U.S. Department of the Interior
Geological Survey

Text and references accompanying

MAP SHOWING RECENTLY ACTIVE BREAKS ALONG THE SAN ANDREAS FAULT BETWEEN POINT DELGADA AND BOLINAS BAY, CALIFORNIA

in two sheets

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1970

prepared in cooperation with the Department of Housing and Urban Development

PURPOSE OF THIS STRIP MAP

This strip map is one of a series of maps showing recently active fault breaks along the San Andreas and other active faults in California. It is designed to inform persons who are concerned with land use near the fault of the location of those fault breaks that have moved recently. The lines on the map are lines of rupture and creep that can be identified by field evidence and that clearly affect the present surface of the land. Map users should keep in mind that these lines are intended primarily as guides to help locate the fault; the mapped lines are not necessarily shown with the precision demanded by some engineering or land utilization needs.

THE SAN ANDREAS FAULT AND FAULT ZONE

The San Andreas fault zone is a major flaw or break in the earth's crust. It extends from Point Arena in northern California southeastward to the Gulf of California in northern Mexico, a distance of more than 600 miles. Either the main fault zone or a branch that is closely related to it intersects the California coast line at Point Delgada, 74 miles northwest of Point Arena.

Movement within the fault zone has been distributed along many nearly parallel faults that differ both in age and in amount of total relative displacement. This complex zone of movement--active over a span of millions of years and marked by cumulative displacements measurable in hundreds of miles--varies in width from a few hundred feet to several miles. It is termed the <u>San Andreas fault zone</u> or <u>rift zone</u>, as distinguished from the <u>San Andreas fault</u>, which consists of the traces of the most recent (in many places, historic) movement (Noble, 1926, p. 416-417).

Historic movement on the San Andreas fault is predominantly horizontal, with the earth's crust southwest of the fault relatively displaced toward the northwest. This type of movement is termed right-lateral strike slip, or for brevity, right slip, because to an observer standing on one side of the fault, the land on the opposite side is displaced to his right. The right-slip character of the modern San Andreas fault is well established by observations of the surface faulting that has accompanied numerous earthquakes, by the observed deformation of triangulation nets that cross the fault, by observed changes in the distances (as measured by highly precise methods) between points on opposite sides of the fault, and by linear features--both manmade and natural--that are displaced in a right-slip sense where they cross the fault. Vertical movements along the modern San Andreas fault are also known, but historically these have been small and localized as compared to right slip.

LOCATION OF THE FAULT BREAKS

The fault breaks were located chiefly by study of 1:12,000-scale (1 inch = 1000 feet) aerial photographs flown on June 24, 1966 and were transferred to topographic maps by visual inspection and by optical projection. Some of them were also mapped during field verification of the aerial photo interpretation.

The location and nature of some of the fault breaks are also based on field studies made by G. K. Gilbert and F. Matthes after the 1906 earthquake. Gilbert's description of the area between Bolinas Bay and Tomales Bay and Matthes' descriptions of the area between Fort Ross and Point Arena, as well as the Shelter Cove area at Point Delgada, are contained in the comprehensive report on this earthquake (Lawson and others, 1908). Matthes' plane table map of the area southeast of Fort Ross (Lawson and others, 1908, Folio Map No. 3), generalized to meet the scale requirements of this strip map, is the source for the main fault break shown between Fort Ross Creek and the sea cliff northwest of Timber Gulch.

A $3\frac{1}{2}$-mile segment of the fault from Mill Creek to Kolmer Gulch near Fort Ross was mapped by Higgins (1961, figure 2). Although Higgins' data were not used as a source for this strip map, his location of the most recent fault breaks agrees well with that shown here.

Map users should consider a line on this map not as a precisely located fault, but as a guide for field location of fault-break features. Where such features are large enough or distinctive enough to be shown by the contours of the topographic map, the fault break is accurately located to within 100 feet--that is, the mapped break is no more than 100 feet from its correct position. Where these features are more subtle or where topographic maps show comparatively little detail, the mapped line may be as much as 200 feet from the actual fault break, and in areas of featureless topography, the accuracy of location may be even less. On this strip map, dense redwood forest and somewhat generalized topographic maps (especially parts of the Plantation and Stewarts Point $7\frac{1}{2}$-minute quadrangles), make accurate location more difficult than elsewhere along the fault.

Special effort was made in the field to accurately locate the main fault breaks. Some subsidiary fault breaks may be unrecognized, and even where these are recognized and shown they may be less accurately mapped than the main fault breaks. Consulting geologists, engineers, and others using these strip maps will need to make more detailed ground surveys to confirm and refine the position of these fault lines in relation to structures and land boundaries.

LAND USE SIGNIFICANCE OF LOCATING RECENT FAULT BREAKS

The most recent breaks along the San Andreas fault should be recognized as hazardous by builders, planners, engineers, public works agencies, utility companies, homeowners, landowners, developers, highway departments, school boards, civil defense officials--in short, anyone connected with present structures, land use, or planned construction on or near these most recent fault breaks.

Sudden movement along the San Andreas fault in 1857 in southern California and again in 1906 in northern California produced disastrous earthquakes. The horizontal displacement across the fault was as much as 16 feet near Manchester on the northern California coast in 1906, and displacements accompanying the 1857 earthquake in southern California were probably comparable or greater.

In 1906, the entire area shown in this strip map was affected, and surface faulting was essentially continuous along the onshore segments of the fault from Point Delgada to San Juan Bautista, about 95 miles southeast of Bolinas Bay. Evidence of faulting of the sea floor along this trend is sparse, chiefly because of a lack of detailed knowledge of the offshore parts of the San Andreas fault, but it is very likely that the sea floor was also disrupted by the San Andreas fault in 1906 and that surface rupture was continuous from Point Delgada to San Juan Bautista--a distance of nearly 300 miles.

Some fault movement in the San Andreas fault system is by gradual tectonic creep rather than by such catastrophic events as the 1906 and 1857 earthquakes. Measurable tectonic creep on the San Andreas fault was first noted at a winery near Hollister (Steinbrugge and Zacher, 1960; Tocher, 1960). It has subsequently been described on the Hayward fault zone (Radbruch and others, 1966), on the Calaveras fault (Rogers and Nason, 1968; Radbruch and Rogers, 1969), and as an apparently continuous process affecting a 60-mile-long segment of the San Andreas fault zone from Cholame north to the vicinity of San Juan Bautista (Brown and Wallace, 1968). In some of these areas such manmade structures as bridges, buildings, roads, and railroad tracks have been dislocated or otherwise damaged by tectonic creep along the faults.

Well-defined topographic lineaments mark the most recent fault breaks, for the entire length of the San Andreas fault. They are about as evident in areas where movement is by tectonic creep as in those where it accompanies catastrophic earthquakes. Nearly all of the lineaments are the product of repeated episodes of fault movement localized on long-established planes of weakness.

The implication of these observations is that the line of most recent ground breakage has a good chance of breaking again during another major earthquake or another creep episode on the fault. Substantiation of this line of reasoning was afforded by the 1966 Parkfield-Cholame earthquake (Brown and others, 1967) and by the 1968 Borrego Mountain earthquake (Allen and others, 1968), both of which resulted in extensive surface faulting along previously mapped recent fault breaks. Additional evidence of recurrence is found in Wallace's (1968) studies of the San Andreas fault in the Carrizo Plain. There displacements during the last 10,000 to 20,000 years have occurred again and again on the same break of the San Andreas fault, most recently in 1857.

At present, no one can accurately predict when movement on these faults will recur, which segments will move next, or whether movement will be catastrophic or by tectonic creep, but it is certain that some will move again in the future. Movement will not necessarily be confined to mapped faults and fractures, and indeed surface fracturing could develop anywhere within the fault zone, and even on branching or otherwise related faults beyond the fault zone.

FIELD RECOGNITION OF MOST RECENT FAULTING

The most recent fault breaks can be recognized by topographic discordances, by anomalous drainage patterns, by offset manmade structures, or by historic records of fault displacements at the earth's surface. Such evidence not only defines where the fault breaks are, but it also demonstrates that movement has been so recent that it has not yet been obliterated by other geologic or biologic processes. Once a lineament is recognized as a recent break, its position can be further documented by other criteria that mark it as a fault but do not necessarily prove recent movement. Such criteria include such features as saddles, spring lines, vegetation changes, or cliff exposures of fault planes. Both kinds of evidence were used in preparing this map and others in this series.

The most common fault-break features on this map are scarps, trenches, notches, ridges, offset streams, sag ponds and sag depressions, and lines of springs or trees. These features have developed in complex and different ways, but they are all controlled by repeated movements along the fault, or by erosion along its trace. Horizontal and vertical displacements of a few inches or a few feet accumulate from successive displacements accompanied by earthquakes, from slow tectonic creep between earthquakes, or from a combination of both. Whether they are caused by creep or by sudden movements, the displacements produce scarps and other topographic features that delineate the fault lines shown on the map. The brief notes along the fault trace on the map indicate especially clear examples of these features; the evidence is not limited to the spots indicated, but is present to some degree along the entire length of the mapped fault breaks. As the edges of opposing fault blocks slide by one another, topographic irregularities are juxtaposed to form sags, sag ponds, or low ridges. Notches and trenches along the fault line commonly reflect increased erosion of the less resistant crushed and broken rock of the fault zone, or they may be down-dropped slivers lying between parallel breaks in the fault zone.

Recently active fault breaks are recognized chiefly by geomorphic features that are short lived. The degree to which such features are preserved depends on such complexly interrelated variables as rate and periodicity of fault movement, bedrock type, and climate. Geomorphic evidence of faulting is as pronounced on the ground in the area of this strip map as anywhere north of the Transverse Ranges, although this is not evident either from published topographic maps or from aerial photographs. The statement on an earlier strip map (Brown, 1970) that geomorphic evidence of faulting is best preserved under arid conditions does not appear to be supported by comparisons of the part of the San Andreas fault between Pt. Delgada and Bolinas Bay with those in more arid parts of California; however, unrecognized variations in recurrence rates of faulting and in the amount and times of most recent fault movements may also affect the degree of preservation.

Despite their general continuity, fault-break features may be obliterated by a number of geologic and nongeologic processes. Recent erosion and deposition by streams, erosion and deposition by the sea, landsliding, and soil creep have erased the record of recent faulting at many places on this strip map. Fault-break features may also be obliterated by works of man. In some parts of the San Francisco Peninsula and also in the developed area at Point Delgada on this map, much of the evidence of the 1906 break has been destroyed by grading and other construction activities accompanying development for residential or industrial sites, and in some parts of this strip map logging operations have destroyed or confused the evidence of recent faulting. But most important, only where fault movement has been relatively recent are fault features as well preserved and nearly continuous as they are along the San Andreas fault zone.

The absence of identifiable evidence of recent displacement in places along the fault zone does not necessarily imply stability. Even where surface evidence of recent breaks is missing, it is clear that the San Andreas fault is a throughgoing structural feature with a long history of systematic fault movements.

SPECIAL FEATURES OF THE SEGMENT FROM POINT DELGADA TO BOLINAS BAY

This segment of the San Andreas fault zone is about 175 miles long, but only about half of it--about 85 miles--lies on land where it can be studied by conventional geologic methods. From north to south the accessible on-land parts of the fault and their lengths are: Point Delgada, about 3 miles; Point Arena to Fort Ross, about 45 miles; Bodega Head, 5 miles; and from the mouth of Tomales Bay to the mouth of Bolinas Bay, about 30 miles.

Intervening reaches of the fault, as well as those south of Bolinas Bay and north of Point Delgada, are covered by the sea. The fault can be confidently extrapolated across most of these areas of ocean cover, for most are short with consistent linear fault trends, and with similar rock types on opposite shores.

Some uncertainty surrounds the nature of the offshore extension of the San Andreas fault north of Point Delgada, and some investigators, noting that Point Delgada is well east of the extrapolated main trend of the fault further south, have questioned whether the Point Delgada fault break is the main San Andreas fault or a subsidiary branch. The nature of the northern offshore extension of the San Andreas is a complex and interesting question, and one that is now under investigation, but it is neither directly related nor essential to the purpose of this strip map.

All of the on-land portion of the San Andreas fault between Bolinas Bay and Point Delgada moved during the 1906 earthquake. The movement was sudden and chiefly horizontal; the block seaward of the fault shifted relatively to the northwest. The amount of this movement was evident in offset roads and fences, and offsets of 15 feet are well documented in several places. A reported 20-foot dislocation of a road at the head of Tomales Bay, often cited as the maximum slip accompanying the 1906 earthquake, was considered excessive by G. K. Gilbert (Lawson and others, 1908, p. 71). He ascribed some of this to nontectonic horizontal shifting of the road bed on soft marshy sediment. If this interpretation of Gilbert's statements is correct, the maximum known offset on the fault occurs near Manchester and is about 16 feet (Lawson and others, 1908, p. 59-60); however, offsets that are nearly as great ($15\frac{1}{2}$ feet) are reported from the area between Bolinas Bay and Tomales Bay (Lawson and others, 1908, p. 70-71). Measured offsets following the 1906 earthquake were somewhat less in other parts of the area and the average offset is probably about 13 feet.

Vertical movement of as much as a foot occurred at least locally during the faulting that caused the 1906 earthquake. Gilbert (in Lawson and others, 1908, p. 70, 72, 81-87) describes evidence of such movement in the vicinity of Bolinas where the block west of the fault was evidently raised about a foot relative to the block east of the fault. Evidence of similar vertical movement elsewhere was sought unsuccessfully in the course of the field investigations that followed the 1906 earthquake. Any vertical component of faulting in 1906 thus was relatively small as compared to the horizontal component. The geologic record suggests that earlier movement on the fault was similarly dominated by the horizontal component, although some vertical slip is likely.

So far as can be determined from the evidence, all the historic movement on this part of the San Andreas was abrupt and accompanied the 1906 earthquake. Postearthquake fences and roads are not systematically deformed where they cross the fault, nor has any other evidence of post-1906 fault displacement been found. The possibility that some tectonic creep may have accompanied or immediately followed the 1906 aftershock sequence cannot be eliminated, but little if any creep postdated the earthquake investigations, for some offset features measured in those investigations are still accessible and show the same amount of offset as in 1906-7, the years of the initial investigation.

Landslide deposits are common in all parts of the area north of Fort Ross. Some of those outlined are active now, but many appear not to be, for they support an undisturbed redwood forest that is about 60 to 80 years old and they are cut by the recent breaks along the San Andreas fault. In some places the fault breaks crossing landslide areas are so deep and so well defined that they must represent at least several episodes of fault movement comparable to that which occurred in 1906. This relationship provides added evidence for the recent age of the fault breaks, because landslide deposits are short-lived components of the landscape.

The landslide deposits are also significant because all of them, even those that are not currently active, are potentially unstable if they are disturbed. The kinds of disturbances that can result in instability may be caused by man, by a large earthquake, by unusually heavy rainfall, or by combinations of these and other processes. The proximity of many of the landslide deposits to the mapped recent breaks suggests that the triggering of landslides by large earthquakes may be a major problem in the area of this strip map.

Because of their importance, those landslides that could be recognized, either on air photos or in the field, were delineated by reconnaissance methods. Those shown on the map represent only a few of the larger areas of landslide deposits. Detailed mapping would add many more similar landslide deposits and would greatly refine the boundaries of those that are shown. The important point is that landslide deposits are widespread and numerous at Point Delgada and between Point Arena and Fort Ross, and that because of their proximity to the San Andreas fault they are a serious problem with respect to the future development of this area.

Although, as is implied by the preceding discussion, most parts of this strip map are remarkably similar and consistent in their field relations, minor differences are apparent. These differences are treated below for each fault segment.

Point Delgada

At Point Delgada (strip A) several surface fault breaks accompanied the 1906 earthquake, and most of them are still recognizable. The most obvious one trends about N. 15° W. from the mouth of Deadmans Gulch at the east side of Shelter Cove to the beach just north of the mouth of Horse Mountain Creek. Parts of this break are now obscured by access roads and grading for homesites, but it can be located easily on predevelopment aerial photography and from data in the report by Lawson and others (1908) concerning the 1906 earthquake.

The main break is exposed in at least 3 places near the top of the Kaluna Cliff. Landslides there have stripped the cover from the upper cliff face and exposed about 150 feet of the uppermost part of the fault. At these localities the fault cuts highly brecciated sandstone and siltstone that are mantled with locally derived fan or wash deposits consisting chiefly of clasts of the brecciated sediment. Faulting is most evident in the juxtaposition of rocks exhibiting different degrees of weathering or in the contrast between brecciated sedimentary rock and reworked surficial deposits. At the two best exposures, one about 700 and the other 1,500 feet north of BM 1471 in sec. 4, T. 5 S., R. 1 E., the fault dips northeast about 60° and consists of a single well-defined plane that branches upward into 2 subsidiary and subparallel breaks at a point about 50 feet below the top of the cliff. The other exposure, about 3,000 feet northwest of BM 1471, also exhibits a northeast-dipping (55-60°) fault zone with at least 2 parallel breaks about 40 feet apart.

Uncertainty concerning the relation of the Point Delgada faulting to that south of Point Arena arises chiefly from the change in fault trend that is required if these two breaks are on the same line. The index map accompanying this report illustrates the problem. Several interpretations of the Point Delgada faulting are possible:

1. The Point Delgada fault is the main San Andreas fault and is an extension of the fault mapped from Point Arena to Fort Ross.

2. The Point Delgada fault is a branch of the main San Andreas fault. The main fault continues northward along the trend of the segment between Point Arena and Fort Ross. At Point Delgada the main fault would therefore be about 30 miles offshore.

3. The Point Delgada fault is related to the main San Andreas fault but is not connected to it.

Although this problem is not resolved, most of the evidence favors the first interpretation, that a continuous line of faulting extended offshore northward from Point Arena to Shelter Cove. The evidence may be summarized as follows:

1. High and relatively uniform seismic intensities were noted all along the coast from Point Arena to Shelter Cove during the 1906 earthquake. This was interpreted (Lawson and others, 1908, p. 336) as evidence that the fault was continuous along this stretch of coast, and that it lay only a short distance offshore and approximately parallel to the coastline.

2. Sea-floor topography south of Point Delgada (Nason, 1968), and reflection profiling of the sea floor north of Point Arena (Curray and Nason, 1967) disclose evidence of faulting along a line connecting Point Arena and Point Delgada, but no evidence of a continuous line of faulting farther west along the offshore extrapolation of the Fort Ross-Point Arena segment.

3. Geomorphic features associated with the faulting at Point Delgada are as prominent and as well defined as those on the main fault break further south. This suggests that most or all of the fault displacement and energy were localized on the Point Delgada fault breaks.

Point Arena to Fort Ross

The line of fault breaks can be traced with only a few interruptions from the mouth of Alder Creek north of Manchester to a point on the sea cliffs $1\frac{1}{2}$ miles southeast of Fort Ross, a distance of about 45 miles. As was first noted during investigation of the 1906 earthquake (Lawson and others, 1908, p. 26), the average trend of the fault becomes more easterly toward the north. Near Fort Ross it is about N. 40° W. but near Point Arena the average trend is about N. 33° W. If the main fault north of Alder Creek continues toward the break at Shelter Cove (average trend N. 15° W.), this trend change is even more pronounced toward the north.

The line of faulting between Alder Creek and Fort Ross is defined by a series of relatively short overlapping or branching fault segments. Most of these are 2 to 3 miles long and none of them is much longer than about $3\frac{1}{2}$ miles. The segments are essentially parallel and in most places they overlap each other by a third of a segment length or less. Adjacent segments are typically no more than a few hundred feet apart but exceptions are numerous.

Despite the relative shortness of the fault segments and their branching and overlapping nature, they constitute an essentially straight and well-defined line of faulting. The chief exceptions to this linearity occur where short ($\frac{1}{2}$ to 1 mile) fault segments define an en echelon pattern. Such patterns are evident on the strip map for about a mile along Brush Creek (northern part of strip B) and north of Garcia Creek (or Garcia River on some parts of this strip map); for about 4 miles northwest of the drainage divide between the Garcia River and the Gualala River basins (southern part of strip 3), and for about 2 miles between the Wheatfield Fork of the Gualala River and Stewarts Point Creek (central part of strip C). In each of these areas consistent trends and patterns of the individual fault breaks are considered to be evidence that past failures have occurred in an en echelon pattern in which individual breaks are oriented a few degrees clockwise from the average trend of the fault zone.

The mapped fault breaks between Alder Creek and Fort Ross are evident on aerial photos chiefly as natural openings or lineaments in second-growth redwood forest. On the ground these openings are found to be natural meadows, swamps, marshes, or ponds that occupy depressions caused by fault movements. Nearly all of the openings are clearly due to ponding or to near-surface ground water in such abundance that the growth of timber is inhibited. Some of the openings contain no trees, stumps, or fallen timber and probably have been natural clearings for a long time prior to the 1906 earthquake. Other openings, however, contain standing dead timber suggesting that changes in drainage and ground water levels are relatively recent and possibly date from the 1906 earthquake. Although drowning by the 1906 faulting is likely, it is difficult to prove. Much of the area was logged at about the same time as the earthquake, and some of the logging operations no doubt also blocked drainages along the trace of the San Andreas fault.

Where the fault trace in timbered areas is well drained, it is generally difficult to delineate on the aerial photos. Locally the underlying topography is discernible in the vegetation pattern, but in many places the dense second-growth forest effectively masks faultline topographic expression with vertical relief of as much as 50 feet. The forest growth also inhibits the recognition on aerial photos of offsets in small streams, as well as other relatively subtle topographic or drainage features that help delineate the fault. Because of these limitations much of the wooded area between Fort Ross and Point Arena was mapped on the ground. For these areas, the main fault breaks are as accurately located and as well defined by ground detail as those that can be clearly seen on aerial photos; however subsidiary and branch faults are more difficult to find on the ground, and some of these may have gone unrecognized.

The continuity of the fault breaks is clearly evident from the strip map despite the large number of individual overlapping or branching fault segments. Recent landslides locally have obliterated the evidence of faulting but most of the recent breaks traverse landslide areas without significant interruption. Along the Garcia River, in secs. 32 and 33, T. 13 N., R. 16 W. and in sec. 4, T. 12 N., R. 16 W., evidence of faulting has been destroyed by erosion and deposition in the channel and adjoining flood plain of the river. Similarly, evidence of recent faulting is ill defined or destroyed along flood plains adjoining the Little North Fork Gualala River, the North Fork Gualala River, and the South Fork Gualala River from a point about half a mile northwest of Elk Prairie (northern part of strip C) to a point about 2 miles southeast of it. Both the Garcia River area and the area near the forks of the Gualala River exhibit abundant evidence of seasonal flooding or erosion, and these interruptions in the recent fault breaks are clearly due to processes acting at the surface of the earth. At very shallow depth the fault must be continuous.

Numerous small ponds and depressions lie along or near the crest of the ridge between the Gualala River and the Pacific Ocean and about a half mile southwest of the traces of the San Andreas fault shown on this map. Some of the ponds and depressions are shown on the map but many are not. These features are especially numerous along the ridge crest between the mouth of the Gualala River at Gualala (shown only on index map, but near northern end of strip C) and the confluence of the South Fork and Wheatfield Fork of the Gualala River (center of strip C), but similar smaller depressions are found nearly as far south as Fort Ross. Higgins (1961, p. 57) thought that the ponds and depressions were evidence of small dislocations along faults that are part of, or closely related to, the San Andreas.

Although their proximity to the San Andreas fault and, in some places, their position at the crest of ridges would seem to favor this view, evidence gathered during this investigation favors an alternative interpretation: that the depressions are due to massive landslides that in places have affected the entire summit area of the ridge. A full discussion of the origin of these features is beyond the scope of this report, but some of the evidence that favors a landslide origin is summarized here:

1. Although most of the ponds and depressions are elongate, they exhibit diverse orientations. Depressions along the San Andreas and along other active faults are commonly oriented within a few degrees of the fault trend.

2. Many of the ponds and depressions are bordered by arcuate topographic highs that are suggestive of eroded and modified landslide scars. Some of these clearly are on preexisting drainages that have been blocked by tilting.

3. Where lithology surrounding a basin is exposed it is uniform. Although depressions are found in different lithologic units, at none of the depressions studied was more than one lithologic unit recognized and none of the depressions showed evidence of faulting in the surrounding rocks.

4. The map position of the depressions is such that no single fault would pass through all of them; several faults with somewhat different trends would be required, and no topographic lineaments with these trends are evident.

5. Small local landslides are numerous and currently active in the slopes northeast of and below the depressions, and they are especially evident along the steep slopes bordering the South Fork of the Gualala River.

Bodega Head

The fault trace shown on the strip map near the town of Bodega Bay is located on the basis of descriptions in the report of the State Earthquake Investigation Commission (Lawson and others, 1908, p. 65) and from information supplied by local residents. Elsewhere in the Bodega Head area data are inadequate to accurately map recent breaks along the San Andreas fault, and even most of the 1906 fault effects have been concealed or destroyed by windblown sand and silt or by recent sedimentation.

Additional, somewhat ambiguous, evidence of the fault trend is found in 2 gravity profiles and 1 aeromagnetic profile discussed by Mabey and Peterson (in Schlocker and others, 1963, p. 11-13). J. Schlocker and M. G. Bonilla (unpublished data, October 1964) discuss fault movement at Bodega Head that occurred no more than 400,000 years ago and is possibly much more recent. The Shaft fault along which this movement was recognized was exposed by excavations for a nuclear reactor. Its surface extent and its relation to the San Andreas fault are not well known, but at the excavation it trends N. 40° E. and exhibits evidence of right-lateral strike-slip movement.

Several published maps (Johnson, 1943, fig. 277; Koenig, 1963a; and Koenig, 1963b, p. 5) show the trace of the 1906 fault about 1,000 feet southwest of but essentially parallel to its position as shown on this strip map. The location of the fault shown on the strip map is based chiefly on the location of the site of the Johnson house (Mr. Harold Ames, oral commun., October 3, 1967) which was 50 yards east of the 1906 fault break. This location is corroborated by its topographic similarity to features described in Lawson and others (1908).

Sand Point (Tomales Bay) to Bolinas

The fault trace in Tomales Bay is concealed except at Toms Point and at the southeast end of the bay. On the strip map its position between these points is inferred as a straight line which intersects land only at Hog Island and the marshy peninsula about a mile northwest of Millerton Point. The actual nature of the fault breaks beneath Tomales Bay is probably as complex as it is on land, but the line derived by extrapolation from areas of known mappable fault breaks does indicate the most likely course for the axis of the fault zone. Evidence gathered after the 1906 earthquake (Lawson and others, 1908, p. 65, 78-80) indicates that fault movement must have occurred beneath the bay, but recent attempts to identify that faulting by marine geophysical techniques were largely unsuccessful (Calvin C. Daetwyler, unpublished data, 1965).

From the head of Tomales Bay to the town of Bolinas, the most recent fault breaks are identifiable both by physiographic features and in recoverable points shown in photographs of the 1906 faulting. In many places it is clear that the mapped break was the site of the main fault movement in 1906, but some of the mapped breaks either did not move then or moved so little that they are not mentioned in the 1908 earthquake report. The mapped fault break that approximately follows California Highway 1 for $5\frac{1}{2}$ miles southeast of the Olema Cemetery is the most obvious example: no 1906 movement is known on this break, but it exhibits abundant physiographic evidence of geologically recent activity.

Not all the fault breaks reported in 1906 are shown, for many have been obliterated by geologic processes, by man, or by vegetation. Bedrock cracks, apparently of tectonic origin, were reported at several points southwest of Tomales Bay and on Mount Wittenburg (Lawson and others, 1908, p. 75) but their exact location is now uncertain. Elsewhere along the fault zone, descriptions in the 1908 earthquake report make it clear that surface faulting was more complex than the pattern shown on the strip map. Many of the shorter breaks are no longer recognizable on aerial photographs, although a meticulous on-the-ground search might help define more detail.

The line of faulting between Tomales Bay and Bolinas shows the same branching and overlapping pattern of fault segments as that noted farther north. Location of the fault breaks is somewhat uncertain in the delta of Lagunitas or Papermill Creek, but elsewhere fault-line physiographic features are numerous enough to delineate accurately.

ANNOTATED REFERENCES

Allen, C. R., Grantz, A., Brune, J. N., Clark, M. M., Sharp, R. V., Theodore, T. G., Wolfe, E. W., and Wyss, M., 1968, The Borrego Mountain, California earthquake of 9 April 1968-a preliminary report: Bull. Seismol. Soc. America, v. 58, no. 3, p. 1183-1186.

Describes surface faulting and other effects along an active 20-mile-long segment of a major branch of the San Jacinto fault zone. Fault movements are related to an earthquake of magnitude 6.5.

Bonilla, M. G., 1967, Historic surface faulting in continental United States and adjacent parts of Mexico: Interagency Report (IR)-Reactor Siting Research I, U.S. Geol. Survey open-file report, 36 p.

Summarizes data on 35 episodes of surface faulting with particular emphasis on geometric relations, amount of displacement, and on nature of secondary and branch faults.

Brown, R. D., Jr., 1969, Map showing recently active breaks along the San Andreas and related faults between the northern Gabilan Range and Cholame Valley, California: U.S. Geol. Survey open-file map[1/], scale 1:62,500. Also U.S. Geol. Survey Misc. Geol. Inv. Map I-575. (In press.)

Map of recently active breaks along the central part of San Andreas fault, where fault movement is dominantly tectonic creep.

Brown, R. D., Jr., Vedder, J. G., Wallace, R. E., Roth, E. F., Yerkes, R. F., Castle, R. O., Waananen, A. O., Page, R. W., and Eaton, J. P., 1967, The Parkfield-Cholame, California, earthquakes of June-August 1966--Surface geologic effects, water resources aspects, and preliminary seismic data: U.S. Geol. Survey Prof. Paper 579, 66 p.

Describes surface faulting, movement rates, engineering geology, and seismic activity along an active 23-mile-long segment of the San Andreas fault. Fault movements are related to a 5.5 magnitude earthquake and to its lower magnitude aftershocks.

Brown, R. D., Jr., and Wallace, R. E., 1968, Current and historic fault movement along the San Andreas fault between Paicines and Camp Dix, California, in Dickinson, W. R., and Grantz, A., eds., Proceedings of conference on geologic problems of the San Andreas fault system: Stanford Univ. Spec. Pub. Geol. Sci., v. 11, p. 22-39.

Between Paicines and Cholame rates of movement at the fault zone are determined from offset fences and recent activity is shown by fresh breaks in pavement. South of Cholame the most recent break along the fault shows no evidence of movement for at least 40 years, although this segment was active during the great Fort Tejon earthquake of 1857.

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Geologic map showing bedrock relations and location of San Andreas fault zone for about 7 miles northwest of Bolinas. Text contains a brief description of relations in the fault zone.

Higgins, C. G., 1961, San Andreas fault north of San Francisco, California; Geol. Soc. America Bull., v. 72, no. 1, p. 51-68.

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Jennings, C. W., and Burnett, J. L., 1961, Geologic map of California, Olaf P. Jenkins edition--San Francisco sheet: Calif. Div. Mines and Geology, scale 1:250,000.

State geologic map sheet, shows location of San Andreas fault and adjacent geology from near Olema southeast to southern San Francisco Peninsula. Fault-zone location and other geologic data based chiefly on previously published sources, which are listed.

Johnson, F. A., 1943, Petaluma region, in Geologic formations and economic development of the oil and gas fields of California: Calif. Div. Mines Bull. 118, p. 622-627.

Figure 277 shows San Andreas rift and 3 related faults between Tomales Bay and Fort Ross. Rift zone is stated to be 1 to 1½ miles wide.

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One of the first reports to distinguish between the San Andreas fault and the San Andreas fault zone.

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Sharp, R. V., 1970, Map showing recently active breaks along the San Jacinto fault zone between the San Bernardino area and Borrego Valley, California: U.S. Geol. Survey open-file map, scale 1:24,000. Also U.S. Geol. Survey Misc. Geol. Inv. Map I-675. (In press.)

Map of recently active breaks along a fault zone in the southern, complexly splayed part of the San Andreas fault system.

Steinbrugge, K. V., and Zacher, E. G., 1960, Creep on the San Andreas fault--Fault creep and property damage: Bull. Seismol. Soc. America, v. 50, no. 3, p. 389-396.

Damage to a winery on Cienega Road near Hollister is recognized as due to tectonic creep; probably the first recognition of the importance of this kind of movement on the San Andreas fault.

Strand, R. G., 1962, Geologic map of California, Olaf P. Jenkins edition--Redding sheet: Calif. Div. Mines and Geology, scale 1:250,000.

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Presents evidence of repeated fault movements along the same fault break and evidence that fault movement is right-lateral and largely spasmodic. Study is in the Carrizo Plain area of southern California.

1/ Note: Copies of U.S. Geological Survey open-file maps showing recently active breaks along the San Andreas and other faults in California are available for inspection in the Geological Survey libraries, 1033 GSA Bldg., Washington, D. C. 20242, 345 Middlefield Road, Menlo Park, Calif. 94025, and Bldg. 25, Federal Center, Denver, Colo. 80225, and Public Inquiries Offices, 504 Custom House, San Francisco, Calif. 94111, and 7638 Federal Bldg., Los Angeles, Calif. 90012. [Material from which copy can be made at private expense is available in the Los Angeles and San Francisco Public Inquiries Offices.]