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Suggestions on the Analysis of 16-mm Seismic Data from Local Networks

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By

Richard L. Dart

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SUGGESTIONS ON THE ANALYSIS OF 16-MM SEISMIC DATA FROM LOCAL NETWORKS

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INTRODUCTION

This report is intended as a training aid in the analysis of data acquired by local seismographic networks. It is focused towards the project analyst who is responsible for the location of earthquake hypocenters using P- and S-phase arrival times, the directions of first motions, the determination of magnitudes from coda durations, and station location quality from the station trace clarity. To this end, the analyst must distinguish the seismic activity from cultural, transient electrical, and microseismic background noise.

All examples are from data acquired by the Puerto Rico Seismic Program (fig. 1). The Puerto Rico seismic network consists of 19 seismometers at 15 permanent station sites (15 vertical and 4 horizontal Geotech S-13 seismometers). At each station there are one or more seismometers, an amplifier-vco/transmitter package, and a transmitting antenna. All station data are transmitted via radio telemetry and to the central recording site located at the San Juan Geophysical Observatory at Cayey, Puerto Rico. A 20-channel Develocorder (galvanometric, 16-mm automatic film-recording and developing system) at the observatory records the 19 data channels plus a WWVB radio time code (Tarr and King, 1976). Forty-eight hours of data are recorded on each film from which the analyst must locate and evaluate seismic and nonseismic activity.

DATA EVALUATION

This section deals with timing, determining the P- and S-phase arrival times, and coda duration of local, regional, and teleseismic earthquakes (figs. 3, 4, 5, and 6). First, a word on definitions: phases, P and S, are seismic waves (Bolt, 1978; Hodgson, 1964) that radiate from the earthquake focus, or hypocenter, which is the earthquake's point of origin within the earth. P- and S-waves travel at different speeds and thus are received by the station seismometer at different times. This time difference is a reflection of the distance from the earthquake hypocenter to the seismographic station. Coda duration, or the duration of the recorded signals, refers to length of time, in seconds, that is required for the amplitude of the recorded earthquake signal to fall below a certain level, measured in millimeters. Timing an earthquake consists of determining the time of the P- and S-phase arrivals: year, month, day, hour, minute, second, to the nearest half-tenth second. A detailed scheme for evaluating P- and S-phase arrivals and P-phase first motions, the direction up or down, of the signal is included (tables 1 and 2), and a list of trace character remarks used in film scanning is provided.

QUALITATIVE EVALUATION OF P- AND S-PHASE ARRIVALS

A phase arrival is indicated by a distinct change in signal character and usually a sharp increase in its amplitude (see figs. 3 and 4). The phase arrival is also referred to as signal response, a unique change in trace character. Phase arrivals are either impulsive (IP or IS) or emergent (EP or ES) depending on the amount of initial increase in the amplitude of the signal when compared to the normal trace or background noise level (table 1). The weighting or scaling of the signal response is an arbitrary method of determining the quality of the phase reading. In table 1 the weighting portion of the first motion weight, the evaluation of the signal response, and

TABLE 1

P- AND S-PHASE WEIGHTING METHOD USED IN DATA EVALUATION

Phase	First Motion Weight	Amplitude Contrast	Signal Response	Degree of Certainty
Impulsive P	$IP^{C*}_{D}0$**	$A \geq 5a$	very strong	100%
	$IP^{C}_{D}1$	$A \geq 3a$	strong	100%
	$EP\pm2$	$A \geq 2a$	moderate	100-75%
Emergent P	$EP\pm3$	$A<2a$	weak	75-25%
	EP 4	$A<2a$	very weak	25%-guess
Impulsive S	IS 0	$A>5a$	very strong	100%
	IS 1	$A>3a$	strong	100%
Emergent S	ES 2	$A \geq 2a$	moderate	100-25%
	ES 3	$A<a$	weak	25%-guess

A=initial P or S phase amplitude, a=normal trace amplitude level

*First motion direction: impulsive P-phase, Up = C, Down = D
emergent P-phase, Up = +, Down = -

**Weighting of signal response: 0 = impulsive
1 = impulsive
2 = emergent
3 = weak
4 = perceptible or guess

The first motion weight scheme, column 2, is the actual notation used when recording your evaluations of P and S phases.

the estimation of the degree of certainty are all arbitrary and are based totally on the analyst's judgment. Degree of certainty is meant to aid the analyst in a self-evaluation of his judgment.

SUGGESTIONS ON SCALING EARTHQUAKES

1. All possible P and S-phase arrivals should be picked and coda durations for local and regional earthquakes determined, (figs. 3, 4, and 5). (See the section on Trace Character Remarks.)
2. All earthquakes are timed if at least three P-phase arrival times can be determined (figs. 2 and 3).
3. The ability to locate epicenters for regional earthquakes becomes questionable if the signal amplitude on at least three stations never exceeds 3 cm and if the S-minus-P time, that is the S-phase arrival time minus the P-phase arrival time, for the first station reporting is greater than 25 s (200 km is $\cong$ 25 s S-minus-P time) (figs. 3 and 5). In cases like these the magnitude of the earthquake is usually small, <2.0, and the distance between the hypocenter and the nearest station is great enough that P-phases will be quite emergent, thus, limiting the analyst's ability to accurately determine their arrival times.
4. All possible P-phase arrivals should be picked and coda durations estimated whenever possible for all well-recorded teleseisms with distinct, clearly discernible first motions (figs. 3, 5, and 6).
5. Teleseisms are timed if the first motion response for three station traces is clearly distinguished from the normal trace noise (figs. 3 and 4). (See the section on Trace Character Remarks.)
6. It is possible to measure coda duration accurately if the trace amplitude for an earthquake exceeds 1 cm (fig. 3).

7. Duration is measured from the P arrival to a point where the trace amplitude falls below 1 cm (Lee and others, 1972) or where the earthquake trace amplitude is equal to twice the amplitude of the normal trace or background noise level for at least 3 seconds. This is known as the "3-second rule" (fig. 3). A station trace for a given earthquake is considered WEAK if the P-phase first-motion amplitude is not at least double the amplitude of the trace background noise and if the trace amplitude for the earthquake never exceeds 1 cm (figs. 2 and 3).

PHASE SCALING PROCEDURE

The actual timing, determining the phase arrival times, of earthquakes and (or) blasts is accomplished by first projecting onto a reading surface that portion of the data film containing the event. Projection of 16-mm negative film on a Geotech Film Viewer, model 6585 or a 3M-brand, "500" reader-printer or some other visual display system allows the analyst to make fast, accurate phase-time readings. With the aid of a 30-cm scale, scaling measurements to the nearest .05 second can be easily made. Data as recorded on the 16-mm film is continuous for 48 consecutive hours. The beginning of each minute is indicated by a four digit number which appears above the uppermost trace (fig. 11). The first two digits are the hour and the last two the minute, in Coordinated Universal Time. Thin vertical fiducial lines cross all the traces from top to bottom at 10-second intervals. By placing a centimeter scale against the display screen and alining two of the film's 10-second lines with the scale's 0- and 10-cm tick marks, accurate time readings, one second per cm and one-tenth second per mm (fig. 11), can be made and recorded. After the P- and S-phase arrival times have been determined and recorded (fig. 12), the various station traces should be reexamined and evaluated for first-motion weights.

TRACE CHARACTER REMARKS

Listed here are commonly used remarks pertaining to trace character. Trace character remarks are recorded along with other permanent data when timing earthquakes. The use of trace character remarks will aid in reviewing the data.

1. NOISE: Any of a number of nonseismic signal responses (cultural, environmental, or electrical problems). Noise is either continuous, which is a steady frequency with usually an amplitude >2 mm; or intermittent, which is regularly, or irregularly spaced signal bursts. Noise can completely distort or interfer with usable data (fig. 10). Cultural noise includes noise created by highway traffic, road construction, and so forth; environmental noises might be livestock grazing near the seismometer, or severe storms or high wind; and electrical noise can be attributed to any malfunction in or adjustment to the telemetry equipment.
2. SM: Stretch marks--gaps or spaces in the station traces occurring on all traces simultaneously (fig. 9). (An electrical problem due to Develocorder malfunction.)
3. DT: Drifting trace--the station trace has shifted from its normal position or has exchanged positions with or is overlapping another trace (fig. 8). (An electrical problem.)
4. CF: Cross feeding--the character of one trace is interfering with that of another trace. Usually such traces are adjacent. (A telemetry problem.)

5. SP: Spiking--an extremely sharp burst of electrical noise of short duration, usually less than one second, often at regular intervals (figs. 4 and 6).

6. ?ID: Questionable identification of station code--this remark is used where crossfeeding or drifting traces are suspected.

7. ?P: The P-phase time is questionable, and an alternate time is given; example of alternate, ?P = 0736.50.

8. ?SIGN: Not certain of the first motion given.

9. VERY-E: Very emergent response--the amplitude of the P-phase is very weak or impossible to distinguish from the normal background activity (fig. 3).

10. LOCAL: Local earthquake--the S-minus-P time for the first reporting station is $\leq$ 10 seconds (0 to 80 km), (figs. 3 and 4).

11. N-REG: Near regional earthquake--the S-minus-P time for the first reporting station is $\geq$10 and $\leq$20 seconds (180 to 160 km).

12. REG: Regional Earthquake--The S-minus-P time for the first reporting station is $\geq$10 and $\leq$30 seconds (160 to 240 km), (figs. 3 and 5).

13. D-REG: Distant regional earthquake--the S-minus-P time for the first reporting station is >30 sec ($\leq$240 km).

14. TELE: Teleseismic earthquake--a very distant earthquake, the S-minus-P time is >75 sec (>1,000 km). (See Richter, 1958 and figs. 3, 6, and 7.)

15. SWARM: One of a series of similar earthquakes. (The sequence in which the stations report is the same for all earthquakes in the swarm.)

16. FSHOCK: Foreshock--a smaller earthquake that precedes a main shock. Both earthquakes have the same or similar hypocenters.

17. MSHOCK: Main shock--a large earthquake followed by aftershocks (fig. 9).

18. ASHOCK: Aftershock--an earthquake that follows the main shock. Aftershocks typically have the same or similar hypocenters.

19. ?QUAKE: Questionable earthquake--a response on two or more traces that has an appearance of an earthquake with emergent or impulsive P-phases and indistinct S-phases (figs. 3 and 8). A degree of uncertainty exists in the mind of the analyst. The event could just be noise!

20. BLAST: A quarry blast usually has impulsive P-phases and indistinct S-phases (fig. 9). In Puerto Rico blasts are usually recorded by no more than three stations, depending on station proximity to the quarry or road construction. The closest station shows a very impulsive signal and the rest are contrastingly emergent.

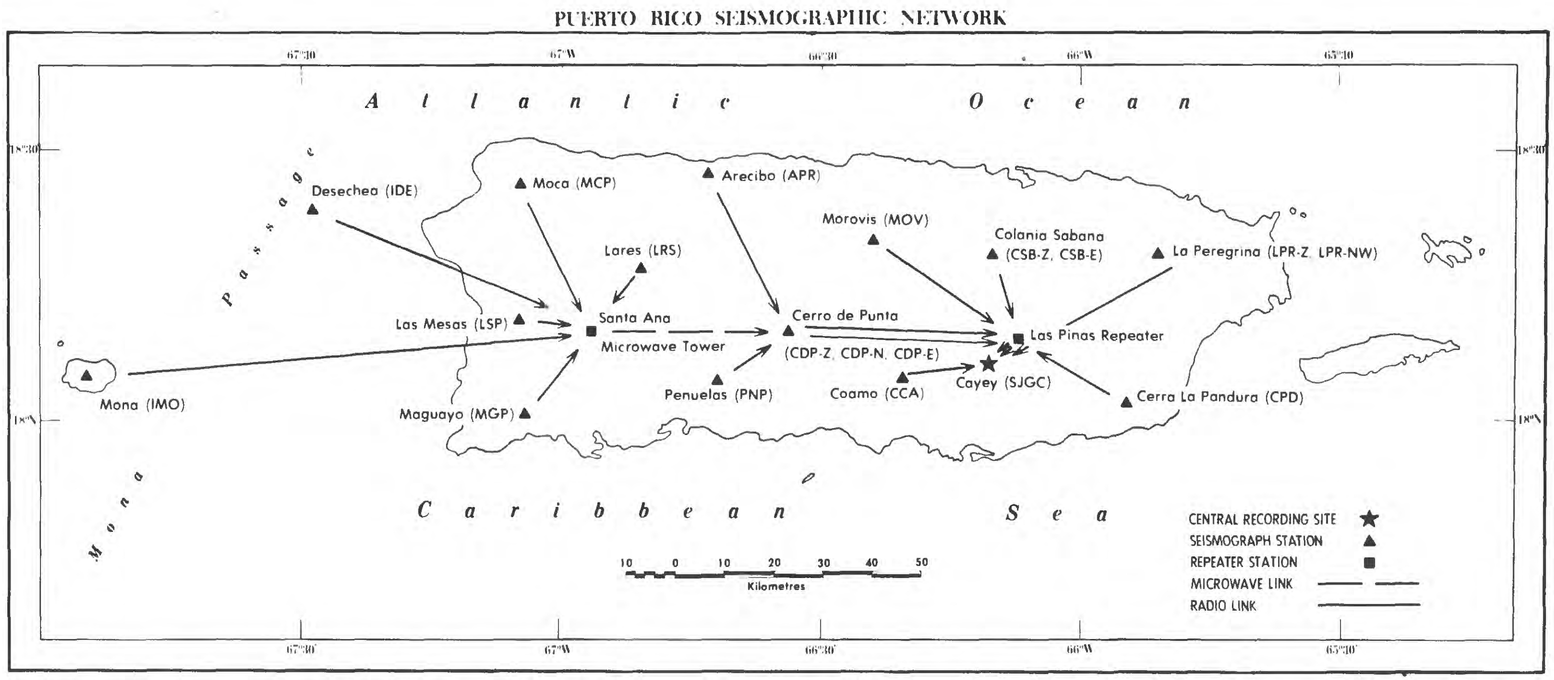

FIG. 1.--Puerto Rico Seismic Network. Vertical-component seismometers are installed at each site; stations with horizontal components contain suffixes in their code name to indicate the orientation (Z=vertical, N=north, E=east, and NW=northwest).

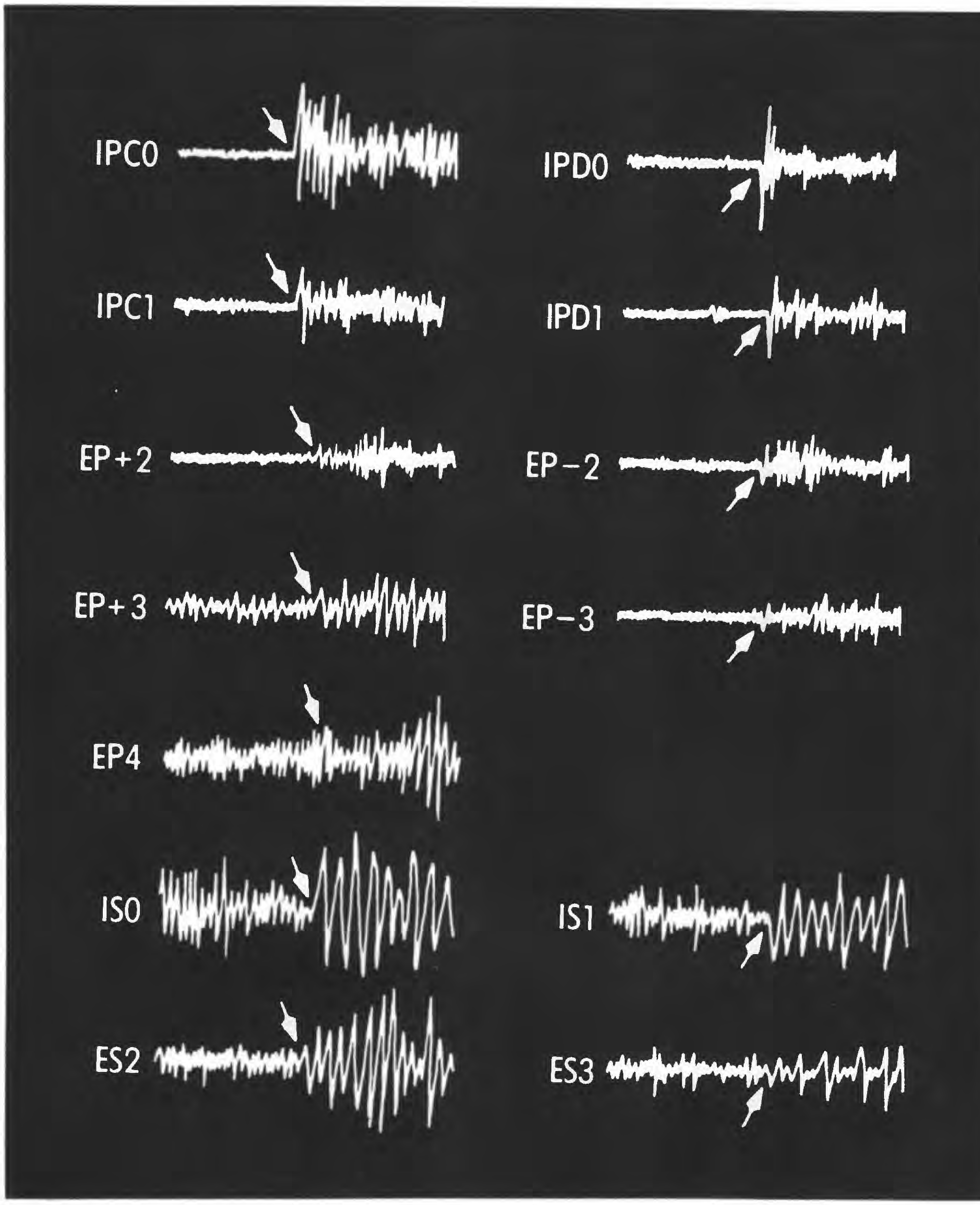

FIG. 2.--Examples of first-motion weighting: ⟶ indicates phase arrival.

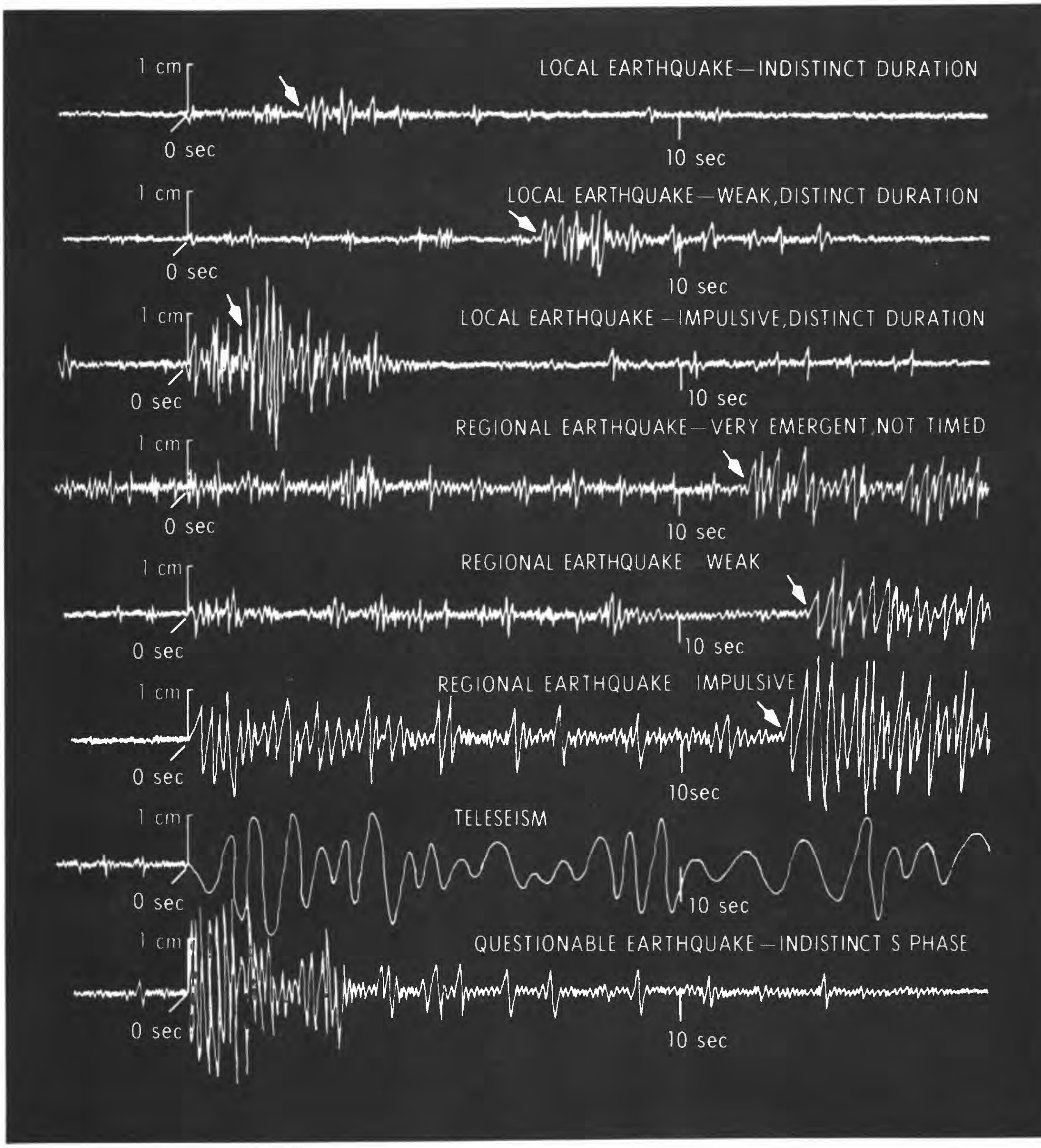

FIG. 3.--Timing examples: ➔ indicate phase changes.

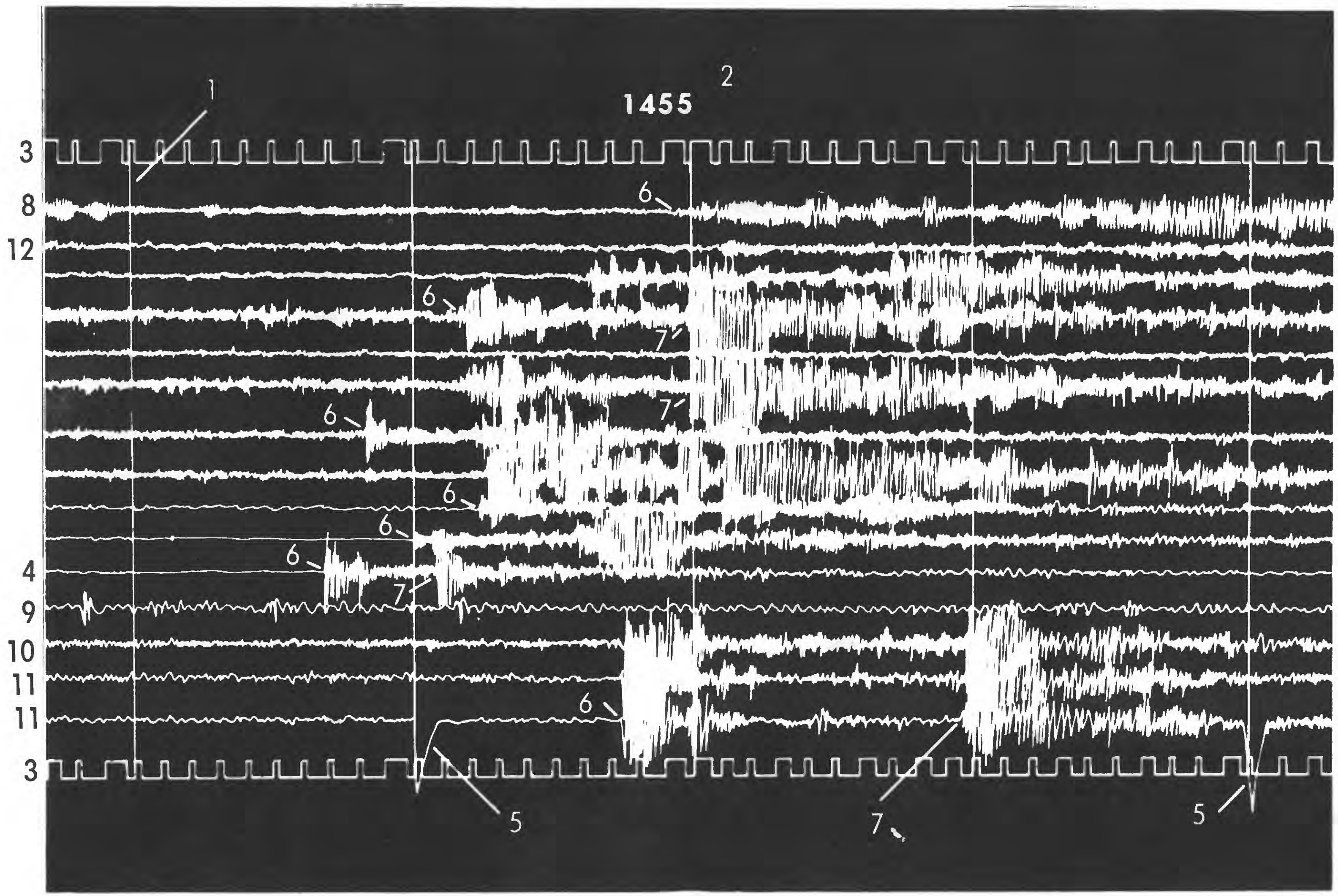

FIG. 4.--Local earthquake: 1, WWVB 10-s time line (40th s); 2, min change (14th h, 55th min); 3, WWVB timing code; 4, first station (closest station to the hypocenter); 5, spiking (NOISE); 6, P-phase; 7, S-phase; 8, last station (farthest station from the hypocenter); 9, distant station (this station is too far from the hypocenter to record the earthquake); 10, vertical channel; 11, horizontal channel; 12, most distant station trace.

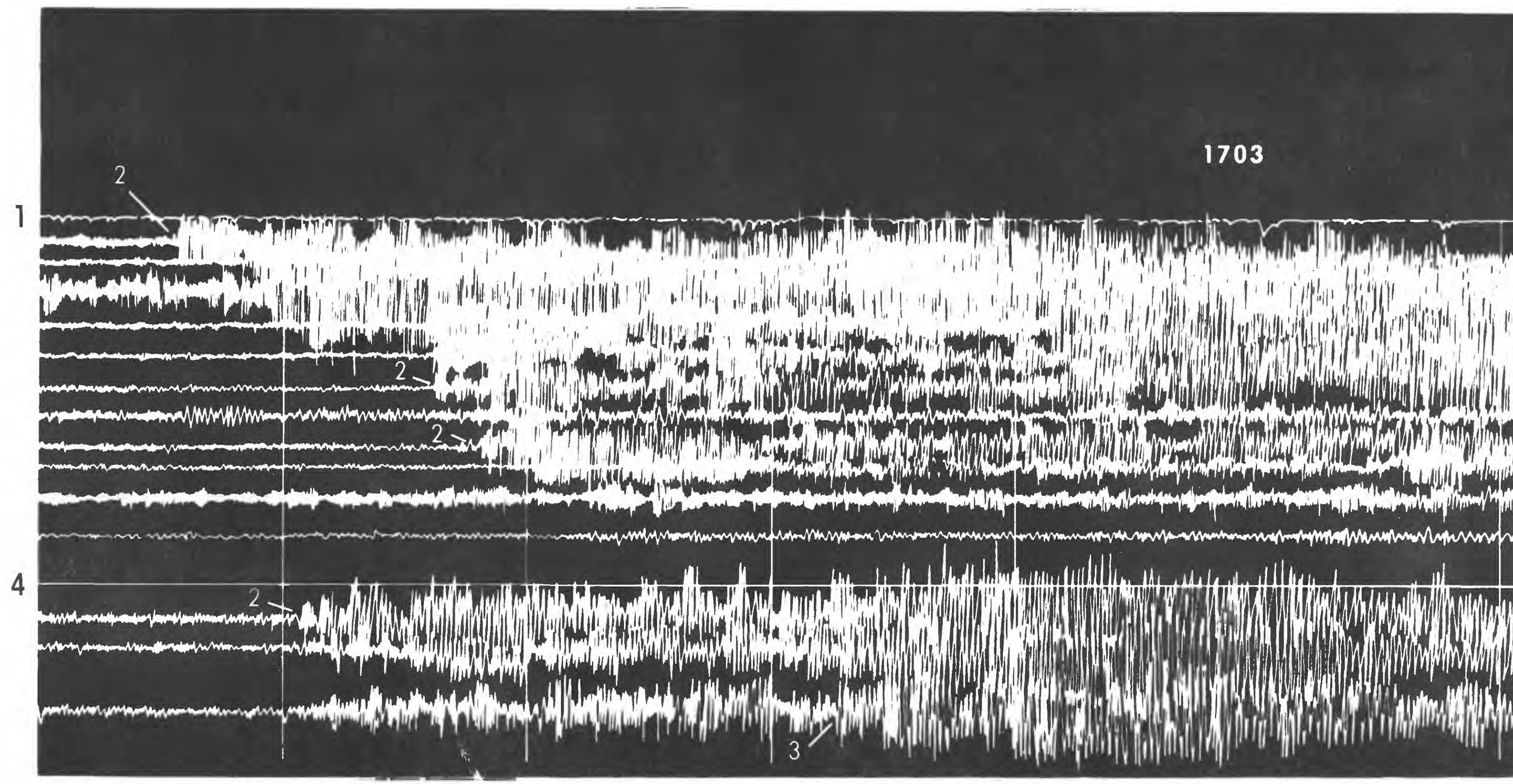

FIG. 5.--Regional earthquake: 1,WWVB timing code was not recorded; 2,P-phase; 3,S-phase; 4,dead trace (interruption in signal transmission due to mechanical or electrical failure).

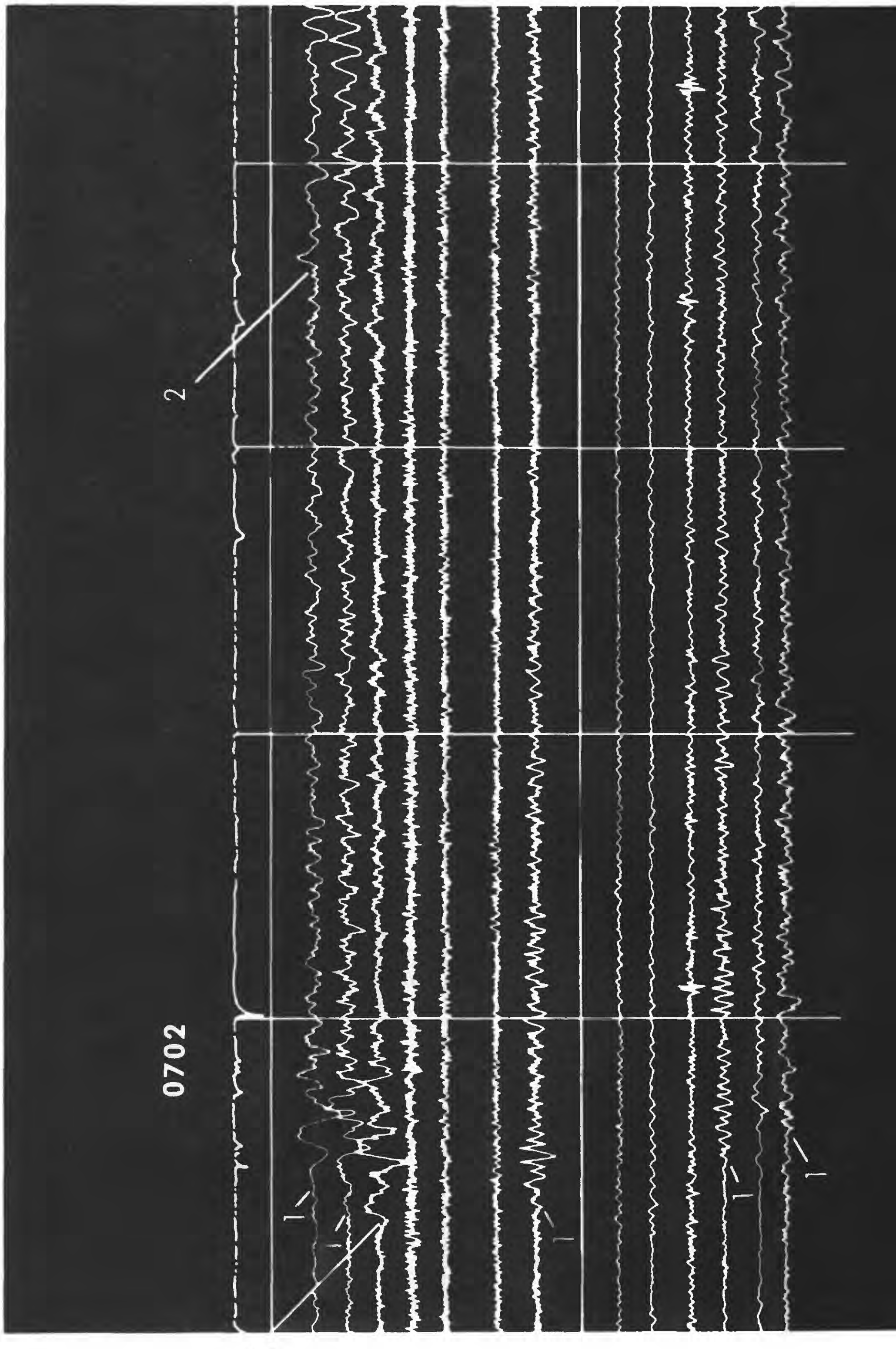

FIG. 6.--Teleseism: 1,P-phase; 2,phase change (S-phase).

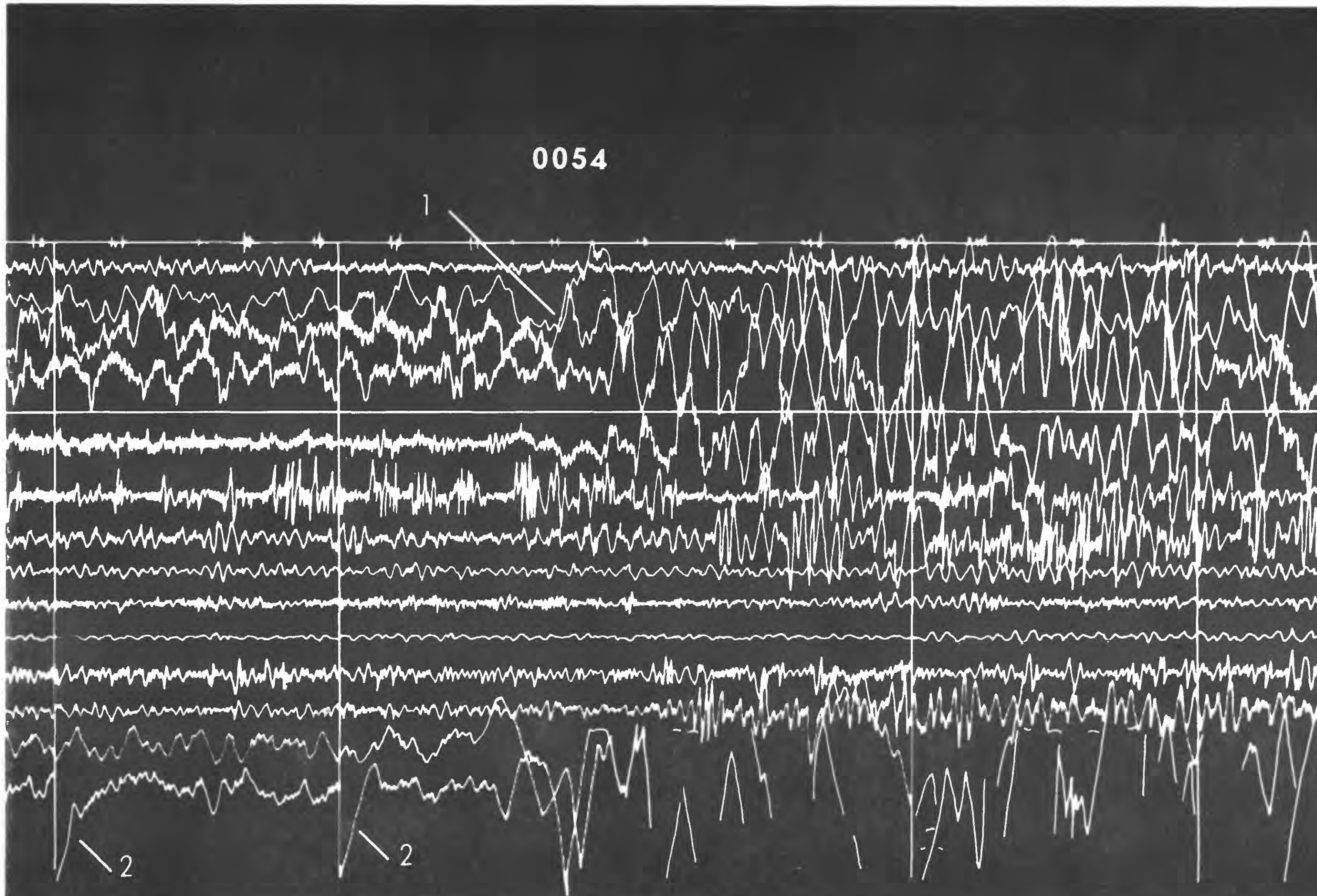

FIG. 7.--Teleseismic surface waves: 1,phase change; 2,spiking.

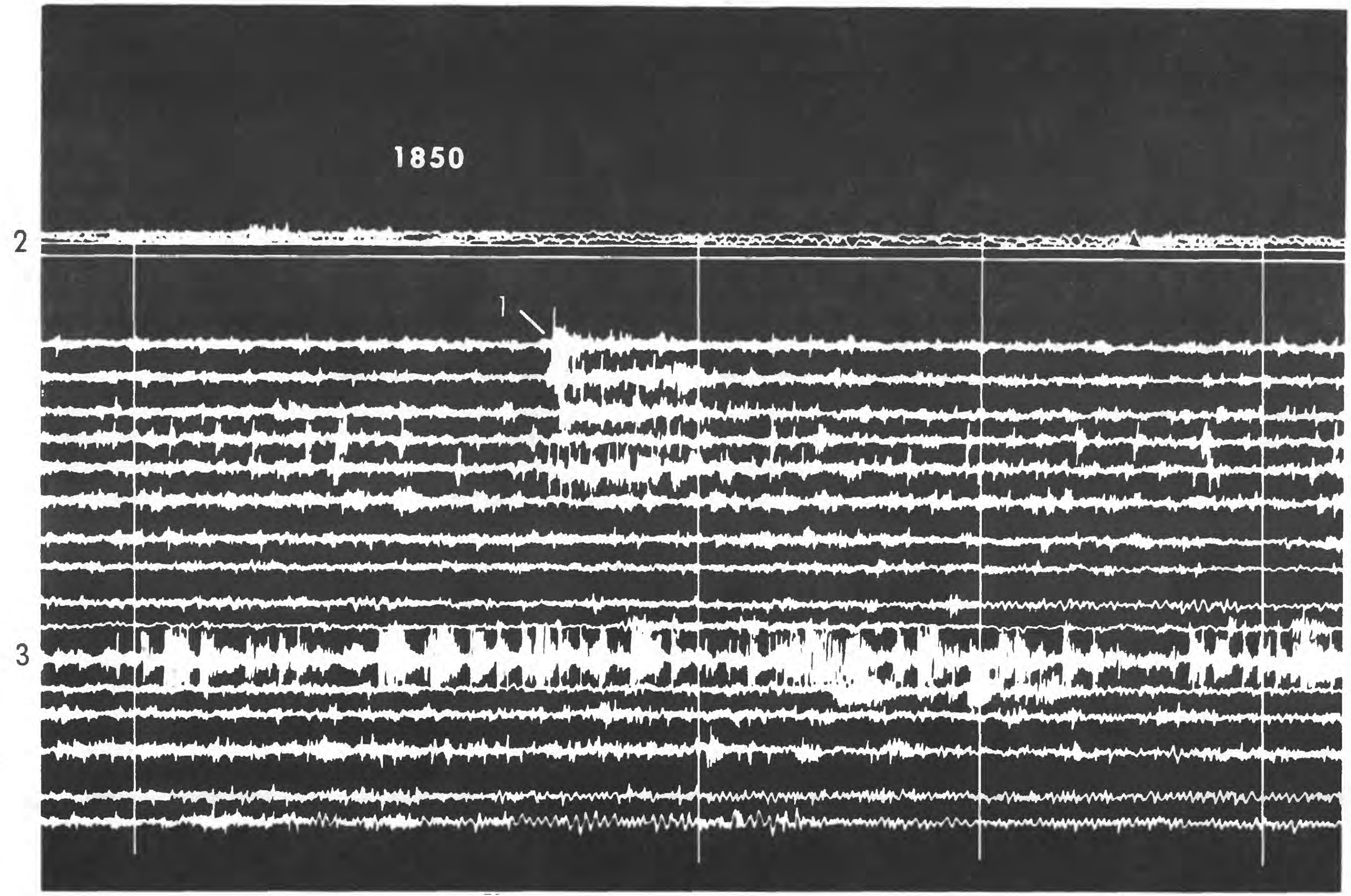

FIG. 8.--Questionable earthquake: 1, questionable P-phase; 2, overlapping traces; 3, noisy trace.

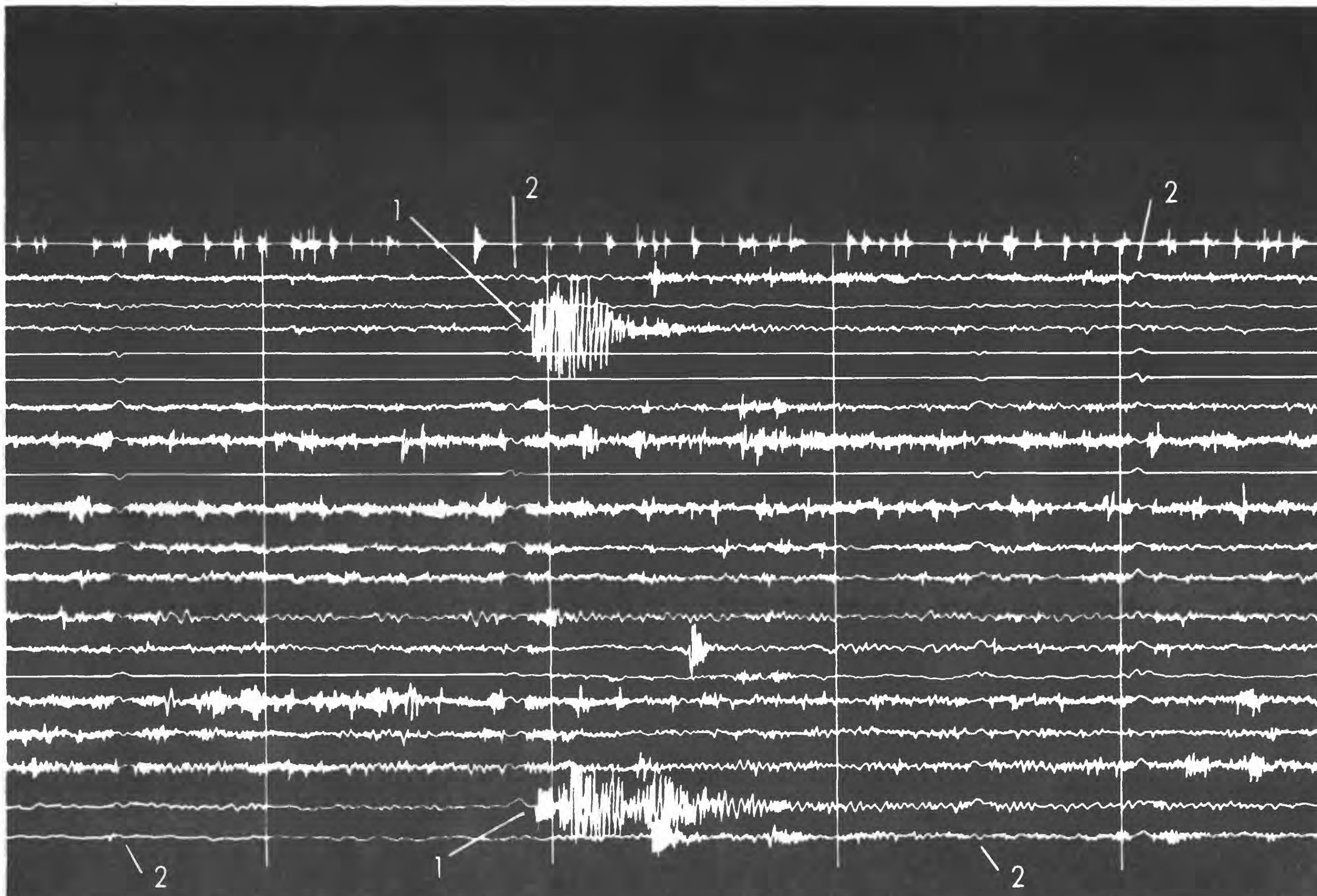

FIG. 9.--Quarry blast: 1, phase arrival; 2, stretch mark. Stretch marks are found in all stations across the network.

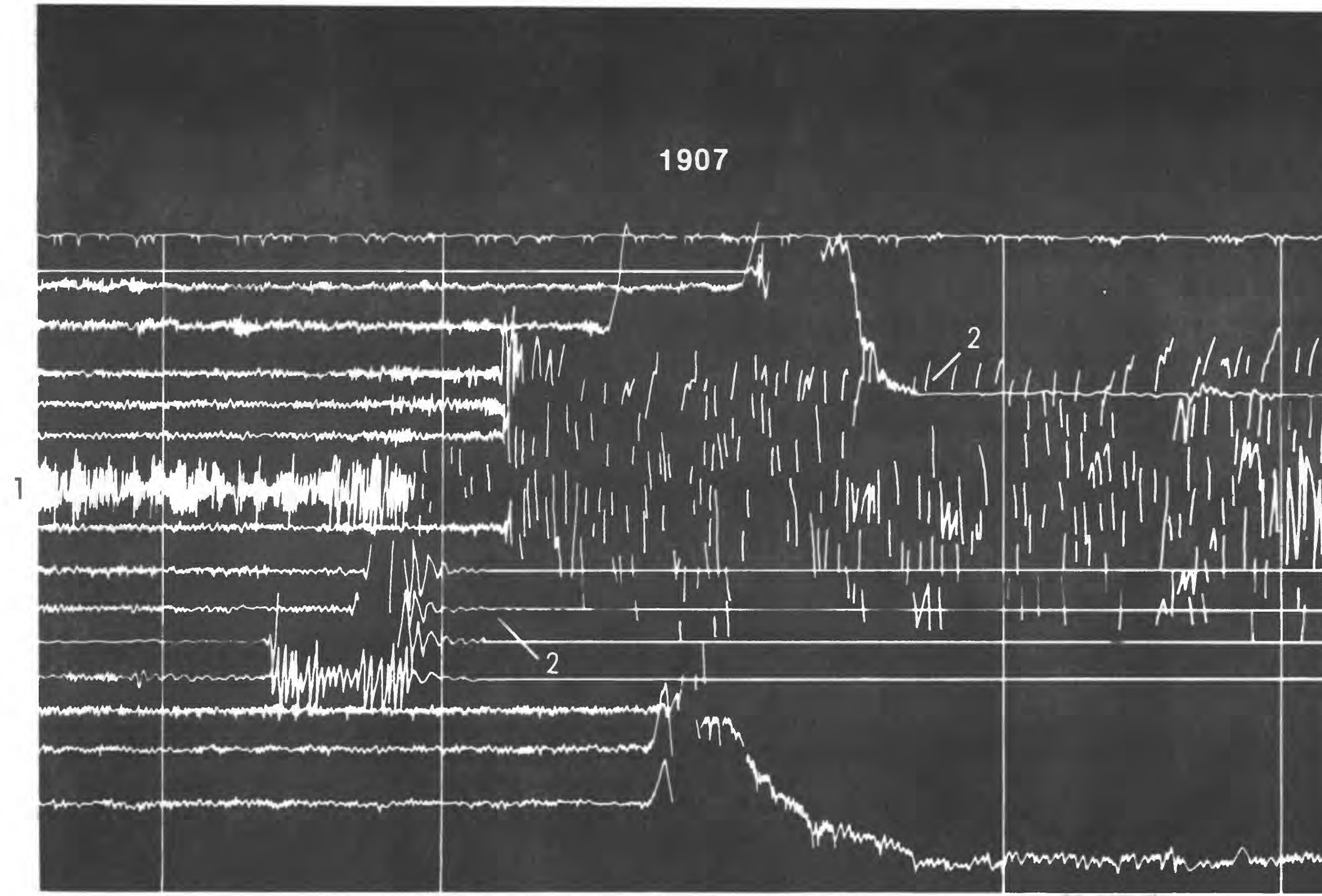

FIG. 10.--Large earthquake, magnitude (m_b) 4.5: 1, noisy trace; 2, temporary loss of radio telemetry transmissions.

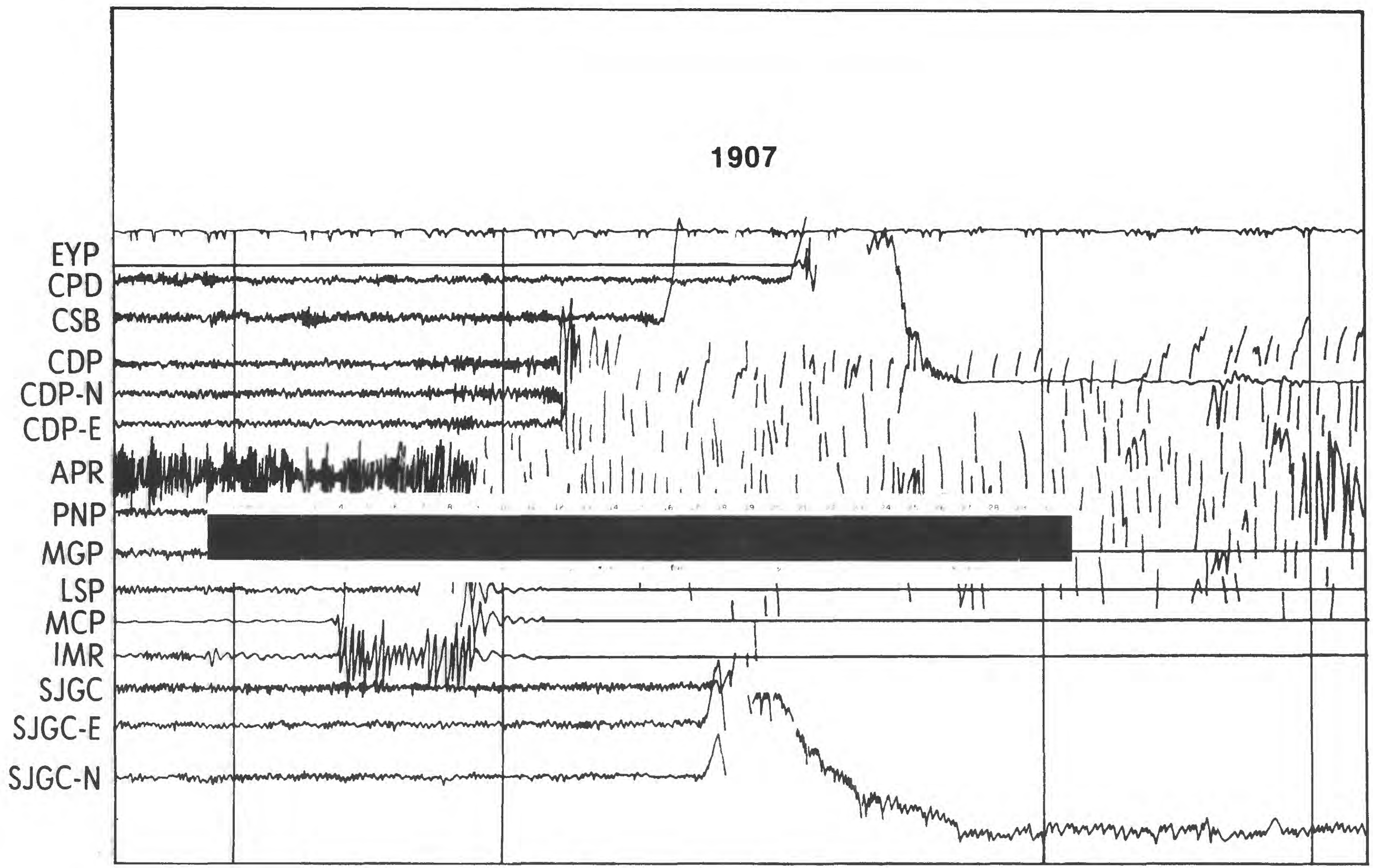

FIG. 11.--Film timing. The P phase on station trace APR is read in the 6th minute of the 19th hour at 49.0 s. The first motion is IPDO.

DATE: JUNE 13, 1976 U.T.C.: 19 hr. 06 min. STATION GROUP: Puerto Rican Network

STA.	P I(CD)E(+-)	YR.	MO.	DY.	HR.	MIN.	READ P	READ S	S	AMP. (mm.)	PER. (sec.)	MIN.	REREAD P	REREAD S	REMARKS	DUR. (sec.)
EYP ~~LPR~~	IPCU	76	06	13	19	07	00.85		S						MAINSHOCK	
CPD	IPCO						00.65		S							
CSB	IPCO	76	06	13	19	06	55.90		S							
CDP	EP-2						52.00		S							
CDP-N	P								S							
CDP-E	P								S							
APR	IPDO						49.00		S							
PNP	EP+2						52.15		S							361.0
MGP	EP-2						47.20		S							
LSP	EP-2						46.70		S							
MCP	EP+3						43.50		S							387.0
IMR ~~IMO~~	IPCO						43.80		S							
CCA	P								S							
MOV	P								S							
LRS	P								S							
IDE	P								S							
SJGC	EP 3						57.70		S							380.0
SJGC-E	P								S							
SJGC-N	P								S							

FIG. 12.--Example of the Seismic Data Record for the large earthquake in Figures 10 and 11. This earthquake was the main shock for several hundred aftershocks. P-phase times were recorded for each station (vertical component seismometers), but no S phase data could be determined. CDP-N, CDP-E, SJGC-E, and SJGC-N are horizontal component seismometers. Stations CCA, MOV, LRS, and IDE were installed after 1976 and EYP, IMR, SJGC-E, and SJGC-N have since been relocated and their names changed.

REFERENCES CITED

Astrodata, A handbook of time code formats; Astrodata Inc., P.O. Box 3003, 240 E. Palais Rd., Anaheim, Calif. 92803, 51 p.

Bolt, B. A., 1978, Earthquakes, a primer: San Francisco, Calif., W. H. Freeman and Company, p. 10, 27-30, 108-111.

Hodgson, J. H., 1964, Earthquakes and earth structure, Englewood Cliffs, N.J., Prentice-Hall, Inc., p. 69, 70.

Howe, S. L., ed., 1976, NBS time and frequency dissemination services: National Bureau of Standards, Special Publication 432, 16 p.

Lee, W. H. K., Bennett, R. E., and Meagher, K. L., 1972, A method of estimating magnitude of local earthquakes from signal duration: U.S. Geological Survey, Open-File Report, 28 p.

Lee, W. H. K., and Lahr, J. C., 1975, HYPO71 (rev.): A computer program for determining hypocenter, magnitude, and first motion pattern of local earthquakes: U.S. Geological Survey, Open-File Report 75-311, 113 p.

Richter, C. F., 1958, Elementary seismology: W.H. Freeman and Company, San Francisco, Calif., 768 p.

Tarr, A. C., and King, K. W., 1976, Puerto Rico seismic program: U.S. Geological Survey Open-File Report 76-49, 23 p.

APPENDIX A

Alternate weighting method

The data-weighting scheme illustrated in this report is not absolute. Problems include its complexity and analytic subjectivity in timing the data. Furthermore, such a weighting system may complicate the two weighting methods built into the earthquake location program HYPO71 (Lee and Lahr, 1975) that generates the actual hypocenter solutions and magnitudes.

Some type of first-motion evaluation should be included with the data when timed. This information will help in further analysis or rereading of the data. The following weighting method is offered as an alternative. Impulsiveness and emergence is implied in the phase numbering.

Table A-1.--Alternate weighting method

Numeric weighting	First motion	Phase	Degree of certainty
0	C or D	P or S	100%
1	C or D	P or S	75%-100%
2	+ or -	P or S	50%- 75%
3	+ or -	P or S	Guess - 50%

Either of the two weighting methods offered in this report are sufficient. The differences between them are minimal; essentially the former offers completeness and the latter, because it is briefer and possibly more easily understood, offers ease of comprehension.

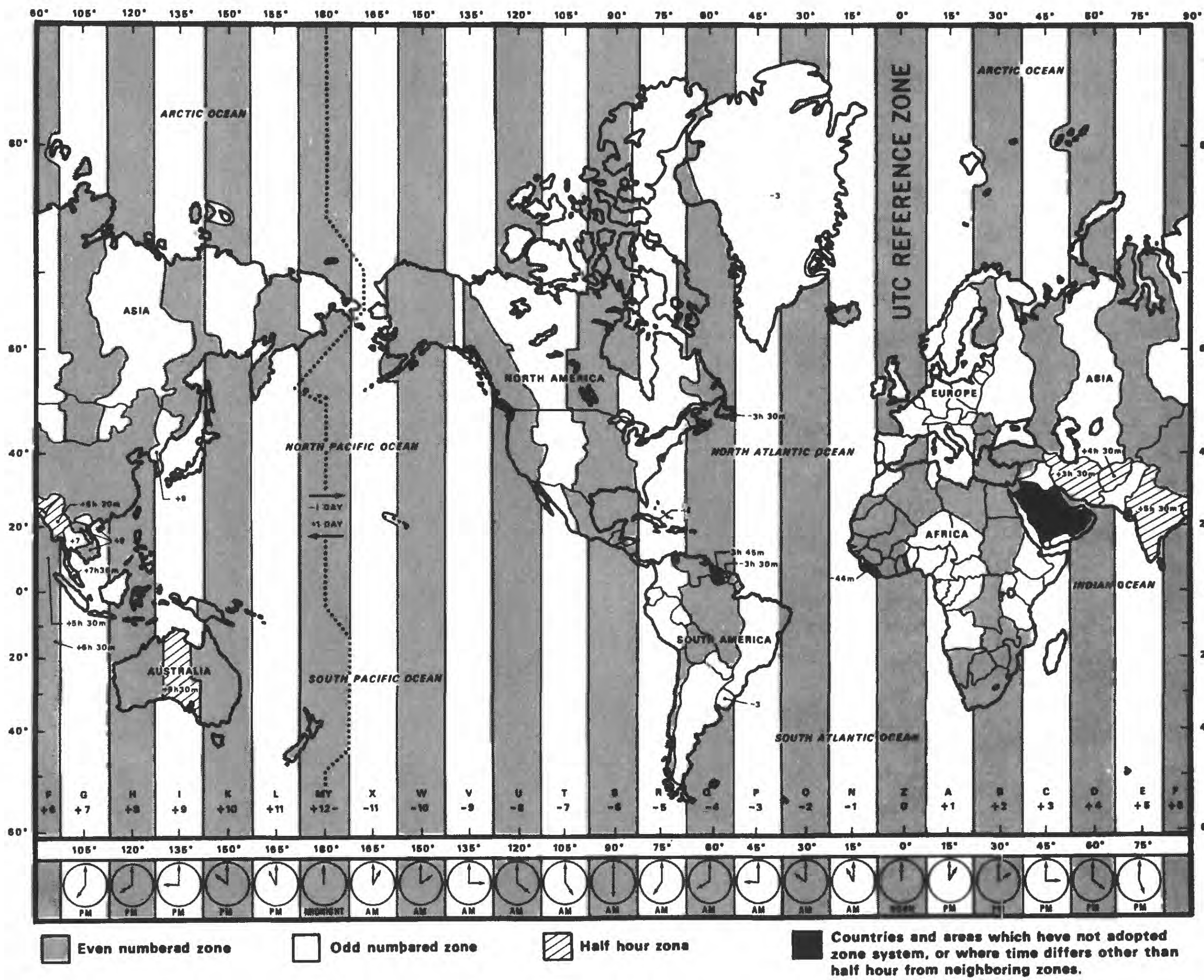

FIG. B-1.--International time zones map: add or subtract hours from Coordinated Universal Time (UTC) in order to determine current time elsewhere on earth (Howe, 1976). The U.S.S.R. is on daylight saving time permanently.

APPENDIX C

Timing systems

WWV, WWVH, and WWVB: The National Bureau of Standards (NBS) in Boulder, Colorado, broadcasts Coordinated Universal Time (UTC) by radio signal (Howe, 1976). UTC is equivalent to "Greenwich Mean Time" (GMT) which differs from local times by an integral number of hours. In order to compensate for ionospheric conditions, the NBS broadcasts continuously on stations WWV and WWVB, from Ft. Collins, Colo, and WWVH from Kauai, Hawaii, at a variety of frequencies. WWV and WWVB use frequencies 2.5, 5, 10, 15, 20, and 25 MHz, and WWVB uses 60 MHz. UTC is used by seismologists to calibrate seismic instruments and mark recorded data. Figure C1 shows how UTC would appear on a seismic record (Howe, 1976).

IRIG standard timing: IRIG time codes are very similar to WWV, WWVH, and WWVB in that they use binary number systems that can be recorded on the seismic record, magnetic tapes, oscillographs, strip charts, printers or film (Astrodata). The difference between NBS time broadcasts and IRIG is that IRIG is an internal timing system that is unique to the data recording instrument. The IRIG time-code formats used vary according to the manufacturer.

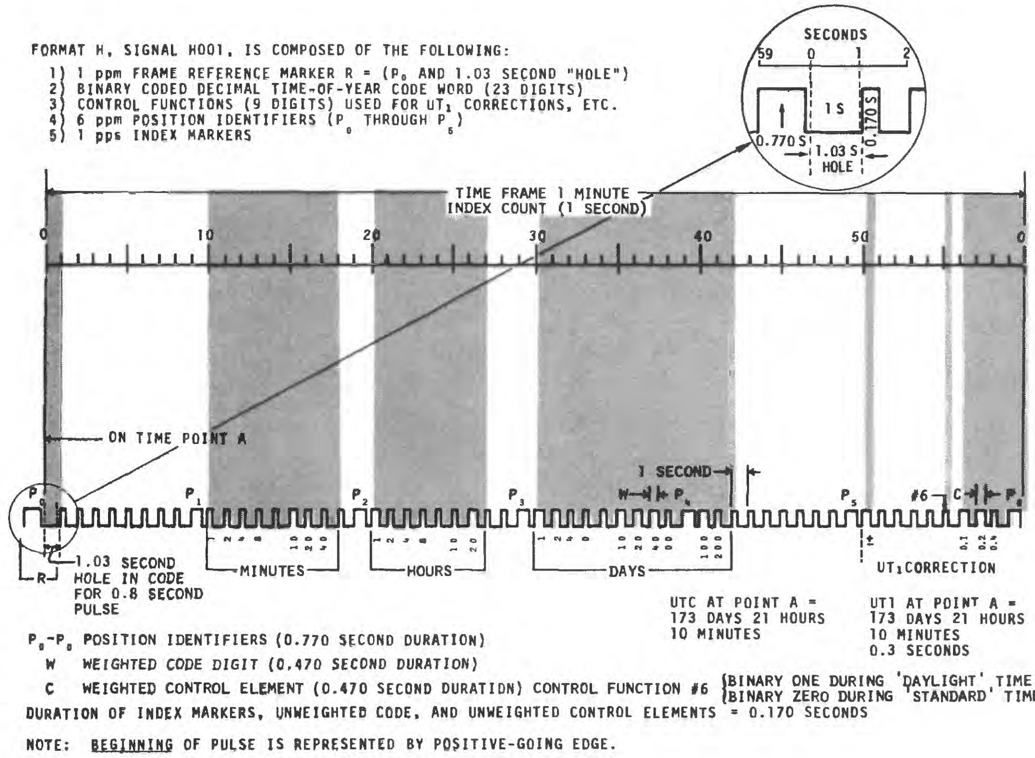

FIG. C-1a.--UTC code format used by WWV and WWVH, (from Howe, 1976).

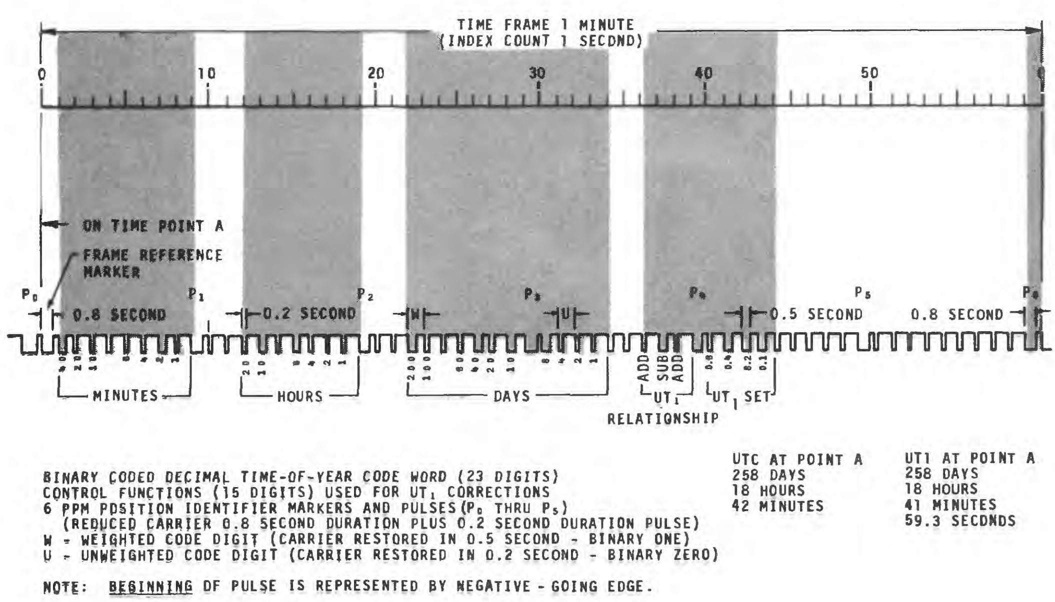

FIG. C-1b.--UTC code format used by WWVB, (from Howe, 1976).

APPENDIX D

Suggested reading:

Bolt, B.A., 1978, Earthquakes, a primer: W. H. Freeman and Company, San Francisco, Calif., 241 p.

Neumann, F., 1966, Principles underlying the interpretation of seismograms: U.S. Dept. of Commerce, Special Publication No. 254, 50 p.

Richter, C. F., 1958, Elementary seismology: W. H. Freeman and Company, San Francisco, Calif., 768 p.

Simon, R. B., 1968, Earthquake interpretations: Colorado School of Mines, 99 p.

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