Parkfield Strong-Motion Array

Monterey and San Luis Obispo Counties

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INTRODUCTION

A strong-motion array was recently deployed by the California Strong-Motion Instrumentation Program (CSMIP) in the vicinity of Parkfield, in central California. This array is a network of earthquake strong-motion recorders, or accelerographs, which begin recording when a certain level of ground shaking occurs. It is part of the on-going deployment efforts of CSMIP, a program within the Division of Mines and Geology (DMG).

The purpose of the Parkfield array is to measure ground shaking close to an earthquake. There are several outstanding problems in strong ground motion, a few of which include: (1) the attenuation, or decay, of ground motion with distance in the vicinity of an earthquake; (2) understanding and predicting local variations in ground motion (amplifications or reductions) arising from the rupture process or the local geologic conditions; and (3) fundamental parameters of earthquake faulting such as the rupture velocity and time-history of slip have yet to be directly measured.

Historically, the San Fernando earthquake of 1971 underscored the need for ground motion measurements. It indicated, first, that the response of buildings to strong shaking was not well understood, and second, that the level and characteristics of strong ground shaking near an earthquake were highly variable and difficult to predict. These aspects were a major impetus for the initiation of CSMIP in the early 1970s (described by Wootton, 1980). The installation of the Parkfield array, among other special fault-zone and structural instrumentations, is a response to the need for increased data.

The Parkfield-Cholame area has experienced moderate earthquakes which have occurred every 15-30 years since, at least, 1885 (McEvilly and others, 1967). The last moderate earthquake in the area was the 1966 5.5 M_L (McEvilly and others, 1967) event from which the closest strong-motion record (80m) ever obtained from earthquake ground rupture was recovered. Because of the nature of the local seismicity, this area was first cited as a prime candidate for a strong-motion array by D. Boore, A. Lindh, and W. Joyner of the U.S. Geological Survey (USGS) in an informal proposal in 1977. This article describes the strong-motion array which was eventually deployed near Parkfield by CSMIP.

Photo 1. Northwest aerial view of Cholame Valley. The most active branch of the San Andreas fault (Brown and Vedder, 1967) can be traced along the base of the Cholame Hills (left) where it crosses the valley (poorly defined) and continues northwestward along the opposite side toward Parkfield in the extreme distance. Cholame Creek and its tributaries meander across the valley floor. Cholame Valley Road extends through vertical center of photo.

GEOLOGIC SETTING

The Cholame Valley occupies the southern portion of the Coast Ranges geomorphic province. Within this portion of the Coast Ranges province, the San Andreas fault zone forms the boundary between the Salinian block to the west and the southern Diablo Range to the east. Geologic structure is very complex east of the fault where mostly Mesozoic sedimentary and metamorphic rocks are exposed. West of the fault, less structurally deformed sedimentary deposits of middle to late Cenozoic age cover older and more structurally complex Mesozoic terraine of the Salinian block.

San Andreas Fault

The most notable geologic element of the Cholame Valley-Parkfield region is the San Andreas fault which transects the area from southeast to northwest (Figure 1). The San Andreas fault in this area (cover photo) represents a zone of deformation one to two miles wide (Dickinson, 1966a) and defines the eastern boundary of the Cholame Hills adjacent to Cholame Valley (Photo 1).

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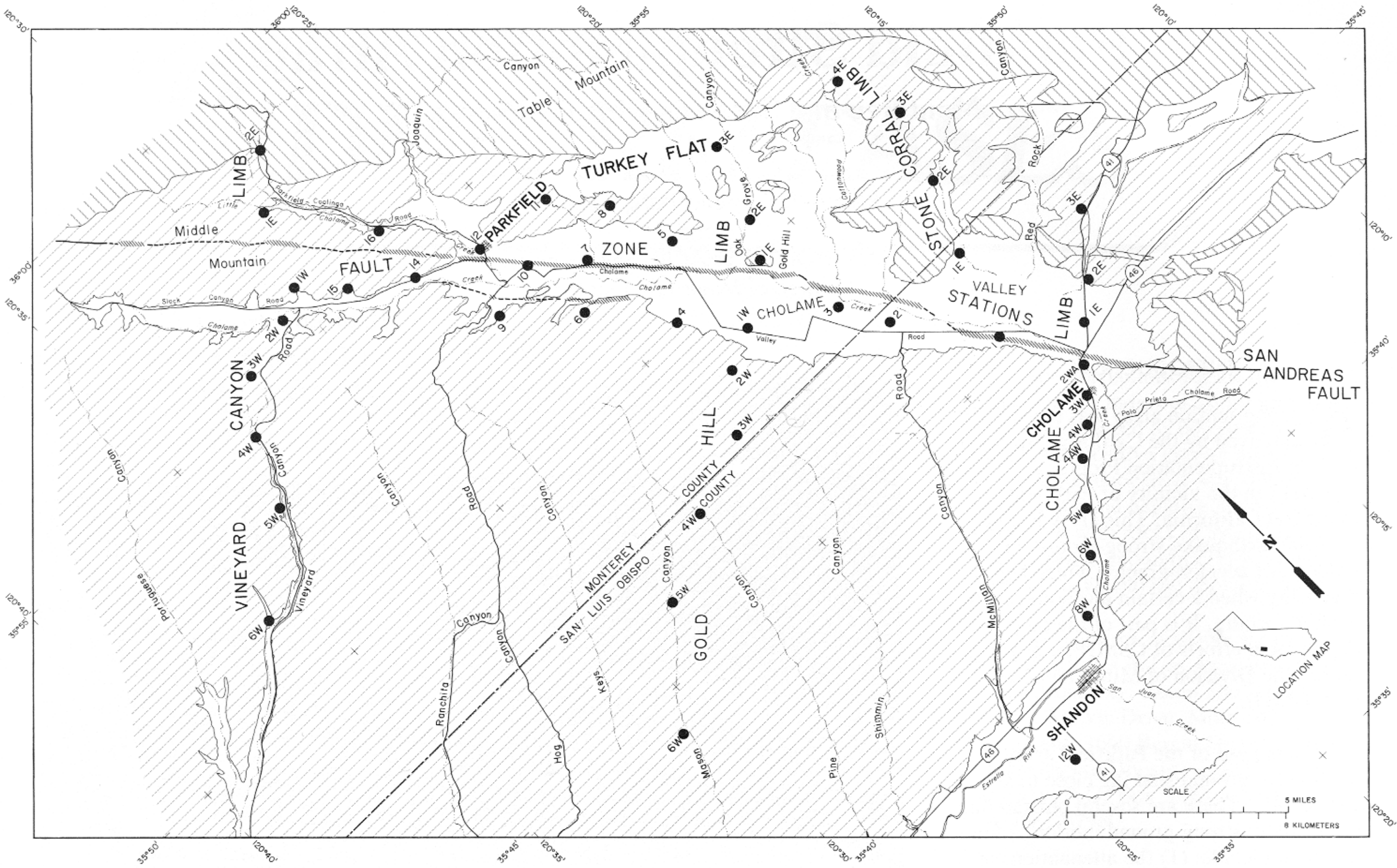

Quaternary Deposits
Unconsolidated stream and floodplain deposits of sand, silt, and gravel and terrace deposits of similar composition. Also includes landslide debris.

Cenozoic Rocks and Deposits
Poorly to well indurated predominantly clastic rocks including sandstone, siltstone, and conglomerate of several formations. Most rocks are marine except for the Plio-Pleistocene Paso Robles Formation which underlies the greatest amount of terrain southwest of the San Andreas fault.

Mesozoic Rocks
Moderately to well indurated marine rocks including predominantly sandstone, siltone, and shale with, in addition, pillow lavas and chert abundant in Franciscan assemblages. Also includes tabular and lenticular bodies of serpentine and intrusive rock.

Figure 1. Map of CDMG Parkfield strong-motion array and generalized geology along the San Andreas fault in central California. The array configuration forms four limbs (Cholame, Stone Corral, Gold Hill, Vineyard Canyon) oriented perpendicular to the San Andreas fault, and a central zone of stations paralleling the fault. The only fault trace plotted is San Andreas ground rupture from the 1966 Parkfield earthquake (Brown and Vedder, 1967; Brown, 1970) and unbroken fault segments at the north and south ends of the rupture zone. All other faults, including those that represent major lithologic boundaries between Cenozoic and Mesozoic rocks, are omitted. Hachured portions of the San Andreas fault, a diagrammatic pattern that exaggerates fracture-zone width, represent 1966 en echelon ground fractures with measureable right slip. Dashed segments indicate discontinuous or absent ground rupture. *Geologic data are modified after Jennings (1958), Dickinson (1966a, b). Hanna and others (1972), and Dibblee (1973).*

The complex forces that generate motion on the San Andreas fault and its associated faults are related to the plate tectonic development of western North America (Atwater, 1970). In a more localized sense, motion of the San Andreas fault is the major influence for geologic development of the region and accounts for compressional faulting and folding of rocks in the area, uplift of the Cholame Hills (Photo 2), southern Diablo Range and surrounding areas, and downdropping of the Cholame Valley. In the vicinity of the Parkfield array the San Andreas fault is defined by scarps, depressions, sidehill benches, linear compression ridges, linear stream courses and troughs, and springs and seeps.

South of Cholame Valley, the San Andreas fault zone narrows and is better defined (Photo 3) than to the north in the Parkfield array area. The fault is best defined at the southwestern margin of Cholame Valley and the northern end of the Parkfield array in the vicinity of Middle Mountain. Differences in surface expression probably arise because as the fault enters Cholame Valley from the south it separates into several branches (cover photo). In addition, during major earthquakes associated with the fault, such as last occurred January 9, 1857 (Trask, 1864; Agnew and Sieh, 1978), any of the branches may accommodate sympathetic displacement. Several branches sharing part of the total offset tend to produce less spectacular fault-line topographic expression. In fact, during the 1966 Park-

Photo 2. South-southwest aerial view of the Cholame Hills and west side of Cholame Valley. Two major period of uplift of the Cholame Hills are identified from topographically-defined erosional surfaces (arrows). These surfaces represent periods when no uplift was occurring and erosion was leveling the land. Subsequent uplift raised portions of these older surfaces now preserved above the present valley floor. The San Andreas fault crosses through the center of view. Note that the far side of the fault has been uplifted a few meters. In addition, the fault truncates alluvial fans that, when formed, had a continuous unbroken surface from the hills to the valley floor. Cholame Valley Road parallels the fault in near view and meets McMillan Canyon Road at right-center.

field earthquake, sympathetic movement occurred on a nearly parallel fault one mile west of the main break and generated approximately seven miles of discontinuous ground rupture (Brown and Vedder, 1967; Figure 1). During this event, approximately 23.5 miles of almost continuous ground rupture occurred (Figure 1). The major zone of ground rupture was along a previously mapped fault trace which is interpreted as the active branch of the San Andreas system in the Cholame Valley (Brown and Vedder, 1967).

Near the southern end of the Cholame Valley, the San Andreas fault makes a transition from a 'locked' zone to the south, where significant stress is relieved only during major events (Sieh, 1978), to a zone characterized by moderate-sized earthquakes and measurable ongoing slippage. The slippage begins just south of Cholame Valley and increases to the north (Bacon and others, 1975; Bennett, 1979). Similar slippage is also observed farther to the north beyond Middle Mountain (Jennings, 1975). It is interpreted that transition of the fault from a locked to a slipping state causes Cholame Creek to breach the Cholame Hills at its present location (Figure 1). In this setting, Cholame Creek drains southwest from Cholame Valley to the Estrella River through a localized rift (extensional) valley.

At the north end of the Parkfield array, the active branch of the San Andreas fault forms a northwest-southeast trending compression ridge called Middle Mountain. The fault is poorly defined on most of Middle Mountain because of large-scale active landsliding (Photo 4). However, most published maps of the area show the fault as a well defined through-going structure on the mountain. Massive landslides on Middle Mountain are mentioned by Brown and Vedder (1967) and Hanna and others (1972), and have been identified in current mapping by John Sims (personal communication) of the USGS.

West of the San Andreas fault zone, very few faults are identified that offset late Cenozoic cover sediments. In contrast, to the east many faults are mapped in the southern Diablo Range (Jennings, 1958; Dickinson, 1966a,b; Hanna and others, 1972; Dibblee, 1973). There are several reasons for the greater fault exposure to the east: (1) rock from a deeper level is exposed by uplift and erosion of the southern Diablo Range, (2) rocks in this area represent older terrane, and (3) the occurrence of numerous rock types allows better fault identification.

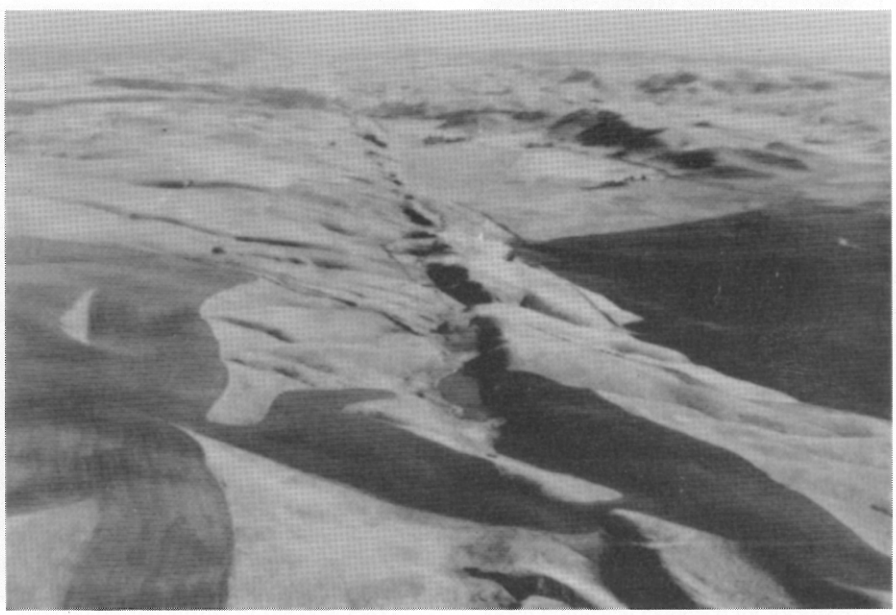

Photo 3. South-southwest aerial view of the San Andreas fault zone a few miles south of Cholame Valley. Linear valleys and troughs, shutter ridges, beheaded and off-set drainages, and depressions and sag ponds define the prominent fault trace.

Photo 4. East-southeast aerial view of the western crest of Middle Mountain showing active landsliding. Note that the inclination of landslide head wall scarps is nearly vertical indicating recent failures. The active trace of the San Andreas fault is on the far side of the mountain just beyond the ridge. The terrace in the distance (center right) is Turkey Flat.

The age of fault activity east of the San Andreas fault is probably, in most cases, uncertain. Many of the faults east of the San Andreas are not continuous and can be associated with late Mesozoic emplacement of serpentinite. More continuous faults that are parallel or subparallel to the San Andreas fault may have experienced Holocene activity.

Rock Types

The oldest and most complex rock types in the Parkfield-Cholame Valley area underlie the southern Diablo Range east of the San Andreas fault. Structurally, the lower-most rocks within this sequence are Franciscan melange which includes serpentinite breccia, greenstone, argillite, graywacke, chert, and minor blueschist and tectonic slivers of granitic rock that crop out in proximity to the San Andreas fault. Most Franciscan rocks are slightly metamorphosed, well-indurated, and pervasively sheared. Serpentinite breccia occurs as pods and fault-bounded lenticular masses that, in most places, are oriented parallel to shear planes of melange matrix. Age of local Franciscan rock is uncertain; however, Dickinson (1966b, p. 462) suggests that it is Jurassic-Cretaceous (?). A similar age for Franciscan rock from other areas of the Coast Ranges is reported by Bailey and others (1964) and Blake and Jones (1974). Granitic rock east of the San Andreas fault is primarily hornblende gabbro that underlies Gold Hill and is exposed in this general vicinity. Using potassium-argon techniques, the gabbro has been radiometrically dated as 143 million years old (Hay, 1963).

Cretaceous Panoche Group rocks, after Payne (1962), structurally overlie Franciscan melange in this area. The boundary is identified as a folded thrust fault by Dickinson (1964, 1966b). Local Panoche Group rocks are predominantly dark, silty mudstones and arkosic sandstones with local interbeds of conglomerate. These comprise approximately 10,000 feet of section and are deformed by pre-Eocene compression and uplift (Dickinson, 1966a).

Tertiary marine deposits rest unconformably upon Panoche Group rocks and can be subdivided into several formations. Dickinson (1966a, b) subdivided the local Tertiary sequences into Acebedo and Point of Rocks Sandstone (Eocene), Temblor Formation (middle Miocene), Monterey Formation (upper Miocene), and Etchegion Formation (Pliocene). Further, he established that each time-grouping of rock is separated by an unconformity.

Late Cenozoic (Pliocene ?), poorly consolidated continental deposits named Varian gravels unconformably overlie the older Tertiary and Mesozoic rocks east of the San Andreas fault. These deposits are primarily composed of granitic and metamorphic detritus with admixtures of sand, silt, and clay. Clasts of Franciscan

Photo 5. Active landslide formed in thin veneer of Paso Robles Formation over Tertiary marine rocks just north of Vineyard Canyon. The head scarp of the landslide (left center) is approximately six feet high. Note other back-facing scarps and grabens. This is part of a much larger landslide that underlies approximately 0.5 square mile.

Photo 6. Typical strong-motion station in the Parkfield array (Cholame limb 6W). The fiberglass enclosure housing the accelerograph is 3.5 feet high and mounted on a partially embedded concrete pad (4 foot square). Solar cell on south-facing sloped enclosure roof charges batteries which power the accelerograph.

rock are absent in Varian gravel indicating that the source region was to the west across the present trace of the San Andreas fault.

The geology west of the San Andreas fault is less complex than to the east because fewer and younger rock units are exposed that have undergone less deformation. The oldest rocks exposed within this area are upper Miocene to lower Pliocene (?) friable, moderately to well consolidated marine sandstone of the Santa Margarita Formation and lower Pliocene diatomaceous mudstone of the Pancho Rico Formation. Subaerial extent of these formations, both of which are estimated to include approximately 1200 feet of section, is restricted to areas west of Cholame Valley (Hanna and others, 1972).

Most of the surface of the Cholame Hills from Cholame Valley westward to the Salinas Valley is underlain by Pliocene-Pleistocene gravels of the Paso Robles Formation. This deposit is a medium to coarse grained, poorly to moderately consolidated sandy gravel that dips gently westward and unconformably overlies the older Pliocene and Miocene formations. Paso Robles Formation was derived from erosion of the Santa Lucia and La Panza Ranges to the southwest of the area and the Temblor and Diablo Ranges to the northwest (Hanna and others, 1972). The unit has been used to establish post-depositional slip of the San Andreas fault. Based on a heavy mineral study, Galehouse (1967) suggests that approximately 25 miles of right-lateral displacement has occurred after the gravels were deposited during Plio-Pleistocene time.

A more complete section of rocks west of the San Andreas fault is described from oil well data for wells drilled northwest of Shandon. Data from these well logs indicate several formations in addition to the Pancho Rico and Santa Margarita formations below the Paso Robles gravel. These subsurface units include upper Pliocene terrestrial gravel of the Morales Formation (?), an unnamed Pliocene sequence of sandstone and siltstone, middle Miocene argillaceous and siliceous shale of the Monterey Formation, and lower Miocene marine sandstone and terrestrial red beds of the Vaqueros Formation. In addition, many of the wells bottom in granitic rock several thousand feet below the surface (Hanna and others, 1972). The level at which granitic rock is encountered in some of these wells varies by hundreds of feet. This indicates that the old erosional surface was one of exaggerated relief or that the disconformity has been broken and differentially uplifted by post-depositional faulting, or possibly a combination of these factors.

Quaternary alluvium consisting of silt, sand, clay, and gravel underlies most low areas along streams and valleys. Several generations of alluvial deposits are present throughout the region. Along the San Andreas fault, scarps and compression ridges, including Middle Mountain (Dickinson, 1966a), are in places created from deformed alluvial deposits. In more hilly portions of the area, older alluvium is commonly uplifted and now being eroded. These examples testify to the dynamics of the region which is in a continual state of deformation.

Quaternary landslides are common throughout the region (Photo 5). All rock types, especially Franciscan melange and Paso Robles Formation, are susceptible to failure if surface slopes are adequate. Massive landslides, in places underlying one-to-two square miles, occur along the south side of Cholame Creek southwest of Cholame Valley and on Middle Mountain (Photo 4). Most of these landslides are interpreted to be active. These areas were avoided during sitting of the new Parkfield array stations. Station 2E of the Vineyard Canyon limb is the only station recognized to be underlain by a landslide (Figure 1).

ARRAY CONFIGURATION

The configuration of the Parkfield strong-motion array was designed to meet several measurement objectives. A major goal is to provide near-fault ground motion data complete enough that details of the rupture propagation process may be resolved. For example, one basic parameter of earthquake faulting is the velocity with which the rupture propagates. This has never been directly measured, although it is quite important both in understanding and predicting strong motion. One of the earliest estimates of rupture velocity (2.2 km/second) was obtained for the 1966 Parkfield earthquake by Eaton (1967) who used the timed record of an instrument at Gold Hill that failed at the onset of strong shaking.

Near-fault data is also needed to address even more complex issues. Recent developments in the theory of faulting (Aki, 1979) indicate that the ends of an earthquake fault may simply be zones of particularly high strength, or barriers, which the propagating rupture was unable to fracture. Along the fault, zones of slightly lower-strength materials rupture during the earthquake, locally radiating short-duration high-frequency and high-amplitude bursts of energy. Recent earthquakes, particularly the well-recorded Imperial Valley earthquake of 1979 (Hartzell and Helmberger, 1980), have provided empirical evidence for localized zones of high stress-drop or large dislocation. The significance for strong-motion and earthquake-resistant design is that near-fault structures can be subjected to short bursts of quite high ground acceleration, even for moderate-size earthquakes.

Another measurement objective of the Parkfield array is to simply increase the set of strong-motion data recorded at close-in distances to a fault. The existing data set used to develop attenuation models for predicting ground motion is quite limited for distances less than about 10 km.

The final configuration of the array deployed at Parkfield is shown in Figure 1, and the station locations are listed in Table 1. The station locations reflect a compromise between idealized geometries and the practical aspects of field access and site conditions. As shown in Figure 1, the array is comprised of a central near-fault pattern of stations paralleling the fault (named fault zone stations), complemented by three lines of stations, or limbs, named the Cholame, Gold Hill, and Vineyard Canyon limbs extending perpendicularly from the fault. A subset of stations in the Cholame limb (2WA, 5W, 8W, and 12W) comprises the original Parkfield array in place at the time of the 1966 earthquake. The three principal limbs extend to the west primarily because the underlying Paso Robles Formation in this region is more uniform and structurally less complex than the geologic structure to the east. In addition to these three limbs, the shorter Stone Corral limb extends to the east. This set of stations extends from the alluvial valley to exposed bedrock (sandstone) at station Stone Corral 4E.

In total, the array extends over an area approximately 30 km by 10 km. Array stations were sited to be accessible for service from normally passable roads. A typical installation is shown in Photos 6 and 7. The instrument housing is a low fiberglass hut, and both the instrument and the housing are anchored to a concrete pad. This construction was developed to be environmentally resistant and appears to have little, if any, effect on incoming ground motion. Most sites in the array are powered by a solar cell (Photo 6), and have a radio and antenna for reception of a reference time signal (WWVB).

TABLE 1.
PARKFIELD ARRAY ACCELEROGRAPH STATIONS[1]

Station Number	Station Name[2]	N. Lat.	W. Long.	Site Geology[3]
		Cholame Limb		
36450	3E	35.770	120.247	Sandstone
36230	2E (Temblor II)	35.752	120.264	Sandstone
36452	1E	35.742	120.276	Alluvium, Sandstone (?)
36228	2WA (Sta. 2)	35.733	120.290	Alluvium, Sandstone
36410	3W	35.726	120.296	Alluvium, Sandstone
36411	4W	35.717	120.305	Alluvium, Sandstone
36412	4AW	35.707	120.316	Alluvium, Sandstone
36227	5W (Sta. 5)	35.697	120.328	Alluvium, Sandstone
36451	6W	35.684	120.341	Alluvium, Sandstone
36226	8W (Sta. 8)	35.671	120.359	Alluvium, Sandstone
36229	12W (Sta. 12)	35.639	120.404	Alluvium, Sandstone
		Stone Corral Limb		
36438	4E	35.855	120.281	Sandstone
36437	3E	35.833	120.270	Alluvium, Sandstone
36422	2E	35.801	120.282	Sandstone
36419	1E	35.788	120.294	Alluvium, Serpentine
		Gold Hill Limb		
36439	3E	35.870	120.334	Alluvium, Sandstone
36421	2E	35.843	120.348	Alluvium, Sandstone
36137	1E (Gold Hill)	35.831	120.353	Soil, Gabbro
36415	1W	35.828	120.378	Alluvium, Sandstone (?)
36416	2W	35.812	120.391	Alluvium, Sandstone
36420	3W	35.798	120.411	Sandstone
36433	4W	35.785	120.444	Soil, Sandstone
36434	5W	35.770	120.477	Soil, Sandstone
36432	6W	35.739	120.507	Alluvium, Sandstone
		Vineyard Canyon Limb		
36177	2E (Parkfield Grade)	35.973	120.467	Franciscan (Qls)
36455	1E	35.956	120.483	Alluvium, Sandstone
36448	1W	35.934	120.497	Alluvium, Sandstone
36447	2W	35.927	120.509	Alluvium, Sandstone
36176	3W (Vineyard Canyon)	35.922	120.534	Sandstone
36446	4W	35.905	120.550	Alluvium, Sandstone
36440	5W	35.885	120.565	Alluvium, Sandstone
36441	6W	35.861	120.600	Alluvium, Sandstone
		Fault-Zone Stations		
36407	1	35.752	120.307	Alluvium
36413	2	35.787	120.334	Alluvium
36408	3	35.803	120.344	Alluvium
36414	4	35.837	120.396	Soil, Sandstone
—	5	In Deployment		Alluvium, Sandstone
36454	6	35.837	120.396	Soil, Sandstone
36431	7	35.872	120.404	Soil, Sandstone
36449	8	35.878	120.381	Alluvium, Sandstone
36443	9	35.879	120.445	Alluvium, Sandstone
36444	10	35.884	120.422	Sandstone
36453	11	35.896	120.565	Alluvium, Sandstone
36138	12 (Parkfield Fire Sta.)	35.899	120.433	Alluvium, Sandstone (?)
36456	14	35.908	120.458	Alluvium, Sandstone
36445	15	35.921	120.481	Alluvium, Sandstone
36457	16	35.927	120.456	Alluvium, Sandstone

[1] All instruments are deployed in low fiberglass housings on a pad as shown in photos 6 and 7 with the following exceptions: Cholame limb stations 2E, 2WA, 5W, and 12W, Vineyard Canyon 2E and 4W, and Fault-Zone 12, which are aluminum instrument shelters 7 feet high on a 4-to-8-foot square concrete pad; Cholame 8W is in a small one-story building.

[2] Station names in parentheses are previously used station names.

[3] Field studies are continuing and will refine site-specific descriptions of geology.

SUMMARY

The Parkfield strong-motion array deployed near the San Andreas fault in central California will record ground motion from earthquakes which occur in this region. This array, representing a joint effort of CSMIP and USGS, will provide valuable data for understanding near-fault strong ground motion. These data are vital to the improvement of design codes for constructing earthquake-resistant buildings and other facilities. This will contribute to the safety and well being of the people of California by minimizing loss of life and damage to property from earthquakes.

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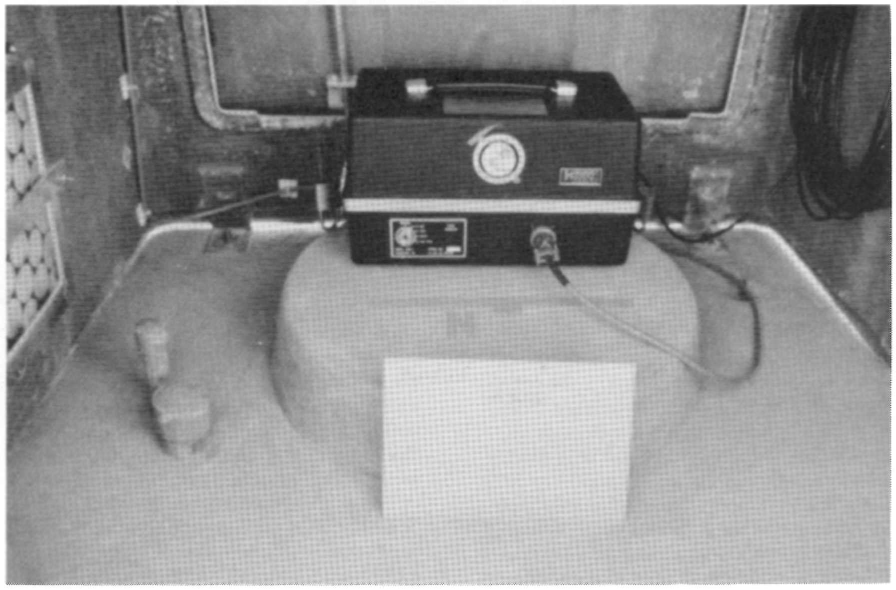

Photo 7. Interior view of typical installation (Cholame limb 6W). Accelerograph is bolted to the raised reinforced-concrete pedestal. Weather stripping, silicon caulk, and filtered air vents protect the enclosure from severe weather, dust, insects, and rodents. The line and letter on pedestal near the instrument provide the reference orientation for accelerograph.

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