

Québec Mine Explosions
recorded at the
La Malbaie Array

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Summary

The purpose of this report is to investigate the possibility of using industrial mine or quarry explosions as sources in the monitoring of the stability of seismic P-velocities. The results are not favourable for different reasons at each of the mines. The mines at Schefferville are at a distance of 900 km and are not usefully recorded at the La Malbaie array site, but asbestos mine shots from near Thetford Mines are recorded. Unfortunately these are at a distance of 190 ± 20 km from the array. At these distances three different P-phases arrive at nearly the same time, resulting in a complex waveform that is a very sensitive function of distance and is thus unsuitable for cross-correlating from one explosion to the next. First arrivals are too emergent to be read.

A quartz mine about 40 Km north of Baie St. Paul is in operation from June to October northwest of the array. Changes in direction of the source orientation at the mine produce changes in the waveforms prohibiting the use of cross-correlation for comparing travel times accurately. First arrivals could be read if the signal-to-noise ratio is satisfactory, but with the attendant loss in precision.

Introduction

Since 1974 one or two explosions per year have been set off by the Division in an abandoned mine on the north shore of the St. Lawrence River and since 1975 in drilled holes on the south shore (Buchbinder and Keith, 1979; Buchbinder, 1981). The aim has been to monitor possible changes in the travel times of P-waves. The data were recorded on the six-element telemetered array, and lately by up to 11 Backpacks. Since the waveforms generated by the explosions usually do not vary from one shot to another, the waveforms from two shots can be cross-correlated and differences in arrival time can be determined precisely. For most records this precision, due to errors in the cross-correlation, amounts to ± 2 ms. Other contributing errors are the uncertainties in the clocks of the shooting and the recording systems and instrumental phase delays. The overall precision should be better than ± 10 ms and optimally ± 4 ms. The principal advantages of the method are that the origin time and position of the explosions are known. The disadvantage is that the drilling of holes and the use of explosives is expensive.

An attempt was made to find other sources that were repeated regularly and had sufficient amplitude to be useful for study. Two sources fitted those requirements: one is a quartz mine northwest of the array at a distance equivalent to an S-P interval of 4.5 seconds (37 km) from LMQ and the others are the asbestos mines in the vicinity of Thetford Mines, southwest of the array and of about a 22 seconds (190 Km) S-P time from LMQ. Potentially, both these sources could produce P-waves at the Charlevoix array that would lend themselves to the monitoring of changes in velocity. Since the origin times of the explosions are not known, only changes with respect to one of the elements of the array can be determined.

Array

Since the Fall of 1977 the 6 element telemetered array has been recording continuously in the Charlevoix Region. The array produces analog magnetic tapes that can be digitized in the Data Lab in Ottawa. Usually this is done at 120 samples per second and the time on a digitized trace can be determined to within a few ms.

Cross-Correlation Technique and Source Migration

The cross-correlation technique that is used and described in detail for the calibration shots in the references, can also be used for the mine explosions. In brief, for the explosions of known origin times, two waveforms are cross correlated and the program will determine the time difference between the arrival times of the two explosions. If there are no apparent changes in travel time due to changes in velocity, the time difference between the waveforms with suitable amplitudes should be 0 ± 2 ms. For explosions of unknown origin time, only the travel time differences with respect to the travel time to a fixed reference station can be derived.

Another source of uncertainty has been source migration. In the timed explosions on the north shore the same water-filled quarry has been used and the source migration from shot to shot amounted to changes in travel time ± 1 ms at worst. On the south shore drilled holes have been used, and corrections have been applied to the travel times from each hole to make it appear as if the shot came from the first or reference hole, to an uncertainty of ± 1 ms.

Mine or quarry explosions generally do not occur in the same location

and one may ask how far can they move before they introduce significant errors of let us assume 20 ms. From simple geometry and the typical source to station distance of the quartz mine this amounts to about .27 Km and similarly for the asbestos mines this amounts to 1.20 Km movement of the source.

Sources

Quartz Mine: This near surface quartz mine, situated 40 km northwest of LMQ, near Petit Lac Malbaie, started operations in August 1977. Since then, the mine has operated between June and October of each year detonating, 3-4 shots per month. A visit to the mine in June 1978 showed that the 20m wide vein of was being mined in a systematic manner so that neither source migration nor variations in the direction of the source were problems.

However, towards the end of 1980 mining operations spread to 3 different sites with different shot line directions. From the dramatic variation of the wave forms since 1980 it is concluded that this site is no longer useful for accurate travel time studies.

Asbestos Mines: There are a number of mines operating in the Thetford Mines area. D. Forsyth visited there in 1974 and reported that mining operations were carried out principally in three areas: A) by Lake Asbestos (NAQ) northeast of Thetford Mines; B) Asbestos Corp., (ACL), essentially in Thetford Mines and C) Lake Asbestos of Quebec Ltd. at Black Lake (BLA) southwest of Thetford Mines. The distances and azimuths of these three sites from LMQ are given in Table 1. The regional seismic stations locate the sources of these explosions very poorly, since the pertinent stations form a linear array. The times of the blasts considered later are all within -14 to -1 minute of the time that the Lake Asbestos Corporation at Black Lake intends

to shoot. The other mines shoot around 16:00 hours local time. Therefore, we are assured that we use only shots from Black Lake.

Data Analysis:

Asbestos Mines: Five blasts were digitized and cross-correlated. Details about the shots are given in Table 2. Since the waveforms arriving at the array stations are not impulsive from these blasts, 200 samples or 1.67 s were used in cross-correlating the waveforms. The seismograms have the highest frequency content at the nearest station on the north shore, 54, and the lowest frequencies at the furthest station on the south shore, 21 (Fig. 1). As Lyons et al., (1980) pointed out, these distances are close to the cross-over point between Pg, Pn and some intermediate phase. The rapid succession of phases makes these waveforms a sensitive function of distance and source migration, and the waveforms from the different shots are variable. For shots 104 and 105 there is a reasonable similarity between waveforms. More details about the cross-correlation results are given in Table 3 and an example of two waveforms is shown in Fig. 2. In the column under 105 x 104 in Table 3, are given the changes in relative arrival times between blasts 105 and 104 and under cc are the cross-correlation coefficients. The next two columns give the changes with respect to stations 54 and 11. These changes are too large to be due to real changes in travel time. In addition these changes are too large to be due to uncertainties in the location of shot point.

A source a few tens of km further from the array would have produced large amplitude reflected Moho phases, which may have given better results.

Quartz Mine: Again 5 blasts were considered as listed in Table 2.

Since the waveforms are impulsive and the array is near to the source, 100 samples or 0.83 s were used in the cross-correlation. Visual inspection of the wave forms in Fig. 3 a, b and c shows that the pulses from blast 3 and 5 are reasonably similar and that the others are dissimilar. This is also supported by the cross-correlation values and relative changes in travel times given in Table 4. For controlled shots the cross correlation coefficient is over 0.9 whereas for the quartz mine they do not exceed 0.76. Fig. 3d shows an apparent similarity for the pulses for blasts 1 and 2 but this is a station effect that removes source effects.

Cross-correlation values from waveforms where the first breaks arrive together, such as in Fig. 3a, are underlined by a solid line; values where the first arrivals arrive at different times with respect to the main part of the waveform, as shown in Fig. 3b, are underlined by a dashed line. In cases like Fig. 3a the two shots had the same source location and charge direction whereas in Fig. 3b and c they were different. The data in table 4 confirm the poor quality of the results obtained from cross-correlating for these sources.

Conclusion

Five explosions from the Black Lake Asbestos mines were recorded by the array and analyzed. The source is about 189 km from LMQ which is near to the center of the array. This is close to the distance at which three different P-phases arrive together and the waveform is very sensitive to small changes in distance. The waveforms produced by such blasts do not lend themselves to useful cross-correlation, neither can arrival times be read because of their emerging nature.

The only other blasts that are regularly recorded at the array are from a quartz mine about 40 km NW from LMQ. It is found that differences in orientation of the source can give erroneous differences of relative arrival times when cross-correlating waveforms or reading the arrival times of the peak in amplitude.

References

Buchbinder, G.G.R. Velocity changes in the Charlevoix region, Quebec. Maurice Ewing Series 4, Earthquake Prediction, An International Review. American Geophysical Union, 367-376, 1981.

Buchbinder, G.G.R. and Keith, C. Stability of P. travel times in the region of la Malbaie, Québec. Bull, Seism. Soc. Am., 69, 463-481, 1979.

Lyons, J.A., Forsyth, D.A. and Mair, J.A. Crustal studies in the La Malbaie Region, Quebec. Can. J.E.S. 17, 478-490, 1980.

FIGURE CAPTIONS

1. Array recording stations.
2. Example of 2 waveforms from Black Lake Asbestos Mine, used in cross-correlating. Station 64, shots 104 and 105, cc = cross-correlation coefficient, DT = change in relative travel time.
3. Waveforms from quartz mine blasts used in cross-correlating. Details as in Figure 3.
 - a) Station 60, shots 3 and 5
 - b) Station 60, shots 1 and 4
 - c) Station 16, shots 2 and 3
 - d) Station 20, shots 1 and 2 *

* Station 20 is equal to station 21

Table 1

Asbestos Mines Parameters

CODE	LAT N	LONG W	DIST + AZM FROM LMQ	
NAQ	46.1297°	71.2647°	173.3 km	204.8°
ACL	46.0738°	71.3143°	180.6 km	205.1°
BLA	46.0155°	71.3955°	189.1 km	206.0°

NAQ - Lake Asbestos, National Mines

ACL - Asbestos Corp. Ltd., Thedford Mines

BLA - Lake Asbestos, Black Lake

Table 2

Asbestos Mine Blasts

No.	Date	Day	Approximate	
			Time*	U.T.
101	28 Aug. 1980	241	15:49:06	
102	18 Sept. 1980	262	15:41:15	
103	17 Oct. 1980	291	15:44:38	
104	25 May 1981	145	15:42:42	
105	9 June 1981	160	15:35:38	

Quartz Mine Blasts

1.	27 Aug. 1980	240	20:37:40	
2.	12 Sept. 1980	256	21:27:30	
3.	03 Oct. 1980	277	20:15:28	
4.	29 Oct. 1980	303	23:25:31	
5.	05 June 1981	156	22:03:24	

*Time of the P-wave arrival at station nearest to the source.

Table 3

Relative Travel Time Differences for Shots 104 and 105.

STN	105x104*	cc	I (-54)	II (-11)
54	-2.816	.40	0	-.280
64	-2.909	.68	+0.093	-.187
11	-3.096	.59	+0.280	0
16	-3.410	.43	+0.594	+.314

*negative time means blast 105 was early with respect to 104

cc cross-correlation coefficients

I Stn 54 used as reference

II Stn 11 used as reference

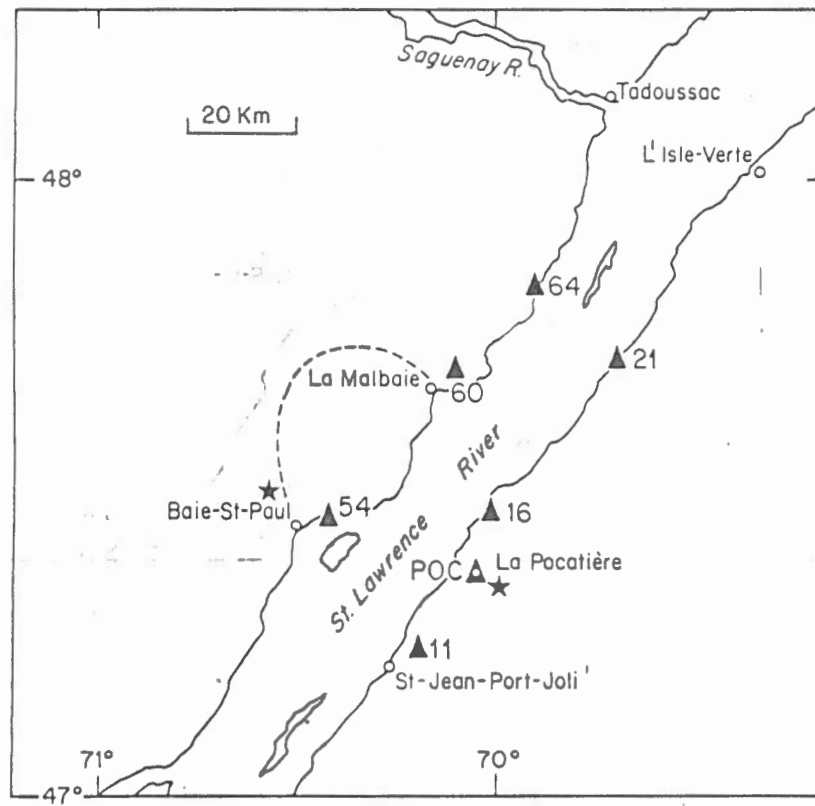
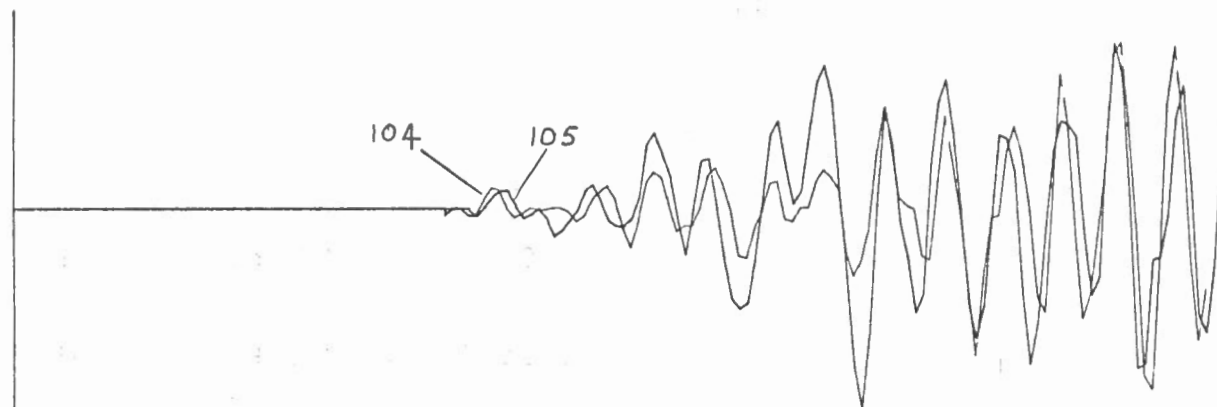


Fig. 1

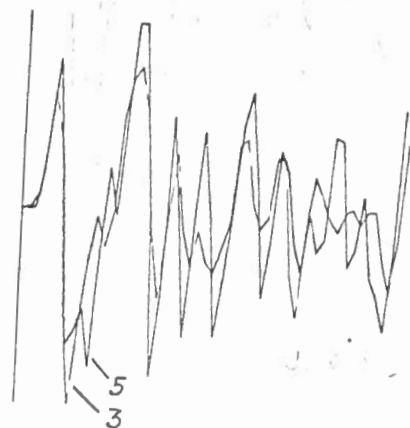


A 64 104 25 MAY 81 15 42 42000 50

A 64 105 9 JUN 81 15 35 38000 50

LAG = -6.4 CC = .677 DT = -2.909 105 EARLY

Fig 2

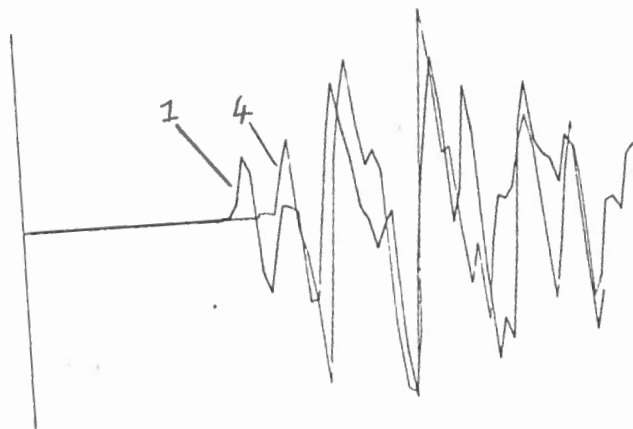


A 60 3 3 OCT 80 20 15 28000 29

A 60 5 5 JUN 81 22 3 24000 29

LAG = 1.2 CC = .759 DT = -3.833 S EARLY

Fig. 3a

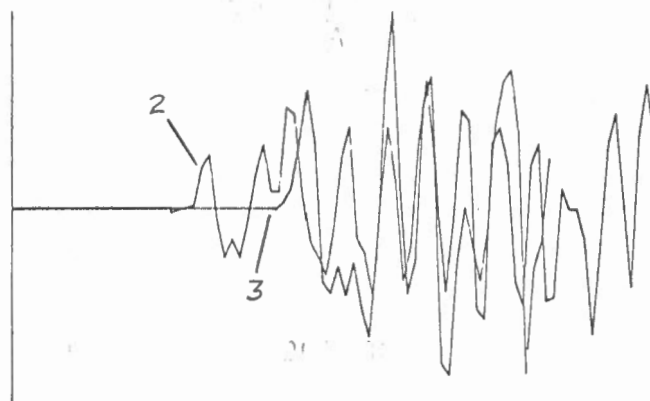


A 60 1 27 AUG 80 20 37 40000 41

A 60 4 29 OCT 80 23 25 31000 41

LAG = 9.8 CC = .537 DT = -8.840 4 EARLY

Fig. 3 b

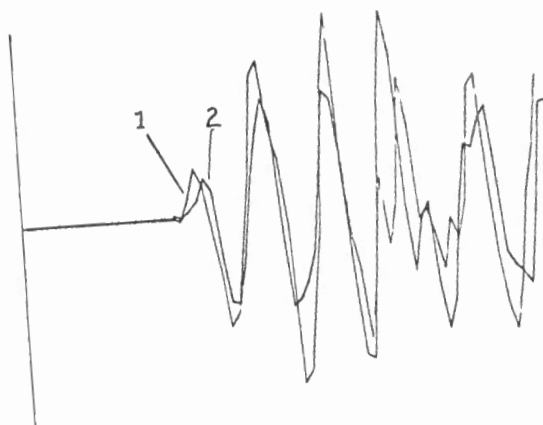


A 16 2 12 SEP 80 21 27 30000 33

A 16 3 3 OCT 80 20 15 28000 33

LAG = -27.2 CC = .353 DT = -2.056 • 3 EARLY

Fig. 3C



A 20* 1 27 AUG 80 20 37 40000 46

A 20* 2 12 SEP 80 21 27 30000 46

LAG = -2.4 CC = .657 DT = -10.614 2 EARLY

* Station 20 is equal to station 21

Fig. 3d