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SEISMICITY OF THE CENTRAL NEVADA TEST AREA*

26 September 1969 - 1 October 1970

by

B. E. Smith, R. M. Hamilton, and W. H. Jackson

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* Work performed in cooperation with the U.S. Atomic Energy Commission

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Abstract

The U.S. Geological Survey operated seven seismograph stations in the vicinity of the Central Nevada Test Area (CNTA), Hot Creek Valley, for a period of about one year. Locations were determined for 36 earthquakes. A few of the larger shocks were located with additional recordings from stations elsewhere in Nevada. Earthquake activity was observed in Hot Creek Valley, Little Fish Lake Valley, and northern Stone Cabin Valley. Magnitudes ranged from -0.2 to 3.4. Depths of focus ranged from 0.6 to 12.2 km. A composite first-motion plot for 21 earthquakes yielded a fault-plane solution consistent with a strike-slip pattern striking approximately N40°E (right-lateral) or N50°W (left-lateral). Large underground nuclear explosions at NTS did not stimulate earthquake activity at CNTA. The infrequent seismic activity at CNTA suggests that any earthquakes closely following a future explosion probably have been initiated by that explosion.

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Introduction

A program to monitor seismic activity in the vicinity of the Central Nevada Test Area (CNTA), located in Hot Creek Valley (fig. 1), was conducted by the National Center for Earthquake Research (NCER), U.S. Geological Survey, for a period of about one year starting 26 September 1969. The purpose of the program was to establish the seismicity of the area prior to any future underground nuclear explosions at CNTA. The monitoring of seismic activity was discontinued on 1 October 1970, after the Atomic Energy Commission decided to postpone indefinitely testing at CNTA. This report contains the results obtained during the period of monitoring.

Interest in seismicity at CNTA had been stimulated by reports of earthquake activity following the Faultless underground nuclear explosion in Hot Creek Valley on 19 January 1968. Faultless, one of the largest nuclear tests conducted in Nevada ($m_b = 6.5$), was followed by both surficial faulting (fig. 6) and at least several dozen earthquakes, one of which was reported to have a magnitude of 4.5 (Boucher and others, 1969). Twenty seven of the reported earthquakes were located with a tripartite array which was installed in Hot Creek Valley seven weeks after Faultless, and operated for one week. Most of the earthquakes were located within about 5 km of Faultless ground zero, although six were located in the Monitor Range (fig. 1) about 40 km to the west.

The largest earthquakes recorded during the period 1852-1960 in the Hot Creek Valley area were of Richter magnitude 5 and occurred in 1942 and 1954 (Slemmons and others, 1965).

Figure 1

Location of all seismograph stations (triangles) used in locating earthquakes. Stations BMN, TPH, and TSV are operated by the National Ocean Survey. Stations FPN, SMN, BMN, and TNP are operated by the University of Nevada, Reno. NTS, RRV and CNTA are seismic arrays operated by the U.S. Geological Survey.

Instrumentation

Seven seismograph stations were operated in the vicinity of Hot Creek Valley for the duration of the program. In addition, seismograph stations outside the Hot Creek Valley area operated by the National Ocean Survey (formerly the U.S. Coast and Geodetic Survey), University of Nevada, Reno, and the U.S. Geological Survey (fig. 1) were used to help locate some of the larger events. The locations of the U.S. Geological Survey CNTA stations are listed in table 1 and plotted in figure 2.

The seismograph system can be explained by block diagrams (fig. 3 and 4). The equipment at each of five outlying stations (CNHR, CNHC, CNPS, CNSB, and CNEC) included: a vertical-component 1 Hz seismometer (Mark Products, L-4C); a combined preamplifier and voltage-controlled oscillator (Develco, Model 6202); a VHF FM, 100-milliwatt, transmitter (Develco, Model 3401); a yagi antenna; and batteries. The frequency-modulated signal produced at each of the above five stations was transmitted by radio to five separate receivers at station CNHM. Station CNHM was equipped with a full complement of the above-mentioned components plus a multiplexer to combine the six seismic signals before their transmission by radio to station CNBC. Station CNBC was equipped with the full complement of components except for the transmitter. From station CNBC the combined seismic signals were transmitted by telephone lines to the NCER office in Menlo Park, California, where they were separated and demodulated by discriminators (Develco, Model 6203), and recorded on 16-mm film (Geotech Division, Teledyne Industries, Develocorder). Readings from the film yielded locations and magnitude determinations of the earthquakes.

Table 1
U.S. Geological Survey Seismograph Station Data

Geographic Coordinates

<u>Station Code</u>	<u>Latitude, N.</u>		<u>Longitude, W.</u>		<u>Elevation, meters</u>
	<u>deg.</u>	<u>min.</u>	<u>deg.</u>	<u>min.</u>	
CNHR	38	31.39	116	22.38	1786
CNBC	38	18.68	116	16.64	1591
CNHC	38	35.44	116	14.73	1811
CNPS	38	45.96	116	12.22	1942
CNSB	38	37.68	116	8.88	1960
CNEC	38	28.13	115	59.90	1682
CNHM	38	30.28	116	8.79	2210

Figure 2

Locations of CNTA seismograph stations (triangles). Arrows indicate direction of radio transmission.

Center frequencies:

Channel 1	680 Hz
2	1020 Hz
3	1360 Hz
4	1700 Hz
5	2040 Hz
6	2380 Hz
7	2720 Hz

Maximum deviation: ± 125 Hz

Guard band: 90 Hz

Signal frequency: 0.5 to 25 Hz

Figure 3a. Basic equipment used at remote locations such as Stations CNHR, CNHC, CNPS, CNSB, and CNEC.

Figure 3. Constant bandwidth channels used for telemetry of seismograph data via telephone and radio.

Figure 4. Equipment located at stations CNHM and CNBC. A total of 7 seismograph data channels are transferred to telephone line 8GD-7022 at the Base Camp station for transmission to the NCER office, Menlo Park, California.

The overall response of the seismic system is shown in figure 5. The peak-to-trough record amplitude for a 10 μ v rms, 5 Hz, calibration signal, input in parallel with the seismometer is defined as C_{10} . Values of C_{10} for CNTA stations range from 9 to 22 mm.

The CNTA seismic network experienced technical difficulties that caused some of the stations to be inoperative for several periods lasting as long as two weeks. The most serious problem arose when lightning struck station CNHM and damaged the transmitter and most of the receivers. CNBC was the only station that remained operative. Other operational problems were mostly connected with telephone transmission.

Figure 5

Overall magnification of the seismic system that includes a Mark Products, Model L-4C, vertical-component seismometer; a Develco, Model 6202, VCO/Preamplifier; and a Geotech Division, Teledyne Industries, Develocorder. Curve shown is for settings yielding a 1-mm peak-to-trough record amplitude for an input signal of 10 μ v rms at 5 Hz. The true magnification for each station can be obtained by multiplying the curve value by C_{10} , which ranged from 9 to 22 mm for the CNTA stations.

Hypocenter Determination

The earthquake locations were derived from arrival times of P seismic waves using a Fortran program written by Eaton (1969) for the IBM 360/65 computer. Locations were determined for all earthquakes yielding sufficient data.

There was insufficient information available to determine an accurate velocity model for the Hot Creek Valley area. Further, the geology changed considerably from station to station. Therefore, the velocity model used in the earthquake location program was that previously used for Pahute Mesa at the Nevada Test Site (Hamilton and Healy, 1969), with the addition of station corrections to allow for variations from the model. The station corrections were derived by observing the delay in expected P arrival times from earthquakes at teleseismic distances and underground nuclear explosions at NTS. These delays probably reflect variations in the crustal thickness as well as variations in the upper crust. However, it is felt that the latter is more significant, and the delays used have been found to be consistent with station residuals calculated by the location program. The velocity model and station corrections, expressed as a delay, are listed in table 2.

Locations were determined for earthquakes inside the network that had sharp arrivals at three or more stations. Earthquakes outside the network were located with six or more stations. Only a few of the located earthquakes had station distributions adequate to calculate reliable depths. Other earthquakes were restricted to a depth of 5 km in the location program.

Table 2

Velocity model used in locating seismic events

<u>Depth to layer, km</u>	<u>Layer velocity, km/sec</u>
0.0	2.7
0.94	3.4
1.33	3.8
2.14	4.4
2.50	5.1
5.00	6.1
25.00	7.0
35.00	8.0

Station corrections

<u>Station code</u>	<u>P-delay, seconds</u>
CNHR	-0.26
CNBC	0.61
CNHC	0.00
CNPS	0.29
CNSB	0.13
CNEC	0.18
CNHM	0.19

Magnitudes were calculated for all located earthquakes from signal duration, i.e., the elapsed time from the first arrival to the point that the peak-to-trough amplitude falls below 1 cm for the last time. The duration was measured for all stations on which first arrivals could be timed. The average duration for each earthquake was then converted to M_L (Richter local magnitude) using a curve that was derived empirically from seismic data collected at the U.S. Geological Survey seismograph network near Rangely, Colorado (J. H. Healy, 1971, written communication). This curve has been found to be consistent with several dozen magnitudes calculated from the maximum peak-to-trough amplitude of earthquakes at both CNTA and NTS. The duration magnitudes were the only ones that could be uniformly computed for all of the CNTA earthquakes because reliable calibrations were not obtained for the whole recording period.

A chronological listing of all located earthquakes is given in table 3 along with the data discussed above. The readings of CNTA seismic stations for all located earthquakes with $M_L \geq 1.5$ are listed in table 4.

Table 3.

Chronological List of Located Earthquakes

		Origin Time				Lat N		Long W		Depth	MD ⁺	No	M _L
		Day	Hr	Mn	Sec	Deg	Min	Deg	Min	Km	Sec	Stns	
1969	Nov	02	03	35	50.45	38	19.75	116	13.26	5.0*	0.06	7	1.5
		<u>08</u>	<u>04</u>	<u>35</u>	<u>2.28</u>	<u>38</u>	<u>42.73</u>	<u>116</u>	<u>9.09</u>	<u>5.0*</u>	<u>0.01</u>	<u>4</u>	<u>0.6</u>
1970	Jan	25	01	41	57.16	38	34.08	116	12.28	8.9	0.05	7	1.6
	Feb	06	20	02	48.63	38	28.57	116	4.42	12.2	0.02	4	0.4
		10	20	28	31.02	38	29.24	116	37.18	5.0*	0.08	7	1.0
		11	02	53	42.74	38	38.24	116	11.08	6.2	0.03	6	1.0
		15	15	14	23.61	38	28.70	116	13.71	5.0*	0.00	3	0.7
		18	16	42	19.27	38	34.41	116	4.67	1.5	0.04	4	0.9
	Mar	06	20	28	6.07	38	41.60	116	10.02	1.0	0.10	7	2.3
		06	20	29	21.97	38	42.11	116	10.65	5.0*	0.06	4	1.7
		06	20	43	8.22	38	42.11	116	10.42	5.0*	0.03	5	2.4
		06	21	57	19.82	38	42.06	116	11.51	5.0*	0.01	4	0.6
		07	00	07	45.29	38	42.12	116	11.13	5.0*	0.04	4	1.0
		07	01	04	37.18	38	42.16	116	11.05	5.0*	0.05	4	1.1
		08	10	23	36.68	38	41.98	116	8.54	5.0*	0.00	3	1.4
		08	17	38	30.43	38	42.19	116	11.53	5.0*	0.00	4	0.8
		09	05	05	45.91	38	41.97	116	10.48	5.0*	0.04	4	1.6
		11	22	15	45.70	38	37.99	116	3.88	5.0*	0.00	3	1.0
		26	17	04	16.08	38	51.59	116	21.34	5.0*	0.14	6	2.4
		28	09	38	42.95	38	52.69	116	22.05	5.0*	0.09	11	3.4
		28	10	53	39.05	38	52.47	116	22.21	5.0*	0.16	9	2.6
		28	15	45	34.31	38	52.46	116	20.67	5.0*	0.21	7	2.2
		29	21	23	57.41	38	42.75	116	9.26	5.0*	0.02	4	1.0
		31	03	18	4.33	38	29.15	115	52.21	0.6	0.16	8	1.0
	Apr	09	11	55	3.47	38	38.45	116	9.17	5.0*	0.0	3	1.0
		09	12	28	36.09	38	38.24	116	9.00	5.0*	0.00	3	0.6
		19	11	09	1.12	38	36.53	116	3.29	5.0*	0.09	4	1.0
		19	11	57	15.06	38	36.64	116	3.07	5.0*	0.09	4	0.4
		19	13	06	8.41	38	36.49	116	3.25	5.0*	0.09	4	0.9
		30	11	57	28.68	38	46.14	115	55.39	1.5	0.08	4	2.4
	May	17	17	23	8.82	38	28.89	116	6.21	12.0	0.04	6	1.1
		19	13	59	22.92	38	31.94	116	30.47	5.0*	0.07	7	1.2
	Jun	17	06	05	24.75	38	36.83	116	13.34	7.4	0.06	5	1.4
	Sep	11	13	39	41.44	38	10.43	116	23.98	5.0*	0.09	7	0.6
		20	13	01	25.66	38	26.18	116	1.98	5.0*	0.00	3	0.2
		28	10	46	9.62	38	13.04	116	23.58	5.0*	0.10	11	1.4

⁺ Mean deviation of arrival-time residuals.

* Depth restricted to 5.0 km in location program.

Table 4

CNTA Seismic Station Readings for Earthquakes with $M_L \geq 1.5$

- (1) First motion (C - compression, D - Dilation).
 (2) Weighting factor for arrival time (0 - excellent, 1 - good, 2 - fair, 4 - not used in location routine).
 (3) Arrival time in seconds.

Origin Time	CNHR			CNBC			CNHC			CNPS			CNSB			CNEC			CNHM		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Nov 2 0335	2	55.25		C 0	52.83		2	56.25		2	59.55		2	57.10		D 0	55.65		D 0	54.80	
Jan 25 0141	C 0	60.52		1	63.48		C 0	59.19		C 0	61.97		C 0	59.89		C 0	61.78		0	59.88	
Mar 6 2028	C 0	11.48		2	15.10		C 0	09.53		C 0	08.87					C 0	12.52				
Mar 6 2029	1	27.00					1	25.00		1	24.38					1	28.03				
Mar 6 2043	C 0	13.23		0	17.00		C 0	11.32		0	10.65					C 0	14.23				
Mar 9 0505	C 0	50.90					D 0	48.95		C 0	48.37					C 0	51.90				
Mar 26 1704				C 0	27.41					C 0	19.92		C 0	22.43					C 0	24.30	
Mar 28 0938				C 0	54.60					C 0	47.17		C 0	49.72		C 0	53.14		C 0	51.60	
Mar 28 1053	4	43.50		C 0	50.74					C 0	43.24		C 0	45.78					C 0	47.62	
Mar 28 1543				0	45.78					C 0	38.24		C 0	40.77					C 0	42.65	
Apr 30 1157	4	34.70								C 0	34.30		D 0	34.39		D 0	34.83		D 0	35.85	

Discussion

Thirty six earthquakes were located by the CNTA network during the one-year period of its operation. Excluding the intermittent periods during which the network was not operating, we believe that all earthquakes above magnitude 1.0 that occurred inside the network, were located (fig. 6). Figure 7 shows the relationships between these same earthquakes, Cenozoic faulting, and bedrock (F.J. Kleinhampl and J.I. Ziony, written communication, January, 1971).

Four earthquakes are considered to have good computed depths, i.e., the first arrival could be read from at least one station with an epicentral distance less than the focal depth and other readings were from stations with a good azimuthal distribution. These depths were: 6.2 km, 7.4 km, 8.9 km, and 12.0 km. Other depths ranged from 0.6 to 12.2 km. This depth range is greater than that found at NTS, where earthquakes occur from near surface to about 6 km, but about the same as was found in a study conducted by NCER in December, 1968, of earthquakes near Fairview Peak, Nevada.

The four earthquakes to the northwest of the network occurred from 26 to 28 March 1970. These events were located with the help of the National Ocean Survey stations BMN and TPH, and the University of Nevada stations TNP, BMN, FPN and SMN (fig. 1). Several dozen smaller earthquakes, mostly aftershocks of the four larger events, appeared to come from this same area but could not be located. The largest of these earthquakes had a magnitude of 3.4 and was the largest earthquake located.

The two earthquakes to the south of the network were located with additional readings from the NTS seismograph network operated by the U.S. Geological Survey, and the National Ocean Survey station TSV.

Figure 6

Epicenter map. Stations shown as triangles. Surficial faulting from the Faultless explosion is indicated by the lines in the upper center (McKeown and Dickey, 1969).

Figure 7.

Relationship of epicenters to major geologic features. Mapped faults are shown by solid lines, probable faults by dotted lines. Circular faults bound calderas. Areas of bedrock are cross-hachured to distinguish them from alluviated areas (F. J. Kleinhampl, and J. I. Ziony, U.S. Geological Survey, 1971, written communication).

The most easterly earthquake was located with the help of six portable seismograph stations in Railroad Valley which were operated by the U.S. Geological Survey during the time of the Handley underground nuclear explosion.

The eleven earthquakes in the area midway between stations CNSB and CNPS (fig. 6) occurred from 6 to 9 March 1970, with two exceptions: one on 8 November 1969, and the other on 29 March 1970. The magnitudes of these eleven events ranged from 0.6 to 2.4. These earthquakes fell to the northeast of the faulting produced by Faultless and may possibly represent a continuation of those northeasterly-trending faults (fig. 6).

The two earthquakes to the west of the CNTA network are near those located in the Monitor Range following Faultless (Boucher and others, 1969). These shocks had magnitudes of 1.0 and 1.2.

Fault-plane solutions for the located earthquakes were in general ambiguous due to insufficient data. However, 21 of the 36 earthquakes were consistent with the fault-plane solution shown in figure 8. We do not believe that this composite fault-plane solution is definitive for earthquakes in this area. More data might yield solutions showing dip-slip movement, especially considering that many of the earthquake solutions had poor depth control. Nevertheless, it is interesting to compare the range of possible solutions (fig. 8) with the faulting observed following Faultless (fig 6). Most of the relative displacement was down toward the southeast. However, some right-lateral movement was observed and confirmed by preliminary analysis of geodetic surveys (McKeown and Dickey, 1969). The observed right-lateral movement has a strike which falls within the range of possible fault-plane solutions (fig. 8).

Figure 8

Composite plot of first motions from 21 CNTA earthquakes.

The figure is an equal-area projection of the lower focal hemisphere. Symbols are: compressional first motion - solid circle, dilatational first motion - open circle. Solid and dashed lines represent range of possible strike-slip solutions. The arrows bisect the angles formed by the nodal planes. The bisector of the dilatational quadrant is labeled as the pressure axis and the bisector of the compressional quadrant is labeled as the tension axis.

Large underground nuclear explosions from NTS did not trigger any activity at CNTA. The first of the earthquakes in late March, to the northwest of the network, occurred two hours prior to the Handley test ($m_b = 6.5$) at NTS. If this earthquake had occurred two hours later, it would have been tempting to incorrectly correlate these two events. Two low-yield NTS tests (Cyathus, $m_b = 4.5$, and Arabis, $m_b = 4.3$) occurred about five hours before the first of the series of earthquakes starting on 6 March. However, the small size of these tests makes it unlikely that they are related to the earthquakes at CNTA.

During the monitoring period at CNTA, there were only two areas of concentrated activity: midway between stations CNSB and CNPS, and northwest of the network. The activity in these areas occurred primarily during earthquake sequences lasting for less than one week. The small number and limited duration of the earthquake sequences suggests that if any earthquakes closely follow a future underground nuclear explosion at CNTA, the activity would probably have been stimulated by that explosion.

If underground nuclear testing is resumed in Hot Creek Valley, likely areas for stimulated earthquake activity would be northern Hot Creek Valley, Little Fish Lake Valley, and northern Stone Cabin Valley.

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