00 ohms
Roof To Roof = 9,000 ohms
Floor To Floor = 9.00 ohms
Roof Blt To Roof Blt = 2.40 ohms
Roof To Roof = 6,000 ohms
Floor To Floor = 12.70 ohms
Roof Blt To Roof Blt = 0.003 ohms
Roof To Roof = 5,000 ohms
Floor To Floor = 8.00 ohms
Roof Blt To Roof Blt = 2.30 ohms
Roof To Roof =10,000 ohms
Floor To Floor = 9.00 ohms
Roof Blt To Roof Blt = 3.50 ohms
Roof To Roof = 2.30 ohms
Floor To Floor = 7.90 ohms
Roof To Roof = 2.80 ohms
Floor To Floor = 8.00 ohms
Roof Blt To Roof Blt = 2.30 ohms
Roof To Roof = 3,300 ohms
Floor To Floor = 7.85 ohms
Roof Blt To Roof Blt = 0.004 ohms
Roof To Roof = 6.80 ohms
Floor To Floor = 8.00 ohms
Roof Blt To Roof Blt = 2.80 ohms
Roof To Roof = 3,300 ohms
Floor To Floor = 7.48 ohms
Roof Blt To Roof Blt = 0.004 ohms
Roof To Roof = 8,600 ohms
Floor To Floor = 14.90 ohms
Roof Blt To Roof Blt = 0.003 ohms
Roof To Roof = 7.40 ohms
Floor To Floor = 12.00 ohms
Roof Blt To Roof Blt = 0.02 ohms
Roof To Roof = 9,200 ohms
Floor To Floor = 5.70 ohms
Roof Blt To Roof Bolt = 0.0 ohms
Roof To Roof = 4.14 ohms
Floor To Floor = 11.70 ohms
Roof Blt To Roof Blt = 4.20 ohms
Roof To Roof = 5,600 ohms
Floor To Floor = 8.27 ohms
Roof Blt To Roof Blt = 0.003 ohms
Test 2 4-3-06
Roof To Roof = 3.90 ohms
Floor To Floor = 11.70 ohms
Roof Blt To Roof Blt = 8.30 ohms
Belt Power Center
Resistivity Testing Of Floor & Roof Across Area Of Pre-Explosion Seals
Roof To Roof = 6,200 ohms
Floor To Floor = 11.00 ohms
Roof Blt To Roof Blt = 6.00 ohms
Measurements Were Taken By Utilizing A Hilti Gun - This Process Isolates The Nails From Any Carbon On The Surfaces
Roof To Roof = 61,000 ohms
Floor To Floor = 6.80 ohms
Roof Blt To Roof Blt = 0.0 ohms
Resistivity Testing Of Floor & Roof - From End Of Track & Belt To Pre- Explosion Seals
Roof To Roof = 12,600 ohms
Floor To Floor = 5.40 ohms
Roof Blt o Roof Blt = 0.0 ohms
1
2
3
4
5
6
7
8
9
10
Data use subject to license.
© 2004 DeLorme. XMap®/GIS Editor.
www.delorme.com
MN (8.5° W)
ft
0 40 80 120 160 200 240 280
Data Zoom 17-0

Figure 4

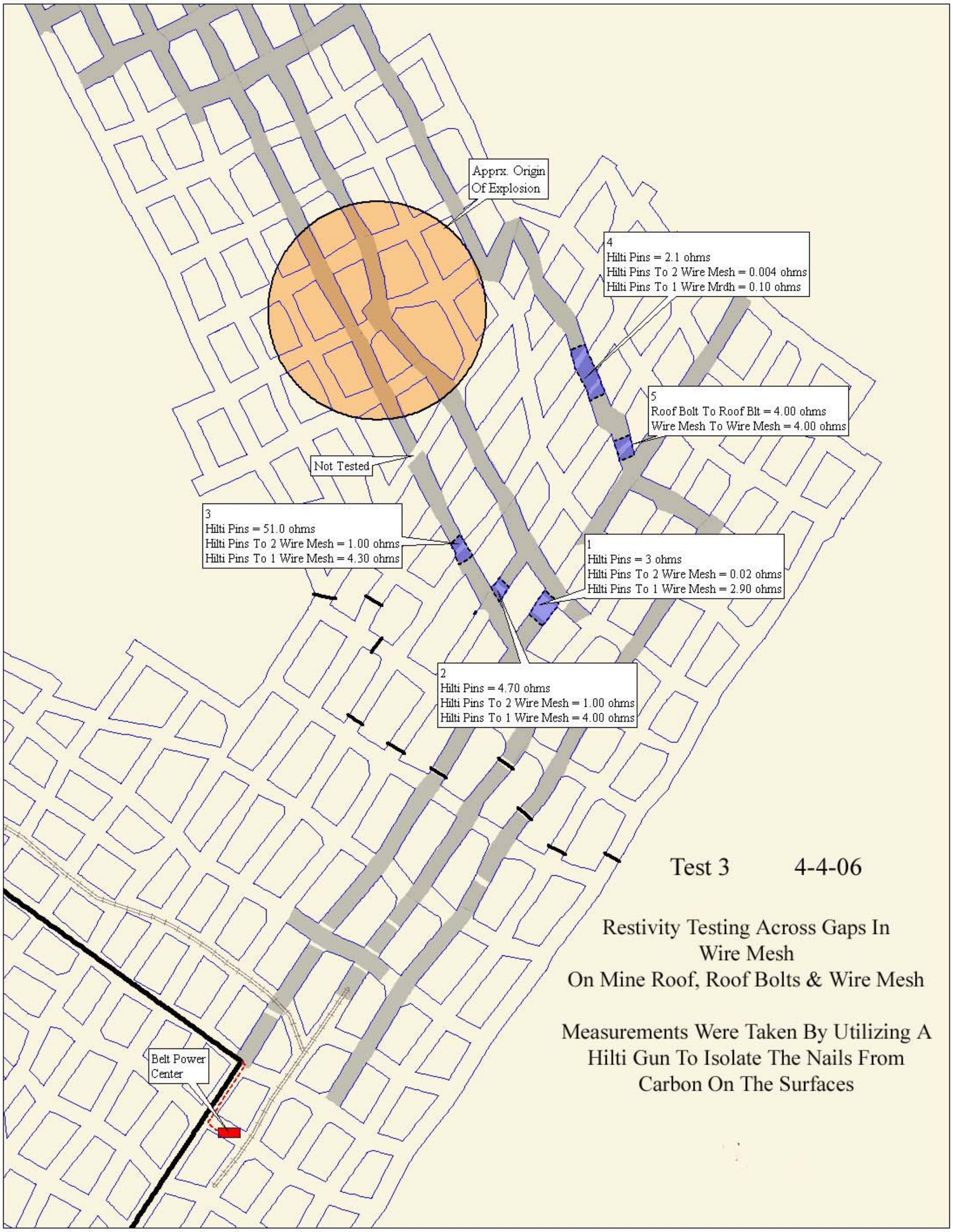





**Figure 5**

MN (8.5° W)

ft
0 40 80 120 160 200 240 280
Data Zoom 17-0

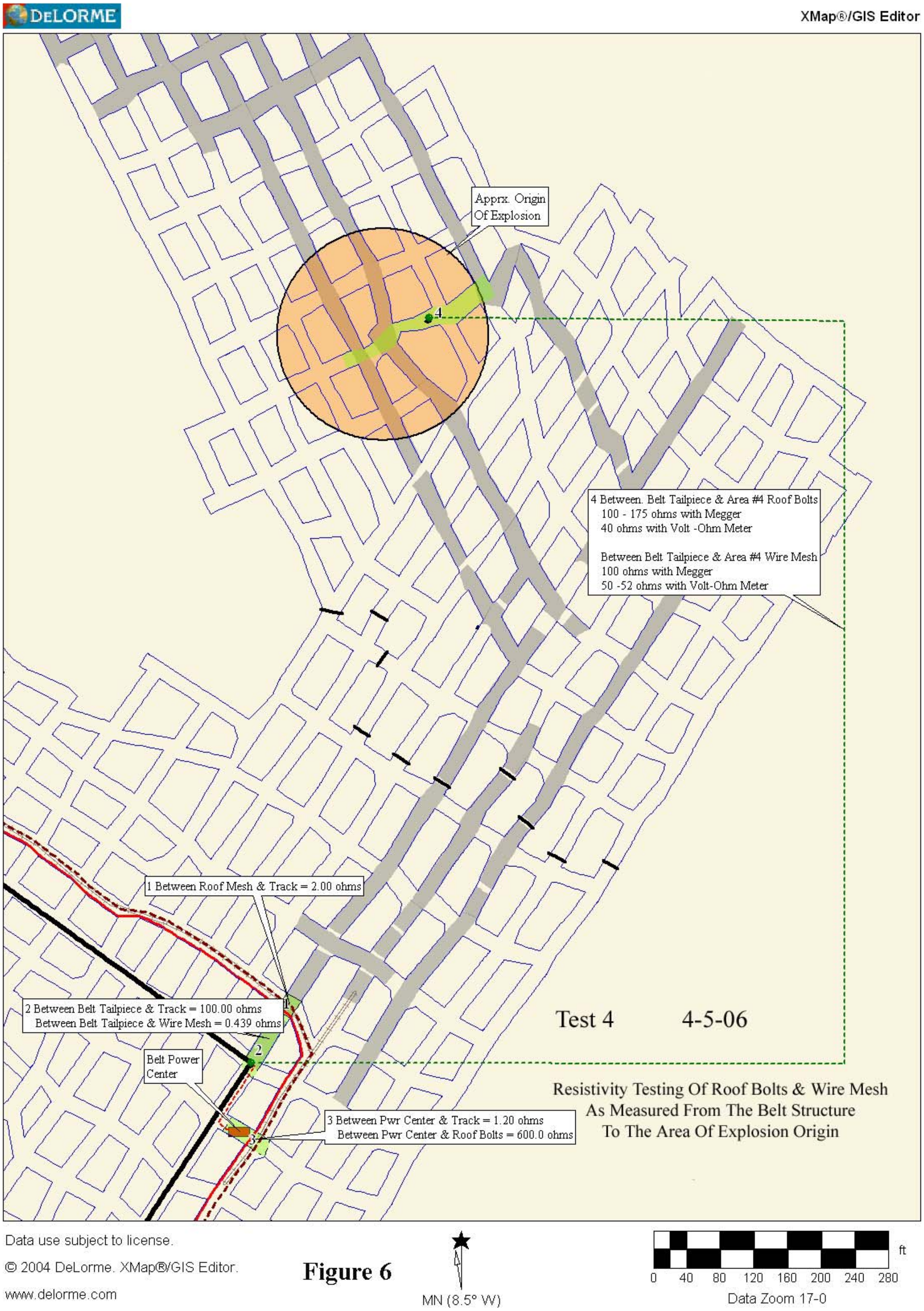
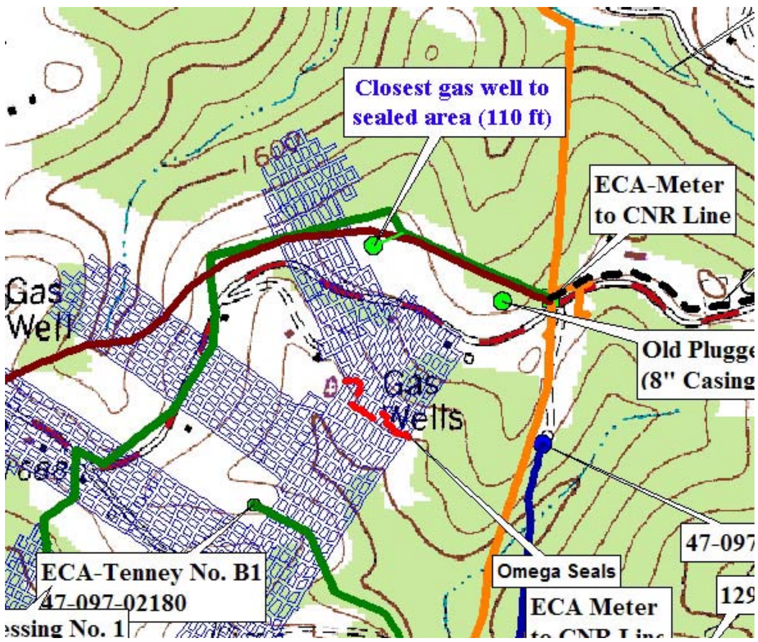

DeLORME
XMap®/GIS Editor
Apprx. Origin Of Explosion
4 Between. Belt Tailpiece & Area #4 Roof Bolts
100 - 175 ohms with Megger
40 ohms with Volt -Ohm Meter
Between Belt Tailpiece & Area #4 Wire Mesh
100 ohms with Megger
50 -52 ohms with Volt-Ohm Meter
1 Between Roof Mesh & Track = 2.00 ohms
2 Between Belt Tailpiece & Track = 100.00 ohms
Between Belt Tailpiece & Wire Mesh = 0.439 ohms
Belt Power Center
3 Between Pwr Center & Track = 1.20 ohms
Between Pwr Center & Roof Bolts = 600.0 ohms
Test 4 4-5-06
Resistivity Testing Of Roof Bolts & Wire Mesh
As Measured From The Belt Structure
To The Area Of Explosion Origin
MN (8.5° W)
0 40 80 120 160 200 240 280 ft
Data Zoom 17-0



**Figure 6**

### 5.5-3f Gas lines and wells

An extensive network of gas lines connects conventional gas wells on the surface over the Sago Mine and surrounding areas. Two lines are known to cross the surface over the Old 2nd Left sealed section. One well is located approximately one-hundred ten (110) feet from the sealed area mine works (see **Map 3**). A map showing the geometry of these lines within a 1.5 mile radius of Old 2nd Left Section is given in **Map 4.** A larger and more detailed map is included in **Appendix 5.5-3**: *Map of Gas Lines and Wells.*




**Map 3**. The closest gas well to the sealed area is approximatel 110 ft.

The gas line network contains seven (7) separate owner-operators. The main gas transmission line shown (see **Map 4**) gathers gas from feeder lines that are predominantly steel pipelines of approximately two (2) inch diameters, although occasionally small sections of plastic line are used. Approximately sixty (60) active gas wells and approximately twenty-seven (27) miles of active gas pipelines exist within a 1.5- mile radius over the top of the sealed area at Sago. The average depth of these wells is approximately 3800 feet. With the assistance of representatives of the various operating companies involved in this gas line network, OMHS&T prepared a detailed map showing the location of all known wells and lines within this area for purposes of determining whether they may have been involved in the transmission of lightning current into the sealed area.

Any large loops in electrical conductors, either inside or outside the mine, could have acted as a magnetic antenna and produced a large potential difference (voltage) across any gap in that loop in response to the lightning magnetic field. A metal gas well casing could act as an electric field antenna and cause large voltages to appear at the extremities of the antenna if it is exposed to a high electric field[14].

Lightning-related explosions in longwall gob areas that are near networks of methane degasification wells and pipeline systems have been documented in previous reports[15]. Deep gas wells[16] (like those in the Sago area) on the other hand rarely have steel casings that penetrate from the surface into the region of an active mine because of the recognized dangers of doing so. In the case of Sago Mine, there are several wells near the mine, but none pass through the mine void. The closest active well to the Old Second Left section were the Omega seals were located was approximately 110 feet from the eastern perimeter of the mine works.

Two gas lines run eastward from the general vicinity of the 101+ kA lightning strike. These are referred to for purposes of this illustration as the Trubie Run Gas Line and the Ridgetop Gas Line (see **Map 4**). These both connect to the north-south trending Main Gas Transmission Line. Descriptions of these two lines are contained in **Appendix 5.5-3:** *Description of Gas Lines and Wells.*

Conductivity testing

Soil resistivity testing was conducted at a gas well (**Photo 12**) located on the surface near the underground sealed area on January 18, 2006. A three (3) pole soil resistivity test was preformed using a model DET5/4D Megger (**Figure 7**). The metal well casing was used for one connection and ground rods approximately eight (8) inches in length were driven into the ground at distances of thirty (30) feet and sixty (60) feet from the well. 2.62 ohms of resistance was measured. Measurements were then taken in a radial sweep pattern of

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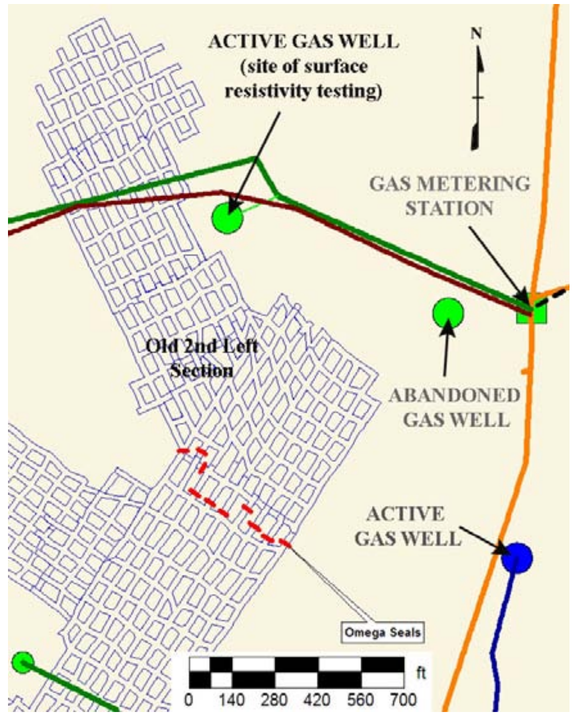
14 Dr. E.P. Krider, Dept. of Atmospheric Sciences, University of Arizona, November, 2006.

15 H.K. Sacks, T. Novak; Corona Discharge-Initiated Mine Explosions; IEEE Transactions on Industry Applications, VOL. 41, pp. 1316-1322, 2005.

16 Deep is defined here as 3500 to 4000 feet and target gas reservoirs that are unrelated to coal degasification wells which are sometimes drilled ahead of mining and in the gob of longwall-mined areas for purposes of recovering liberated methane from coal.

approximately thirty (30) feet each.  Only two additional readings were taken and they were 4.83 ohms and 5.6 ohms of resistance.

**Photo 12.** Nearest known gas well to the Old 2nd Left Section.  Soil resistivity tests were conducted here.




**Map 3A.** Location of the nearest active gas well to Old 2nd Left Section.

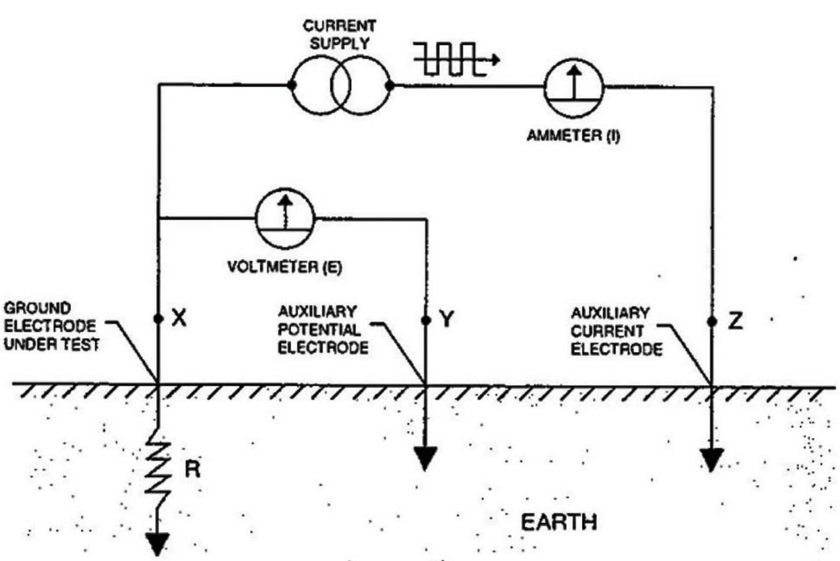
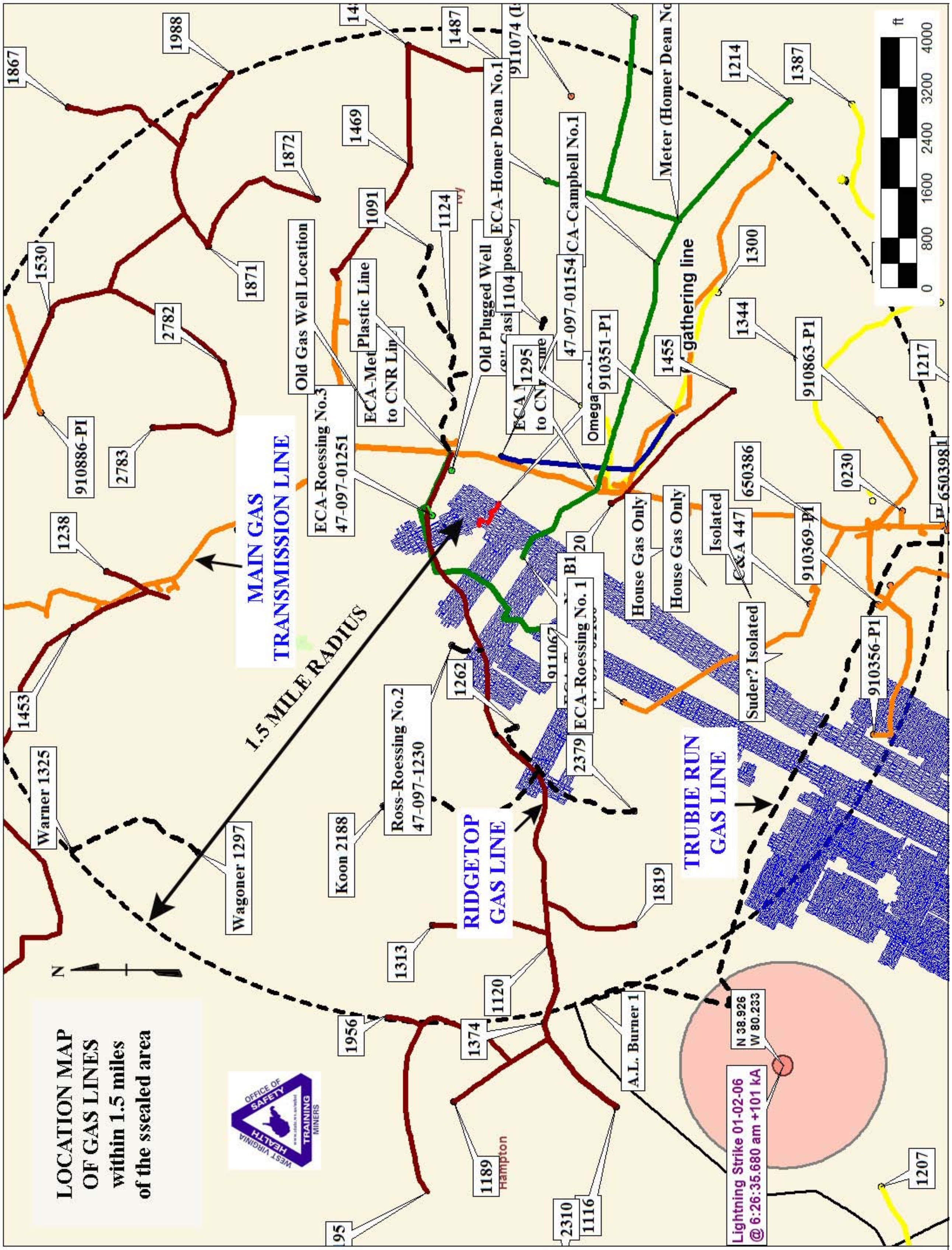



**Figure 7.** Three pole Resistivity testing




**Map 4.** Illustration of the location of gas wells and gaslines within a 1.5-mile radius of the Old Second Left Section of Sago Mine.

Summary

All known gas well and gas line owners and operators in the area were contacted to inquire if there was any damage to their equipment or infrastructure from the electrical storms of January 2, 2006. None were reported. Almost all the lines and wells within a 1.5 mile radius around Old 2nd Left Section were traveled and examined at the surface for evidence of damage. No visible damage attributable to lightning was discovered in the course of this work.

Work is still on-going to determine whether the network of gas wells and gaslines may have played a role in coupling high voltages into the sealed area, and particularly with respect to any upward lightning that may have been initiated by tall towers several miles away. A network of vertical gas wells 4000 deep connected to a network of gaslines on the surface could also have acted as a large electric field antenna in the ground at low frequencies.

### 5.5-3g Earth conduction

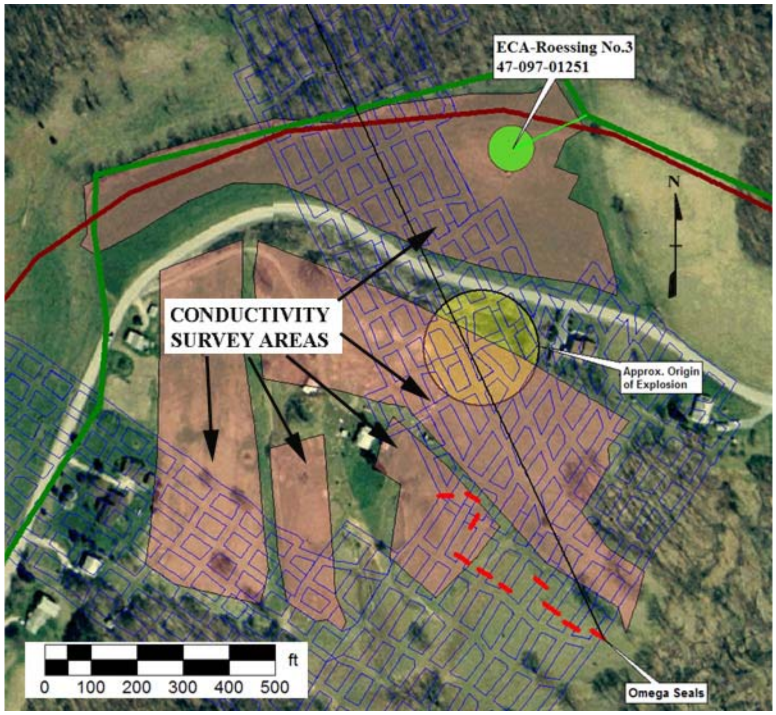
In July 2006, hydroGEOPHYSICS, Inc (HGI) performed a series of geophysical surveys for International Coal Group (ICG), involving the surface and underground areas of the Sago Mine Old 2nd Left section. The objective of this geophysical investigation was to characterize and map subsurface conditions in order to determine if a specific electrical pathway existed. This electrical path could have originated from either anthropogenic[17] features or natural geologic features.

Two different surveys were performed:

1) Electromagnetic Conductivity Survey

This involved searching for metallic infrastructure such as pipelines, wells, powerlines, or other features that could have provided a low resistance path from the surface to the underground mine works. Testing methods involved magnetic gradiometer (MAG survey) and electromagnetic induction (EM survey **Map 5**).

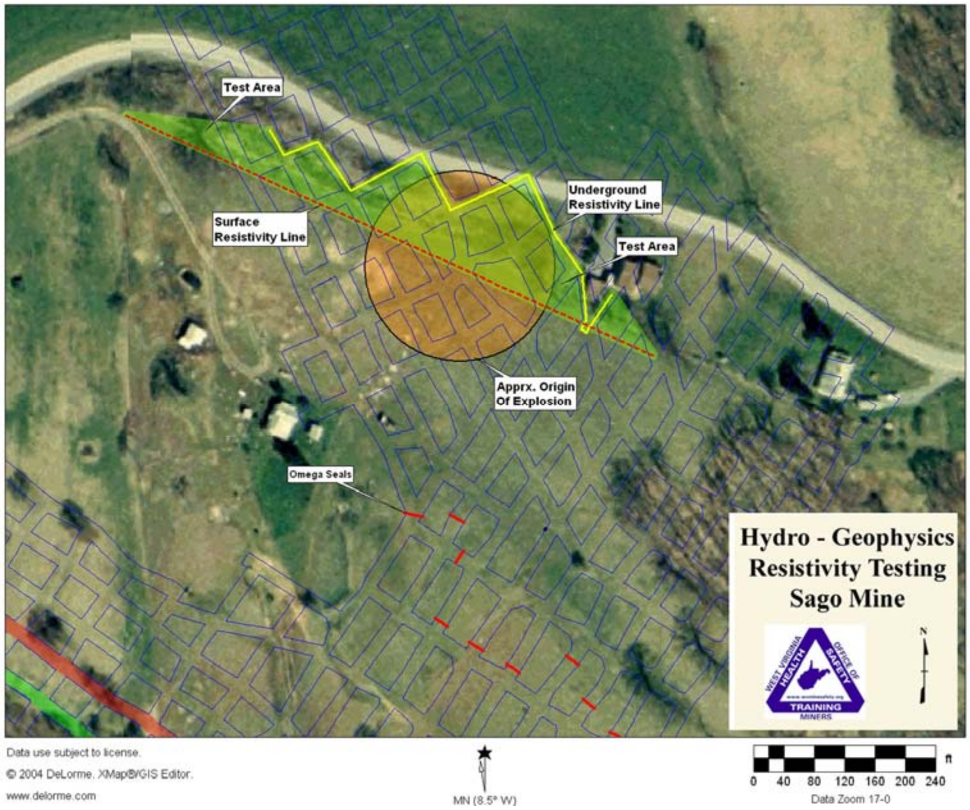
[17] man-made origins




**Map 5**: Location the areas where the electromagnetic conductivity surveys were performed.

2) High Resolution Resistivity Survey

This involved measuring the electric potential on a series of electrodes while injecting current on a nearby electrode. Testing methods involved High Resolution Resistivity (HRR) survey which utilized a nearby recently-drilled open borehole to drop lines to the mine to measure electric potentials between the surface and underground at various intervals along a baseline (see **Map 6**). The survey was arranged such that a set of electrodes at the surface could be used in combination with electrodes on the mine roof. Testing occurred over the vicinity of the approximated origin of the explosion.




**Map 6**: Location of area where high-resolution resistivity survey was performed

This survey consisted of individually wiring existing roof bolts (total of 56) in the mine to a communication center and connecting electrodes (total of 56) placed on the surface to the same communication center. An electrical current at varying frequencies (5, 7, 10, 15 and 20 kHz) was injected to an individual surface electrode and resistivity readings were recorded from all the wired roof bolts. This was repeated, injecting current to all 56 electrodes individually. This procedure was then reversed by injecting current to an individual roof bolt and recording resistivity at all the wired surface electrodes. Each roof bolt (total of 56) was injected with electrical current. The data were then processed to determine if any electrically conducting structures existed within the test area.

<u>Results of the testing:</u>

- No vertical well casings were detected within the survey area.
- No compelling vertically oriented conductive zones that could act as an electrical conduit were detected.

### 5.5-3h Verizon telephone lines

The poplar tree that is believed to have been the strike object of the +101 kA lightning stroke is located about 50ft from a buried telephone utility line that is owned by Verizon. This line was examined for evidence of lightning damage.

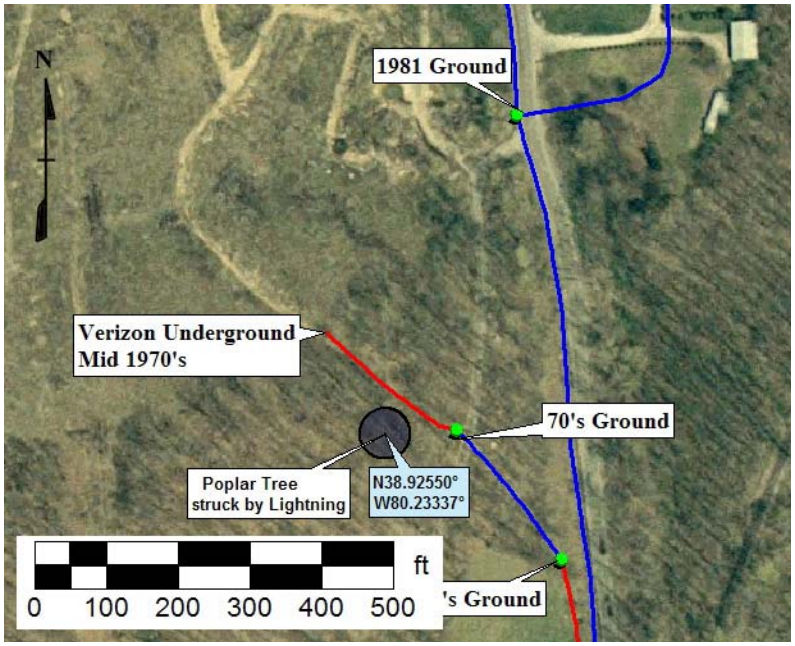



**Photo 13.** A buried telephone cable lies within approximately 50' of the poplar tree that was struck by lightning,

In mid May 2006 the area engineer for Verizon Telephone Company accompanied OMHS&T personnel on a field inspection of the telephone lines near the ICG – Sago Mine. There are two separate lines that service the Sago area and pass near the poplar tree lightning strike.

The first telephone line was installed in the mid 1970's. This is a buried line that passes closest to the lightning strike and does not service the Sago Mine. It is also the line that spurs off and feeds the nearby residence (the family that lost service immediately after the lightning strike) and is referred to as the 70's line on the attached map. The second line was installed in 1981 (and is referred to as the 1981 Line) and runs parallel to the Sago Road. It is an aerial line that starts at Route 20 to about halfway between the lightning strike area and the Sago Mine. This line then becomes a buried line and parallels the mid 70's line along the Sago Road. The distance between the 1970's buried line and the 1981 buried line is approximately 2 feet horizontally. The 1981 line services the Sago Mine.

**Photo 14:** Junction box of 1970's line (closest box to lightning-struck poplar tree.

**Photo 15:** Junction box of 1981 line - where line changes from aerial to buried

The Verizon engineer indicated that when the lines are spliced a junction box is used. At each junction box the line is grounded, and the ground is common with the incoming line and the outgoing line. This is done to insure that no interference will cause poor line service to the customers. The location of the junction box is site-specific and is referred to as: 70's Ground for the 1970's Line and 1981 Ground for the 1981 Line, on the attached map. These two lines are grounded separately.

The nearest line that the lightning could have contacted and used as a conductor of electricity is the 70's buried line. The closest junction box (70's Ground 1) to the poplar tree is approximately one hundred (100) feet. At this time the line temporarily becomes aerial for a road crossing and then is buried again at junction box (70's Ground 2). This is where the Verizon engineer indicated repair service for the nearby resident was done. OMHS&T staff had found wire at the previous junction box (70's Ground 1) and assumed that the repairs were there.

**Photo 16:** Junction boxes of the 1970's buried line and the 1981 buried line.

**Photo 17:** Typical grounding of buried cable at junction box

The Verizon engineer indicated that that box is safely off the road and the service/repair men often use it to trouble shoot. They can narrow down any problem by checking for faults and determine if the problem is inby or outby that box. When the "70's Ground 1" Junction Box was opened it was found that rodents were living in the junction box, and several wires had places where they had eaten the insulation from them (see **Photo 18**). The wire insulation was tarnished from animal waste. The nest was rather large; the occupants had been there for quite some time. Connections are coated with a gel to prevent moisture intrusion at the splices. The individual insulated lead wires in the telephone line are roughly 19 gauge wires (visually the diameter of "0.5 mm pencil lead"). The Verizon engineer stated that the 70's line and 1981 line are 70 to 80 pair lines (140 to 160 leads).

**Photo 18:** Mouse nest in 1970's junction box closest to lightning strike**.**

In order for electricity from the lightning strike at the poplar tree to have traveled to the Sago Mine via the telephone lines it would need to have continuity with the "70's" line and transfer through the earth to the "1981" line. There are two locations where the two lines are in close proximity.

The first possibility is where the 1981 line becomes buried. It would be necessary for the lightning current to travel approximately 1,750 feet along the 70's line and pass through five (5) grounded junction boxes, leave the fifth box and enter the nearest 1981 grounded junction box, which is approximately 200 feet from the fifth 70's grounded junction box.  At this point both the 70's and 1981 lines could be energized.

The second possiblity is where 2 to 3 pairs (4 to 6 wires) are bridged between the 70's line and the 1981 line.  This connection was done to bypass a fault in either the 70's line or the 1981 line.  The lightning current would need to travel approximately 2,000 feet along the 70's line and pass through six (6) grounded junction boxes.  At this point both lines could be energized.

The total length of line from the lightning source to the Sago Mine is approximately 6,350 feet and would have to pass through 12 grounded junction boxes.

The public telephone distribution boxes at the Sago Mine were also examined. The Verizon phone company had installed a larger box after the January 2, 2006 explosion, but the original box and wiring were still there. The old wiring, coming in from across the Buckhannon River, did not have a ground or messenger wire attached. The only ground wire is inside the distribution box. This wire is attached to a ground lug inside the distribution box and is only tied to the solid copper ground wire coming down the telephone pole. No other wires inside the Distribution Box were attached to the ground lug.

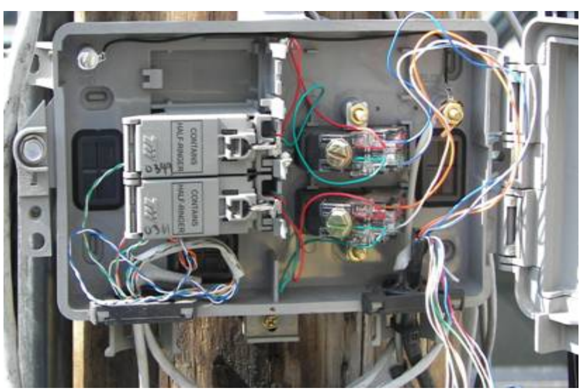


**Photo 19:** 1 of 2 original phone distribution boxes (still in use).  Only the distribution box itself is

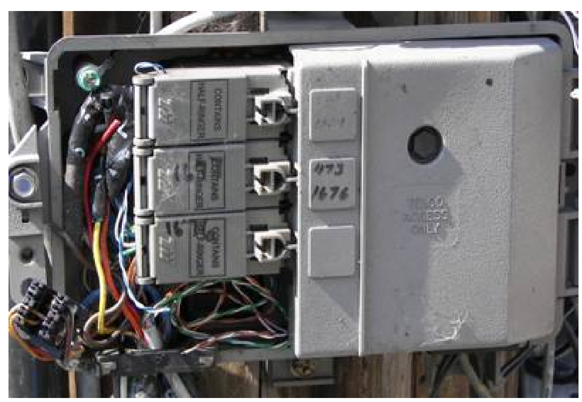


**Photo 20:** 2nd Original distribution box (still in use)

**Photo 21:** Messenger wire on new line (not grounded on pole)

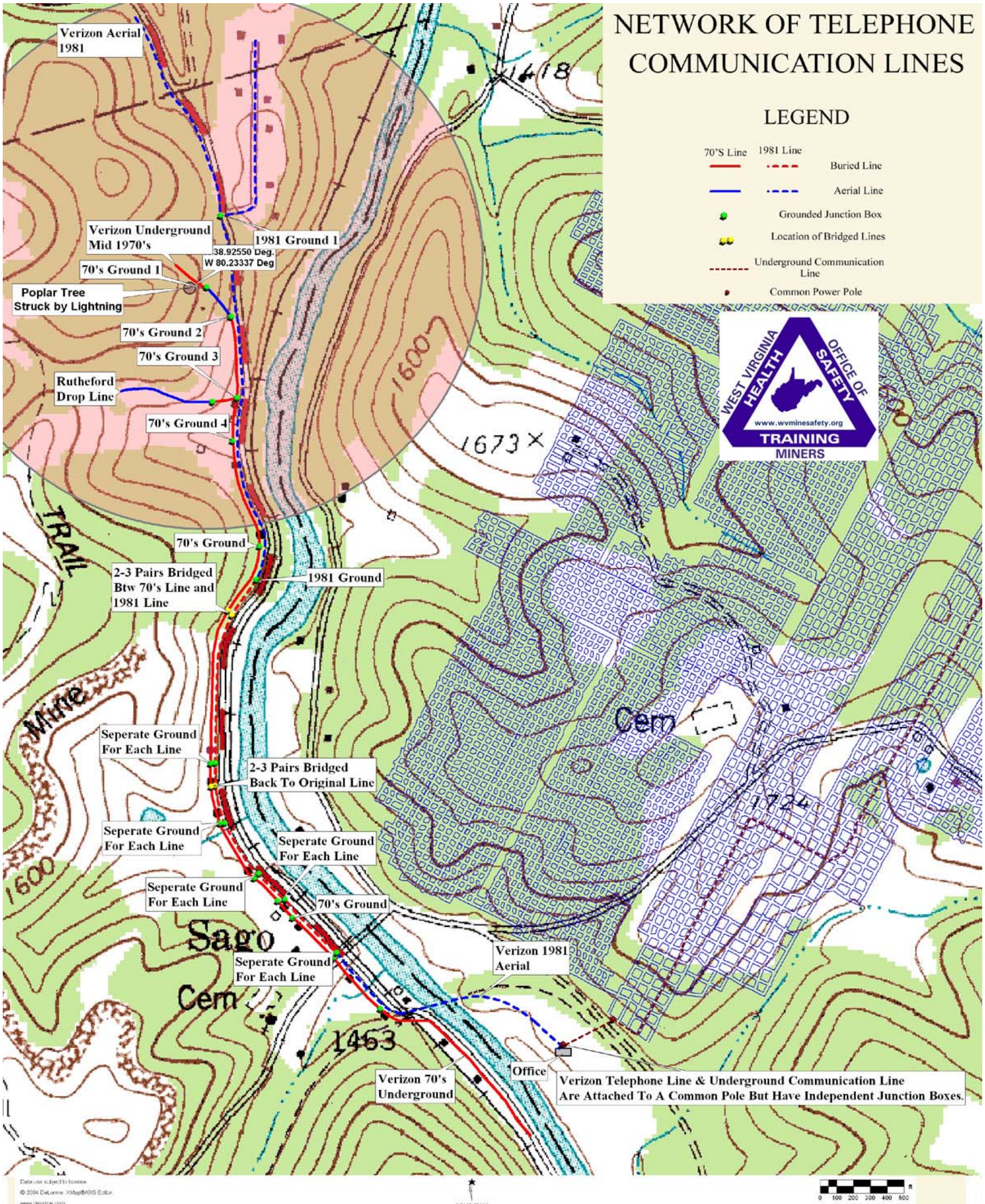
**Photo 22:** Ground Connection On Pole For Distribution Box

New wiring had been run to the new distribution box by the phone company. This new wiring has a messenger wire attached but it is not connected to a ground on the pole or inside the new distribution box. The only ground wire is inside the distribution box. This wire is attached to a ground lug inside the Distribution Box and was only tied to the solid copper ground wire coming down the telephone pole. No other wires inside the distribution box were grounded.

The telephone service to this mine site was not affected by the lightning strike to the popular tree across the Buckhannon River, on the morning of January 2, 2006, and there is no visual damage inside the phone distribution box.  Temporary interference and an acoustic impulse was observed by a Sago worker who was talking on the telephone and he dropped the phone at the same time as a lighting strike.

The Verizon telephone company provided service reports of customers within a three (3) mile radius of the town of Sago, from January 2, 2006 to February 2, 2006.  Only one (1) repair was performed.  This repair was to the buried 1981 line which does not go to the Sago Mine.  This repair was recorded as a broken lead in a junction box.

Another note is that the line that supplies service to Sago Mine also provides service to customers along the Sago road (from the lightning strike to the Sago Mine).  The only affected customer was the Rutheford family, and they are on a spur line that branches from the 1981 line (approximately 850 feet of line distance from the lightning strike).  Sago Mine's service is provided by the 1970's line.  It is highly unlikely that a significant lightning current could travel along the telephone line, enter the mine, and cause a methane ignition without affecting service or causing disruption to the customers between the lightning strike and the Sago mine.




**Map 7.** Map showing layout of Verizon telephone lines. A larger version of this map is contained in **Appendix 5.5-3**: *Map of Telephone Lines*

### 5.5-3i Pump cable and wire roof mesh

During the investigation a length of cable with a cable coupler attached to one end was found in the general vicinity of where the explosion appears to have originated. This cable was eventually traced back to a pump that lay submerged in water at the top end (back) of the Old 2nd Left section **(Map 8)**. It was found to be broken in three (3) places over its 1300-ft. length, and was lying with and tangled up among scattered crib blocks and other explosion debris along much of the outby half of its length. The cable lengths are numbered 1 through 4, with the piece terminating at the cable coupler being length #1. Through the work of John Collins, OMHS&T Inspector, and others, these cable lengths were determined to be approximately as follows:

| Cable ID | Length | Comments |
|---|---|---|
| #1 | 199.6' | Outby end terminates with cable coupler near spad 4028 |
| #2 | 188 ' | Intimately tangled with crib blocks on floor |
| #3 | ~93' | Brattice curtain looped around outby end at spad 4089 |
| #4 | ~812' | Inby end terminates at pump 3 br. inby spad 3713 |
| TOTAL | 1293' | |

Cable condition at the time of explosion

Although it has not been proven, it is suspected that this 1300'+/- cable may have been intact at the time of the explosion[18]. Reasons for this belief include the following:

- The inby ½ of the pump cable was underwater at the time of the explosion and so escaped damage. Much of this length is still tied by wires to nail anchors in the coal rib or to the wire roof mesh. Similar ties are on the roof, rib, and cable for much of the outby ½ of its length, indicating it could have been similarly hung over much of its total length at the time of the explosion. In addition, the cable lengths one (1) and two (2) were found to be intertwined among crib blocks and brattice in a manner that suggests it was not lying on the floor at the time of the explosion.

- The preliminary results of microscopic examination of the cable ends indicates the breaks were consistent with having failed in tension from pull-apart forces. None of the cable breaks appear to be caused by mechanical cutting tools.

- Visual inspection of the cable shows little evidence of trauma as might be expected if the cable breaks were caused by a piece of mobile face equipment.

- The cable breaks generally occurred in the vicinity of intersections. Blast forces acting perpendicular to a hanging cable by a secondary pressure wave acting through the cross-cuts may have been the mechanism of rupture.

In the presence of a large area of wire roof mesh and wet conditions at the top end of the section, it is not essential that the pump cable be involved to produce the sparks that ignited the methane explosion. Rather, it is just the fact that the explosion appears to have originated close to where the pump cable terminated in a cable coupler that makes it an item of interest. In the absence of a lightning-induced transient on the pump cable, the wire roof mesh itself could have acted as an electric field antenna or been part of a magnetic ground loop that, under the right conditions, could have produced sparks across small gaps and discontinuities in the mesh that ignited the methane.

<u>Voltage differences</u>

As shown in **Map 8**, a large metallic roof mesh overlies the pump cable from the cable coupler to the pump at the top end of the section. That cable is also suspected to have been electrically connected to the wire mesh in the vicinity of the submerged dewater pump at the time of the explosion because the pump control box was tied close to the wire mesh[19] at that time. Therefore the insulated cable ran parallel to and was isolated from the well-grounded wire roof mesh up to the point where it terminated at the cable coupler.

The horizontal pump cable may have brought the ground potential (voltage) of the nearby well casing, the pump, and water (see **Map 8**) into close proximity to a different ground potential (i.e that of the walls, floor, or roof mesh) in the mine void, and if these differences were large enough, they could have produced corona discharges.

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[18] Preliminary results of a forensic analysis on the ends of the cables indicates the breaks were not due to tool cutting but rather were ruptured in tension in a manner consistent with a longitudinal or pull-apart failure. Additional testing is required to determine if equipment or the explosion caused one or more of the ruptures.

An arrangement of a long, insulated cable running parallel to a grounded roof mesh would normally present little cause for concern, however, the unusually intense lightning events such as occurred on the morning of January 2, 2006 and the possibility of *upward or triggered lightning* phenomena, may pose risks to mine safety that have not been fully appreciated

The winter lightning storm of January 2, 2006 was no ordinary storm and the near-simultaneous occurrence of two large positive cloud-to-ground strokes with peak currents of +39 kA and +101 kA, near the Sago mine was extraordinary. As discussed earlier in **Section 5.5-3c** a large lightning flash to ground has the ability to trigger an upward discharge to a tall structure that is several miles from the cloud-to-ground strike point. There are four (4) tall radio antennas on elevated terrain east of Sago mine (see **Map 1**). Upward lightning could have been triggered from one or more of those towers and the current could have coupled into the Sago mine on the large network of gas pipes and wells. Again, upward lightning is not usually detected by the NLDN or other lightning detection networks currently in use.

The possibility that the pump cable and/or wire mesh or the nearby gas well and the associated gas pipeline may under unusual conditions produce large voltage differences and corona when they are energized by lightning are possibilities that are still being investigated. Such phenomena are not well-understood but the need to increase our understanding is great. In that respect, the Sago investigation is not complete.

A possible scenario involving the pump cable

A cross-section view of Old 2nd Left Section is given in **Figure 8**. As shown, the rock strata contain sandstone layers that are separated by other layers[20]. Measurements of resistivity are given in **Appendix 5.5-3**: *Geophysical Log for SF 52-06.* Layers of shale and sandy shale are between the sandstone layers, and have comparatively low resistivity. The layer of shale between the coal and the Rider seam appears to generally have the lowest resistivity of all.

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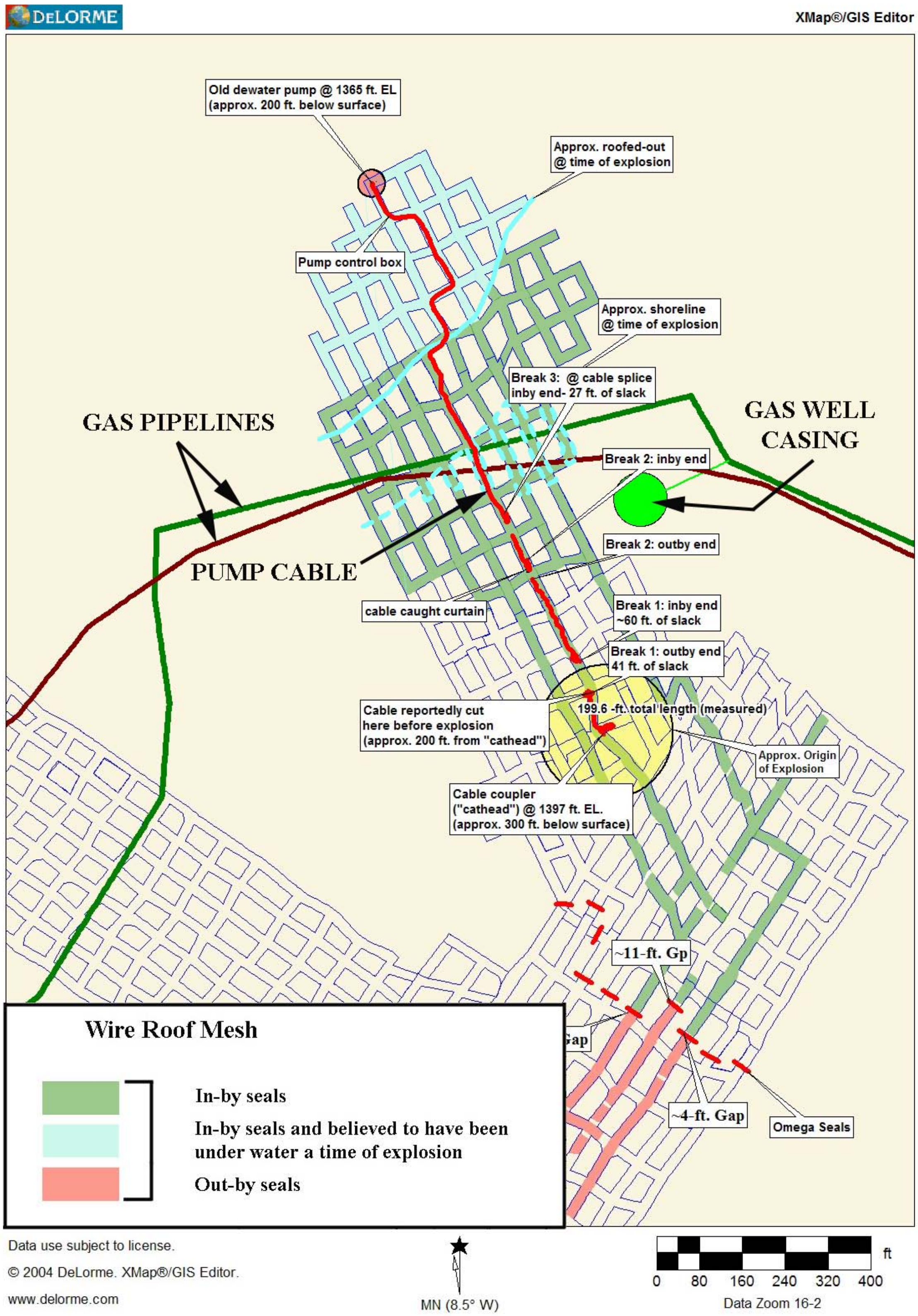
[19] The pump control box is the switch box for the pump and separate from the pump. It was submerged below water at the time of the explosion and was reportedly suspended from the wire roof mesh by its retainer chain.

[20] Principally shale and sandy shale




**Map 8.** Illustration of the arrangement of wire roof mesh to a pump cable and gas well. The gas well is part of a system of approximately 60 wells within a radius of approximately 1.5 miles that are interconnected by a network of gas transmission pipelines at the surface.

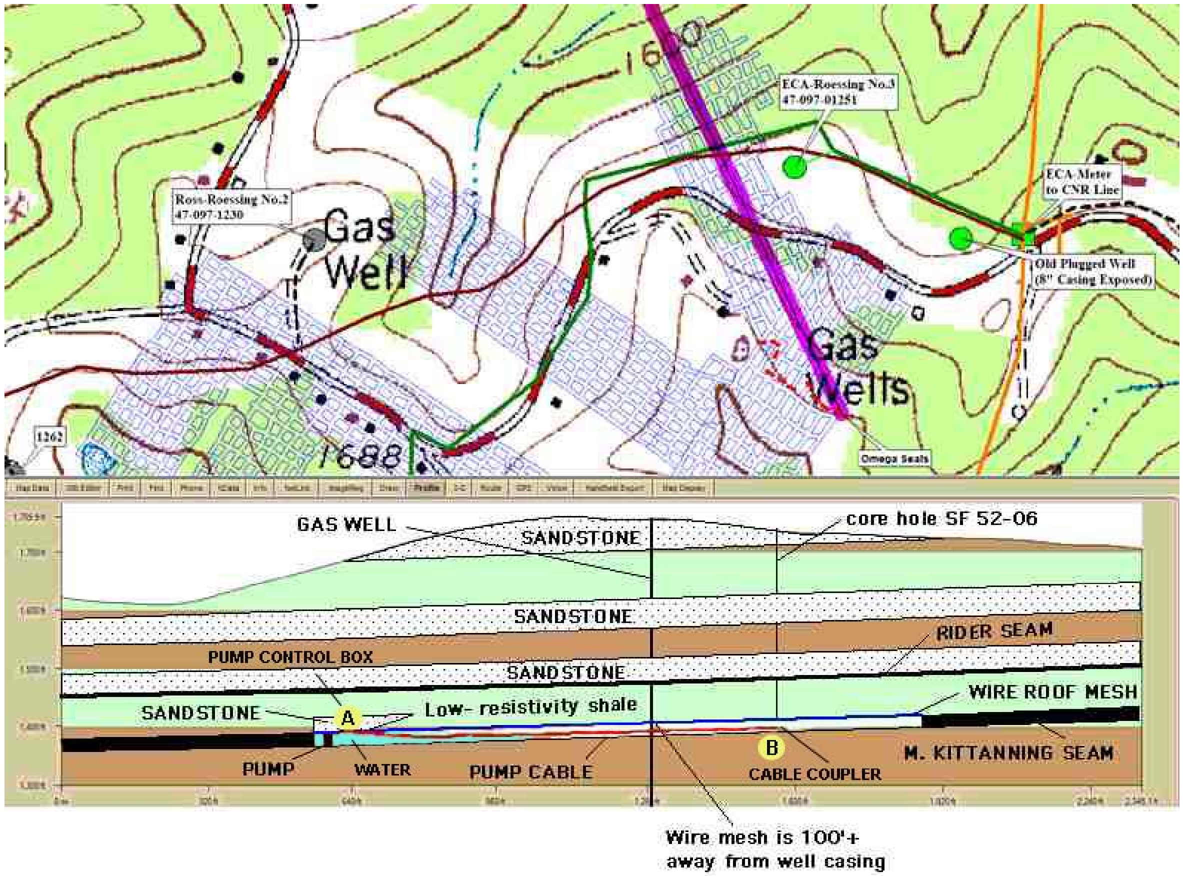



**Figure 8.** Geologic cross-section through Old 2nd Left Section. E-log to SF 52-06 shows sandstones are high resistivity. The shale roof is low resistivity. The wire roof mesh is bolted to this shale. The pump cable is insulated from the wire roof mesh except at the pump control box.

A local channel sandstone has replaced the shale roof at location "A," and at this location a pump control box connects that cable to a submersible pump. The pump control box was tied to the wire roof mesh at this location. The channel sandstone at "A" produces considerable water, and at the time of the explosion the pump, the pump control box, and the wire mesh at location "A" were underwater. Because the pump control box does not have a waterproof gasket, it was full of mine water and thus the pump cable was probably electrically connected to the wire mesh at "A."

The wire roof mesh covers the mine roof extensively between "A" and "B" as a continuous, uninsulated metallic conductor and the insulated pump cable was either suspended from the roof or lying on the floor of the mine. A time-varying magnetic field could have created a potential difference across the gap at "B," in the metallic loop formed by the roof mesh and the cable shield and of course any current flowing through the finite resistivity of the ground could have created potential differences between the floor, the vertical rock faces, and the roof mesh.

The next step

The region of the Sago Mine will continue to experience lightning and as the winter season approaches it is recommended that we install a number of FSD circuits (see **Figure 9**) within Old 2nd Left Section and at other points in Sago Mine in order to measure the transient voltages and currents that appear underground when there is lightning in the area. Due to the intensive investigations that have taken place at Sago during the past 11 months, we now know more about the arrangement of metallic structures at the surface and underground at Sago and will, hopefully, soon be able to supplement that information with a model of how the electromagnetic energy from lightning penetrated from the surface into the Sago mine[21]. If we can monitor and detect transient currents and voltages from future lightning activity we may be able to correlate them to specific types of lightning and field conditions. This is the first step in developing protective measures to guard against similarly destructive lightning accidents in the future.

The chances of obtaining positive lightning in the Sago area during the winter are as good or better than other geographical locations in the U.S. It is recommended that such a study be implemented at the Sago mine. The types of device that are proposed for monitors are available, inexpensive, and require very little maintenance. They could be left underground, unattended, and will monitor for any current and voltage surges continuously. When a surge is detected, the monitor will shut down and record the time until it is reset. The devices merely need to be checked periodically. By correlating readings of the lightning transient underground, to lightning detected on the surface, we will be in a good position to understanding how lightning entered this mine.

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[21] The results of preliminary tests performed for MSHA by Sandia National Labs measuring direct and indirect electric field coupling from the surface to the underground are not yet available to OMHS&T

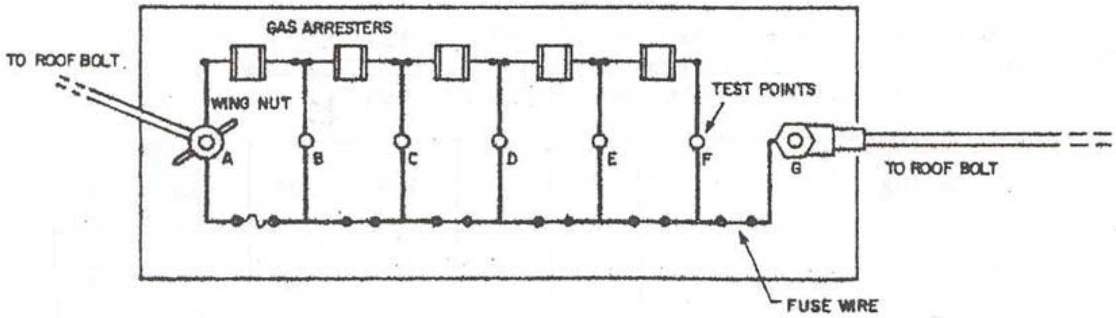


**Figure 9.** Schematic diagram of the fuse surge detector (FSD) for monitoring of transient currents underground. The FSD comprises six fusable wires in series, with gas arrestors in parallel to five of the six fuses (the electronic circuit is not shown)[22].

[22] H.J. Geldenhuys; Further Progress on Research into Lightning-related incidents in shallow South African Coal Mines, Proceedings of the 23rd International Conf. of Safety in Mines Research Institute, September 11-15, 1989, pp. 1180-1190.