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Seismograms for historic Canadian earthquakes: the 5 September 1944 Cornwall-Massena earthquake

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Yukon Goverment

Canada

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Nota : On prévoit diffuser ce dossier public plus tard cette année sous la forme d'un bulletin de la Commission géologique du Canada.

SEISMOGRAMS FOR HISTORIC CANADIAN EARTHQUAKES: THE 5 SEPTEMBER 1944 CORNWALL-MASSENA EARTHQUAKE

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ABSTRACT

This paper is one in a series of reports designed to catalog the Geological Survey of Canada's (GSC) collection of seismograms for historical Canadian earthquakes. The data set has been assembled by past and present seismologists at the GSC. The seismogram collection for the 1944 Cornwall-Massena earthquake consists of records from 32 North American seismograph stations. To assist those who may study this earthquake in the future, this report describes the seismograms in the collection and indicates which record segments have been digitized. The digital data files may be obtained from the GSC.

RÉSUMÉ

Cet article fait partie d'une série de rapports qui énumère la collection de séismogrammes pour les tremblements de terre historiques canadiens disponible à la Commission géologique du Canada (CGC). Des données furent amassées par plusieurs générations de séismologues de la CGC. Les données du tremblement de terre de Cornwall-Massena de 1944 comprennent les séismogrammes enregistrés à 32 stations séismologiques en Amérique du Nord. Cet article fournit une description des séismogrammes de la collection pour ceux intéressés par l'étude de ce tremblement de terre dans l'avenir, et aussi indique quelles parties des séismogrammes furent chiffrées. On peut obtenir ces fichiers de données numériques de la CGC.

INTRODUCTION

The 1944 Cornwall-Massena earthquake, while moderate in size (M_W 5.8), was one of the most damaging Canadian earthquakes ever recorded instrumentally. It occurred at the southern end of the Western Quebec seismic zone (as described by *Basham et al.*, 1982) near the Ontario- Quebec- New York border. Although the epicenter was actually in New York State a few kilometers from the Canadian border (GSC earthquake database; *Dewey and Gordon*, 1984; *Smith*, 1966; *Milne*, 1949), it is considered a significant Canadian earthquake in that the uncertainty in its location would allow a Canadian epicenter and because the damage was roughly equal on both sides of the border. The earthquake caused two million dollars worth of damage (1944 dollars) in the cities of Cornwall, Ontario and Massena, New York [*Hodgson, 1945; Bodle, 1946*]. The proximity of the epicenter to heavily populated regions of eastern Canada (both Ottawa and Montreal are within 100 km) renders the earthquake important in terms of regional seismic hazard analysis.

Milne [1949] who published one of the earliest instrumental studies of this earthquake concentrated primarily on determining the epicenter and origin time. Later studies by *Street and Turcotte* [1977] and *Ebel et al.* [1986] provided magnitude data. The latter also suggested a focal mechanism based on first motions. Most recently *Bent* [1995] modeled the regional waveforms to determine a well constrained focal mechanism and other source parameters (depth, duration, seismic moment). Thus as new techniques are developed, seismograms may continue to provide new information long after the earthquake has occurred.

Often however, historical earthquakes are overlooked because of the difficulty in obtaining either seismograms or adequate information concerning the instrument responses. The principal intentions of this paper are to catalog the Geological Survey of Canada's (GSC) seismogram collection for the 1944 Cornwall-Massena earthquake, to provide a record of those seismograms that have been digitized by the GSC, and to provide as much information as possible concerning the instrument responses for the seismograms in the collection.

DATA SET

The GSC data set for the Cornwall-Massena earthquake consists of records from 32 stations (Fig. 2) all located in North America. Most of the seismograms in this collection are photographic copies of the originals and were collected by seismologists at the Dominion Observatory (now part of the GSC) shortly after the 1944 earthquake. The original collection had been misplaced and unavailable to researchers attempting to study this earthquake using modern analysis techniques, but it reappeared during building renovations in the early 1990s. The collection has been recently supplemented by additional data from seismograph stations in the northeastern United States. The available records and instrument constants are summarized in Table 1. A brief description of each of the seismograms can be found in the following section of this paper, and some examples of the original seismograms are shown in Figure 3.

SUMMARY OF SEISMOGRAMS

Brief qualitative descriptions of the seismograms are provided below. The format and origin of the data are also noted. Those listed as being part of the original collection were amassed during the 1940s by seismologists at the Dominion Observatory. These records were used by *Milne* [1949] to locate the earthquake. There are also a few photocopies in the collection. Presumably they were added at a later date, but are listed as being part of the original collection for lack of further information. The author examined either the original records or photographic copies of the originals for any records listed as photocopies that were not part of the original collection. While the "originals" may be somewhat clearer, if a copy is noted as being faint, the original was also faint. A complete list of components and instrument parameters can be found in Table 1 and a list of digitized records in Table 2.

Boulder City, Nevada: Very good surface waves. Body waves small but visible. Photographic copy; original collection.

Buffalo, New York: Everything well recorded on Weicherts. Surface waves have significant curvature. Generally well recorded on Galitzin-Wilip but there are some faint sections. Photocopy from collection of J. Ebel.

Cape Girardeau, Missouri: Faint surface waves. Photocopy; original collection.

Cheltenham, Maryland: Everything was recorded but there are some faint sections. Photographic copy; original collection.

Cincinnati, Ohio: Well recorded and on-scale, but body waves are small. Photocopy from collection of J. Ebel.

Columbia, South Carolina: Surface waves well recorded. Body waves very small. Photographic copy; original collection.

Denver, Colorado: Clear surface waves. Photocopy; original collection.

Florissant, Missouri: Galitzin-Wilip has good surface and body waves. Wood-Anderson records have many faint sections. Photographic copies; original collection.

Fordham, New York: Very well recorded on Galitzins with a few faint (but recoverable) sections. Everything was recorded by Benioff but there are many faint (and possibly off-scale) sections, only some of which can be recovered. Photographic copies; original collection.

Georgetown, District of Columbia: All phases well recorded. Photocopy; original collection.

Grand Coulee Dam, Washington: Very good, but sometimes slightly blurred, surface waves. Body waves small but visible. Photographic copy; original collection.

Halifax, Nova Scotia: Very faint but maximum amplitudes can be read. Photocopy; original collection.

Harvard, Massachusetts: Everything was recorded but much of the record is faint (and possibly off-scale). Photocopy from collection of J. Ebel.

La Jolla, California: Well recorded surface waves; almost no body waves. Photographic copy; original collection.

Mt. Wilson, California: Good recording, particularly of surface waves, on Benioff.

Poor recording on Wood-Anderson. Photographic copy; original collection.

Ottawa, Ontario: Benioff is faint and some of it is probably off-scale. Wood-Andersons have faint sections especially near beginning and probably are off-scale in places. Original records; original collection.

Overton, Nevada: Very good surface waves. Body waves small but visible. Photographic copy; original collection.

Pasadena, California: Good surface waves and poorly recorded body waves on EW Wood-Anderson; poorly recorded on NS. Better recorded by Benioff (all components, long- and short-period). Photographic copy; original collection.

Philadelphia, Pennsylvania: Everything recorded. Some surface waves off-scale. Body waves clear on NS, but blurred on EW. Photographic copy; original collection.

Pierce Ferry, Arizona: Very good surface waves. Body waves small but visible. Photographic copy; original collection.

Pittsburgh, Pennsylvania: Benioff has some faint sections particularly near beginning but everything appears to have been recorded. Wenners have generally very good recordings but there are some faint sections. It should be noted that the station location was not written on the records. The absolute times are in Eastern Standard Time and the P arrival corresponds to *Milne's* [1949] P reading for Pittsburgh. The instrument types are also appropriate for Pittsburgh. Therefore, the record is assumed to come from Pittsburgh. Photographic copy; original collection.

Riverside, California: Good recording particularly of surface waves on Benioff. Poor recording on Wood-Anderson. Photographic copy; original collection.

St. Louis, Missouri: Body waves small but clear. Surface waves are faint. Photocopies; original collection.

Santa Barbara, California: Recorded but small on both Wood-Anderson and Benioff. Photographic copy; original collection.

Saskatoon, Sakatchewan: Very blurred. Photocopy; original collection.

Seven Falls, Quebec: Generally good record with a few faint sections. Original record; original collection.

Shasta Dam, California: Very small but body and surface waves are visible. Photographic copy; original collection.

Shawinigan Falls, Quebec: Many clipped and faint sections, although lower amplitude phases are clear. Very strong first motion. Original record; original collection.

Tinemaha, California: Poor recordings on both instruments. Photographic copy; original collection.

Tucson, Arizona: Body waves small. Good surface waves. Photographic copies; original collection.

Victoria, British Columbia: Good surface waves; small body waves. Photocopy; original collection.

Weston, Massachusetts: Some faint and/or off-scale sections but generally well recorded. Photocopy from collection of J. Ebel.

DIGITIZED RECORDS

The body waves of seven of the regional seismograms discussed above were digitized to facilitate their analysis [*Bent*, 1995]. These digitized records, shown in Figure 4, can be purchased from the GSC. The teleseismic body waves were too small to digitize accurately. While every effort was made to digitize the seismograms as accurately as possible, any potential users of this data should bear in mind that there is always some personal bias involved in hand digitizing, and that these records were digitized for a specific study and may not contain phases or sections of the record required for other types of analyses.

The seismograms were digitized at a rate of 1 point per 0.25 mm using a digitizing tablet with a 0.025 mm resolution. To improve the resolution, any small records were enlarged (by photocopier) before digitizing. After digitizing, the Seismic Analysis Code (SAC) interpolation routine [*Tull,* 1989] was used to create equally spaced files with 1 sample per second except at SFA where the spacing of data points is 0.2 seconds. If necessary, the data were also detrended and corrected for curvature and skew. The instrument responses were not removed.

The digitized records are in ASCII format and consist of 4 lines of header followed by x-y pairs of data, where x is the time (relative to the first point digitized) and y is the amplitude in cm (not corrected for instrument magnification). If a record was enlarged before digitizing, the amplitude has been corrected to the original scale. The names of the data files are in the format STN.COMP.PHASE where STN is the station code from Table 1, COMP is the component (z, n or e) and PHASE is the phase (in this case pnl, which may include part of the S_{nl} phase). Appendix A contains a sample annotated data file.

The digitized records are summarized in Table 2. If an available record was not digitized, it generally indicates that it was not considered of sufficient quality to be used in a waveform analysis. The most common reasons for not digitizing a record were that the phases of interest were either too small to digitize accurately or were off-scale.

Table 2 also lists the start times for the digitized records (not including clock corrections) as well as the length of record digitized. Known clock corrections provided by the stations are listed in Table 3.

Unless it was impractical or impossible, the digitizing was started at the beginning of a minute mark. Timing in the digitized files assumes that the beginning of the minute mark corresponds to the beginning of the minute. If absolute timing is essential to any users of this data, it may be worth checking the appropriate station bulletins to determine whether this assumption is valid, and adjusting the time corrections if necessary. *Stevens* [1980] notes that until the end of 1960, the end of the minute mark signaled the beginning of the minute at all Canadian stations. The Fordham record refers to the end of the minute mark as the start of the minute and for the Cheltenham records, the minute begins in the center of the minute mark. If both horizontal components were digitized, the digitized records start at the same absolute time.

All the digitized records are in their original orientations with respect to polarity.

The horizontal records have not been rotated into their radial and tangential components. Table 3 summarizes the instrument polarities marked on the original records as well as some assumptions made by later researchers.

INTERPRETATION OF SEISMOGRAMS

While the previous sections are concerned primarily with cataloguing the seismogram collection and summarizing additional information provided by the station operators, this section will summarize some of the assumptions and interpretations of the data set made by subsequent researchers.

Table 3 summarizes the instrument clock corrections and polarities. There were no obvious errors in polarities at any of the stations modeled by *Bent* [1995]. Any instrument polarities assumed in that study are also noted in the Table.

Similarly no obvious errors were detected in the instrument constants of the records that were digitized, but small errors would not necessarily have been noticed. For example, even when seismograms from modern well-calibrated instruments are modeled, deviations of up to a factor of 2 from the expected amplitudes are not uncommon. Thus, unless an instrument magnification is in error by more than a factor of 2, it is unlikely to be detected.

For several western United States stations (BCN, BCW, OVE, PFA, SHS) the instrument magnifications are listed as relative sensitivities and do not appear to be the true magnifications. The relative sensitivities are all in the 10-50 range. *Charlier and Van Gils* [1953] give the magnifications at these stations as 5000-10000. The raw amplitudes at these stations are comparable to those recorded by the short-period Benioff instruments in southern California suggesting comparable magnifications – on the order of a few thousand.

ACQUISITION OF DIGITIZED SEISMOGRAMS

The digitized seismograms may be purchased from the GSC for a nominal fee. The data files will be distributed on a high density floppy disk or by e-mail and are intended for a single user only. A data order form and sole use agreement may be found in Appendix B.

Acknowledgements: Seismograms not in the original collection were supplied by John Ebel. I thank John Adams and Maurice Lamontagne for their comments.

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TABLE 1
SUMMARY OF SEISMOGRAMS AND INSTRUMENT CONSTANTS

Station	Δ	Az.	Instr.*	Comps.	T_0	T_G	ϵ	V
Boulder City	32	268	B	Z	1.5	0.45		30**
(BCN)				N,E	1.5	0.45		10**
Buffalo	4	234	GW	Z	11.5	11.5		
(BUF)			W	N,E	5		5	80
Cape Girardeau	14	241	WA	N	1.5		∞	1837
(CGM)								
Cheltenham	6	195	NL		3.0		20	
(CLH)								
Cincinnati	9	235	G	Z	12.6	12.6		850
(CNN)								
Columbia	12	206	MR	N,E	12		10	75
(CSC)								
Denver	23	268	W	N,E	5		5	50
(DEN)								
Florissant	13	248	WA	N,E	8		∞	2800
(FLO)			GW	Z	11	13		670
				E	13	13		976
Fordham	4	171	LPB	Z	1.0			
(FOR)			GW	N,E	1.0			
Georgetown	6	197	G	Z				
(GEO)								
Grand Coulee	30	292	B	Z	1.5			20**
Dam (BCW)				N	1.5			15**
				E	1.5			30**
Halifax	8	89	Bo	N,E	5		20	125
(HAL)								
Harvard	3	137	B	E	1	0.2		25000
(HRV)								
La Jolla	35	265	Tor	N,E	0.8			2800
(LJC)								
Mt. Wilson	35	267	SPB	Z	1.0	1.2		31000
(MWC)			WA	N	0.8			2800
Ottawa	1	299	MS	N,E	12		20	300
(OTT)			B	Z	1			

Overton	31	268	B	Z	1.6	0.5		30**
(OVE)				N,E	1.2	0.5		10**
Pasadena	35	267	B	Z,N,E	1.0	90.0		300
(PAS)			WA	N	0.8		65	2800
				E	6.0			2800
			SPB	Z,E	1.0	0.2		3104
Philadelphia	5	184	We	N,E	7.5	4.3	20	1400
(PHI)								
Pierce Ferry	31	267	B	Z	1.5	0.45		50**
(PFA)				N,E	1.5	0.45		30**
Pittsburgh†	6	222	LPB	Z				24000
(PIT)			We	NE,NW	12	15		200
Riverside	34	266	WA	Z	0.8		65	2800
(RVR)			B	N	1.0	0.2		3000
St. Louis	13	247	MaS	Z	2.6	1.3		15000
(SLM)								
Santa Barbara	36	269	B	Z	1.0	0.2		3000
(SBC)			WA	N	0.8		10	2800
Saskatoon	22	300	MS	N	10		20	150
(SAS)								
Seven Falls	3	50	WA	E	1			2500
(SFA)								
Shasta Dam	35	280	B	Z	1.5	0.5		35**
(SHS)				N,E	1.5	0.5		25**
Shawinigan Falls	2	40	WA	N	1			2500
(SHF)								
Tinemaha	33	272	B	Z	1.0	0.2		31000
(TIN)			WA	N	0.8		650	2800
Tucson	31	258	WA	N,E	10		30	430
(TUC)			B	Z	1.0	74		31000
Victoria	33	294	MS	N,E	12		20	300
(VIC)								
Weston	4	136	LPB	Z,E	1	60		3000
(WES)			SPB	N	1	0.25		50000

* B = Benioff (SPB, LPB short- and long-period), Bo = Bosch, G = Galitzin, GW = Galitzin-Wilip, MR = McComb-Romberg, MS = Milne-Shaw, MaS = Macelwane-Sprengnether, NL = Neumann-Labarre, Tor = torsion, W = Weichert, WA = Wood-Anderson, We = Wenner.

** these are listed on records as relative sensitivities; *Charlier and Van Gils* [1953] list the magnifications as 5000-10000; the maximum raw amplitudes recorded at these stations are comparable to those recorded by the short-period Benioff instruments in southern California, suggesting comparable magnifications

† location not written on record; assumed based on P arrival time, instrument type and list of stations used by *Milne* [1949] to locate earthquake

TABLE 2
SUMMARY OF DIGITIZED SEISMOGRAMS

Stn.Comp.Phase	T_0	length (sec)	comments
buf.z.pnl	OT	76	minute marks hard to find near event; origin time marked by station operator
cnn.z.pnl	0440	193	
for.e.pnl	0439	100	
for.n.pnl	0439	102	
for.z.pnl	0439	116	
geo.z.pnl	0440	121	original right to left
phi.n.pnl	0440	51	
pit.ne.pnl	0440	50	
pit.nw.pnl	0440	70	
sfa.e.pnl	0439	36	

TABLE 3
CLOCK CORRECTIONS AND POLARITIES

STN	t_{corr}* (sec)	Direction Positive Z	N	E	P 1st Motion†
BUF		C			C
CLH	0.0,-0.5				
CNN	+10	C†			C
CSC	0		S	E	
FLO(WA)			S	W	
FLO(GW)		D	N	W	C
FOR	+55	C	N	E	C
GEO		D			C
HRV				E	C
LJC			S	W	
OTT		D			D
OVE	-35.6				
PAS		D	N	W	
PFA	+14.7,+13.4				
PHI	-12		S†		C
PIT		D	SW	SE	C
SBC		D	S		
SFA				E	D
SHF			N		D
SHS	-3.4				
TIN		D	N		
TUC	+.05	C	S	E	
WES		C	N	E	C

* if two time corrections are given, they indicate measurements made before and after (within 24 hrs) the Cornwall-Massena earthquake

† assumed by *Bent* [1995]

APPENDIX A
Sample Digitized File

```
test.dig
440 1.0232
30.0 1.00
1.0 0.0 0.0
0.0 1.111111e-01
1.0 2.444444e-01
2.0 1.002233e-01
3.0 -1.234567e-01
        •
        •
        •
```

---

explanation of header:

1st line: id

2nd line: number of data points; ymax in cm (not corrected for gain)

3rd line: horizontal and vertical scales (for plotting purposes only)

4th line: enlargement factor (if greater than 1, record was enlarged before digitizing; amplitudes have been corrected for this) radius of curvature in cm; skew angle

remaining lines: x-y pairs; x is time in sec relative to first point digitized; y is amplitude in cm (not corrected for instrument magnification)

APPENDIX B
Data Order Form for 1944 Cornwall-Massena Digital Data Set and Statement of Sole Use

To obtain digital data files, please complete the form below and either:

A) send cheque or money order for $50.00 Canadian funds (plus PST and GST; Canadian addresses only; shipping included) or $50.00 U.S. funds (all taxes and shipping included; non-Canadian addresses) payable to the "Receiver General for Canada" to:

Seismology Program, Geophysics Division, GSC
1 Observatory Cres., Ottawa, Ont. K1A 0Y3
Attention: Allison Bent

B) fax this form to (613) 992-8836 and enclose standard information for credit card billing or e-mail information to bent@seismo.emr.ca

The digital data supplied is under crown copyright. It is supplied on the understanding that it is for the sole use of the purchaser and not to be redistributed in any digital form to third parties. In acknowledging receipt of the data, the purchaser undertakes to abide by the foregoing legal requirements implicit in the purchase.

____

Company Name

____

Purchaser's Name and Title

____

Signature

____

Date

____

____

____

Mailing Address

____

((Option B) Credit card name, number and expiry date)

FIGURE CAPTIONS

Figure 1. Seismicity of the Western Quebec seismic zone (shaded region). Earthquakes of magnitude 4 or greater since 1900 are plotted. Earthquakes of magnitude 3.0-3.9 and 2.0-2.9 cover the time periods 1970-1994 and 1980-1994 respectively. The epicenters of the 1944 Cornwall-Massena and 1935 Timiskaming earthquakes are indicated.

Figure 2. Seismograph stations from which seismograms are available for the 1944 Cornwall-Massena earthquake. Shaded symbols indicate that (at least part of) the seismogram from that station has been digitized. The epicenter is indicated by the asterisk.

Figure 3. Examples of seismograms for the 1944 Cornwall-Massena earthquake. All are shown at approximately their original scales. a) Horizontal records from Philadelphia. b) Part of east-west record from Seven Falls. c) Part of vertical record from Fordham.

Figure 4. Digitized seismograms for the 1944 Cornwall-Massena earthquake. All are plotted at the same scale.

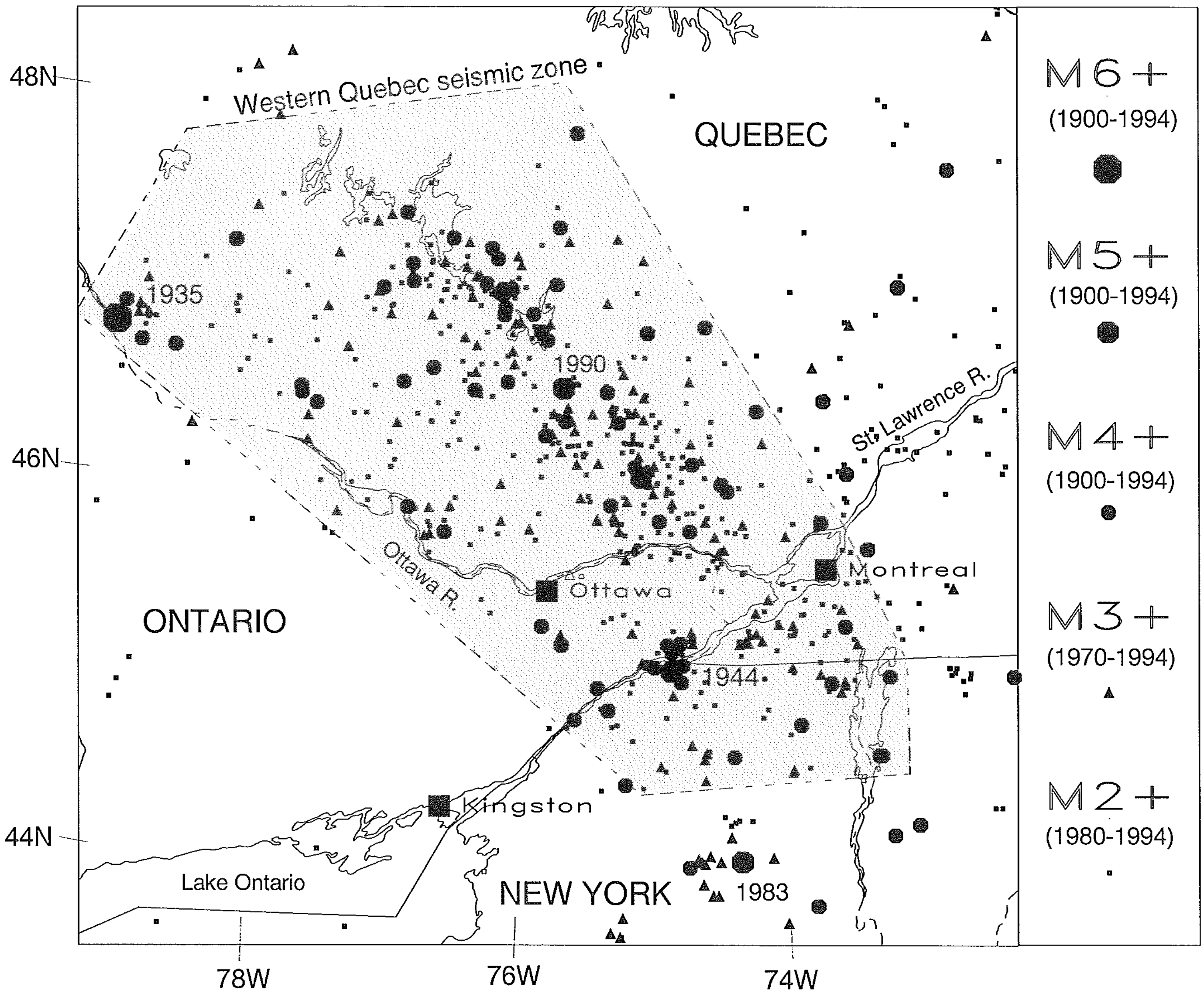

48N
46N
44N
78W
76W
74W
Western Quebec seismic zone
QUEBEC
ONTARIO
NEW YORK
Lake Ontario
Ottawa R.
St. Lawrence R.
Ottawa
Montreal
Kingston
1935
1990
1944
1983
M6+
(1900-1994)
M5+
(1900-1994)
M4+
(1900-1994)
M3+
(1970-1994)
M2+
(1980-1994)

FIG. 1

AVAILABLE SEISMOGRAMS: 1944 CORNWALL-MASSENA EARTHQUAKE

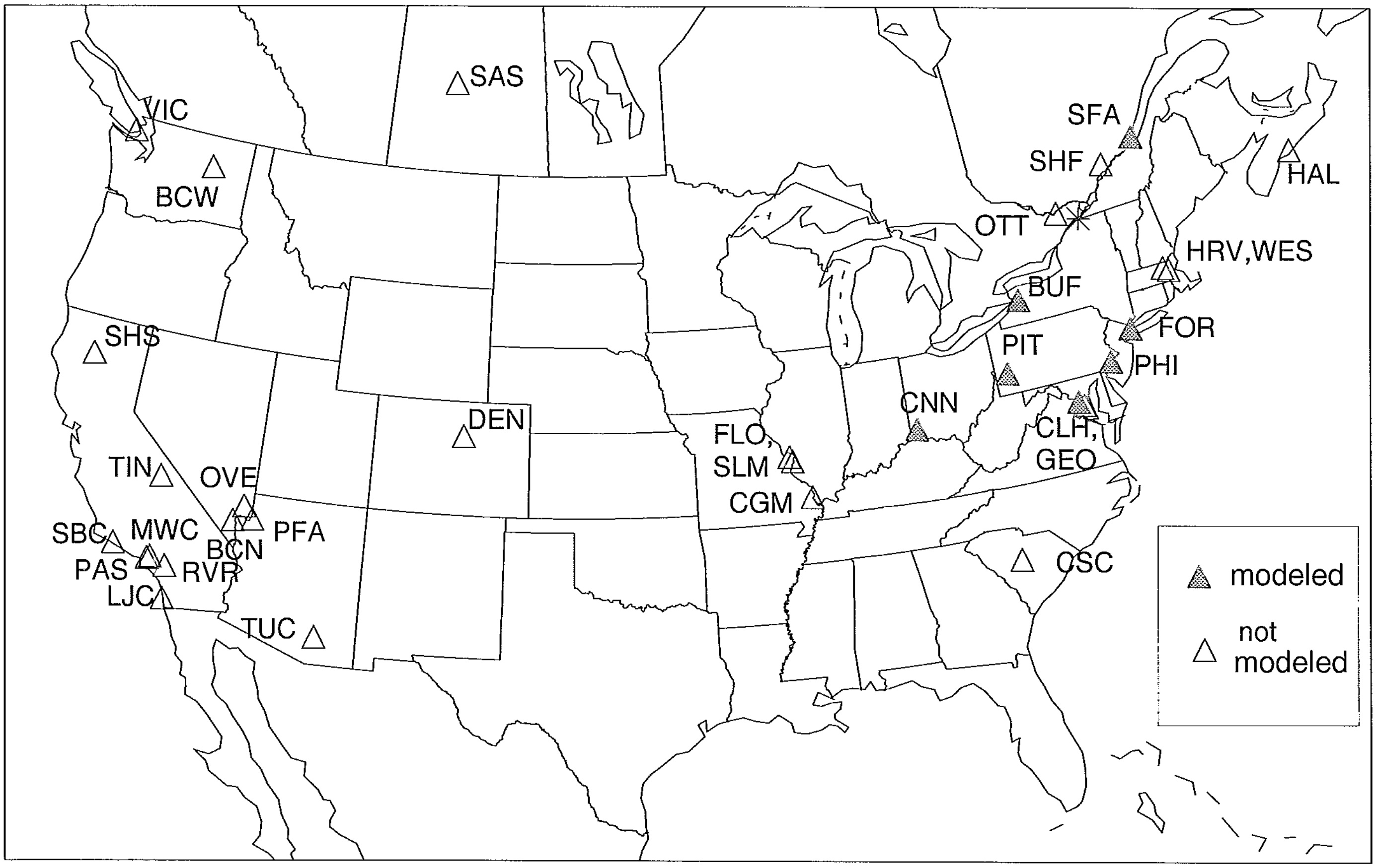
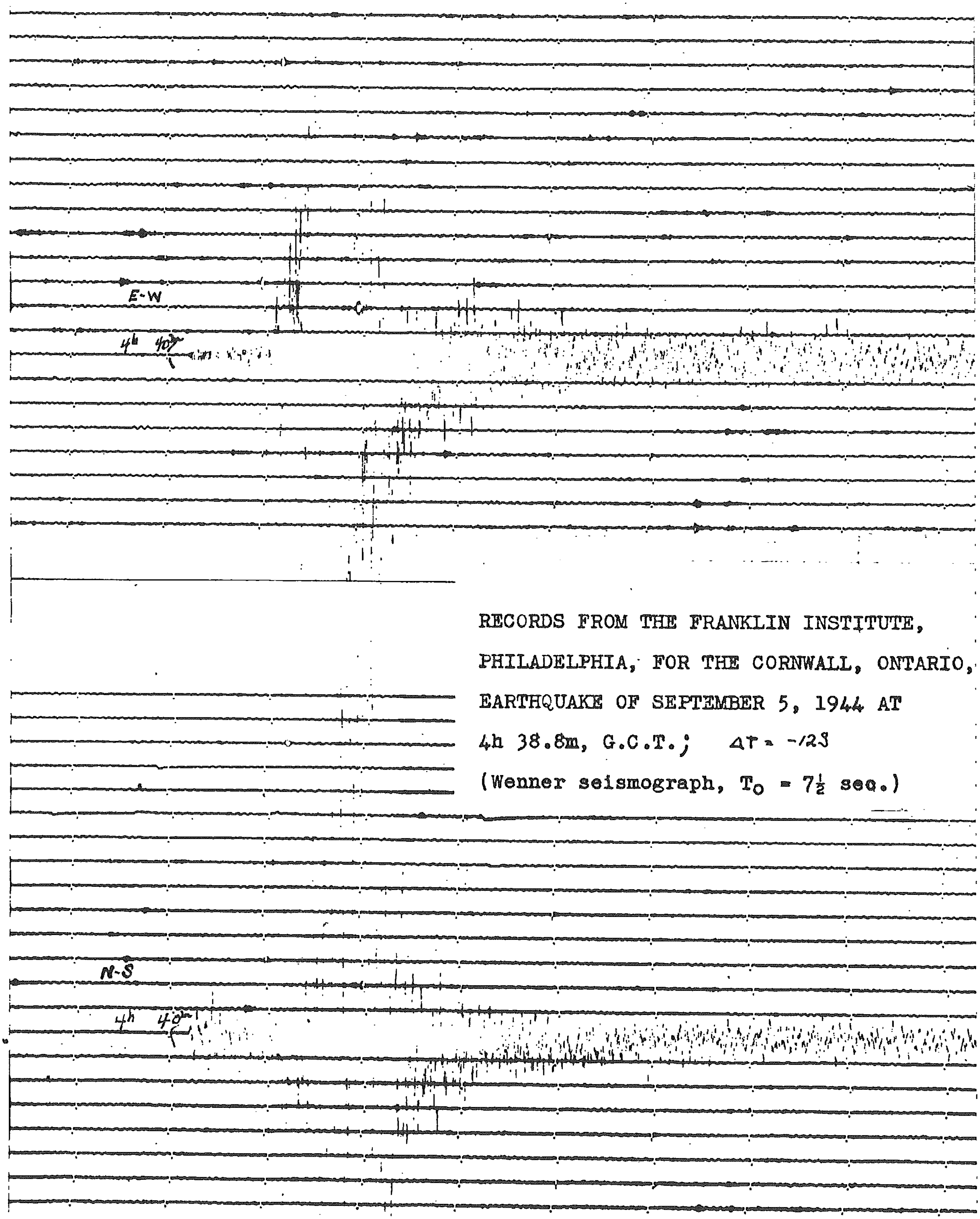


FIG. 2



RECORDS FROM THE FRANKLIN INSTITUTE, PHILADELPHIA, FOR THE CORNWALL, ONTARIO, EARTHQUAKE OF SEPTEMBER 5, 1944 AT 4h 38.8m, G.C.T.; ΔT = -12S

(Wenner seismograph, T_0 = 7½ sec.)

FIG. 30

1944 Cornwall-Massena earthquake
SFA seismogram
E-W component

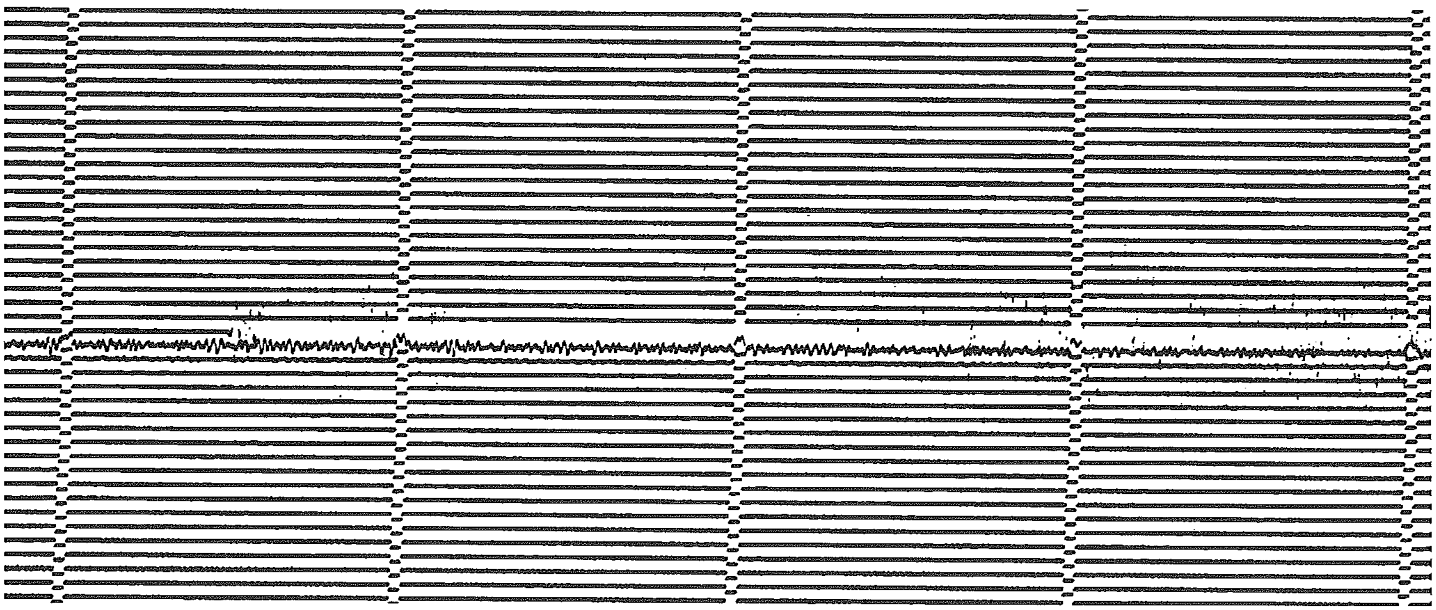


FIG. 3b

1944 Cornwall-Massena earthquake
FOR seismogram
vertical component

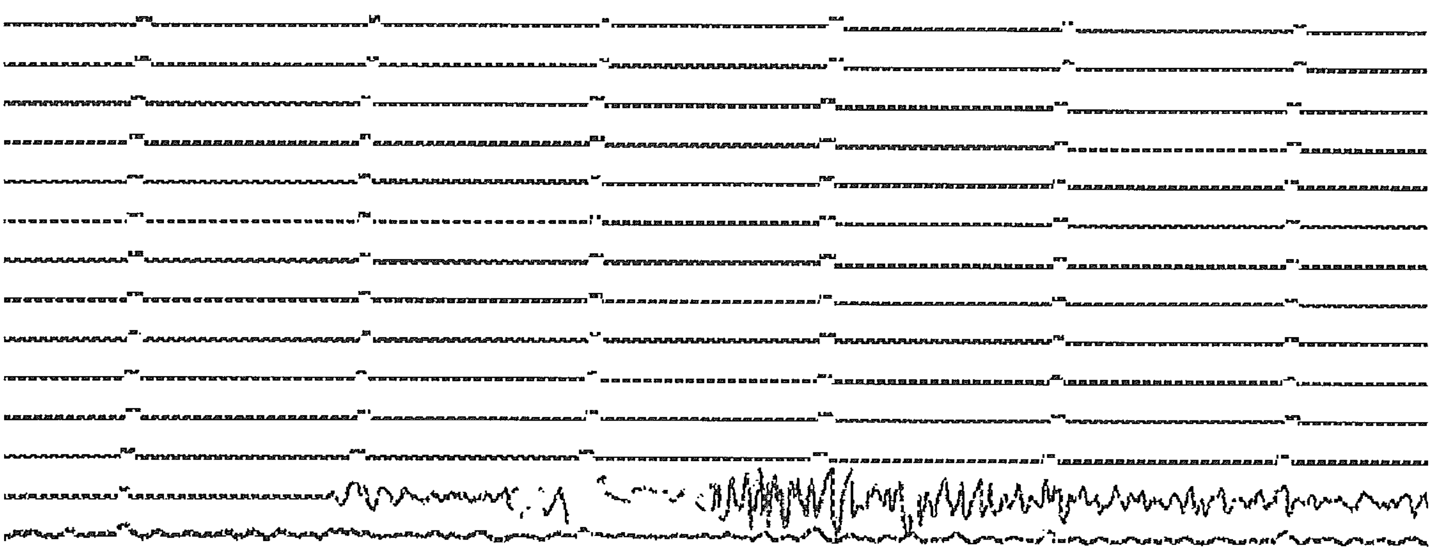


Fig. 3c

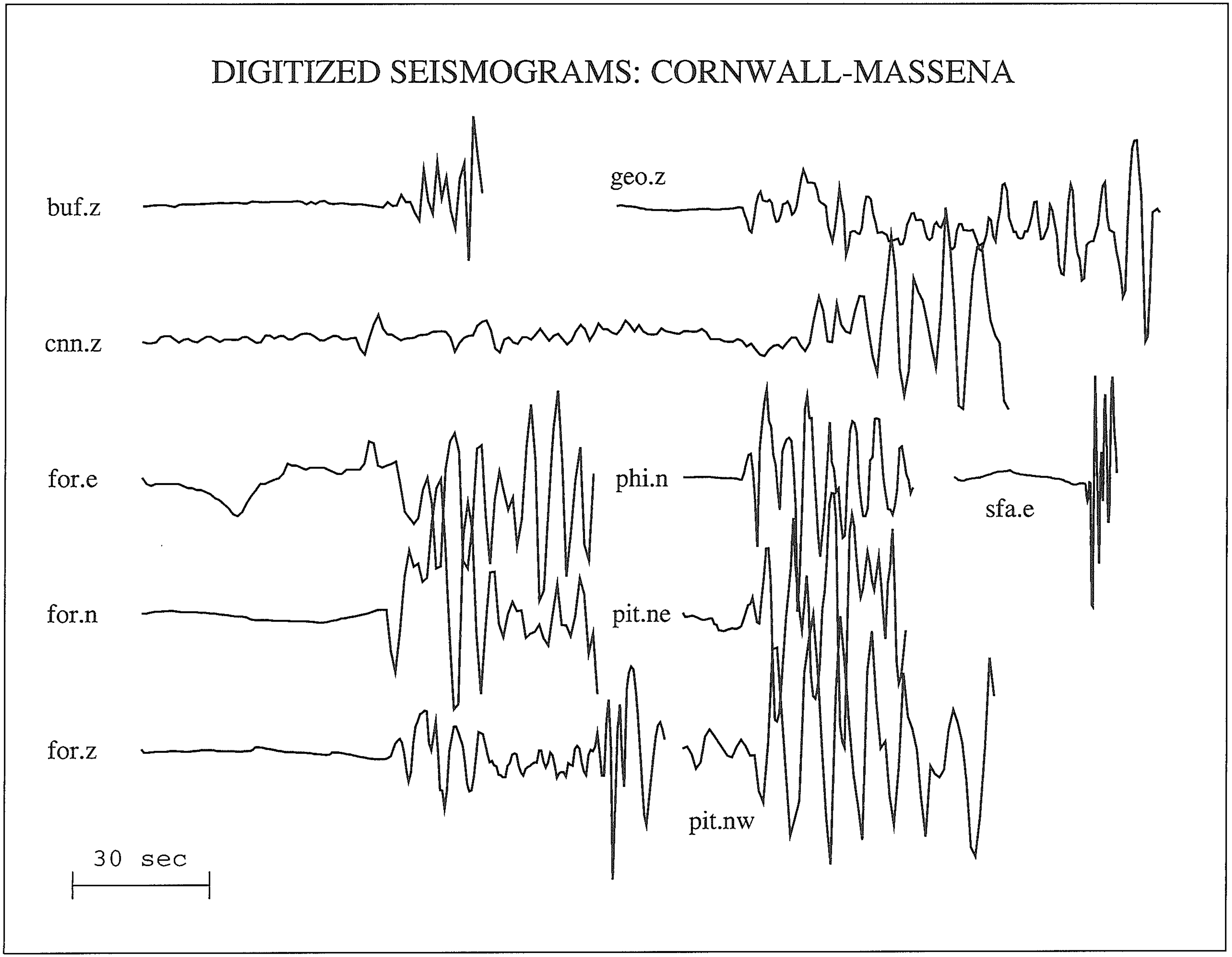

DIGITIZED SEISMOGRAMS: CORNWALL-MASSENA
buf.z
geo.z
cnn.z
for.e
phi.n
sfa.e
for.n
pit.ne
for.z
pit.nw
30 sec

FIG 4