La Malbaie Spring 1978
Experiments

by

G.G.R. Buchbinder

and

A.J. Wickens

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Summary:

As a continuation of the La Malbaie Experiment a shot was set off at the Experimental Farm at La Pocatière on 30 May 1978. Two further shots were set off on 31 May and 1 June 1978 in the mine of St. Jerôme. The first of these was for the purpose of this experiment. The second shot of only 250 kg was essentially set off to continue a line of travel time and amplitude observations. Since some of the same sites were occupied for both these shots, the second shot was very useful as a check on the quality of our method and validity of errors.

The six element portable array was still operating and in addition six temporary backpack systems were in operation.

Absolute P travel times were determined and the data were also analyzed by cross-correlation with all the data from previous shots. Both methods indicate significant changes in travel time at some stations.

All travel time and cross-correlation data will be presented here again for the following reason. In anticipation of having a delayless shooter box all shooter box delays have been removed so that the travel times are now absolute instead of relative. This, of course, does not change the cross-correlation results in the previous report.

Experiments:

All calibration shots are listed in Table 1. In February 1978, four new holes were drilled on the Experimental Farm in La Pocatière, one of these was used for shot No. 105. The shot point migration with respect to the first hole is of the order of 0 to 2 ms and the appropriate corrections have been applied to the data. Thus all data is referred to the first hole.

Shot No. 7 was set off in the mine in the same place as all previous shots, it was of 750 kg and gave very satisfactory results. Shot No. 8 was set off one day later, it was only 250 kg and was not well recorded on the south shore stations, although still useful for some cross-correlation purposes. It was essentially set off for purposes other than this experiment.

Stations:

The stations that were occupied are shown in Fig. 1. Stations 58 and 18 were not occupied. The array operated at stations 56, 60 and 64 on the north shore and stations 10, 16 and 20 on the south shore for all shots. For shot 7 station 56 was also recorded on the array. For shots 105 and 7 station 30 on the south shore was occupied by a backpack. For these two shots stations 52, 56, 62, 74 and 76 were occupied by packpacks on the north shore. For shot 8 the array was recording and of the calibration stations, station 60 was also occupied by a backpack.

Improvements and Changes:

A number of improvements were undertaken with respect to the previous shots.

a. The digitizing program of the BP systems was changed to start digitizing on a known 1/60 of a second, so that the error is now zero. The sampling rate was increased to 120 hz.

b. The shooter box relay delay was measured in the field by strip chart and oscilloscope.

c. Shots 101-104, 5 and 6 were set off with box No. 1. The delay had been determined to be about 26 ms by Dr. A.J. Mair in 1975. This box was sent to Victoria in early 1978 and was thus not available for the 1978 shots. To ascertain that the above mentioned delay is correct Mr.M. Bone in Victoria remeasured it and found it to be 25 ms. It had been planned to use a new all electronic shooter box for the 1978 shots but it did not arrive in time so our box No. 2 had to be used. The delay was measured to be 35 ± 2 ms. Therefore shots 105, 7 and 8 were corrected for 35 ms, shots 101-104, 5 and 6 for 26 ms. Shots 1 to 4 had been fired essentially by a battery and their shot instant determined by a geophone near the shot point. In the previous report the travel time of these shots had been adjusted by 26 ms to make them look like they had been set off by blasting box No. 1. In this report that adjustment has been removed so that all shots now have the relay delay removed and all travel times are absolute travel times. It is further anticipated that future shots will be fired by a box with a delay of microseconds, so that for our purposes the delay will be zero.

d. At station 60 the seismometer site was moved before the 1977 shots. There is therefore no change in the site for the 1977 and 1978 data. For the older data a correction of -12 ms was applied for the mine shots, and a correction of +6 ms for the La Pocatière shots. These corrections are based on an estimate of the position change. When the site has been surveyed these corrections may have to be modified.

Travel times:

Arrival times and corrected travel times for all shots are given in Table 2. The line containing information on each shot gives the shot No., the day number, the date and origin time. Following this are three spaces for errors concerning the shot time, these are followed by up to three corrections concerning the shot time. The sign of the corrections is such that they will be applied to the arrival time.

The lines giving information on the recording stations contain the following data: Station number, recording instrument type and arrival time, which is followed by three errors concerning the arrival time. This is followed by up to three corrections, finally the travel time and R.M.S. error is given.

For the earlier shots the error with the origin time is a combined error, including all sources.

The errors after the arrival time are the reading error of the phase, the recording instrument error and the clock correction error.

For shots 6 to 8 and 104 and 105 the three errors given after the origin time are the shooter clock error, recording instrument error (since they are equal for all instruments) and the shooter box relay delay error. The errors after the arrival time are the reading error, recording clock error and for the BP the digitizing error.

The corrections following the origin time are the shooter clock and relay delay correction where applicable. The three corrections for arrival time are as follows:

For BP systems the digitizing correction, the clock correction and where applicable followed by a site or source migration correction. For array sites the array clock correction and where applicable site or source migration corrections are given. The earlier shots were also recorded by S-systems, where the clock correction is given, and in a few cases also a correction for the time signal if it was WWVB.

Graphic displays will be shown later.

Cross-correlations:

The cross-correlation results for the three recent shots are given in Table 3. Each station was cross-correlated with the record from the preceeding shot. The results for all possible cross-correlations for all shots are given in Table 4. The Tables are self explanatory. The cross-correlation method had been explained in detail in the last report (78-4).

The change in cross-correlation for each station always referred to the earliest shot are shown in Tables 5 and 6. The same data will be displayed graphically later on.

The Table 3 serves also to illustrate an important point regarding the repeatability of the shots and timing with its errors.

In Table 7 are listed stations at which shots 7 and 8 were both recorded, or were two instruments operated for the same shot. At station 60 shot 7 was recorded with the array and shot 8 with the array and BP. The difference in cross-correlating is essentially zero. This may be an indication that the shots are reasonably well timed and that the array and BP have similar instrumental phase delay. At station 54 shot 8 is 10 ms late with respect to shot 7. This is well within the experimental error. One has the choice of either accepting this as a reasonable result or to search for some explanation. In the latter case it may be explained by the rather near distance of 13.8 km and the difference in shot size.

For station 56 the two shots were recorded by the array and show a difference of 6 ms, the shot 7 was also recorded by an array station and a BP and shows a difference of 8 ms. Again this is well within the estimated error.

For stations 64, 10 and 16 that are either at large distance or on the south shore, shot No. 8 is late by between 9 to 12 ms. This is still within the estimated errors but in contrast to the other stations in the Table the cross-correlation functions are lower, under 0.8.

Discussion of the Data:

As an aid in the discussion of the cross-correlation data a number of Figures have been prepared. In Figure 2 the data for the St. Jerôme mine shots are shown. For each station the diagram is as follows. The thin horizontal line is a base line, indicating no change in cross-correlation. All cross-correlations are done with respect to the chronologically earliest shot, which is indicated by a dot. A vertical line above the base line indicates the arrival was late with respect to the origin and a line below means the arrival was early with respect to the origin. For example for station 54 the origin is in 1974 and for the four following years there are increases in travel time. (A scale of 20 ms is given between stations 58 and 60 in the Figure). A time scale of 500 days is given at the top.

For stations 54 and 60 the lag increases and reaches a maximum in 1977. For 1978 a decrease from the maximum is observed. These changes are larger than the estimated errors and significant. Station 30 has one fewer data point but otherwise shows the same increase to 1977 and drop in 1978. For stations 18 and 58 no data was obtained in 1978 so that only the increase to 1977 can be seen. For station 74 a maximum is also seen in 1977 and the decrease from it to the advance in 1978 is 20 ms and therefore still above the level of significance; station 56 shows the same pattern but below the level of significance. For stations 20 and 10 there is only one data point each, both show a decrease from 1977 to 1978, but only for station 20 is it larger than the error. The last station, 64, shows changes that do not correspond to the pattern of station 54, but their magnitude is also smaller than the estimated error.

In summary seven stations display the same pattern with changes larger than the estimated error. Each shows a maximum in 1977 and a decrease in 1978. Stations 56 and 10 show the same pattern but below the level of significance. Station 64 shows no change of significance.

Figure 3 shows the changes in cross-correlation from the La Pocatière shots. The experiment at this shot point started only in 1975, on the other hand there were 2 shots in 1976. Station 60 shows the same pattern as for the St. Jerôme Mine shots : a maximum in 1977 and a decrease in 1978. The changes are significant. The same can be seen at station 54 but the magnitude is only 14 ms. Stations 56 and 58 also show significant changes. At station 58 the maximum occurs, however, one year earlier than for stations 60 and 54. At station 56 the data only start in 1976, but decreases are seen for 1977 and 1978. Of the remaining stations only 20 shows a significant change, a decrease, from 1977 to 1978.

Figure 4 is shown to demonstrate the similarity of changes at stations 54 and 60 from the two shot points. In the Figure the solid vertical bars are the changes in cross-correlation lag for the St. Jerôme Mine shots, the open bars are those for the La Pocatière shots.

The base lines for the latter have been raised to coincide with the change from the mine shots in 1975. Now it is evident that for both stations the changes from 1975 to 1978 parallel closely.

Interpretation:

The changes in travel time obtained by cross-correlating wave forms are not equal at all stations for a shot point. It can therefore, be concluded that the changes are not source related. Since stations 54 and 60 exhibit significant changes of equal magnitude in travel time as seen from the two shot points this may be used to argue that the changes are induced near the stations. The stations show the same pattern of change, with a maximum in 1977, but of different amplitude. These stations are separated by 35 km with station 58 nearly equally distanced between them also showing a maximum in 1977 but lacking observations in 1976 and 1978. Station 56, about 9 km WNW from station 58 as seen from La Pocatière shows a decrease from at least 1976 on. That is at least one year earlier than at stations 54 and 60.

The temporal variation of the peak in the cross-correlation changes can be explained in at least two ways, either the effects are independent of one another or the peak occurred at least in 1976 at station 56 and migrated away towards the SW and NE to reach stations 54 and 60 in 1978. More observations will tell us more about the temporal variation in travel times.

The data as presented in Fig. 4 show an anomaly in travel time with a period of at least 1500 days. Because of the historical occurrence of earthquakes makes it very probable that another large event will eventually occur it is imperative that the data of this report be considered critically and that the experiment be continued.

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
105	30 May 78 (150)	21:30:00.000 UT	1000

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 77 (242)	22:30:00.000 UT	2000
7	31 May 78 (151)	21:30:00.000 UT	1500
8	1 Jun 78 (152)	21:30:00.000 UT	500

TABLE 2

TRAVEL TIMES FOR LA MALBAIE AREA SHOTS

SHOT	DAY	DATE	ORIGIN TIME	ERRORS		CORRECTIONS ALL IN MS			
1	170	19. 6.1974	12 8 9.305	8	0	0	0	0	0

ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL TIME	+/- ERRORS
52	T	11.460	7	5	0	0	0	0	2.155	.012
54	A	11.713	10	5	5	0	0	0	2.408	.015
56	S	12.150	23	5	0	112	0	0	2.957	.025
58	A	13.697	10	5	5	0	0	0	4.392	.015
60	A	15.812	10	5	5	0	-12	0	6.495	.015
62	S	17.137	24	5	0	-51	0	0	7.781	.026
64	T	19.212	7	5	0	0	0	0	9.907	.012
74	S	11.597	32	5	0	-60	0	0	2.232	.033
76	T	13.767	7	5	0	0	0	0	4.462	.012
16	S	16.302	128	5	0	184	4	0	7.185	.128
20	T	20.664	49	5	0	0	0	0	11.359	.050

SHOT	DAY	DATE	ORIGIN TIME	ERRORS		CORRECTIONS ALL IN MS			
2	194	13. 7.1974	12 11 6.752	8	0	0	0	0	0

ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL TIME	+/- ERRORS
52	T	8.890	7	5	0	0	0	0	2.138	.012
54	A	9.140	10	5	5	0	0	0	2.388	.015
58	A	11.129	10	5	5	0	0	0	4.377	.015
60	A	13.242	10	5	5	0	-12	0	6.478	.015
62	S	14.522	48	5	0	28	0	0	7.798	.049
74	S	8.826	18	5	0	54	0	0	2.128	.020

SHOT	DAY	DATE	ORIGIN TIME	ERRORS		CORRECTIONS ALL IN MS			
3	204	23. 7.1974	12 26 8.925	8	0	0	0	0	0

ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL TIME	+/- ERRORS
52	T	11.081	7	5	0	0	0	0	2.156	.012
54	A	11.328	8	5	5	0	0	0	2.403	.013
58	A	13.300	10	5	5	0	0	0	4.375	.015
60	A	15.415	10	5	5	0	-12	0	6.478	.015
74	S	11.003	33	5	0	16	0	0	2.094	.034
76	T	13.370	7	5	0	0	0	0	4.445	.012
10	A	16.195	10	5	0	0	0	0	7.270	.014
30	A	17.909	10	5	0	0	0	0	8.984	.014
16	S	15.672	28	5	0	431	8	0	7.186	.030
18	A	17.832	10	5	0	0	0	0	8.907	.014
20	T	20.326	30	5	0	0	0	0	11.401	.031

SHOT	DAY	DATE	ORIGIN TIME	ERRORS		CORRECTIONS ALL IN MS			
4	267	24. 9.1975	17 53 .036	8	0	0	0	0	0

ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL TIME	+/- ERRORS
52	S	2.295	140	5	0	23	0	0	2.282	.140
54	A	2.444	4	5	5	0	0	0	2.408	.011
56	S	3.042	31	5	0	-73	0	0	2.933	.032
58	A	4.422	8	5	5	0	0	0	4.386	.013
60	A	6.550	8	5	5	0	-12	0	6.502	.013
62	S	7.931	43	5	0	-73	0	0	7.822	.044
10	A	7.318	5	5	5	0	0	0	7.282	.012
30	A	9.034	10	5	5	0	0	0	8.998	.015
16	S	7.453	42	5	0	-226	8	0	7.199	.043
18	A	8.940	7	5	5	0	0	0	8.904	.013
20	S	11.356	46	5	0	49	8	0	11.377	.047

SHOT	DAY	DATE	ORIGIN TIME	ERRORS		CORRECTIONS ALL IN MS			
5	350	15.12.1976	20 25 59.989	8	0	0	0	-26	0

ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL TIME	+/- ERRORS
52	S	2.159	110	5	0	-8	5	0	2.141	.110
54	BP	2.422	6	5	5	22	-15	0	2.414	.012
56	BP	2.963	4	5	5	22	3	0	2.973	.011
58	S	4.514	72	5	0	-87	0	0	4.412	.073
60	S	6.713	36	5	0	-141	-12	0	6.545	.037
60	BP	6.517	10	5	5	22	-13	-12	6.499	.015
74	BP	2.160	6	5	5	22	-4	0	2.163	.012
76	S	4.561	56	5	0	-70	0	0	4.476	.057

(Table 2 cont'd)

8	S	2.366	12	5	0	-89	0	0	2.262	.015
10	S	7.292	97	5	0	-19	7	0	7.265	.097

SHOT	DAY	DATE	ORIGIN TIME		ERRORS		CORRECTIONS ALL IN MS			
6	243	31. 8.1977	20 30	0.000	2	5	5	4	-26	0

ST	INST	ARR.TIME	ERRORS			CORRECTIONS			TRAVEL TIME	+/- ERRORS
18	BP	8.925	10	2	4	22	-7	0	8.918	.013
58	BP	4.413	4	2	4	22	-6	0	4.407	.009
74	BP	2.177	6	2	4	22	-3	0	2.174	.010
76	BP	4.508	8	2	4	22	-6	0	4.502	.012
56	BP	2.980	4	2	4	22	-2	0	2.978	.009
30	BP	9.032	15	2	4	22	-4	0	9.028	.017
52	S	2.188	3	10	0	-58	0	0	2.108	.013
60	A	6.535	6	4	0	10	0	0	6.523	.010
54	A	2.429	4	4	0	10	0	0	2.417	.009
64	A	9.699	4	4	0	10	0	0	9.687	.009
21	A	11.364	8	4	0	10	0	0	11.352	.012
11	A	7.294	8	4	0	10	0	0	7.282	.012

SHOT	DAY	DATE	ORIGIN TIME		ERRORS		CORRECTIONS ALL IN MS			
7	151	31. 5.1978	21 30	0.000	2	5	2	5	-35	0

ST	INST	ARR.TIME	ERRORS			CORRECTIONS			TRAVEL TIME	+/- ERRORS
60	A	6.508	4	2	0	11	0	0	6.489	.007
54	A	2.432	4	2	0	11	0	0	2.413	.007
64	A	9.706	4	2	0	11	0	0	9.687	.007
56	A	2.985	4	2	0	11	0	0	2.966	.007
16	A	7.230	6	2	0	11	0	0	7.211	.009
10	A	7.288	8	2	0	11	0	0	7.269	.010
74	BP	2.183	4	2	0	2	-6	0	2.149	.007
52	BP	2.180	4	2	0	2	-9	0	2.143	.007
56	BP	3.017	4	2	0	2	-9	0	2.980	.007
30	BP	9.047	16	2	0	2	-26	0	8.993	.017

SHOT	DAY	DATE	ORIGIN TIME		ERRORS		CORRECTIONS ALL IN MS			
8	152	1. 6.1978	21 30	0.000	2	5	2	4	-35	0

ST	INST	ARR.TIME	ERRORS			CORRECTIONS			TRAVEL TIME	+/- ERRORS
54	A	2.417	4	2	0	34	0	0	2.420	.007
60	A	6.491	4	2	0	34	0	0	6.494	.007
60	BP	6.538	4	2	0	2	-6	0	6.503	.007

SHOT	DAY	DATE	ORIGIN TIME		ERRORS		CORRECTIONS ALL IN MS			
101	280	7.10.1975	15 16	0.000	8	0	0	0	-26	0

ST	INST	ARR.TIME	ERRORS			CORRECTIONS			TRAVEL TIME	+/- ERRORS
56	S	5.878	44	5	0	-33	0	0	5.819	.045
58	A	4.638	8	5	5	0	0	0	4.612	.013
60	A	6.847	8	5	5	0	6	0	6.827	.013
10	A	3.492	10	5	5	0	0	0	3.466	.015
30	A	1.254	4	5	5	0	0	0	1.228	.011
16	S	2.863	18	5	0	-126	0	0	2.711	.020
18	A	4.158	10	5	5	0	0	0	4.132	.015
20	S	8.703	14	5	0	-93	0	0	8.584	.017

SHOT	DAY	DATE	ORIGIN TIME		ERRORS		CORRECTIONS ALL IN MS			
102	302	28.10.1976	16 26	0.000	8	0	0	0	-26	0

ST	INST	ARR.TIME	ERRORS			CORRECTIONS			TRAVEL TIME	+/- ERRORS
56	BP	5.950	20	5	5	22	-19	0	5.927	.023
58	BP	4.667	8	5	5	22	-28	0	4.635	.013
60	BP	7.044	30	5	5	22	-3	6	7.043	.032
74	BP	8.008	8	5	5	22	0	0	8.004	.013
8	S	6.498	197	5	0	24	0	0	6.496	.197
10	S	3.564	32	5	0	96	0	0	3.634	.033
16	S	2.658	27	5	0	45	0	0	2.677	.029

SHOT	DAY	DATE	ORIGIN TIME		ERRORS		CORRECTIONS ALL IN MS			
103	351	16.12.1976	17 26	0.000	8	0	0	0	-26	0

ST	INST	ARR.TIME	ERRORS			CORRECTIONS			TRAVEL TIME	+/- ERRORS
52	S	6.983	22	5	0	12	0	0	6.969	.024
54	BP	5.875	8	5	5	22	-10	0	5.861	.013
56	BP	5.892	8	5	5	22	-22	0	5.866	.013
58	S	4.551	76	5	0	117	-8	0	4.634	.077
58	BP	4.600	8	5	5	22	9	0	4.605	.013
60	S	6.969	88	5	0	-100	-8	6	6.841	.089

(Table 2 cont'd)

60	BP	6.833	8	5	5	22	-4	6	6.831	.013	
76	S	6.695	14	5	0	-70	-8	0	6.591	.017	
8	S	6.635	36	5	0	-59	0	0	6.550	.037	
10	S	3.436	50	5	0	19	0	0	3.429	.051	
16	BP	2.683	4	5	5	22	-4	0	2.675	.011	
SHOT	DAY	DATE		ORIGIN TIME			ERRORS		CORRECTIONS ALL IN MS		
104	242	30. 8.1977		23 30	0.000		2	5	5	5 -26	0
ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL	TIME +/- ERRORS	
62	BP	7.742	8	2	4	22	-6	0	7.737	.012	
56	BP	5.842	8	2	4	22	-1	0	5.842	.012	
76	BP	6.567	8	2	4	22	-6	0	6.562	.012	
74	BP	8.008	8	2	4	22	-6	0	8.003	.012	
58	BP	4.617	8	2	4	22	-7	0	4.611	.012	
18	BP	4.027	6	2	4	22	-4	0	4.024	.010	
52	S	6.997	3	20	0	-42	0	0	6.934	.022	
60	A	6.871	8	4	0	3	0	0	6.853	.012	
64	A	9.206	4	4	0	3	0	0	9.188	.009	
20	A	8.375	12	4	0	3	0	0	8.357	.015	
10	A	3.562	26	4	0	3	0	0	3.544	.027	
54	A	5.879	10	4	0	3	0	0	5.861	.013	
SHOT	DAY	DATE		ORIGIN TIME			ERRORS		CORRECTIONS ALL IN MS		
105	150	30. 6.1978		21 30	0.000		2	5	2	7 -35	0
ST	INST	ARR.TIME	ERRORS		CORRECTIONS				TRAVEL	TIME +/- ERRORS	
16	A	2.713	4	2	0	1	0	2	2.688	.007	
11	A	3.582	4	2	0	1	0	2	3.557	.007	
21	A	8.369	4	2	0	1	0	2	8.344	.007	
54	A	5.913	4	2	0	1	0	0	5.886	.007	
60	A	6.855	6	2	0	1	0	2	6.830	.009	
56	BP	5.878	4	2	0	2	-12	0	5.840	.007	
76	BP	6.592	4	2	0	2	-13	1	6.554	.007	
52	BP	6.980	4	2	0	2	-13	-1	6.940	.007	
30	BP	1.258	4	2	0	2	-15	1	1.218	.007	

Table 3

ST	YR	DAY	SHOT	START TIME	CORRECTIONS CLOCKS	CORRECTIONS BP	CORRECT TIME	A-B	CROSS-CORR. COEFF.
74BP	77	243	6	2.000	-25	22	-.003	.031	CC = .936
74BP	78	151	7	2.000	-36	2	1.966		
	.6	LAGS	DT=	.010 -.031= -.021		7	EARLY		
56BP	77	243	6	2.716	-24	22	2.714	.026	CC = .853
56BP	78	151	7	2.725	-39	2	2.688		
	.6	LAGS	DT=	.010 -.026= -.016		7	EARLY		
56BP	77	243	6	2.716	-24	22	2.714	-.011	CC = .537
56A	78	151	7	2.744	-19	0	2.725		
	-1.9	LAGS	DT=	-.032 .011= -.021		7	EARLY		
56BP	78	151	7	2.725	-39	2	2.688	-.037	CC = .648
56A	78	151	7	2.744	-19	0	2.725		
	-5.4	LAGS	DT=	-.045 .037= -.008		7	LATE		
30BP	77	243	6	8.766	-26	22	8.762	.041	CC = .852
30BP	78	151	7	8.775	-56	2	8.721		
	1.1	LAGS	DT=	.019 -.041= -.022		7	EARLY		
60BP	78	152	8	6.350	-37	2	6.315	-.011	CC = .878
60A	77	243	6	6.338	-12	0	6.326		
	2.4	LAGS	DT=	.020 .011= .031		8	EARLY		
60BP	78	152	8	6.350	-37	2	6.315	.037	CC = .864
60A	78	151	7	6.297	-19	0	6.278		
	4.4	LAGS	DT=	.037 -.037= -.000		8	LATE		
60BP	78	152	8	6.350	-37	2	6.315	.039	CC = .869
60A	78	152	8	6.273	3	0	6.276		
	4.5	LAGS	DT=	.038 -.039= -.001		8	LATE		
60A	77	243	6	6.338	-12	0	6.326	.048	CC = .806
60A	78	151	7	6.297	-19	0	6.278		
	2.0	LAGS	DT=	.016 -.048= -.032		7	EARLY		
60A	77	243	6	6.338	-12	0	6.326	.050	CC = .786
60A	78	152	8	6.273	3	0	6.276		
	2.1	LAGS	DT=	.017 -.050= -.033		8	EARLY		
60A	78	151	7	6.297	-19	0	6.278	.002	CC = .947
60A	78	152	8	6.273	3	0	6.276		
	.1	LAGS	DT=	.001 -.002= -.001		8	EARLY		
64A	77	243	6	9.597	-12	0	9.585	.013	CC = .876
64A	78	151	7	9.591	-19	0	9.572		
	-.1	LAGS	DT=	-.000 -.013= -.013		7	EARLY		

64A	77	243	6	9.597	-12	0	9.585	.002	CC = .684
64A	78	152	8	9.580	3	0	9.583		
	-.3	LAGS	DT= -.002	-.002=	-.004	8	EARLY		
64A	78	151	7	9.591	-19	0	9.572	-.011	CC = .745
64A	78	152	8	9.580	3	0	9.583		
	-.2	LAGS	DT= -.002	.011=	.009	8	LATE		
54A	77	243	6	2.131	-12	0	2.119	.007	CC = .934
54A	78	151	7	2.131	-19	0	2.112		
	-.6	LAGS	DT= -.005	-.007=	-.012	7	EARLY		
54A	77	243	6	2.131	-12	0	2.119	-.010	CC = .893
54A	78	152	8	2.126	3	0	2.129		
	-1.4	LAGS	DT= -.012	.010=	-.002	8	EARLY		
54A	78	151	7	2.131	-19	0	2.112	-.017	CC = .922
54A	78	152	8	2.126	3	0	2.129		
	-.9	LAGS	DT= -.007	.017=	.010	8	LATE		
20A	77	243	6	11.261	-12	0	11.249	.013	CC = .732
20A	78	151	7	11.256	-20	0	11.236		
	-.8	LAGS	DT= -.006	-.013=	-.019	7	EARLY		
10A	77	243	6	6.917	-12	0	6.905	.005	CC = .788
10A	78	151	7	6.919	-19	0	6.900		
	-1.1	LAGS	DT= -.009	-.005=	-.014	7	EARLY		
10A	77	243	6	6.917	-12	0	6.905	-.013	CC = .679
10A	78	152	8	6.915	3	0	6.918		
	-2.1	LAGS	DT= -.017	.013=	-.004	8	EARLY		
10A	78	151	7	6.919	-19	0	6.900	-.018	CC = .658
10A	78	152	8	6.915	3	0	6.918		
	-1.0	LAGS	DT= -.008	.018=	.010	8	LATE		
16A	78	151	7	7.166	-19	0	7.147	-.014	CC = .780
16A	78	152	8	7.158	3	0	7.161		
	-.3	LAGS	DT= -.002	.014=	.012	8	LATE		

Table 3 cont'd

ST	YR	DAY	SHOT	START TIME	CORRECTIONS CLOCKS	BP	CORRECT TIME	A-B	CROSS-CORR. COEFF.
16BP	76	351	103	2.500	-30	22	2.492	-.008	CC = .716
16A	78	150	105	2.525	-25	0	2.500		
	-.1	LAGS	DT=	-.002 .008=	.006	105	LATE		
76BP	77	242	104	6.350	-27	22	6.345	.032	CC = .924
76BP	78	150	105	6.350	-39	2	6.313		
	1.4	LAGS	DT=	.023 -.032=	-.009	105	EARLY		
56BP	77	242	104	5.566	-22	22	5.566	-.021	CC = .743
56BP	78	150	105	5.625	-40	2	5.587		
	-1.8	LAGS	DT=	-.031 .021=	-.010	105	EARLY		
30BP	78	150	105	1.150	-42	2	1.110	.003	CC = .838
30A	75	280	101	1.133	-26	0	1.107		
	.6	LAGS	DT=	.005 -.003=	.002	105	EARLY		
64A	77	242	104	9.086	-18	0	9.068	.032	CC = .756
64A	78	150	105	9.061	-25	0	9.036		
	2.6	LAGS	DT=	.021 -.032=	-.011	105	EARLY		
60A	77	242	104	6.645	-18	0	6.627	.039	CC = .792
60A	78	150	105	6.613	-25	0	6.588		
	.3	LAGS	DT=	.002 -.039=	-.037	105	EARLY		
54A	77	242	104	5.614	-18	0	5.596	.001	CC = .777
54A	78	150	105	5.622	-27	0	5.595		
	-1.7	LAGS	DT=	-.014 -.001=	-.015	105	EARLY		
20A	77	242	104	8.284	-18	0	8.266	.013	CC = .886
20A	78	150	105	8.278	-25	0	8.253		
	-.2	LAGS	DT=	-.001 -.013=	-.014	105	EARLY		
10A	77	242	104	3.245	-18	0	3.227	-.002	CC = .846
10A	78	150	105	3.254	-25	0	3.229		
	-1.3	LAGS	DT=	-.011 .002=	-.009	105	EARLY		

Table 3 cont'd

Table 4

All Data

ST	YR	DAY	SHOT	START TIME	CORRECTIONS CLOCKS	BP	CORRECT TIME	A-B	CROSS-CORR. COEFF.
74BP	76	350	5	2.000	-19	22	2.003	.006	CC = .946
74BP	77	243	6	2.000	-25	22	1.997		
	1.0	LAGS	DT=	.017 -.006=	.011	6	LATE		
74BP	76	350	5	2.000	-19	22	2.003	.037	CC = .870
74BP	78	151	7	2.000	-36	2	1.966		
	1.7	LAGS	DT=	.028 -.037=	-.009	7	EARLY		
74BP	77	243	6	2.000	-25	22	-.003	.031	CC = .936
74BP	78	151	7	2.000	-36	2	1.966		
	.6	LAGS	DT=	.010 -.031=	-.021	7	EARLY		
60BP	76	350	5	6.300	-40	22	6.282	-.033	CC = .895
60BP	78	152	8	6.350	-37	2	6.315		
	-2.4	LAGS	DT=	-.040 .033=	-.007	8	EARLY		
60BP	76	350	5	6.300	-40	22	6.282	-.002	CC = .831
60A	74	204	3	15.221	-8937	0	6.284		
	-1.5	LAGS	DT=	-.025 .002=	-.023	5	LATE		
60BP	76	350	5	6.300	-40	22	6.282	-.008	CC = .841
60A	75	267	4	6.338	-48	0	6.290		
	-.6	LAGS	DT=	-.010 .008=	-.002	5	LATE		
60BP	76	350	5	6.300	-40	22	6.282	-.044	CC = .836
60A	77	243	6	6.338	-12	0	6.326		
	-1.1	LAGS	DT=	-.018 .044=	.026	6	LATE		
60BP	76	350	5	6.300	-40	22	6.282	.004	CC = .845
60A	78	151	7	6.297	-19	0	6.278		
	-.1	LAGS	DT=	-.002 -.004=	-.006	7	EARLY		
60BP	76	350	5	6.300	-40	22	6.282	.006	CC = .840
60A	78	152	8	6.273	3	0	6.276		
	-.1	LAGS	DT=	-.002 -.006=	-.008	8	EARLY		
60BP	78	152	8	6.350	-37	2	6.315	.031	CC = .727
60A	74	204	3	15.221	-8937	0	6.284		
	1.8	LAGS	DT=	.015 -.031=	-.016	8	LATE		
60BP	78	152	8	6.350	-37	2	6.315	.025	CC = .769
60A	75	267	4	6.338	-48	0	6.290		
	3.7	LAGS	DT=	.031 -.025=	.006	8	EARLY		
60BP	78	152	8	6.350	-37	2	6.315	-.011	CC = .878
60A	77	243	6	6.338	-12	0	6.326		
	2.4	LAGS	DT=	.020 .011=	.031	8	EARLY		

60BP	78	152	8	6.350	-37	2	6.315	.037	CC = .864
60A	78	151	7	6.297	-19	0	6.278		
	4.4	LAGS	DT=	.037 -.037=	-.000	8	LATE		
60BP	78	152	8	6.350	-37	2	6.315	.039	CC = .869
60A	78	152	8	6.273	3	0	6.276		
	4.5	LAGS	DT=	.038 -.039=	-.001	8	LATE		
60A	74	204	3	15.221	-8937	0	6.284	-.006	CC = .919
60A	75	267	4	6.338	-48	0	6.290		
	1.8	LAGS	DT=	.015 .006=	.021	4	LATE		
60A	74	204	3	15.221	-8937	0	6.284	-.042	CC = .655
60A	77	243	6	6.338	-12	0	6.326		
	.8	LAGS	DT=	.007 .042=	.049	6	LATE		
60A	74	204	3	15.221	-8937	0	6.284	.006	CC = .752
60A	78	151	7	6.297	-19	0	6.278		
	2.5	LAGS	DT=	.021 -.006=	.015	7	LATE		
60A	74	204	3	15.221	-8937	0	6.284	.008	CC = .721
60A	78	152	8	6.273	3	0	6.276		
	2.7	LAGS	DT=	.022 -.008=	.014	8	LATE		
60A	75	267	4	6.338	-48	0	6.290	-.036	CC = .704
60A	77	243	6	6.338	-12	0	6.326		
	-.9	LAGS	DT=	-.008 .036=	.028	6	LATE		
60A	75	267	4	6.338	-48	0	6.290	.012	CC = .768
60A	78	151	7	6.297	-19	0	6.278		
	.8	LAGS	DT=	.007 -.012=	-.005	7	EARLY		
60A	75	267	4	6.338	-48	0	6.290	.014	CC = .730
60A	78	152	8	6.273	3	0	6.276		
	.9	LAGS	DT=	.007 -.014=	-.007	8	EARLY		
60A	77	243	6	6.338	-12	0	6.326	.048	CC = .806
60A	78	151	7	6.297	-19	0	6.278		
	2.0	LAGS	DT=	.016 -.048=	-.032	7	EARLY		
60A	77	243	6	6.338	-12	0	6.326	.050	CC = .786
60A	78	152	8	6.273	3	0	6.276		
	2.1	LAGS	DT=	.017 -.050=	-.033	8	EARLY		
60A	78	151	7	6.297	-19	0	6.278	.002	CC = .947
60A	78	152	8	6.273	3	0	6.276		
	.1	LAGS	DT=	.001 -.002=	-.001	8	EARLY		
56BP	76	350	5	52.716	9988	22	2.726	.012	CC = .767
56BP	77	243	6	2.716	-24	22	2.714		
	1.5	LAGS	DT=	.024 -.012=	.012	6	LATE		

56BP	76	350	5	52.716	9988	22	2.726	.038	CC = .763
56BP	78	151	7	2.725	-39	2	2.688		
	2.3	LAGS	DT=	.038 -.038=	-.000	7	EARLY		
56BP	76	350	5	52.716	9988	22	2.726	.001	CC = .532
56A	78	151	7	2.744	-19	0	2.725		
	-.4	LAGS	DT=	-.007 -.001=	-.008	7	EARLY		
56BP	77	243	6	2.716	-24	22	2.714	.026	CC = .853
56BP	78	151	7	2.725	-39	2	2.688		
	.6	LAGS	DT=	.010 -.026=	-.016	7	EARLY		
56BP	77	243	6	2.716	-24	22	2.714	-.011	CC = .537
56A	78	151	7	2.744	-19	0	2.725		
	-1.9	LAGS	DT=	-.032 .011=	-.021	7	EARLY		
56BP	78	151	7	2.725	-39	2	2.688	-.037	CC = .648
56A	78	151	7	2.744	-19	0	2.725		
	-5.4	LAGS	DT=	-.045 .037=	-.008	7	LATE		
54BP	76	350	5	2.116	-30	22	2.108	.027	CC = .851
54A	74	204	3	11.006	-8925	0	2.081		
	.8	LAGS	DT=	.013 -.027=	-.014	5	LATE		
54BP	76	350	5	2.116	-30	22	2.108	.001	CC = .823
54A	75	267	4	2.143	-36	0	2.107		
	-.2	LAGS	DT=	-.003 -.001=	-.004	5	LATE		
54BP	76	350	5	2.116	-30	22	2.108	-.011	CC = .923
54A	77	243	6	2.131	-12	0	2.119		
	.3	LAGS	DT=	.005 .011=	.016	6	LATE		
54BP	76	350	5	2.116	-30	22	2.108	-.004	CC = .930
54A	78	151	7	2.131	-19	0	2.112		
	-.0	LAGS	DT=	-.001 .004=	.003	7	LATE		
54BP	76	350	5	2.116	-30	22	2.108	-.021	CC = .920
54A	78	152	8	2.126	3	0	2.129		
	-.4	LAGS	DT=	-.007 .021=	.014	8	LATE		
54A	74	204	3	11.006	-8925	0	2.081	-.026	CC = .900
54A	75	267	4	2.143	-36	0	2.107		
	-2.0	LAGS	DT=	-.017 .026=	.009	4	LATE		
54A	74	204	3	11.006	-8925	0	2.081	-.038	CC = .878
54A	77	243	6	2.131	-12	0	2.119		
	-1.5	LAGS	DT=	-.013 .038=	.025	6	LATE		
54A	74	204	3	11.006	-8925	0	2.081	-.031	CC = .869
54A	78	151	7	2.131	-19	0	2.112		
	-2.0	LAGS	DT=	-.017 .031=	.014	7	LATE		
54A	74	204	3	11.006	-8925	0	2.081	-.048	CC = .816

54A	78	152	8	2.126	3	0	2.129		
	-2.7	LAGS	DT= -.022	.048=	.026	8	LATE		
54A	75	267	4	2.143	-36	0	2.107	-.012	CC = .885
54A	77	243	6	2.131	-12	0	2.119		
	.6	LAGS	DT= .005	.012=	.017	6	LATE		
54A	75	267	4	2.143	-36	0	2.107	-.005	CC = .832
54A	78	151	7	2.131	-19	0	2.112		
	.0	LAGS	DT= .000	.005=	.005	7	LATE		
54A	75	267	4	2.143	-36	0	2.107	-.022	CC = .783
54A	78	152	8	2.126	3	0	2.129		
	-.8	LAGS	DT= -.006	.022=	.016	8	LATE		
54A	77	243	6	2.131	-12	0	2.119	.007	CC = .934
54A	78	151	7	2.131	-19	0	2.112		
	-.6	LAGS	DT= -.005	-.007=	-.012	7	EARLY		
54A	77	243	6	2.131	-12	0	2.119	-.010	CC = .893
54A	78	152	8	2.126	3	0	2.129		
	-1.4	LAGS	DT= -.012	.010=	-.002	8	EARLY		
54A	78	151	7	2.131	-19	0	2.112	-.017	CC = .922
54A	78	152	8	2.126	3	0	2.129		
	-.9	LAGS	DT= -.007	.017=	.010	8	LATE		
58BP	77	243	6	4.116	-28	22	4.110	.021	CC = .747
58A	74	204	3	13.014	-8925	0	4.089		
	-.6	LAGS	DT= -.010	-.021=	-.031	6	LATE		
58BP	77	243	6	4.116	-28	22	4.110	-.020	CC = .749
58A	75	267	4	4.166	-36	0	4.130		
	-1.6	LAGS	DT= -.027	.020=	-.007	6	LATE		
58A	74	204	3	13.014	-8925	0	4.089	-.041	CC = .897
58A	75	267	4	4.166	-36	0	4.130		
	-2.1	LAGS	DT= -.018	.041=	.023	4	LATE		
30BP	77	243	6	8.766	-26	22	8.762	.041	CC = .852
30BP	78	151	7	8.775	-56	2	8.721		
	1.1	LAGS	DT= .019	-.041=	-.022	7	EARLY		
30BP	77	243	6	8.766	-26	22	8.762	-.003	CC = .942
30A	75	267	4	8.801	-36	0	8.765		
	-.6	LAGS	DT= -.010	.003=	-.007	6	LATE		
30BP	77	243	6	8.766	-26	22	8.762	.016	CC = .920
30A	74	204	3	17.671	-8925	0	8.746		
	-.4	LAGS	DT= -.007	-.016=	-.023	6	LATE		
30BP	78	151	7	8.775	-56	2	8.721	-.044	CC = .839
30A	75	267	4	8.801	-36	0	8.765		

	-3.6	LAGS	DT= -.030	.044=	.014	7	EARLY		
30BP	78	151	7	8.775	-56	2	8.721	-.025	CC = .843
30A	74	204	3	17.671	-8925	0	8.746		
	-3.1	LAGS	DT= -.026	.025=	-.001	7	LATE		
30A	75	267	4	8.801	-36	0	8.765	.019	CC = .931
30A	74	204	3	17.671	-8925	0	8.746		
	.4	LAGS	DT= .004	-.019=	-.015	4	LATE		
18BP	77	243	6	8.716	-29	22	8.709	.003	CC = .844
18A	75	267	4	8.742	-36	0	8.706		
	-.2	LAGS	DT= -.003	-.003=	-.006	6	LATE		
18BP	77	243	6	8.716	-29	22	8.709	.009	CC = .856
18A	74	204	3	17.625	-8925	0	8.700		
	-1.1	LAGS	DT= -.018	-.009=	-.027	6	LATE		
18A	75	267	4	8.742	-36	0	8.706	.006	CC = .892
18A	74	204	3	17.625	-8925	0	8.700		
	-1.8	LAGS	DT= -.015	-.006=	-.021	4	LATE		
10A	75	267	4	7.104	-36	0	7.068	.163	CC = .410
10A	77	243	6	6.917	-12	0	6.905		
	4.8	LAGS	DT= .040	-.163=	-.123	6	EARLY		
10A	75	267	4	7.104	-36	0	7.068	.080	CC = .948
10A	74	204	3	15.913	-8925	0	6.988		
	7.1	LAGS	DT= .059	-.080=	-.021	4	LATE		
10A	75	267	4	7.104	-36	0	7.068	.168	CC = .392
10A	78	151	7	6.919	-19	0	6.900		
	3.7	LAGS	DT= .030	-.168=	-.138	7	EARLY		
10A	75	267	4	7.104	-36	0	7.068	.150	CC = .268
10A	78	152	8	6.915	3	0	6.918		
	3.1	LAGS	DT= .026	-.150=	-.124	8	EARLY		
10A	77	243	6	6.917	-12	0	6.905	-.083	CC = .421
10A	74	204	3	15.913	-8925	0	6.988		
	-11.2	LAGS	DT= -.093	.083=	-.010	6	LATE		
10A	77	243	6	6.917	-12	0	6.905	.005	CC = .788
10A	78	151	7	6.919	-19	0	6.900		
	-1.1	LAGS	DT= -.009	-.005=	-.014	7	EARLY		
10A	77	243	6	6.917	-12	0	6.905	-.013	CC = .679
10A	78	152	8	6.915	3	0	6.918		
	-2.1	LAGS	DT= -.017	.013=	-.004	8	EARLY		
10A	74	204	3	15.913	-8925	0	-.012	.088	CC = .385
10A	78	151	7	6.919	-19	0	6.900		
	11.1	LAGS	DT= .092	-.088=	.004	7	LATE		

10A	74	204	3	15.913	-8925	0	-.012	.070	CC = .254
10A	78	152	8	6.915	3	0	6.918		
	9.9	LAGS	DT=	.082 -.070=	.012	8	LATE		
10A	78	151	7	6.919	-19	0	6.900	-.018	CC = .658
10A	78	152	8	6.915	3	0	6.918		
	-1.0	LAGS	DT=	-.008 .018=	.010	8	LATE		
64A	77	243	6	9.597	-12	0	9.585	.013	CC = .876
64A	78	151	7	9.591	-19	0	9.572		
	-.1	LAGS	DT=	-.000 -.013=	-.013	7	EARLY		
64A	77	243	6	9.597	-12	0	9.585	.002	CC = .684
64A	78	152	8	9.580	3	0	9.583		
	-.3	LAGS	DT=	-.002 -.002=	-.004	8	EARLY		
64A	78	151	7	9.591	-19	0	9.572	-.011	CC = .745
64A	78	152	8	9.580	3	0	9.583		
	-.2	LAGS	DT=	-.002 .011=	.009	8	LATE		
20A	77	243	6	11.261	-12	0	11.249	.013	CC = .732
20A	78	151	7	11.256	-20	0	11.236		
	-.8	LAGS	DT=	-.006 -.013=	-.019	7	EARLY		
16A	78	151	7	7.166	-19	0	7.147	-.014	CC = .780
16A	78	152	8	7.158	3	0	7.161		
	-.3	LAGS	DT=	-.002 .014=	.012	8	LATE		

ST	YR	DAY	SHOT	START TIME	CORRECTIONS CLOCKS	BP	CORRECT TIME	A-B	CROSS-CORR. COEFF.
74BP	76	302	102	7.816	-26	22	7.812	.001	CC = .444
74BP	77	242	104	7.816	-27	22	7.811		
	.4	LAGS	DT=	.006 -.001=	.005	104	LATE		
60BP	76	302	102	6.616	-23	22	6.615	-.033	CC = .475
60BP	76	351	103	6.650	-24	22	6.648		
	-2.1	LAGS	DT=	-.036 .033=	-.003	103	EARLY		
60BP	76	302	102	6.616	-23	22	6.615	.012	CC = .378
60A	75	280	101	6.623	-20	0	6.603		
	-.3	LAGS	DT=	-.005 -.012=	-.017	102	LATE		
60BP	76	302	102	6.616	-23	22	6.615	-.012	CC = .364
60A	77	242	104	6.645	-18	0	6.627		
	.1	LAGS	DT=	.001 .012=	.013	104	LATE		
60BP	76	302	102	6.616	-23	22	6.615	.027	CC = .303
60A	78	150	105	6.613	-25	0	6.588		
	.2	LAGS	DT=	.003 -.027=	-.024	105	EARLY		
60BP	76	351	103	6.650	-24	22	6.648	.045	CC = .781
60A	75	280	101	6.623	-20	0	6.603		
	1.9	LAGS	DT=	.032 -.045=	-.013	103	LATE		
60BP	76	351	103	6.650	-24	22	6.648	.021	CC = .623
60A	77	242	104	6.645	-18	0	6.627		
	2.2	LAGS	DT=	.037 -.021=	.016	104	LATE		
60BP	76	351	103	6.650	-24	22	6.648	.060	CC = .582
60A	78	150	105	6.613	-25	0	6.588		
	2.4	LAGS	DT=	.040 -.060=	-.020	105	EARLY		
60A	75	280	101	6.623	-20	0	6.603	-.024	CC = .524
60A	77	242	104	6.645	-18	0	6.627		
	.3	LAGS	DT=	.002 .024=	.026	104	LATE		
60A	75	280	101	6.623	-20	0	6.603	.015	CC = .510
60A	78	150	105	6.613	-25	0	6.588		
	.7	LAGS	DT=	.006 -.015=	-.009	105	EARLY		
60A	77	242	104	6.645	-18	0	6.627	.039	CC = .792
60A	78	150	105	6.613	-25	0	6.588		
	.3	LAGS	DT=	.002 -.039=	-.037	105	EARLY		
58BP	76	302	102	4.350	-54	22	4.318	-.003	CC = .742
58BP	76	351	103	4.316	-17	22	4.321		
	-1.0	LAGS	DT=	-.016 .003=	-.013	103	EARLY		

58BP	76	302	102	4.350	-54	22	4.318	.008	CC = .546
58BP	77	242	104	4.316	-28	22	4.310		
	-.2	LAGS	DT=	-.003 -.008=	-.011	104	EARLY		

58BP	76	302	102	4.350	-54	22	4.318	-.013	CC = .707
58A	75	280	101	4.357	-26	0	4.331		
	-2.1	LAGS	DT=	-.034 .013=	-.021	102	LATE		
58BP	76	351	103	4.316	-17	22	4.321	.011	CC = .672
58BP	77	242	104	4.316	-28	22	4.310		
	.8	LAGS	DT=	.013 -.011=	.002	104	LATE		
58BP	76	351	103	4.316	-17	22	4.321	-.010	CC = .786
58A	75	280	101	4.357	-26	0	4.331		
	-1.1	LAGS	DT=	-.018 .010=	-.008	103	LATE		
58BP	77	242	104	4.316	-28	22	4.310	-.021	CC = .581
58A	75	280	101	4.357	-26	0	4.331		
	-1.9	LAGS	DT=	-.031 .021=	-.010	104	LATE		
56BP	76	302	102	5.616	-45	22	5.593	.003	CC = .583
56BP	76	351	103	5.616	-48	22	5.590		
	.0	LAGS	DT=	.000 -.003=	-.003	103	EARLY		
56BP	76	302	102	5.616	-45	22	5.593	.027	CC = .622
56BP	77	242	104	5.566	-22	22	5.566		
	-.1	LAGS	DT=	-.002 -.027=	-.029	104	EARLY		
56BP	76	302	102	5.616	-45	22	5.593	.006	CC = .812
56BP	78	150	105	5.625	-40	2	5.587		
	-2.0	LAGS	DT=	-.033 -.006=	-.039	105	EARLY		
56BP	76	351	103	5.616	-48	22	5.590	.024	CC = .808
56BP	77	242	104	5.566	-22	22	5.566		
	-.2	LAGS	DT=	-.004 -.024=	-.028	104	EARLY		
56BP	76	351	103	5.616	-48	22	5.590	.003	CC = .682
56BP	78	150	105	5.625	-40	2	5.587		
	-2.0	LAGS	DT=	-.033 -.003=	-.036	105	EARLY		
56BP	77	242	104	5.566	-22	22	5.566	-.021	CC = .743
56BP	78	150	105	5.625	-40	2	5.587		
	-1.8	LAGS	DT=	-.031 .021=	-.010	105	EARLY		
54BP	76	351	103	5.616	-36	22	5.602	.016	CC = .619
54A	75	280	101	5.612	-26	0	5.586		
	.4	LAGS	DT=	.006 -.016=	-.010	103	LATE		
54BP	76	351	103	5.616	-36	22	5.602	.006	CC = .811
54A	77	242	104	5.614	-18	0	5.596		
	.6	LAGS	DT=	.009 -.006=	.003	104	LATE		

54BP	76	351	103	5.616	-36	22	5.602	.007	CC = .669
54A	78	150	105	5.622	-27	0	5.595		
	-.4	LAGS	DT= -.006	-.007=	-.013	105	EARLY		

54A	75	280	101	5.612	-26	0	5.586	-.010	CC = .586
54A	77	242	104	5.614	-18	0	5.596		
	.3	LAGS	DT= .002	.010=	.012	104	LATE		
54A	75	280	101	5.612	-26	0	5.586	-.009	CC = .451
54A	78	150	105	5.622	-27	0	5.595		
	-1.4	LAGS	DT= -.011	.009=	-.002	105	EARLY		
54A	77	242	104	5.614	-18	0	5.596	.001	CC = .777
54A	78	150	105	5.622	-27	0	5.595		
	-1.7	LAGS	DT= -.014	-.001=	-.015	105	EARLY		
16BP	76	351	103	2.500	-30	22	2.492	-.008	CC = .718
16A	78	150	105	2.525	-25	0	2.500		
	-.1	LAGS	DT= -.002	.008=	.006	105	LATE		
76BP	77	242	104	6.350	-27	22	6.345	.032	CC = .924
76BP	78	150	105	6.350	-39	2	6.313		
	1.4	LAGS	DT= .023	-.032=	-.009	105	EARLY		
18BP	77	242	104	3.816	-25	22	3.813	-.021	CC = .826
18A	75	280	101	3.860	-26	0	3.834		
	-1.4	LAGS	DT= -.023	.021=	-.002	104	LATE		
30BP	78	150	105	1.150	-42	2	1.110	.003	CC = .838
30A	75	280	101	1.133	-26	0	1.107		
	.6	LAGS	DT= .005	-.003=	.002	105	EARLY		
10A	75	280	101	3.326	-26	0	3.300	.073	CC = .420
10A	77	242	104	3.245	-18	0	3.227		
	20.0	LAGS	DT= .166	-.073=	.093	104	LATE		
10A	75	280	101	3.326	-26	0	3.300	.071	CC = .421
10A	78	150	105	3.254	-25	0	3.229		
	18.9	LAGS	DT= .158	-.071=	.087	105	LATE		
10A	77	242	104	3.245	-18	0	3.227	-.002	CC = .846
10A	78	150	105	3.254	-25	0	3.229		
	-1.3	LAGS	DT= -.011	.002=	-.009	105	EARLY		
64A	77	242	104	9.086	-18	0	9.068	.032	CC = .756
64A	78	150	105	9.061	-25	0	9.036		
	2.6	LAGS	DT= .021	-.032=	-.011	105	EARLY		
20A	77	242	104	8.284	-18	0	8.266	.013	CC = .886
20A	78	150	105	8.278	-25	0	8.253		
	-.2	LAGS	DT= -.001	-.013=	-.014	105	EARLY		

TABLE 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	7 151 31.May 78	8 152 1.Jun 7
54	A 0	A +9	BP +14	A +25	+14	+26
56			BP 0	BP +12	BP 0 A -8	
58	A 0	A +23		BP +31		
60	A 0	A +21	BP +23	A +49	+15	BP= +16 A +14
74			BP 0	BP +11	BP -9	
/11	A 0	A +21		A 0	A -14	A -4
18	A 0	A +21		BP +27		
30 30	A 0	A +15		BP +23	BP +1	
64				A 0	A -13	A -4
20				A 0	A -19	
16					A 0	A +12

TABLE 6

Cross - Correlations
La Pocatière

TN	101 280 7. Oct. 75	102 302 28. Oct. 76	103 351 16. Dec. 76	104 242 30. Aug. 77	105 150 30 May 78	
54	A 0		BP +10	A +12	-2	
56		BP 0	BP -3	BP -29	-39	
58	A 0	BP +21	BP +8	BP +10		
60	A 0	BP +17	BP +13	A +26	-9	
74		BP 0		BP +5		
10/8 11	A			A 0	A -9	
18	A 0			BP +2		
64				A 0	A -11	
76				BP 0	BP -9	
16			BP 0		A +6	
20				A 0	A -14	
30	A 0				BP -2	

Table 7

Stn.	Shot	Inst.	ms	
54	7	A		
	8	A	10	late
56	7	BP		late
	7	A	8	
56	7	A		late
	8	A	6	
60	8	BP		
	7	A	0	
60	8	BP		late
	8	A	1	
60	7	A		late
	8	A	1	
64	7	A		
	8	A	9	late
10	7	A		
	8	A	10	late
16	7	A		
	8	A	12	late

List of Figures

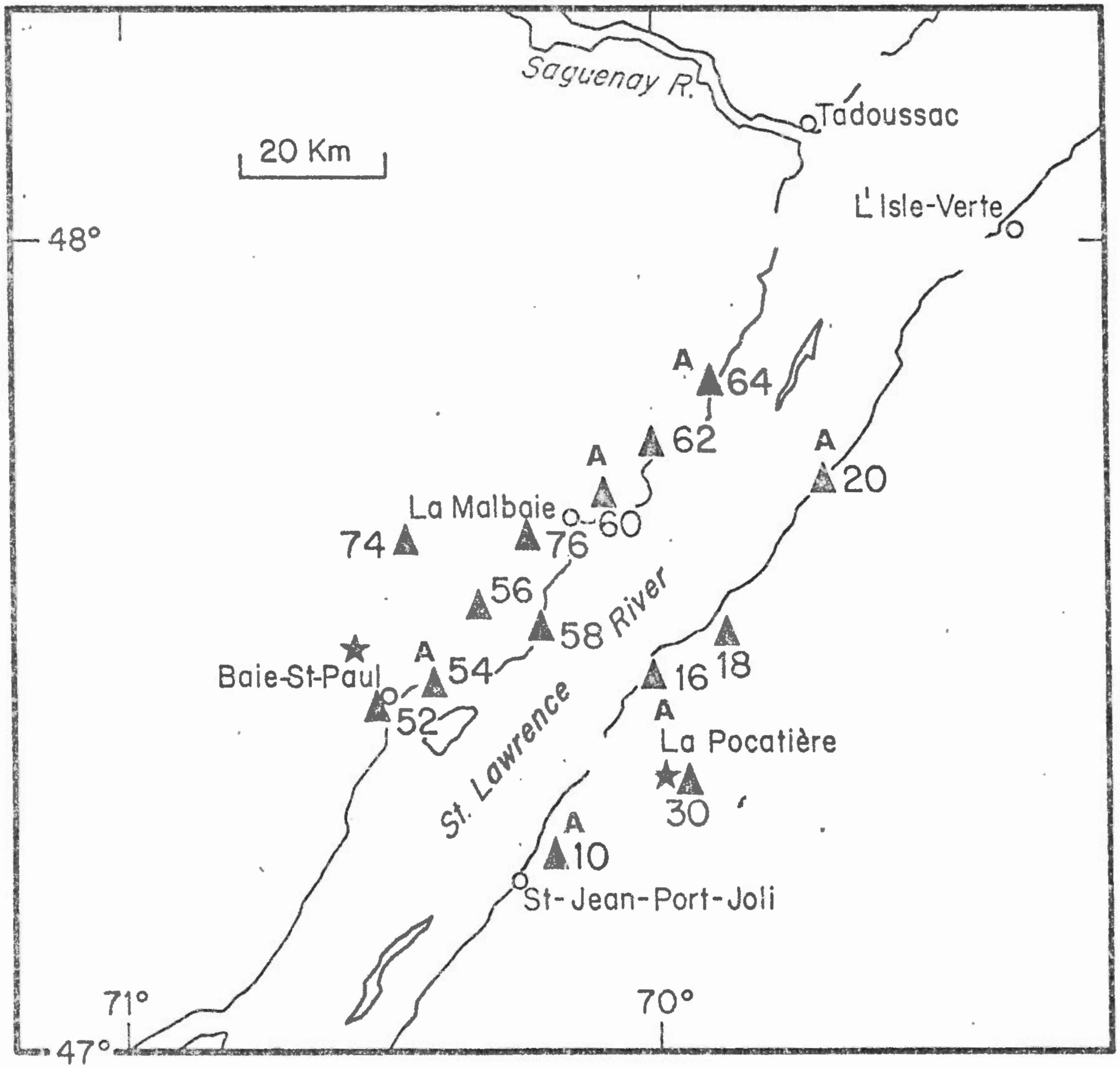

Saguenay R.
Tadoussac
20 Km
L'Isle-Verte
48°
A
64
62
A
20
A
La Malbaie
60
74
76
56
58
St. Lawrence River
A
54
18
16
Baie-St-Paul
52
A
La Pocatière
30
A
10
St-Jean-Port-Joli
71°
70°
47°

Fig. 1

ST. JEROME MINE

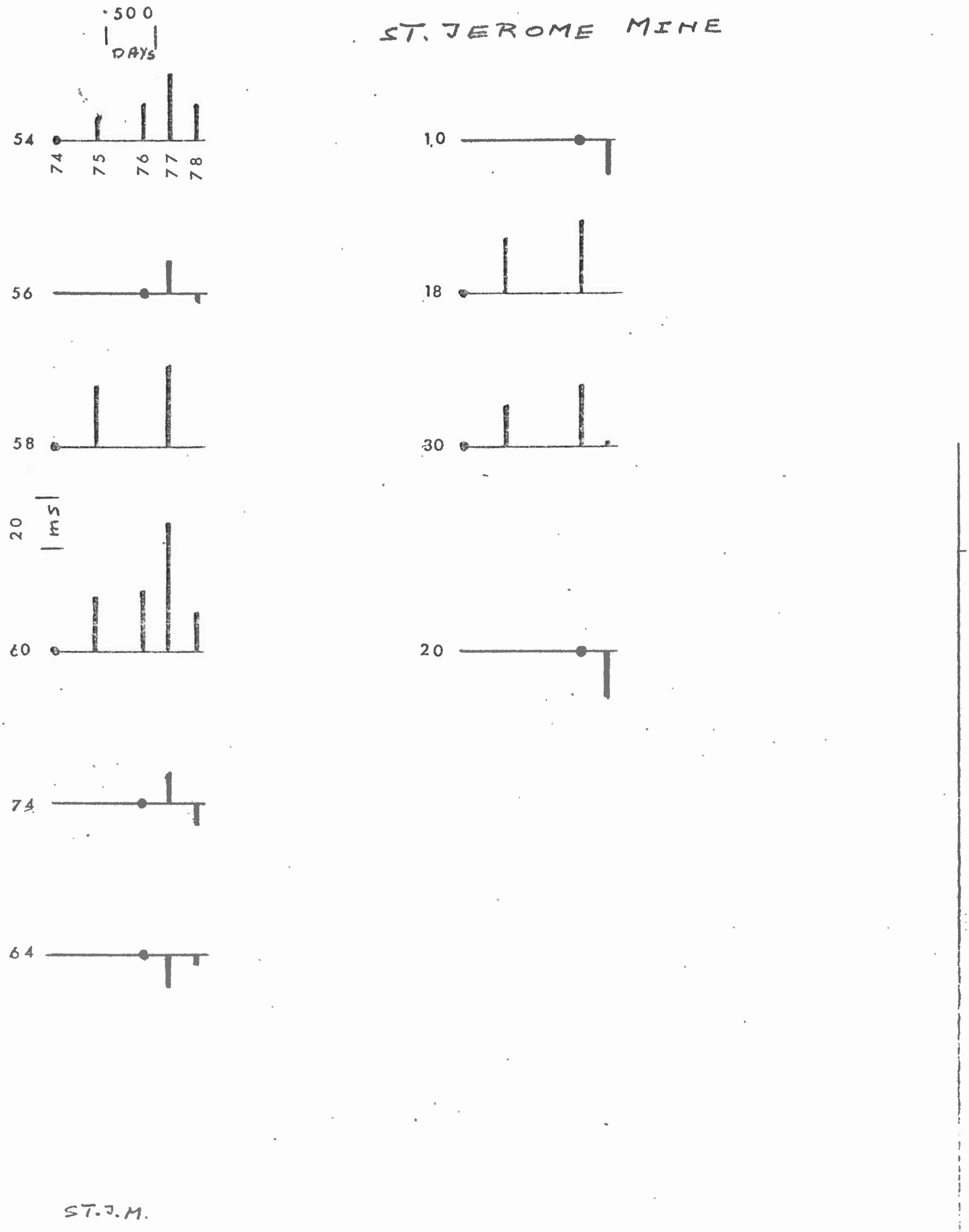
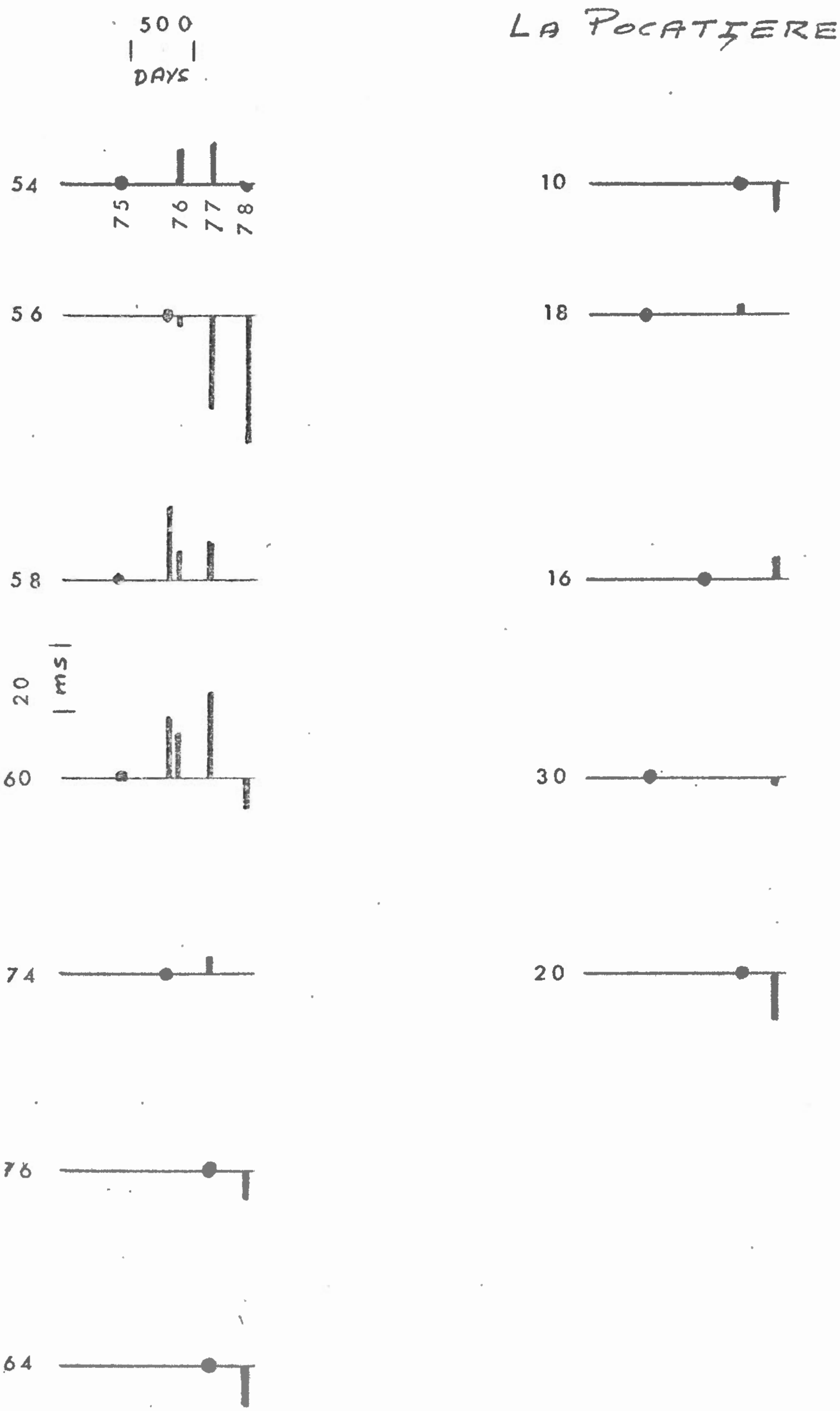
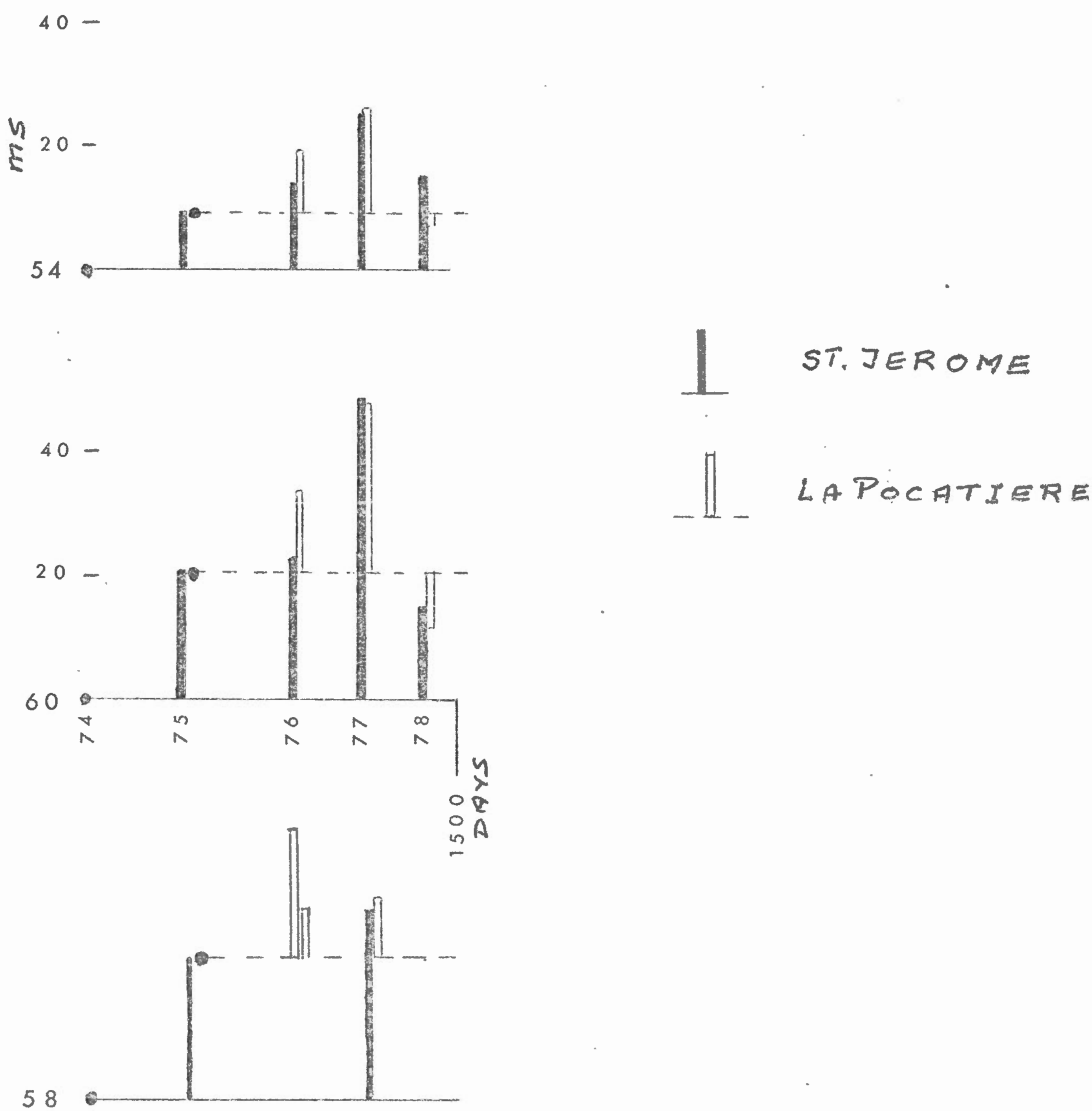


Fig. 2


LA POCATIERE
500
DAYS
54
75
76
77
78
56
58
20
ms
60
74
76
64
10
18
16
30
20

LaPoc

Fig 3



40
20
54
ms
40
20
60
74
75
76
77
78
1500
DAYS
58
ST. JEROME
LA POCATIERE

Fig 4

dilatancy against the overall pressure (6). The change in shape is presumably due to shear stresses associated with a regional tectonic strain. If the pores or cracks contain fluid the effect of dilatancy on a saturated rock is to greatly reduce the fluid pore pressure, and if the dilatancy is large enough a state is reached when the pore or crack volume exceeds the fluid volume, which is defined here as undersaturation. Fluid flow eventually returns the rock to its saturated state. But while the fluid pore pressure is below its normal level the fracture strength of the rock is significantly increased, an effect termed dilatancy hardening (6, 7). The reduction in pore pressure can occur rapidly, whereas the return to a saturated condition occurs slowly since it is controlled by fluid flow processes in a permeable medium. If the velocity anomaly depended on the maintenance of new dry cracks in a saturated medium, as Nur (8) suggests, it would be difficult to get a variable anomaly time because the average distance from a dry crack to a wet one would generally remain constant.

The change in P-wave velocity takes place when a crack or void in the rock opens enough so that a small amount of vapor is present. This greatly reduces the bulk modulus, causing a large drop in the velocity of P waves but little change in that of S waves. Laboratory determinations of V_P and V_S in wet and dry crystalline rocks of low porosity under a range of confining pressures have been published by Nur and Simmons (9). Although these are not true measurements of the effect of dilatancy on saturated rocks (dry cracks are not necessary for the effect), they give a good approximation to the velocity changes expected. The results of Nur and Simmons for saturated and dry Westerly granite are shown in Fig. 4. Nur (8) used these data to explain the changes in the V_P/V_S ratio, although Savarensky (1), whose work he referred to, stated that the stronger effect is shown by the velocities of the transverse (S) waves. This is in disagreement with the data of Fig. 4b and with the results reported here. Shallow saturated crustal rocks would be characterized by point A in Fig. 4. If dilatancy were then to occur, the fluid pore pressure would drop rapidly until the rock becomes undersaturated, the rock would strengthen, and the rock velocities would change toward point B. During this drop of V_P/V_S both V_P and V_S decrease, but the drop of V_P dominates because of the significantly decreased bulk modulus of the rock, which results from undersaturation. Subsequent fluid flow would then bring the rock to a saturated state at a rate dependent on dilatancy volume, permeability, and availability of fluids. When point C (shown in Figs. 1 and 4) is reached, the rock weakens and an earthquake occurs. The characters and amplitudes of the velocity changes between A, B, and C in Figs. 1 and 4 are remarkably similar.

The independence of the size of the precursory drop of $(V_P/V_S - 1)$ with magnitude, found by Semenov (2) and Aggarwal *et al.* (4) and confirmed here, is easily understood. The velocity variations of this model depend mainly on the range of rock velocities between saturated and undersaturated states at low effective confining pressures, which has no relation to earthquake magnitude or volume of dilatant rock.

An implication of the results is that some of the crustal rocks between PAS and RVR, which are more than 35 km from the aftershock region of the San Fernando earthquake, were significantly dilatant before the earthquake, which had characteristic dimensions of only about 20 km. The following proposed sequence may explain this. Some part of the region near San Fernando, not necessarily the location of the earthquake hypocenter, reached its strength limit due to increasing regional tectonic strain. Dilatancy occurred (10) and dilatancy hardening strengthened the dilatant volume. Because stress concentrates around strength inhomogeneities, the next tectonic strain increment dilated the surrounding volume and subsequent increments continued the process over a larger and larger volume. Meanwhile, fluid flow into the volume began from all sides. In general, the fluid pore pressure first reached its saturated value where the permeability was greatest. Thus, permeability may have controlled the location of the initial rupture. Permeability may be greater along deep fracture zones, and it is significant to note that seismicity before the San Fernando earthquake

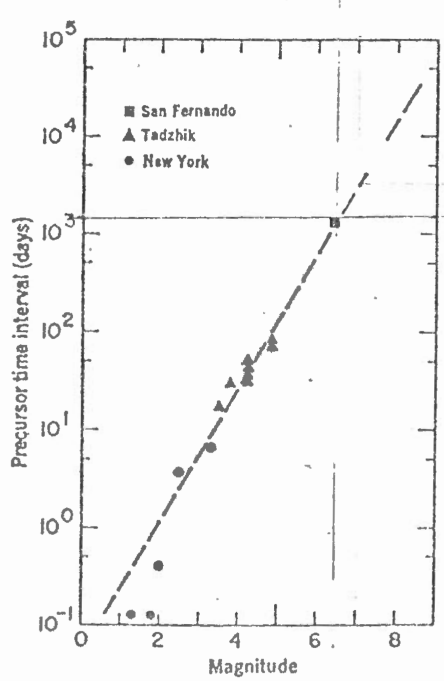


Fig. 3. The anomalous velocity precursor time interval as a function of earthquake magnitude for the 1971 San Fernando earthquake (square) and previous data from Semenov (2) (triangles) and Aggarwal *et al.* (4) (circles).

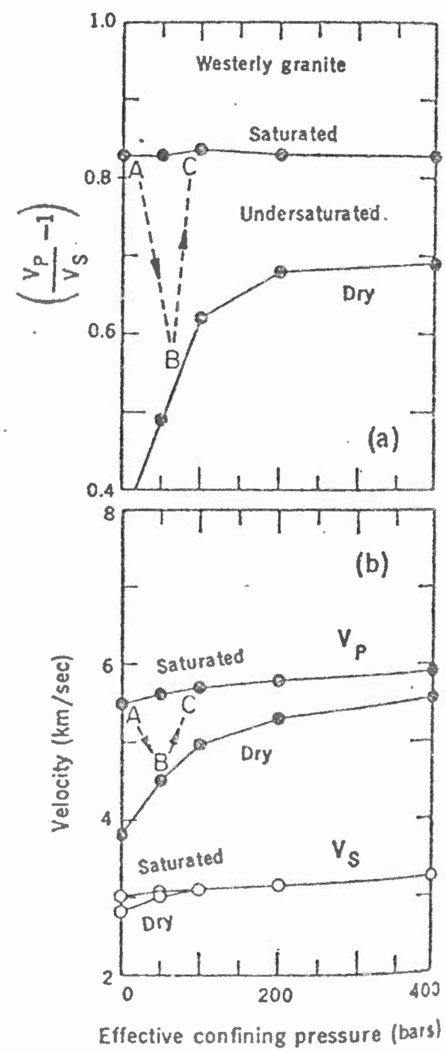


Fig. 4. (a) Velocity data from Nur and Simmons (9) reduced to the form $(V_P/V_S - 1)$ for saturated and dry Westerly granite, as a function of effective confining pressure. See the text for an explanation of A, B, and C. (b) Velocities V_P and V_S for the same data.