

# TRACE MANUAL



institute  
of mine  
seismology

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## SUMMARY

This document provides guidelines for the processing of seismic data from the Institute of Mine Seismology (IMS) microseismic monitoring system through the use of IMS's TRACE software. This document is not intended to be a reference on seismicity concepts or IMS system maintenance and diagnostic procedures.

The scope of this document is limited to providing a set of standard tools and a sound approach for the day-to-day processing of seismic data. For special case seismic events (i.e. large, combination of blast and event, etc.), other seismological instruments will be employed and are not discussed here.

The document represents an updated version of the "Jmts User Instructions" compiled by an unknown enthusiast among the IMS system users. His/her work is appreciated.

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## 1. INTRODUCTION

The aim of this document is to provide IMS TRACE users with a consistent and reliable approach to processing seismic data.

## 2. REVIEW OF BASIC P AND S WAVE CONCEPTS

In order to develop a standard approach to the processing of seismic data, the basic concepts of P (compressional) and S (shear) waves must be well understood. The required background knowledge is presented below as a set of P and S wave facts.

- P Waves
  - Commonly travel at speeds between 4000 and 7000 m/s in rock
  - Ground motion (vibrations) happens along the ray path between the seismic source and the seismic sensor
- S Waves
  - Commonly travel at speeds between 2500 and 4000 m/s in rock
  - Ground motion (vibrations) is perpendicular to the ray path
- General comments
  - P waves will always arrive before the S wave
  - The greater the time between the P and S wave arrival times, the greater the distance between the seismic source and the seismic sensor

## 3. THE SEVEN INVIOABLE RULES

All seismic data best practices in the document are centred on the following seven 'Inviolable Rules', each of which will be explained in depth later.

- 1 Disable non-contributing sensor components

- 2 P and S waves picks must be visually sensible and of the same quality
- 3 Give each seismogram a go
- 4 The more sensors the better
- 5 Location must make sense
- 6 Reduce residual error within reason and where possible
- 7 At least one P-pick and at least one S-pick must be used

## 4. TRACE MAIN WINDOW OVERVIEW

This section provides a useful reference to the layout and information present in the main TRACE window. Only relevant buttons and windows will be covered here to aid in obtaining the best possible quality seismic source locations.

The main TRACE window presents all of the recorded events in the left window and all associated seismograms with the events in the right window, only displaying seismogram information when right-clicking on a given seismogram. The seismograms are ordered according to trigger times, Figure 1 below illustrates the basic layout of TRACE.

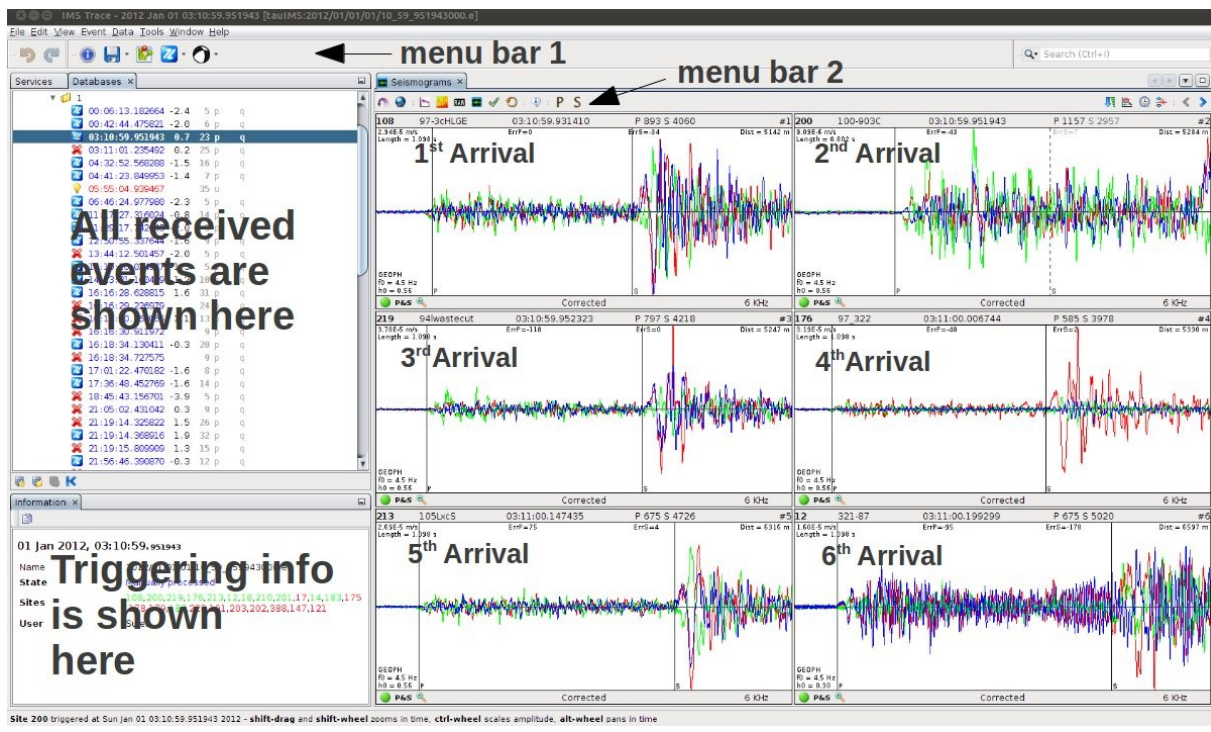












Figure 1 : Trace main window












Only the relevant TRACE buttons to the processing of seismic data, as outlined in this document, are presented here. For further information on the other buttons in the TRACE interface, consult the help menu and IMS. Buttons of interest have been broken down by the menu bars (1 and 2) present in the TRACE interface. See Figure 1 above for the location of the horizontal and vertical menu bars.

## MENU BAR 1 BUTTONS OF INTEREST

-  Shows a summary of event and trigger information, with source parameters
-  Accepts event and recalculates seismic source parameters
-  Performs location on the event
-  Calculates the source parameters of the event
-  Calculates the source mechanism of the event

## MENU BAR 2 BUTTONS OF INTEREST

-  Converts back to the normal view
-  Apply the current selection globally (to all seismograms)
-  Calculates the Fast Fourier Transform of the selected seismogram
-  Calculates the Spectrogram of the selected seismogram
-  Reverts the current seismogram being viewed back the raw original seismogram

-  Applies non-zero offset, but keeps seismogram in sensor coordinate system
-  Rotates tri-axial seismograms to the South West Down coordinate system (all three axes must be enabled)
-  Rotates tri-axial seismograms to the ray coordinate system (P-SV-SH) (all three axes must be enabled)
-  Display amplitude and time information when hovering mouse over seismogram
-  Used to select, or deselect, the P wave arrival  
A solid line indicates that the P arrival is picked, a dashed line that it is disabled
-  Used to select, or deselect, the S wave arrival  
A solid line indicates that the S arrival is picked, a dashed line that it is disabled
-  Change the order in which the seismograms are displayed  
The options are trigger time, ascending site id's or the default
-  Display the seismograms in its individual components for tri-axials.
-  Display the seismograms in common time  
The first sample time will now be the same for every seismogram
-  Display the seismograms in common maximum amplitudes  
The y-axis will be the same range for each seismogram
-  Goes to next/previous page of seismograms

## 5. Trace SENSOR WINDOW LAYOUT

In order to be able to process events to a consistent standard, all relevant aspects of the seismic sensor window must be well understood. All data presented in the seismic sensor window is defined below for easy reference when using this procedure.

### DATA DEFINITION KEY

Below is a definition of each of the relevant elements of the JMST sensor window.

1. Site Identification Number (*commonly known as site id*)

## 2. Site Name

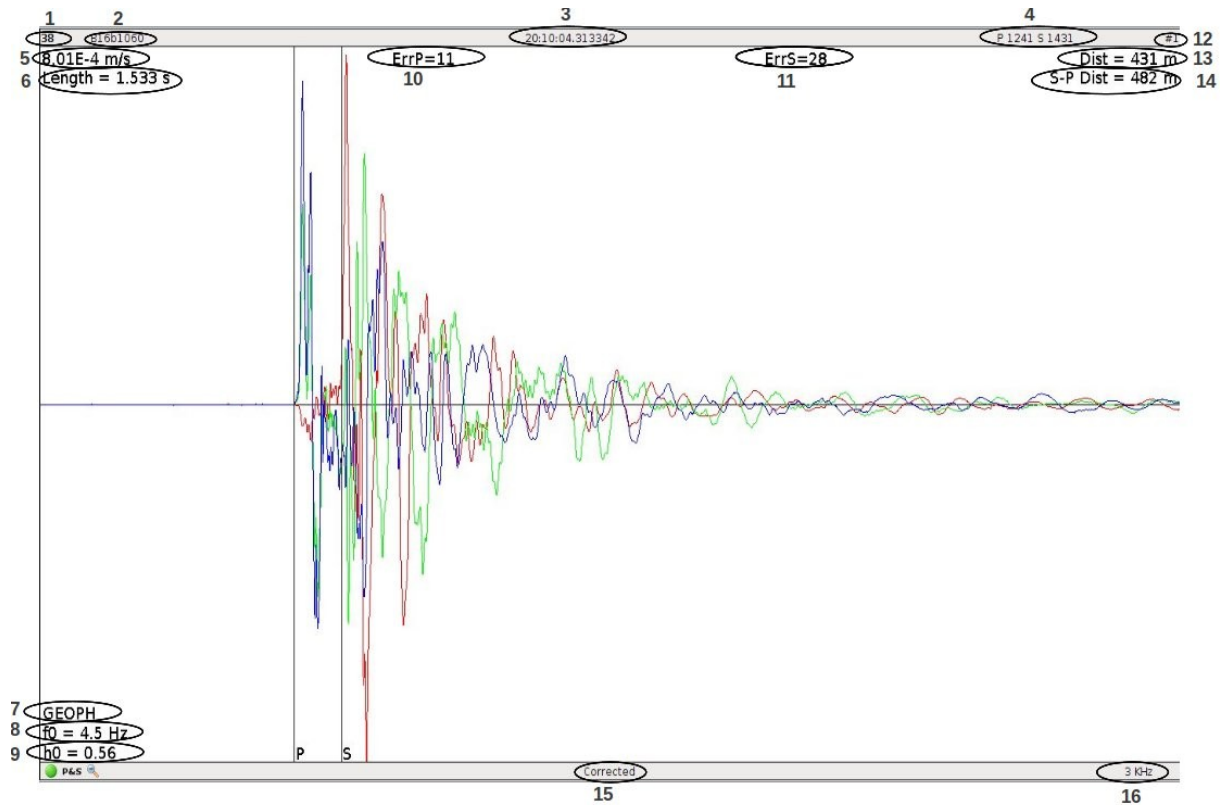


Figure 2 : Seismogram window

### 3. Trigger Time

### 4. P and S-Wave Sample Number

- Starting from start of seismogram

### 5. Waveform Amplitude Scale (m/s or m/s<sup>2</sup>)

- The Y-axis of the seismogram window provides a scale for the amplitude of the seismogram.

### 6. Length Of Seismogram Window (seconds)

- Window 'length' changes with window width

### 7. Sensor Type

- 'ACCEL' for Accelerometers and 'GEOPH' for Geophones



#### 8. Sensor Frequency {f0} (Hz)

- The natural frequency of the Geophone
- Not present for Accelerometers

#### 9. Sensor Damping {h0}

- The damping constant of the Geophone
- Not present for Accelerometers

#### 10. P Wave Error (meters)

- difference between observed/picked arrival and expected arrival, multiplied by  $v_p$ .
- Based on the last source location

#### 11. S Wave Error (meters)

- difference between observed/picked arrival and expected arrival, multiplied by  $v_s$ .
- Based on the last source location

#### 12. Site Arrival Order Number

- In this case this is 1st associated sensor to record the event

#### 13. Distance From Site To Seismic Source Location (meters)

- The distance to the source according to the last location

#### 14. Hypocentral Distance Based On P And S Wave Arrival Picks (meters)

- The distance to the source according to a time difference between P and S wave picks

#### 15. The selected filter of the seismogram

- This can be raw (no filter) or P-SV-SH mode.

#### 16. Sampling rate at which the seismogram was recorded.

The following colouring convention is used for the traces:

- Red trace - orientated along the South(positive)-North(negative) axis
- Green trace - orientated along the West(positive)-East(negative) axis.

- Blue trace - orientated along the Down(positive)-Up(negative) axis.

## 6. DISTINGUISHING BETWEEN BLASTS & NORMAL SEISMIC EVENTS

The first key step in processing seismic data is distinguishing between blasts and normal seismic events (associated with shear fracturing and cracking). All events that are deemed blasts should be saved as a blast (event in left TRACE window pane will get a blast icon next to the event name). The remaining events should not be saved (the events with a red cross next to it) until they have been processed (event will turn blue in the left TRACE window pane).

To aid in determining which events are blasts and which are not, the following set of guide lines have been developed.

### 1. Time

- Does the event occur during normal blasting times?

### 2. Weak S-wave

- Commonly, seismograms capturing a blast will have S-wave weaker than in the case of normal seismic events (i.e. associated with shear fracturing)

### 3. Presence of Blasting Delays

- Blasts, especially stope firings, will have multiple delays, which are expressed in the seismograms as similar signals within a single waveform as shown in Figure 3 below.

### 4. Spectra Does Not Match Brune's Model

- Blasting events will typically not be well matched to the Brune's Model curve as plotted in the Stacked Spectra Plot within TRACE as illustrated in Figure 4.

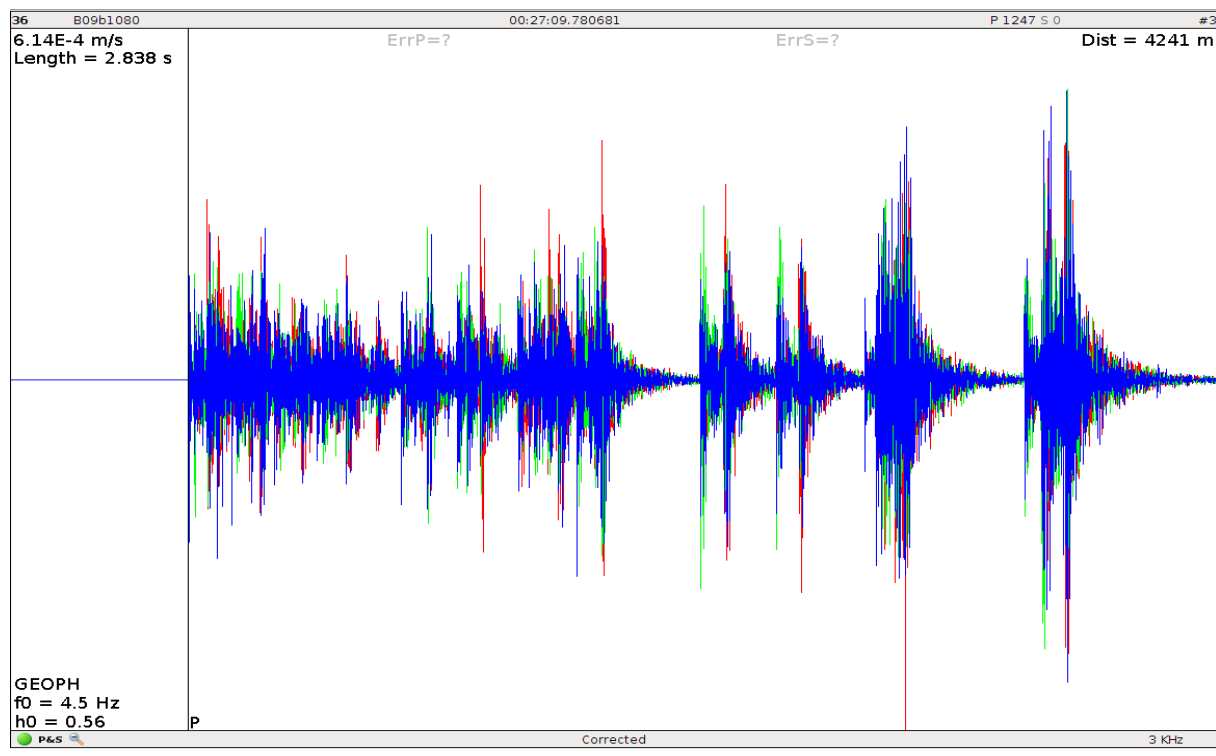


Figure 3 : Typical seismogram of blasts. Note the presence of the blasting delays, as indicated by the multiple waveforms of similar shape within a single seismogram

## 5. High-frequency content of the waveforms

- Typically, blasting generates much higher frequency events than normal seismic events (associated with shear fracturing). Correspondingly Apparent Stress and Corner Frequency are higher than for the normal events. These parameters could be found in the 'Event Information' window within TRACE, which is opened when calculating the source parameters for an event or saving the event, Figure 5.

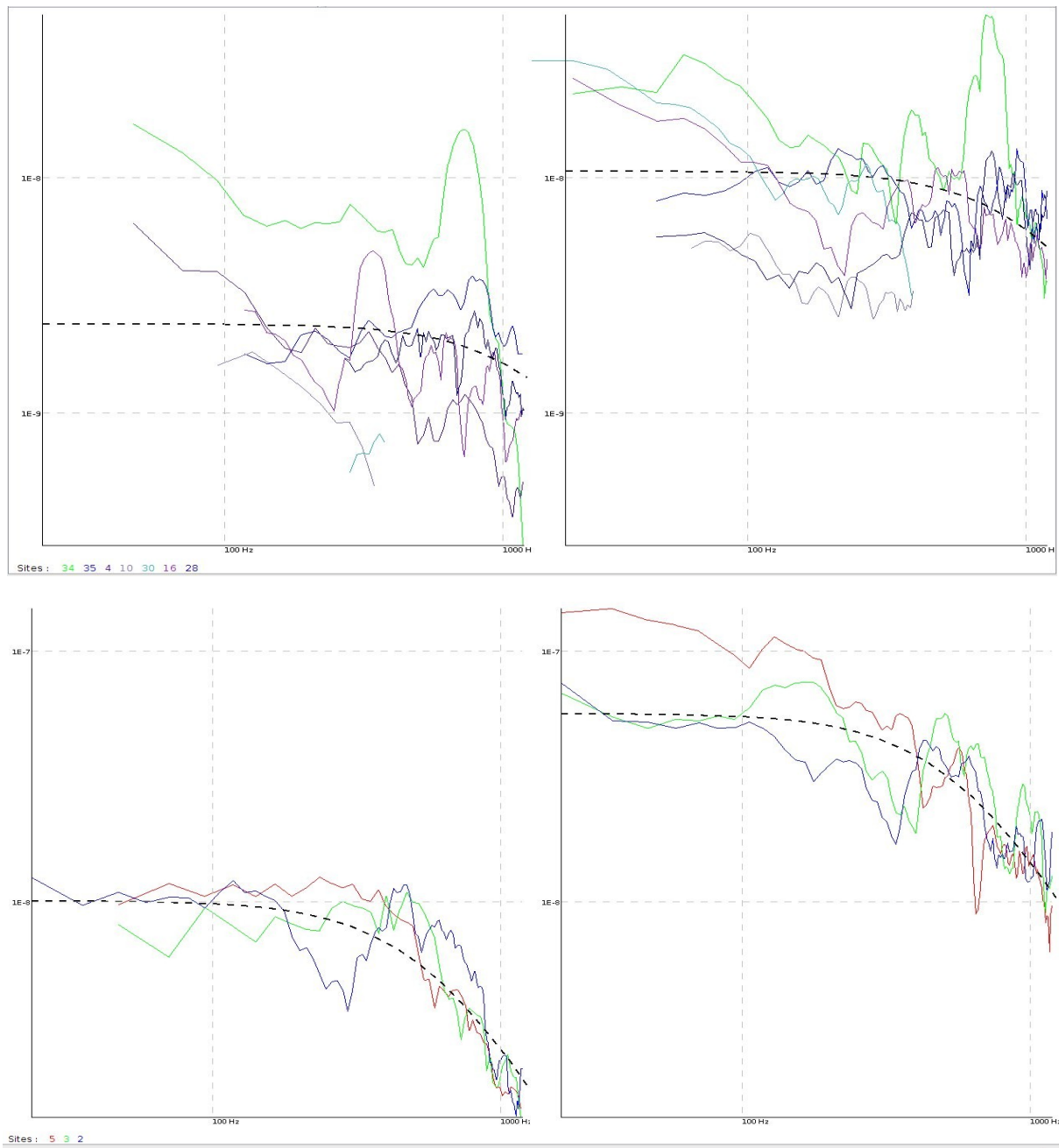


Figure 4 : Source spectra of a typical blast (top) and normal event (bottom)

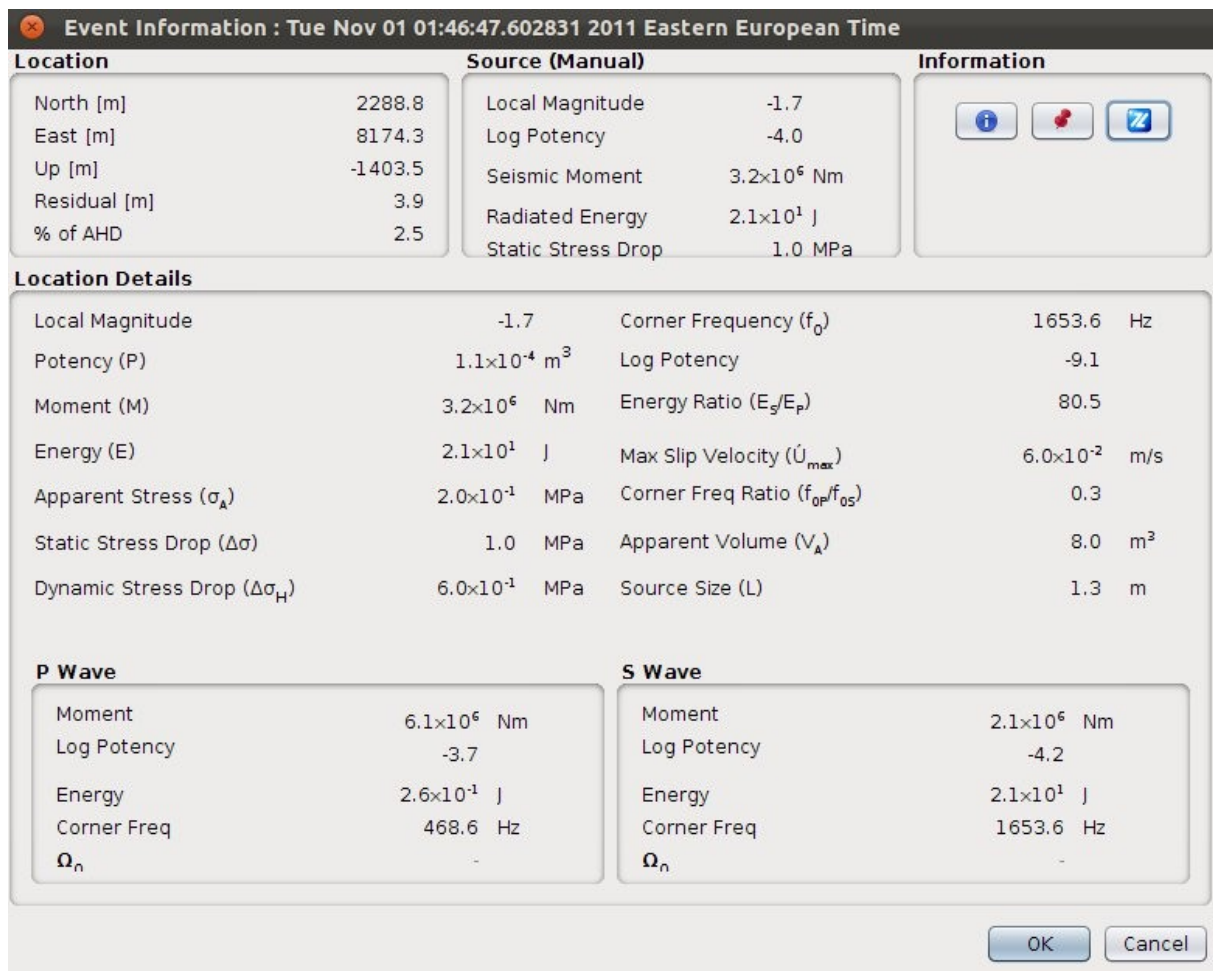


Figure 5 : Source parameters of a typical blast

## 7. SEISMOGRAM DATA QUALITY

A component of a given seismogram may be distorted, occurring as a flat line or is non-existent.

For ease of viewing, 'Inviolable Rule' #1 "Disable non-contributing sensor axes" should be followed to insure that the selection of P or S waves is not biased by the presentation of an erroneous sensor axis. One or more of a given sensor's components can be 'disabled' by right clicking anywhere on the seismogram, in any of the available tools and deselecting the tick mark on the bad component. This can have a positive effect on the presentation of the other sensor components in some situations should the magnitude of the disabled axis be significantly greater than those of the other sensor components; as in the case of a bad component in the sensor. However, the common disabling of an component usually has no other visual

effect on the other components. Bear in mind that this does not have any effect on the processing of the seismogram but rather is for visual convenience. The data from all components will be used in the generation of special charts and in the determination of the seismic source location.

In order to illustrate what the majority of current seismograms look like, Figures 6 and 7 below present some of the common faults found in recorded seismograms in the TRACE software.

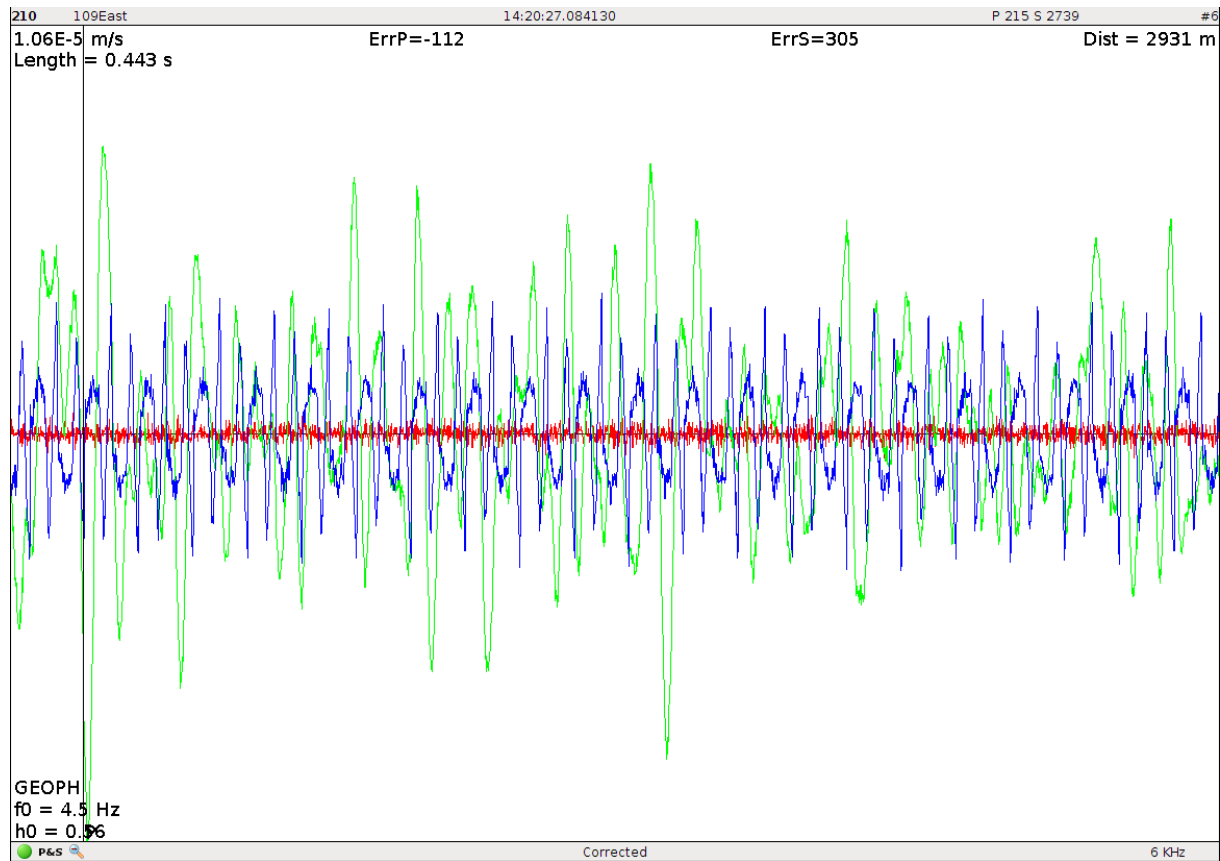


Figure 6 : Example of a seismogram with a damaged component. Note that the X- component (shown in red) appears 'flat lined' and represents a broken channel or sensor.

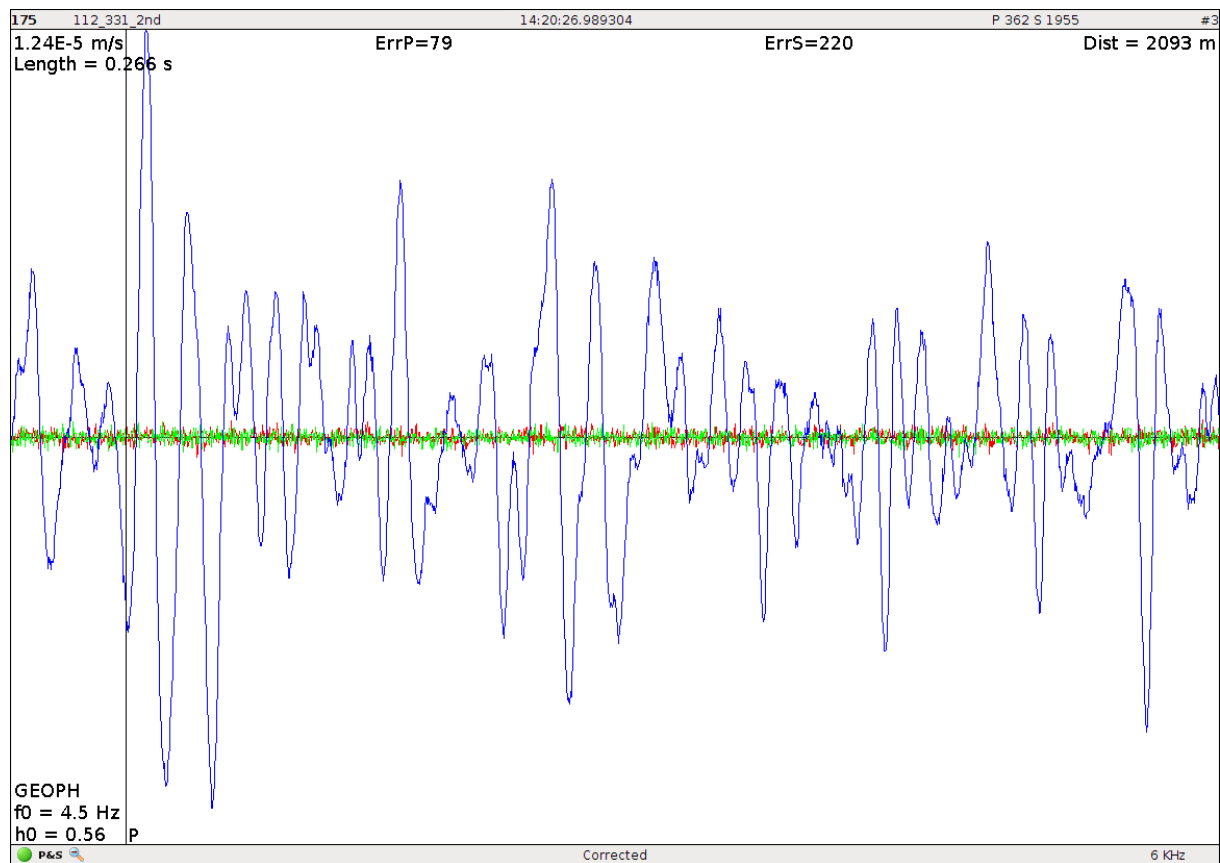


Figure 7 : Example of a seismogram with two damaged components. Note that the X-component (shown in red) and Y-component (shown in green) appears flat and represents broken channels or elements of the Geophone. These components should be disabled when processing the seismogram.

## 8. IDENTIFICATION AND PICKING OF P AND S WAVES

The concepts presented in this section must be well understood to perform seismic data processing to the established standards and to minimise inaccurate seismic event locations. Several examples, including good and poor quality, have been included to aid in conveying key learning points. The best practices presented in this section are not well documented in the mining industry and quite often fall into the 'poetic license' category where there is no absolute answer.

In general, the P or S wave should be placed at the base of the largest peak representing the start of the P or S wave arrival. In practice, the choice of P and S waves on this basis accounts for approximately 20% of the total recorded seismic events, with the rest of the events taking on a variety of waveforms, making P and S

wave picking difficult to impossible. The examples provided illustrate the range of seismograms recorded by the IMS microseismic monitoring system.

The picking of a P or S wave should be done at the first sign of its arrival in the seismogram. This is commonly shown in two different forms namely, as an obvious (sometimes not so obvious) disruption in an oscillating line (electrical noise) or a small spike from a relatively flat line. Figures 8 and 9 below illustrate common P and S wave arrivals in typical seismograms.

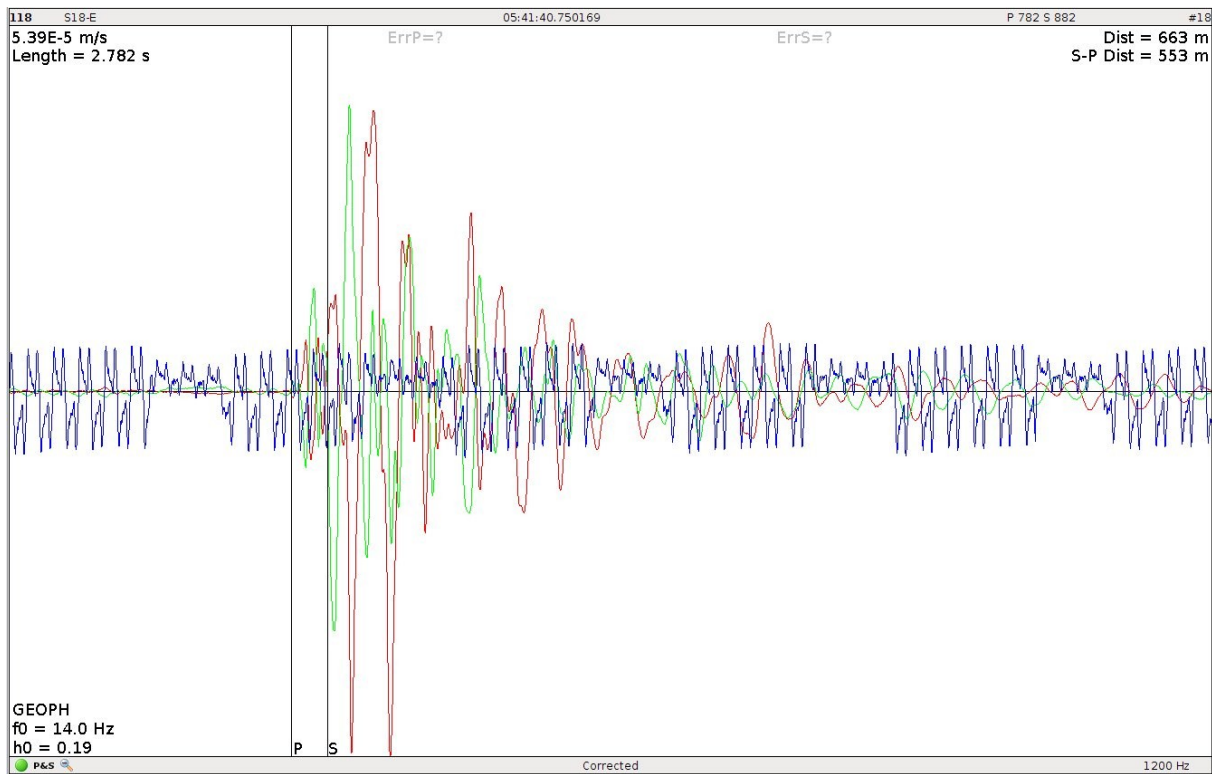


Figure 8 : Example of picking. Note that the Z- component should be disabled, as it does not positively contribute to the seismogram.



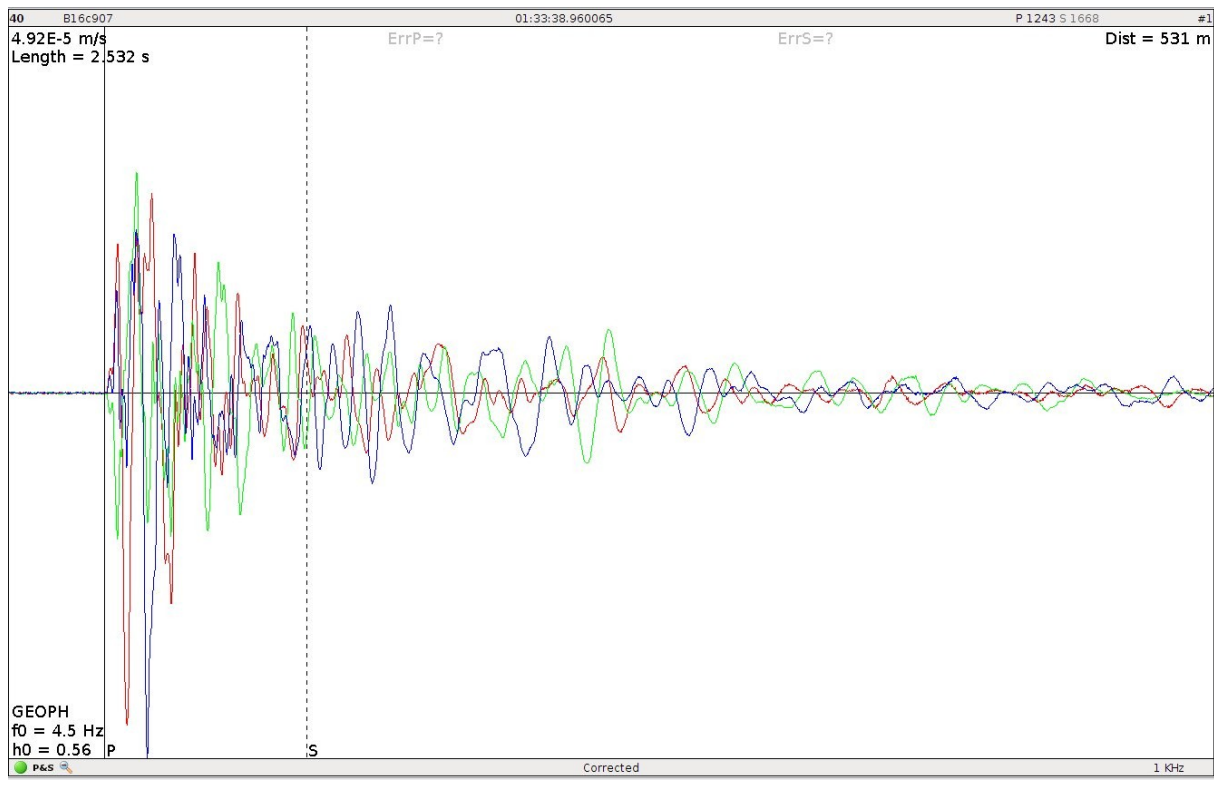


Figure 9 : Example of picking. Note that only a P wave can be picked. There is no clear arrival of the S-wave. The S-wave picked has been disabled – dashed line.

The time of the seismogram can also be expanded to more closely view the details of the waveform, which will sometimes make the first go at selecting P and S waves easier. This operation has the effect of 'Zooming In' on the seismogram and is performed by selecting the SHIFT key can be held down whilst the left mouse button is pressed down and the cursor dragged over the area to be expanded. A colour bar will mark the selection. Releasing the left mouse button will expand the selected area. Clicking the 'normal view' icon in menu bar 2 will restore the original view.

When the seismogram is expanded, the peaks in the waveform are sometimes a bit difficult to see. The peaks can be expanded by holding the 'Ctrl' key down and scrolling up or down with the middle mouse wheel.

As alluded to in 'Inviolable Rule' #3 "Give each seismogram a go", when processing seismic data, an attempt must always be made to pick both P and S wave arrivals unless the pick of either, or both waves, is obviously not possible. This will ensure that the maximum of number of picks are present when determining event locations where otherwise, event locations can be heavily biased without the addition of another P or S wave arrival sometimes moving locations by several hundred meters.

In the event that either or both the P and S waves cannot be picked then one or both of the waves should be disabled by double-clicking on the vertical P or S pick line, which will turn the solid wave arrival line into a broken line as illustrated in Figure 9. It should also be noted here that disabled P and/or S waves are not used in the estimation of the seismic source location. When disabling either/both P and S waves, it is perfectly acceptable to have just a P wave or just an S wave enabled as sometimes, the P wave cannot be chosen due to its arrival not being present in the seismogram.

This will happen occasionally due to the data capturing and configuration of the IMS seismic monitoring system; however, it is more often a rare occurrence. The more common occurrences are P wave arrivals being present, but the S wave arrivals not being easily detectable.

## 9. OTHER TOOLS FOR P AND S WAVE DETECTION

Whilst the 'Select Of P And S Waves' section provided an overview of the selection of P and S waves from the standard triaxial seismogram view window (with each the X, Y and Z components displayed), other tools exist within TRACE that can aid in the detection of P and S wave arrivals.

Note that if any of the sensor axes have been 'disabled', that has no effect on the subsequent display of any of the tool presented in this section but rather only has a visual effect on the 'Separated' view of axes waveforms.

### SEISMOGRAM ROTATOR



The tool works by mathematically rotating the seismogram to a coordinate system related to the ray path in the site (~ direction of ground motion in P wave). This can be applied for tri-axial sites only where all 3 components are working. The algorithm evaluates direction of ground motion in several swings after the P pick and align one of the axes along this direction (red waveform in Figure 10). The other coordinate axes (SV and SH) are selected in such a way that one of them is horizontal.

In an idealized case (homogeneous rock mass and localized seismic source) the P wave must be visible only on a rotated red component, while S wave must be observable only on rotated green and blue components.

The tool provides an efficient way to identify the corresponding pairs of P and S waves in a case of multiple signals (Figure 11).

In order to use the tool, all of the seismogram axes must be enabled, then

select the tool and just click on the seismogram to rotate it.

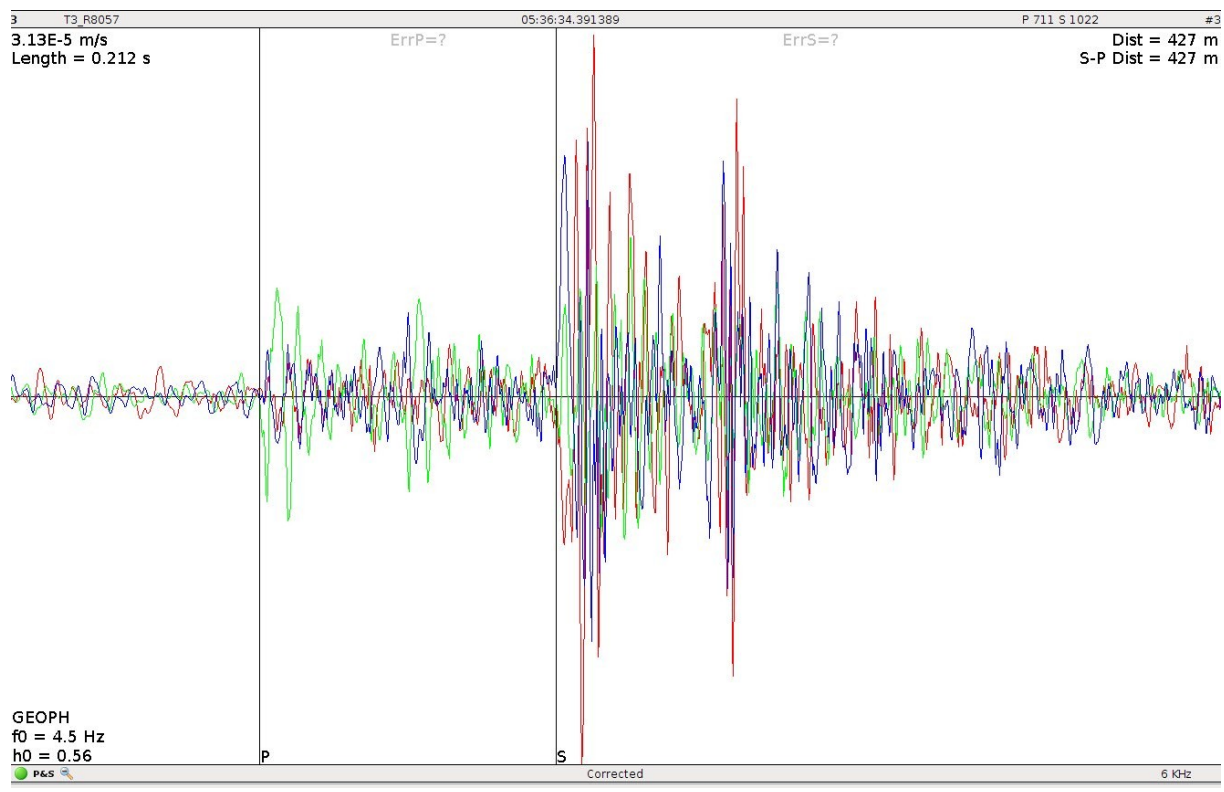


Figure 11 : For a multi-event seismogram corresponding pairs of P and S arrivals could be identified with the help of the 'Seismogram Rotator' tool.

## 10. REJECTING SEISMOGRAMS

This section deals with 'Inviolable Rule' #4 when processing seismic data and, "The more sensors the better" approach to estimating event location. Seismograms should only be rejected if a P or S wave cannot be identified for the seismogram or if the seismogram is found to be erroneously biasing the event location determination. In all other cases, all the seismograms should be used in the determination of event location unless otherwise specified.

## 11. ESTIMATING SOURCE LOCATION

After all seismograms have had their respective P and S waves chosen and any

seismograms that are erroneous, or cannot have P or S waves chosen, rejected, the source location for the event can be evaluated.

Generally, a good location will have the three key attributes listed below:

- Sensible
- Stable
- Low residual error

The following sub-sections focus on the fine-tuning of seismic events and their associated seismograms in order to obtain quality seismic source locations.

## LOCATION SENSIBILITY

As per 'Inviolable Rule' #5, "Location must make sense" such that all accepted locations should be sensible. As with most aspects of seismic data processing, the 'sensitivity' of a location is left up to the person processing the data.

- Seismic events can occur well within the rockmass when associated with shear seismic source mechanisms. Stress re-distribution source mechanisms will likely produce events close to existing excavations.
- Events picked up by sensors in the upper region of the mine should not be locating events in the lower region of the mine, and vice versa with the lower sensors in the mine.
- Events should not be occurring well (hundreds of meters) into the rockmass in areas where no mining activity has ever taken place.
- The first seismogram, the first sensor at which the P and S waves are detected, will be the closest sensor to the seismic source.
- The sites nearest to the source should have greater amplitude.

The most important concept to bear in mind when processing seismic data is to use common sense and that someone will be analysing the data in depth after it has been processed.

## LOCATION STABILITY

Commonly, for events that trigger more than four sensors, a determination of location stability is possible; the more stable a location is, the better the event quality. A

determination of location stability should be used whenever the location quality is suspect, or by making micro adjustments to one or more seismograms that cause large (>50-100m) fluctuations in the source location. For these instances, the sensitivity of various, or just the suspect, seismograms on the source location must be evaluated.

Several methods for determining the stability of an apparently unstable source location are available and are summarized below.

- If marginal or suspect P or S waves have been picked on one or more seismograms, disable one wave at a time, recalculating the source location each time observing the change in 'Residual Error' and the location the seismic source moved to. Perform this iterative task on all suspect seismograms.
- If all seismograms appear reasonable, with good P and S (not necessarily for all seismograms) wave picks, all seismograms with their respective P and S wave picks should be kept and used in the source location determination.
- Poor quality seismograms with 'guesstimated' P and S wave picks in some cases, can be 'Rejected' and then 'Unrejected' to determine seismic source location movement due to the existence/non-existence of the poor quality reading. In some cases, poor quality seismograms will only further skew a location instead of improving its location/stability.
- In some cases, the first seismogram must be rejected when the waveform is of poor quality or the P and/or S wave arrivals cannot be obviously chosen. This is quite common in very large events ( $\geq m2.0$ ). The source location should be monitored when rejecting or altering the first received seismogram in order to ensure a sensible location is obtained.

## LOCATION RESIDUAL

After the poor quality P and S waves and seismograms have been treated accordingly, 'Inviolable Rule' #6 should be followed to "Reduce residual error within reason" while keeping in mind 'Inviolable Rule' #7. Typically, if the five other 'Inviolable Rules' were followed in analysing a given event, there will likely be few opportunities for the reduction of residual error without violating one of the 'Six Inviolable Rules'. The most common areas for reducing residual error include the following:

- P or S wave picks that are not visually suited to the seismogram. This includes 'guesstimated' P and S wave pick that might have been made in order to determine the location of an event.

- For triaxial sensors, when one or more of the sensor axes are erroneous or non-functional, the resulting waveform from the remaining one or two axes will bias the location.
- When multiple seismic events are captured within the seismogram making P and S wave arrival selection difficult and easily performed incorrectly.

The main objective here is to reduce residual error while maintaining a balance of the number of seismograms and wave picks used in the seismic source location determination to obtain a more accurate source location. Again, if the previous procedures have been followed, in general, little room for additional improvement in residual error will be possible at this stage. To just reject sensors to try and reduce the residual error without sound reasoning will incorrectly bias the quality of the seismic event.

Location residual should be reduced, if possible, at all times, but it is absolutely essential for seismic source locations with more than 5% of AHD. If an event has a location residual greater than 5%, the location should be re-analysed. The following section explains in detail the methods available for reducing residual error present in seismic source locations.

## 12. REDUCING LOCATION RESIDUAL

In general terms, the residual exists for the large part due to either the inability of the seismic monitoring system to locate the event accurately, perhaps only using 3-4 sensors to locate an event, or that the P and S wave arrival times are incorrect. In cases where the residual can be reduced, two common techniques exist and are presented below.

### SCRUTINISING ALL P AND S WAVE ARRIVALS

The most common way of reducing the residual is to go through all of the seismograms again in great detail and scrutinise each P and S wave pick to see if they can be fine-tuned. In some cases, the P wave arrival will look different from one seismogram to the next. In this situation, the P waves must be selected at the same starting point to ensure each seismogram waveform is being treated like the next and measuring the same wave arrival times. This is one of the most common data processing errors, especially for events larger than m1.0 .

## COMPARING P WAVE ARRIVAL TIMES

Another very powerful tool is the 'Travel Time Processing Mode' tool. It can be found in 'Windows' → 'Seismograms' → 'Travel Times'. This allows for the viewing of all seismograms and their respective P and S wave arrival times in regards to all other seismograms. The basic rule to bear in mind here is that the seismograms ordered in the TRACE window should arrive one after another in order from being the closest to the furthest away from the seismic event. This is not always the case.

The plots that are produced by this functionality are similar to the basic split view of the seismograms but have distance (meters) from the calculated seismic source as the basis for the spacing of the seismograms in the plot in the Y-axis. An example of the 'Travel Time Processing Mode' tool is shown in Figure 12 below.

In the example presented in Figure 12, the 3<sup>rd</sup> seismogram in event should be reviewed and location stability tested around that reading. Trying 'S-P' location mode for this seismogram may help in improving the location and the residual. This could be caused by a small timing issue with this site. If it does not improve the residual it is likely that the sensor position in the system is incorrect and this seismogram can be rejected in these circumstances. Another reason may be that the site velocity is inaccurate. Of notable mention here is that if seismograms are rejected then they will appear in the 'Travel Time Processing Mode' window in grey colour.

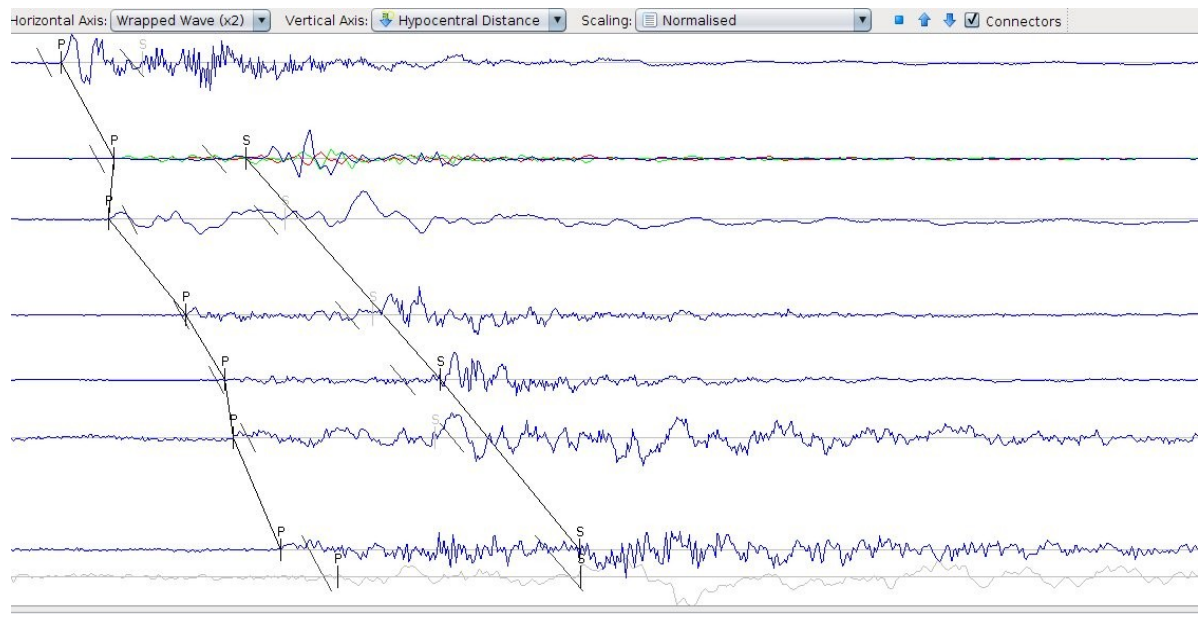


Figure 12: Example of a Travel Time plot. Note that the 3<sup>rd</sup> sensor's P wave arrival (counting down from the top) appears out of order and counterintuitive to how the

sensors should have received the event.

### 13. USEFUL SHORTCUT KEYS FOR EASY PROCESSING

s	P pick
d	S pick
shift, left mouse button and drag	Expanding timing of waveforms 'zooming in to selected area'
ctrl, right mouse button	Increase amplitude of waveforms
ctrl, left mouse button	Decrease amplitude of waveforms
Middle mouse button	Zoom seismogram to normalised P-S window
1, 2	Previous page, Next page
q	Save event as blast
c	Accept event
w	Calculates event location
e	Event and trigger info and source parameters
r	Rejects the event

### 14. CONCLUSIONS

In following the techniques highlighted by this document, the resulting seismic data quality will be of a consistent and acceptable standard such that when locating events, as accurate as possible locations can be determined.

Good luck with using IMS TRACE!