Installation Trip to the Open-Pit Copper Mines of the Southwestern United States

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INTRODUCTION

As part of the DTRA funded contract no. DSWA01-98-C-0176, the Department of Geological Sciences at Southern Methodist University will be conducting local and regional seismic and acoustic experiments in the Western United States. Sources for the seismic and acoustic energy will be rock fragmentation explosions at the copper mines in eastern Arizona and western New Mexico.

Acoustic and seismic energy from explosions in western New Mexico copper mines are routinely detected at the TXAR in West Texas. These explosions provide an opportunity to study long distance seismic and acoustic propagation in the western US, to study the relationship between industrial mining practices and the characteristics of recorded explosions, and to study the relation of the near-source seismic energy to industrial explosion design. In addition, near-source instrumentation within the mine, provides the opportunity for collaborative studies with mine engineers to study the relationship between near-source seismic signatures, fragmentation efficiency, and explosion design.

The proposed plan for beginning field acquisition is early 2000, delayed from the original plan of late 1999. It is expected that a full field acquisition will be in place in the late summer of 2000.

This January 17-21, 2000 visit had the following purposes:

- To report the results and deliver the raw data from the May 1999 reconnaissance experiments to the mining engineers at the Phelps Dodge Morenci and Tyrone copper mines,
- To arrange for routine information and data exchange of shooting geometry and seismo-acoustic recordings,
- To install one 3-component seismometer, infrasound microphones, and a RefTek 114 recording system connected to a telephone line in the mines,
- To test the installation procedures and design of the prototype systems prior to deploying the other systems across the western US.

A second trip February 3-4 was made to correct problems in the Tyrone seismometer installation.

This report discusses the following:

- Trip preparation,
- The discussion with engineers at Morenci,
- The installation of the equipment in the Morenci and Tyrone mines,
- Suggested modifications to the testing, installation, and configuration of the equipment,
- A sample of the first blasts recorded,

- And suggested plans for building a dataset.

Trip Preparation

Three sets (one for each site and a spare) of RefTek 114 recording systems were configured, tested, and packed at SMU. Two STS-2 seismometers, borrowed from LANL were tested on the SMU pier and packed. A third spare STS-2 was held at SMU in case a spare might be needed. Six infrasound sensors had previously been tested at an experiment in McKinney, Texas.

Jessie Bonner reviewed the procedures for configuring and operating the 114 with Karl Thomason, Chris Hayward, and Paul Golden.

The new laptop was loaded with the RefTek utilities and tested in the basement. The spare batteries were charged and tested.

Jim Hanson at Morenci prepared a mini-vault and mounted the NEMA enclosure on a building (bulkhead mounting). John Gregory at Tyrone prepared the hole for the mini-vault.

Most of the equipment was shipped by Central Freight to El Paso. One portion of the shipment missed the deadline for surface freight to El Paso when Central arrived at our dock without a lift gate (the pallet was about 450 lbs). We shipped the essentials out of the missed package by FedEx and the non-essentials by Central Freight to Silver City.

The laptop, palmtop, and APS camera were packed in hand baggage.

We flew from Dallas to El Paso by SW.

We picked up a U-Haul cargo van in El Paso, bought a battery at Sam's for the Morenci installation, picked up the freight at the Central dock (intercepting the shipment for Silver City), and picked up the rush package from FedEx.

Discussion with Engineers at PD Morenci

On January 18, 2000, members of the SMU Geophysics Laboratory met with the Phelps Dodge Morenci mine (Table 1).

During the meeting, the results of the prior quick look report were reviewed and the plans for the SMU experiment, including both the regional and close-in deployments, were briefly reviewed. The engineers were enthusiastic and were particularly interested in how the results from both local and regional experiments might improve fragmentation and give some feedback on misfires. We informally discussed the following:

- An email list for communications between Morenci and SMU would be constructed using the recipient list from the first two exchanged messages. R. Gerdes will send us shot parameters and we will reply with an acknowledgement and any summary information we have on the shot. The first email from SMU will be directed to the list in Table 1.

- SMU will forward copies of the quarterly and semi-annual technical reports to all people on the distribution list. In addition, SMU will provide any raw data described in the reports.

- SMU is planning to deploy additional equipment in mid-March over the SMU spring break. We discussed possibilities of near-source measurements (close enough that humans would not be present, but far enough away that the equipment would probably survive) during this time period and agreed that additional planning would need to be done prior to an in-mine deployment.

- Morenci is currently experimenting with two high-speed video cameras, one capable of 10,000 frames/sec in full color. These are currently being deployed on a routine basis. In addition uphole indicators (flash loops) are deployed on some patterns. We discussed the value of a coordinated data set with seismic recordings, blast parameters, multiple high-speed cameras, acoustic measurements and rock property measurements.

- Engineers expressed interest in being able to determine rock properties (such as in-situ shear strength) perhaps as part of the test data set.

- The seismic acquisition box will be not be secured other than with the standard slotted latches. SMU requested that the seismometer vault be pinned shut with a simple bolt or screw if there was a likelihood of the curious people opening the top to peek inside.

- The results of the first cooperative experiment should be published as a paper with joint SMU-PD authors.

- A topographic or layout map of the mine with the location of the equipment marked on the map is needed to understand the seismic and acoustic recordings. SMU will request such a map from PD Morenci.

- SMU will duplicate 6 more copies of the Mining explosions CD and mail them to Jim Hanson for distribution.

Installation at Morenci and Tyrone Mines

Morenci Installation

At 8 am Tuesday morning we met Jim Hanson at the front gate, moved the instruments from our truck to his pickup, and rode into the site. The site is at the mine office, inside the pit area. When the mine is fully developed, the site will be on a ridge separating two pits (Figure 1). For the current mine plan, the site would be available (unmined) for at least 10 years.

The enclosure is mounted on the outside of an office trailer with the seismometer vault about 2 feet from the end of the trailer (Figure 2). There is about 20 feet between the office trailer and the main offices. A parking lot abuts one side of the trailer. In back of the trailer about 250 feet is a haul truck road.

The vault was perfectly level, had been cemented as required, and had already had flexible conduit plumbed into the side of the vault. Power was available inside the box with a standard GFI outlet. Jim supplied a Max-2 surge protector for the outlet. A conduit to route telephone from the box to a telephone jack inside the trailer was in place.

The shelves were rearranged in the box to allow for the internal power outlet (Figure 3). Morenci technicians punched holes for the GPS cable and acoustic sensor cables, glued the GPS and three infrasound microphones to the roof with RTV. Infrasound microphones were arranged on a five-foot triangle (Figure 4).

RefTek cabling was completed using the diagrams that Karl and Jessie put together from the test setup (Figure 5). The RefTek setup was reviewed and modified as follows:

- Preamp gains were changed from 8 to 1.
- Pretrigger length was increased slightly
- Channels 5 and 6 with the extra two acoustic sensors were enabled
- Some of the header information, such as sensor serial number was completed.

The completed configuration is shown in Tables 2 and 3. Power was applied to the microphones using the test function on the handheld.

Leveling the STS-2 seismometer proved problematic (Figure 6). After four attempts to install and level it, it finally began to work. The added top bubble level, while convenient for rough leveling was not sensitive enough for adjusting the mass center. Seeing the bottom level was nearly impossible. Jim Hanson finally got the seismometer leveled and playing. Orienting the seismometer was also difficult. Just finding true north in an area with steel buildings, overhead powerlines and limited sight lines is a challenge, never mind scribing the line on a tube and orienting a seismometer that doesn't have a north indicator anywhere on the case.

Morenci installed a private incoming direct dial telephone line (520-865-2278) for the installation. Dialing in from Jim's office telephone and connecting with the laptop tested the line and final installation.

Operation of the seismometer and infrasound microphones was verified by retrieving data directly from the RefTek disk using the laptop's SCSI interface. The waveforms were examined on the laptop using RTSCOPE. We left the mine at a little past 5 PM.

Tyrone Installation

After a very long day, we left Morenci, telephoned back to check messages, and began the drive the Silver City. We picked up concrete and related supplies (a 5-gallon bucket, mixer, gloves, concrete blocks) at Foxworth in Silver City and arrived at Tyrone at 8:30. After meeting John and getting organized, we followed him out to the site in the rental truck and observed the hole (Figure 7).

The excavation was blasted with about 5 lbs. of explosives in one hole 12 feet deep and several others only a few feet deep. A backhoe was then used to clean out the fragments.

The vault was set in concrete mixed by hand on the site and leveled using the base level on a Brunton (Figure 8). It was allowed to set the rest of the day while the electronics was assembled and cabled together (Figure 10). This required the remainder of the day.

On Thursday, we started at dawn. Tyrone backfilled the vault with fine material (Figure 9) and connected a direct dial telephone line.

We then installed the microphones on a 10-foot triangle (Figure 12) and then attempted to install the seismometer. Even with multiple attempts to level the seismometer, we were unable to confirm that the velocity outputs were valid. The mass position output indicated that the seismometer was leveled within operating range, but the velocity outputs seemed to be clipped. We finally closed the seismometer site (Figure 11), hoping that the velocity problem was a thermal shock problem and that the system would stabilize within the next few days.

Unfortunately, in the confusion surrounding the seismometer centering, we neglected to turn power on to the infrasound microphones.

Since the installation, RefTek supplied software patches to allow remote control of power and sensor power can now be turned on and off remotely.

SAMPLE RECORDED SIGNALS

Several signals were retrieved from the Morenci system based upon signal detections at the West Texas, Lajitas seismic station (TXAR). Based upon the arrival times at TXAR (Figure 13), predicted origin times at Morenci were used to look for signals at the Morenci site. This 24-January event at Lajitas looks interesting, but it is not immediately apparent that it is the result of two closely fired shots. Retrieval of the data from Morenci (Figures 14 and 15) illustrate that that signal at Lajitas was from two shots fired at about one minute separation. The recordings of the vertical ground motion are quite different for the two shots.

The complexity caused by multiple shots is not unusual. Examining a record from the 25-January events (Figures 16 and 17) demonstrates that the problem is more complex than the prior 1 minute separation (which an experienced analyst might be able to detect from the TXAR data). In this case, the seismic data at TXAR appears to be a simple arrival with an easily detected Pn arrival. The data recorded at Morenci (Figure 17) appears to be a signal seismic pattern, but the acoustic data indicates that this was probably two patterns detonated near simultaneously. The high frequency signals at the front of the seismic pattern were not seen in the prior 24-January recordings.

ACTION LIST

Required to complete the installation

The following items must be completed in order to complete the installation. Most of these items do not require a visit to the mine.

Morenci

- Obtain mine map with surveyed seismometer location

  It will be important to consider the relation of the geometry of the shot relative to the topography between the shot and seismometer. In addition, it will be useful to be able to plot the shot information on the map as it is received.

- Complete RefTek headers

The RefTek headers were left incomplete in the field due to lack of full information, especially sensor calibration. Empty fields (shown in red in Tables 2 and 3) may be completed remotely.

- Update trigger parameters

  Default triggers are set so low that local traffic causes a large number of false alarms. By setting the thresholds higher, we limit high rate recordings to local blasts, saving disk space and making it easier to detect events of interest. Since the system records continuous data at 40 samples per second, it will still be possible to retrieve recordings of Tyrone blasts.

- Setup automatic seismometer centering

  The STS-2 seismometer drifts and periodically needs recentering. The current cables are built to allow remote automatic centering, but the RefTek calibration must also be enabled.

- Calibrate sensors

  The seismometer has not been formally calibrated. In addition we don't currently have nominal calibrations, (which is sufficient for this application). This will need to be obtained from LANL. Acoustic sensors were previously calibrated (during the McKinney test). The calibration results need to be added to the header.

- Routine exchange of shot information

  In order to minimize the time required to retrieve the data, and to correlate the seismic and acoustic attributes with blast design, we need to match shot design data with the recorded seismic and acoustic recordings. A routine email exchange of shot and seismic information needs to be initiated.

Tyrone

The same tasks must be completed at the Tyrone installation as for the Morenci installation above, with the addition of correcting the sensor problems.

- Mine map with surveyed seismometer location

- Relevel and/or replace seismometer and turn on the microphones

  According to remote diagnostics, the STS-2 seismometer at Tyrone does not appear to be centered. Power is currently turned off to the infrasound microphones. We will attempt remote recentering. If this fails, it will be necessary to replace the seismometer with a spare.

- Map of infrasound microphones

- Complete headers

- Update trigger parameters

- Calibrate sensors

- Routine exchange of shot information

Second Tyrone Trip

After additional investigation we found that the seismometer at Tyrone was not operating correctly. Furthermore, the LANL instruments are not wired to allow remote centering via RefTek calibration commands. This is because the LANL RefTeks were rewired to supply power out the connectors usually used for calibration signals. A trip was made to Tyrone to replace the seismometer with a spare. The spare STS-2 and an emergency S6000 seismometers were carried as baggage.

The problem was found to be a poorly constructed connector with the keyway rotated about 30 degrees from the correct position. The plug would not correctly fit the seismometer connector. In connecting it, several pins had been bent and pushed back into the connector. We replaced both the seismometer and cable and were able to level the seismometer without problems.

Conclusions

Installation at Morenci required one full day. In planning for future installations, at least 1½ days should be allocated. This would allow installers to verify the installation, adjust trigger levels, and perform tests on the equipment prior to leaving the site.

Installation at Tyrone was not completed after two full days. At least 2½ days should be allocated to future such installations. The seismometer at Tyrone was extremely difficult to install. Future installations may use a different method of seismometer locking. In addition, installers need copies of the seismometer breakout box, breakout cables, and filter jumpers so that seismometer problems may be identified in the field. In completing the installation at Tyrone, we inadvertently forgot to turn power on to the microphones. An installation checklist needs to be added to the documentation.

Orienting the seismometer in the borehole is difficult. At Morenci, blocked sight lines, no orientation on the seismometer, and proximity to power lines and metal buildings made obtaining an accurate north orientation difficult. Future installation should consider better case markings prior to fielding the seismometer.

Additional time during installations would also allow us to better document the installation.

An initial look at the data indicates that trigger levels are far too low and should be adjusted upward such that triggers only occur for local blasts. Local acoustic signals are large enough that triggers could even be set on the acoustic channels. Analysis of the data, indicates that there is energy about 80 Hz in both the seismic and acoustic data. It may be useful to run a cross trigger of one acoustic channel and one seismic channel at 1000 samples/second.

Data log files show that the disk is currently acquiring data at about 1 Gbyte per week. The disk will then loop about once per month. Adjusting trigger parameters and enabling a 1000 sample/second stream will result in about the same acquisition rate.

Dial-up access to the Morenci data is reliable in that a session connects without problems and remains connected until automatic timeout. Inspecting the log file, while cumbersome, is straightforward. A weeklong file was inspected in about 30 minutes. Data transfer rates are somewhere between 2400 and 4800 baud and are slower than optimal due to the large number of error timeouts. Retrieving one triggered waveform requires about 15 minutes.

A quick look at two events indicates the complexity of signals from mining events. Both are cases of multiple shots. In the prior visit, we also recorded a multiple shot. This suggests that signals from hard rock production mines may be more complex than may have been anticipated.

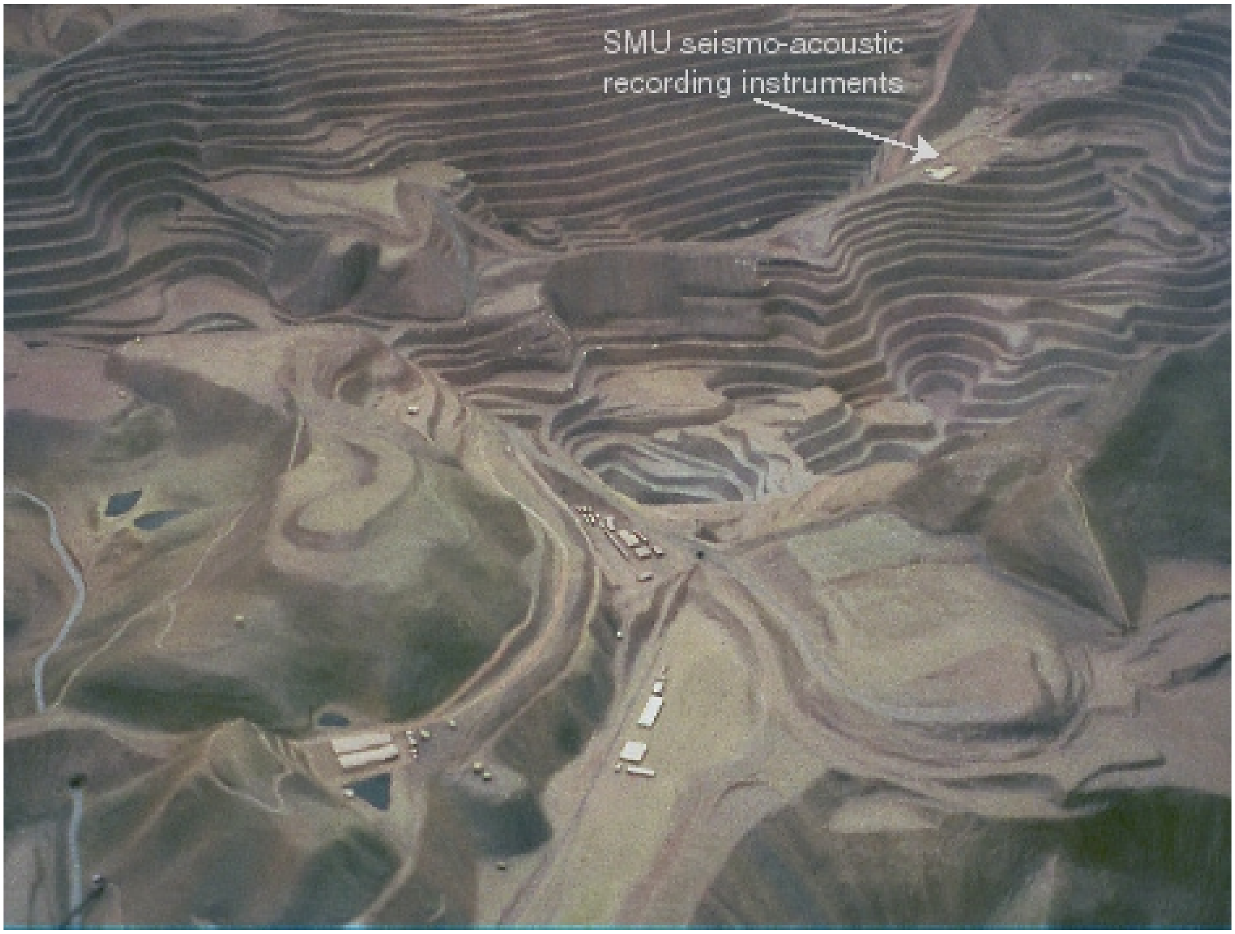
ACKNOWLEDGEMENTS

At Tyrone and Morenci, installation support from Phelps-Dodge personnel, particularly James Hanson at Morenci and John Gregory at Tyrone was particularly important in successfully completing the installation.

FIGURES, TABLES, AND ILLUSTRATIONS

• Table 1 . PD Morenci mine and SMU meeting participants and email addresses

Name	Email	Telephone
SMU		
Karl Thomason	thomason@passion.isem.smu.edu	214-768-2798
Chris Hayward	hayward@passion.isem.smu.edu	214-768-3031
PD Morenci		
Lia Lowery	llowery@phelpsdodge.com	
James Hanson	jhanson@phelpsdodge.com	520-865-6774
Ronnie M. Gerdes	rmgerdes@phelpsdodge.com	520-865-6465
Not Present, but on email distribution list		
Brian Stump	Stump@passion.isem.smu.edu	214-768-1223



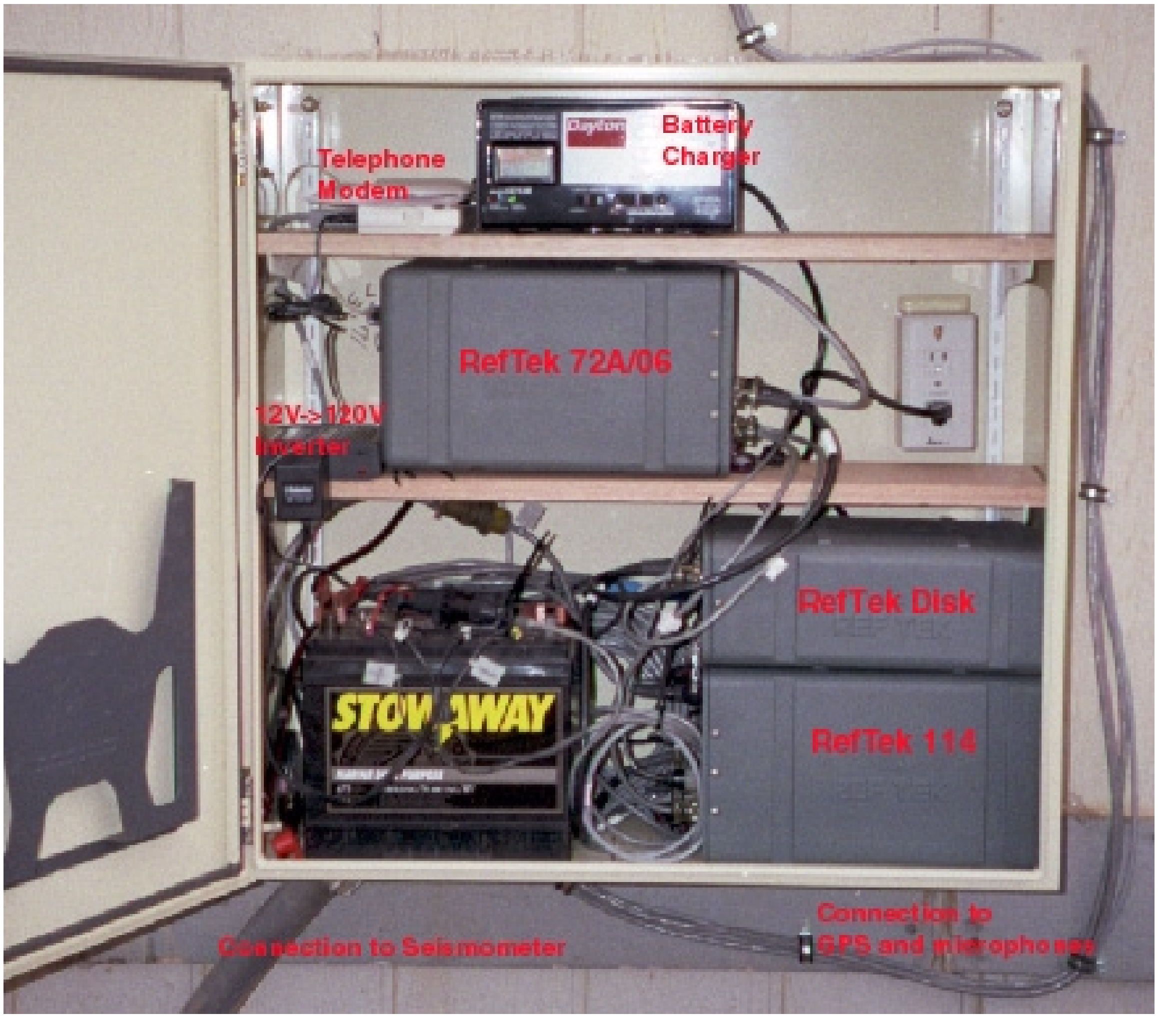
• Figure 1. Location of SMU seismic instrumentation relative to the Morenci mine plan.

The location next to the main mine office buildings will be usable throughout the current mine plan should experiment be extended beyond the currently funded period. This image is from the PD Morenci mine plan model.

- Figure 2. Completed Installation at Morenci.

The GPS and infrasound microphones are glued to the shingled roof with silicon RTV. PD Morenci may elect to remounted these with a more permanent bracket. The infrasound microphones are designed to operate horizontally. The small incline from the pitched roof will cause a DC offset in the data which will need to be removed by filtering.

A haul road runs in back of the building. Directly south of the building is a small parking lot. The wall of the building is approximately parallel to a North-South line, with north in the direction from the box to the seismometer



• Figure 3. Installed equipment at Morenci.

From upper left to lower right, the equipment consists of the following:

A 56K telephone modem connected to a direct inward dial line. The modem is used to transfer data from the system back to SMU for analysis. The equipment is currently configured to accept incoming calls only (to avoid placing expensive outgoing calls). Because SMU's long distance rates for dialing to the station are less than those placed via a calling card, we currently do not anticipate changing this method.

A standard full cutoff trickle charger. The charger should be set for charge at 10 amps. It will automatically switch from full change to off when the battery is fully charged. When the equipment was tested at SMU, it could operate about a day on batteries alone.

A 12 volt DC to 120 AC inverter connected to the dial up modem. This is used to power the modem from batteries. In the future one may wish to consider switching to low power DC modems. This could reduce the power consumption enough that the system could be supported by solar panels.

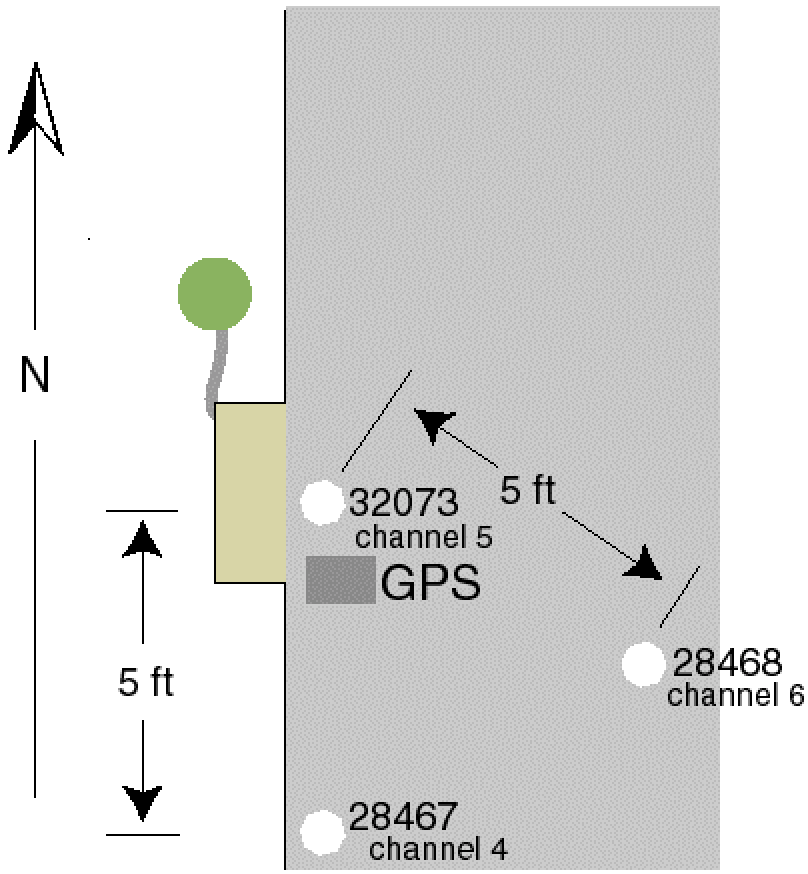
A RefTek 72A/06 Digital Acquisition System. This is a 6 channel 24-bit recording system that digitizes the seismic and acoustic data, time tags it with GPS timing information, and writes the output to disk. In addition, it runs automatic event detection algorithms to identify blasts. The system records continuous seismic and acoustic data to disk at 30 samples per second. In addition, during blasts, it records data at 200 samples per second.

A RefTek 4 Gbtye disk. The disk has a capacity of at least 6 weeks of continuous recording. Once the disk is full, it may be either overwritten, if there is no reason to examine the continuous recording further, or may be hot swapped with a spare.

A RefTek 114 remote dial up unit. This is a small PC that examines the data on the disk for events of interest and allows a dial-in user to retrieve events of interest or to modify recording parameters.

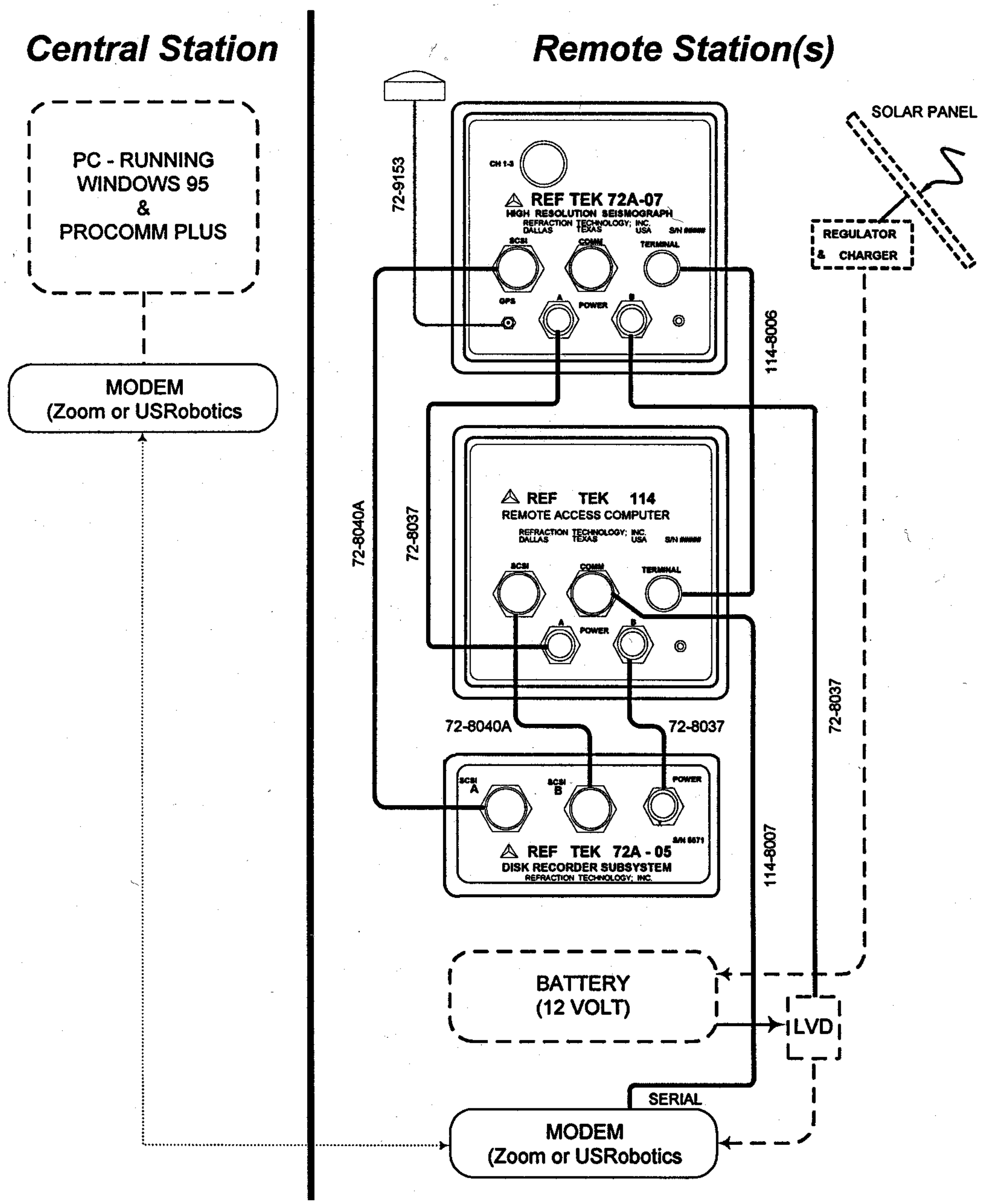
Cables to the seismometer. The STS-2 seismometer cable is protected by a 2 inch flexible conduit.

Cables to the GPS and microphones. Signal cables to the GPS and infrasound microphones are clamped to the side of the building and run to the roof where the gauges are glued down.



• Figure 4. Diagram of Morenci infrasound configuration.

Infrasound microphones were placed on a lightly pitched roof on a 5 foot triangle.



• Figure 5. RefTek cable diagram.

Power cables into the A or B outlets of the 114 or 72A/06 may be reversed from the diagram without affecting the functionality of the system.

• Table 2. Morenci RefTek configuration.

Morenci RefTek configuration based on FSC configuration stored in the RefTek Header.

Morenci Header from most recent log file of 25-Jan-2000	
Experiment header: 1 Experiment name: EMPIRICAL ACOUSTIC Experiment comment:	Power state: CP Recording mode: SC
Station #: 1100 Station name: SWmore Station comment: System for use as at Morenci DAS model #: DAS serial #: Experiment start: * + : : Clock type: OTHR Clock serial #: NONE	Start time: * + : : Repeat interval: + : : # of intervals: Length (sec): Step: OFF Step period: Step size: Step amplitude: Step coil/amp sel:
Stream #: 1 Stream name: SW1 Channels included: 123456 Sampling rate: 40 Data type: 32 Trigger type: CON Record length: 3600	Stream #: 2 Stream name: SW2 Channels included: 123456 Sampling rate: 200 Data type: 32 Trigger type: EVT Trigger channels: 1 Minimum channels: Trigger window: Pre-trigger len: 15 Post-trigger len: 30 Record length: 60 STA length: .1 LTA length: 10 Mean removal sec: Trigger ratio: 6 De-trigger ratio: LTA hold: ON
SH 00*018+23:07:48.845 X:01 U:1100 Q:0007 B:0000001794 018:23:07:48 ACQUISITION STARTED 018:23:07:48 STANDARD FORMAT EXTERNAL CLOCK 018:23:07:48 EXTERNAL CLOCK IS UNLOCKED 018:23:07:48 INTERNAL CLOCK RF DELAY IS 0 MSECS 018:23:07:50 SCSI COMMAND COMPLETE	

• Table 3. RefTek Channel Definitions.

Channel #: 1 Channel name: bz Azimuth: Inclination: Local X coord: Local Y coord: Local Z coord: Data unit, X & Y: Data unit, Z: Preamp gain: 1 X Sensor model #: STS2 Sensor serial #: unknown Comment: Bit weight: 125.0 mV	Channel #: 2 Channel name: bn Azimuth: Inclination: Local X coord: Local Y coord: Local Z coord: Data unit, X & Y: Data unit, Z: Preamp gain: 1 X Sensor model #: Sensor serial #: Comment: Bit weight: 125.0 mV	Channel #: 3 Channel name: be Azimuth: Inclination: Local X coord: Local Y coord: Local Z coord: Data unit, X & Y: Data unit, Z: Preamp gain: 1 X Sensor model #: Sensor serial #: Comment: Bit weight: 125.0 mV
Channel #: 4 Channel name: sd Azimuth: Inclination: Local X coord: Local Y coord: Local Z coord: Data unit, X & Y: Data unit, Z: Preamp gain: 1 X Sensor model #: dp250 Sensor serial #: 28467 Comment: Bit weight: 125.0 mV	Channel #: 5 Channel name: sd Azimuth: Inclination: Local X coord: Local Y coord: Local Z coord: Data unit, X & Y: Data unit, Z: Preamp gain: 1 X Sensor model #: dp250 Sensor serial #: 28468 Comment: Bit weight: 125.0 mV	Channel #: 6 Channel name: sd Azimuth: Inclination: Local X coord: Local Y coord: Local Z coord: Data unit, X & Y: Data unit, Z: Preamp gain: 1 X Sensor model #: Sensor serial #: 32073 Comment: Bit weight: 125.0 mV

• Figure 6. Installation and leveling of the STS-2 seismometer in the Morenci vault.

Leveling the seismometer proved difficult. The green vault cap is to the left on top of the seismometer shipping container (stored at Morenci). The orange transport case was used to carry the installation electronics. The white transport container was used to carry the three microphones. A laptop underneath the enclosure and on top of the white shipping container was used to verify the configuration.

• Figure 7. Excavation for the site at Tyrone.

The excavation is in hard rock southwest of the SX/EW plant. It was blasted using one 12 foot hole and 4 shallower holes with about 5 pounds of explosive. The hole was then cleaned out with a backhoe. The hole is about 24 inches deeper than the mini-vault is tall. The site is on a low hill and drainage is not expected to be a problem.

• Figure 8. Tyrone Vault at end of first day.

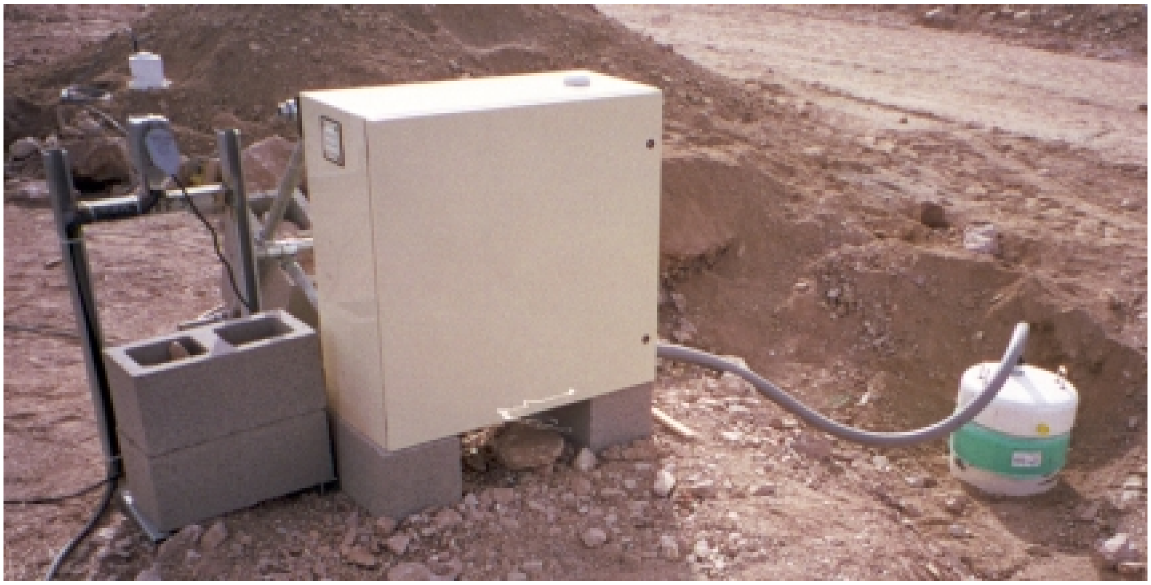
The Tyrone value was set using 3 bags of concrete (240 pounds). It was leveled with the base level of a Brunton compass and allowed to set overnight.

• Figure 9. Backfilling the Tyrone vault.

The Tyrone vault was backfilled with fine grained alluvial material up to the bottom of the cap. Consolidation of the fill over the next month will probably require some addition backfill. In addition to the backfill, the side road around the site was closed with berms.

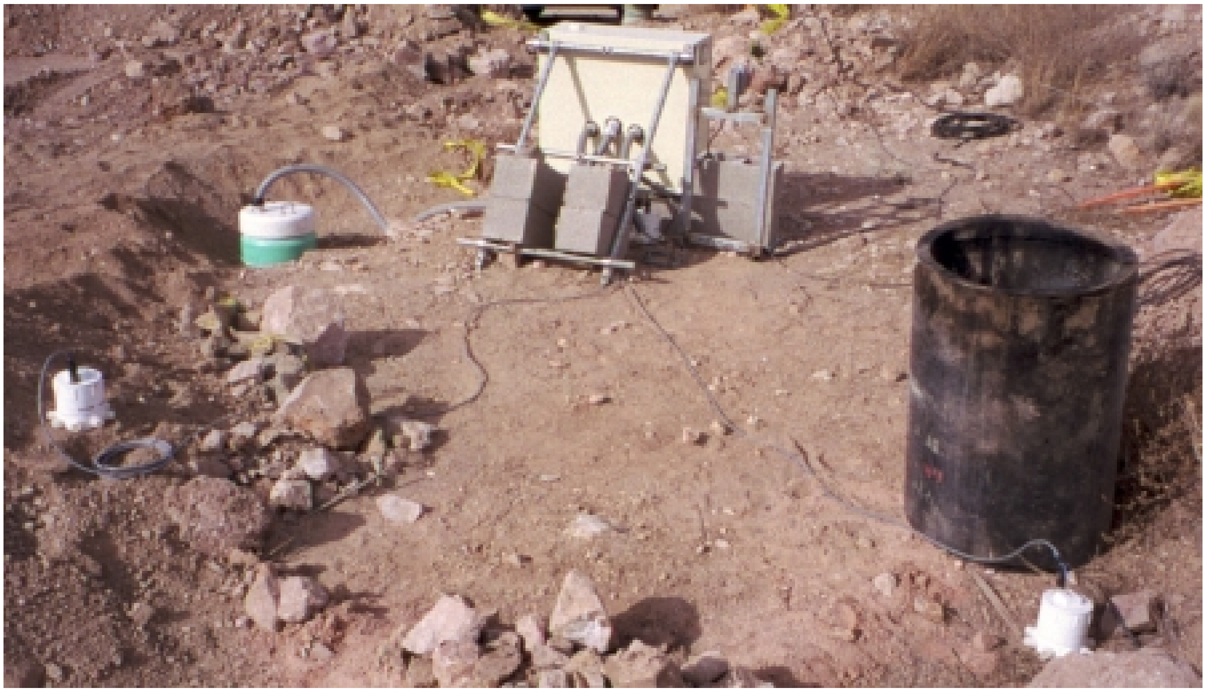
• Figure 10. Wiring the box at Tyrone.

The system at Tyrone connected following the diagram (figure 5).



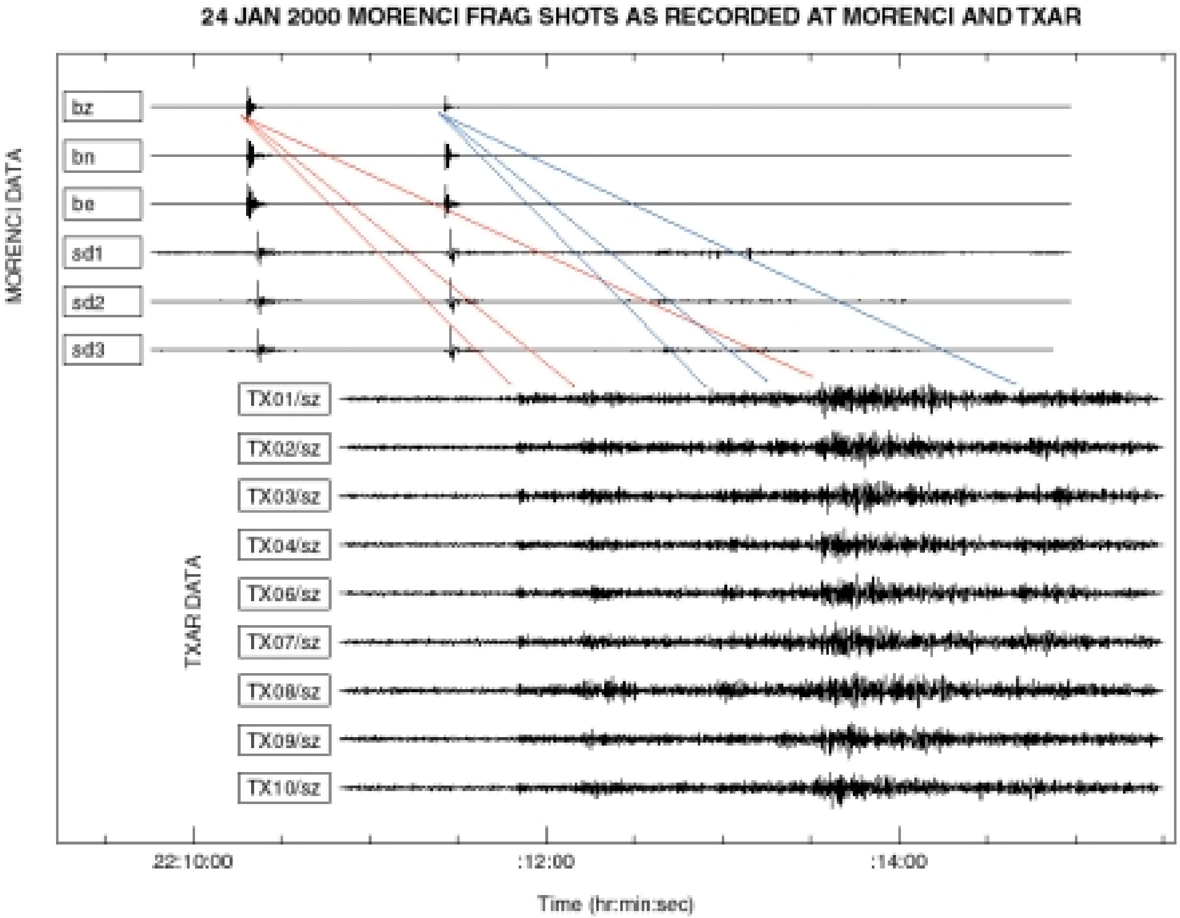
• Figure 11. The completed installation at Tyrone.

The completed vault is on the right. In the upper left, one of the infrasound microphones is visible. Power is supplied through the GFI outlet to the left of the box.



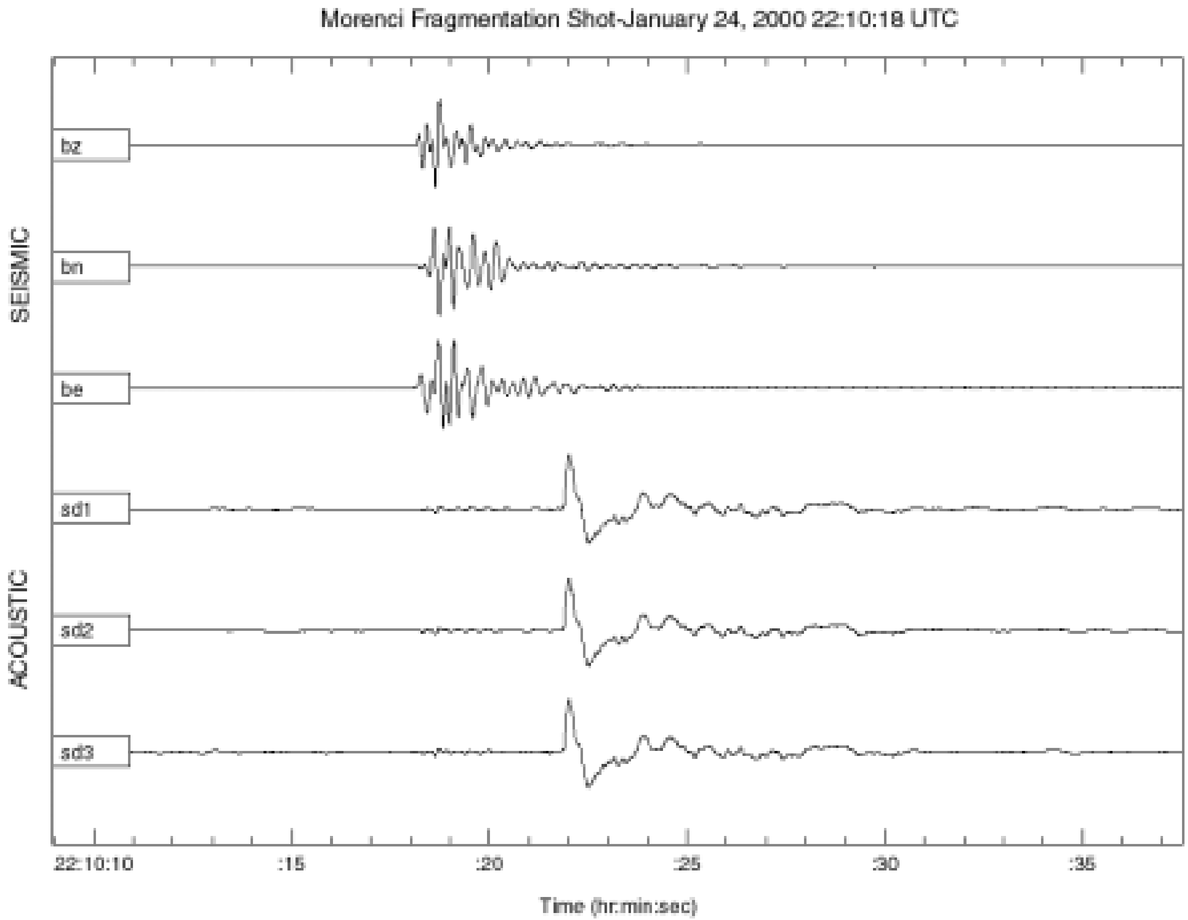
• Figure 12. Complete layout at Tyrone.

North is to the top of the photo. Infrasound microphones are arranged on a triangle with 10 foot sides. A light vehicle road is about 10 feet to the right of the right most infrasound microphone. The box is mounted on a simple sled and weighted with concrete blocks.



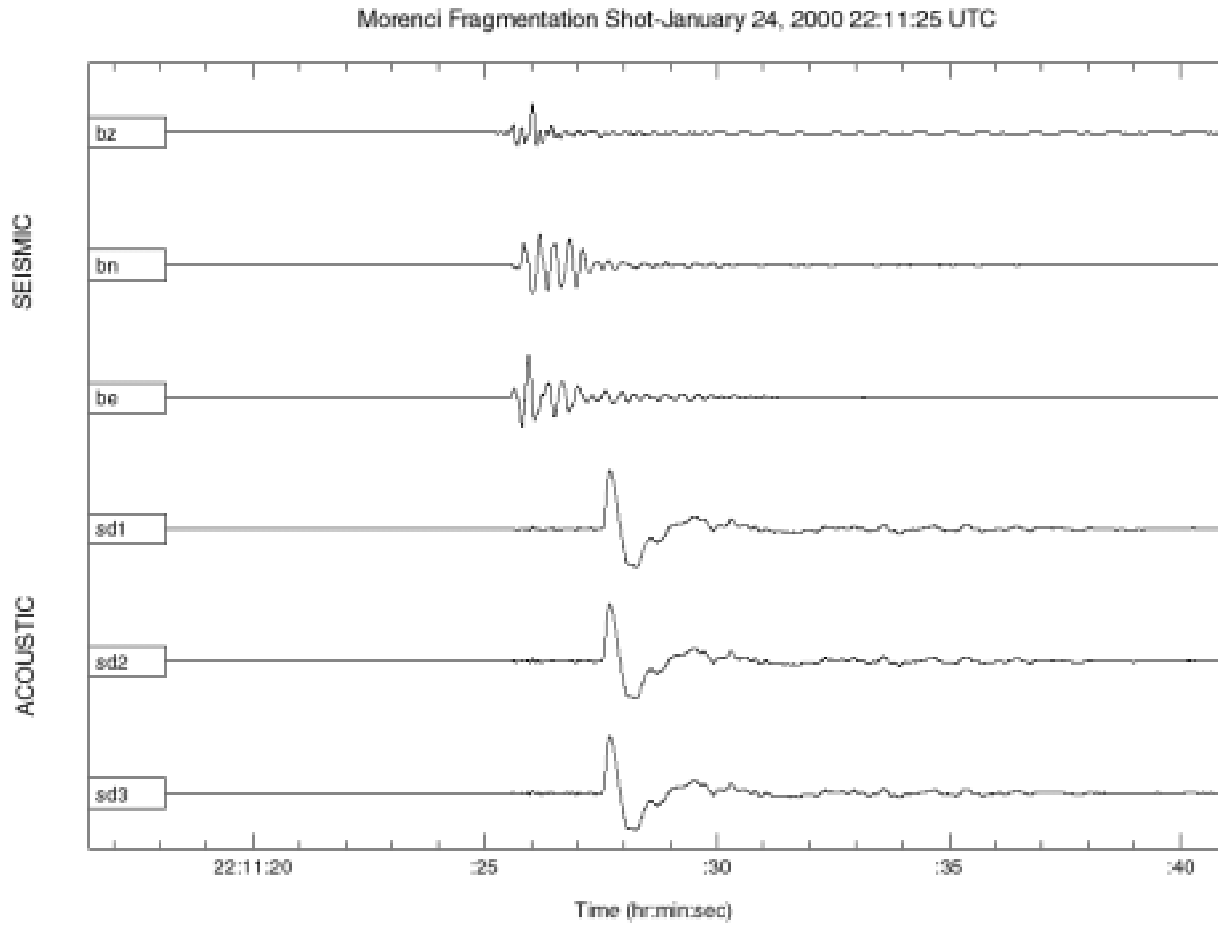
• Figure 13. 24 Jan 2000 event detected at TXAR.

From the initial signal at TXAR, it is not obvious that there are two blasts separated by about a minute with overlapping phases. The two three traces are the seismic recordings (vertical, North-South, and East-West) at Morenci. The next three are the microphones at Morenci. The bottom traces are vertical velocity recorded at TXAR.



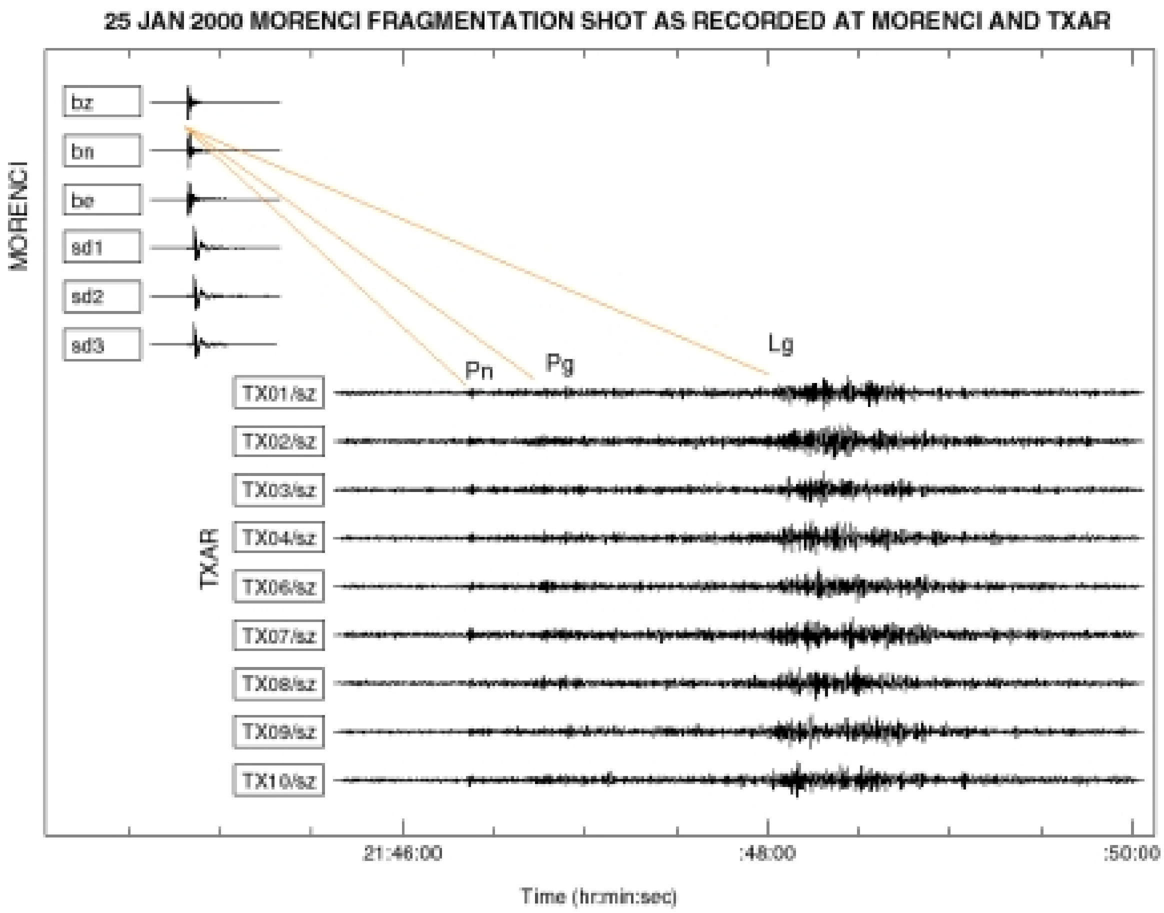
• Figure 14. Morenci Shot – Jan 24, 2000 22:10 recorded at Morenci.

Top three time series are vertical, north-south, and east-west velocity. Bottom three are acoustic channels. The acoustic response is a classic N shaped waveform. A small precursor is visible on the acoustic correlated with the seismic arrival. This is probably an acoustic wave generated by the building motion at the recording site. The waveforms are unfiltered and uncalibrated.



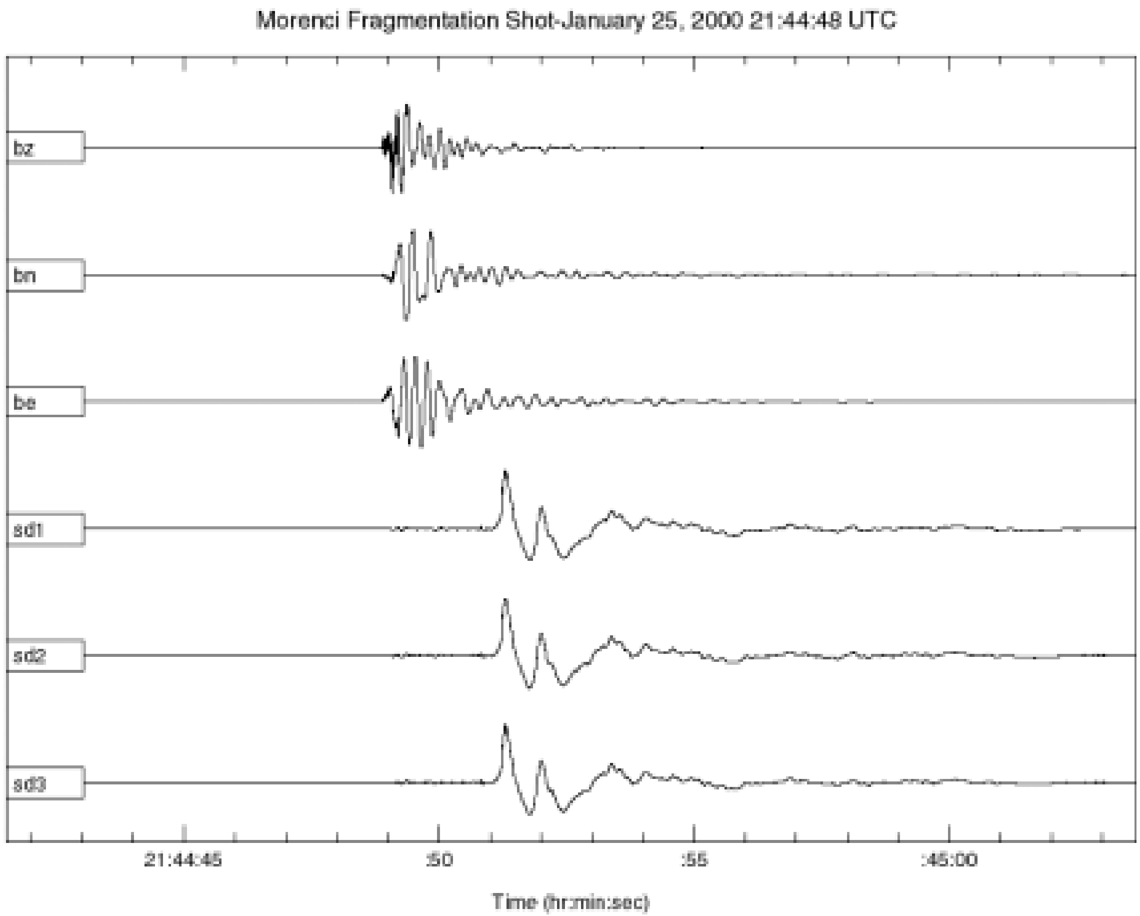
• Figure 15. Morenci Shot – Jan 24, 2000 22:11 recorded at Morenci.

Second of two sequential shots recorded at Morenci. In this case the time separation is great enough that the signals do not overlap at Morenci (although by the time they get to Lajitas this is no longer the case. Note how similar the acoustic arrivals look in contrast to the seismic signals from the two shots. Neither of the shots has a dominant high frequency component.



• Figure 16. 25 Jan 2000 Morenci Fragmentation Shot as recorded at TXAR and at Morenci.

From the seismic data, this appears to be a single pattern. Note the clear Pn Phase.



• Figure 17. 25 Jan 2000 Fragmentation shot recorded at Morenci.

The enlarged view of the shot shows a high frequency component at the front of the vertical seismic recordings unlike recordings from 24 Jan. The acoustic arrival suggest that this was two patterns separated by about 1000 feet.