La Malbaie 1977 Experiments

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Index

Summary:

On Aug. 30, 1977, a calibration explosion was set off at the Experimental Farm in La Pocatière and on Aug. 31, 1977 another one was set off in the mine at St-Jerôme. The six element portable seismic array had been installed on a rather permanent basis just prior to the shots and in addition six temporary backpack systems were in operation.

Absolute P wave travel times were determined. The data were also analyzed by cross-correlation with data from previous shots. Both methods indicate that changes of at most a few tens of milliseconds occurred. About one half of the stations for which cross-correlation data were obtained show changes in travel time.

Experiments:

All calibration shots are listed in detail in Table 1. For the La Pocatière hole this is the fourth shot in a series that started in October 1975, it is shot No. 104. For the St-Jerôme Mine this is the sixth shot (No. 6) in a series that started in June 1974. For shot No. 104 three existing drill holes were used and were destroyed by the explosion. Shot No. 6 was set off in the mine in the same place as before, however, this time the water level was 0.5m lower.

Stations:

The stations that were occupied are shown in Figure 1. Stations 54, 60 and 64 on the northshore and 10, 16 and 20 on the southshore are now the "permanent" array stations (A). Station 52 was occupied by a Smoker system. The six Backpack systems (BP) were deployed at the remaining 7 sites. For shot 104 station 30 was not occupied, for shot 6 station 62 was not occupied.

The instrumentation has been described in detail in Internal Report No. 77-7 (IR 77-7) and will not be repeated here.

Improvements and changes:

A number of improvements or changes were undertaken with respect to the previous experiments:

a. The station sites were improved by pouring concrete pads and the instruments were all encased in metal containers or buried.

b. In the recommendations of IR 77-7 it was stated that shooting should be done around sunrise to reduce local noise. For logistical reasons this was not possible but instead we shot after sundown. This in fact greatly reduced the local wind-generated noise.

c. All BP clocks, the array clock and the shooter clock were compared to WWV radio signals on an oscilloscope and time corrections so determined are good to within 1.5 ms, a considerable improvement over earlier methods of determining time corrections.

d. The BP digitizing program had not been changed before the experiments to remove the uncertainties of ±8 milliseconds nor to increase sampling rate to 120 hz.

e. Stations 10 and 20 had to be moved because the land was no longer available. Station 10 was changed by 450 m and is now called 10/11. Station 20 was moved by 220 m and is called 20/21. For station 20/21 no earlier data exist to allow cross-correlation, however, for station 10/11 such data do exist and show that the P wave signal has changed so much that cross-correlation is no longer appropriate.

Traveltimes:

The traveltimes for shot 104 are given in Table 2. The first column shows the station number and instrument type. The second column gives the arrival times. For the array two readings were made. "a" is the reading from the analogue record and "d" is the reading from the print of the digitized record. The error in milliseconds is given. The combined errors are the RMS errors. Table 3 gives the travel times for shot No. 6.

In Tables 4 and 5 are given the summaries of the travel times for all 10 calibration shots. A starred travel time in the newer data indicates that the signal-to-noise ratio was less than 3. In these cases the arrival may not have been correctly identified. The error here refers to the "pick". The BP travel times for 1976 have been adjusted from those of IR 77-7 to allow for the BP digitization correction, which was not included in the tables of that report.

Cross-correlation:

Cross-correlations were performed wherever suitable data exist. Both the BP and the array digital data require corrections that will be explained in detail here since they have changed partly from the explanation given in IR 77-7.

BP digitizing correction:

The BP digitizing is controlled by the 480 Hz signal put out by the clock, thus 480 program interupts, (PI), are available to the microprocessor program. The program uses eight PIs to make up a sample, of 1/60 of a second, in which to multiplex and save the 3 seismic channels. This is shown in Figure 2. Then 80 samples are formed into a block. The first block is formed somewhat differently from the following ones. Since it is, however, never used this is of no interest here. During the last sample in a block, time is determined by the program at the 6th PI. This time is placed at the start of the new block. The time is given in hours, minutes, seconds and 1/60 second, but not to 1/480 second. Time is only given once in each block, but time in the block may be determined by counting samples from the beginning of the block.

From Figure 2 it is evident that the time at the start of a block needs a correction of 3 PIs. Since the 3 seismic channels are sampled sequentially, two channels need a further correction. In sum channel 3 needs to be corrected by 3PIs or 3/480 second, channel 2 by 5/480 and channel 1 by 7/480. These values are indicated in Figure 2.

It is a peculiarity of the digitizing program that digitizing can commence at any PI in the 1/60 of the second that is given as the time of the sample at the beginning of the block. To allow for this we assume it started in the middle of the sample and is no more than ½ sample early or late with respect to the middle. This requires that we apply a correction of 4 ± 4 PIs or 8 ± 8 ms. Here we are only concerned with the vertical seismic component so that its correction and uncertainty is 22 ± 8 ms, call this t_{IC}. This correction is different from what it was thought to be when IR 77-7 was written. The new corrections are also listed in Table 6.

For cross-correlation purposes one needs to know the time of the start of the time series. This is obtained from the BP data from the time in the header of a block plus the number of samples N minus one, into the block where the time series starts, that is (N-1)/60 seconds. This raw start time t_R must be corrected for the digitizing correction t_{IC}, the shooter clock correction t_{SH} and the BP clock correction t_I so that the start time is:

$$t_i = t_R + t_{IC} + t_{SH} + t_I \quad .$$

Array digitizing correction:

To use the analogue magnetic tape records of the array for cross-correlation, the high or low gain channel is digitized at 120 hz, along with the time track. Since the rise time of the time marks stretches over 2-3 samples, we plot a few samples around the beginning of the time mark and by interpolating can estimate its start. This is shown in Figure 3. It has been found that the digitizing frequency is not usually 120 Hz but varies between 116 and 123 Hz. Assuming that it is constant between the two time marks surrounding the signal of interest we can determine a correction factor for the time of any sample by also plotting the second time mark. As shown in Figure 3 this factor is of the form (I + a)/Int. I is the number of the sample from a time mark, "a" a correction for the start of the time mark and Int is the length, in number of samples, between the two time marks. The time marks are generally second marks, so that if our time series for cross-correlating starts between the Nth and N + 1th second the starting time is:

$$t_s = N + (M + a)/Int,$$

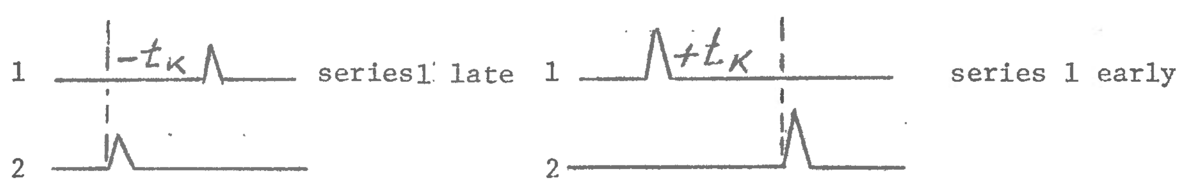
where M is the number of the sample in the time series after the start of the second N.

From the starting sample onward the samples that were used in the cross-correlation were adjusted so that the sampling intervals become 120Hz.

The start time has to be corrected for shooter correction t_{SH} and instrument clock correction t_I so that

$$t_i = t_s + t_{SH} + t_I.$$

Computing the cross-correlation lag between two time series i = 1 and 2 gives the number of lags as ±K samples. When cross-correlating between BP and BP systems or BP and A systems a sample is 1/60 second, between A and A systems it is 1/120 second. Then converting K samples to time gives t_K. The time difference between the two time series is $t_1 - t_2 = \Delta t$, so that we obtain for the total corrected time lag $t_c = t_K - \Delta t$. Our convention is such as to give a positive lag if series 1 is moved to the right and a negative lag if series 1 is moved to the left, in other words, t_2 is the origin.



The maximum of the cross-correlation function was determined and then improved upon by quadratic line fitting using also the two points on either side of the maximum. As a result the computed lags are given to 1/10 the cross-correlation interval or lag.

To simplify matters the computed lags are given for the 1977 time series with respect to an earlier one. That is, 1977 is either late or early. A few wave forms used in cross-correlating are shown in Figures 4a to 4d.

In addition to the 1977 data, all possible cross-correlations were determined using all data available. In each case the lag is given of a recent time series with respect to an older time series. In all, with 44 wave forms, 47 cross-correlations were performed.

In order to test the stability of the cross-correlations another set was calculated in which the windows were shifted by 20 samples, thus instead of having 10 noise samples before the start of the signal, there were 30 noise samples. The resulting maximum cross-correlation lag change was 5 ms.

There was one case where the change was 10 ms and this can be explained by the fact that adding noise started the time series in an earlier second where the digitizing interval was very different than in the second used initially.

The results for all the possible cross-correlations for the La Pocatière shots are given in Table 7 and for the St-Jerôme Mine shots in Table 8. Under the heading ST are given the numerical station code and instrumental type. YR contains the years, DAY are the Julian days, SHOT contains the shot numbers START TIME contains the starting times of the time series, this is followed by the clock and BP corrections, and the corrected start time. A-B is the difference in corrected start times followed by the cross-correlation coefficient. A large coefficient near one, indicates high similarity between the wave forms being correlated. The third line contains the sample lags necessary to maximize the cross-correlation function. This is followed by the lag converted into seconds minus the A-B time, which is equated to the final lag. Finally the shot number and LATE or EARLY refer to the chronologically later shot that is either late or early with respect to the earlier shot.

The cross-correlation lags are presented graphically in Figures 5 and 6. Lines sloping up to the right indicate increasing time lags and lines sloping down to the right indicate decreasing time lags. The amount of change is indicated by the + or - number of milliseconds.

Errors:

For the last shots there has been an improvement in the clock errors. Use of an oscilloscope permitted reducing the clock errors to about ± 1.5 ms if linear clock drift can be assumed.

The individual contributing errors are indicated in Tables 2 and 3. The error on the arrival time is rather variable and contributes only to travel time but not to cross-correlation. The shooter and instrument clock errors are given as ± 2 ms. The instrument delay error is assumed to be ± 5 ms. For the BP the digitizing error is ±8 ms, and a ± 5 ms relay delay error is assumed for the shooter box. Thus each time series from a BP has an RMS error of ± 11, allowing for ± 2 ms in cross-correlating gives a combined RMS error of ±16 ms for two BP time series.

The error on an array time series should be smaller than for a BP time series because of the higher sampling rate. However this advantage is partially removed by the uncertainty in the start of the second marks and estimate of the sampling frequency.

Thus all cross-correlation errors will be taken as ± 16 ms. The errors in the travel times are determined from the RMS error of the contributing errors as given in Tables 2 and 3. The final error given refers to the point of the time series that was picked to be the arrival of the P phase. However the sampling interval of the digital equipment may produce variations in the apparent arrival time. Then differences in travel time may be in some extreme cases ±2 sampling intervals.

Discussion of the Data:

The general quality of travel time and cross-correlation data will be discussed with the aid of Figures 7-9. Similar Figures for the two shot points for all stations are given at the end of this report. Figure 7 shows the data for station 58 for the St-Jerôme shots. The horizontal axis is time in months and years. The 6 shot times are indicated by short slashes at the bottom of the Figure. The lower vertical scale is travel time in seconds. The observations are shown by an X and the error bars are indicated. The letters refer to the recording system. Over the 38 months period between shots an increase in travel time of 32 ms has occurred, only a few milliseconds larger than the stated errors.

The upper scale in Figure 7 is cross-correlation time change in ms. Over the 38 months period a change of 30 ms is indicated, about twice the error. The cross-correlation via two different paths close to within one ms. The agreement between arrival time changes and cross correlation changes is good.

Figure 8 shows similar data for station 60. The cross-correlation and travel-times show changes of 49 and 33 ms respectively. The cross-correlation and travel time changes are larger than the estimated errors.

Figure 9 shows the data for station 58 for the La Pocatière shots. The travel-time of the shot 102 is marked by an asterisk. This indicates that the signal to noise ratio is less than 3 or in general that a phase is uncertain. In the cross-correlation part of the Figure cross-correlations with shot 102 are indicated by dashed lines. It has been found that the clock of the BP for this station either drifted non-linearly or jumped and a reliable correction could not be determined. However, the wavetrain for this shot is still useful because it results in closure with the wavetrains of the other 3 shots. The resultant change in cross-correlation is 10 ms, which is less than the level of significance. The travel times show no significant changes either.

The observed changes in cross-correlation have been summarized in Figure 10 in a plot of change in cross-correlation vs. distance. It is evident that 9 out of 15 observations are outside the error bounds. The maximum changes are -30 and +49 ms. Under the assumption that paths in the paleozoic sediments under the south shore, produce no changes in travel time, the source-to-station distance can be shortened. The path length in the sediments can be estimated from the known slope of the contact and assuming that the maximum depth of penetration is $\Delta/3$. This has been done for three stations for the St. Jerôme shots, and the 3 data points have been moved to the arrow heads. The only statement that can be made regarding the St. Jerôme shots is that cross-correlation changes increase with distance.

For the La Pocatière shot point only 3 points are outside the error bounds. The two positive points do not violate the remarks regarding the data for the St.-Jerôme shot point. The negative data point for station 56 is lightly anomalous, since it is the only significant negative point. The geographic distribution of changes in cross-correlation are shown in Figure 11.

To test the correlation of changes in travel time by cross-correlation or travel time observations, Figures 5 and 6 are again shown as Figures 12 and 13 but the changes in travel time have been added in brackets. For station 60 from both shot points the correlation is good. The difference between the two methods is at most 16 ms. For the rest of the data the difference is of the same order. Thus in the instances where changes in travel times could be compared to changes in cross-correlation, agreement is found.

The arrival times from smoker systems had been shown to be affected by large errors in IR 77-7. Thus no statement will be made here of any apparent changes in travel time that are based on smoker records. The only significant change in travel time based on phase arrival is shown in Figure 14, station 74 for the St. Jerôme shot point. The change is nearly 50 ms, based on two Tape system records in 1974 on the one side and a BP observation in 1977 on the other.

Interpretation:

When attempting to interpret the above results it must be kept in mind that if a change in velocity of 10% occurred over .5 km of ray path a change in 10 ms would occur. Thus any changes observed here involve only 2.5 km of path length. Alternatively a much smaller velocity anomaly may extend over an appropriately larger volume.

Because of the size of the observed changes in travel times and the attendant errors it is not yet possible to model the changes in velocity. For the St. Jerôme Mine shots the anomaly may increase with distance. The positive anomalies from the stations for the La Pocatière shot are in agreement with this.

The negative anomaly at station 56 at a distance of 33 km from La Pocatière is unique. Stations 74 and 58 are on very nearly the same azimuth as station 56 but at distances of 46 and 25 km respectively. The maximum depth of penetration for the three stations is about 8, 11 and 15 km, this separates the ray paths sufficiently so that the path to station 56 samples a unique part of the crust. In addition the ray path passes underneath the central peak of the Charlevoix impact structure, Mont Les Eboulements.

LMQ Regional Station

The regional seismic station LMQ is located at the Charlevoix Observatory, which is identical to station 56 in Figure 1. The station began operating in Oct. 1976. In the following a period of 480 days is analyzed during which 207 microearthquakes were recorded.

Figure 15 shows a 10 day histogram of number of earthquakes recorded. During the period from day 300 to day 530 (day 1 is Jan 1 1976), 61 microearthquakes were recorded for an average of 2.5 events per 10 days. In the period from days 540 to 770, 146 microearthquakes were recorded with an average of 6.3 events per 10 days. The two averages are significantly different but fall on either side of the average for the 1974 microearthquake survey.

It can be shown that the increase in the number of events is also associated with an increase in energy, so that the increased activity is not only an increase in small magnitude events.

It is commonly recognized that the slope of the cumulative frequency magnitude distribution, referred to as b, is diagnostic of different stress conditions. Values of b less than 1 are commonly obtained in shield areas and values larger than 1 are obtained in tectonicly active regions. High b values are also prevalent in foreshock sequences and small b values in aftershock sequences. The question thus arises if the change in seismicity at LMQ is also associated with a change in b.

The cumulative frequency magnitude relation in the form $\Sigma N(M) = aM^{-b}$ is known as the Ishimoto-Iida relation, where M are the magnitudes of the earthquakes. In the case of the LMQ station where only microearthquakes are recorded, the events are not recorded by the Canadian station net and magnitudes cannot be determined. An approximation to magnitude can, however, be made. From explosions and earthquakes at very small distances in the Charlevoix region an attenuation law of the form $10^{\Delta/K}$ was postulated where K = 30, so that for each 30 km distance the amplitude decreases by 10. Distance of the events from LMQ was obtained from $\Delta = (S-P) * 8.2$. With these assumptions the magnitudes of the event were determined.

Suzuki has shown that under conditions where the Ishimoto-Iida relation holds the magnitude in the relation may be replaced by the amplitude of the events recorded at one station so that $\Sigma N\ (A) = a'\ A^{-b}$, and the b values will be equal. If this can be shown to hold near station LMQ it is of interest, since an attenuation law needsno longer be assumed and the distance of an event is of no importance.

We therefore, computed b balues for the following cases. The data were used in three different sets: all the data, N = 207; the first 240 days with N = 61, and the second 240 days with N = 148. The b values were computed by least squares (LSQ) and maximum likelihood estimate (MLE). In addition to the attenuation law with k = 30, k = 25 and k = 35 were also used. These b values are listed in Table 9. Inspection of the table shows the following: b values computed from magnitudes based on k = 35 are closest to the b values based on amplitudes. A better correspondence would have been obtained with a somewhat larger value of k, that is less severe attenuation. Thus Suzuki's hypothesis holds in the region of LMQ.

The b values obtained by LSQ for the 3 sets of data based on amplitudes vary from -.9 to -1. so that there is no significant difference between them. The b values obtained by MLE vary from -.72 to -.78 and again there is no significant difference between them. The cumulative frequency magnitudes are plotted in Figure 16 for 61 microearthquakes. The LSQ lines are shown, the starred data points were deleted because of incompleteness. On the left are the "magnitude" lines, on the right is the amplitude line.

Thus in the region of LMQ, changes in b values based on amplitudes can be used to monitor the stress field, provided the number of earthquakes is sufficiently large. On a weekly or monthly basis the method will not be useful. On the other hand the method may prove to be of value for the determination of b in other cases where one station is near a source of moderate seismicity.

Conclusion:

The observed small changes in travel time of at most 49 ± 16 ms are only somewhat beyond the experimental error and demand that conclusions be made with great caution.

Except for a ray path underneath the central peak of the Charlevoix impact structure, Mont Les Eboulements, the region appears to show decreases in velocity.

The decreasing experimental errors of the next few calibration shots and the total length of observations then available should confirm the reality of the changes in velocity.

Recommendations:

1. To further define the observed changes in travel times it is recommended that further calibration blasts be set off in May and October 1978. This is in agreement with our philosophy of being dominantly interested in damaging earthquakes.
2. The uncertainty of ±8 ms in the BP's must be removed and the sampling frequency should be increased to 120 Hz. (Done April 1978)
3. The shooter box with its delay should be replaced by a solid state box with insignificant delay. (on order since February 1978)

Figure captions

1. Station distribution for the August 1977 shots. A's are array sites, stars are shot points.

2. BACKPACK program timing. There are eight program interupts in a sample of 1/60 second. MUX is the interupt when a seismic channel is digitized.

3. Array time track digitizing correction term. The start of one second is near I = 1, the start of the following second is near I = 118. "a" corrects for the first second not starting at I = 1, and L corrects for the digitizing interval not being 120.

4a. Wave forms used in cross-correlating. Solid line is described first in legend: BP74, shot 5, date and start time. Dashed line is described second in legend as shot 6.

In third line the computed lag is given in samples followed by the cross-correlation factor CC, DT is the corrected change in cross-correlation. 6 LATE means shot 6 was late with respect to shot 5. Note that shot 5 was 500 lbs and shot 6 was 2000 lbs. Traces are nomalized to 1 inch.

4b. Waveforms similar to Figure 4a. Shot 4 was 5000 lbs and shot 5 was 500 lbs.

4c. Waveforms similar to Figure 4a. Shot 103 was 2000 lbs and shot 104 was 1500lbs.

4d. Wave forms similar to Figure 4a. Shot 104 was 1500 lbs and shot 101 was 1000 lbs. Note the difference in initial rise of phases.

5. Cross-correlations for La Pocatière shots. Downsloping to right indicates the more recent shot arrived earlier, upsloping right indicates more recent shot arrived later. Lines connect shots that were cross-correlated. Number indicate change in milliseconds. Right hand column gives sum of change by different combinations of cross-correlations.

6. Cross-correlations for St-Jerôme Mine, similar to Figure 5.
7. Data for station 58 from St-Jerôme Mine shots. The arrival times with error bars are shown by an X at the bottom of the Figure. Cross-correlation changes in ms, error bar is ±16 ms, are shown at the top.
8. Data for station 60 from St-Jerôme Mine shots similar to Figure 7.
9. Data for station 58 from La Pocatière shots. Dashed lines in the cross-correlation indicate an uncertainty clock correction for shot 102.
10. Summary of cross-correlation results vs. distance. Station numbers are indicated along the bottom. In the Figure the numbers 1, 2 and 3 refer to cross-correlation between respectively the first and second, the second and third and the third and fourth shots.
11. Geographic distribution of cross-correlation results. The X's are shotpoints. Dots are stations. Top number refers to change in ms for St.-Jerôme Mine shots, bottom number refers to La Pocatière shots.
12. Cross-correlation results for La Pocatière shots to which in brackets changes from travel time observations have been added.
13. Similar to Figure 12 for St. Jerôme Mine shots.
14. Significant change of travel time observed at station 76 for St.-Jerôme Mine shots. No cross-correlation was performed.
15. Ten day histogram of microearthquakes recorded at LMQ.
16. Cumulative frequency magnitude relation for 61 microearthquakes. On the left for "magnitude" using the attenuation indicated, on the right are the amplitudes. The starred data were not used in the solution for the regression lines.

LIST OF TABLES

TABLE 1

List of Explosions

La Pocatière Shot hole

47.3500° N 70.0112° W

No.	Date	Hour	Charge Size (lb)
101	7 Oct. 75 (280)	15:16:00.000 UT	1000
102	28 Oct. 76 (302)	16:26:00.000 UT	1000
103	16 Dec. 76 (351)	17:26:00.000 UT	2000
104	30 Aug 77 (243)	23:30:00.000 UT	1500

St-Jerome Mine

47.534° N 70.556° W

No.	Date	Hour	Charge Size (lb)
1	19 Jun. 74 (170)	12:08:09.305 EST	1000
2	13 Jul. 74 (194)	12:11:06.752 EST	1000
3	23 Jul. 74 (204)	12:26:08.925 EST	5000
4	24 Sep. 75 (267)	17:53:00.036 UT	5000
5	15 Dec. 76 (350)	20:25:59.989 UT	500
6	31 Aug 17 (242)	22:30:00.000 UT	2000

Table 2

La Pocatière

SHOT	DAY	DATE	ORIGIN TIME			ERRORS		CORRECTIONS ALL IN MS			
104	242	30. 8.1977	23	30	0.000	2	5	5	5	0	0

ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL TIME	+/- ERRORS
62	BP	7.742	8	2	4	22	-6	0	7.763	.012
56	BP	5.842	8	2	4	22	-1	0	5.868	.012
76	BP	6.567	8	2	4	22	-6	0	6.588	.012
74	BP	8.008	8	2	4	22	-6	0	8.029	.012
58	BP	4.617	8	2	4	22	-7	0	4.637	.012
18	BP	4.027	6	2	4	22	-4	0	4.050	.010
52	S	6.997	3	20	0	-42	0	0	6.960	.022
60	A	6.871	8	4	0	3	0	0	6.879	.012
64	A	9.206	4	4	0	3	0	0	9.214	.009
20	A	8.375	12	4	0	3	0	0	8.383	.015
10	A	3.562	26	4	0	3	0	0	3.570	.027
54	A	5.879	10	4	0	3	0	0	5.887	.013

Table 3

St. Jerôme Mine

TRAVEL TIMES FOR LA MALBAIE AREA SHOTS

SHOT	DAY	DATE	ORIGIN TIME			ERRORS		CORRECTIONS ALL IN MS			
6	243	31. 8.1977	20	30	0.000	2	5	5	4	0	0

ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL TIME	+/- ERRORS
18	BP	8.925	10	2	4	22	-7	0	8.944	.013
58	BP	4.413	4	2	4	22	-6	0	4.433	.009
74	BP	2.177	6	2	4	22	-3	0	2.200	.010
76	BP	4.508	8	2	4	22	-6	0	4.528	.012
56	BP	2.980	4	2	4	22	-2	0	3.004	.009
30	BP	9.032	15	2	4	22	-4	0	9.054	.017
52	S	2.188	3	10	0	-58	0	0	2.134	.013
60	A	6.535	6	4	0	10	0	0	6.549	.010
54	A	2.429	4	4	0	10	0	0	2.443	.009
64	A	9.699	4	4	0	10	0	0	9.713	.009
21	A	11.364	8	4	0	10	0	0	11.378	.012
11	A	7.294	8	4	0	10	0	0	7.308	.012

TABLE 4

Travel Time Summary

La Pocatière Hole Shots

Shot No.		101			102			103			104		
Date		75 Oct. 07			76 Oct. 28			76 Dec. 16			77 Aug. 30		
		280			302			351			242		
Stn.	Δ km	System	Travel Time s	Error ms ±	System	Travel Time s	Error ms ±	System	Travel Time s	Error ms ±	System	Travel Time s	Error ms ±
52	39.39							S	6.995	24	S	6.960	22
54	32.60							BP	5.887	14	A	5.887*	13
56	32.61	S	5.845	45	BP	5.953*	23	BP	5.892	14	BP	5.868	15
58	24.72	Aa d	4.620 4.638	15 15	BP	4.661*	23	S BP	4.660 4.631	77 15	BP	4.637	15
60	38.55	Ad	6.853	18	BP	7.061*	32	S BP	6.867 6.857	89 14	A	6.885*	12
74	46.28				BP	8.030*	22				BP	8.029	15
76	36.92							S	6.617	17	BP	6.588	15
8	36.86				S	6.522	198	S	6.576	37			
10/ 11	17.98 18.42	A	3.492*	14	S	3.660	33	S	3.455	51	A	3.570*	26
30	5.53	A	1.254	14									
16	13.13	S	2.737	20	S	2.703	28	BP	2.701	15			
18	21.84	A	4.158*	14							BP	4.050	13
20/ 21	46.42 46.23	S	8.610	17							A	8.383*	12
64	53.84										A	9.210*	12
62	44.73										BP	7.763	15

SYMBOLS

A array
T tape
S smoker
* poor arrivals

BP backpack
a analog
d digital

TABLE 5

Travel Time Summary

St-Jerôme Mine Shots

Shot No.		1			2			3			4			5			6		
Date		74 June 19			74 July 13			74 July 23			75 Sept. 24			76 Dec. 15			77 Aug. 31		
		170			194			204			267			350			243		
Stn.	Δ km	System	Travel Time s	Error ms ±	System	Travel Time s	Error ms ±	System	Travel Time s	Error ms ±	System	Travel Time s	Error ms ±	System	Travel Time s	Error ms ±	System	Travel Time s	Error ms ±
52	12.21	T	2.181	12	T	2.164	12	T	2.176	12	S	2.308	140	S	2.167	111	S	2.134	13
54	13.77	Aa d	2.423 2.434	12 15	Aa d	2.414 2.414	12 15	Aa d	2.426 2.429	12 13	Aa d	2.444 2.434	13 13	BP	2.440	15	A	2.443	12
56	17.34	S	2.983	25		/			/		S	2.959	32	BP	2.998	15	BP	3.004	13
58	25.87	Aa d	4.406 4.418	12 15	Aa d	4.404 4.403	12 15	Aa d	4.421 4.401	12 15	Aa d	4.420 4.412	13 13	S	4.438	73	BP	4.433	12
60	39.02 38.95	Aa d	6.509 6.521	12 15	Aa d	6.511 6.504	12 15	Aa d	6.519 6.504	12 15	Aa d	6.528 6.528	13 13	S BP	6.571 6.525	37 15	A	6.537	12
62	47.75	S	7.807	26	S	7.824	49		/		S	7.848	44		/				
64	59.66	T	9.933*	12		/			/			/			/		A	9.713*	12
74	13.13	S	2.258	33	S	2.154	20	S	2.120	34		/		BP	2.189	15	BP	2.200	12
76	26.63	T	4.488	12		/		T	4.471	12		/		S	4.502	57	BP	4.528	14
8	13.31		/			/			/			/		S	2.288	15			
10/11	42.81 42.24		/			/		A	7.296	12	A	7.308	13	S	7.291	98	A	7.306*	12
30	51.39		/			/		A	9.010	12	A	9.024	13		/		BP	9.054*	18
16	41.82	S	7.211	128		/		S	7.212	30	S	7.225	43		/				
18	52.18		/			/		A	8.933*	12	A	8.930	13		/		BP	8.944*	15
20/21	67.90 67.84	T	11.385	50		/		T	11.427	31	S	11.403	47		/		A	11.378	12

Table 6

BACKPACK - SAMPLE TIME CORRECTIONS

Channel	3	2	1
Seismic component	E	N	Z
PI (program Interupts)	+7	+9	+11
milli seconds	15	19	22

error: ±4 PI or ±8ms

TABLE 7

ST	YR	DAY	SHOT	START TIME	CORRECTIONS CLOCKS	BP	CORRECT TIME	A-B	CROSS-CORR. COEFF.
74BP	76	302	102	7.816	0	22	7.838	.001	CC = .444
74BP	77	242	104	7.816	-1	22	7.837		
	.4	LAGS	DT=	.006 -.001=	.005	104	LATE		
60BP	76	302	102	6.616	3	22	6.641	-.033	CC = .475
60BP	76	351	103	6.650	2	22	6.674		
	-2.1	LAGS	DT=	-.036 .033=	-.003	103	EARLY		
60BP	76	302	102	6.616	3	22	6.641	.012	CC = .378
60A	75	280	101	6.623	6	0	6.629		
	-.3	LAGS	DT=	-.005 -.012=	-.017	102	LATE		
60BP	76	302	102	6.616	3	22	6.641	-.012	CC = .364
60A	77	242	104	6.645	8	0	6.653		
	.1	LAGS	DT=	.001 .012=	.013	104	LATE		
60BP	76	351	103	6.650	2	22	6.674	.045	CC = .781
60A	75	280	101	6.623	6	0	6.629		
	1.9	LAGS	DT=	.032 -.045=	-.013	103	LATE		
60BP	76	351	103	6.650	2	22	6.674	.021	CC = .623
60A	77	242	104	6.645	8	0	6.653		
	2.2	LAGS	DT=	.037 -.021=	.016	104	LATE		
60A	75	280	101	6.623	6	0	6.629	-.024	CC = .524
60A	77	242	104	6.645	8	0	6.653		
	.3	LAGS	DT=	.002 .024=	.026	104	LATE		
58BP	76	302	102	4.350	-28	22	4.344	-.003	CC = .742
58BP	76	351	103	4.316	9	22	4.347		
	-1.0	LAGS	DT=	-.016 .003=	-.013	103	EARLY		
58BP	76	302	102	4.350	-28	22	4.344	.008	CC = .546
58BP	77	242	104	4.316	-2	22	4.336		
	-.2	LAGS	DT=	-.003 -.008=	-.011	104	EARLY		
58BP	76	302	102	4.350	-28	22	4.344	-.013	CC = .707
58A	75	280	101	4.357	0	0	4.357		
	-2.1	LAGS	DT=	-.034 .013=	-.021	102	LATE		
58BP	76	351	103	4.316	9	22	4.347	.011	CC = .672
58BP	77	242	104	4.316	-2	22	4.336		
	.8	LAGS	DT=	.013 -.011=	.002	104	LATE		
58BP	76	351	103	4.316	9	22	4.347	-.010	CC = .786
58A	75	280	101	4.357	0	0	4.357		
	-1.1	LAGS	DT=	-.018 .010=	-.008	103	LATE		

58BP	77	242	104	4.316	-2	22	4.336	-.021	CC = .581
58A	75	280	101	4.357	0	0	4.357		
	-1.9	LAGS	DT= -.031	.021=	-.010	104	LATE		
56BP	76	302	102	5.616	-19	22	5.619	.003	CC = .583
56BP	76	351	103	5.616	-22	22	5.616		
	.0	LAGS	DT= .000	-.003=	-.003	103	EARLY		
56BP	76	302	102	5.616	-19	22	5.619	.027	CC = .622
56BP	77	242	104	5.566	4	22	5.592		
	-.1	LAGS	DT= -.002	-.027=	-.029	104	EARLY		
56BP	76	351	103	5.616	-22	22	5.616	.024	CC = .808
56BP	77	242	104	5.566	4	22	5.592		
	-.2	LAGS	DT= -.004	-.024=	-.028	104	EARLY		
54BP	76	351	103	5.616	-10	22	5.628	.016	CC = .619
54A	75	280	101	5.612	0	0	5.612		
	.4	LAGS	DT= .006	-.016=	-.010	103	LATE		
54BP	76	351	103	5.616	-10	22	5.628	.006	CC = .811
54A	77	242	104	5.614	8	0	5.622		
	.6	LAGS	DT= .009	-.006=	.003	104	LATE		
54A	75	280	101	5.612	0	0	5.612	-.010	CC = .586
54A	77	242	104	5.614	8	0	5.622		
	.3	LAGS	DT= .002	.010=	.012	104	LATE		
18BP	77	242	104	3.816	1	22	3.839	-.021	CC = .826
18A	75	280	101	3.860	0	0	3.860		
	-1.4	LAGS	DT= -.023	.021=	-.002	104	LATE		
10A	75	280	101	3.326	0	0	3.326	.076	CC = .420
10A	77	242	104	3.245	5	0	3.250		
	20.0	LAGS	DT= .166	-.076=	.090	104	LATE		

TABLE 7 (continued)

TABLE 8

ST	YR	DAY	SHOT	START TIME	CORRECTIONS CLOCKS	BP	CORRECT TIME	A-B	CROSS-CORR. COEFF.
74BP	76	350	5	2.000	7	22	2.029	.006	CC = .946
74BP	77	243	6	2.000	1	22	2.023		
	1.0	LAGS	DT=	.017 -.006=	.011	6	LATE		
60BP	76	350	5	6.300	-14	22	6.308	-.002	CC = .831
60A	74	204	3	15.221	-8911	0	6.310		
	-1.5	LAGS	DT=	-.025 .002=	-.023	5	LATE		
60BP	76	350	5	6.300	-14	22	6.308	-.008	CC = .841
60A	75	267	4	6.338	-22	0	6.316		
	-.6	LAGS	DT=	-.010 .008=	-.002	5	LATE		
60BP	76	350	5	6.300	-14	22	6.308	-.044	CC = .836
60A	77	243	6	6.338	14	0	6.352		
	-1.1	LAGS	DT=	-.018 .044=	.026	6	LATE		
60A	74	204	3	15.221	-8911	0	6.310	-.006	CC = .919
60A	75	267	4	6.338	-22	0	6.316		
	1.8	LAGS	DT=	.015 .006=	.021	4	LATE		
60A	74	204	3	15.221	-8911	0	6.310	-.042	CC = .655
60A	77	243	6	6.338	14	0	6.352		
	.8	LAGS	DT=	.007 .042=	.049	6	LATE		
60A	75	267	4	6.338	-22	0	6.316	-.036	CC = .704
60A	77	243	6	6.338	14	0	6.352		
	-.9	LAGS	DT=	-.008 .036=	.028	6	LATE		
56BP	76	350	5	52.716	10014	22	2.752	.012	CC = .767
56BP	77	243	6	2.716	2	22	2.740		
	1.5	LAGS	DT=	.024 -.012=	.012	6	LATE		
54BP	76	350	5	2.116	-4	22	2.134	.027	CC = .851
54A	74	204	3	11.006	-8899	0	2.107		
	.8	LAGS	DT=	.013 -.027=	-.014	5	LATE		
54BP	76	350	5	2.116	-4	22	2.134	.001	CC = .823
54A	75	267	4	2.143	-10	0	2.133		
	-.2	LAGS	DT=	-.003 -.001=	-.004	5	LATE		
54BP	76	350	5	2.116	-4	22	2.134	-.011	CC = .923
54A	77	243	6	2.131	14	0	2.145		
	.3	LAGS	DT=	.005 .011=	.016	6	LATE		
54A	74	204	3	11.006	-8899	0	2.107	-.026	CC = .900
54A	75	267	4	2.143	-10	0	2.133		
	-2.0	LAGS	DT=	-.017 .026=	.009	4	LATE		

54A	74	204	3	11.006	-8899	0	2.107	-.038	CC = .878
54A	77	243	6	2.131	14	0	2.145		
	-1.5	LAGS	DT= -.013	.038=	.025	6	LATE		
54A	75	267	4	2.143	-10	0	2.133	-.012	CC = .885
54A	77	243	6	2.131	14	0	2.145		
	.6	LAGS	DT= .005	.012=	.017	6	LATE		
58BP	77	243	6	4.116	-2	22	4.136	.021	CC = .747
58A	74	204	3	13.014	-8899	0	4.115		
	-.6	LAGS	DT= -.010	-.021=	-.031	6	LATE		
58BP	77	243	6	4.116	-2	22	4.136	-.020	CC = .749
58A	75	267	4	4.166	-10	0	4.156		
	-1.6	LAGS	DT= -.027	.020=	-.007	6	LATE		
58A	74	204	3	13.014	-8899	0	4.115	-.041	CC = .897
58A	75	267	4	4.166	-10	0	4.156		
	-2.1	LAGS	DT= -.018	.041=	.023	4	LATE		
30BP	77	243	6	8.766	0	22	8.788	-.003	CC = .942
30A	75	267	4	8.801	-10	0	8.791		
	-.6	LAGS	DT= -.010	.003=	-.007	6	LATE		
30BP	77	243	6	8.766	0	22	8.788	-.068	CC = .920
30A	74	204	3	17.755	-8899	0	8.856		
	-5.4	LAGS	DT= -.091	.068=	-.023	6	LATE		
30A	75	267	4	8.801	-10	0	8.791	-.065	CC = .929
30A	74	204	3	17.755	-8899	0	8.856		
	-9.6	LAGS	DT= -.080	.065=	-.015	4	LATE		
18BP	77	243	6	8.716	-3	22	8.735	.003	CC = .844
18A	75	267	4	8.742	-10	0	8.732		
	-.2	LAGS	DT= -.003	-.003=	-.006	6	LATE		
18BP	77	243	6	8.716	-3	22	8.735	.009	CC = .856
18A	74	204	3	17.625	-8899	0	8.726		
	-1.1	LAGS	DT= -.018	-.009=	-.027	6	LATE		
18A	75	267	4	8.742	-10	0	8.732	.006	CC = .892
18A	74	204	3	17.625	-8899	0	8.726		
	-1.8	LAGS	DT= -.015	-.006=	-.021	4	LATE		
10A	75	267	4	7.104	-10	0	7.094	.163	CC = .410
10A	77	243	6	6.917	14	0	6.931		
	4.8	LAGS	DT= .040	-.163=	-.123	6	EARLY		
10A	75	267	4	7.104	-10	0	7.094	.080	CC = .948
10A	74	204	3	15.913	-8899	0	7.014		
	7.1	LAGS	DT= .059	-.080=	-.021	4	LATE		

TABLE 8 (continued)

10A	77	243	6	6.917	14	0	6.931	-.083	CC = .421

10A	74	204	3	15.913	-8899	0	7.014
	-11.2	LAGS	DT= -.093	.083= -.010		6	LATE

TABLE 8 (continued)

Table 9

b values for station LMQ

	Amplitudes		1/10 in 25km		1/10 in 30km		1/10 in 35km	
N. Eqs	LSQ	MLE	LSQ	MLE	LSQ	MLE	LSQ	MLE
213	-1.0	-.72	-.76	-.44	-.82	-.49	-.90	-.53
61	-.99	-.78	-.62	-.44	-.69	-.50	-.78	-.55
152	-.90	-.77	-.97	-.54	-1.0	-.60	-1.0	-.64

A'

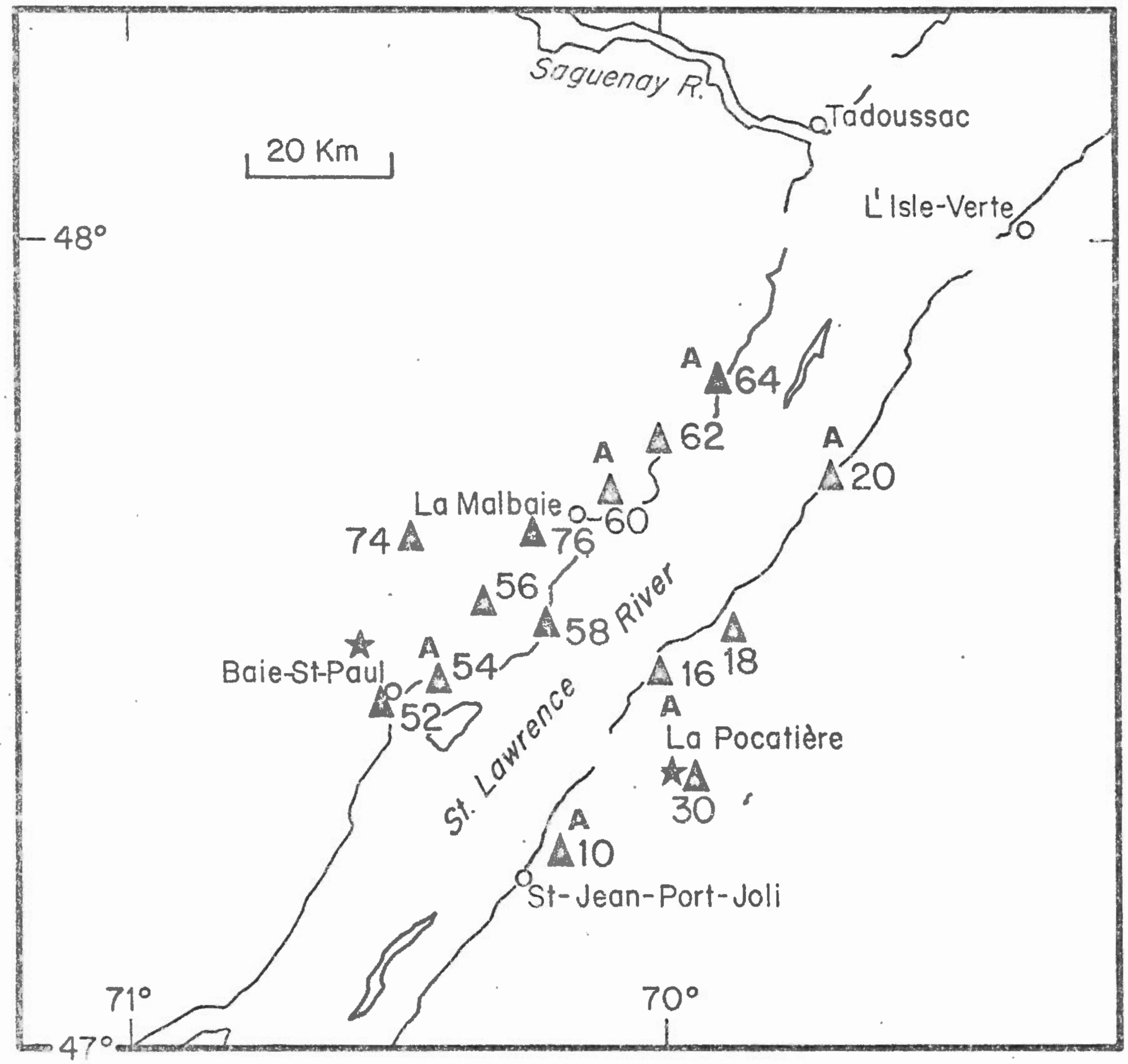
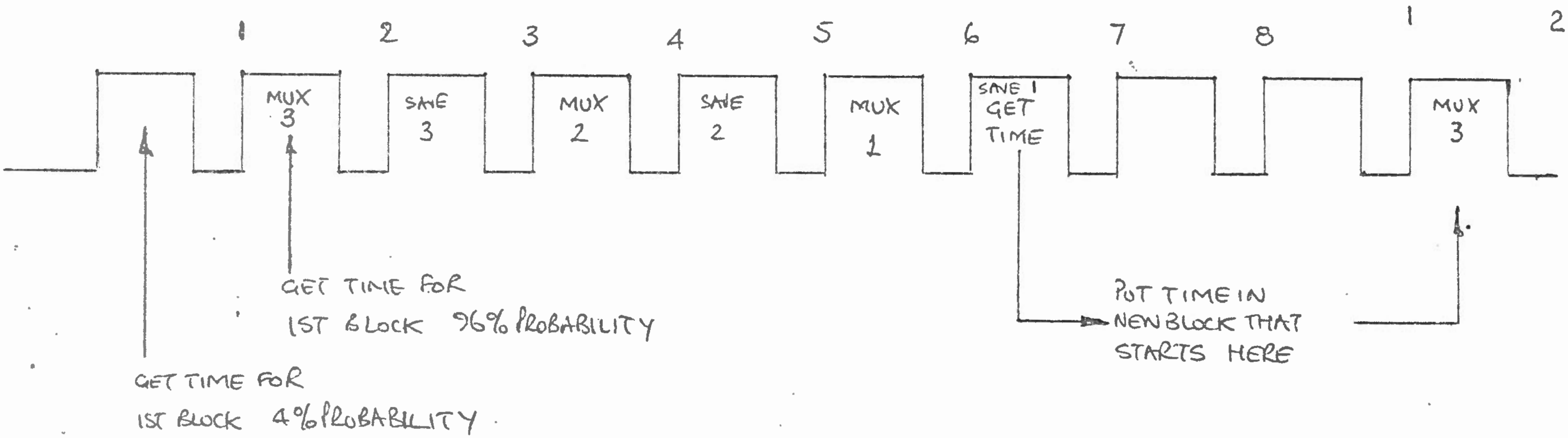

Saguenay R.
Tadoussac
20 Km
48°
L' Isle-Verte
A
64
62
A
A
20
La Malbaie
60
74
76
56
58
St. Lawrence River
A
54
Baie-St-Paul
52
16
18
A
La Pocatière
30
A
10
St-Jean-Port-Joli
71°
70°
47°

Fig-1



		TIME CORRECTION		
CHANNEL	1ST BLOCK (96%)	1ST BLOCK 4%	SUBSEQUENT BLOCKS	TOLERANCE
3	φ/480	1/480	3/480	−φ, +1/60
2	2/480	3/480	5/480	−φ +1/60
1	4/480	5/480	7/480	−φ +1/60

These figures apply to ALL field experiments.

Fig. 2

BAKPAK TIME CORRECTIONS REVISED 26JAN78

DRA

Shot No 6

STN 10

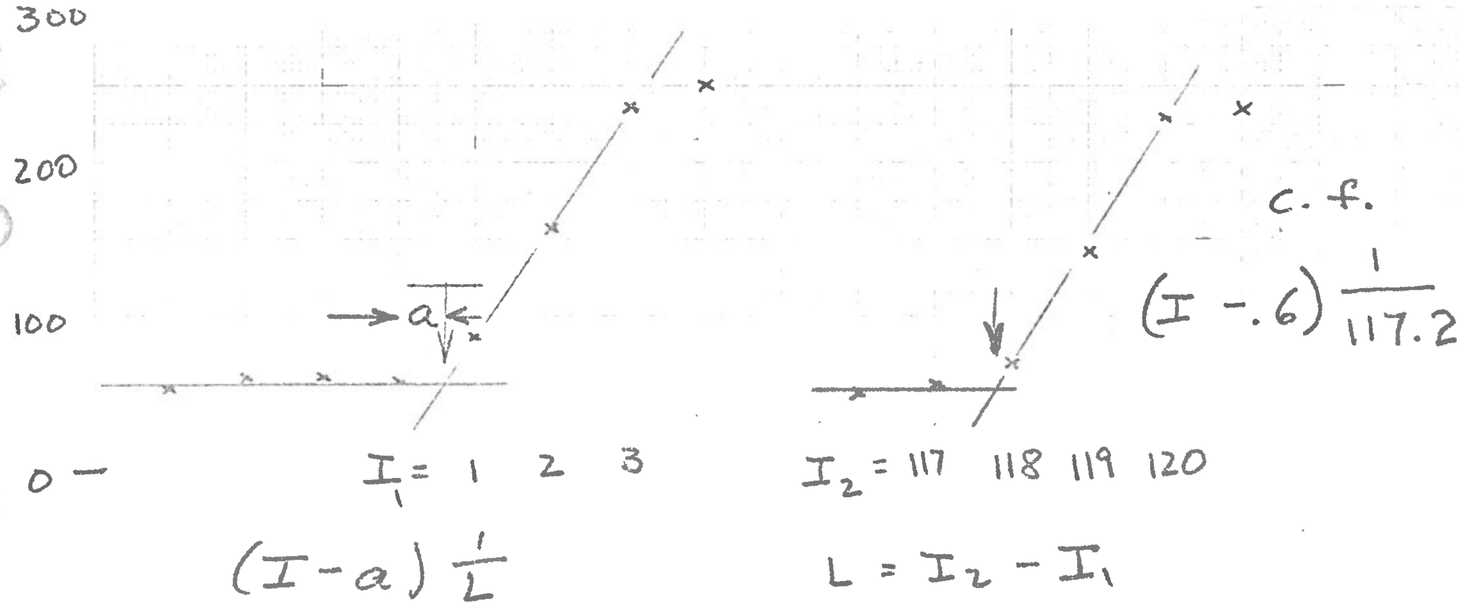
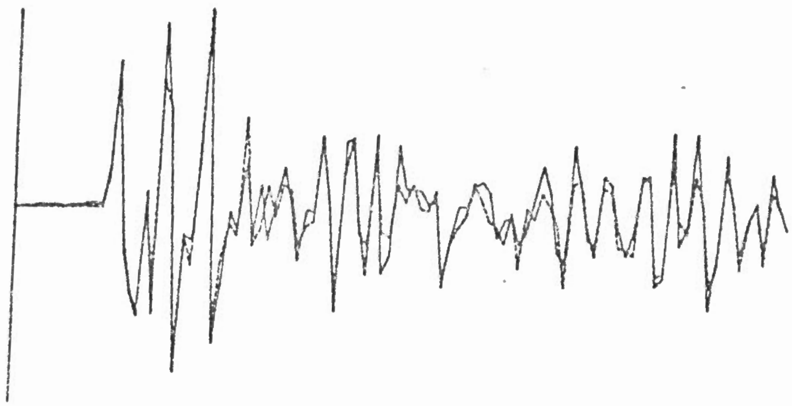


Fig 3

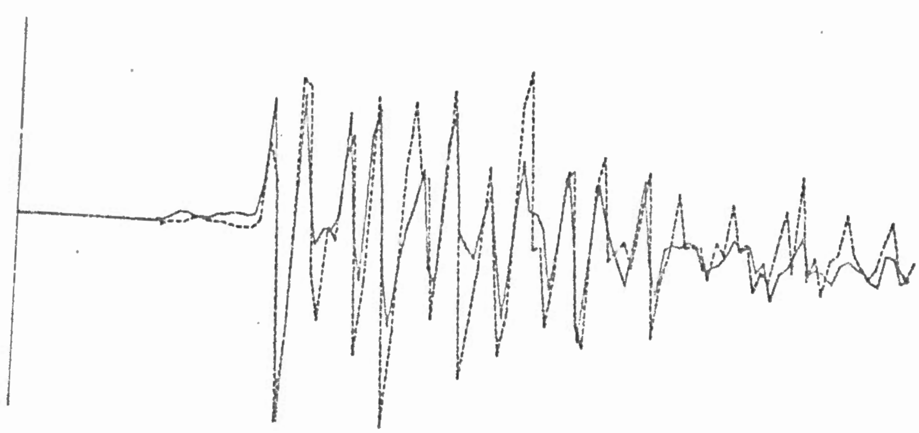


BP74 5 15 DEC 76 20 26 0 2

BP74 6 31 AUG 77 22 30 0 2

LAG = 1.0 CC = .946 DT = .011 6 LATE

Fig. 4a

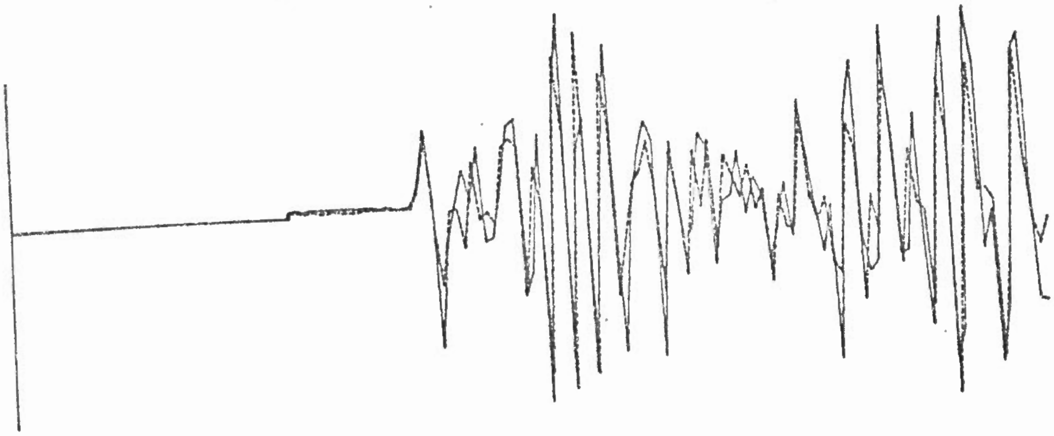


BP60 5 15 DEC 76 20 26 0 6

A 60 4 24 SEP 75 17 53 0 6

LAG = -.6 CC = .841 DT = -.002 5 LATE

Fig. 4b

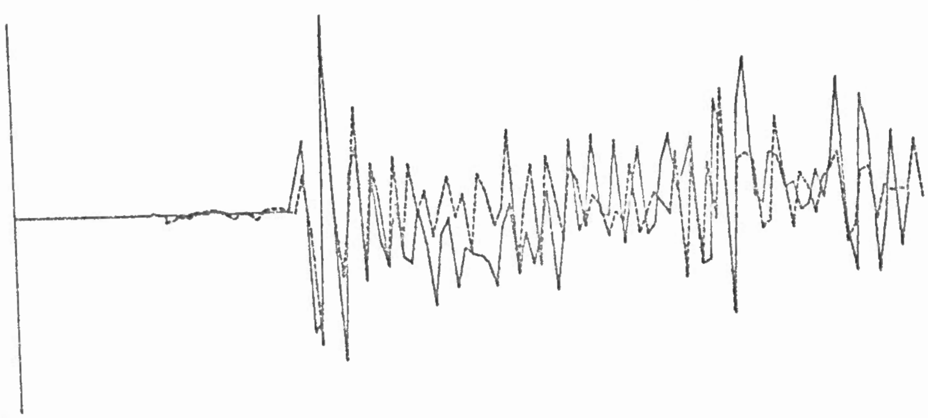


BP56 103 16 DEC 76 17 26 0 5

BP56 104 30 AUG 77 23 30 0 5

LAG = -.2 CC = .808 DT = -.028 104 EARLY

Fig. 4c



BP58 104 30 AUG 77 23 30 0 4

A 58 101 7 OCT 75 15 16 0 4

LAG = -1.9 CC = .581 DT = -.010 104 LATE

Fig. 4d

Cross - Correlations
La Pocatière

STN	101 280 7. Oct. 75	102 302 28. Oct. 76	103 351 16. Dec. 76	104 242 30. Aug. 77	
54	A		BP +10	A +12 +3	+12 +13
56		BP	BP -3	BP -28 -29	-31 -29
58	A	BP +21	BP +8 -13	BP +10 +2 -11	+10 +10 +10 +10
60	A	BP +17	BP +13 -3	A +26 +13 +16	+29 +26 +30 +30
74		BP		BP +5	
0/11	A			A +90	STATN CORR ≈ +73
18	A			BP +2	

Fig. 5

Cross-Correlations

St.-Jerôme Mine

TN	3 204 23.Jul.74	4 267 24.Sept.75	5 350 15.Dec.76	6 243 31.Aug 77		
54	A	A +9	BP +14 +4	A +16 +25 +17	+29 +30 +25 +26	
56			BP	BP +12		
58	A	A +23		BP +31 +7	+31 +30	
60	A	A +21	BP +23 +2	A +49 +28 +26	+49 +49 +49 +49	
74			BP	BP +11		
/11	A	A +21		A -123 +10	-102 +10	STN. CORR -95
18	A	A +21		BP +27 +6	+27 +27	
30	A	A +15		BP +23 +7	+23 +22	

Fig.6

10/3/78

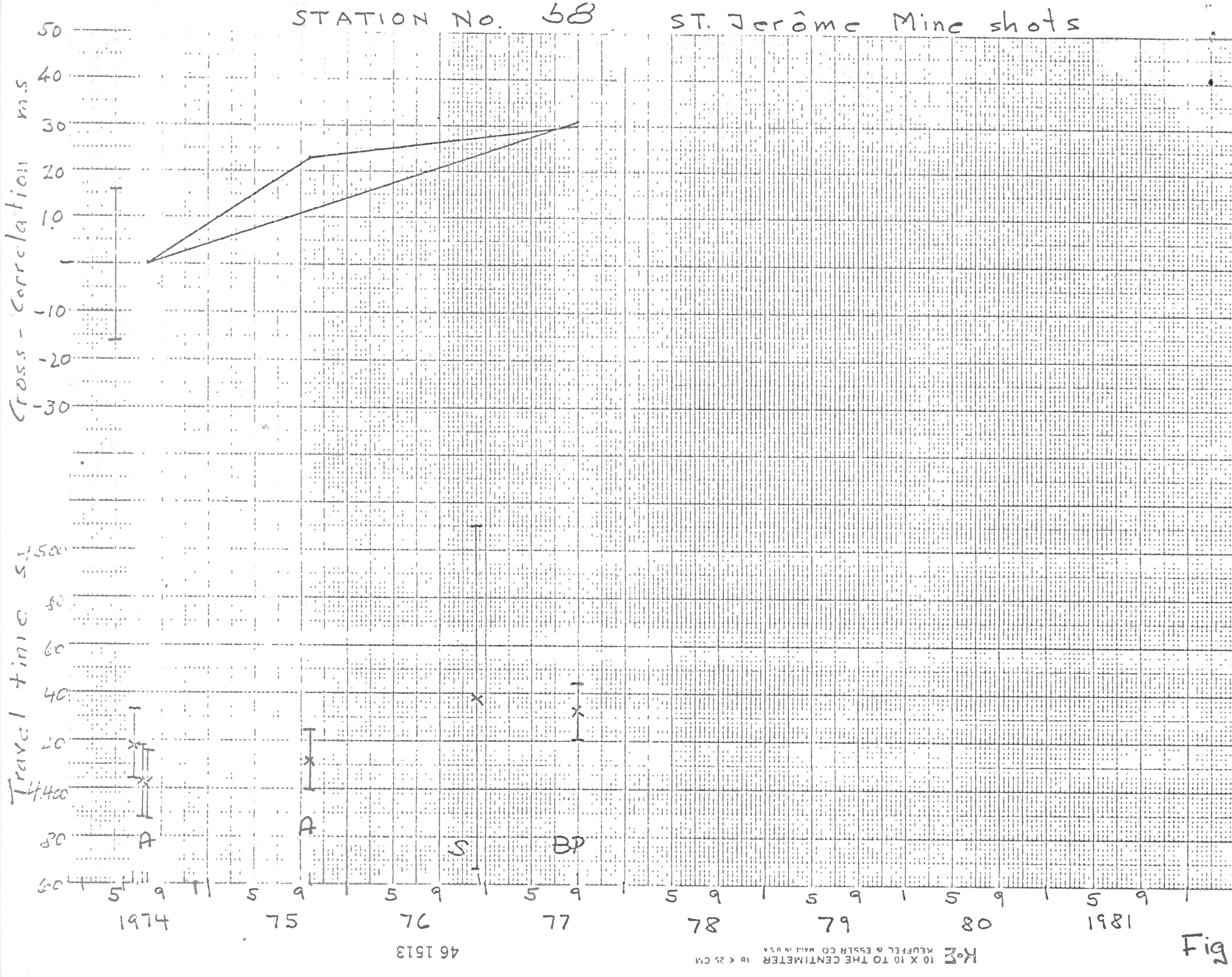

STATION No. 68
ST. Jerôme Mine shots
Cross-Correlation ms
Travel time s
1974
75
76
77
78
79
80
1981
A
A
S
BP
46 1513
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

Fig. 7

STATION No. 60 ST. Jerôme Mine shots

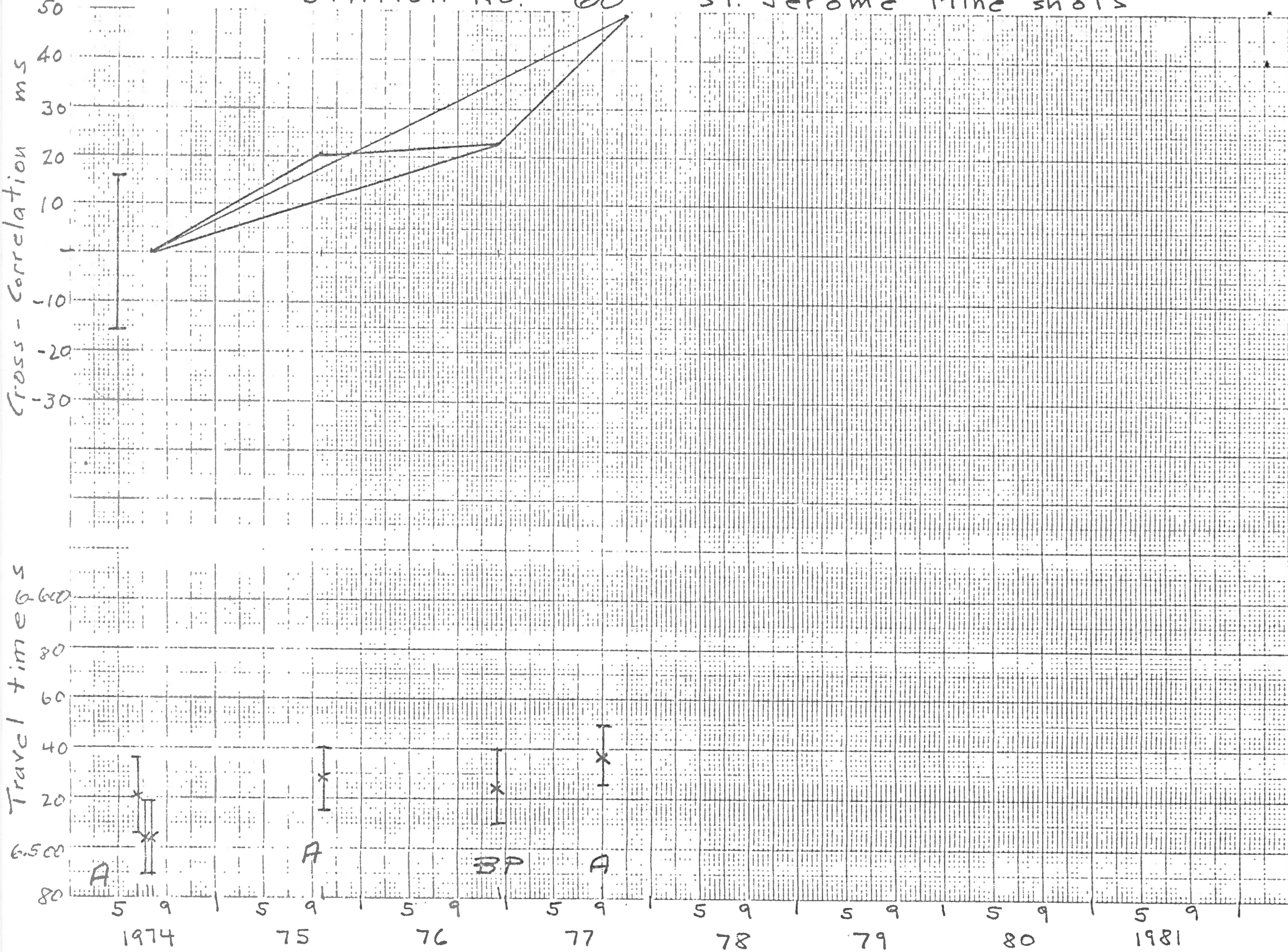
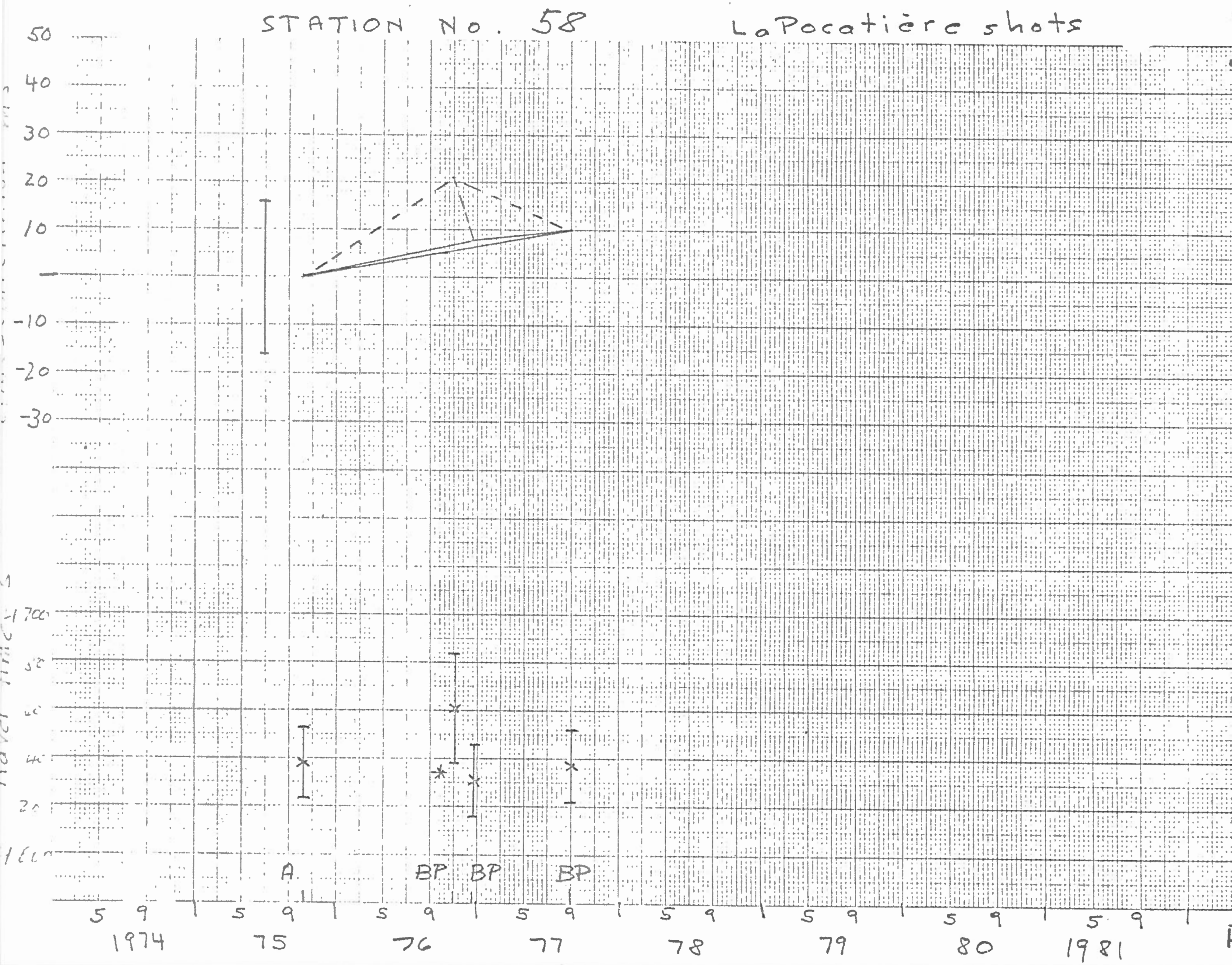


Fig 8


STATION No. 58
LaPocatière shots
50
40
30
20
10
-10
-20
-30
A
BP
BP
BP
5
9
1974
75
76
77
78
79
80
1981
Fig.9

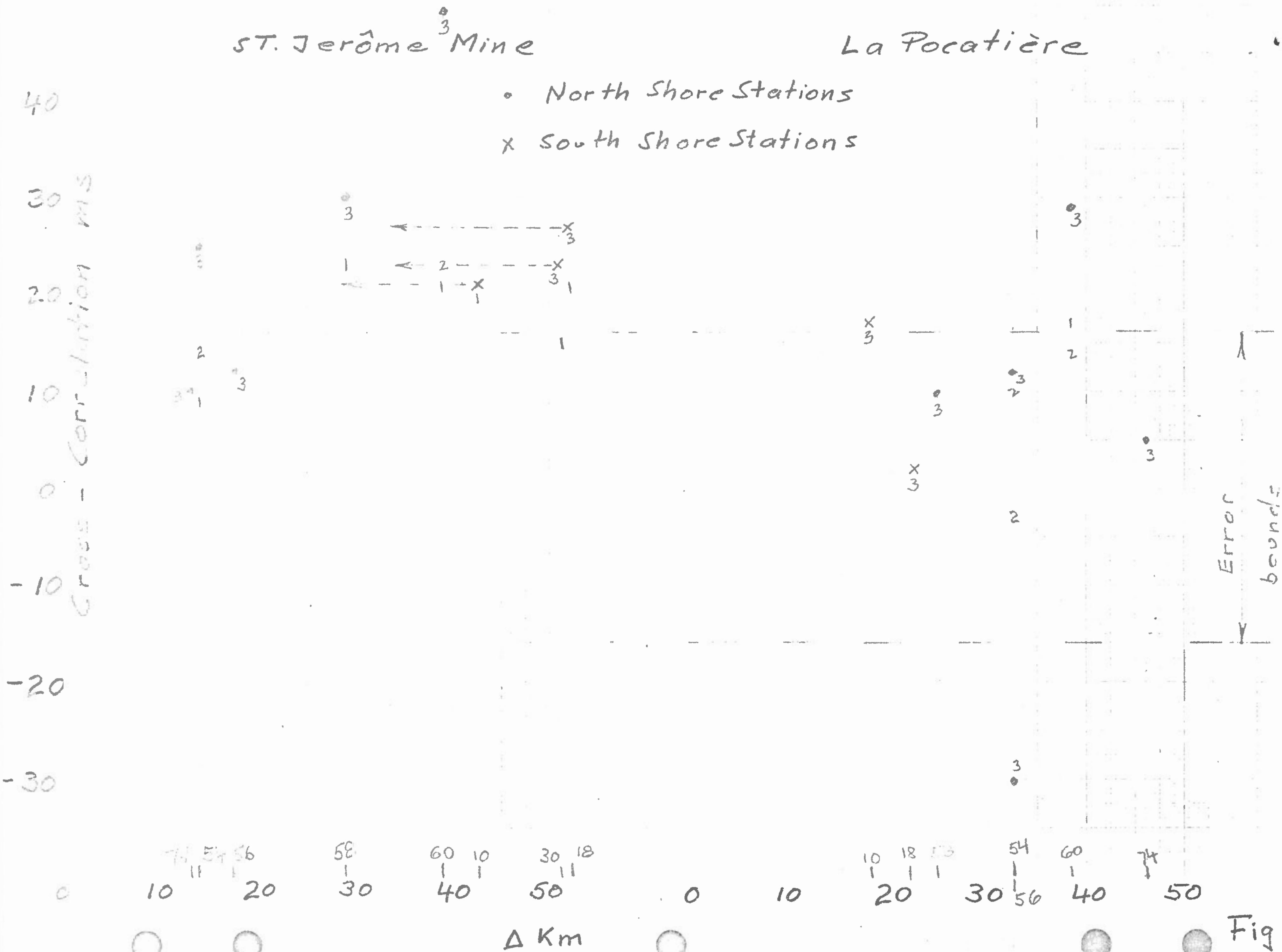
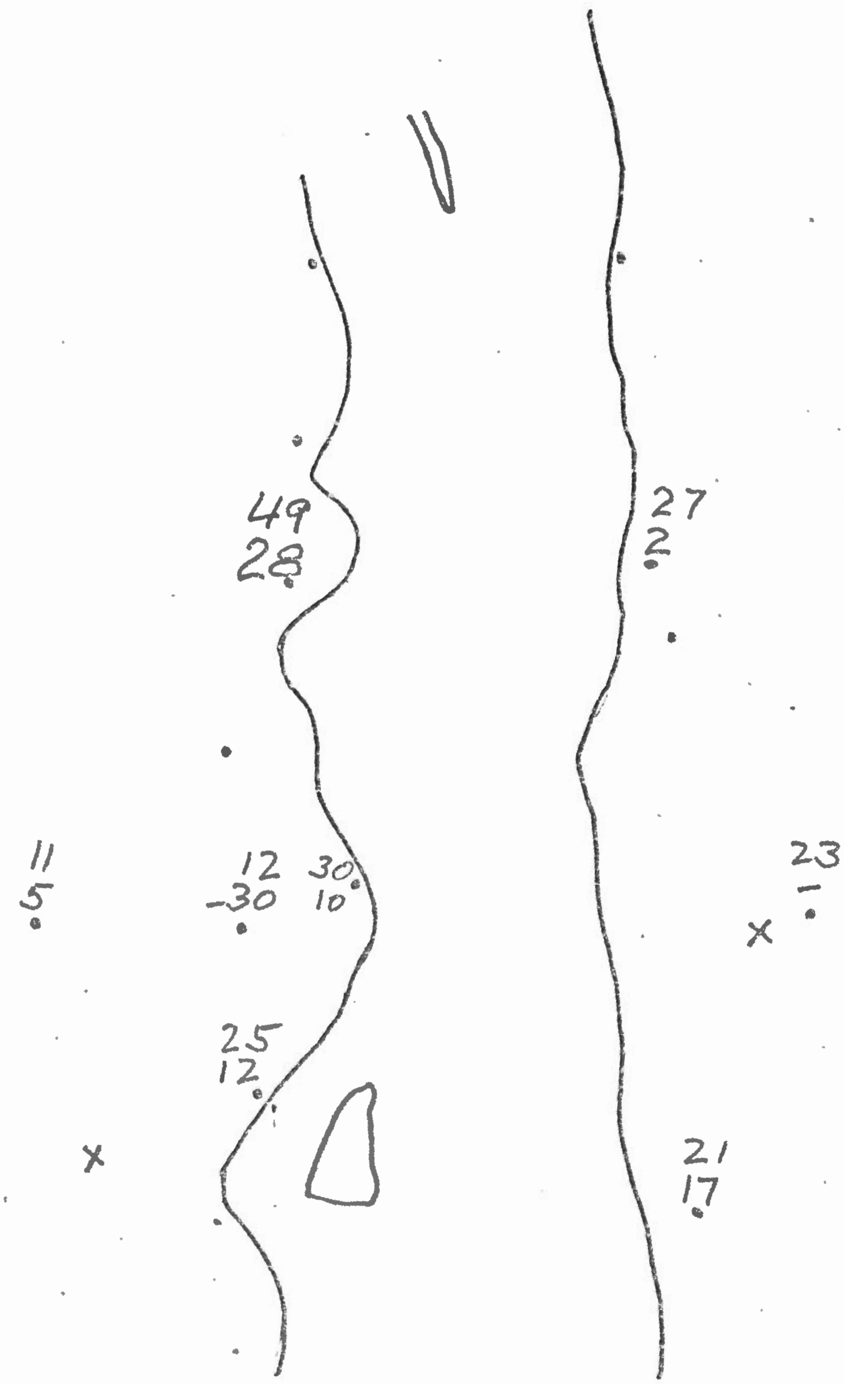

ST. Jerôme Mine
La Pocatière
North Shore Stations
South Shore Stations
Cross - Correlation ms
Error bounds
Δ Km

Fig 10

Cross-Correlation changes in ms

27 ST. Jerôme Mine
2 La Pocatière



Cross - Correlations
La Pocatière

STN	101 280 7. Oct. 75	102 302 28. Oct. 76	103 351 16. Dec. 76	104 242 30. Aug. 77	
54	A		BP +10	A +12 +3 (0)	+12 +13
56		BP	BP -3	BP (-24) -28 -29	-31 -29
58	A	BP +21	BP +8(-7) -13	BP (-1) +10 +2 (+6) -11	+10 +10 +10 +10
60	A	BP +17	BP +13(+4) -3	A (+32) +26 +13 +16 (+28)	+29 +26 +30 +30
74		BP		BP (-1) +5	
10/11	A			A (+78) +90	STATN CORR ≈ +73
18	A			BP +2	

Fig 12

Cross-Correlations

St.-Jerôme Mine

STn	3 204 23.Jul.74	4 267 24.Sept.75	5 350 15.Dec. 76	6 243 31. Aug 77		
54	A	A (+5) +9	BP +14 (+10) (+6) +4	A (+3) +16 (+14) +25 +17 (+9)	+29 +30 +25 +26	
56			BP	BP (+6) +12		
58	A	A (+11) +23		BP (+32) +31 (+21) +7	+31 +30	
60	A	A (+24) +21	BP (+21) +23 +2 (-3)	A (+33) +49 +28 (+9) +26 (+12)	+49 +49 +49 +49	
74			BP	BP (+11) +11		
10/11	A	A (+12) +21		A -123 +10	-102 +10	STN. COR -95
18	A	A +21		BP +27 +6	+27 +27	
30	A	A (+14) +15		BP +23 +7	+23 +22	

Fig. 13

STATION No. 16 ST. Jerôme Mine shots

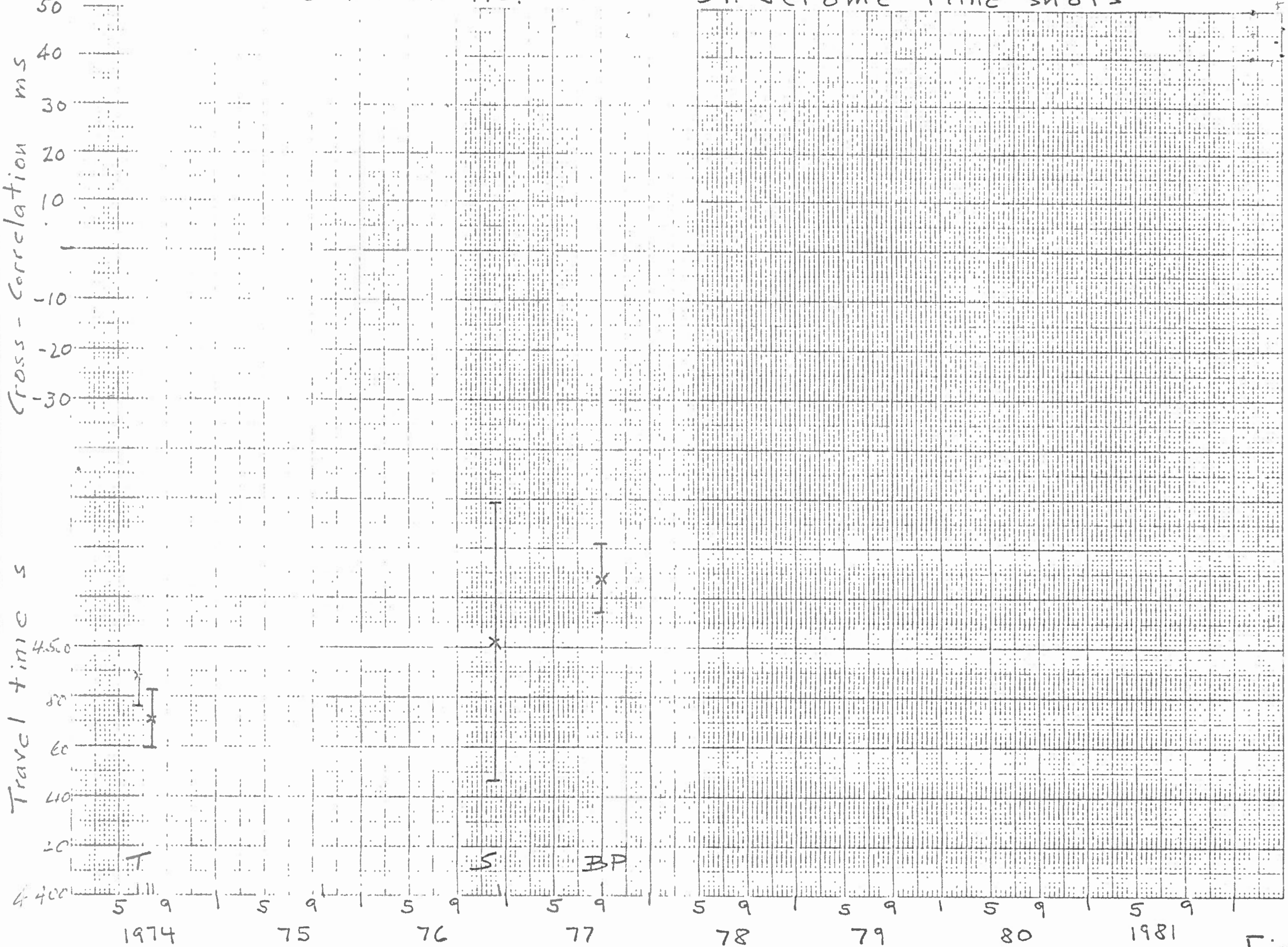


Fig.1

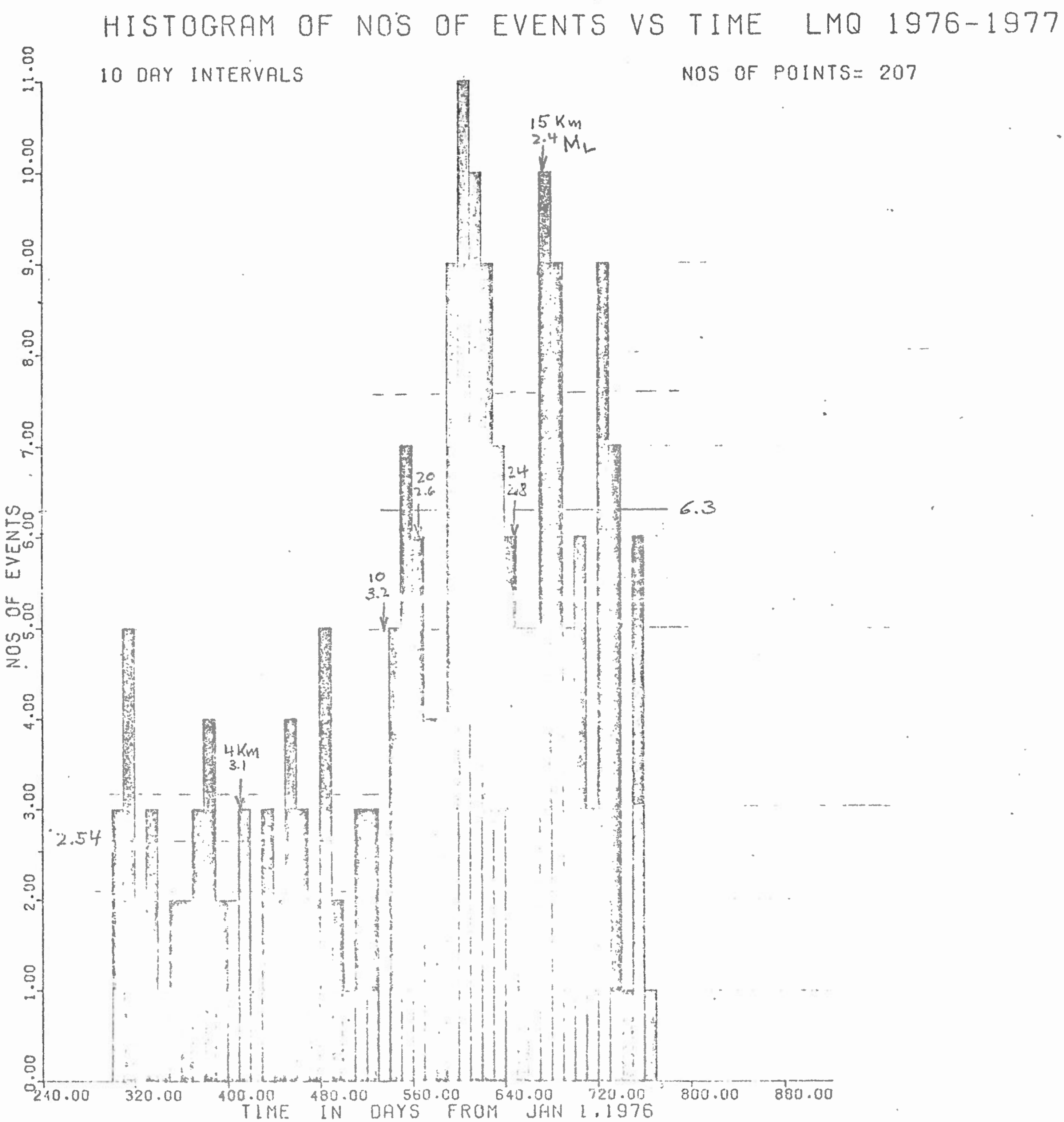

HISTOGRAM OF NOS OF EVENTS VS TIME LMQ 1976-1977
10 DAY INTERVALS
NOS OF POINTS= 207
NOS OF EVENTS
TIME IN DAYS FROM JAN 1,1976
240.00
320.00
400.00
480.00
560.00
640.00
720.00
800.00
880.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
15 Km
2.4 ML
20
2.6
24
2.8
10
3.2
4 Km
3.1
2.54
6.3

Fig.15

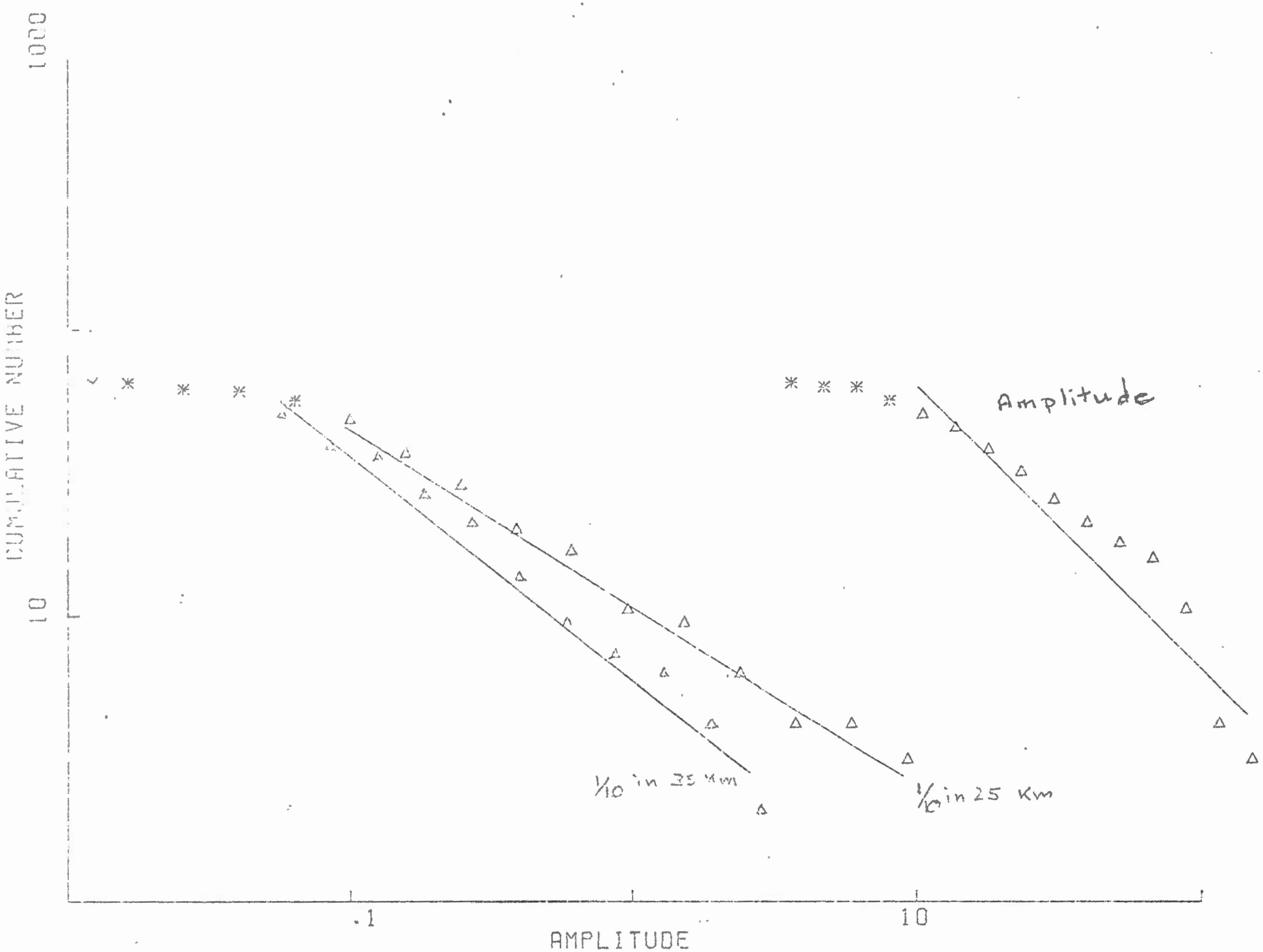

1000
CUMULATIVE NUMBER
10
.1
10
AMPLITUDE
Amplitude
1/10 in 25 Km
1/10 in 25 Km

Fig 16