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STRONG-MOTION DATA FROM THE COALINGA, CALIFORNIA EARTHQUAKE AND AFTERSHOCKS

by

A.F. Shakal[1] and J.T. Ragsdale [2]

ABSTRACT

Strong-motion records from the Coalinga aftershocks indicate that accelerations in the city of Coalinga are commonly three times higher than at a rock site 3 km west of the city. The high levels of damage in Coalinga during the mainshock are probably due in part to this effect. The alluvium underlying the Coalinga valley appears to be the reason for the increased accelerations relative to the rock site at the valley edge, observed in all but one of the six large (5 - 6 ML) aftershocks. No strong-motion records were obtained in Coalinga during the mainshock but accelerations as high as 70% in the aftershocks imply that equivalent or larger accelerations probably occurred during the mainshock.

The set of free-field strong-motion records obtained during the Coalinga earthquake is the largest ever obtained from a single event. The data set is important for studies of ground motion attenuation and local variations of ground motion. Proximate stations in the Parkfield strong-motion array recorded significantly different acceleration levels though sited on the same geologic formation.

Significant records were also obtained from the Coalinga aftershocks. The 5.1 ML event of 9 May was very well recorded, with some 26 strong-motion records obtained in the epicentral area by various agencies. Deployment of co-located analog and digital accelerographs for instrument-evaluation purposes yielded several accelerogram pairs and triplets with peak accelerations of 10 - 70%g.

INTRODUCTION

The 6.7 ML (BRK) Coalinga earthquake of 2 May 1983 and its aftershocks generated a large set of important strong-motion data. The first part of this paper is an overview of the mainshock strong-motion data. The second part considers in greater detail the strong-motion records from the aftershocks. These records were recovered from instruments deployed in the immediate epicentral area as well as in the city of Coalinga. Accelerations of over 70%g were recorded in Coalinga.

1 Seismologist, California Division of Mines and Geology
2 Structural Engineer, California Division of Mines and Geology

COALINGA MAINSHOCK STRONG-MOTION DATA

The Coalinga earthquake generated the largest set of strong-motion records since the San Fernando earthquake of 1971. Nearly 100 records were recovered from the earthquake, mostly from stations in the 25-60 km distance range. Sixty records were recovered by stations of the California Strong-Motion Instrumentation Program (CSMIP). A report on these records by Shakal and McJunkin (1983) gives the station locations, accelerations, and reproductions of the records. The largest accelerations recorded at CSMIP stations were about 30%g, at about 30 km from the epicenter. Most of the CSMIP records were obtained at stations of the recently completed Parkfield strong-motion array described by McJunkin and Shakal (1983).

In addition to the 60 CSMIP records, 37 records were recovered from stations maintained by the USGS. One of these stations, at the Pleasant Valley Pumping Plant, was only about 10 km from the epicenter. The records obtained at this station are described by Maley et al. (1983). The remaining USGS data are from distant (> 75 km) stations.

In many ways, the strong-motion data set from the Coalinga earthquake is similar to that from the San Fernando earthquake of 1971. The earthquakes had similar magnitudes and both were of thrust mechanism. For both earthquakes, the predominance of data was recorded at stations on the down-thrown block, at epicentral distances of 30-80 km. The Coalinga data set will moderate the influence of the San Fernando data on ground motion attenuation relationships. A significant feature of the Coalinga data set is that most records were obtained in small instrument shelters (described in McJunkin and Shakal, 1983). Much of the San Fernando data were recorded in moderate to large structures which can significantly affect the recorded strong motion (e.g., Boore et al., 1980).

Peak Acceleration versus Distance

Study of the attenuation of strong shaking with distance is often complicated by the need to define source-to-station distance (e.g., Shakal and Bernreuter, 1981). However, epicentral distance is adequate for initial comparison of the data from the Coalinga and San Fernando earthquakes because of their similar source mechanisms and earthquake-station geometries.

The Coalinga peak-acceleration data are plotted against epicentral distance in Fig. 1. The San Fernando data, from Maley and Cloud (1973), are also plotted (open symbols). The similarity of the data sets is apparent, with much of the data for both earthquakes being recovered from distances between 30 and 80 km. There appears to be some evidence for higher accelerations from the Coalinga earthquake than the San Fernando event at a given epicentral distance but more detailed studies will be necessary to investigate the differences between the two data sets. Boore et al. (1983) have begun detailed analyses incorporating the distance to a postulated surface of fault rupture.

Differences in Ground Motion at Nearby Stations

The CSMIP Parkfield strong-motion array (Fig. 2) recorded the Coalinga mainshock at 46 stations within a 20 km by 30 km area. The records obtained at some nearby stations show marked differences, both in frequency and amplitude. For example, the accelerograms from three nearby stations are compared in Fig. 3. These stations, Fault-Zone stations 9, 14 and 15, are all on the west side of the San Andreas fault, and are underlain by materials of the Pliocene-Pleistocene Paso Robles Formation (McJunkin and Shakal, 1983). They are also very close to one another relative to their epicentral distance (approx. 40 km). Yet, as shown in Fig. 3, the station 14 record is significantly higher in amplitude and shows a predominance of long period energy compared to either the station 9 or 15 record. The amplification at station 14 may be due to low-velocity materials at depth, not indicated by the surficial geology. That would be consistent with the arrival times indicated in Fig. 3. The S(?) signal arrives at station 14 over 1/2 sec later than at station 15, although station 14 is only 1/2 km more distant from the epicenter.

The response spectra computed from the records after digitization are shown in Fig. 4. The spectrum from station 14 is three times as high as the station 9 or 15 spectra near 1 Hz. At higher frequencies, the station 9 spectrum is quite low compared to the station 14 and 15 spectra. Full understanding of these differences will require increased knowledge of the geologic materials underlying the sites as well as analyses of possible topographic effects.

Records from other neighboring stations in the Parkfield array also show significant differences. However, these generally appear explainable in terms of the site geology. For example, station Cholame 1E, at the southeast end of Cholame Valley, shows amplitudes more than double those at Cholame 2E (formerly Temblor II), approximately 1.5 km away. This is consistent with the contrasting geology at the two sites, however. Cholame 2E is on sandstone while Cholame 1E is in the middle of the valley, underlain by recent alluvium. In fact, the long period nature of the Cholame 1E record is shared by nearly all the stations located in Cholame Valley. Further analyses of these data will improve our understanding of site effects on velocity and displacement as well as acceleration.

STRONG-MOTION DATA FROM COALINGA AFTERSHOCKS

The 2 May 1983 Coalinga earthquake occurred in an area with few existing strong-motion instruments. Within a few days following the earthquake, however, various agencies had deployed a total of over 30 strong-motion recorders in the epicentral area. Significant results from these deployments are outlined here, in addition to the presentation of the principal results of CDMG/SMIP deployments.

Coalinga Aftershock of 9 May, 02:49 UTC

During the days following the Coalinga mainshock on 2 May there were many aftershocks, but none were large enough to trigger many of the strong-motion recorders deployed in the area. However, a 5.1 ML (BRK) aftershock at 02:49 UTC on 9 May, located near the mainshock epicenter, triggered nearly all of the recorders in place at that time. CDMG personnel, in a joint effort with personnel of U.C. Santa Cruz, had nine accelerographs deployed during this aftershock. The station locations are shown on Fig. 5 and are listed in Table 1. Accelerograms were recovered at five stations from this aftershock. The accelerograms are shown in Fig. 6. A peak acceleration of 35%g was obtained at the Skunk Hollow station; 28%g was recorded at the Palmer Ave. station; 13%g was recorded in the city of Coalinga (CHP station).

In addition to the records shown in Fig. 6, records were obtained by other agencies during the 9 May aftershock. Caltech recovered accelerograms from 5 stations in the area, recording a peak acceleration of 30%g near the Palmer Ave. station shown in Fig. 5 and 16%g in a residence in the city of Coalinga (Jennings, 1983). Records were recovered at six temporary USGS accelerograph stations (Maley et al., 1983) as well as at the permanent Pleasant Valley Pumping Plant which recorded the main shock. Maley et al. (1983) report a peak acceleration of over 50%g at a station about 4 km NW of the Palmer Ave. station in Fig. 5. Accelerograms were also recovered from 9 additional USGS temporary stations at which digital accelerographs had been deployed (Borcherdt et al., 1983). This total set of 26 accelerograms is an unprecedented suite of strong-motion data from the epicentral area of a moderate earthquake and will allow important studies of the earthquake source and radiation.

Increased Shaking Levels in Coalinga

During the week after the earthquake, CDMG deployed an accelerograph in the city of Coalinga, which overlies an alluvial valley, and one on Pliocene rock at the western edge of the valley. The Coalinga station (CHP) is at the California Highway Patrol building, which suffered significant damage during the mainshock. The valley-edge station (Baths) is at an abandoned mineral baths facility. Fig. 5 shows the relative locations of the stations and the local geology. These two instruments were left in place after other temporaries were withdrawn. Pairs of records were obtained from the six M > 5 aftershocks which occurred during the following three months, including the magnitude 5.9 ML (BRK) event on 22 July, 02:40 UTC. Comparisons of the four largest record pairs are shown in Fig. 7. These records indicate a significantly higher intensity of shaking in downtown Coalinga than at the rock site to the west. The highest acceleration obtained was 71%g during the 5.1 ML earthquake of 25 July; the corresponding acceleration at the valley-edge station was only 19%g. It is interesting that this event was recorded with higher acceleration than the 53%g of the largest aftershock (5.9 ML), though it had nearly the same epicenter. The media quoted Coalinga residents as stating that the 25 July event produced the strongest shaking since the mainshock; the records of Fig. 7 confirm that fact, at least in terms of ground acceleration. In addition, the implication is that the mainshock itself had an acceleration level of at least 71%g in Coalinga.

The four accelerogram pairs in Fig. 7 (events 4 through 7 in Fig. 5 and Table 2) all show amplitudes approximately three times larger at station CHP than at the valley-edge station. All six of the M > 5 aftershocks showed the higher accelerations at CHP (event 2 is shown in Fig. 6) except for event 3, which was recorded with very small amplitudes (near 5%g) at both stations. It is of interest that event 3 is also the only shallow event, and the only event of the entire sequence for which surface rupture was observed (Hart and McJunkin, 1983). Analyses of these data is just beginning and will require digitization and spectral analysis of the records. The CHP records, for example, seem to indicate a predominance of 6-8 Hz energy in the Coalinga ground shaking. The spectral analysis will allow the clarification of this response and study of its stability from earthquake to earthquake.

Comparison Between Analog and Digital Accelerographs

The ongoing Coalinga aftershocks provide the opportunity for field evaluation of new types of strong-motion instruments. The most popular analog accelerograph is the SMA-1 (Kinemetrics), which produces a record of the acceleration time-history on a 70-mm photographic film. During the last few years several digital recorders designed for deployment as strong-motion accelerographs have been introduced. Following the Coalinga earthquake, two types of digital accelerographs were co-located with analog recorders. The 25 July aftershock, which was recorded at CHP with a peak acceleration of 71%g, was actually recorded by three adjacent accelerographs: the analog SMA-1, a digital DSA-1 (Kinemetrics), and a digital DCA-333 (Terra Technology). The analog record and the strip-chart playbacks of the digital records are shown in Fig. 8.

Other comparative recordings were also obtained, but with lower amplitudes or fewer recorders. For example, the 22 July events of 02:40 and 03:43 UTC (events 5 and 6) were recorded by both the SMA-1 and DSA-1 at CHP (peak accelerations of 53 and 21%g). An additional deployment (in cooperation with Lawrence Livermore Laboratory) of a DSA-1 near the SMA-1 at Cantua Creek also yielded a pair of records, of about 30%g. Jennings (1983) reports on a co-location which resulted in a SMA-1/PDR-1 (Kinemetrics) record pair, of about 12%g. Digitization of these various analog records in conjunction with processing of the digital records will provide invaluable checks on instrument performance as well as certification of digitization procedures.

ACKNOWLEDGEMENTS

The CSMIP technical staff installed and maintained the stations of the Parkfield array and is responsible for the high level of accelerograph performance. Gene Guyer maintained the digital accelerographs deployed for evaluation and assisted in the instrument comparison effort. K. McNally of UC Santa Cruz worked with R. McJunkin and other CDMG personnel in the deployment of accelerographs at the temporary CDMG/UC Santa Cruz sensitive seismographic stations. J. Scheimer of Lawrence Livermore National Laboratory cooperated in the analog/digital accelerograph co-location experiment at the CDMG Cantua Creek station. B. Tucker reviewed the manuscript and made suggestions materially improving its structure.

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TABLE 1

Coalinga Temporary Accelerograph Stations

Station No.	Station Name	N.Lat. W.Long.	Dates of Occupancy	Instr. Ser.No.	
36T01	Avenal	35.983 120.146	5/3 - 5/19	5036*	CAVL
46T01	Huron - CDF Garage	36.205 120.103	5/3 - 5/6	2522	
46T02	Huron - CDF Grounds	36.205 120.103	5/3 - 5/19	5065*	CFIR
46T03	Coalinga - Sulphur Baths	36.121 120.397	5/6 - N.A.	2592	
46T04	Coalinga - CHP	36.151 120.353	5/6 - N.A.	4813	
46T05	Anticline Ridge - Palmer Ave.	36.210 120.305	5/3 - 5/19	1860	CPAL
46T06	Oilfields - Skunk Hollow	36.282 120.305	5/3 - 5/19	1700	CINT
45T07	Harris Ranch Hdqtrs	36.343 120.216	5/6 - 5/19	2522	
46T08	Five Points - Airway Farms	36.446 120.119	5/3 - 5/19	4571*	C5PT
46T09	Cantua - Gravel Quarry	36.414 120.393	5/3 - 5/19	4574*	CANT

* Instruments deployed in cooperation with UC Santa Cruz. Four-letter code is the name of the sensitive station co-located with the accelerograph, as described in Sherburne et al. (1983).

TABLE 2

Coalinga Mainshock and Aftershock Parameters#

Event	Date	Time(UTC)	N.Lat.	W.Long.	Depth (km)	Magnitude ML (BRK)
1	2 May	23:42:38	36.233	120.293	10.5	6.7
2	9 May	02:49:12	36.231	120.312	12.5	5.1
3	11 June	03:09:52	36.242	120.457	3.4	5.0
4	9 July	07:40:51	36.237	120.409	9.5	5.2
5	22 July	02:39:54	36.228	120.416	9.2	5.9
6	22 July	03:43:01	36.209	120.413	9.5	5.0
7	25 July	22:31:39	36.216	120.406	9.5	5.1

Hypocenter and origin times as determined by the USGS network (Cockerham, personal communication, 1983).

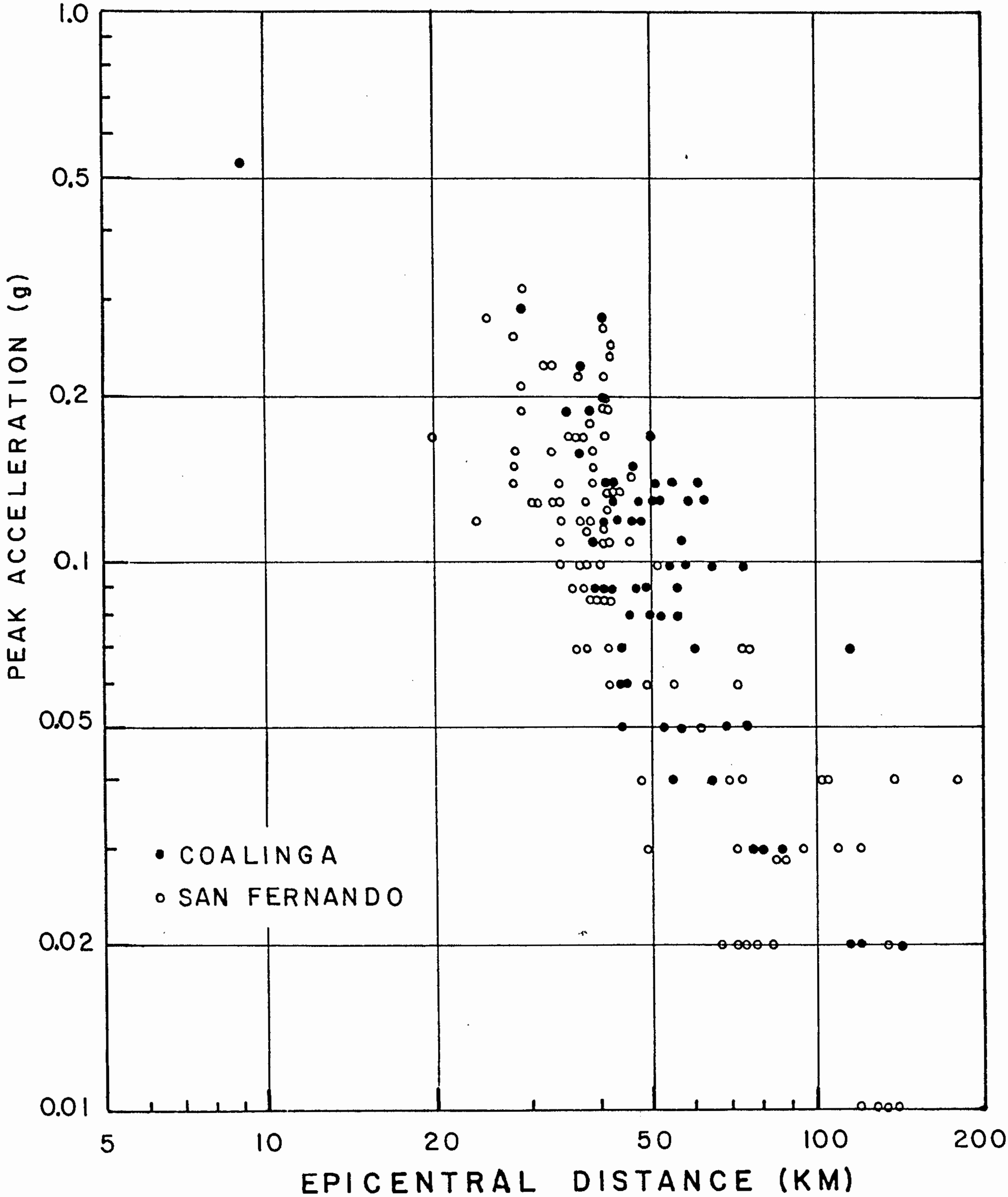


Figure 1. Peak acceleration data from the 2 May 1983 Coalinga earthquake with data from the 1971 San Fernando earthquake included for reference. This plot is preliminary and does not include the Coalinga data from the distant (> 75 km) stations mentioned by Maley et al. (1983).

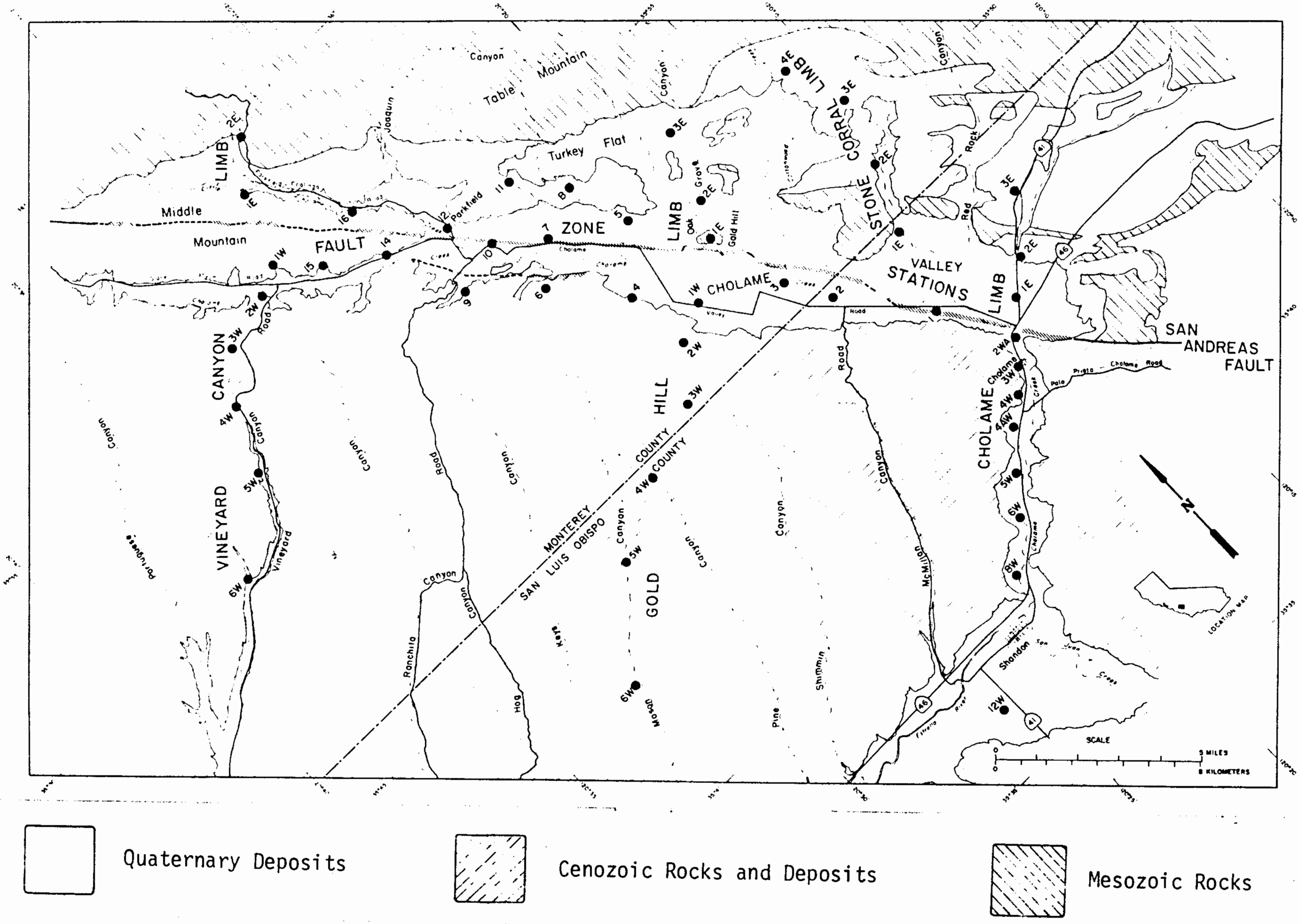


Figure 2. CDMG Parkfield strong-motion array and generalized geology. The array configuration forms four limbs (Cholame, Stone Corral, Gold Hill, Vineyard Canyon) oriented perpendicular to the San Andreas and a central zone of stations paralleling the fault. Fault trace (diagrammatically shown) is of ground rupture in the 1966 Parkfield earthquake. (From McJunkin and Shakal, 1983).

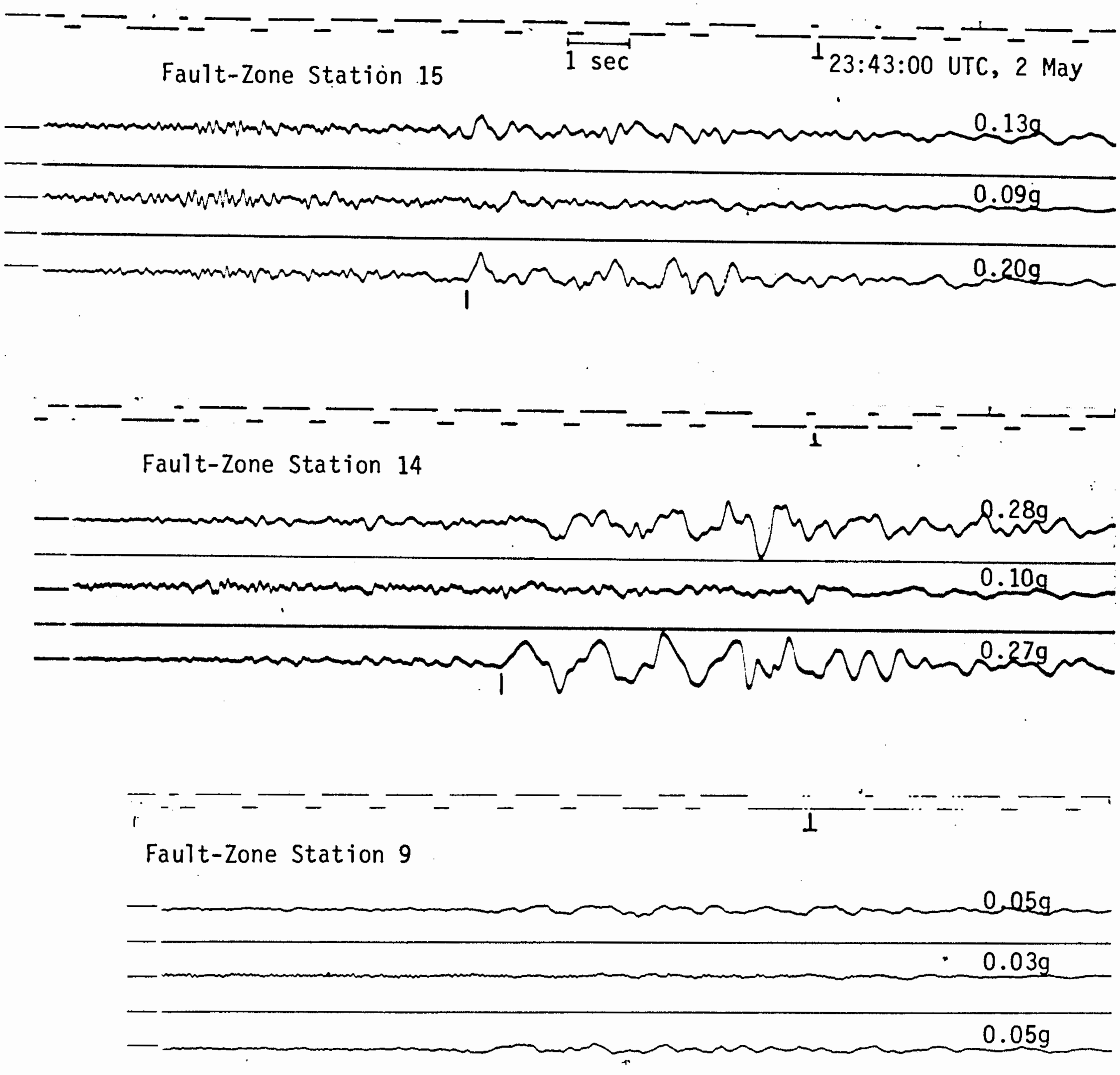


Figure 3. Accelerograms recorded at three neighboring stations in the Parkfield array during the 2 May 1983 Coalinga earthquake. The accelerograms are aligned relative to the WWVB time code on the records. The components are East, Up, and North, respectively.

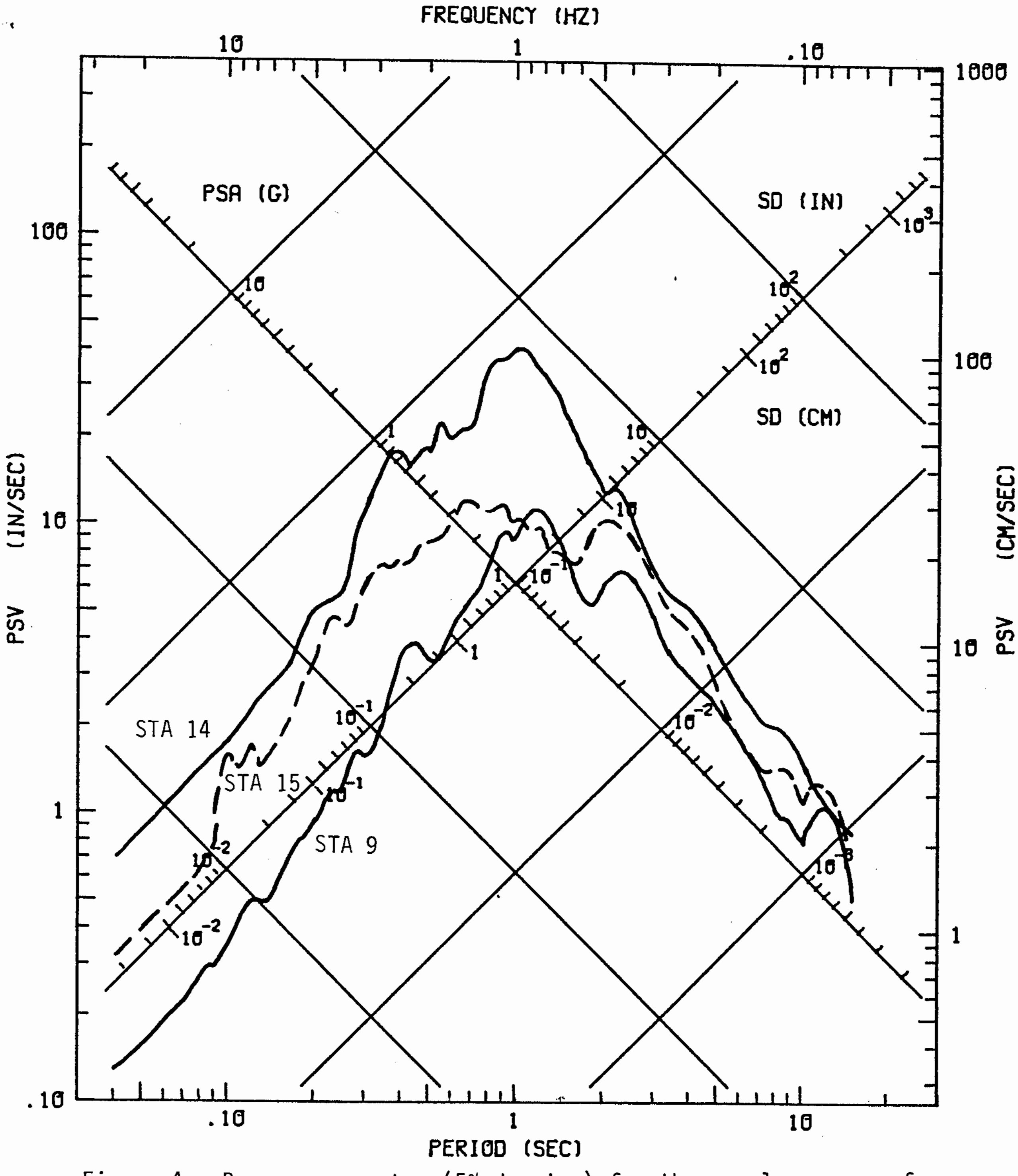
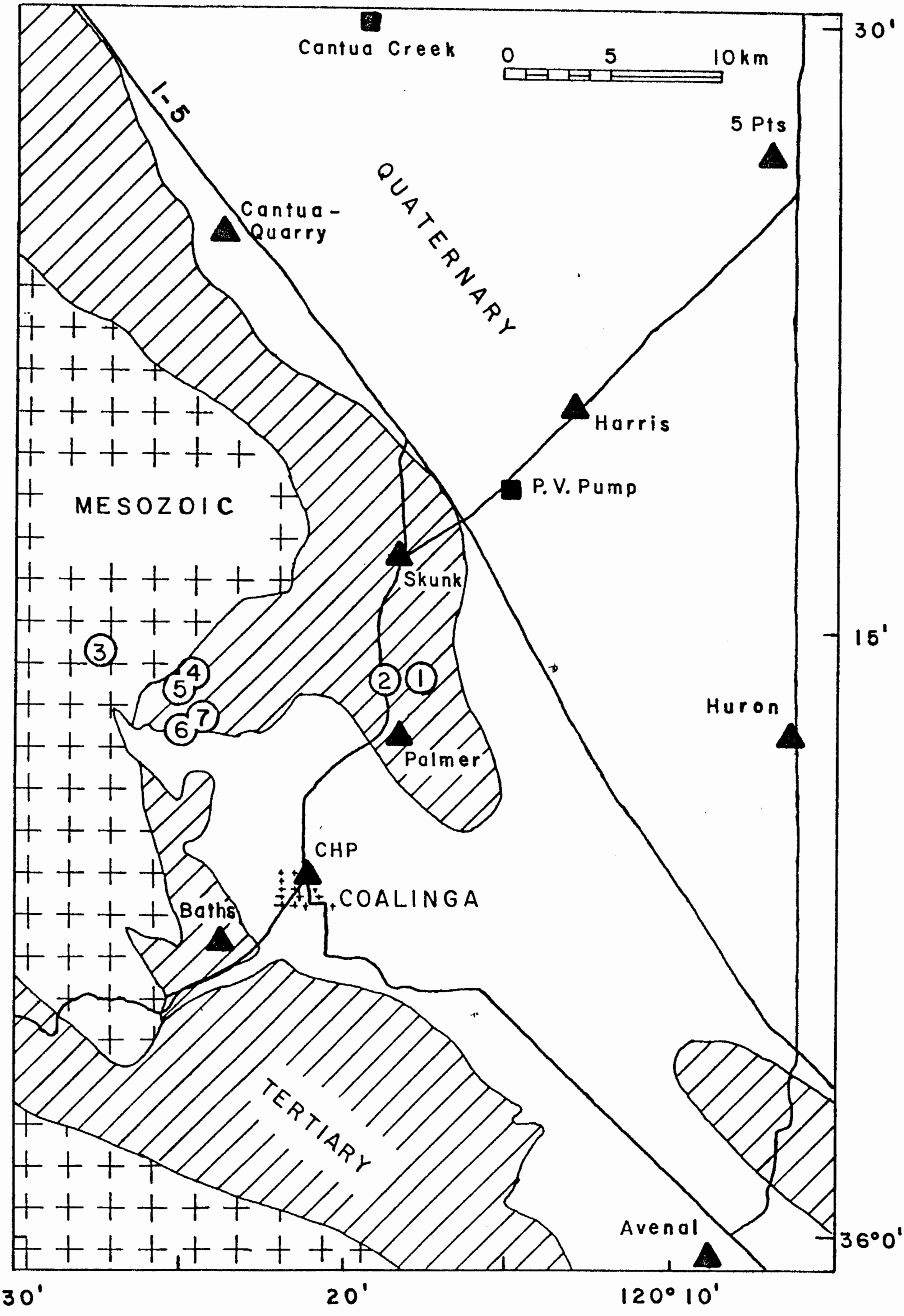


Figure 4. Response spectra (5% damping) for the accelerograms of Fig. 3, East component (chan 1).

Figure 5 (Overleaf). Accelerograph stations, epicenter locations and local geology in the vicinity of Coalinga (geology simplified from Jennings and Strand, 1958). Temporary accelerograph stations (triangles) were deployed to augment the two permanent stations (squares) at Cantua Creek (CDMG) and Pleasant Valley pump station (USGS) which recorded the mainshock. The epicenters (circles) are numbered from 1 (mainshock) through 7, and are identified in Table 2.



Cantua Creek
0 5 10km
30'
I-5
5 Pts
QUATERNARY
Cantua-Quarry
Harris
P. V. Pump
MESOZOIC
Skunk
15'
3
4
5
2
1
7
6
Huron
Palmer
CHP
COALINGA
Baths
TERTIARY
Avenal
36°0'
30'
20'
120° 10'

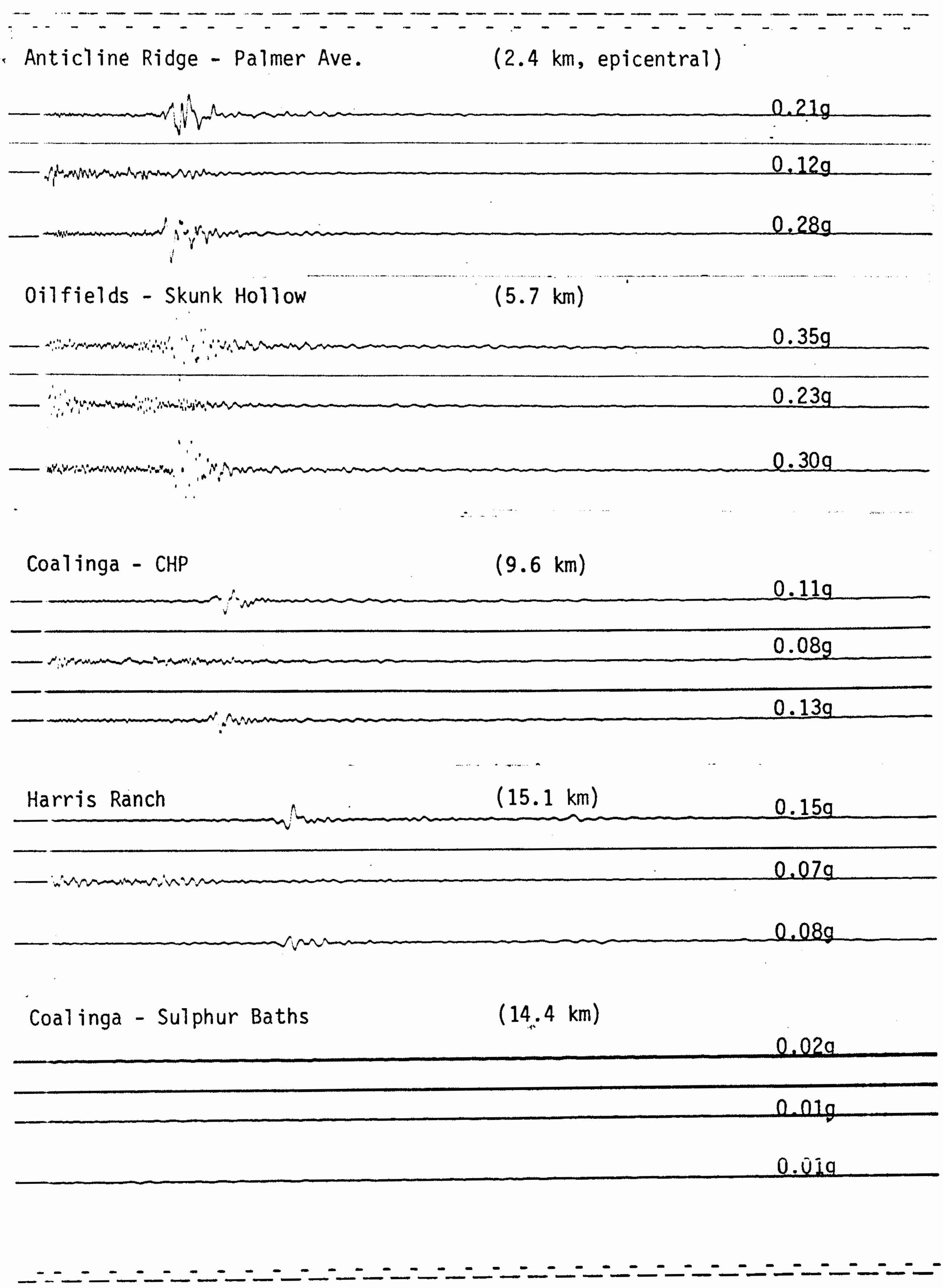


Figure 6. Accelerograms recovered from the 9 May 5.1 M_L aftershock (event 2 of Fig. 5 and Table 2). Components are East, Up and North, respectively.

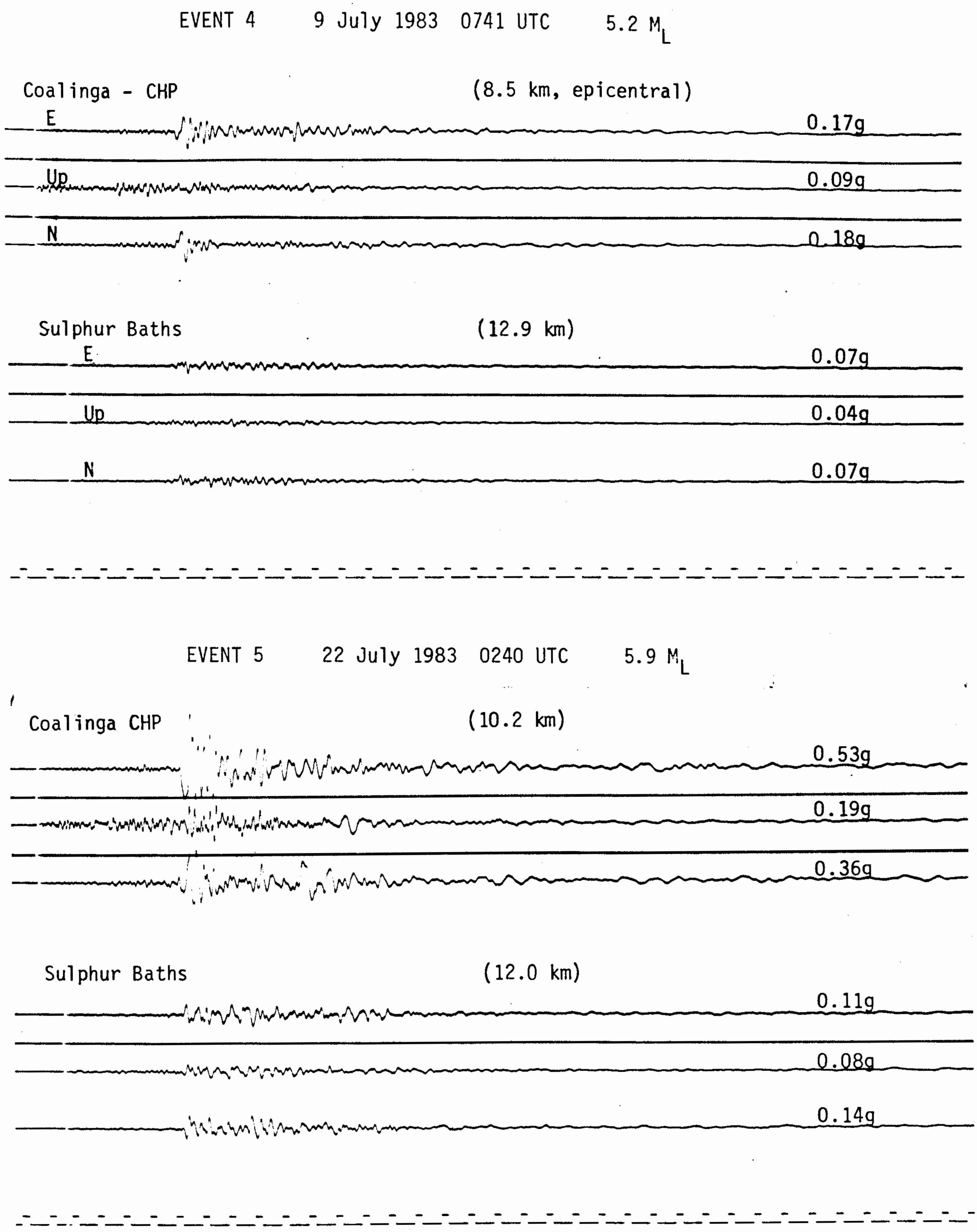
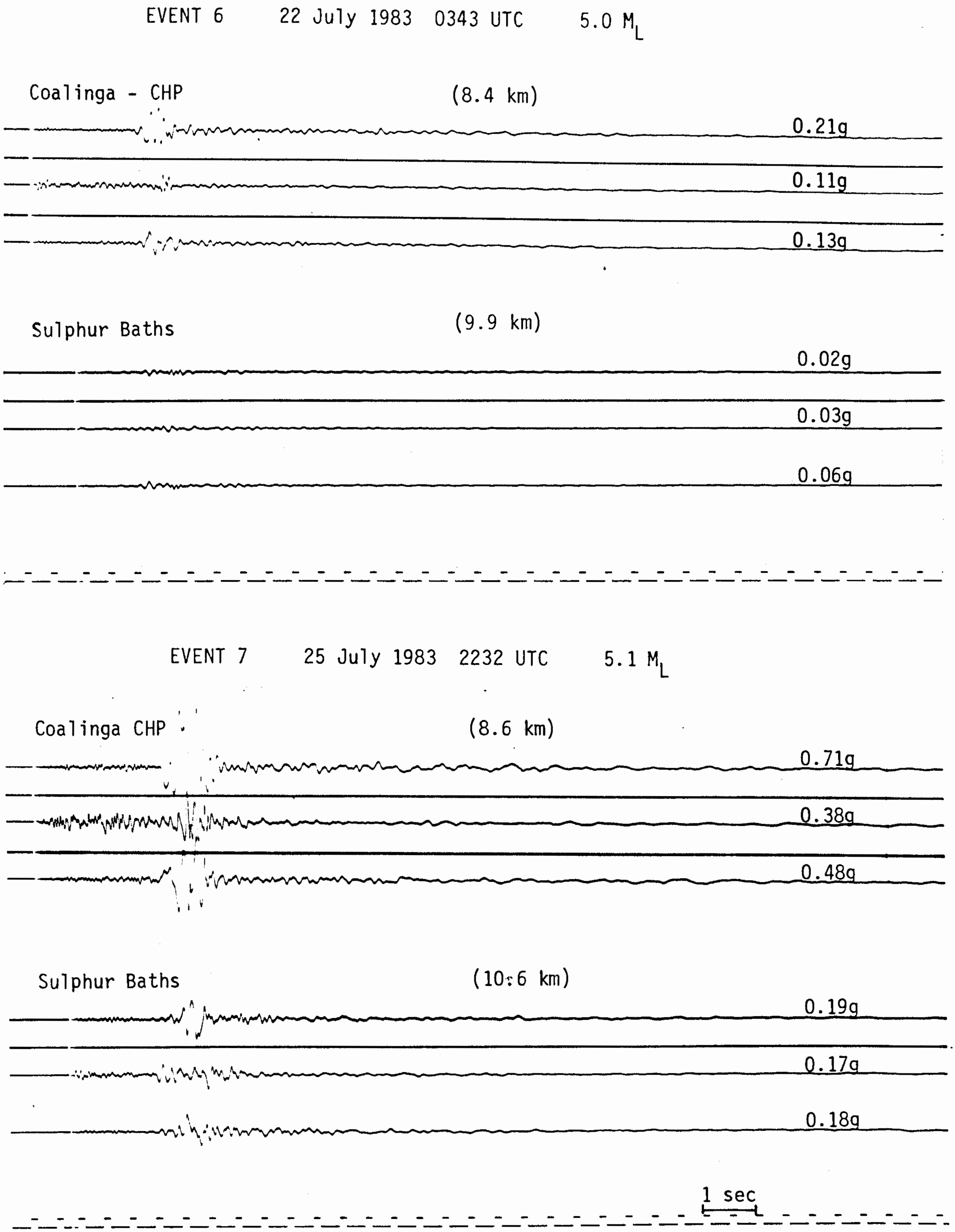


Figure 7. Coalinga aftershock accelerogr
and at a station on Pliocene rock at the



ams recorded at a station in Coalinga (CHP)
edge of the valley (Sulphur Baths).

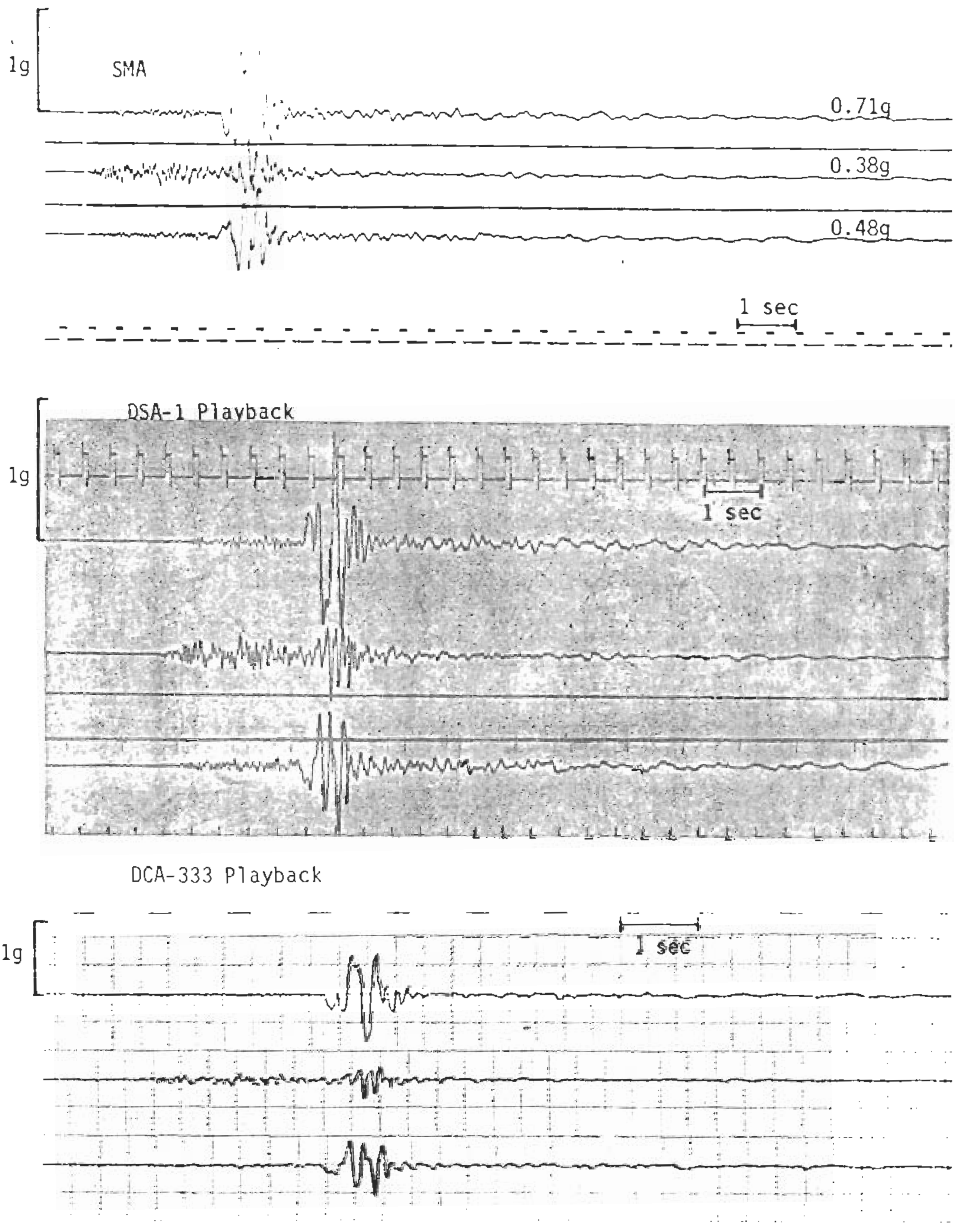


Figure 8. Accelerograms from analog (SMA) and digital (DSA-1, DCA-333) accelerographs co-located at Coalinga-CHP during the 25 July 1983 aftershock. Channel polarities and scaling on the digital playbacks differ from the SMA.