Mr. Ralph Stein, Acting Director
Licensing and Regulatory Division
Office of Geological Repositories
Office of Civilian Radioactive Waste Mgt.
U. S. Department of Energy RW-24
Washington, D. C. 20545

MAR 18 1988

Dear Mr. Stein:

Subject: Summary of February 29 to March 3, 1988 Seismic Monitoring Program Visit

Enclosed for your information is the summary of the February 29 to March 3, 1988 staff visit concerning the Nevada Nuclear Waste Storage Investigation seismic monitoring program. The summary itself is identified as Enclosure 1. Enclosure 2 is a copy of the attendees at the entrance and exit meetings and Enclosure 3 is a copy of the U. S. Geological Survey (USGS) presentation.

As is discussed in the summary, this was a visit and not an audit; therefore, the acceptability of the program for licensing will be addressed later after a detailed staff review. Based on the information presented to it, the staff found no major problems with the Department and USGS seismic monitoring program. With respect to quality assurance (QA), DOE and the USGS noted during the presentation that the QA program was not fully implemented. However, the staff believes that the QA program is working well for the level at which it is established.

As a result of the visit, the staff has several suggestions that the Department should consider for implementation. The suggestions are contained in Enclosure 4 and were presented to members of the DOE staff and the USGS during the March 3, 1988 exit meeting. The NRC staff does not expect a written response with regard to the suggestions contained herein. However, in future QA audits, the NRC staff will include those areas covered by the suggestions.

If you have any additional questions on the summary or site visit, please feel free to contact the cognizant project manager, Joe Holonich, at FTS 492-3403.

Sincerely,

/s/

B. J. Youngblood, Chief
Operations Branch
Division of High-Level Waste Management
Office of Nuclear Materials Safety
and Safeguards

Enclosures: As stated

cc: G. Gertz
R. Loux
M. Glora

Delete all dist. except PDR, LPDR, CNWRA, CF & NLSS

NH16
102.8
WM-11

LETTER TO:	Mr. Ralph Stein, Acting Director
FROM:	B. J. Youngblood, Chief
SUBJECT:	SUMMARY OF FEBRUARY 29 TO MARCH 3, 1988 SEISMIC MONITORING PROGRAM VISIT
DATE:	MAR 18 1988

DISTRIBUTION

R. E. Browning	R. L. Johnson	P. T. Prestholt
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LSS	M. Blackford	L. Riddle

CONCURRENCES

ORGANIZATION/CONCUREE	INITIALS	DATE
HLOB/J. Holonich	JH	03/17/88
HLOB/J. Linehan	JJ	03/17/88
HLTR/R. Ballard	Raw for	03/18/88
HLOB/B. J. Youngblood	BJY	03/17/88
HLTR/M Blackford	[illegible]	03/17/88
HLTR/PS JUSTUS	PJ	03/17/88

102.8
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ltr dtd 8/18/88

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MAR 1 8 1988

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Office of Nuclear Materials Safety
and Safeguards

Enclosures: As stated

cc: G. Gertz
R. Loux
M. Glora

Enclosure 1

Summary of Staff Visit on the Seismic Monitoring Program

From February 29, 1988 to March 2, 1988, members of the staff met with representatives from the Department of Energy (DOE) and its contractors Science Application (SAIC) and the U. S. Geological Survey (USGS). The purpose of the visit was for the staff to gain an understanding of the DOE seismic monitoring network for the Yucca Mountain Site. Also present were representatives from the State of Nevada and its contractor the University of Nevada at Reno. A list of attendees at the entrance and exit meetings is given in Enclosure 2.

On Monday February 29, 1988, the staff was briefed by the USGS on the layout of the network. This presentation included a discussion of the present network as well as a description of planned upgrades to the network. Enclosure 3 is a copy of the USGS presentation on the present network. Planned upgrades that were discussed included:

(1) making the system broad-band versus the narrow-band, low-frequency that it is;

(2) having on-scale digital data, digital versus FM analog telemetry, and near-real-time, single-pass auto processing;

(3) increased station density; and

(4) both horizontal and vertical seismometers at some stations as opposed to the mostly vertical seismometers that are presently in place.

During the presentation the staff was asked about the level of quality assurance (QA) that would be needed for the computer programs that are used to analyze the seismic data. Of particular concern to the USGS was the fact that it was not possible to provide the degree of documentation for old software that would be available to QA the new software. It was noted by the USGS that the older software had been in use for many years and that it had undergone extensive technical reviews. These reviews provided assurance that the programs did perform their intended functions. In response to this question, the staff stated that it was not prepared to present any position; however, the QA level of documentation should be based on the degree of importance assigned to a program by DOE and the USGS. Therefore, it was up to the DOE to justify that the use of these programs was acceptable.

The morning of Tuesday March 1, 1988 was spent touring the data collection facility for the Southern Great Basin Network. As part of the tour the staff was shown the data collection and calibration instrumentation; the record storage for the calibration of instruments; and the 1134, 1170, and Vax computers used to process the data. In the afternoon of March 1 the staff received a presentation on the QA aspects of the seismic monitoring program. Areas of the QA program that were covered included: (1) the organization and reporting authority; (2) a history of the QA Program Plan; (3) a discussion of how QA is involved in the development of implementing and technical procedures; (4) a description of the personnel certification process for the USGS and training records; and (5) a presentation on the instrument calibration portion of QA.

Wednesday March 2, 1988 was spent visiting the USGS Sheep Range seismic station (SHRG), the Angel Peak seismic station (APKW), and the collection point for seven additional signals. (Station names and codes are taken from figures and tables in Enclosure 3.)

Based on the information presented and the station visits, the staff was impressed with the program and felt that the USGS had adequate coverage of the seismicity in the Yucca Mountain vicinity. With respect to the QA aspects of the seismic monitoring program, the staff felt that it appeared to be working adequately at the level at which it established and that the program was heading in the proper direction. Because this was only a visit and not an audit, the acceptability of the program for licensing will be determined later. Therefore, the staff did not offer any findings on the acceptability of the program. However, the staff did have several suggestions that DOE and the USGS should consider. These are contained in Enclosure 4.

The staff conclusions and suggestions were based on the information presented to the staff during its visit. No detailed staff effort was undertaken prior to the visit.

Enclosure 2

Attendees at the February 29 and March 3, 1988 Meetings

NRC

J. Holonich
M. Blackford
L. Riddle
P. Prestholt

DOE

U. S. Clanton
O. Thompson
I. Alterman
M. P. Kunich**

SAIC

J. King
F. D. Peters
M. Lou Brown
M. Glora

WESTON

W. Haslebacher

USGS

L. Hayes*
J. Willmon
J. Banth*
G. Shideler
C. Bufe*
R. B. Raup*
A. Rogers*
D. Overturf*
S. Harmsen*
M. Meremonte*
P. Chang*

STATE OF NEVADA

J. Grubb
W. Hicks**

UNIVERSITY OF NEVADA

J. Brune
W. Peppin*

* Attended February 29, 1988 entrance meeting only.
** Attended March 3, 1988 exit meeting only.

ENCLOSURE 3

U. S. GEOLOGICAL SURVEY

FEBRUARY 29, 1988

PRESENTATION

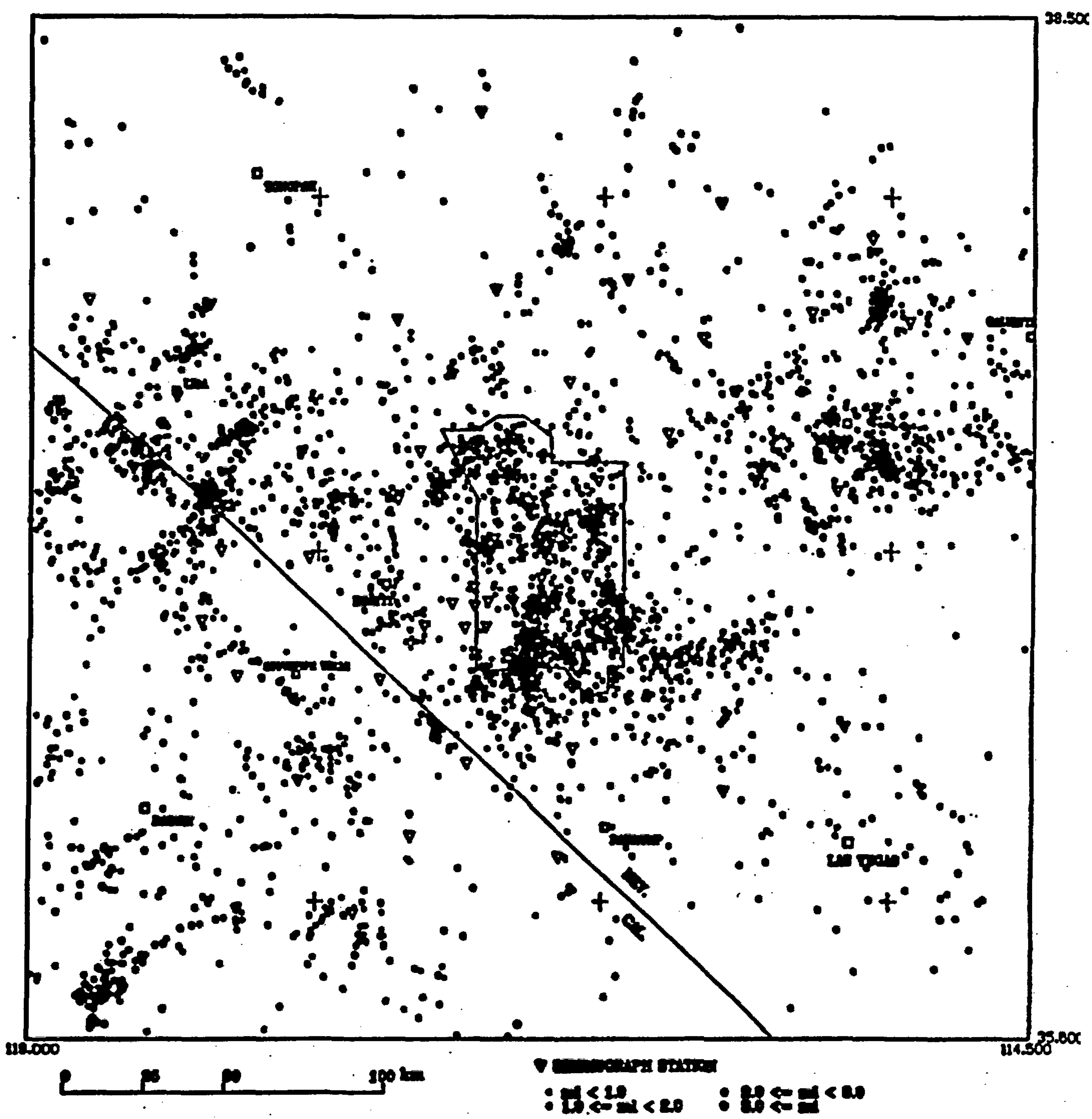
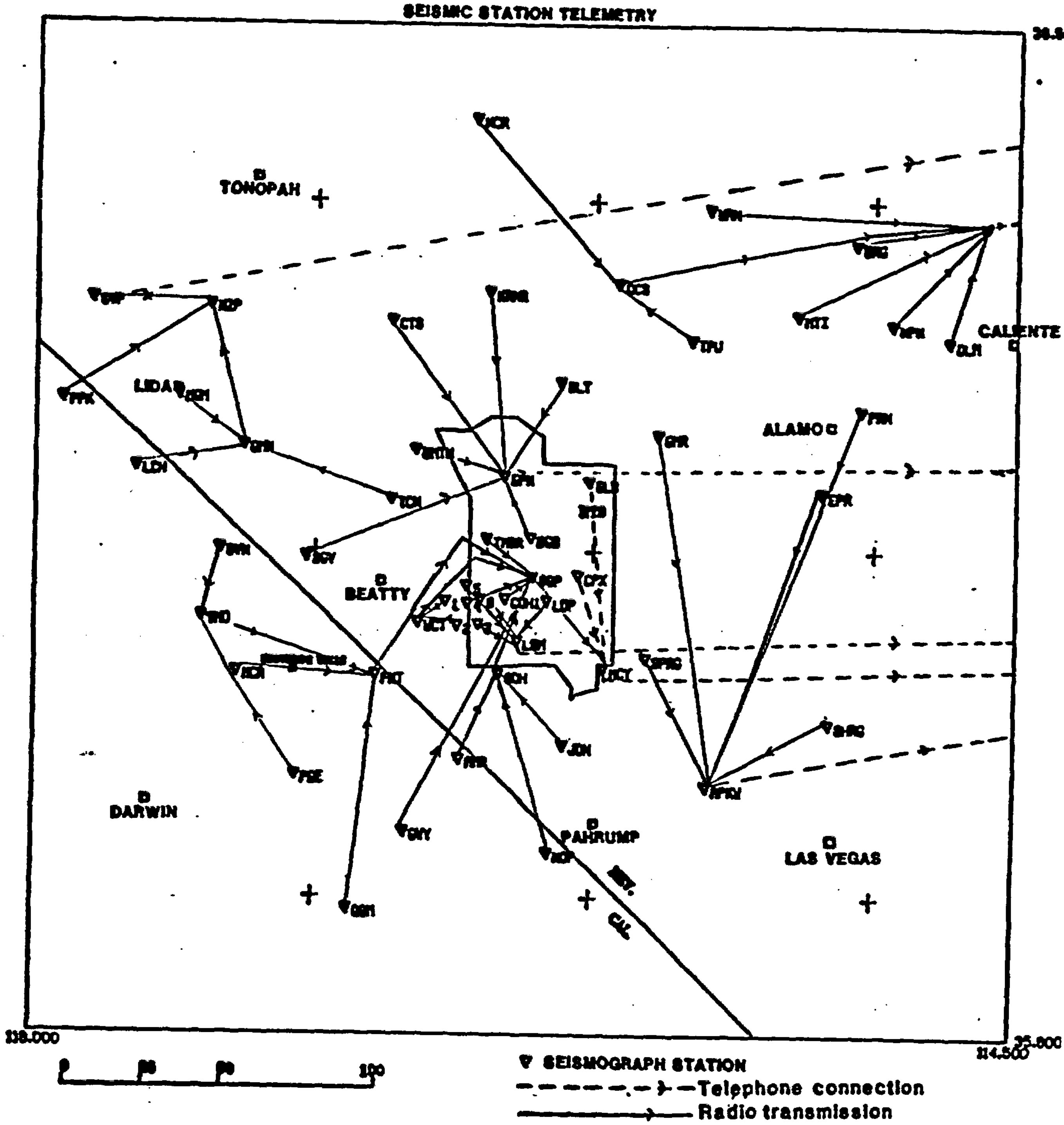
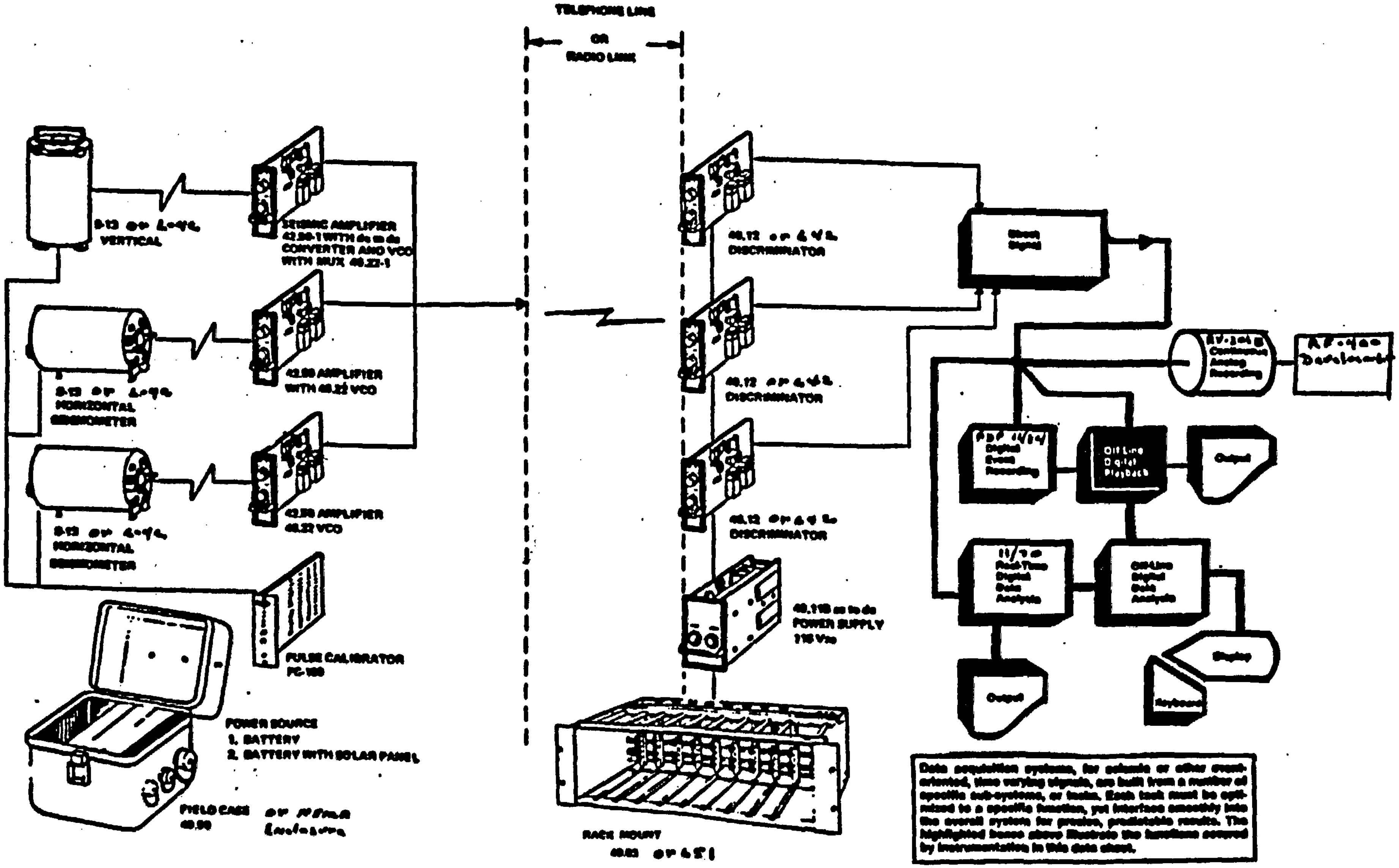


Figure 4.– Seismicity in the southern Great Basin for the period August 1, 1978, through December 31, 1986.


SEISMIC STATION TELEMETRY
TONOPAH
LIDA
BEATTY
DARWIN
PAHRUMP
LAS VEGAS
ALAMO
CALIENTE
NEV.
CAL.
118.000
114.500
0
25
50
100
SEISMOGRAPH STATION
Telephone connection
Radio transmission



Data acquisition systems, for seismic or other event-oriented, time varying signals, are built from a number of specific sub-systems, or tasks. Each task must be optimized to a specific function, yet interface smoothly into the overall system for precise, predictable results. The highlighted boxes above illustrate the functions covered by instrumentation in this data sheet.

TYPICAL EQUIPMENT OF THE GBSN SEISMIC TELEMETRY SYSTEM

A. **Field Stations:**

Seismometer model S-13 or L4C
Seismic Amplifier, model 4250-1 (special design for telemetry use) or 649
Seismic Amplifier, model 42.50 for additional incoming signals
Voltage Controlled Oscillator model 46.22-1, including Multiplexer
Voltage Controlled Oscillator, model 46.22, without Multiplexer
Pulse Calibrator, model PC-100, for automatic calibration of field seismometer.
Multiplexer, model 46.31. Required when more than 3 signals (up to 8 from different sources) need to be multiplexed.
Field Package (case) model 49.50 or NEMA enclosure to provide electrical connections and weather protection to amp VCO, PC-100, multiplexer, etc.
Radio Transmitter, VHF model 810-038 or TR-150, as required for transmission of signal
Antenna, either VHF model CA-150 or model DB-230 as required
Antenna Mast, model L-40 (12 m high) or L-50 (15 m high)
Battery, usually 80 A/hr capacity
Heavy duty steel enclosure for housing of the Field Case, the battery, and the transmitter
Solar Panel, model ARCO-M-65, as required, or
Battery Charger for reposition of battery load where AC power is available

B. **Radio Repeating Stations:**

Radio Receiver(s) VHF model 1810-055 or R-16F as required
Multiplexer, model 46.31
Radio Transmitter, VHF model TR-150 as required
Antennas: one for the receiver, another one for the transmitter
Antenna mast (usually two) with mounting hardware
Rechargeable 12 V. battery (usually 80 A/hr capacity)
Heavy duty steel enclosure for installation of equipment above
Solar Panel, model ARCO M-65, where no AC power is available
Battery Charger, if AC power is available at repeating site

C. **Central Receiving Site:**

Radio Receivers for incoming signals, VHF model 810-055 or R-16F
Antennas for radio receivers, model CA-150 for VHF operations
Antenna masts, including mounting hardware

D. **Central Recording Station:**

Discriminators, model 46.12 or 642 for the conditioning of the incoming signals
Power Control Module, model 48.31B or 48.11, for DC or AC operation
Rack Mount Chassis, model 49.03 or 651 to hold up to 8 or 18 modules plus the Power Supply Module
Seismic Amplifier, model AR-311, single channel version
Seismic Recorder, model RV-301B, Helicorder, up to three channels, heat recording
Seismic Recorder model RF-400 Develocorder
DEC computer model PDP 11/34 and 11/70
Time Signal Radio Receiver, model TR-4, with antenna model AK-8
Microprocessor Based Timing System, model TG-120, for accurate time and time marks program
Equipment Consoles, models E1-1 and E1-2, for housing of all equipment at the Central Recording Station
Coaxial cables, interconnecting wiring, connectors, etc., usually fabricated and installed during the Systemizing Service
Radio Receiver model CS-60 WWVB
GOES satellite clock model 968 FPC

PDP 11/34 Computer Sytem for Seismic Data Acquisition

The PDP 11/34 is an on-line, dedicated seismic data acquisition system in 24-hour use (except for down time) since September, 1981. The system initially was designed to monitor up to 64 channels of southern Great Basin data sampled at 104 sps. In February, 1984, additional circuit boards and revised software were installed to increase the capacity to 96 channels. The system uses a "Laboratory Peripheral Accelerator" (LPA) processor to handle the A→D conversion and data buffering. The computer operating system is RSX, version 4.1. Software was originally developed at the University of Washington and at St. Louis University for their respective network data processing. The U. S. G. S. system at Golden, Co., is a hybrid of the St. Louis University seismic system.

A list of component hardware for the seismic data acquisition system is given in the table that follows.

PDP 11/34 Hardware for real-time data acquisition

Component	Purpose
CPU	System supervision and computation
LPA-11	Data Buffering
AD-11K	Two analog-to-digital converters
AM-11	32-channel input board
77-DIS	Two 32-channel distribution panels
FP-11A	Floating Point processor
KW-11K	LPA clock
DL0& DL1	Two RL01 disk drives
MM0,MM1, MT1	Three 1600 bpi tape drives
TT0 .	Decwriter terminal
Various	Output device controllers
H754	Power control, transformer

System maintenance is performed by Telos Field Service Engineering. Contract specifies 24-hour response time to problems, and bimonthly preventative maintenance.

Telemetry Station Coordinate Determination

- In 1977, the preliminary station distribution was plotted on $7\frac{1}{2}$ minute topo maps
- Actual site locations were plotted on $7\frac{1}{2}$ minute topo maps after geology and R.F. path profiles were tested in early 1978
- In 1977, stations were located by triangulation methods using a bruton compass and $7\frac{1}{2}$ minute topo maps at all locations
- In 1985, a magnavox satellite navigator model mx4102 was purchased jointly with another project and the stations are being located using this system which has an accuracy of ±50 meters with 3 satellite fix solutions

N/A	-BLD 116 R	BLD 116 R		
N/A	-HLD PK R	HIGHLAND PK R		
N/A	-LSM R	LITTLE SKULL R		
N/A	-SIL PK R	SILVER PK R		
Y	AMR	ARMARGOSA	36 23 82	116 28 58
Y	APK-W	ANGEL PEAK	36 19 19	115 35 30
N	BGB*	BIG BUITE		
N	BLT*	BELTED RNG		
N	BMT*	BLACK MNT		
Y	BRO	BARE MNT	36 47 55	116 37 37
N	CDH	CALICO DOWNHOLE		
N	CPX	CP-55		
N	CTS*	CATUS		
Y	DLM	DELMAR	37 36 37	114 44 42
Y	EPN	ECHO PK	37 12 88	116 19 41
Y	EPR	EAST PAHRANAGAT	37 10 14	115 11 23
N	FMT	FUNERAL MNT		
N	GLR	GROOM LAKE		
N	GMN	GOLD MNT		
N	GMR	GROOM RANGE		
N	GVN	GRAPE VINE CYN		
Y	GWV	GREEN WATER VAL	36 11 10	116 40 32
Y	HCR	HOT CREEK	38 14 01	116 26 30
Y	JON	JOHNNY	36 26 39	116 06 32
N	KRN-A*	KAWICH RNG		
N	LCH	LAST CHANCE RNG		
N	LOP*	LOOK OUT PK		
N	LSM	LITTLE SKULL MN		
N	MCA	MARBLE CANYON		
N	MCV	MERCURY		
N	MGM	MAGRUDER MNT		
Y	MTI	MOUNT IRISH	37 40 52	115 16 55
N	MZP	MONTAZUMA PK		
Y	NOP	NOPAH RNG	36 07 64	116 09 21
Y	NPN	NORTH PAHROC RNG	37 39 13	114 56 23
N	PGE	PANAMINT RNG		
N	PPK	PIPER PK		
Y	PRN	PAHRANAGAT	37 24 41	115 02 99
Y	QCS	QUEEN CITY SUMM	37 45 46	115 56 49
N	QSM	QUEEN SHEEBA MN		
Y	SDH	STRIPED HILLS	36 38 74	116 20 44
N	SGV	SOUTHERN GRP VN		
Y	SHRG	SHEEP RNG	36 30 28	115 09 54
N	SPRG*	STRIPED RNG		
Y	SRG	SEAMAN RNG	37 52 90	115 04 07
N	SSP	SHOESHONE PEAK		
N	SVP	SILVER PEAK		
N	TMBR*	TIMBER MNT		
N	TMO	TIN MNT		
Y	TPU	TIMPIUTI	37 36 26	115 39 13
	TRC	THIRSTY CANYON	37 08 52	116 42 99
	WRN	WHEELER PK	37 58 91	115 35 53
	YMT#1	YUCCA MNT 1	36 51 23	116 31 84
	YMT#2	YUCCA MNT 2	36 47 10	116 29 17
	YMT#3	YUCCA MNT 3	36 47 15	116 24 94
	YMT#4	YUCCA MNT 4	36 50 93	116 27 13
	YMT#5	YUCCA MNT 5	36 53 90	116 27 21
	YMT#6	YUCCA MNT 6	36 51 34	116 24 11

STATION COORDINATE LOCATION LOG

DATE 4/18/85

STATION NAME YMT #3

STATION ELEVATION 1060 METERS; FROM ALTIMETER (x) FROM TOPO MAP ( )

ANTENNA HEIGHT ABOVE GROUND AND STATION ELEVATION ______ METERS

STATION LOCATION Antena at vault.

OPEN HORIZON - N (x) - S (x) - E (x) - W (x)

INITIAL LATITUDE ENTERED 36° 38' 74'' N

INITIAL LONGITUDE ENTERED 116° 20' 44'' W

TIME 'ON' 1700 UTC OFFSET -8

SATELLITE ACQUISITION ______ UTC MAXIMUM SIGNAL/NOISE RATIO 61.6

SATELLITE FIX 1753 UTC SATELLITE ELEVATION 36° SATELLITE # 130

Final — LATITUDE FIX 36° 47' 16'' N LONGITUDE FIX 116° 24' 67'' W

QUALITY SOLUTION OK DOPPLER COUNTS 29 ITERATIONS 3

INSTRUMENT OPERATOR [signature]

REMARKS Fix #1

PDP 11/34 Event-Oriented Detection Algorithm

I. Based on a time-domain detection algorithm developed by Dr. Carl Johnson, of the U. S. G. S., Pasadena, California (his PhD dissertation has details).

II. Essence of algorithm: compare short-term ($\approx$ 0.5 sec) rectified signal average,

$$RBAR_k = \sum_{j=1}^{48} |s_j|/48,$$

with long-term rectified average ($\approx$ 4.0 sec),

$$RBRBR_k = \frac{1}{8}(RBAR_k + 7RBRBR_{k-1}),$$

where s_j is a digital sample amplitude ("counts") in the kth time window. Remove "drift"-effects visible in unrectified signal, whose short-term average is

$$SBAR_k = \sum_{j=1}^{48} s_j/48,$$

and whose long-term average is

$$SBRBR_k = \frac{1}{8}(SBAR_k + 7SBRBR_{k-1}),$$

and subtract a global sensitivity constant, $ECONST$, to obtain the ith station's momentary "yea or nay" vote, η_k, ($\eta > 0$ is a "yea") where

$$\eta_k = RBAR_k - 2RBRBR_k - |SBRBR_k - SBAR_k| - ECONST$$

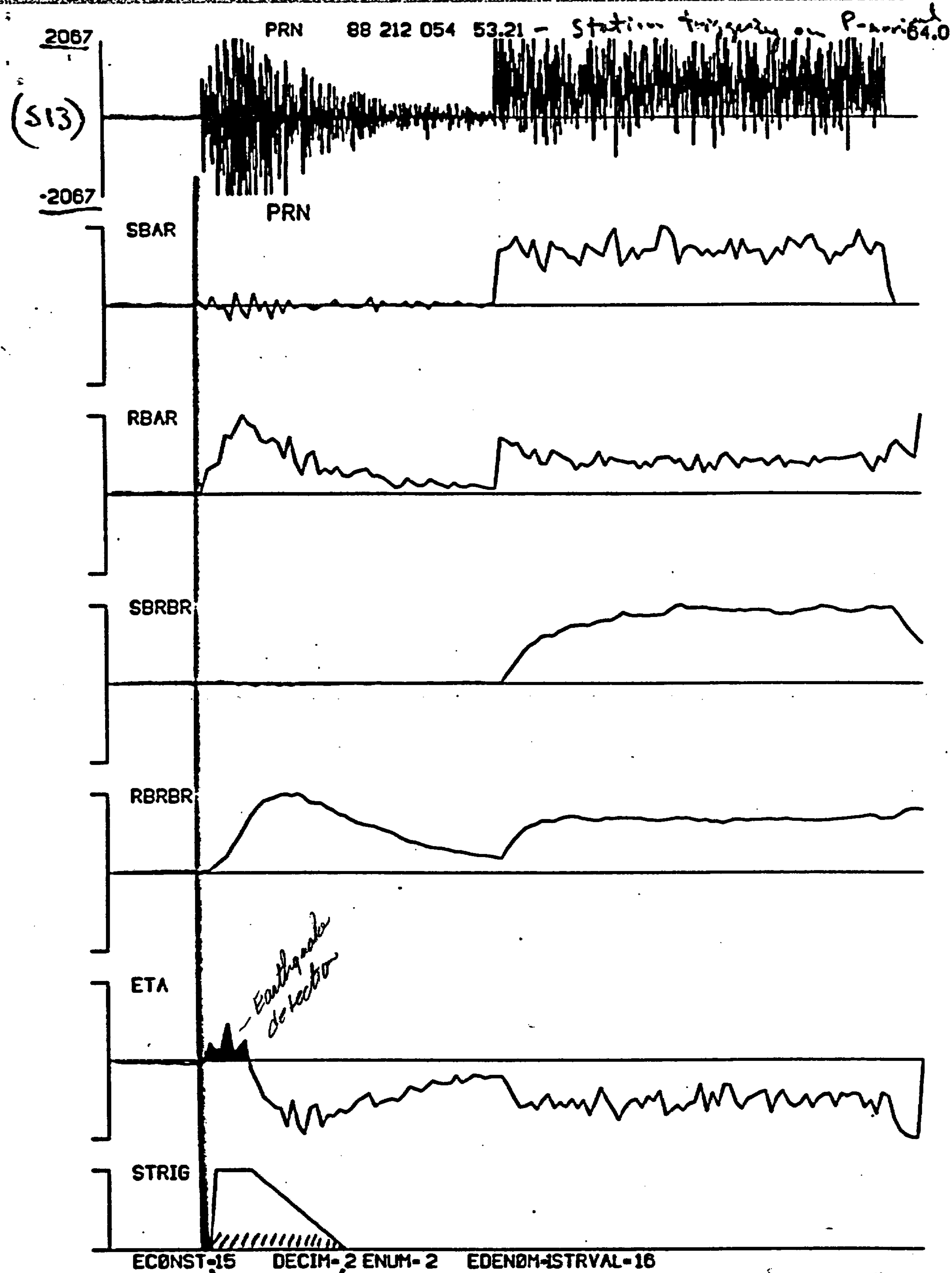
III. Software polls subnets of seismic stations every 0.5 sec to determine if a potentially seismic event is happening.

A. Subnets composed of 5 to 10 stations within a limited geographic region

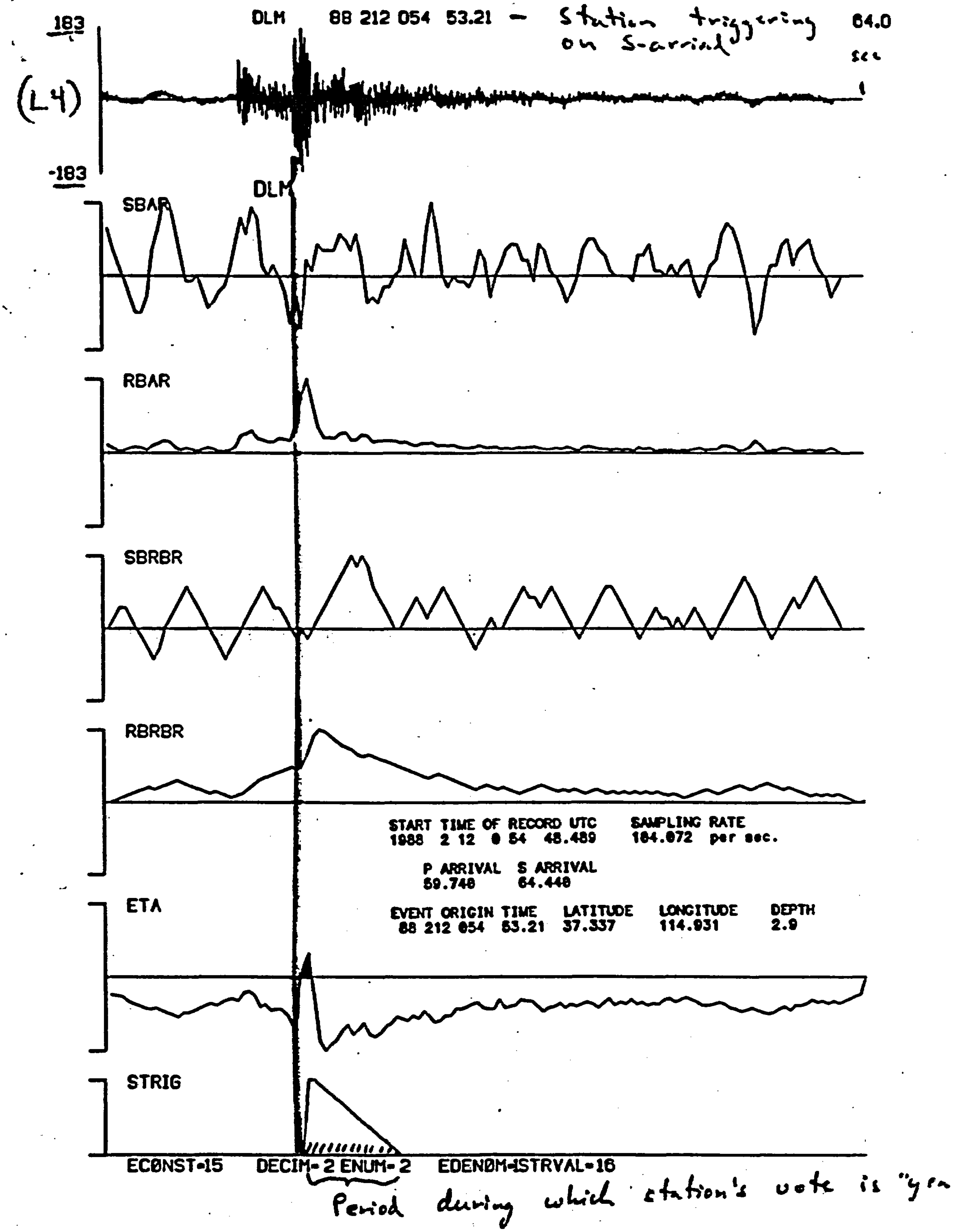
B. Variable sensitivity "triggered" mode of a subnet: $\eta > 0$ at $n = 3$ to 5 stations

$$n = \begin{cases} 3, & \text{if subnet is in a seismically and culturally quiet region;} \\ 4, & \text{if subnet is in a slightly more active region;} \\ 5, 6, \ldots, & \text{if wind storms or regional activity are overwhelming system capacity.} \end{cases}$$

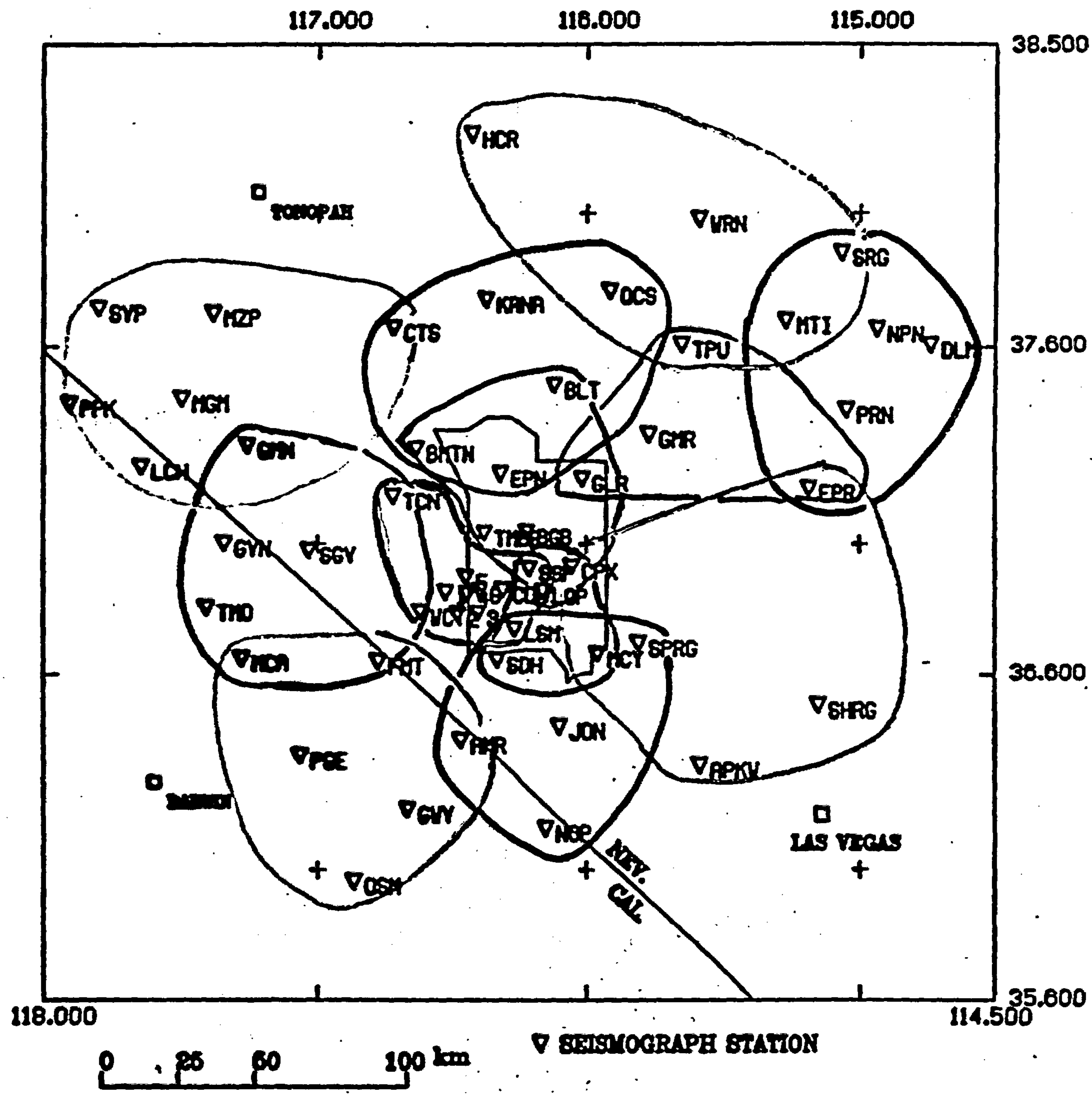
Thus, when the analyst increases n at a subnet, he is decreasing the local sensitivity or limiting the detection threshhold.



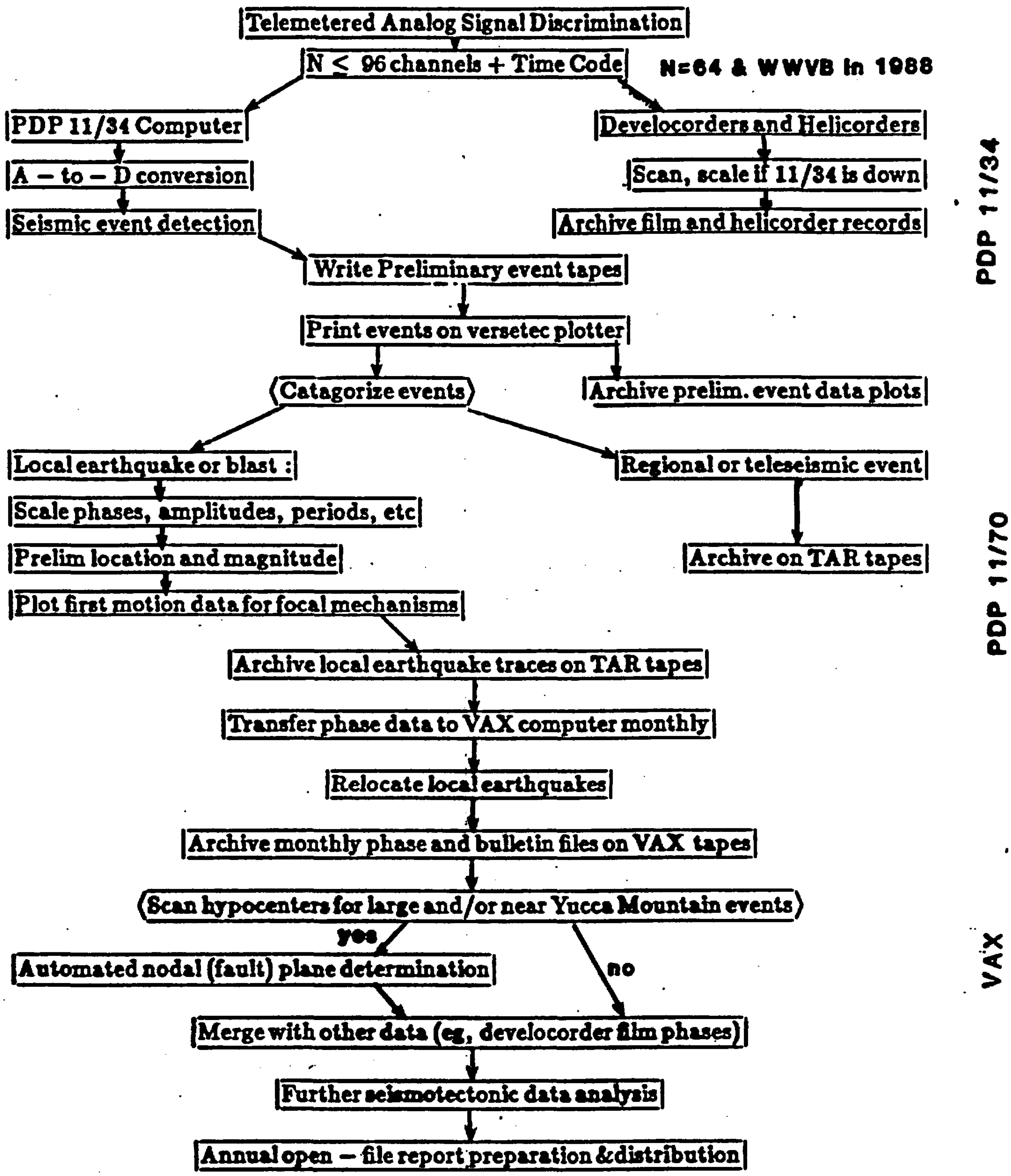
Period during which station's vote is "yea"


183
DLM 88 212 054 53.21 – Station triggering on S-arrival
64.0
sec
(L4)
-183
DLM
SBAR
RBAR
SBRBR
RBRBR
START TIME OF RECORD UTC
1988 2 12 0 54 48.489
SAMPLING RATE
104.072 per sec.
P ARRIVAL S ARRIVAL
59.740 64.440
EVENT ORIGIN TIME LATITUDE LONGITUDE DEPTH
88 212 054 53.21 37.337 114.931 2.9
ETA
STRIG
ECØNST=15 DECIM=2 ENUM=2 EDENØM=1 STRVAL=16
Period during which station's vote is "yes"

SGB subnets for event detection



Southern Great Basin Seismograph Network Data Flow at Golden

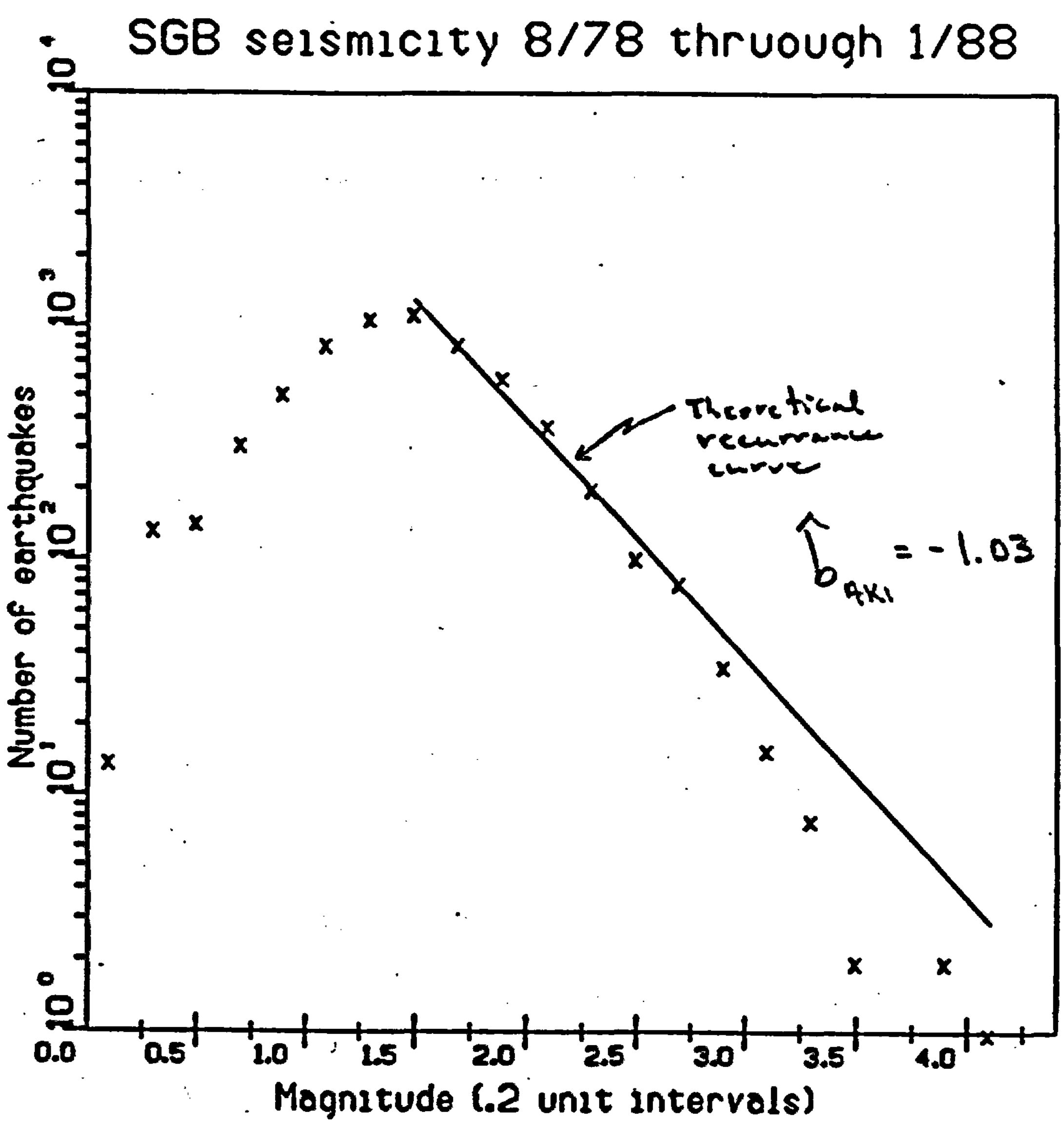


IV. Software is in use at several other networks in the U. S. (e.g., Universities of Nevada, Utah, and Washington, St. Louis University, and Virginia Polytechnic Institute). Southern Great Basin network uses same/similar parameter settings as other networks for triggering sensitivity, length of data record to save, etc.

V. Regional detection threshold is controlled both by parameter settings and seismometer characteristics (density of stations and seismometer quality). For the SGB, the greatest sensitivity or smallest-event detection threshold is achieved at Yucca Mountain and vicinity.

A. Earthquakes having $M_L \approx 0.0$ have been located at Yucca Mountain.
B. Regional M_L minimum is $\approx 1.0 - 1.5$.

◇ ◇ ◇



Network Amplitude Calibrations

- Station gain settings have been recorded in station visit logs, station data sheets, and published since 1978
- Pulse calibrations were conducted from 1978-1981 during routine station visits and repair trips
- Harmonic calibration wave trains have been used during routine station visits and repair trips since 1981
- Individual electronic components were calibrated and used to construct theoretical nominal system transfer functions for each system configuration (1983)
- Biannual station calibrations since 1983
- Automatic calibration triggering algorithm since 1985
- Network polarity calibrations

    > Polarity checks using NTS nuclear tests

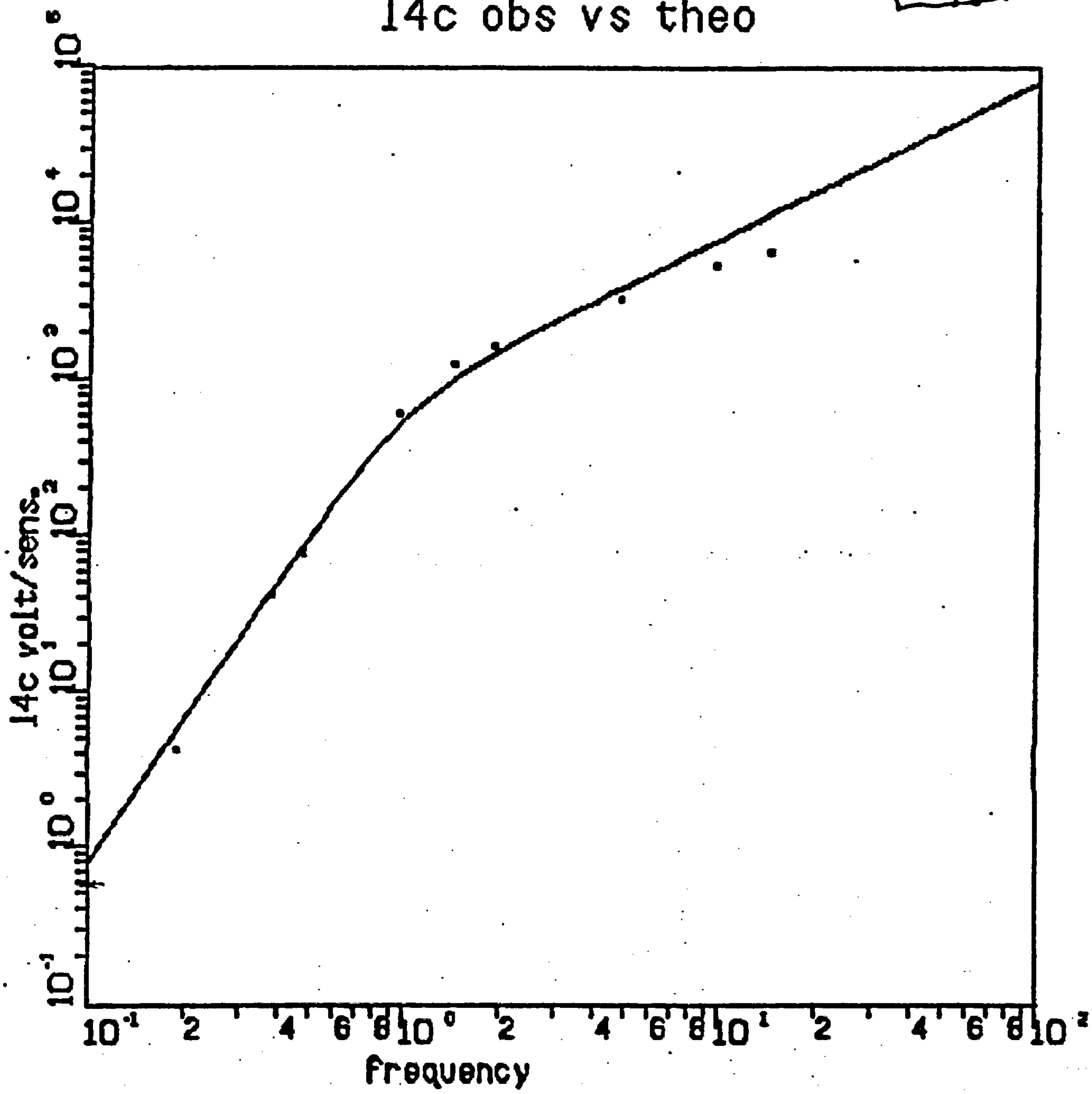
    > S13 weight lift checks

    > 8 hour calibration pulse at S13 stations

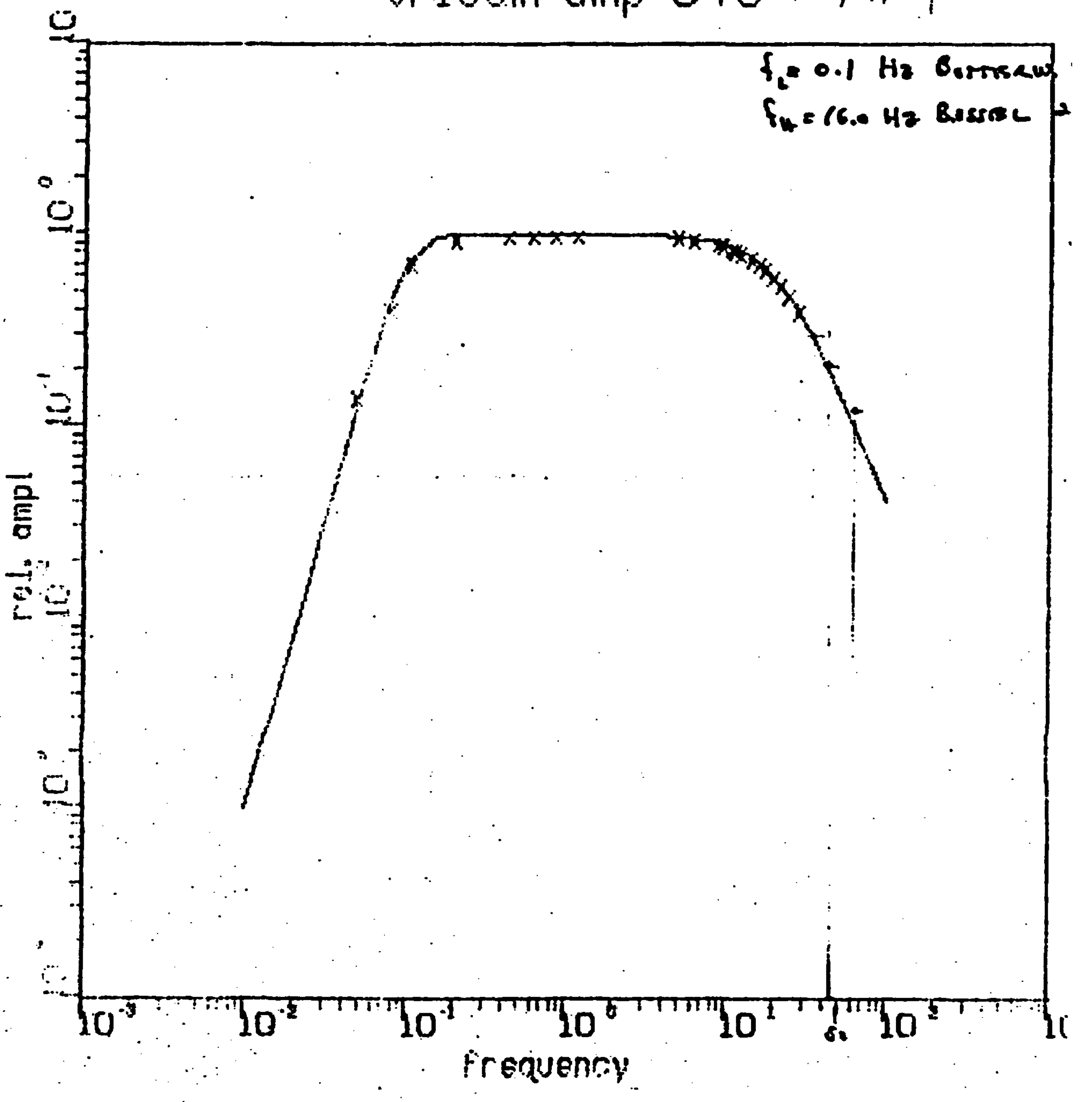
— Theor. $G_{LE} = 126.5$ $\zeta = 0.71$

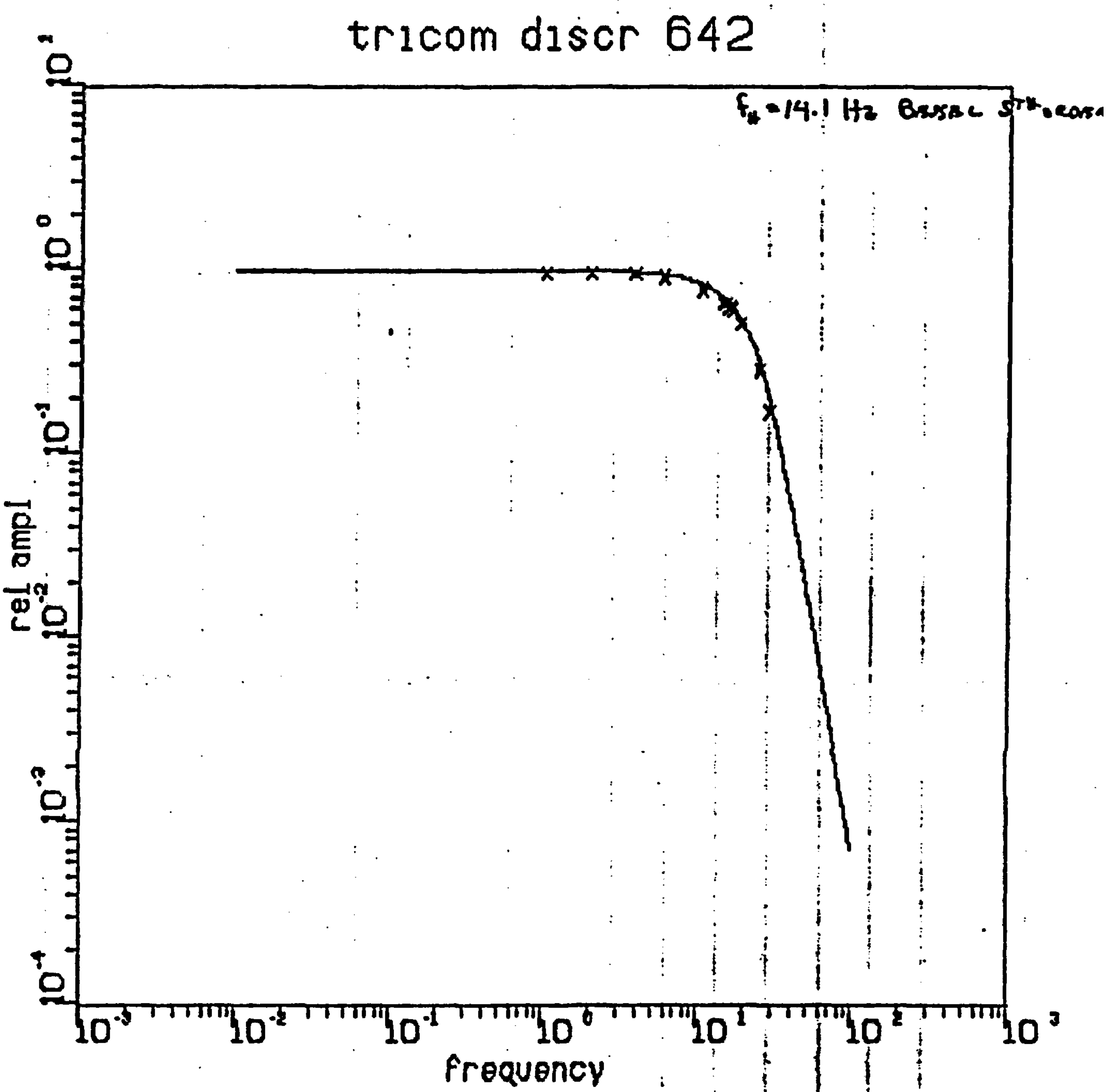
• obs L4C into [illegible] on Tricom Amp/VCO cal coil calib.
measured using strip chart across shunt resistor

14c obs vs theo

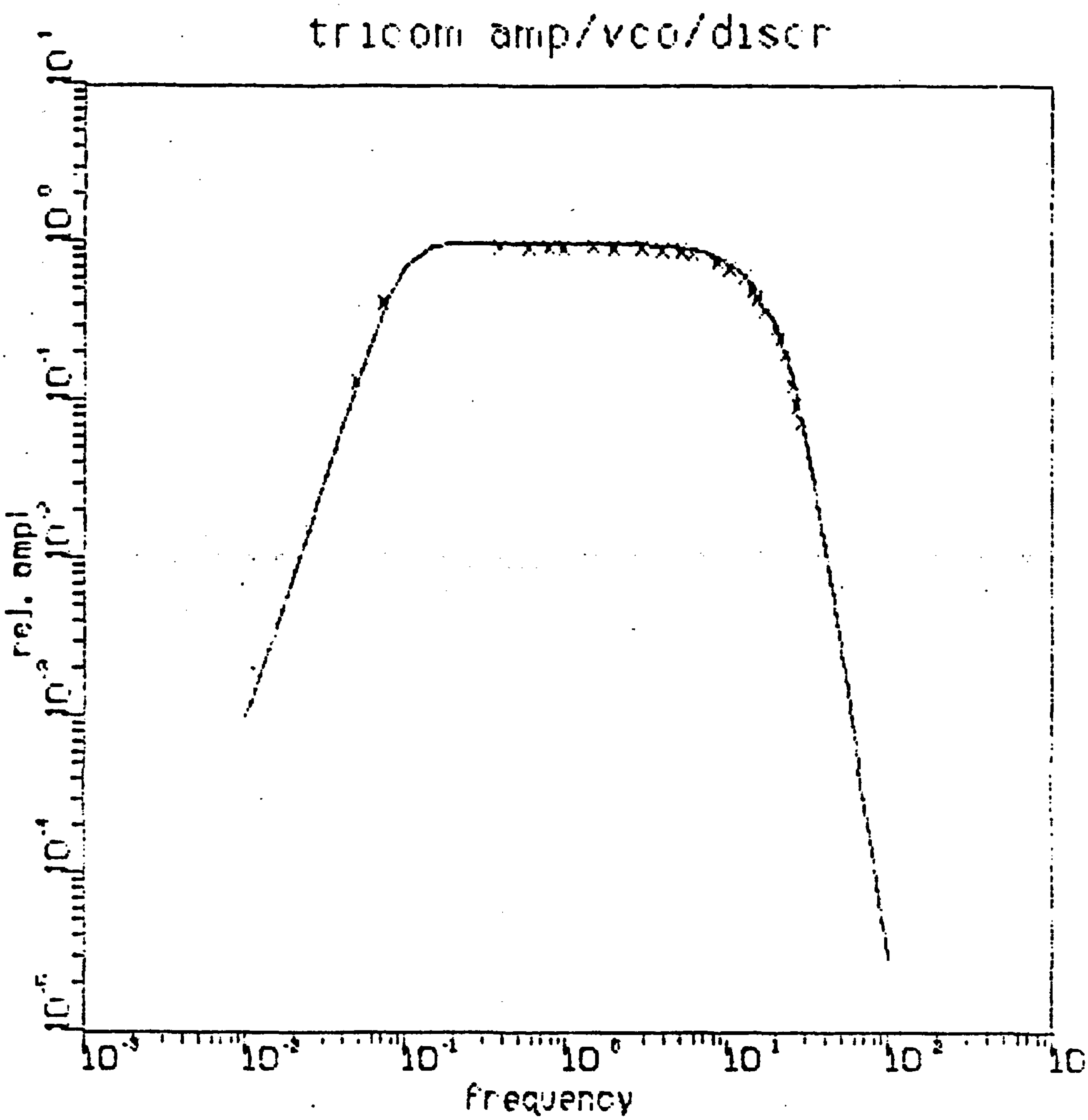


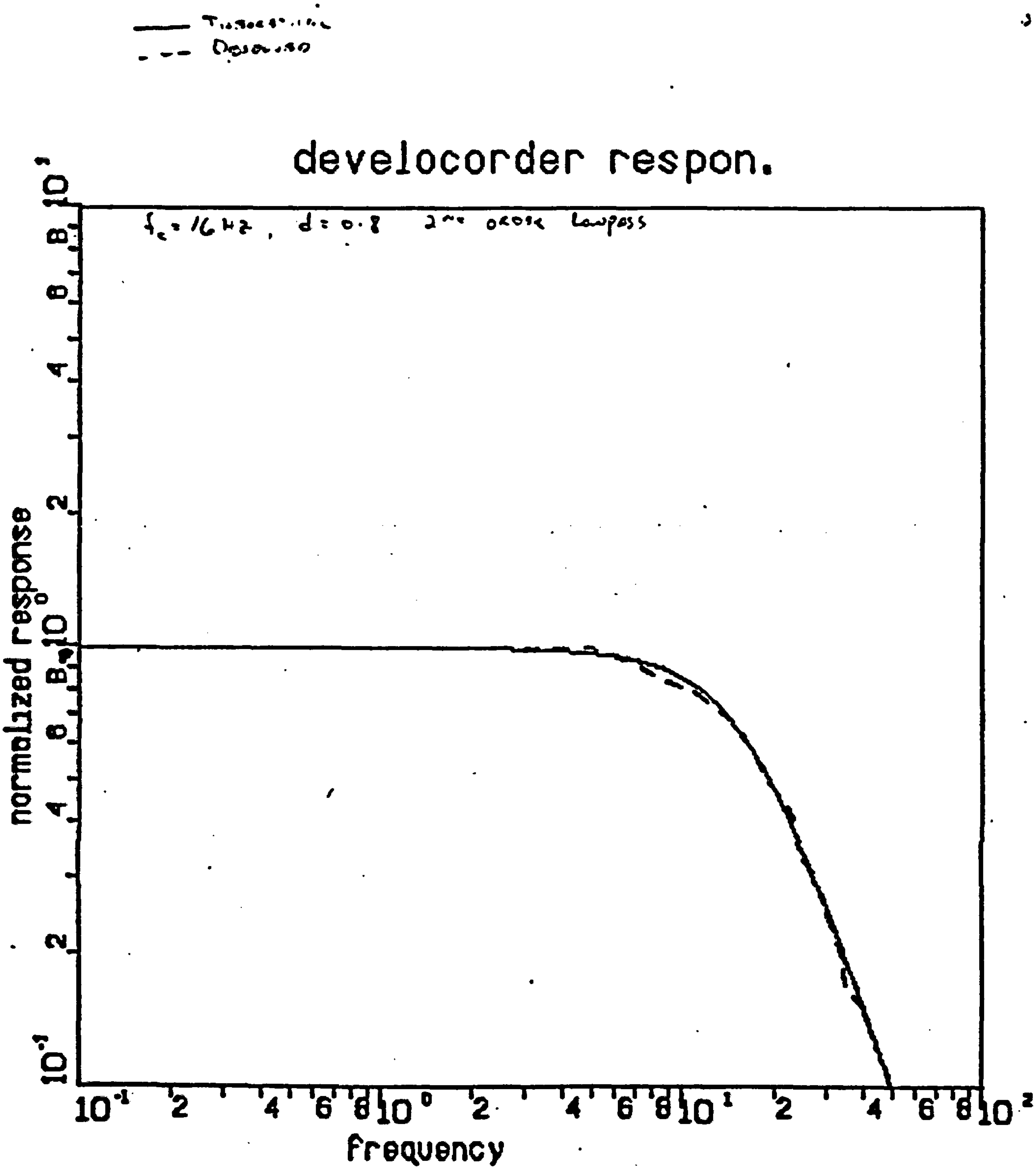
tricom amp 649 12/14/84

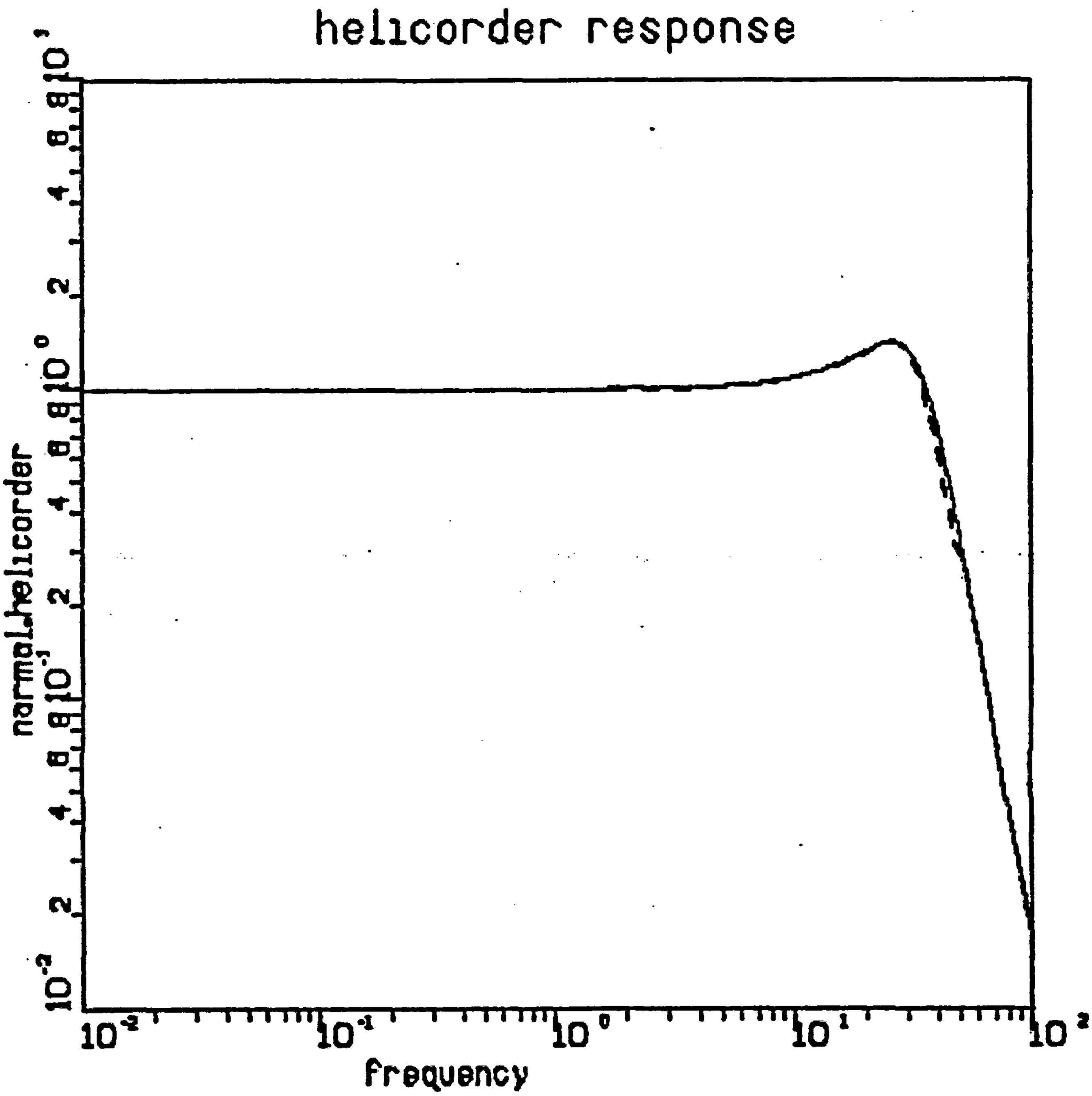




tricom discr 642
14.1 Hz
rel ampl
frequency
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}


tricom amp/vco/discr
rel. ampl
frequency


develocorder respon.
normalized response
frequency
10^1
10^0
10^-1
10^2
fc = 16 Hz, d = 0.8 2nd order lowpass



helicorder response
normal.helicorder
frequency

Appendix A

Derivations of the frequency response curves of the seismograph instrument packages used in this study are presented below. The individual components are first described as analog or digital filters. The complete systems are then described, and finally, figures of some representative southern Great Basin system calibrations, from seismometer to playout, are shown.

Seismometer Response

For both S13 and L4C seismometers, the frequency response is written as the ratio of seismometer voltage out, E_s, to ground displacement (meters) input, Y_f. The complex transfer function $H_1(f)$ is

$$H_1(f) = E_s/Y_f = 2\pi f_n G_{le} \frac{f/f_n}{1-(f_n/f)^2 + 2i\lambda(f_n/f)}$$

where $i = \sqrt{-1}$. The values of the effective loaded motor constants, G_{le}, the seismometer natural frequencies, f_n, and the ratios of actual to critical damping, λ, corresponding to the different seismometers, which appear in the above equation, are shown in Table A1.

Seismometer	G_{le} $\left(\frac{\text{volts}\times\text{sec}}{\text{meter}}\right)$	f_n (Hz)	λ
L4C	126.5	1.0	0.71
S13O	377.8	1.0	0.70
S13Y	368.0	1.0	0.73

Table A1. The values of constants appropriate for SGB seismometers.

Tricom 649 Amplifier/VCO

The frequency response of the Tricom 649 amplifier is modeled using a second-order Bessel low pass filter (-12 db/octave) cascaded with a third-order Butterworth high pass filter (-18 db/octave). Because this amplifier is broadband, it is designed by overlapping high and low pass filters. Letting $H_L(f)$ = the low pass filter, and $H_H(f)$ = the high pass filter, the complex transfer function $H_2(f)$ is written as

$$H_2(f) = AH_L(f)H_H(f),$$

where $A = 10^{(g/20)}$, $g =$ amplifier gain (dB),

$$H_L(f) = \frac{1}{1-(f/f_1)^2 + id_1(f/f_1)},$$

where $f_c = 16$ Hz (nominal -3 dB point), $f_1 = 1.274 f_c$, $d_1 = 1.732$, and

$$H_H(f) = \frac{f/f_2}{(1+i(f/f_2))} \frac{(f/f_3)^2}{(1-(f/f_3)^2 + id_2(f/f_3))},$$

where $f_c = 0.1$ Hz (nominal -3 dB point), $f_2 = 1.0 f_c$, $f_3 = 1.0 f_c$, and $d_2 = 1.0$.

The filter design constants in these and the following formulas are from Lancaster (1975).

Tricom 642 Discriminator

The Tricom 642 discriminator is analytically modeled by a fifth-order Bessel low pass filter having dropoff of 30 db/octave. This is factored into a first-order and two second-order filters, having the complex transfer function $H_3(f)$ as follows:

$$H_3(f) = \frac{1}{(1+i(f/f_1))(1-(f/f_2)^2 + id_1(f/f_2))(1-(f/f_3)^2 + id_2(f/f_3))},$$

where $f_1 = 1.613 f_c$, $d_1 = 1.775$, $f_2 = 1.819 f_c$, $d_2 = 1.091$, $f_3 = 1.557 f_c$, and $f_c = 14.1$ Hz.

Geotech 4250 Amplifier/VCO

The mathematical filter simulating this broadband amplifier is written as a second-order Bessel low pass filter (-12 db/octave) cascaded with a second-order Butterworth high pass filter (-12 db/octave). Letting $H_L(f)$ and $H_H(f)$ represent the low and high pass filters, respectively, and letting $H_4(f)$ represent the amplifier response, we have

$$H_4(f) = AH_L(f)H_H(f),$$

where $A = 10^{g/20}$, g = amplifier gain (db),

$$H_L(f) = \frac{1}{1-(f/f_1)^2 + id_1(f/f_1)},$$

where f_c = 20 Hz (nominal -3 db point), $f_1 = 1.274 f_c$, $d_1 = 1.732$, and

$$H_H(f) = \frac{(f/f_1)^2}{1-(f/f_1)^2 + id_1(f/f_1)},$$

where f_c = 0.2 Hz (nominal -3 db point), $f_1 = 1.0 f_c$, and $d_1 = 1.414$.

Geotech 4612 Discriminator

This component is modeled with a third-order Paynter low pass filter having a corner frequency, f_c, at 22.5 Hz. The complex frequency response, $H_5(f)$, is given by

$$H_5(f) = \frac{1}{(1-(f/f_{01})^2 + id_1(f/f_{01}))(1+i(f/f_{02}))},$$

where f_c = 22.5 Hz (nominal 3 db point), $f_{01} = 1.206 f_c$, $f_{02} = 1.152 f_c$, and $d_1 = 1.203$. This filter was preferred to that specified by the manufacturer (Butterworth third-order low pass with f_c = 25 Hz), because the Paynter filter better approximated the observed response of the discriminator.

Playout gain/shape - Analog Develocorder

The Develocorder is modeled as a second-order low pass filter having complex frequency response $H_6(f)$ given by

$$H_6(f) = \frac{A}{1-(f/f_1)^2 + 2id_1(f/f_1)},$$

where $A = 17.730 \cdot 10^{-3}$ meters/volt, f_1 = 16 Hz, and d_1 = 0.8.

Playout gain/shape - Helicorder

The Helicorder has a variable gain, g, and is modeled as a fourth- order low pass filter. Its complex response, $H_7(f)$, may therefore be written as

$$H_7(f) = 10^{(6-g)/20}(H_6(f))^2$$

where g = Helicorder playout gain (dB), and $H_6(f)$ is defined above, except that, for the Helicorder, f_1 = 35.0 Hz, and d_1 = 0.48.

The PDP 11/34 Digital Computer Response

The frequency response of the 12-bit analog to digital converter, PDP AD/11K, and the subsequent components on the digital computer, including magnetic tape and software, is flat for input signals having frequencies between 0 and 50 Hz, the Nyquist frequency. The system output is in digital counts, such that ±1 volt input results in ±409.6 counts output, respectively, for all frequencies below the Nyquist frequency. Letting $H_8(f)$ be the system response of the PDP 11/34 computer, we have

$$H_8(f) = 409.6 \text{ counts/volt}, \quad 0 \leq f \leq 50 \text{ Hz}, \text{ and } -5 \leq \text{volts in} \leq 5.$$

SGB Seismograph Systems

The entire system from ground motion input to playout has a frequency response, $H(f)$, that may be described by

$$H(f) = H_1(f)H_2(f)H_3(f)H_j(f) \quad \text{for system L4C,}$$

$$H(f) = H_1(f)H_2(f)H_3(f)H_j(f) \quad \text{for system S13O, and}$$

$$H(f) = H_1(f)H_4(f)H_5(f)H_j(f) \quad \text{for system S13Y,}$$

where $j = 6, 7,$ or 8 depending on the medium on which the playout occurs (Develocorder, Helicorder, or digital computer, respectively) and the parameters G_{ts} and λ are chosen for the proper seismometer (Table A1). S13O refers to S13 instruments other than those on Yucca Mountain, and S13Y refers to S13 instruments on Yucca Mountain.

The constants, G_{ts}, are computed knowing the manufacturer's nominal motor constants, the circuit design, shunt resistance, and input impedance to the amplifier. The proper equations have been derived by Eaton (1975). The constants, λ, have been measured in the lab.

Calibration

Although each component of these seismograph systems has been individually calibrated and compared with its ideal or theoretical performance, in the following we show only several representative examples of calibrations of the frequency response of complete systems. The first example, shown in Figure A1, is for the Mark Products L4C seismometer-Tricom amplifier system, having nominal gain of 48 dB, with playout being sampled by a DEC PDP 11/34 digital computer. The lack of agreement between the theoretical response (*solid curve*) and the observed system amplification (× symbols) above about 10 Hz is believed to be due to interaction (induction) between the L4C calibration coil and main coil, and does not represent the actual system response. This interpretation is supported by the fact that shake table calibrations of the L4C do not show this discrepancy (R. Navarro and D. Overturf, 1970; S. Morrisey, written commun., 1986). That this difference arises in the seismometer and not in subsequent electronics-telemetry was established by examining the seismometer response alone. The second example, shown in Figure A2, compares theoretical (*solid curve*) and observed (× symbols) frequency responses for the Teledyne Geotech S13 seismometer-Geotech amplifier system, with playout on a Helicorder paper record.

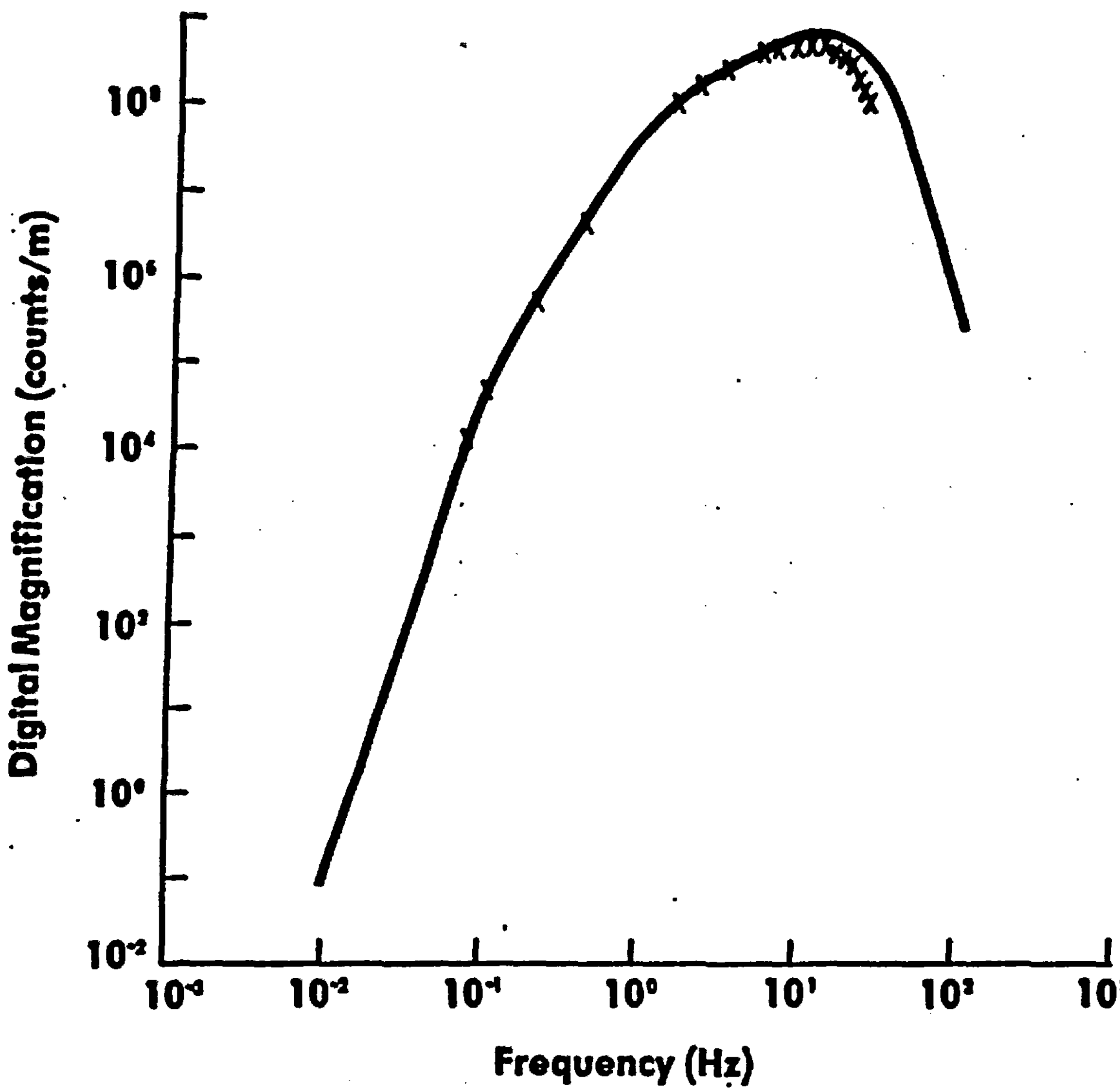


Figure A1. Amplitude response of L4C system into PDP 11/34 digital computer (theoretical, *solid curve*, observed ×s) for a nominal amplifier gain of 48 db.

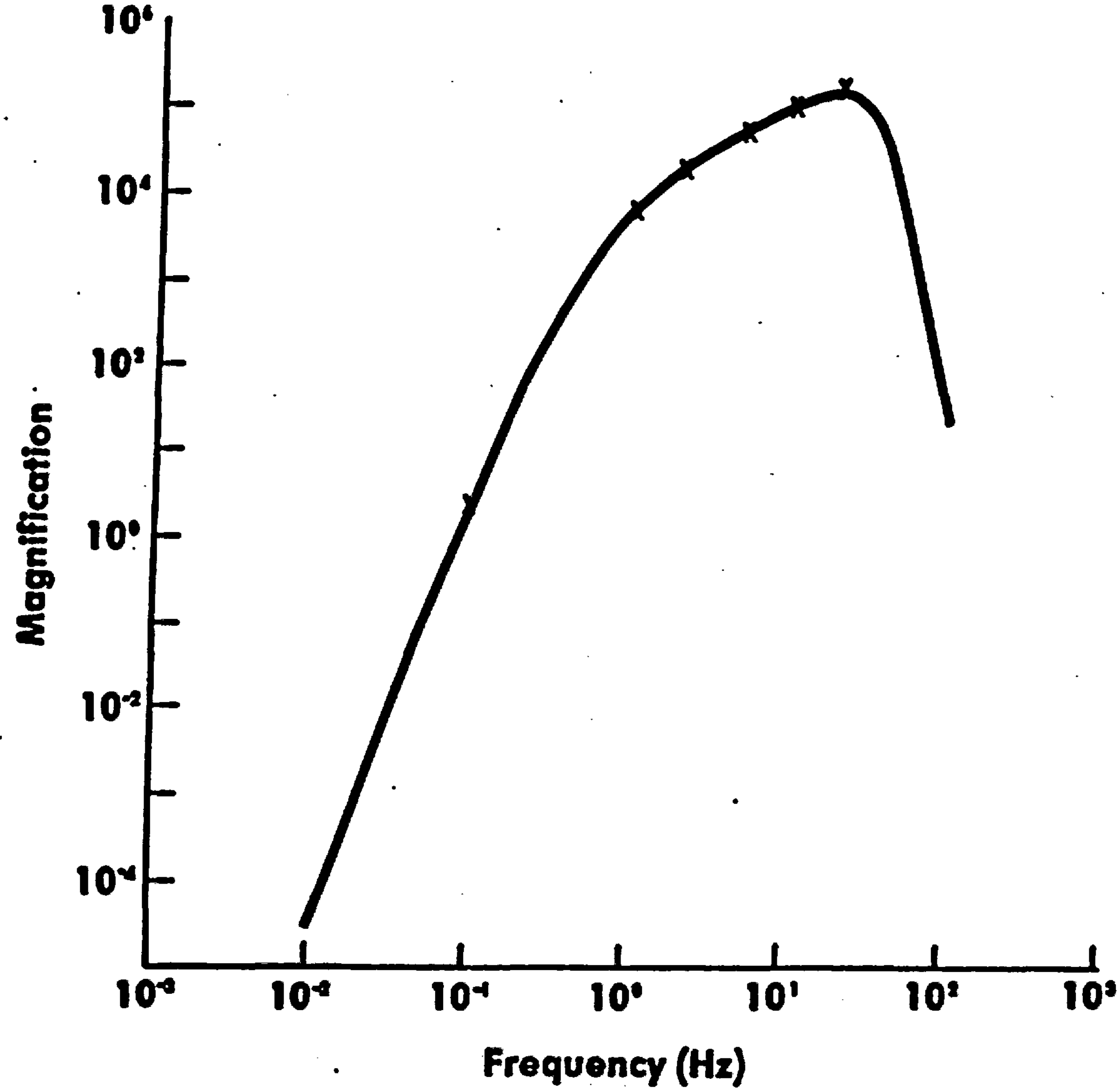


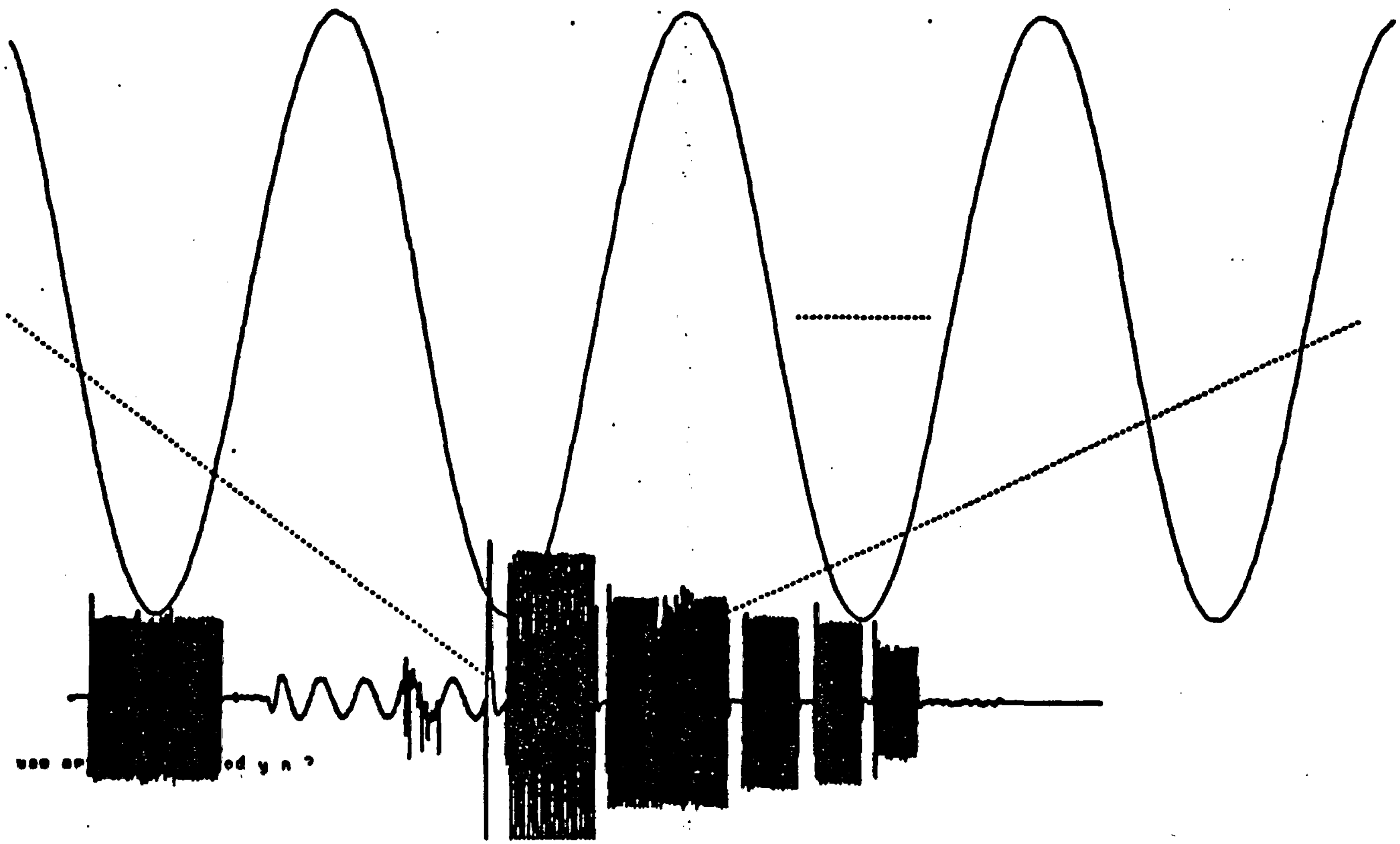
Figure A2. Amplitude response of S13Y system into helicorder for a nominal amplifier gain of 48 db.

```
Station: VRT4  119.28 -- 123.12 - - - - 1987/12/08  19:46:17.35        no comment
autopick amp 1717.000000 per 1.098141 sec! use amplitude-period y/n?n

Pick two points for period
Pick zero line

P
 ck maximum amplitude

period 1.008914 sec ampl 3456.000000 counts
```



```
use ap          od y n ?
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Southern Great Basin Seismographic Station Field Calibrations

The SGB network as of February, 1988 deploys 54 vertical- and 10 horizontal-component seismometers in southern Nevada and California. Six sites have single-component horizontals (N-S), and the other two, at Yucca Mtn. and Little Skull Mtn., have double-component horizontals (N-S and E-W). These seismometers and associated electronics for signal amplification, telemetry, discrimination, and A-to-D conversion may be catagorized into one of six systems or "kinds", summarized in the table below.

KIND	SEISMOMETER	Motion	Amp/VCO	Discriminator
1	L4C	vertical	Tricom 649	Tricom 642
2	S13	vertical	Tricom 649	Tricom 642
3	S13	vertical	Teledyne Geotech 4250	Teledyne 4612
4	L4C	vertical	Teledyne Geotech 4250	Tricom 642
5	L4C	horizontal	Teledyne Geotech 4250	Teledyne 4612
6	S13	vertical	Teledyne Geotech 4250	Tricom 642

During field calibrations, observed system response, monitored on the PDP 11/34 computer in Golden, is compared with expected response in the ground-motion domain. This is done at six frequencies, f = 0.1, 1.0, 2.0, 5.0, 10.0, and 20.0 hz, respectively. Computed ground-motion, Y_C, is obtained by deconvolving the appropriate system response from the calibration sinusoid telemetered to Golden and scaled from the PDP 11/34 digital record. Expected or equivalent ground-motion, Y_E, is

$$Y_E = \frac{i_s G_c}{4\pi^2 M f^2}.$$

In this equation, Y_E = equivalent ground displacement for a given calibration current, i_s = current input into calibration coil, G_c = cal coil constant, M = transducer mass, and f = frequency (hz) at which test is being conducted. The discrepency between the two is reported by the computer program "CALIBRATE" as a per-cent difference, $D(f)$, for each frequency:

$$D(f) = 100 \times \frac{Y_C(f) - Y_E(f)}{Y_E(f)}.$$

Frequency response differences greater than 20 to 30% are reported to our field engineer so that he may take further action (e.g., replace seismometer).

Program calibrate. Version 1.001. Tech contact: Steve Harmsen, USGS-NNWSI
User Initials: PC Run on 12-JAN-88 at 14:00:03
Date of calibration: Jan 6, 1988 JB Transducer const= 126.5 v s/m
Cal motor const = 0.419 v s/m. Transducer mass (kg)=0.982 Seis serial # 3633

STA. NAME	TYPE	FREQ. HZ	PK-PK MAMPS	GAIN DB	COUNTS PDP A->D	gr.displ E meters	gr. displ.O meters	% error 100•(O/E-1)
WRN	L4C	0.100	6.0	60.	1296.0	0.64848E-02	0.56307E-02	-13.17
WRN	L4C	1.000	6.0	48.	2984.0	0.64848E-04	0.51957E-04	-19.88
WRN	L4C	2.000	6.0	48.	2320.0	0.16212E-04	0.14811E-04	-8.64
WRN	L4C	5.000	6.0	54.	1976.0	0.25939E-05	0.25993E-05	0.21
WRN	L4C	10.000	6.0	60.	1516.0	0.64848E-06	0.62180E-06	-4.11
WRN	L4C	20.000	6.0	66.	361.0	0.16212E-06	0.94400E-07	-41.77

Program calibrate. Version 1.001. Tech contact: Steve Harmsen, USGS-NNWSI
User Initials: PC Run on 12-JAN-88 at 14:02:09
Date of calibration: Jan 6, 1988 JB Transducer const= 126.5 v s/m
Cal motor const = 0.487 v s/m. Transducer mass (kg)=0.983 Seis serial # 3832

STA. NAME	TYPE	FREQ. HZ	PK-PK MAMPS	GAIN DB	COUNTS PDP A->D	gr.displ E meters	gr. displ.O meters	% error 100•(O/E-1)
QCS	L4C	0.100	6.0	60.	2120.0	0.75333E-02	0.92106E-02	22.26
QCS	L4C	1.000	6.0	48.	4012.0	0.75333E-04	0.69857E-04	-7.27
QCS	L4C	2.000	6.0	48.	3576.0	0.18833E-04	0.22830E-04	21.22
QCS	L4C	5.000	6.0	54.	3048.0	0.30133E-05	0.40094E-05	33.05
QCS	L4C	10.000	6.0	60.	2308.0	0.75333E-06	0.94539E-06	25.49
QCS	L4C	20.000	6.0	66.	502.0	0.18833E-06	0.13127E-06	-30.30

Program calibrate. Version 1.001. Tech contact: Steve Harmsen, USGS-NNWSI
User Initials: PC Run on 12-JAN-88 at 14:05:33
Date of calibration: Jan 6, 1988 JB Transducer const= 126.5 v s/m
Cal motor const = 0.508 v s/m. Transducer mass (kg)=0.981 Seis serial # 4052

STA. NAME	TYPE	FREQ. HZ	PK-PK MAMPS	GAIN DB	COUNTS PDP A->D	gr.displ E meters	gr. displ.O meters	% error 100•(O/E-1)
MTI	L4C	0.100	6.0	60.	1216.0	0.78702E-02	0.52918E-02	-32.76
MTI	L4C	1.000	6.0	48.	3160.0	0.78702E-04	0.55022E-04	-30.09
MTI	L4C	2.000	6.0	48.	2428.0	0.19676E-04	0.15501E-04	-21.22
MTI	L4C	5.000	6.0	54.	2000.0	0.31481E-05	0.26308E-05	-16.43
MTI	L4C	10.000	6.0	60.	1436.0	0.78702E-06	0.58821E-06	-25.26
MTI	L4C	20.000	6.0	66.	216.0	0.19676E-06	0.56483E-07	-71.29

Program calibrate. Version 1.001. Tech contact: Steve Harmsen, USGS-NNWSI
User Initials: PC Run on 12-JAN-88 at 14:07:25
Date of calibration: Jan 7, 1988 Transducer const= 126.5 v s/m
Cal motor const = 0.462 v s/m. Transducer mass (kg)=0.980 Seis serial # 3629

STA. NAME	TYPE	FREQ. HZ	PK-PK MAMPS	GAIN DB	COUNTS PDP A->D	gr.displ E meters	gr. displ.O meters	% error 100•(O/E-1)
NPN	L4C	0.100	6.0	60.	1028.0	0.71649E-02	0.44663E-02	-37.66
NPN	L4C	1.000	6.0	48.	2792.0	0.71649E-04	0.48614E-04	-32.15
NPN	L4C	2.000	6.0	48.	2164.0	0.17912E-04	0.13815E-04	-22.87
NPN	L4C	5.000	6.0	54.	1768.0	0.28659E-05	0.23257E-05	-18.85
NPN	L4C	10.000	6.0	60.	1360.0	0.71649E-06	0.55708E-06	-22.25
NPN	L4C	20.000		NO DATA AVAILABLE				

Program calibrate. Version 1.001. Tech contact: Steve Harmsen, USGS-NNWSI
User Initials: PC Run on 12-JAN-88 at 14:08:29
Date of calibration: Jan 7, 1988 JB Transducer const= 126.5 v s/m
Cal motor const = 0.409 v s/m. Transducer mass (kg)=0.979 Seis serial # 5850

STA. NAME	TYPE	FREQ. HZ	PK-PK MAMPS	GAIN DB	COUNTS PDP A->D	gr.displ E meters	gr. displ.O meters	% error 100•(O/E-1)
DLM	L4C	0.100	6.0	60.	1736.0	0.63520E-02	0.75510E-02	18.88
DLM	L4C	1.000	6.0	48.	3512.0	0.63520E-04	0.61151E-04	-3.73
DLM	L4C	2.000	6.0	48.	2768.0	0.15880E-04	0.17672E-04	11.28
DLM	L4C	5.000	6.0	54.	2428.0	0.25408E-05	0.31938E-05	25.70
DLM	L4C	10.000	6.0	60.	1824.0	0.63520E-06	0.74714E-06	17.62
DLM	L4C	20.000		NO DATA AVAILABLE				

Program calibrate. Version 1.001. Tech contact: Steve Harmsen, USGS-NNWSI
User Initials: PC Run on 12-JAN-88 at 14:41:43
Date of calibration: Jan 7, 1988 JB Transducer const= 368.0 v s/m
Cal motor const = 0.198 v s/m. Transducer mass (kg)=5.000 Seis serial # n/a

STA. NAME	TYPE	FREQ. HZ	PK-PK MAMPS	GAIN DB	COUNTS PDP A->D	gr.displ E meters	gr. displ.O meters	% error 100•(O/E-1)
PRN	S13	0.100	5.0	72.	622.0	0.50027E-03	0.57072E-03	14.08
PRN	S13	1.000	5.0	60.	3312.0	0.50027E-05	0.49110E-05	-1.83
PRN	S13	2.000	5.0	60.	2304.0	0.12507E-05	0.12595E-05	0.71
PRN	S13	5.000	5.0	66.	1898.0	0.20011E-06	0.21291E-06	6.40
PRN	S13	10.000	5.0	72.	1618.0	0.50027E-07	0.54484E-07	8.91
PRN	S13	20.000	5.0	78.	688.0	0.12507E-07	0.12534E-07	0.22

STATION INFORMATION

CODE	STATION	PERIOD OF OPERATION (DAY/MONTH/YEAR)	LATITUDE (DEG MINUTES)	LONGITUDE (DEG MINUTES)	ELEVATION (METERS)	SEISMOMETER MODEL	GAIN (DB)
AMR	Amargosa, Cal.	24/07/78-present	36 23.86 N	116 28.45 W	720	L-4C	84
APK	Angels Peak, Nev.	15/06/75-05/08/83*	36 19.17 N	115 34.46 W	2680	S-13 to 21/3/81 L-4C 21/3/81-end	 84
APKW	Angels Peak, Nev.	05/08/83-present*	36 19.19 N	115 35.22 W	2512	L-4C	84
BGB	Big Butte, Nev.	23/01/79-present	37 02.27 N	116 13.66 W	1720	L-4C	84
BLT	Belted Range, Nev.	30/05/79-present	37 28.93 N	116 07.35 W	1820	L-4C	84
BMT	Black Mountain, Nev.	26/02/80-01/04/83	37 17.02 N	116 38.74 W	2191	L-4C	84
BMTN	Black Mountain, Nev.	01/04/83-present	37 17.35 N	116 38.43 W	1900	L-4C	84
BRO	Bare Mountain, Nev.	28/11/78-08/04/81	36 45.76 N	116 37.52 W	920	L-4C	84
CDH1	Calico Hills, Nev.	06/02/80-18/11/81	36 51.62 N	116 19.05 W	1387	L-1-3DS (vert.) L-4C 18/11/81-pr	90 84
CDH5	Calico Hills, Nev.	06/02/80-18/11/81	36 51.62 N	116 19.05 W	1655	L-1-3DS (horiz.)	100
CPX	CP-1, Nev.	--/--/77-01/03/80*	36 55.80 N	116 03.33 W	1285	NGC-21 to 5/8/80 L-4C 5/8/80-pr.	 84
CTS	Cactus Peak, Nev.	24/04/79-present	37 39.40 N	116 43.54 W	1890	L-4C	84
DLM	Delamar Mountains, Nev.	08/06/78-present*	37 38.35 N	114 44.33 W	1730	L-4C	84
EPN	Echo Peak, Nev.	02/09/75-present	37 12.85 N	116 19.42 W	2285	S-13 to 25/4/80 L-4C 25/4/80-pr.	 84
EPNH	Echo Peak, Nev.	06/06/84-present	37 12.85 N	116 19.42 W	2285	L-4C horizontal	78
EPR	East Pahranagat Rg, Nev	23/01/79-present*	37 10.12 N	115 11.19 W	1300	L-4C	84
FMT	Funeral Mountains, Cal.	28/11/78-present	36 38.38 N	116 40.73 W	1025	L-4C	84
GLR	Groom Lake Road, Nev.	20/11/75-present*	37 11.96 N	116 01.06 W	1435	L-4C	84
GMN	Gold Mountain, Nev.	13/07/79-present*	37 18.01 N	117 15.58 W	2155	L-4C	84
GMNH	Gold Mountain, Nev.	30/07/84-present	37 18.01 N	117 15.58 W	2155	L-4C horizontal	78

POLARITY REVERSALS (PERTAINS TO DEVELOCORDER FILMS ONLY)

CODE	STATION	PERIOD OF REVERSE POLARITY (DAY/MONTH/YEAR)
APK	Angels Peak, Nev.	21/3/81 - 05/08/83
APKW	Angels Peak, Nev.	05/08/83 - present
CDH1	Calico Hills, Nev.	30/3/81 to 3/8/81; also 1/12/81 to present
CPX	CP-1, Nev.	5/8/80 to 13/12/80
DLM	Delamar Mts., Nev.	28/6/79 to 29/8/79
EPN	Echo Peak, Nev.	1/11/78 to 01/05/80
EPR	East Pahranagat Range, Nev	10/12/79 to 20/2/80
GLR	Groom Lake Road, Nev.	1/11/78 to 22/2/79
GMN	Gold Mountain, Nev.	28/6/79 to 29/8/79; also 5/8/80 to 17/12/80
JON	Johnnie, Nev.	1/11/78 to 22/2/79
LSM	Little Skull Mtn., Nev.	17/07/84 to present
LCH	Last Chance Range, Nev.	28/6/79 to 29/8/79
MGM	Magruder Mountain, Nev.	28/6/79 to 29/8/79
MTI	Mount Irish, Nev.	28/6/79 to 29/8/79
MZP	Montezuma Peak, Nev.	28/6/79 to 29/8/79
NPN	North Pahroc Range, Nev.	28/6/79 to 29/8/79
PGE	Panamint Range, Cal.	11/10/84 to present
PPK	Piper Mountain, Cal.	28/6/79 to 29/8/79
PRN	Pahroc Range, Nev.	10/12/79 to 20/2/80; also 28/08/84 to present
QCS	Queen City Summit, Nev.	28/6/79 to 29/8/79
QSM	Queen of Sheba Mine, Nev.	28/6/79 to 29/8/79
RVE	Reveille Range, Nev.	28/6/79 to 29/8/79
SRG	Seaman Range, Nev.	28/6/79 to 29/8/79
SSP	Shoshone Peak, Nev.	28/6/79 to 01/06/80
SVP	Silver Peak Range, Nev.	28/6/79 to 29/8/79
TPK	Tolicha Peak, Nev.	11/06/79 to 29/8/79
TPU	Tempiute Mountain, Nev.	28/6/79 to 29/8/79
WRN	Worthington Mts., Nev.	28/6/79 to 29/8/79
YMT1	Yucca Mountain, Nev.	05/03/81 to present
YMT2	Yucca Mountain, Nev.	05/03/81 to present
YMT3	Yucca Mountain, Nev.	05/03/81 to present
YMT3	Yucca Mountain, Nev.	05/03/81 to present
YMT4	Yucca Mountain, Nev.	01/04/81 to present
YMT5	Yucca Mountain, Nev.	01/04/81 to present
YMT6	Yucca Mountain, Nev.	01/04/81 to present

VERSION: 2.0 DATE: 5/15/87
Version 1.0 is pre-QA

STATION: Yucca Mountain
DATE OPEN: March 1981

DATE CLOSED: XXXXXXXXXXXXX

GEOGRAPHIC COORDINATES:

LATITUDE: 36°51.51' N.

LONGITUDE: 116°24.26' W.

ELEVATION: ~1150 m

ABBREVIATION: YMT6
OPERATED BY: U.S. Geol. Survey

ADDRESS: 1711 Illinois Street
Golden, CO 80401

ADDRESS TO OBTAIN RECORDS:
U.S. Geological Survey
Branch of Geologic Risk Assessment
Room 436, P.O. Box 25046, MS 966
Denver, Colorado 80225

TELEPHONE NO. (303) 236-1603 com.
or FTS 776-1603
TELEX NO. 5106014123 ESL UD

GEOLOGICAL FOUNDATION:

GEOLOGIC AGE:

INSTRUMENTATION:

TYPE	SEISMOMETER COMP.	T_o	GALVO T_g	TYPE OF RECORDING	MAGNIFICATION
S-13	Vert.	1.0	.0625	analog data:	78 db
				16 mm film;	66 db 10/81
				digital data: magnetic tape	84 db 7/83

TIMING SYSTEM: WWVB

SYSTEM RESPONSE CURVES: Available on request

HISTORY:

TYPES OF STATION REPORTS DISTRIBUTED BY THE STATION OR THE OPERATING ORGANIZATION;
(CONTINUED ON REVERSE SIDE)

Periodic USGS Open-File Reports

(From SGB Station file -- showing, in blue box, record of amplifier gain changes through station's history.

U.S.G.S. - NEVADA NETWORK
OFFICE OF EARTHQUAKE STUDIES

STATION NOP FREQUENCY 1020 Hz DATE 01-05-88

AMP/VCO Manufacture Tri-Com, Inc. Model No. 649 Serial No. 41 Frequency 1020 Hz Output Level -7 dbm Atten. Level 84 dbm

RADIO Transmitter Frequency 164.8406 Mhz Serial Number 10659 T
Input Level -7 dbm Forward Power 1.5 W SWR .001
Deviation Level 2.5 KC Receiver Site SSP

SEISMOMETER Manufacture Teledyne-Geotech Model S-13 Serial No. 363

MULTIPLEXERS
Serial No. ______ Output Level ______
Input Sites 1 ___ 2 ___ 3 ___ 4 ___ 5 ___ 6 ___ 7 ___ 8 ___
Input Levels
Output Levels

Serial No. ______ Output Level ______
Input Sites 1 ___ 2 ___ 3 ___ 4 ___ 5 ___ 6 ___ 7 ___ 8 ___
Input Levels
Output Levels

CALIBRATION
Time 1819GMT Duration 3 min Current 11 mA

Att	60	Att	48	Att	48	Att	54	Att	60	Att	66
0.1Hz	2.5	1Hz	6.0	2Hz	4.7	5Hz	4.3	10Hz	3.8	20Hz	2.5

VOLTAGE Battery 11.75 VDC Solar Panel 14.20 VDC Power Supply None

REASON FOR VISIT Preventive maintenance and calibration.

ACTION TAKEN Preventive maintenance and calibration.

REMARKS Same.

Maintenance Time 1.0 hrs. Travel Time 4.75 hrs.

DEPART TIME 1845GMT SIGNATURE [signature]

> Resistance is very dynamic
> ± 20% Tolerance

INSPECTION DATA

L-4 C Vertical

1. General Serial Number: 3612

   a) Case height: 13 cm.
   b) Case diameter: 7.6 cm.
   c) Total weight: 2.15 Kg.
   d) Operating pressure under water: 500 PSI
   e) Polarity of voltages produced at A and C terminal when each suspended mass moves toward the bottom negative

2. Calibration coil

   a) Turns: 12 Turns
   b) Resistance: 62 Ohms @ 68°F

3. Signal coil

   a) Turns: 4950 Turns on each of 2 coils connected in series/
   b) Electrodynamic constant: 6.6 V/In./Sec.
   c) Resistance: 5620 Ohms @ 68°F
   d) Leakage to case: >100 Megohms at 500 volts
   e) Motor constant: .467 Newton/Ampere
   f) Frequency (fo) 1.003 HZ
   g) Suspended mass (m) 978.9 grams
   h) Open circuit damping (bo) .280 of critical damping

Date: October 14, 1987 Inspector: Lola Luigy

ALLEN R. REED
ELECTRICAL CONTRACTOR
P. O. BOX 1276
THOUSAND OAKS, CA 91360

NEVADA NETWORK

Subject: Monthly Technical Report
Contract No. 14-08-0001-22501
Reporting Period: 1 January through 31 January, 1988

Date: 4 February 1988

A. INTRODUCTION.

This report reflects the monthly activities of our technicians in the conduct of maintenance of 63 Nevada remote seismic sites.

B. PERSONNEL UTILIZATION

The personnel utilization for the reporting period was:

	Straight Time (Hrs.)	Overtime (Hrs.)
1st Technician	160	0
2nd Technician	160	0

Per diem days utilized this month - 6

C. FIELD MAINTENANCE.

The sites visited during the reporting month are tabulated below.

Date	Site Visited	Action Taken
01/04/88	EPN WT (0.75 hrs.) TT (6.5 hrs.)	Reinstalled BMT Monitron receiver.
01/04/88	TMO WT (1.75 hrs.) TT (8.25 hrs.)	Reseated, repaired, and/or replaced all bad or faulty components.
01/05/88	NOP WT (1.0 hrs.) TT (4.75 hrs.)	Preventive maintenance and calibration.

JOHN FLUKE MFG. CO., INC.

U.S. GEOLOGICAL SURVEY
BRANCH OF FINANCIAL MGMT
MAILSTOP 270

RESTON VA 22094

U.S. GEOLOGICAL SURVEY
1711 ILLINOIS STREET

GOLDEN CO 80401

FROM: FLUKE TECHNICAL CENTER
14180 E. EVANS AVE
AURORA, CO 80014

SERVICE NO. 400692

SHIP TO: U.S. GEOLOGICAL SURVEY
1711 ILLINOIS STREET

GOLDEN CO 80401

	MODEL/PART NO.		SERIAL NO.	ACCESSORIES/PARTS INCLUDED
SROW	1900A-01	115	2026019	NONE

	CALIBRATION STATUS	CAL CONDITIONS
05/04/87	IN TOLERANCE	23 °C
05/12/87	IN TOLERANCE CALIBRATED PER MIL-STD-45662	40 % RH

SERVICE INFORMATION

NO UNUSUAL CONDITIONS NOTED
CALIBRATED UNIT - TRACEABLE TO N.B.S.
VERIFIED OPERATION OF ALL FUNCTIONS
SPECIAL DATA PROVIDED AS REQUESTED

TRACEABLE NBS NUMBERS

DC VOLTAGE	237840
AC VOLTAGE	234877
RESISTANCE	236930
TEMPERATURE	229053
FREQUENCY	VLF WWVB

REMARKS

CALIBRATION DATA

S.N. ▶ 2026019 BY
DATE ▶ 05/12/87 4
DUE ▶ 05/12/88

SHIP VIA: FLUKE TRUCK

CUSTOMER

JOHN FLUKE MFG. CO. INC.
FLUKE
METROLOGY SYSTEMS
SEAL OF CERTIFIED CALIBRATION
CUSTOMER SUPPORT SERVICES

ENDING
THE
LITY

400692

	MODEL/PART NO.		SERIAL NO.	
SRCW	1900A-01	115	2026019	NONE

	CALIBRATION STATUS	CAL CONDITIONS
RECEIVED 05/04/87	IN TOLERANCE	23 °C
RETURNED 05/12/87	IN TOLERANCE CALIBRATED PER MIL-STD-45662	40 %RH

CERTIFICATE OF CALIBRATION

The John Fluke Mfg. Co., Inc. does hereby certify the above listed instrument meets or exceeds all published specifications and has been calibrated using standards whose accuracies are traceable to the National Bureau of Standards within the limitations of the Bureau's Calibration Services, or have been derived from accepted values of natural physical constants, or have been derived by the ratio type of self-calibration techniques.

APPLICABLE NBS NUMBERS	
VOLTAGE	237840
C VOLTAGE	234877
ESISTANCE	236930
EMPERATURE	229053
REQUENCY	VLF WWVB

TECH. NO. 42

CERTIFIED BY

RON VIDICK — 05/12/87

SERVICE MANAGER — CALIBRATION DATE

Representative Computer Software for NNWSI Earthquake Parameter Determination

Program Name	Computer(s)	Author	Language	Purpose
core	PDP 11/34	Various	Fortran	Seismic data throughput from analog to magnetic tapes
ntrigr	11/34	C. Johnson	Fortran	Real-time seismic event detection
examin	11/34	R. Herrmann	Fortran	Examine and modify 11/34 image of network parameters
prtcom	11/34	S. Harmsen	Fortran	Print "snapshot" of 11/34 image of seismic network
seismic	11/34	R. Jordan	RSX	Command file to run real-time seismic system
ptplot	PDP 11/70	D. Hesser	C	Plot 11/34 prelim. event tapes to versetec
ldmux	11/70	S. Malone	C	Demultiplex 11/34 seismic data to filesystem
ping	11/70	Malone *et al*	C	Interactive phase & amplitude picker
punt	11/70	D. Leaver	C	Plot unmultiplexed traces with phase picks
fastpong	11/70	R. Herrmann	Fortran	Earthquake hypocenter determination
squash	11/70	S. Malone	C	Reduce size of trace data file by removing uninteresting channels
tpong	11/70	R. Herrmann	C	Use trace cross-correlation to locate teleseisms
autopa	11/70	A. Rogers	Fortran	Compute peak wavelet amplitudes for band-filtered traces
tar	11/70	Unknown	C	Unix tape archiving utility: all local data saved with "tar"
vaxsend	11/70	Oetting	C	Sends Unix ascii files (eg, local phase data) to VAX/VMX
foruv	VAXes	Harmsen	Fortran	Convert phase data to HYPO71 input format for relocation
hypo71	VAXes	Lee, Lahr	Fortran	Local earthquake hypocenter determination
hypo71	VAXes	Harmsen	Fortran	hypo71 modified for variable-thickness surface layer, etc
epmap	VAXes	Harmsen	Fortran	Plots maps of stations, faults, seismicity, geography
epiplt	VAXes	A. Rogers	Fortran	Plots maps and depth-sections of seismicity
focmec	VAXes	Snoke *et al*	Fortran	Computerized focal mechanism determination
fpfit	VAXes	F. Klein	Fortran	Computerized focal mechanism determination from P-polarities
boorfq	VAXes	A. Rogers	Fortran	Synthetic seismograms: variable EQ sizes, attenuation, etc
calibrate	VAXes	Harmsen	Fortran	Frequency response calibration of seismograph stations

Magnitude Calculations

•Coda Duration Magnitude

$$M_D = 1.666 \log_{10} \tau + .00227r - 1.28 + STA_k^D,$$

where τ = total coda duration (sec), from P-onset to return to background, r = hypocentral distance (km), and STA_k^D = kth station correction.

•Wood-Anderson Peak Amplitude Magnitude

$$M_{bLg} = \log_{10} PWA + 0.833 \log_{10} r + 0.00125 Cfr + 0.88 + STA_k^{Lg},$$

where PWA = pseudo Wood-Anderson amplitude, r = hypocentral distance, $C = \log_{10} e$, f = peak-amplitude wavelet frequency (hz), and STA_k^{Lg}= station correction. All terms following the first on the *right-hand* side are a regionally calibrated "log A_0," appropriate to the southern Great Basin.

•Coda-Average Magnitude (Carl Johnson)

This magnitude, M_{ca}, may be scaled on a clipped (overdriven) trace. The method fits an asymptotic envelope to the post-S coda:

$$M_{cj} = \overline{R(t - t_p)} + 1.8 \log_{10}(t - t_p) - A_0.$$

Here, $\overline{R(t - t_p)}$ is $\log_{10}$ of the rectified signal average in a 5-second non-clipped coda window, $1.8 \log_{10}(t - t_p)$ is a lapse time effect, t_p is the P-arrival time, and A_0 is a correction incorporating station sensitivity and site geology. By regressing M_{cj} against M_{bLg}, we have obtained A_0 for each station and our coda magnitude is

$$M_{ca} = 0.85 M_{cj} - 1.77 + STA_k^{ca}.$$

Magnitude

The reported event magnitude is

$$M_L = 0.5 M_{bLg} + 0.25 M_{ca} + 0.25 M_D,$$

if all three magnitudes have been scaled at an event. Other weighted averages are used for other combinations of magnitudes.

Regional Crustal Velocity Model

Variable basin and range surface elevation

$\alpha = 3.8$ km/sec, $\beta = 2.22$ km/sec to 1 km below sea level

---

$\alpha = 5.9$ km/sec, $\beta = 3.45$ km/sec to 8 km below sea-level

---

$\alpha = 6.15$ km/sec, $\beta = 3.60$ km/sec to 24 km below sea-level

---

$\alpha = 6.9$ km/sec, $\beta = 4.04$ km/sec to 32 km below sea-level

---

$\alpha = 7.8$ km/sec, $\beta = 4.56$ km/sec beyond Moho discontinuity

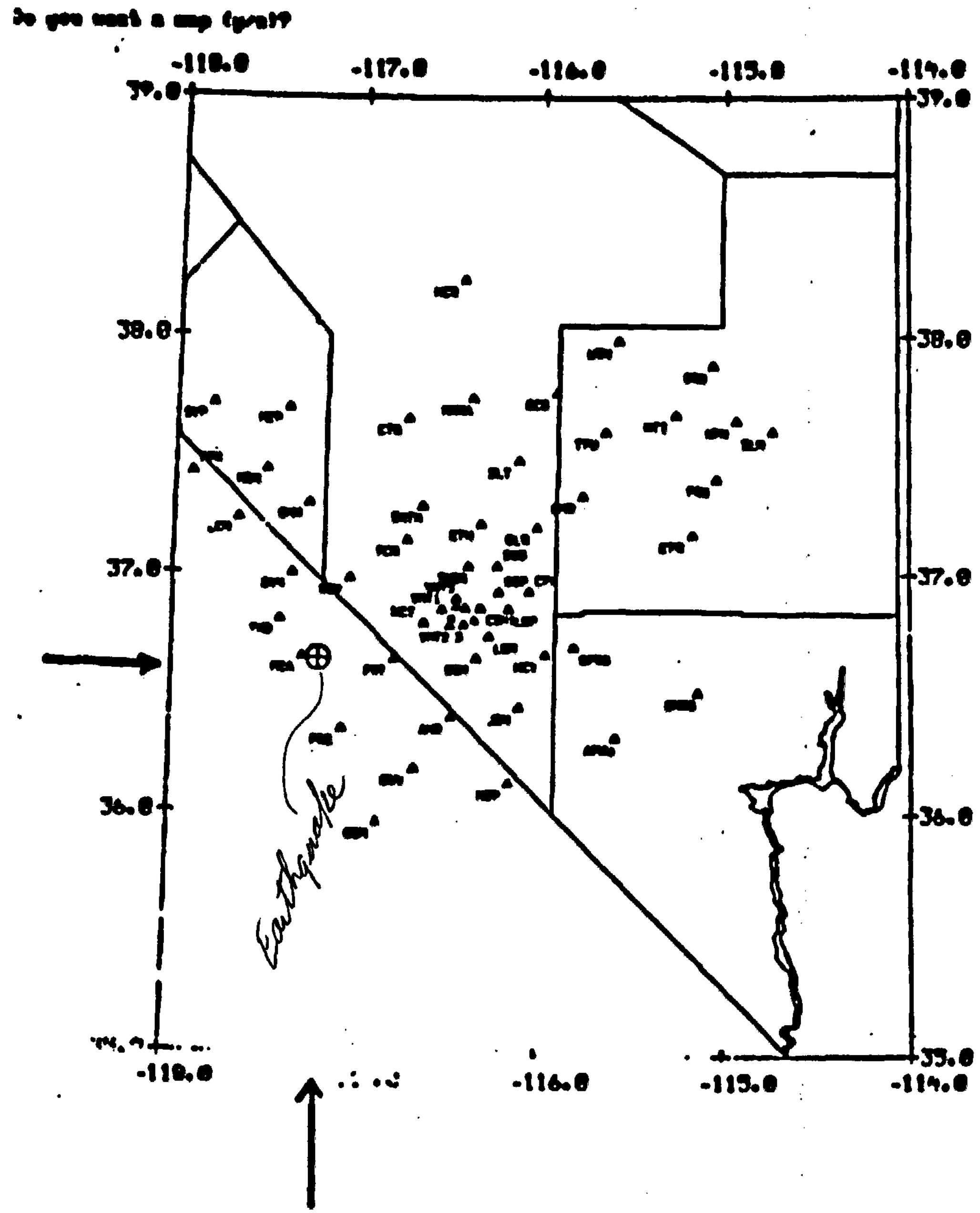
Regional Peak-Amplitude Attenuation Model for Magnitude Determination

The southern Great Basin shear-wave (or L_g wave) attenuation model used to estimate earthquake size from peak wavelet amplitude and frequency is

$$A = A_0 r^{-n} \exp^{-(\pi f r)/(QU)},$$

where A = ground displacement at the station, A_0 = ground displacement at the earthquake source, r = hypocentral distance (km), n = geometric spreading exponent = 0.833, f = frequency (hz) of peak ground motion in the S or L_g wavetrain, Q = attenuation parameter = 720, and U = 3.5 km/sec is the L_g group velocity. Station/site effects are also removed during routine magnitude determination. A geometric spreading exponent of $n = 0.833$ is a L_g-wave decay-with-distance parameter, so the Q model is selected to correspond with that exponent.[1] Software used for routine magnitude calculation is HYPO71, subroutine *xfmags*. (If one insisted on using a body-wave geometric spreading parameter, $n = 1$, then the appropriate Q-model is $Q = 1000$.)

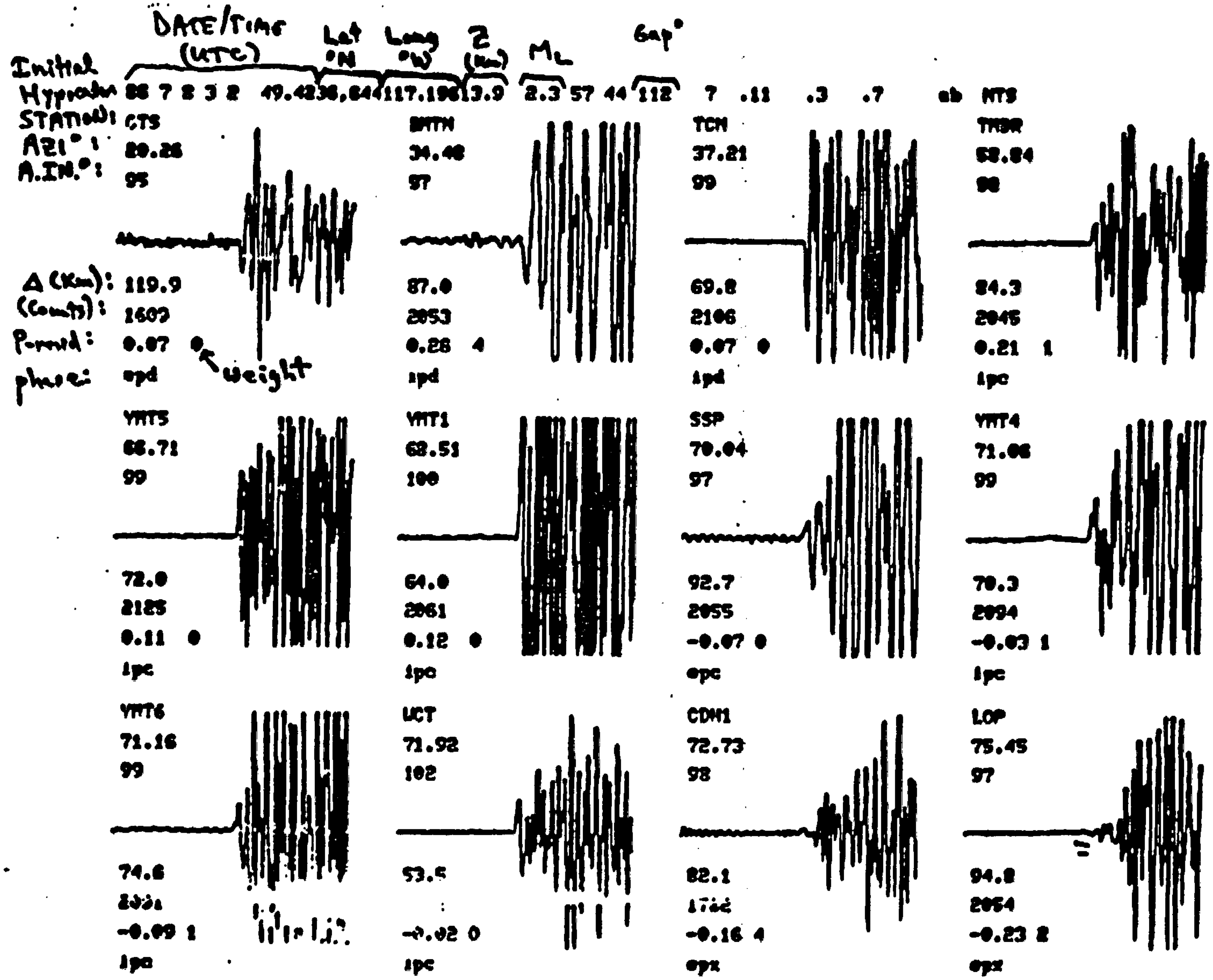
[1] Rogers, A. M., Harmsen, S. C., Herrmann, R. B, and Meremonte, M. E., 1987, A study of ground motion attenuation in the southern Great Basin, Nevada-California, using several techniques for estimates of Q_s, $\log A_0$, and coda Q, *Journal of Geophysical Research*, 92, p. 3527-3540. See table 4.



MARBLE CANYON EARTHQUAKE

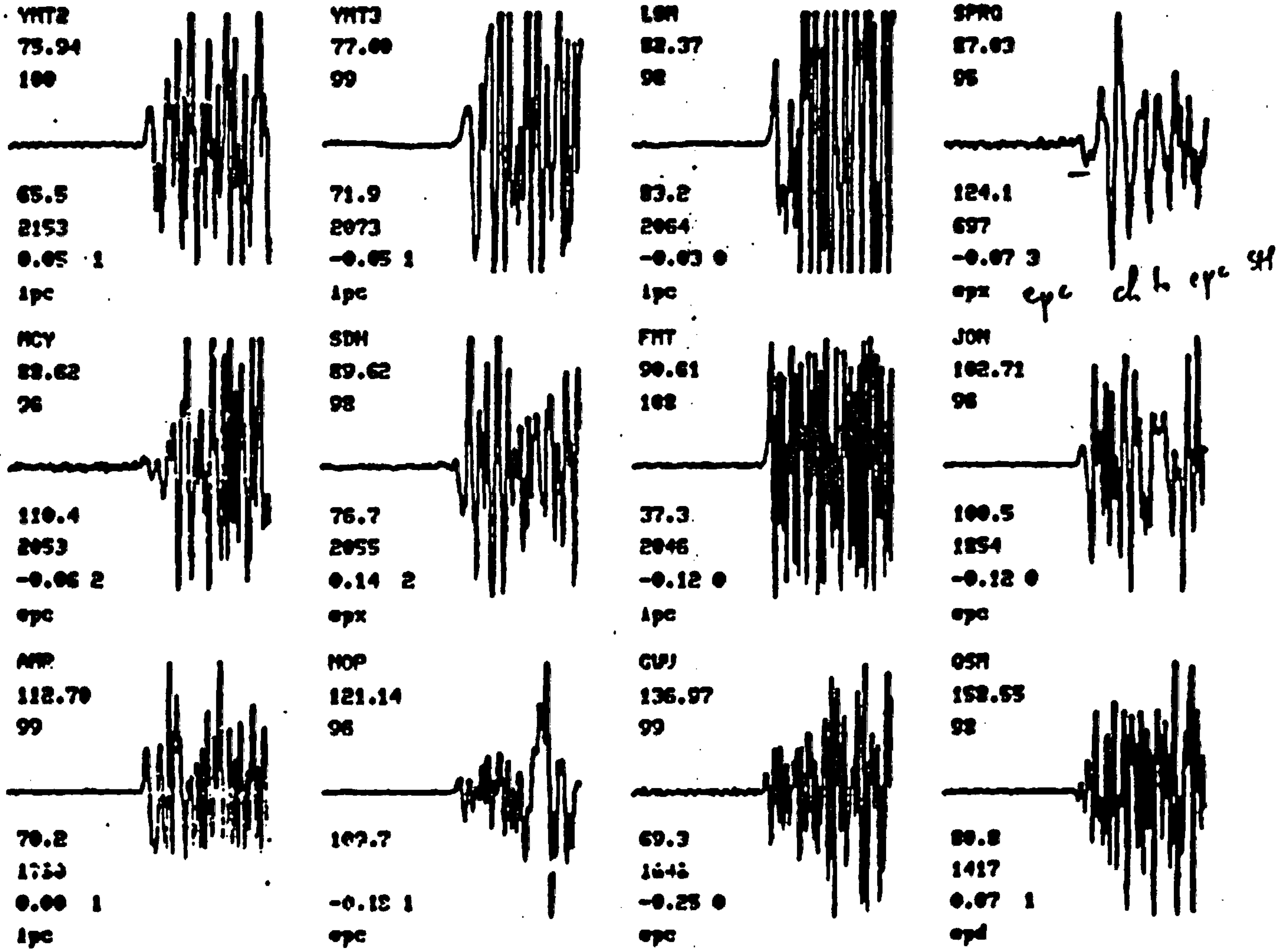
860708 3:02 UTC --

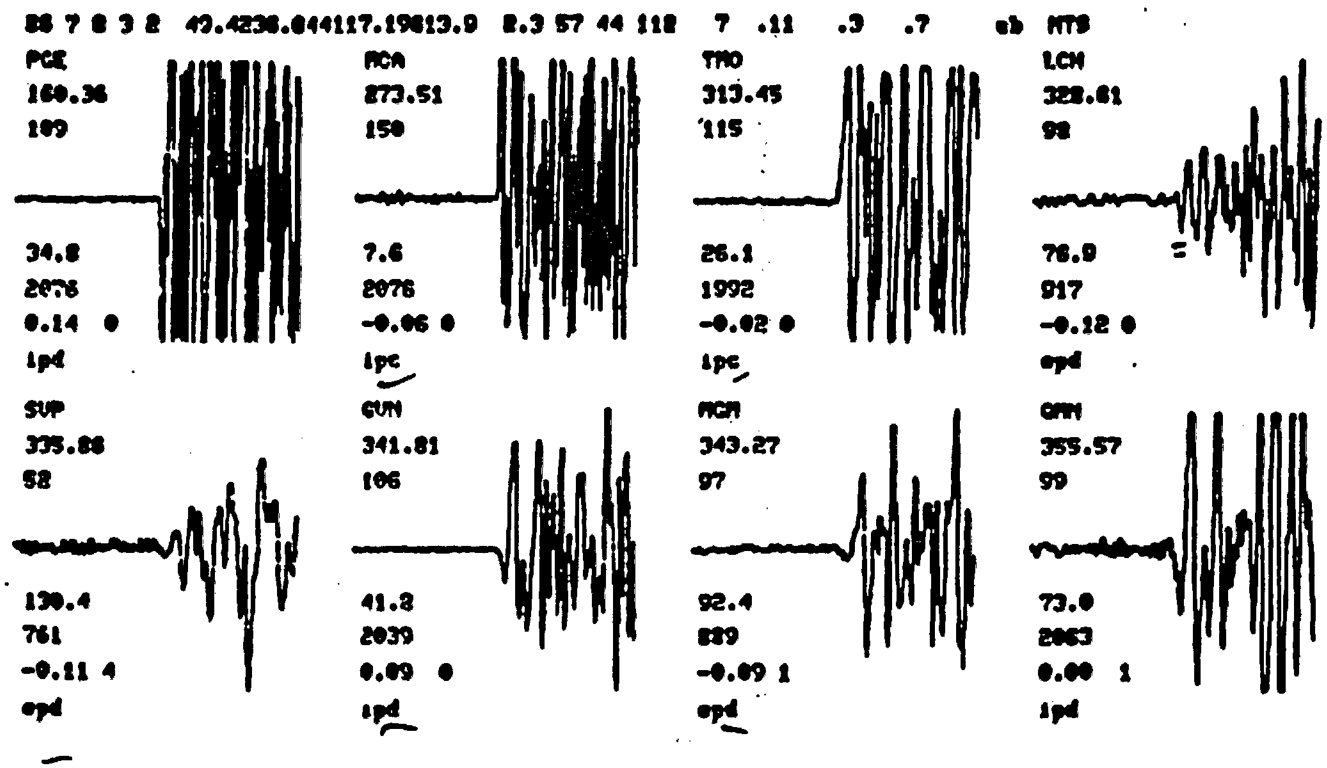
EXAMPLE EVENT TO DEMONSTRATE
P-wave POLARITIES AND
FOCAL MECHANISM.

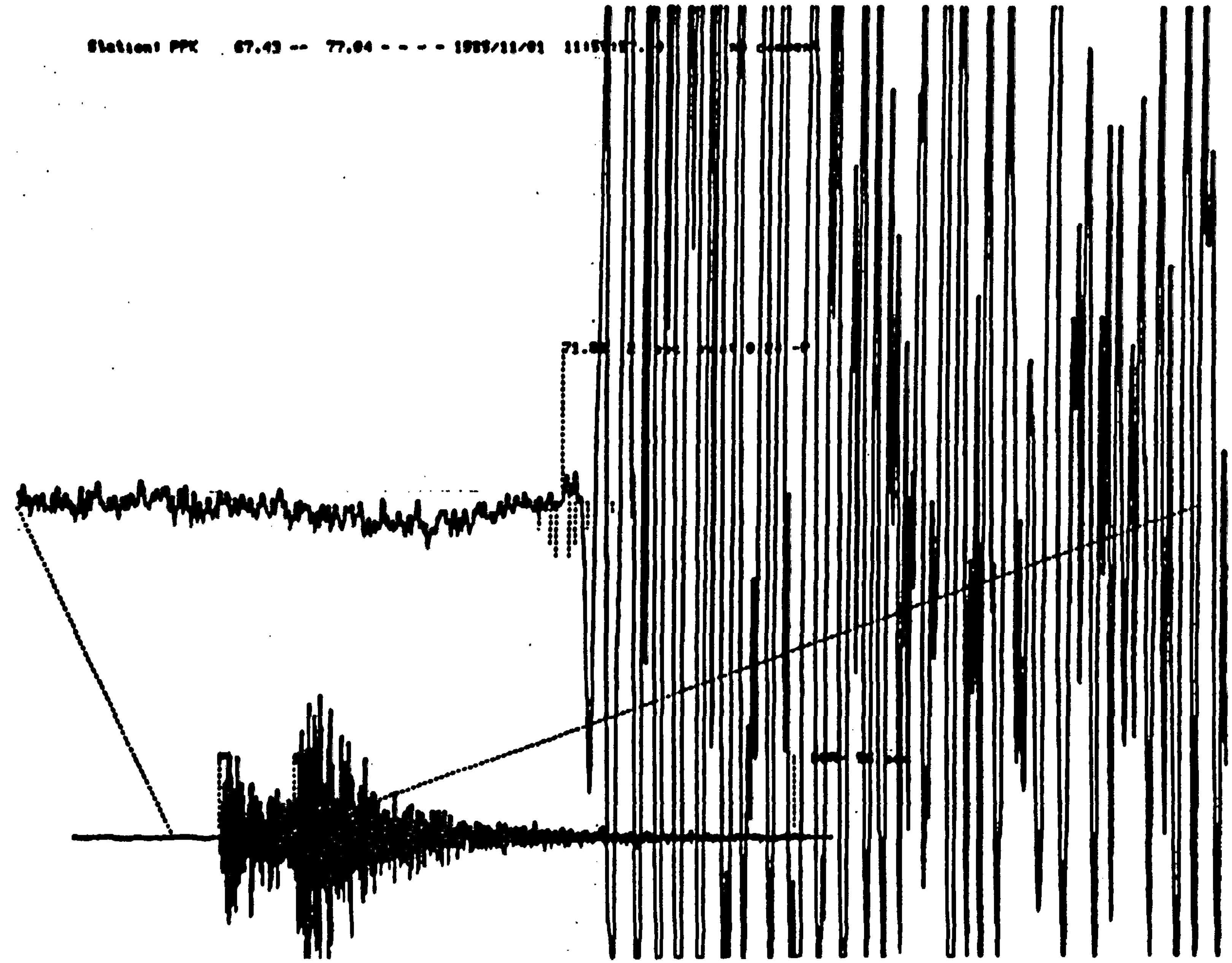


A.IN. = angle of incidence of source-station ray with lower focal hemisphere
Δ = epicentral distance
Counts = digital counts (0-to-peak, of maximum wavelet)

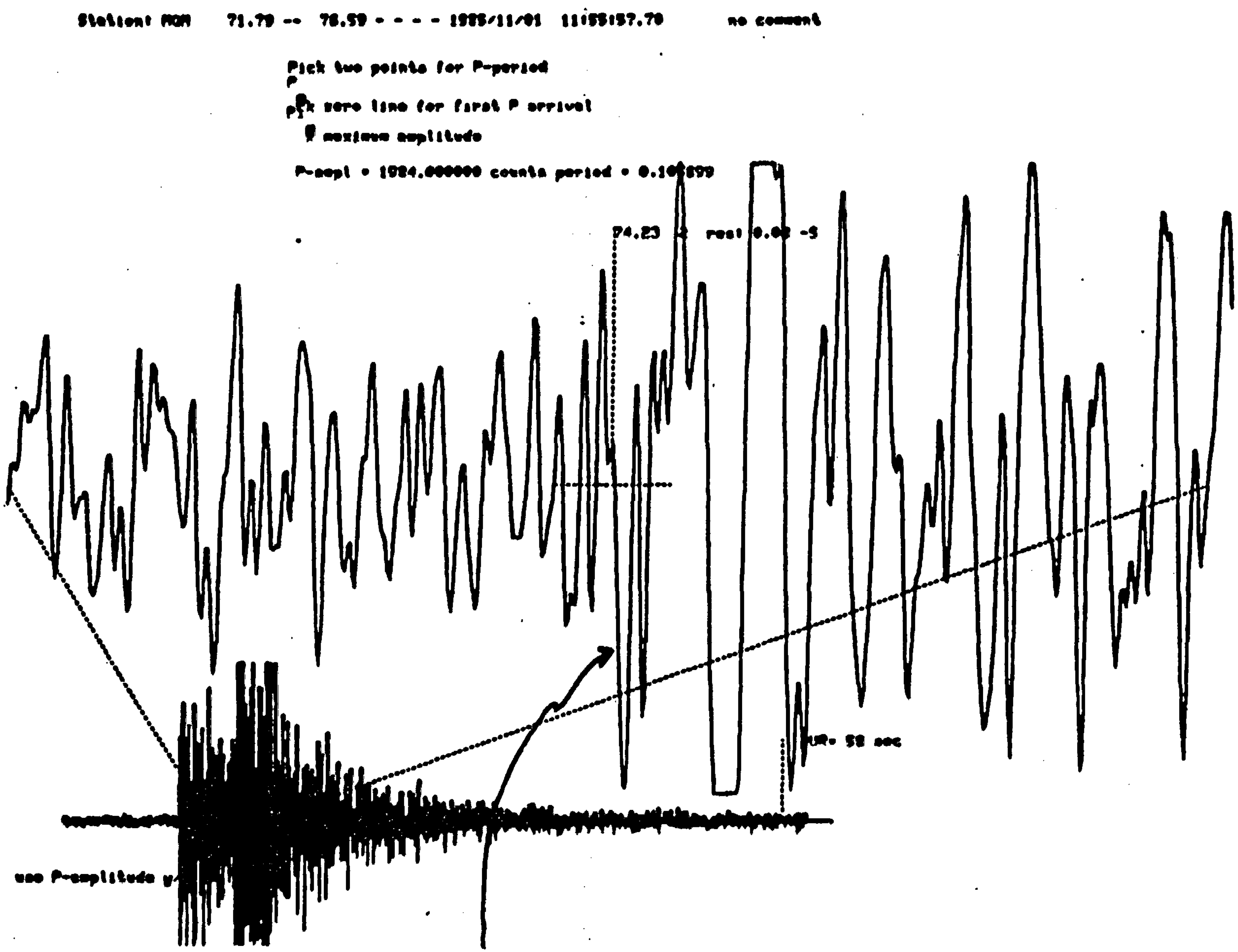
86 7 8 3 2 49.4238.644117.19813.9 2.3 57 44 112 7 .11 .3 .7 ab NTS




86 7 8 3 2 49.4238.044117.19813.9 8.3 57 44 118 7 .11 .3 .7 ab MTS
PGE
160.36
109
34.8
2078
0.14 0
ipd
RCA
273.51
150
7.6
2076
-0.06 0
ipc
TMO
313.45
115
26.1
1992
-0.02 0
ipc
LCM
328.81
98
76.9
917
-0.12 0
epd
SUP
335.88
58
130.4
761
-0.11 4
epd
GVN
341.81
106
41.8
2039
0.09 0
ipd
MCM
343.27
97
92.4
889
-0.09 1
epd
GMN
355.57
99
73.0
2063
0.00 1
ipd



Station PPK -- blowup indicates emergent compressional arrival



Example of wavelet identified as "S" for amplitude-ratio data

Example Focal Mechanism Determination

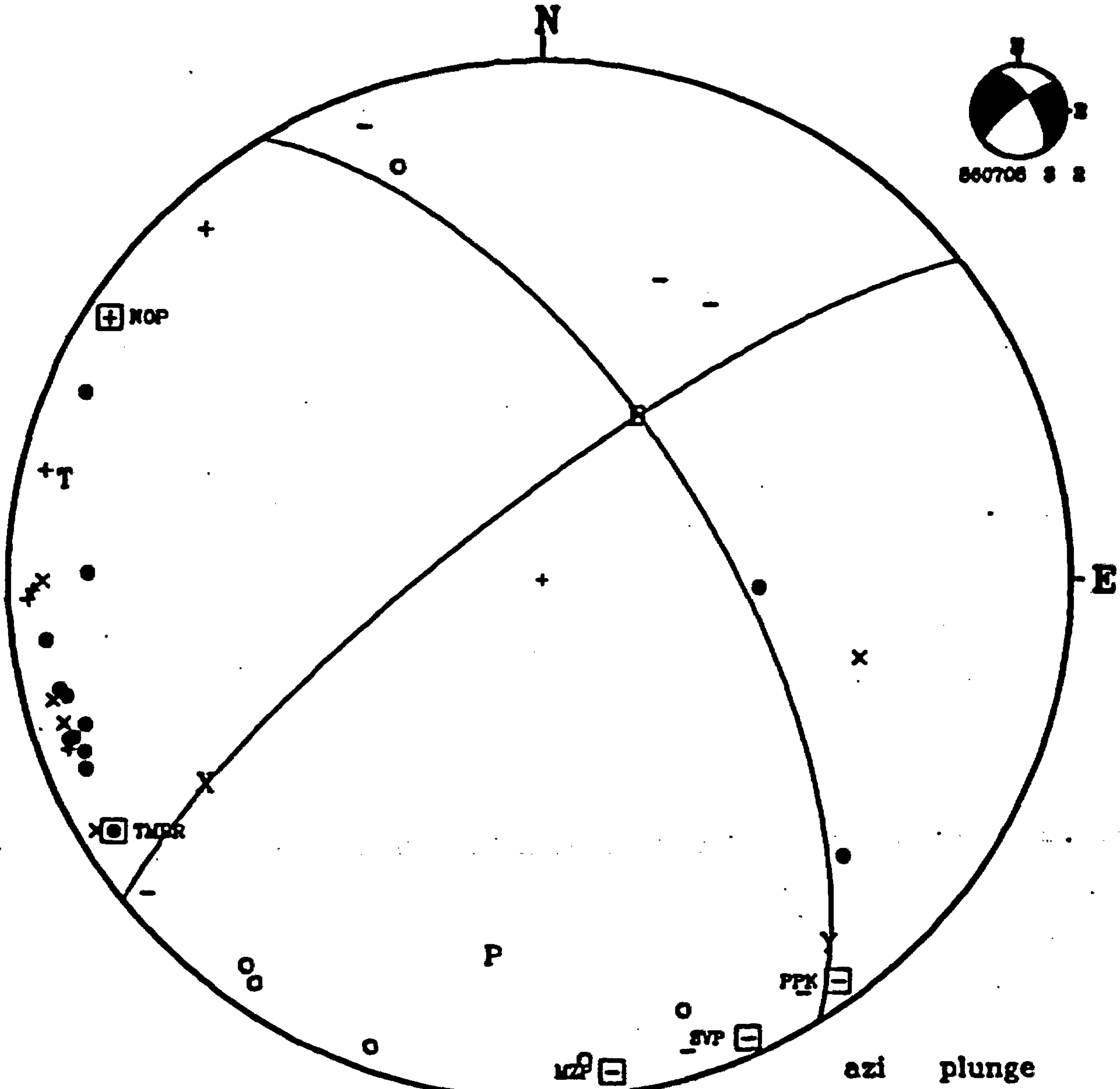
Focal mechanisms are routinely computed using computer programs "FOCMEC" and "FPFIT," both in wide use by seismographic network personnel throughout the U. S. and world. Example solutions for a run of "FOCMEC" on the Marble Canyon earthquake of 860708 3:02:49 are shown in the table below. For this event, 34 P-wave polarities and 5 SV/P_z amplitude ratios constrained the set of solutions. FOCMEC searches the universe of potential solutions by incrementing the *null vector's* and a corresponding *slip vector's* azimuth and plunge by 5°, and writes solutions that fall within prescribed error bounds.

860708 3:02 "FOCMEC" candidate solutions

Strike°	Dip°	Rake°	Polarity Errors	Ratio Errors	$(SV/P)_t$ RMS Misfit
231.2	73.3	-25.3	1- PPK	1 - NOP	0.125
230.3	73.3	-31.2	1- PPK	1 - NOP	0.096
232.0	77.8	-27.6	1- PPK	1 - NOP	0.080
233.1	82.6	-29.2	1- PPK	1 - PPK	0.168
85.8	55.9	24.7	1- TMO	1 - MZP	0.176

The strike, dip, and slip are for one of the two equally-likely nodal planes that represent a "solution." The *final* column lists the difference between logarithms of theoretical and observed SV/P_z ratios for the mechanism specified. Final selection of a single or a few focal mechanisms for publication is based on minimizing this ratio for a given number of polarity errors. Also, we do not allow solutions that have polarity errors at nearby stations. For example, the last entry in the table above has a polarity error at station TMO, which is the second-nearest station to the earthquake. The P-arrival at TMO is an impulsive compression, so the polarity error there would be considered a serious deficiency in the solution (notwithstanding the other problem, the somewhat larger ratio error). For the other solutions in the table above, the polarity error is at PPK, a station nearly four times as distant as TMO, and the P-arrival is an emergent dilitation, very near a nodal plane of these solutions.

Although focal mechanism parameters are reported without "standard errors," uncertainty exists in the solutions for a number of reasons. Confidence intervals of approximately ±5° about the reported strike, dip, and rake angles should be assumed in *all* cases for results reported for SGB, or indeed, for any ***regional, low-station-density*** network focal mechanisms.



STOVEPIPE WELLS
DATE/TIME: 860708 3 2 49.47
LAT: 36.646 LONG: 117.195
DEPTH, km: 11.75 +/- 0.6 ML: 2.3

	azi	plunge
P axis	187.20	28.02
T axis	282.50	9.85
B axis	30.00	60.00
X axis	238.30	26.95
Y axis	141.99	12.20

	strike	dip	rake
Soln 1	231.99	77.80	−27.62

Log10(SV/P)z

Observed	Theoretical	Difference	Station
0.6990	0.7114	-0.0124	TMBR
1.5193	1.6220	-0.1027	PPK
0.5456	0.2035	0.3421	*NOP
0.6065	0.4838	0.1227	MZP
0.9012	0.8884	0.0128	SVP

The RMS error for all amplitudes is 0.08.

PUBLICATIONS RELATED TO THE NNWSI SEISMIC NETWORK

Rogers, A.M., Wuollet, G.M., 1980, Southern Great Basin Seismological Data Report: 1979, prepared for Department of Energy for the Nevada Nuclear Waste Storage Investigations. 164 p.

Rogers, A.M., Harmsen, S.C., and Carr, W.J., 1981, Southern Great Basin Seismolgical Report for 1980 and Preliminary Data Analysis: U.S. Geological Survey Open-File Report 81-1086, 148 p.

Rogers, A.M., Carr, W.J., and Harmsen, S.C., 1982, Relations between seismicity and structure in the Southern Great Basin of Nevada and California, Fall AGU 1982, San Fransisco: Transactions of the American Geophysical Union, v. 63, p. 1033.

Carr, W.J., and Rogers, A.M., 1982, Tectonics, seismicity, and volcanism and erosion rates in the Southern Great Basin, in U.S. Geological Survey Research in Radioactive Waste Disposal in Fiscal Year 1979: U.S. Geological Survey Circular 847, p. 7-10.

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Hill, D.P., Cockerham, R.S., Eaton, J.P., Ellsworth, W.L., Lindh, A.G., Allen, C.R., Hutton, L.K., Johnson, C.E., Rogers, A.M., Carr, W.J., and Ryall, A.S., 1983, Seismicity along the Pacific-North American plate boundary in California and Western Nevada, 1980-81: Earthquake Notes, 54, p. 46.

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U.S. Department of Energy, 1984, Draft environmental assessment of Yucca Mountain site, Nevada Research and Development Area, Nevada: U.S. Department of Energy, DOE/RW-0012, 816 p.

Rogers, A.M., Meremonte, M.E., and Herrmann, R.B., 1984, Wave attenuation in the Southern Great Basin, Nevada-California [abs.]: Earthquake Notes, v. 55, p. 24.

Sinnock, W., Fernandez, J.A., Twenhofel, W.S., and contributing authors, 1984, Attributes and associated favorability graphs for the NNWSI Area-to-location screening activity: Sandia Report, Sand82-0838 UC70, 188 p.

Science Applications International Corp., 1985, Tectonic stability and expected ground motion at Yucca Mountain, Final Report, SAIC Report No. DOE/NV/10270-2, 33 p. I was one of a panel of eight experts who participated in the writing of this document to advise DOE for the high-level nuclear waste repository at Yucca Mountain.

Harmsen, S.C., and Rogers, A.M., 1986, Inferences about the local stress field from focal mechanisms--Applications to earthquakes in the Southern Great Basin of Nevada: Seismological Society of America Bulletin, v. 76, p. 1560-1572.

Rogers, A.M., Anderson, R.E., and Harmsen, S.C., 1986, Strike-slip seismicity in the Great Basin: American Geophysical Union Transactions 67, p. 1236. (Poster).

Tarr, A. C., and Rogers, A.M., 1986, Analysis of earthquake data recorded by digital field systems, Jackass Flats, Nevada: U.S. Geological Survey Open-File Report 86-420, 67 p.

Rogers, A.M., Harmsen, S.C., Herrmann, R.B., and Meremonte, M.E., 1987, A study of ground-motion attenuation in the Southern Great Basin, Nevada-California, using several techniques for estimates of Q_s, Log A_o, and Coda Q: Journal of Geophysical Research, v. 92, p. 3527-3540.

Meremonte, M.E., and Rogers, A.M., 1987, Historical catalog of Southern Great Basin earthquakes 1868-1978: U.S. Geological Survey Open-File Report 87-80, 179 p.

Rogers, A.M., Harmsen, S.C., Meremonte, M., 1987, Evaluation of the seismicity of the Southern Great Basin and its relationship to the tectonic framework of the region: U.S. Geological Survey Open-File Report 87-408, 200 p.

Harmsen, S.C., and Rogers, A.M., 1987, Earthquake location data for the Southern Great Basin of Nevada and California: 1984 through 1986: U.S. Geological Survey Open-File Report 87-596, 92 p.

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Perkins, D.M., Thenhaus, P.C., Hanson, S.L., and Algermissen, S.T., 1986, A reconnaissance assessment of probabilistic earthquake accelerations at the Nevada Test Site: U.S. Geological Survey Open-File Report 87-199.

Enclosure 4

Staff Suggestions

(1) In the annual earthquake report issued by the USGS, it may want to identify those periods of time where data has yet to be hand picked and reported.

(2) When it is published, the USGS should identify the hand-picked data in the annual report. (This suggestion was made by Mr. Peppin of the University of Nevada and the staff agrees.)

(3) The DOE and USGS should consider protection for the develocorder data since in some cases this data is the only record available.

(4) The USGS should consider developing tighter controls on data that represents the only available record and is provided to investigators within and outside of the USGS.

(5) The USGS should address any discrepancies in different data records to ensure consistency or provide a discussion of the reasons for the discrepancies.

(6) Although the NRC staff did not review any qualification records, DOE should ensure that the personnel certification records for the USGS personnel are sufficiently detailed so that an individual's qualifications are readily apparent.

(7) The USGS should place "No Calibration" labels on that field equipment that need not be calibrated. Plus, all field equipment should be labeled so that the status is known, even if the equipment is still under manufacturer calibration warranty.

(8) As the QA program matures, the staff would expect to see an increase in the number of audits.