VELOCITY OF THE Lg PHASE FROM LOWER ST. LAWRENCE EARTHQUAKES

By

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ABSTRACT

The onset of the Lg phase propagates from Lower St. Lawrence earthquakes at 3.62 km/sec, and not at the standard model velocity of 3.57 km/sec. Adopting the new velocity removes a 10 km bias in the epicentres of some early earthquakes.

INTRODUCTION

The relocation of early, instrumentally-recorded earthquakes is strongly dependent on the velocity model assumed and requires a better value for the Lg velocity than the present "standard" velocity model for the shield. For modern (post-1968) earthquakes the seismograph coverage is good and the locations are based on many Pn, Pg, Sn, and Sg phases; distant Lg phases are seldom used. However, for earthquakes recorded on early seismographs ("early-instrumental"), the seismograph coverage is frequently poor in terms of azimuth and Lg is often the only phase showing a sharp onset. Accordingly, relatively small changes in the Lg velocity model can move the epicentres by significant distances. The routinely-applied Lg group velocity of 3.57 km/sec (Wetmiller et al., 1983) seems too low for eastern Canada (see comments by Dr. A. E. Stevens in the first paragraph of Appendix B), and therefore requires revision. Wetmiller and Cajka (1988) studied accurately-timed surface blasts and found 3.65 km/sec to be better for the northern Ontario shield, while Woodgold (1988), who studied very long paths from shield earthquakes and so obtained accurate average velocities, found an Lg velocity of 3.62 km/sec for the eastern shield of Canada, and 3.58 km/sec for the western, sediment-covered shield.

METHOD AND RESULTS

The Lg velocity to each recording station (Fig. 1) was determined for ten Lower St. Lawrence earthquakes (Table 1; see also Appendix A). The epicentres and origin times of the ten 1980-1987 earthquakes had been redetermined for focal mechanism studies (Adams et al., 1988a), using a Sg and Lg velocity of 3.57 km/sec but without using the Lg phase readings beyond 190 km. The Lg paths analysed were longer than 190 km and mostly shorter than 1100 km, and the period of the Lg waves were between 0.1 - 0.6 sec.

It was assumed that all the Lg phases had been read with the standard care for routine locations; the same degree of accuracy appropriate to the readings made for the early earthquakes. Present Geophysics Division practice labels phases whose beginnings are determined to within ±0.25 sec 'A', to ±1 sec 'B', and to ±4 sec 'C'. Phases whose onsets are not determined with much precision are given a zero weight of 'X'. Phases with very large residuals (>4 sec) – even those read precisely – are given zero-weight (XA, XB, etc) to avoid biasing the solution. Unfortunately, until recently this meant replacing the quality code with an 'X', so that while many of the 'X'-ed Lg phases in the Appendix may have been read precisely, this information has been lost. We have assumed that if a phase was read at all, it was moderately well defined, and have used it in the analysis.

The Lg velocities were obtained for each station by dividing the epicentral distance to the station by the travel time (Lg phase arrival time minus origin time) and are given in Table 2 according to station and event. (Appendix B recommends the alternative method of determining an Lg velocity for each earthquake.) Figure 2 shows the range of velocities and the mean value for each station, ordered by the mean azimuth of the Lower St. Lawrence – station path. The stations on Figure 2 apparently show a sinusoidal variation. However Figure 3 plots velocity against azimuth and shows that the scatter for any single azimuth is large, and that there is no systematic relationship between the mean Lg velocity and the azimuth of propagation. Such an azimuthal dependence might have been expected for paths from Lower St. Lawrence to the south (180°), where the Lg phase has to propagate through the complex Appalachian terrane (mixed sedimentary and plutonic rocks, and partially underlain by the Grenville Province of the Canadian Shield) and where a lower mean velocity might have been expected.

From the 104 individual velocities (Fig. 4) a mean velocity of 3.624 km/sec was derived, with a standard deviation of the population of 0.058 and a standard error of the mean of 0.006.

Figure 5 presents all 104 velocity determinations, and demonstrates that the "standard" shield Lg velocity of 3.57 km/sec is far too slow. There is a very large scatter of data; those points above the mean line represent late arrivals, while those below represent early arrivals, relative to the mean. It is possible that some of the early readings are spurious arrivals in the Sn coda. For example, the residual of -6.46 sec for LMQ (278 km) is an unlikely result if the Lg phase was actually read. Some of the points which lie above the line are possibly late readings due to uncertain phase onsets.

Further analysis, such as precisely reading the Lg onsets for a suite of earthquakes, might justify adopting a slightly higher Lg velocity than 3.62 km/sec, as readings are more likely to be read late than early, thus biasing the error distribution. Perhaps 3.65 km/sec, as suggested by Wetmiller and Cajka (1988), would be a better estimate than the 3.62 km/sec velocity determined in this report.

DISCUSSION

Considering a station 700 km from the epicentre, the travel time of the Lg phase using a velocity of 3.62 km/sec would be approximately 3 seconds less than the Lg travel time using the 3.57 km/sec model. A bias of 3 seconds represents a bias in distance of 10 km, and, depending on the location of the epicentre relative to the seismographs, could produce a bias in the epicentre of 10 km. Considering the scatter of ±3 sec about the 3.62 km/sec line, which is equivalent to ±10 km, use of the "standard" model might have mislocated the earthquake by up to 20 km (10 km bias plus ±10 km error).

In the future, similar studies should be completed for the other 3 main phases; Pn, Pg, Sn. It would be beneficial to make comparisons between the standard deviation of each of the four phases and comparisons, in kilometres, of epicentral precision.

Although this study is not conclusive in determining the best velocity for Lg, it is clear that the "standard" Lg velocity of 3.57 km/sec is too slow, and that adopting a mean velocity of 3.62 km/sec for the Lg velocity from the Lower St. Lawrence seismic zone earthquakes would be a substantial improvement for relocating the early Lower St. Lawrence earthquakes.

IMPLICATIONS

To demonstate the difference the new velocity has made, previously revised Lower St. Lawrence earthquakes of Sharp (1987) and Vatcher (1987) – a completely different data set from the earthquakes used for the Lg velocity determination – were relocated using the standard epicentre location program with the Lg velocity changed to 3.62 km/sec (see Fig. 6). Full details on the final revisions are given by Adams et al. (1988b). The epicentres moved on average 8 km to the northeast, away from the seismological stations, as was to be expected. Because most pre-1968 earthquakes must be located using Lg phases that were read in a routine fashion, the analysis in this report shows their locations are very dependent on the Lg wave velocity.

CONCLUSIONS

- For earthquakes in the Lower St. Lawrence valley an Lg velocity of 3.62 km/sec is an improvement on the standard value of 3.57 km/sec.

- Adopting an Lg velocity of 3.62 km/sec would remove a potential 10 km bias in the epicentres of poorly-recorded continental earthquakes lying around the southeastern periphery of Canada, which must be located using the Lg phase.

- Reading error alone might mean that relocated early-instrumental epicentres are imprecise to $\pm$ 10 km, if based on the routinely-read Lg phase. Improving the precision of reading the Lg phase onset (e.g. by filtering of digital records) together with a new analysis of the Lg velocity might allow improved epicentral precision of future epicentres relative to epicentres not using the Lg phase.

ACKNOWLEDGEMENTS

We would like to thank J.A. Drysdale, H.S. Hasegawa, M. Lamontagne, R.G. North, R.J. Wetmiller, A.E. Stevens and C.R.D. Woodgold for their comments on an early draft of this report. A full analysis along the lines of Dr. Stevens' comments is beyond the scope of the present report, but her comments provide both a valuable critique of the report's usefulness and the directions that must be taken in any comprehensive study of the velocity of the Lg phase; for these reasons her comments have been included as Appendix B.

REFERENCES

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FIGURE CAPTIONS

Figure 1. Ray paths to the recording seismograph stations used for velocity determinations and the centroid location of the ten Lower St. Lawrence earthquakes. The five stations not shown on the map are IGL, FRB, GTO, LHC, and FCC.

Figure 2. Range of Lg velocities and mean Lg velocity for each seismograph station.

Figure 3. Mean Lg velocity plotted against azimuth of propagation to the recording stations.

Figure 4. Histogram of all Lg velocities determined in this report.

Figure 5. Time travel chart for Lg phase onsets, reduced by 3.57 km/sec (the 'standard' Lg velocity).

Figure 6. Map of Lower St. Lawrence earthquakes, previously located by Sharp (1987) and Vatcher (1987), showing the result of changing the Lg velocity from 3.57 km/sec to 3.62 km/sec (arrow points from old to new epicentre).

TABLE 1

Lower St. Lawrence Earthquakes Used For Lg Velocity Determination

DATE YY/MM/DD	TIME HH:MM:SS	LAT. (N)	LONG. (W)	MAG. m_N
1980 04 03	16 57 25.1	48.707	67.812	4.1
1983 01 17	19 35 53.1	48.992	67.214	4.1
1984 03 29	22 52 49.6	49.609	66.456	3.2
1984 11 04	19 07 41.6	49.314	67.514	3.8
1984 05 28	21 04 52.5	49.606	66.350	3.2
1985 08 16	22 48 36.6	49.263	67.601	3.2
1986 11 09	19 57 19.1	49.250	67.392	4.2
1987 05 03	00 21 53.8	48.737	68.246	3.6
1987 06 17	19 39 20.5	48.868	68.708	3.0
1987 08 06	08 44 13.7	49.608	66.983	3.3

Table 2

Individual Lg Velocities by Station and by Event

STATION	800403	830117	840329	840411	840528	850816	861109	870503	870617	870806
A10						3.55				
A16						3.65				
A20						3.57				
A54						3.72				
A64						3.54				
CBK				3.57	3.65					
CIIQ	3.68									
CKO		3.63				3.61		3.53		
EBN										3.60
EEO					3.61	3.62	4.45	3.60		3.62
FCC		3.58								
FHO	3.64									
FRB	3.62	3.64		3.59						
GAC	3.66	3.69				3.62		3.68		3.67
GBN				3.60						
GGN				3.58			3.48	3.54		3.52
GNT	3.66	3.64					3.64	3.60		
GRQ						3.66	3.67	4.13		3.66
GTO		3.59		3.56						
HAL				3.66						
IGL		3.59								
JAQ						3.60				3.59
JOQ									3.63	
KAO		3.61		3.58						
KLN		3.64		3.63				3.79		
LDQ	3.57									
LHC		3.65								
LMN		3.58	3.59	3.59		3.53	3.59			
LMQ			3.57		3.63	3.88			3.61	
LPQ		3.68	3.66	3.67		3.59	3.67	3.69	3.67	3.70
MIQ	3.73									
MNQ									3.60	
MNT	3.68	3.76					3.63	3.67		
OTT		3.68								
PBQ	3.61	3.62								
QCQ				3.60						
SBQ		3.55					3.61	3.63		
SCH	3.65	3.62	3.68	3.57				3.68		3.60
SUD	3.63							3.59		
SZO								3.64		
SLQ										3.64
TRQ						3.55	3.65	3.68		3.60
UNB		3.60		3.47						
VDQ		3.64		3.59		3.58				
WBO		3.64				3.63		3.66		

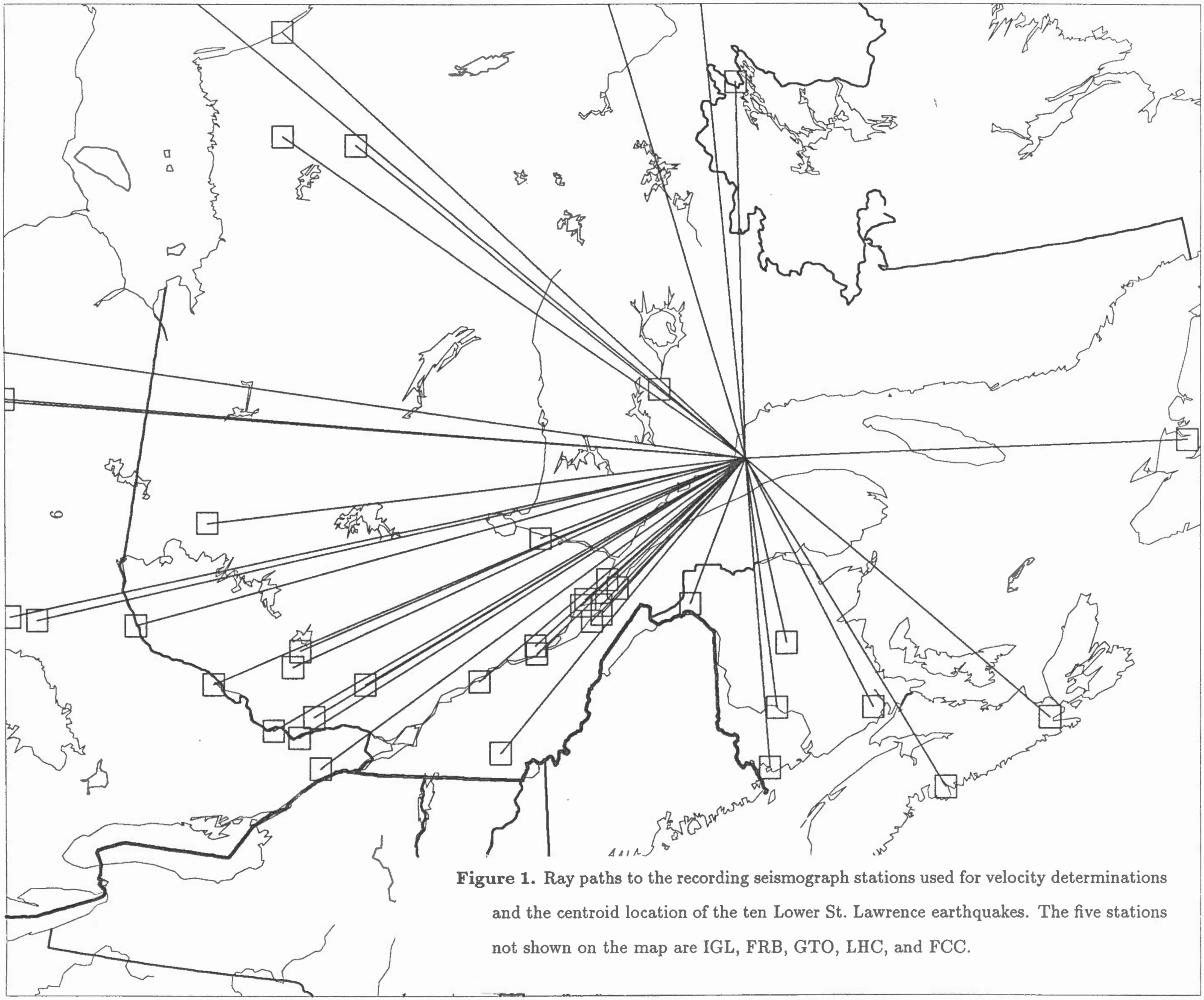


Figure 1. Ray paths to the recording seismograph stations used for velocity determinations and the centroid location of the ten Lower St. Lawrence earthquakes. The five stations not shown on the map are IGL, FRB, GTO, LHC, and FCC.

Figure 2. Range of Lg velocities and mean Lg velocity for each seismograph station.

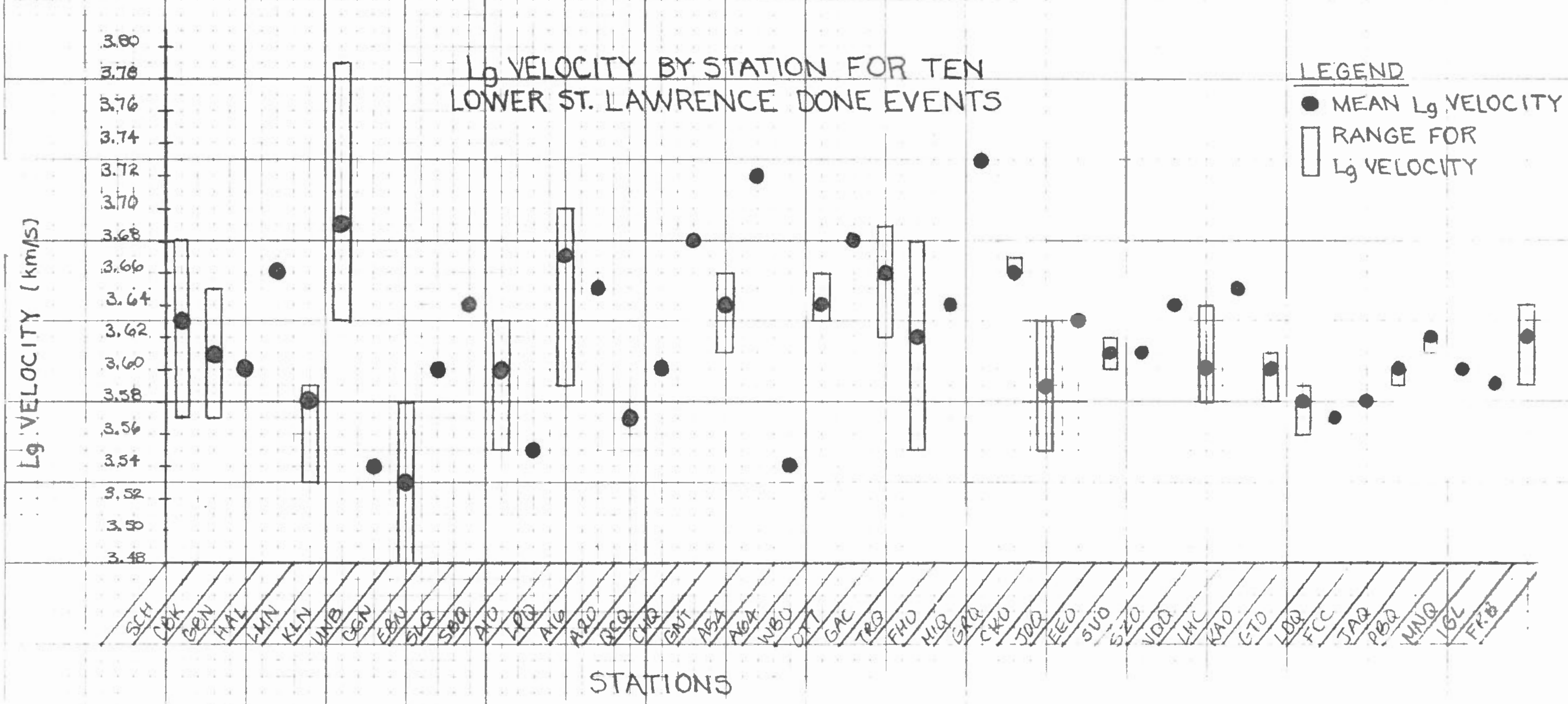
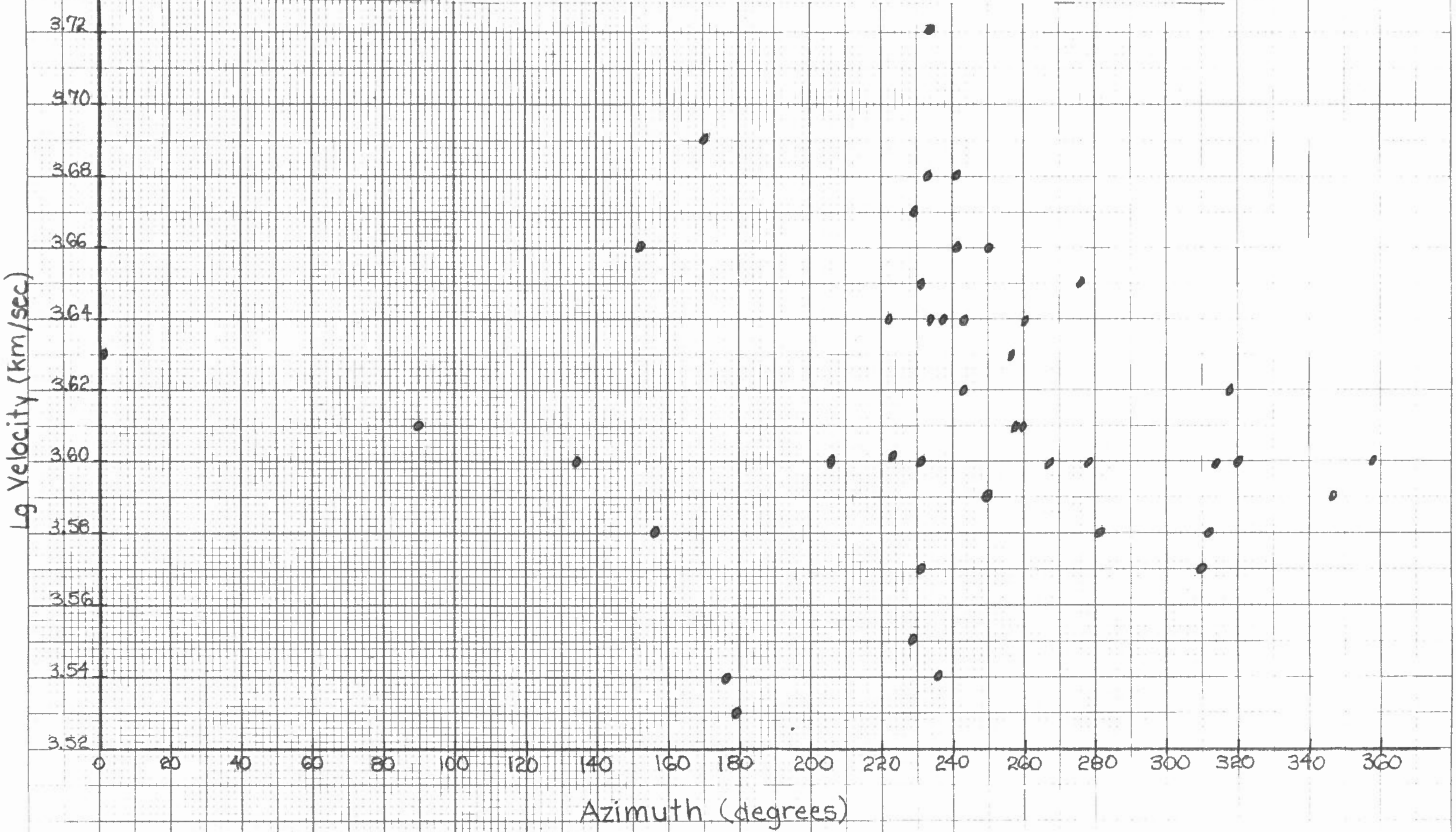


Figure 3. Mean Lg velocity plotted against azimuth of propagation to the recording stations.



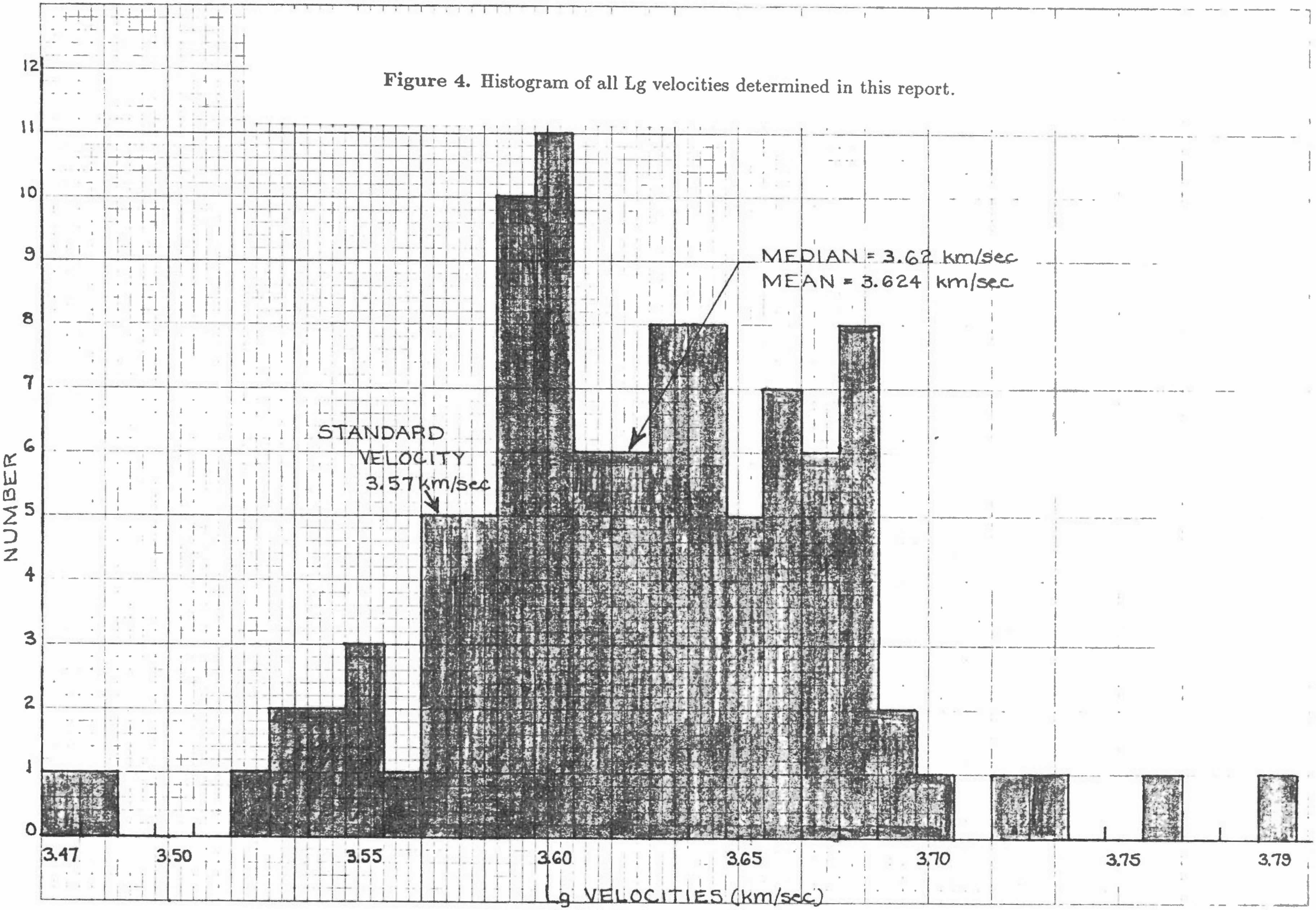


Figure 4. Histogram of all Lg velocities determined in this report.

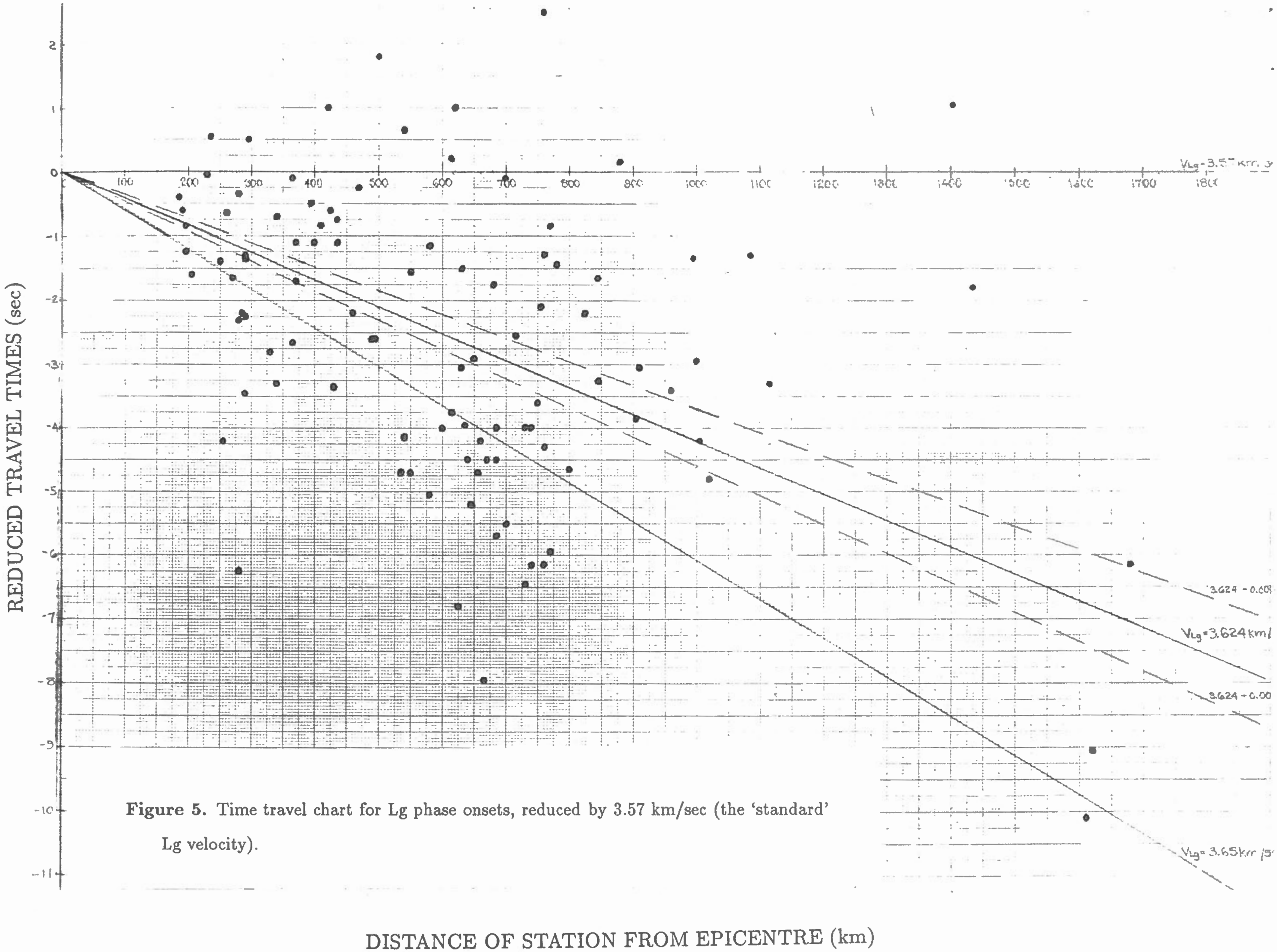


Figure 5. Time travel chart for Lg phase onsets, reduced by 3.57 km/sec (the 'standard' Lg velocity).

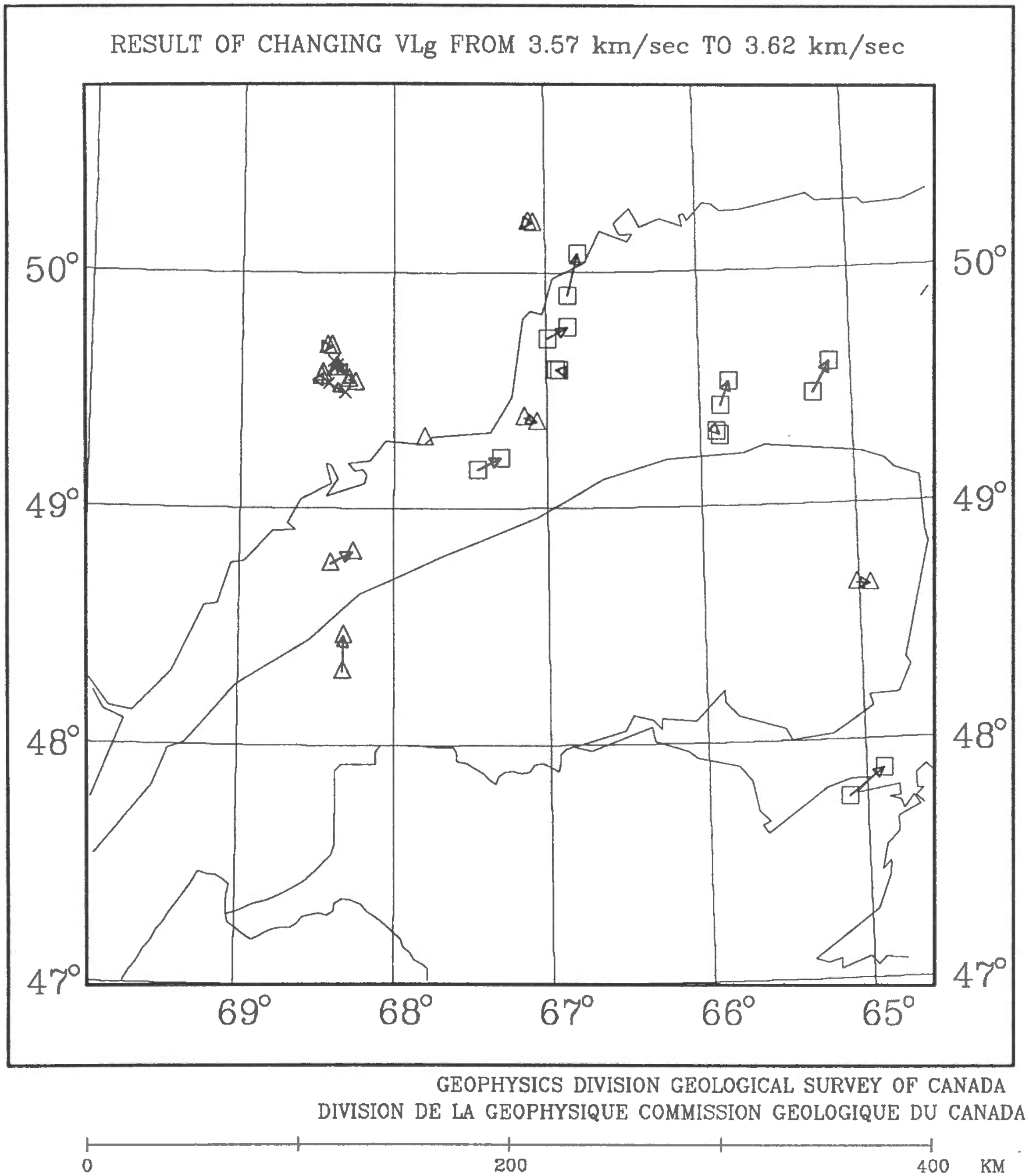
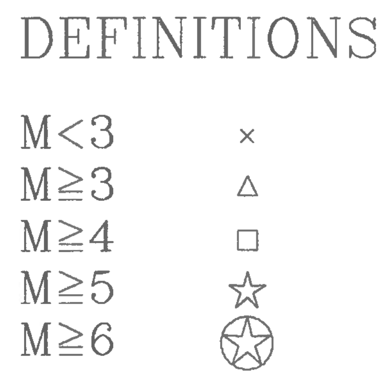


Figure 6. Map of Lower St. Lawrence earthquakes, previously located by Sharp (1987) and Vatcher (1987), showing the result of changing the Lg velocity from 3.57 km/sec to 3.62 km/sec (arrow points from old to new epicentre).



APPENDIX A

Pikfiles for the Lower St. Lawrence earthquakes used in this report

```
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$048.67 - 67.98 F MN=4.1 165724. 03041980   11KM 11KM 0   15 17 04 0.6 800
$FELT(IV) AT MATANE, BAIE-DES-SABLES     RESSENTI(IV) A MATANE,
$AND ST-MOISE                            BAIE-DES-SABLES ET ST-MOISE
$(III) AT VAL-BRILLANT  AND METIS BEACH  (III)  A  VAL-BRILLANT  ET METIS BEACH
$(II) AT ST-HILARION (GASPE)             (II) A ST-HILARION (GASPE)
$NOT FELT AT MONT-JOLI, LAC-HUMQUI       NON RESSENTI A  MONT-JOLI, LAC-HUMQUI
$AND ST-THARCISIUS                       ET ST-THARCISIUS
$ 180 KM SW FROM SEPT-ILES, QUE.         180 KM SO DE SEPT-ILES, QUE.
$ FOCAL MECHANISM COMPILED BY ADAMS/STAGG
A208004031657P A575246C                             581585                     1
A20    SW 0179KM23 -018  232 49                    06  039     0000000 00ML00MN
SIC8004031657P A5753  D                                                        1
SIC    NE 0181KM23  008  025 49                                0000000 00ML00MN
A648004031657P A575265C                             581609                     1
A64    SW 0183KM23 -051  238 49                    06 -054     0000000 00ML00MN
CBM8004031657P  57549                                      020 200 274         1
CBM    S  0199KM06 -025  187 49                                0004304 31ML36MN
A608004031657P  575498                              582144                     1
A60    SW 0204KM06 -076  237 49                    06 -104     0000000 00ML00MN
D3A8004031657P  57558                                                          1
D3A    SW 0207KM06 -030  210 49                                0000000 00ML00MN
MNQ8004031657P A575705C                            B582293 017 100 205           583321
MNQ    N  0215KM23 -005  341 49                    06 -262     0007577 34ML39MN
D5A8004031657P  57572                                                          1
D5A    SW 0218KM06 -025  211 49                                0000000 00ML00MN
POC8004031657P  57585 +                   5821                                 1
POC    SW 0224KM06  037  229 49          06 -158               0000000 00ML00MN
LMQ8004031657P  57580 +                  X5801                                 1
LMQ    SW 0227KM06 -062  236 49          00 ****$              0000000 00ML00MN
A548004031657P  580021                                                         1
A54    SW 0239KM06  021  235 49                                0000000 00ML00MN
A108004031657P  580020+                                                        1
A10    SW 0241KM06 -004  228 49                                0000000 00ML00MN
HN 8004031657P  58048                                                          1
HN     S  0284KM06 -067  183 49                                0000000 00ML00MN
UNB8004031657P C58077 -                                    04   79 240         1
UNB    S  0319KM01 -211  163 49                                0004772 40ML39MN
CHQ8004031657P  58115 +                            X5855   02  173 350         1
CHQ    SW 0331KM06  032  234 49                    00 -286     0006356 39ML41MN
QCQ8004031657P X58165 E
QCQ    SW 0337KM00  454  232 49                                0000000 00ML00MN
JKM8004031657P  58179                                                          1
JKM    SW 0386KM06 -009  209 49                                0000000 00ML00MN
PQ08004031657P  58204                                                          1
PQ0    S  0415KM06 -105  176 49                                0000000 00ML00MN
GNT8004031657P B582382+                   5905     X592299 027 100 177           593220
GNT    SW 0431KM06  037  234 49          06 -174   00 -306     0004119 43ML41MN
EMM8004031657P  58237                                                          1
EMM    S  0443KM06 -119  177 49                                0000000 00ML00MN
TRM8004031657P  58348                                      020 200 171         1
TRM    S  0529KM06 -058  202 49                                0002686 42ML41MN
DVT8004031657P                                             030 200 284         1
DVT    SW 0533KM         220 49                                0002974 44ML41MN
HAL8004031657P  58385 +                  X59285            02   85 140         1
HAL    SE 0556KM06 -016  143 49          00 -480               0005174 45ML44MN
MNT8004031657P C583911                   C593458   X595918 023 100 122           000513
MNT    SW 0567KM01 -093  233 49          01 -113   00 -496     0003333 44ML42MN
PNY8004031657P  58453                                                          1
PNY    SW 0615KM06 -053  228 49                                0000000 00ML00MN
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MIQ8004031657P A585295D                  C595827   X602402 057 100 230           003998
MIQ    W  0667KM23  075  250 49          01  135   00 -800     0002535 49ML42MN
GAC8004031657P B585169E                            X602834 020 1002033           003658
GAC    SW 0670KM06 -087  243 49                    00 -455     0063869 59ML56MN
SCH8004031657P  58538 -                  C6002     X60325  03  105 120         1
SCH    N  0684KM06 -052  006 49          01  138   00 -431     0002394 47ML42MN
OTT8004031657P X594765E
OTT    SW 0704KM00 5087$ 241 49                                0000000 00ML00MN
FHO8004031657P A590122D                  C601325   X604636 037 100 155           005969
FHO    SW 0733KM23  091  244 49          01  218   00 -431     0002632 49ML43MN
WES8004031657P  59035                                                          1
WES    SW 0755KM06  063  203 49                                0000000 00ML00MN
UCT8004031657P                                             050 200 378         1
UCT    SW 0840KM         206 49                                0002375 51ML43MN
LDQ8004031657P                                      613124
LDQ    NW 0878KM         314 49                    06  000     0000000 00ML00MN
PBQ8004031657P                                     C6202   04   93  40         1
PBQ    NW 0999KM         321 49                    01 -303     0000676 48ML39MN
SUD8004031657P                            6110     X6206   04  104  40         1
SUD    W  1020KM         261 49          06 -198   00 -481     0000604 47ML39MN
LHC8004031657P                                             05   67  16         1
LHC    W  1580KM         277 49                                0000300 50ML39MN
FRB8004031657P X60525                    X6328     X6509   06   79  13         1
FRB    N  1678KM00 -292  359 49          00 -390   00 -606     0000172 49ML37MN
PWM8004031657P                                             15    5  02         1
PWM    W  2043KM         285 47                                0000168 49ML38MN
BLC8004031657P                                             13   50  20         1
BLC    NW 2421KM         326 39                                0000193 51ML40MN
YKA8004031657P X6407  +
YKA    NW 3233KM00 4303$ 316 33                                0000000 00ML00MN
             Z
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+48.992- 67.214F1MN=4.1 1935531 17011983 00.0150.027 0.2 17 22 220.58 217.00    0 1ML=3.8 100  0 0.00
$ NO T.C. ON SIC.
MAG (NEIS) 4.5MB (2 OBS)                 MAG (NEIS) 4.5MB (2 OBS)
NEAR LES MECHINS, QUEBEC.                PRES DE LES MECHINS, QUEBEC.
FELT.  MAXIMUM INTENSITY IV.             RESSENTI.  INTENSITE MAXIMALE DE IV.
PERCEPTIBLE TO 60 KM.                    PERCEPTIBLE JUSQU'A 60 KM.
QUESTIONNAIRES SENT TO POST-             QUESTIONNAIRES ENVOYES AUX MAITRES
MASTERS.                                 DE POSTE.
$ DEPTH PHASES ON YKA: P=50.78 SEC, PP=55.42, SP=57.65
$ APPROXIMATE DEPTHS:                   16.6      16.8 KM
$ DEPTH PEGGED AT 17 KM
$FOCAL MECHANISM DETERMINED BY ADAMS/SHARP
$RATIO=  0.538 GSQ      0.00  15309.59  52887.16
$RATIO=  0.616 HTQ    -12.18  -1035.14   4213.62
  20 KM N  FROM GROSSES-ROCHES, QUE.    20 KM N  DE GROSSES-ROCHES, QUE.
GSQ  8301171935P                  A355717C           B355934 008 1.0 065         1
GSQ   SE 0011KM         139-34    21  065            05  034   0510509 28ML48MN
HTQ  8301171935P                  A360825D           B361970 010 020 107         1
HTQ   W  0089KM         285-79    21  046            05  113   0033615 31ML39MN
SIC  8301171935P                  X36147 C                                       1
SIC   N  0136KM         015-83    00 -055                      0000000 00ML00MN
EBN  8301171935P  A362145C                   B364384         015 102 153         1
EBN   SW 0187KM 21 -029 205 49               05  092           0006283 31ML37MN
MNQ  8301171935P  A362365D                           B36498  020 022 109         1
MNQ   NW 0205KM 21 -040 327 49                       05 -105   0015565 37ML41MN
CBM  8301171935P  X362740                    X365270                             1
CBM   S  0239KM 00 -073 197 49               00 -136           0000000 00ML00MN
KLN  8301171935P  B362781+                   C365640 X37008  014 050 115         1
KLN   S  0247KM 05 -134 165 49               01  055 00 -177   0010322 36ML41MN
LPQ  8301171935P  B363270                    X37015  X370910 020 030 145         1
LPQ   SW 0278KM 05 -013 230 49               00 -076 00 -195   0015184 41ML43MN
LMQ  8301171935P  B36326 D        X36356     X37010                              1
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HN   8301171935P  B363720                                                        1
HN    S  0320KM 05 -086 191 49                                 0000000 00ML00MN
UNB  8301171935P                                     B372810                     1
UNB   S  0341KM         172 49                       05 -077   0000000 00ML00MN
LMN  8301171935P  B364509-                           X37426  038 048 105         1
LMN   SE 0394KM 05 -193 152 49                       00 -096   0003617 42ML40MN
GGN  8301171935P  B365052                    X37344          020 089 120         1
GGN   S  0432KM 05 -114 176 49               00 -071           0004236 41ML41MN
MIM  8301171935P  X365130                    X373550                             1
MIM   S  0439KM 00 -126 199 49               00 -119           0000000 00ML00MN
PQ0  8301171935P  X365190                                                        1
PQ0   S  0446KM 00 -148 183 49                                 0000000 00ML00MN
PQ1  8301171935P  X365305                                                        1
PQ1   S  0455KM 00 -140 181 49                                 0000000 00ML00MN
GNT  8301171935P  B365810-                           X38071  056 055 202         1
GNT   SW 0485KM 05 -006 235 49                       00 -211   0004121 47ML42MN
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SBQ   SW 0538KM 05  053 223 49                       00  105   0003531 47ML42MN
BNH  8301171935P  X370865                                                        1
BNH   SW 0579KM 00 -093 214 49                                 0000000 00ML00MN
MNT  8301171935P  X37115                     X381262 X38410  040 161 225         1
MNT   SW 0621KM 00 -324 234 49               00 -277 00 -625   0002195 47ML41MN
SCH  8301171935P  X37189                     X38210  X38520  040 094 230         1
SCH   N  0650KM 00  066 002 49               00 -049 00 -319   0003843 50ML44MN
GAC  8301171935P  B372650                            X39102  050 158 220         1
GAC   SW 0724KM 05 -071 243 49                       00 -569   0001750 48ML41MN
RS   8301171935P  B372950                                                        1
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RS    SW 0746KM 05 -045 231 49                                 0000000 00ML00MN
WBO  8301171935P  B373100+                   X38447  X39216  058 163 226         1
WBO   SW 0757KM 05 -026 237 49               00  050 00 -358   0001502 49ML41MN
OTT  8301171935P                                     X39200                      1
OTT   SW 0758KM         241 49                       00 -561   0000000 00ML00MN
VDQ  8301171935P                                     X39327  045 174 205         1
VDQ   W  0798KM         268 49                       00 -397   0001645 49ML41MN
CKO  8301171935P  C37398                             X39454  045 269 234         1
CKO   W  0840KM 01 -162 250 49                       00 -309   0001215 48ML40MN
PBQ  8301171935P  X38006                     X39345  X40303  050 079 124         1
PBQ   NW 1003KM 00 -075 318 49               00 -219 00 -399   0001972 53ML44MN
KAO  8301171935P  X38116                     X40070  X41020  060 097 079         1
KAO   W  1113KM 00 -308 278 49               00  704 00 -287   0000853 51ML41MN
GTO  8301171935P  X38582                     X41062  X42337  060 115 057         1
GTO   W  1434KM 00  434 281 49               00 -211 00 -112   0000519 52ML41MN
LHC  8301171935P  X3908                              X431750 060 053 021         1
LHC   W  1620KM 00 -855 276 49                       00 -947   0000415 52ML40MN
FRB  8301171935P  X39204                     X41555  X43250  060 079 027         1
FRB   N  1647KM 00  059 358 49               00  192 00 -950   0000358 52ML40MN
RSO  8301171935P  X394750                                                        1
RSO   W  1905KM 00 -268 286 50                                 0000000 00ML00MN
FCC  8301171935P                             X43192  X452800 100 038 014         1
FCC   NW 2056KM         312 47               00 -148 00 -116   0000231 52ML40MN
IGL  8301171935P  X40470                             X47040  070 064 014         1
IGL   N  2407KM 00  480 346 39                       00 -351   0000196 52ML40MN
BLC  8301171935P  X404732
BLC   NW 2420KM 00  396 326 39                                 0000000 00ML00MN
YKA  8301171935P  X415078C
YKA   NW 3240KM 00 -187 315 33                                 0000000 00ML00MN
             Z
```

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+49.609- 66.456F1MN=3.2 2252496 29031984 00.0060.018 0.3 11 21  80.33 218.00    0 1ML=2.7  80
  70 KM S  FROM SEPT-ILES, QUE.          70 KM S  DE SEPT-ILES, QUE.
$ FOCAL MECHANISM DETERMINED BY ADAMS/STAGG
$RATIO=  1.092 GSQ 530495D 0.13   -37.13     60.87 531622 0.09   459.13
SIC8403292253P                 A53004 D                                        1
SIC   N  0066KM          342-74 19 -027                             0000000 00ML00MN
GSQ8403292253P            -0.21 A530496D            B531625 012  64 145        1
GSQ   SW 0092KM          211-78 19 -003             05  010         0011863 28ML34MN
HTQ8403292253P                 A531341D             B533195 010 179 130        1
HTQ   W  0148KM          252-82 19 -031             05  048         0004563 26ML34MN
MNQ8403292253P A531969D                             B53445  010 138 150        1
MNQ   NW 0195KM19  046   303 49                     05 -012         0006830 30ML37MN
EBN8403292253P C53304 +   -0.21           X54015            010 752 120        1
EBN   SW 0273KM01  154   210 49           00  370                   0001003 26ML31MN
KLN8403292253P A533325C   -0.30           C54045            0071191  80        1
KLN   S  0308KM19  002   179 49           01 -084                   0000603 23ML30MN
LPQ8403292253P C534047E   -0.21                     X54289  020 620 135        1
LPQ   SW 0364KM01  046   228 49                     00 -314         0000684 31ML32MN
LMQ8403292253P B53410 +                   B54186    B5432   020 292 092        1
LMQ   SW 0366KM05  093   233 49           05  109   05 -038         0000990 33ML34MN
LMN8403292253P B534878C   -0.30           C54335    C5451   0082583  45        1
LMN   S  0436KM05 -008   163 49           01  087   01 -119         0000137 23ML26MN
GGN8403292253P C5357      -0.30           C54465                               1
GGN   S  0500KM01  035   183 49           01  029                   0000000 00ML00MN
SCH8403292253P B54068 -                   C55050    X55270                     1
SCH   N  0580KM05  060   358 49           01  191   00 -531         0000000 00ML00MN
             Z
```

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+49.314- 67.514F1MN=3.8 1907416 11041984 00.0180.025 0.2 24 41 211.00Z218.50   0 1ML=3.8 100
FELT AT BAIE-COMEAU, QUE.                RESSENTI A BAIE-COMEAU, QUE.
$PAPER CHANGE AT SXO
$ ECTN PN'S FROM SAM
  50 KM NW FROM GROSSES-ROCHES, QUE.     50 KM NO DE GROSSES-ROCHES, QUE.
$FOCAL MECHANISM DETERMINED BY ADAMS/SHARP
GSQ8404111907P            -0.21 A075113D            B07573  020   9 225        1
GSQ   SE 0055KM          147-70 16 -010             04 -080         0078540 35ML39MN
HTQ8404111907P                 A075389D             B08023  010  47 230        1
HTQ   W  0066KM          258-73 16  120             04  152         0030748 29ML36MN
SIC8404111907P                 A07596 C                                        1
SIC   NE 0111KM          030-79 16 -019                             0000000 00ML00MN
EBN8404111907P A081493C   -0.21                     B08389  015 102 185        1
EBN   S  0213KM16  137   195 49                     04 -291         0007597 33ML38MN
A208404111907P         +                                                       1
A20   SW 0241KM          223 49                                     0000000 00ML00MN
A168404111907P         -                                                       1
A16   SW 0276KM          223 49                                     0000000 00ML00MN
LMQ8404111907P A08230 D                                                        1
LMQ   SW 0286KM16  069   228 49                                     0000000 00ML00MN
LPQ8404111907P A082353-   -0.21                     X08598  030  42 180        1
LPQ   SW 0287KM16  093   221 49                     00 -272         0008976 40ML41MN
KLN8404111907P A082270+   -0.30 X08316    C08531    C0901   021 152 150        1
KLN   S  0288KM16 -008   162 49 00  308   01  004   01 -179         0002953 34ML37MN
UNB8404111907P X0831                                B0931   040 074 156        1
UNB   S  0380KM00 -270   170 49                     04  270         0003311 41ML39MN
QCQ8404111907P                 X0842                X0932   040 029 058        1
QCQ   SW 0398KM          226-86 00 -393             00 -126         0003142 42ML39MN
LMN8404111907P A084039C   -0.30                     C0943   030 107  85        1
LMN   SE 0436KM16 -043   151 49                     01 -118         0001664 39ML37MN
GGN8404111907P A084505D   -0.30           C0932     X0953   030 253 215        1
GGN   S  0470KM16  014   173 49           01  034   00 -062         0001780 41ML38MN
SBQ8404111907P C085713                                                         1
SBQ   SW 0550KM01  265   219 49                                     0000000 00ML00MN
HAL8404111907P X09011                     B09596    B10256  030 205 082        1
HAL   SE 0600KM00  060   149 49           04  052   04 -419         0000838 41ML36MN
SCH8404111907P B09028                     B10065    X1034   040 120 153        1
SCH   N  0615KM04  042   004 49           04  415   00  001         0002003 47ML40MN
MNT8404111907P B090465                                      017 539 175        1
MNT   SW 0627KM04  089   230 49                                     0001200 41ML38MN
GBN8404111907P B09040                               B10360  040 141 039        1
GBN   SE 0628KM04  007   132 49                     04 -166         0000434 40ML34MN
TRQ8404111907P A090388                                      038 134 165        1
TRQ   SW 0630KM16 -037   240 49                                     0002036 47ML41MN
GRQ8404111907P A091062-                                     037 113 160        1
GRQ   SW 0692KM16 -116   247 49                                     0002404 48ML42MN
CBK8404111907P B09123                     B1022     B1057                      1
CBK   E  0698KM04 -024   090 49           04  190   04 -037         0000000 00ML00MN
JAQ8404111907P X092020-                   C1034             025 377 165        1
JAQ   NW 0757KM00  050   314 49           01  142                   0001100 44ML39MN
LTQ            P
LTQ   NW 0769KM          313 49                                     0000000 00ML00MN
VDQ8404111907P A092074                    C10365    C11181  038 187 180        1
VDQ   W  0778KM16 -151   265 49           01 -053   01 -159         0001592 48ML41MN
EEO8404111907P A093744D                   C11036    X1154   05012801230        1
EEO   W  0912KM16 -119   255 49           01 -201   00 -328         0001208 50ML41MN
KAO8404111907P C09580                     B11405    X12445  050 126 039        1
KAO   W  1086KM01 -183   276 49           04 -210   00 -152         0000389 47ML37MN
GTO8404111907P X10425                     B12511    B14165  060 099 023        1
GTO   W  1406KM00  366   279 49           04  046   04  095         0000243 48ML37MN

FRB8404111907P X1103                      X1339     X1510   060 081 008        1
FRB   N  1611KM00 -075   358 49           00  488   00 -285         0000103 46ML34MN
YKA            P A13385 C
YKA   NW 3200KM16  071   315 33                                     0000000 00ML00MN
             Z
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+49.606- 66.350F1MN=3.2 2104525 28051984 00.0110.034 0.2 10 16  90.41 218.00  14 1ML=2.9  70
  70 KM SE FROM SEPT-ILES, QUE.          70 KM SE DE SEPT-ILES, QUE.
$ FOCAL MECHANISM DETERMINED BY ADAMS/STAGG
$RATIO=  0.719 GSQ 050869D 0.10   -73.25     88.75 052045 0.06   383.75
SIC8405282105P                 A05044 D                                        1
SIC   NW 0069KM          336-74 15  032                             0000000 00ML00MN
GSQ8405282105P            -0.21 A050870C            A052045 010 212 380        1
GSQ   SW 0096KM          215-78 15  015             15  027         0011262 27ML34MN
HTQ8405282105P A051690    -0.07 A051726-  A05357            020 349 290        1
HTQ   W  0155KM15 -031   254 49 15 -061   15  027                   0002610 27ML32MN
MNQ8405282105P A052295+   -0.10            05459            017 234 315        1
MNQ   NW 0202KM15 -001   302 49           04  046                   0004975 31ML36MN
EBN8405282105P  053357    -0.21           X06048            0201760 380        1
EBN   SW 0277KM04  144   211 49           00  346                   0000678 27ML30MN
KLN8405282105P  053608+   -0.30                             0102240 220        1
KLN   S  0307KM04  007   180 49                                     0000617 25ML30MN
A208405282105P         +                                                       1
A20   SW 0325KM          231 49                                     0000000 00ML00MN
LPQ8405282105P  054360E   -0.21                             0201280 260        1
LPQ   SW 0370KM04  009   228 49                                     0000638 31ML32MN
LMQ8405282105P  05436                      0622      0635   020 292 073        1
LMQ   SW 0372KM04 -001   234 49           04  045   04 -196         0000785 32ML33MN
CBK8405282105P                             0712     X0741   030 184 022        1
CBK   E  0615KM          094 49           04 -118   00 -390         0000250 36ML31MN
JAQ8405282105P  063560D   -0.07           X075044           0114364 190        1
JAQ   NW 0798KM04 -002   309 49           00 -179           ^^^^0249 35ML33MN
             Z
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+49.250- 67.392F1MN=4.2 1957191 09111986 00.0100.014 0.2 23 43 130.58 218.00    0 1ML=4.2  80
$FOCAL MECHANISM DETERMINED BY ADAMS/STAGG
$RATIO=   0.021 HTQ 573152D 0.27 -4275.19 13388.80 574043 0.16  4488.81
$RATIO=   0.851 GSQ 572710D 0.21  -956.08  1768.92 573215 0.09  6783.08
GSQ8611091957P           -0.22 A572709D            C573215                       573279
GSQ    SE 0044KM        152-67 21  003             01 -056     0000000 00ML00MN
HTQ8611091957P           -0.07 A573153D            A574044 020 1001823           574492
HTQ    W  0073KM        265-75 21  013             21  006     0057271 36ML40MN
MNQ8611091957P A574656C  -0.10 X575115   C580705                                 581529
MNQ    NW 0174KM21  034  326 49 00  367   01  085                    0000000 00ML00MN
EBN8611091957P A575110C  -0.22           B581401           037 1001173           581484
EBN    S  0209KM21  056  198 49           05  036                 0019919 41ML43MN
SLQ8611091957P  57515 C
SLQ    SW 0213KM05  063  215 49                                  0000000 00ML00MN
A208611091957P        C
A20    SW 0242KM        226 49                                  0000000 00ML00MN
KLN8611091957P B575862C  -0.29                     B584023 020 100 308           584258
KLN    S  0278KM05 -050  164 49                     05  263     0009676 39ML41MN
LPQ8611091957P A580012-  -0.22 C580542   C582957   X583752 027 100 715           584567
LPQ    SW 0288KM21 -007  223 49 01 -047   01 -091   00 -265     0016639 43ML44MN
LMQ8611091957P  57597 -
LMQ    SW 0288KM05 -035  230 49                                  0000000 00ML00MN
LMN8611091957P B581592+  -0.29           B585911   B591754 023 100  93           592006
LMN    SE 0425KM05 -111  152 49           05 -071   05 -113     0002541 40ML39MN
GGN8611091957P A582103D  -0.29           C590895   X593204 040 100 244           593308
GGN    S  0462KM21 -038  174 49           01  147   00  323     0003833 45ML41MN
GNT8611091957P B582548   -0.06           B591507   X593433 043 100 406           593611
GNT    SW 0492KM05  053  231 49           05  127   00 -287     0005932 48ML43MN
SBQ8611091957P B583283+  -0.07           B592752   B595160 040 100 247           595942
SBQ    SW 0550KM05  075  220 49           05  129   05 -189     0003880 47ML42MN
GBN8611091957P  58405 E
GBN    SE 0617KM05  046  132 49                                  0000000 00ML00MN
SCH8611091957P  58415 -                    5942
SCH    N  0621KM05  083  004 49           05  073                 0000000 00ML00MN
MNT8611091957P B584110   -0.06           B594196   C601225 030 100 123           001459
MNT    SW 0629KM05 -049  231 49           05 -088   01 -315     0002576 47ML42MN
TRQ8611091957P B584076E  -0.09           B594467   X601277 037 100 279           002003
TRQ    SW 0634KM05 -159  241 49           05  052   00 -416     0004738 50ML44MN
GRQ8611091957P B584791+  -0.09           C595765   X602910
GRQ    W  0698KM05 -214  248 49           01  007   00 -564     0000000 00ML00MN
GAC8611091957P B585257-  -0.06
GAC    SW 0726KM05 -086  240 49                                  0000000 00ML00MN
OTT8611091957P B585937   -0.06                             043 100 183
OTT    SW 0761KM05  161  239 49                                  0002674 50ML43MN
WBO8611091957P B585751E  -0.06           C601133           047 100 151           010175
WBO    SW 0762KM05 -034  235 49           01  012                 0002019 49ML42MN
JAQ8611091957P A585823+  -0.07
JAQ    NW 0768KM21 -042  314 49                                  0000000 00ML00MN
CKO8611091957P C590427   -0.06
CKO    W  0838KM01 -284  248 49                                  0000000 00ML00MN
EEO8611091957P B591457-  -0.06           C604441   X604555 033 100  32           010150
EEO    W  0919KM05 -246  256 49           01 -026   00 ****$     0000609 45ML38MN
             Z
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+49.263- 67.60101MN=3.2 2248366 16081985 00.0070.008 0.2 20 29 150.45 218.00    0 1ML=2.7  70
$ 60 KM NW FROM GROSSES-ROCHES, QUE.     60 KM NO DE GROSSES-ROCHES, QUE.
$ FOCAL MECHANISM COMPILED BY ADAMS/STAGG
$RATIO= -0.164 HTQ 484665D 0.13 -1121.99  2157.01 485407 0.08   769.01
$RATIO=  0.705 GSQ 484619D 0.11  -118.81   246.19 485262 0.10   601.81
GSQ8508162248P           -0.21 A484621D            A485261 020 100 407          1
GSQ    SE 0054KM        138-71 21  013             21 -024     0012786 27ML31MN
HTQ8508162248P           -0.07 A484668D            A485408 007 100  70          1
HTQ    W  0058KM        262-72 21  008             21  022     0006283 20ML28MN
SIC8508162248P                 A48565 C
SIC    NE 0119KM        031-80 21  045                         0000000 00ML00MN
MNQ8508162248P A490196C  -0.10                      492160 007 100 105          1
MNQ    NW 0165KM21 -063  330 49                     05 -156     0009425 28ML38MN
EBN8508162248P C490986C  -0.21                     B493391 017 100  52          1
EBN    S  0206KM01  213  194 49                     05 -090     0001922 27ML32MN
SLQ8508162248P C49095 +                            C49355
SLQ    SW 0206KM01  196  211 49                     01  087     0000000 00ML00MN
A208508162248P X491206                             C494155                      1
A20    SW 0232KM00  137  223 49                     01 -035     0000000 00ML00MN
A648508162248P X491214                             C49424                       1
A64    SW 0233KM00  137  227 49                     01  033     0000000 00ML00MN
A168508162248P X491661                             X4950                        1
A16    SW 0268KM00  156  223 49                     00 -190     0000000 00ML00MN
LMQ8508162248P  49175                              X49482
LMQ    SW 0278KM05  120  228 49                     00 -646     0000000 00ML00MN
LPQ8508162248P C491798-  -0.21                     C495435 027 100  73          1
LPQ    SW 0279KM01  138  221 49                     01 -078     0001699 32ML34MN
KLN8508162248P X491879   -0.30                             010 100   9          1
KLN    S  0284KM00  138  161 49                                 0000565 24ML29MN
A548508162248P X491950                             C495750                      1
A54    SW 0290KM00  177  227 49                     01 -045     0000000 00ML00MN
A108508162248P X492026                             C50000                       1
A10    SW 0296KM00  181  222 49                     01  032     0000000 00ML00MN
LMN8508162248P B493678+  -0.2                      C503961
LMN    SE 0434KM05  124  150 49                     01  106     0000000 00ML00MN
GGN8508162248P C494024E  -0.30                             020 100   6          1
GGN    S  0465KM01  089  172 49                                 0000188 29ML28MN
SCH8508162248P C49575
SCH    N  0621KM01 -064  005 49                                 0000000 00ML00MN
TRQ8508162248P X500058E                  X510148   C513180 023 100   9          1
TRQ    SW 0622KM00  231  240 49           00  255   01  092     0000246 35ML31MN
GRQ8508162248P                                     X514372 037 100  27           515394
GRQ    W  0684KM        248 49                     00 -465     0000459 41ML35MN
GAC8508162248P                                     X515378 040 100  16          1
GAC    SW 0713KM        239 49                     00 -280     0000251 39ML32MN
WBO8508162248P                                     X520338 043 100  11          1
WBO    SW 0751KM        234 49                     00 -360     0000161 38ML31MN
JAQ8508162248P C501583-                   512809   X520626 027 100  13          1
JAQ    NW 0756KM01  117  315 49           05  056   00 -237     0000303 39ML34MN
VDQ8508162248P C501591                              521173 040 100  13          1
VDQ    W  0771KM01 -054  265 49                     05 -103     0000204 39ML32MN
CKO8508162248P                           C514289   X522519 047 100   9           522618
CKO    W  0824KM        248 49           01  094   00 -245     0000120 38ML30MN
EEO8508162248P C503172                             X524623 033 100   8          1
EEO    W  0905KM01 -101  256 49                     00 -391     0000152 39ML32MN
             Z
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+48.737- 68.24601MN=3.6 0021538 03051987 00.0070.016 0.2 21 32 150.52Z213.93  13 1ML=3.4   90
LOWER ST.LAWRENCE REGION, QUE.          REGION DU BAS SAINT-LAURENT
NEAR LES BOULES, ON THE                 PRES DE LES BOULES, SUR LA RIVE SUD
SOUTH SHORE
$ MNQ, JAQ DEAD
$ SUO, SZO TRIGGERED ON LG, PN LOST
$ ADD REGIONAL WHEN AVAILABLE
$ KLN, LMN NO SG REALLY DEFINED
$ SG: OFTEN NOT WELL-DEFINED
$ SN: NOT ALWAYS STRONG
$RATIO=  0.547 HTQ 220267C 0.13      970.78    1210.22 22 897 0.10    3422.78
$RATIO= -0.131 GSQ 220776D 0.15     -846.77    1683.23 221811 0.13     625.81
HTQ8705030021P           -0.07 A220269C            A220895 010 1001599     0  0
HTQ   N  0052KM         348-74 14  008             14 -003     0100468 33ML39MN
GSQ8705030021P           -0.22 A220776D            B221799 013 100 255     0  0
GSQ   E  0086KM         076-80 14 -035             03 -045     0012325 28ML34MN
SLQ8705030022P                 A22160 D            X2226
SLQ   SW 0132KM         206-83 14  071             00 -506     0000000 00ML00MN
EBN8705030021P B221799   -0.22 A221729+            A223379 013 100 247     0  0
EBN   S  0142KM03  044  180-83 14  020             14 -023     0011938 31ML38MN
A208705030022P        +
A20   SW 0157KM         224 49                                 0000000 00ML00MN
A648705030022P        D
A64   SW 0159KM         231 49                                 0000000 00ML00MN
A618705030022P        +
A61   SW 0180KM         230 49                                 0000000 00ML00MN
A16          P        E
A16   SW 0193KM         224 49                                 0000000 00ML00MN
SIC8705030022P A22236 D                  A22461
SIC   NE 0194KM14 -005  034 49           14  038               0000000 00ML00MN
LPQ8705030021P A222518C  -0.22           C224801   X224909 013 100 212     0  0
LPQ   SW 0204KM14  011  221 49           01  000   00 -215     0010246 33ML39MN
LMQ8705030022P A222450-
LMQ   SW 0204KM14 -039  230 49                                 0000000 00ML00MN
A548705030022P        -
A54-  SW 0215KM         229 49                                 0000000 00ML00MN
KLN8705030021P B223061-  -0.29                     X230049 010 100  38     0  0
KLN   SE 0253KM03 -061  146 49                     00 -472     0002388 28ML35MN
GNT8705030021P A225081   -0.06                     X234725 033 100  83     0  0
GNT   SW 0408KM14  101  231 49                     00 -096     0001580 39ML36MN
LMN8705030021P A225016+  -0.29           X232904           007 100    4     0  3
LMN   SE 0413KM14 -056  140 49           00 -368               0000359 26ML30MN
GGN8705030021P A225074E  -0.29           C233499    235160 040 100  36     0  3
GGN   S  0417KM14 -041  164 49           01  150   03  055     0000565 35ML32MN
SBQ8705030021P X225888   -0.07           X234532   X240243 027 100  80     0  0
SBQ   SW 0467KM00  186  218 49           00  146   00 -228     0001862 40ML38MN
MNT8705030021P B230683   -0.06           B240019   X242203 013 100  16     0  0
MNT   SW 0544KM03  041  231 49           03 -007   00 -431     0000773 35ML35MN
TRQ8705030021P A230680-  -0.09           B240345   X242374 037 100  48     0  0
TRQ   SW 0552KM14 -067  242 49           03  135   00 -483     0000815 40ML36MN
HAL8705030022P A23114 D
HAL   SE 0578KM14  084  140 49                                 0000000 00ML00MN
GRQ8705030021P B231420E  -0.09           X241785   X244654 033 100  39     0  0
GRQ   W  0619KM03 -141  250 49           00  155   00 -085     0000743 42ML36MN
GBN8705030022P B231750E
GBN   SE 0631KM03  048  123 49                                 0000000 00ML00MN
GAC8705030021P A231813-  -0.06           X242388   X244873 000   0   0     0  0
GAC   SW 0643KM14 -039  241 49           00  247   00 -544     0000000 00ML00MN
WBO8705030021P C232310   -0.06           C242774   X245902 040 100  30     0  0
WBO   SW 0678KM01  034  235 49           01 -104   00 -487     0000471 41ML35MN


SCH8705030022P B23235 E                  X24285    X25000
SCH   N  0685KM03 -004  008 49           00 -169   00 -566     0000000 00ML00MN
JBQ          P X23327 E
JBQ   NW 0747KM00  149  319 49                                 0000000 00ML00MN
CKO8705030021P B233118E  -0.06           X244650   X252891 033 100  25     0  0
CKO   W  0759KM03 -147  250 49           00  045   00  232     0000476 41ML36MN
EEO8705030021P B234162+  -0.06           X250560   X254883 033 100  20     0  0
EEO   W  0845KM03 -157  258 49           00  116   00 -191     0000381 42ML35MN
SUO8705030022P                                     X263090 047 100  10            263738
SUO   W  0994KM         260 49                     00 -143     0000134 41ML32MN
SZO8705030022P                           X254185   X263613 037 100   7            265188
SZO   W  1028KM         261 49           00 -141   00 -577     0000119 40ML32MN
             Z
```

```
+48.868- 68.708F1MN=3.0 1939205 17061987 00.0100.022 0.2 15 22  20.51 213.58   0 1ML=2.2  20  0 0.00
LOWER ST.LAWRENCE REGION, QUE.          REGION DU BAS SAINT-LAURENT, QUE.
$ NEAR BETSIAMITES
$ SOLUTION PEGGED AT FREE DEPTH AND LOCATION OBTAINED BY DATA SUBSET
$ MNQ VERY NEAR NODAL, NEEDS FILTERS 5 - 19 HZ
$ GNT NOISY
$ EEO NOISY, WBO FULL OF SPIKES
$RATIO=  0.218 GSQ 393950D 0.20     -84.44    154.56 395414 0.07     139.44
$RATIO=  0.371 HTQ 392818D 0.09    -585.36    713.64 393317 0.17    1375.36
HTQ  8706171939P            -0.07 A392818D          A393316 007 100 116       3   393367
HTQ   NE 0043KM         032-71    12  030           12 -005   0010412 20ML36MN
GSQ  8706171939P            -0.22 A393950D          B395414 010 100  62           395704
GSQ   E  0117KM         087-82    12 -035           03  024   0003896 23ML31MN
SLQ  8706171939P                  A39426 +          B39583
SLQ   S  0136KM         190-83    12  003           03 -046   0000000 00ML00MN
A64  8706171939P XB39440          A39436 +
A64   SW 0145KM 00 -047 218-84    12 -051                     0000000 00ML00MN
A20  8706171939P XB394457         A39442 +
A20   SW 0148KM 00 -027 210-84    12 -041                     0000000 00ML00MN
EBN  8706171939P            -0.22 A394694-          B400565 013 100  23           400590
EBN   S  0160KM         167-84    12  019           03 -020   0001112 21ML28MN
A61  8706171939P XB39472          A39467 +
A61   SW 0166KM 00  015 219 49    12 -077                     0000000 00ML00MN
A16  8706171939P  A39491 E       XB39495
A16   SW 0183KM 12 -001 212 49    00 -074                     0000000 00ML00MN
MNQ  8706171939P  A394958+  -0.10                   B401193
MNQ   N  0185KM 12  007 359 49                      03 -082   0000000 00ML00MN
LMQ  8706171939P  A39509 D                          B40131
LMQ   SW 0190KM 12  095 220 49                      03 -080   0000000 00ML00MN
JOQ  8706171939P  X3950                             X4014
JOQ   W  0194KM 00 -040 256 49                      00 -107   0000000 00ML00MN
LPQ  8706171939P  A395197+  -0.22                   X401390 030 100 110       3   401569
LPQ   SW 0196KM 12  113 210 49                      00 -183   0002304 30ML33MN
SIC  8706171939P         E
SIC   NE 0204KM         044 49                                0000000 00ML00MN
SIC  8706171939P  A39515 C                   B40145
SIC   NE 0204KM 12 -009 044 49               03 -008          0000000 00ML00MN
KLN  8706171939P  B400118E  -0.29 X400539    X403013        013 100   8       3   403872
KLN   SE 0285KM 03 -068 141 49    00 -153    00 -214          0000387 23ML28MN
GGN  8706171939P  X402406   -0.29
GGN   S  0441KM 00  321 160 49                                0000000 00ML00MN
LMN  8706171939P  B402097   -0.29
LMN   SE 0447KM 03 -057 137 49                                0000000 00ML00MN
TRQ  8706171939P  X403175   -0.09            X412610
TRQ   SW 0530KM 00  024 238 49               00  196          0000000 00ML00MN
JAQ  8706171939P  A405628+  -0.07
JAQ   NW 0735KM 12 -019 321 49                                0000000 00ML00MN
             Z
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+49.608- 66.983F1MN=3.3 0844137 06081987 00.0110.030 0.2 14 17 110.47Z218.48  17 1ML=3.1  70  0 3.65
LOWER ST.LAWRENCE, QUE.                 BAS-SAINT-LAURENT, QUE.
NEAR POINTE-AUX-ANGLAIS                 PRES DE POINTE-AUX-ANGLAIS
AFTERSHOCK AT 08:47 MN=2.2              REPLIQUE A 08:47 MN=2.2
$RATIO=  1.510 GSQ 442681C 0.12      27.85     51.15 443661 0.09     901.15
$RATIO=  0.119 HTQ 443185D 0.20    -142.18    172.82 444530 0.13     187.18
SIC  8708060844P             0.00 A44249 C                   000   0   0    0  0
SIC   N  0065KM         016-73    13  023                      0000000 00ML00MN
GSQ  8708060844P            -0.22 A442682C           A443660 017 100 376    0  0
GSQ   S  0078KM         187-76    13 -002            13  024   0013897 29ML34MN
HTQ  8708060844P            -0.07 A443183D   X444813 B444530 013 100 119    0  0
HTQ   SW 0112KM         246-80    13 -034    00  063 03 -042   0005752 26ML33MN
MNQ  8708060844P XA443924D  -0.10                    B445904 017 100 275    0  0
MNQ   NW 0165KM 00 -036 309 49                       03 -119   0010164 32ML38MN
EBN  8708060844P  A445184+  -0.22           XB451905 B452477 013 100  22    0  0
EBN   S  0256KM 13  097 202 49               00  079 03 -114   0001063 26ML31MN
SLQ  8708060844P  B44525 E   0.00           XB45210 XB4526   030 307 170    0  0
SLQ   SW 0263KM 03  105 215 49               00  156 00 -151   0001160 30ML32MN
KLN  8708060844P  A445758+  -0.29                            000   0   0    0  0
KLN   S  0311KM 13 -004 171 49                                 0000000 00ML00MN
LMQ  8708060844P  B45020 E   0.00           XB4535           000   0   0    0  0
LMQ   SW 0337KM 03  150 228 49               00 -021           0000000 00ML00MN
LPQ  8708060844P  A450066+  -0.22            X453723 X454478 033 100  59    0  0
LPQ   SW 0337KM 13 -007 223 49               00  175 00 -378   0001123 34ML33MN
LMN  8708060844P  A451374E  -0.29           XB455977         013 100   2    0  3
LMN   S  0449KM 13 -067 158 49               00  048           0000097 24ML25MN
GGN  8708060844P  A452040+  -0.29           XB460948XB463557 033 100   9    0  3
GGN   S  0500KM 13 -021 179 49               00 -062 00  146   0000171 31ML28MN
SCH  8708060844P  B4530  E   0.00                   XB4655   030 137  27    0  0
SCH   N  0580KM 03 -021 001 49                       00 -141   0000413 36ML33MN
GBN  8708060844P         E
GBN   SE 0623KM         137 49                                 0000000 00ML00MN
TRQ  8708060844P  B454223+  -0.09           XB464838XB472244 043 100  16    0  0
TRQ   SW 0680KM 03 -022 239 49               00  002 00 -186   0000234 38ML32MN
GRQ  8708060844P  X455103E  -0.09           XB470107 X473582 033 100  11    0  0
GRQ   SW 0740KM 00  124 247 49               00 -008 00 -546   0000209 38ML32MN
JAQ  8708060844P  B455297   -0.07           XB470641XB474613 023 100   9    0  0
JAQ   NW 0763KM 03  042 311 49               00  042 00 -149   0000246 37ML33MN
GAC  8708060844P            -0.06            X471029 X474399 000   0   0    0  0
GAC   SW 0772KM         239 49               00  256 00 -600   0000000 00ML00MN
EEO  8708060844P XA461360+  -0.06                    X483863 053 100  18    0  0
EEO   W  0958KM 00 -270 254 49                       00 -355   0000213 43ML34MN
             Z
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APPENDIX B

Comments on **"VELOCITY OF THE LG PHASE FROM LOWER ST. LAWRENCE EARTHQUAKES"** by Kimberly Connors and John Adams; GSC Seismology Internal Report, draft of August 1988.

To John Adams:

Here follow comments on the content, not strictly in logical order, but as the thoughts came to me. You will see that I have some reservations about the method of data analysis and the implications and conclusions given in the text. [There is no doubt that 3.57 km/s is too low for Lg in eastern Canada and that 3.6 km/s is much better in most cases. That has been known for a long time even though little was done to properly document a better velocity and put it into routine use.]

Figures 1, 2, 3 and 4 all show that 3.57 km/s is too low, but these figures also show a large scatter, indicating that the data do not well define what the higher velocity should be.

Comments on Data Analysis

Figure 1 shows that about half the stations recorded the Lg phase from only one of the earthquakes. Figure 2 shows that the azimuth distribution was probably not too good for most of the earthquakes, since for the 10 earthquakes as a whole, the average azimuths were between 170° and 360°, with only 4 exceptions. There is only one average azimuth between 0 and 140°. Thus it is not surprising that an increase in Lg velocity tended to move the epicentres to the northeast or the east. If the Lg velocity had been reduced below the original 3.57 km/s, the epicentres would have moved southwest or west, since there is no control from stations to the northeast or east quadrants.

Figure 2 appears to have averaged also the azimuths at each station, so that the figure shows average velocity/average azimuth pairs. In fact, Figure 2 is the same as Figure 1; this would be more obvious if the velocity had been plotted at the same scale in both figures. The stations in Figure 1 are plotted in order of increasing azimuth, but at equal spacing. In Figure 2 the actual azimuths are used on the x-axis.

It is unfortunate that the raw data were not plotted directly; the results might have been more meaningful. There has been too much averaging before data were plotted in Figures 1 to 4.

The relocations mentioned in the "Implications" section, and shown on Figure 6, produced epicentre shifts within the usual location error, considering azimuthal distribution as well as reading uncertainties; hence no significant changes due to Lg velocity change. It may be also that Lg did not play a large part in the original epicentre determinations. The text does not indicate how many Lg phases were used, relative to the other phases, and whether "X" weights were removed to allow more Lg to influence the solutions.

I would suggest the following procedure, which permits seeing whether the scatter is due mostly to a few earthquakes and/or to a few epicentre-station paths. The 10 earthquakes of Table 1 are not all plotted in Figure 5, or perhaps none is shown there. However, Table 1 shows that the 10 epicentres cover a rectangle of 1° in latitude and 2½° in longitude, about 100 km by 100 km. Thus the paths are not the same for a given station; there might be thus an azimuth and/or distance effect.

Recommended method of analyzing phase arrival times to determine velocity

Plot arrival time versus delta for each earthquake independently - here 10 different graphs. Since you are interested only in the slope of the line, and not its intercept, the time axis can start wherever convenient; it is not necessary to subtract the origin time H from each arrival time in order to plot travel time.

Draw by eye, or calculate, the best least squares line through the data points for each earthquake. [Note also whether the slope would change if the line were fit to different distance ranges for the same earthquake.] The reciprocal of the slope is the average velocity for that earthquake and set of travel paths. (According to the Appendix, three of the 10 earthquakes have only a few data points; the slope will not be well determined for these; one can, however, examine the trend of the points.)

For some of the earthquakes, it might be worthwhile to try to read Lg at the stations for which it has not been read. The absence of a reading in the Appendix tables may not necessarily indicate that Lg was not well defined; it may not have been read simply because it was not going to be used in the epicentre determination.

From the individual graphs, especially for the events recorded over a larger distance range, you should note whether the average velocity tends to decrease (or increase) as the distance range increases. That is, the scatter in Figures 1 to 4 may be mainly a distance effect. As the path becomes longer, and hence the Lg period lengthens, the wave samples deeper portions of the upper crust and the range of velocities sampled increases, altering the average velocity.

The distance effect is not clear from Figure 3, as the points are not identified by earthquake. In addition, I assume that the residuals are with respect to the origin time of the individual earthquakes, so there could be an unintentional vertical shift of points between earthquakes.

Any serious study of phase velocities must include a re-examination of all relevant seismograms, hence a re-reading of all arrival times. Points whose residuals lie far from the general trend must be examined to verify that they are valid data, hence retained in the data set, or that they are in error for one reason or another, and either corrected or deleted, as appropriate.

Previous papers by Horner et al. (CJES[1], BSSA[2]) should be consulted as an example of velocity determination from earthquake data. Note that when the azimuth distribution of stations is good (stations in all four azimuths), the epicentre is not significantly shifted by velocity changes. The velocity change then affects either or both the depth and origin time. As you note in the Introduction, an appropriate velocity is essential when azimuth distribution is poor. This will prevent an epicentre shift along the azimuth range of the least number of stations.

Anne Stevens

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07 September 1988

1. Can. J. Earth Sci., 10, no. 12, 1973.
2. Bull. Seism. Soc. Am., 68, 619-640, 1978.