Basement-Rock Correlations Across the White Wolf-Breckenridge-Southern Kern Canyon Fault Zone, Southern Sierra Nevada, California

U.S. GEOLOGICAL SURVEY BULLETIN 1651

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Basement-Rock Correlations Across the White Wolf-Breckenridge-Southern Kern Canyon Fault Zone, Southern Sierra Nevada, California

By DONALD C. ROSS

U.S. GEOLOGICAL SURVEY BULLETIN 1651

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1986

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Ross, Donald Clarence, 1924–
Basement-rock correlations across the White Wolf-Breckenridge-southern Kern Canyon fault zone, southern Sierra Nevada, California.

(U.S. Geological Survey Bulletin 1651)
Bibliography: p. 23–25
Supt. of Docs. no.: I 19.3:1651
1. Faults (geology)—Sierra Nevada mountains (Calif. and Nev.). 2. Stratigraphic correlation—Sierra Nevada mountains (Calif. and Nev.). 3. Batholiths—Sierra Nevada mountains (Calif. and Nev.). I. Title. II. Series: United States. Geological Survey. Bulletin 1651.
QE75.B9 no. 1651 557.3s 86–600053
[QE606.5.U6] [551.7'09794'4]

CONTENTS

PLATE

FIGURES

Basement-Rock Correlations Across the White Wolf-Breckenridge-Southern Kern Canyon Fault Zone, Southern Sierra Nevada, California

By Donald C. Ross

Abstract

Reconnaissance geologic studies of the basement rocks in the southern Sierra Nevada south of lat 36°00′ N. along the White Wolf-Breckenridge-southern Kern Canyon fault zone indicate that several basement-rock units are offset across this fault zone in a right-lateral strike-slip sense by as much as 15 km. This offset corroborates the sense of fault movement along the northern section of the Kern Canyon fault. The White Wolf-Breckenridge-Kern Canyon fault zone is probably one continuous, 200-km-long, right-lateral tear in the Sierra Nevada batholith that may have originated some 80 to 90 Ma during the last large magmatic pulse of the batholith. An oroclinal flexure that includes the area of the southern Sierra Nevada may have been the causative force for this right-lateral tear in the batholith.

The recent history of the southern section of this fault zone (the White Wolf and Breckenridge segments) includes fault displacements that contradict the original right-lateral strike-slip pattern deduced from the basement-rock distribution. Surface ruptures of the 1952 Arvin-Tehachapi earthquake, as well as displacements of several subsurface Cenozoic deposits, indicate left-lateral and reverse motion on the White Wolf segment of the fault zone. Although the cause of this change in faulting style is not known, northward impingement of the "Big Bend" section of the San Andreas fault on the southern part of the old basement tear might provide the proper stress regime for the new style of faulting. Also problematic is recent deformation on the Breckenridge segment, which shows normal dip-slip displacement of more than 1,000 m. The reason for this change is even less evident. The regional stress pattern of basin-and-range extension during the late Cenozoic surely has shoved the southern Sierra Nevada to the west. Normal faulting along the Breckenridge fault may be a sag along the old basement break—a small-scale analog of basin and range faulting to the east. Seismic events as large as $M = 4.7$ in 1983–84 show continuing activity (normal displacement with east side down) on a north-south-aligned zone about 10 km east of the Kern Canyon fault near Big Meadow. These events may reflect the incipient development of another basin-and-range fault within the Sierra Nevada batholithic block.

INTRODUCTION

Are the White Wolf, Breckenridge, and Kern Canyon faults sections of one major, throughgoing fault zone, more than 200 km long? Or are they three separate and distinct faults with different senses of movement that are fortuitously aligned in the southern Sierra Nevada (fig. 1)? The White Wolf fault, in 1952, showed left-lateral and reverse fault displacements; the Breckenridge fault has the physiographic appearance of a classic normal fault, with a pronounced mountain scarp against an alluviated valley along a linear front; and the Kern Canyon fault has demonstrably offset several basement-rock units in a right-lateral sense. From the above statements, it would seem that they are, indeed, three separate faults; but questions remain that the following discussion addresses. I summarize the history of investigations on all three faults, followed by data from my present study, which was focused solely on basement-rock characteristics and distribution. Basement-rock distribution along these three faults, and correlations of the basement rocks across them, provide evidence that favors a major, throughgoing fault zone, although some problems still remain.

HISTORICAL BACKGROUND

White Wolf fault

The White Wolf fault was first noted, but not named, on a simplified map of the Tehachapi area by Lawson (1906b). Presumably, the placement of this fault was based on the physiographic contrast between the steep front of Bear Mountain and the alluviated area to the northwest (pl. 1), although the fault was not discussed further in Lawson's (1906b) report. Hoots (1930) noted a prominent westward protrusion of the Sierra Nevada, about 5 km northeast of Comanche Point, from which a scarp can be traced to the northeast to a broad trough in granitic rocks at the White Wolf Ranch. Hoots (1930, p. 314) was probably the first worker to show the White Wolf fault on a geologic map, but apparently he did not name the fault, because he stated, "This fault is commonly called the White Wolf fault." He further noted that

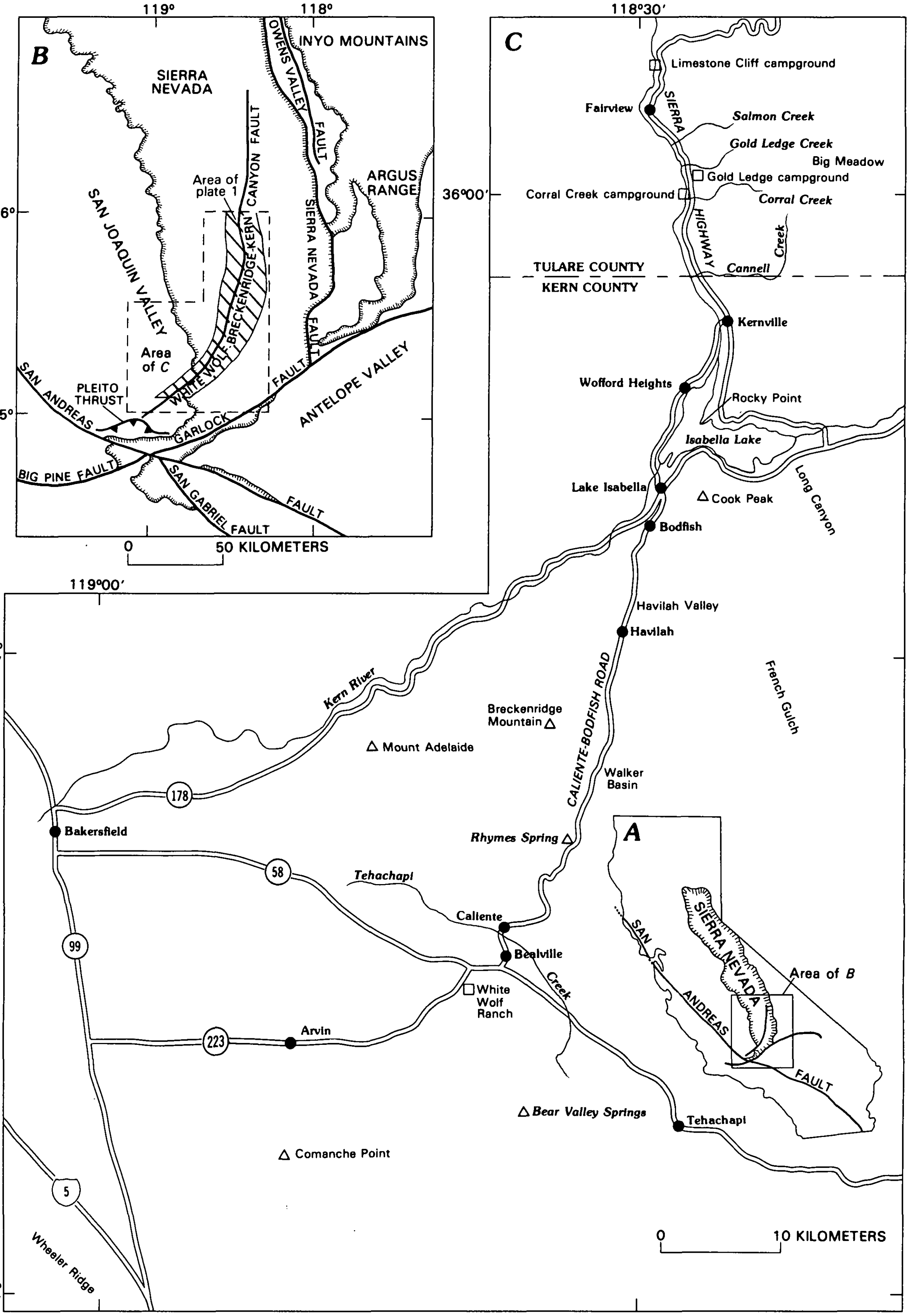


Figure 1. Index maps of California (*A*) and southern Sierra Nevada (*B*). *C*, Selected cultural and physical features in the Bakersfield-Kernville area.

"Distinct evidence of shearing may be found in the crystalline rocks near the alluvium boundary." Hoots (1930, p. 315) also stated that "Large-scale displacement is therefore believed to have occurred along this fracture as late as post-Chanac (post-Pliocene) time. This fault is probably a high-angle fracture, but whether it is a normal or reverse fault appears to be entirely a matter of conjecture." On an accompanying sketch map showing structural features, however, he shows thrust-fault symbols (thrust direction to the northwest) along the White Wolf fault. Dibblee and Chesterman (1953, p. 50) mapped a 5-km-long stretch of the White Wolf fault north of the White Wolf Ranch to where it disappears at Tehachapi Creek. They noted that the steep northwest front of Bear Mountain is uplifted "many thousand feet," that the fault "*** is marked by several feet of gouge and crushed rock," and that "The rock on the northwestern or downthrown block is highly crushed within a mile of this fault." They did not state, however, whether the fault had normal or reverse movement. They also noted that "the White Wolf fault is well expressed topographically indicating it to have been active during Quaternary time." This statement was strikingly emphasized by the Arvin-Tehachapi earthquake of July 21, 1952, on the White Wolf fault, which occurred while their report was still in press.

Dibblee (1955) noted that before this earthquake the evidence of the White Wolf fault was based entirely on topography. Surface ruptures in 1952 formed along nearly the entire 27-km-long known course of the fault, mostly on or near its previously mapped trace. Dibblee (1955) suggested that these surface ruptures indicated reverse movement (southeast side up) and lesser left-lateral offset. However, he saw no physiographic or geologic evidence for extending the White Wolf fault to the northeast of Tehachapi Creek, and no evidence that the White Wolf fault is connected to the Breckenridge fault.

Buwalda and St. Amand (1955, p. 42), in examining evidence from the 1952 Arvin-Tehachapi earthquake, observed that "*** it appears from the distribution of aftershocks and of ground ruptures that the White Wolf fault probably continues northeastward beyond the point where the Kern River or Breckenridge fault projected southward would meet it. Although it has not been possible to trace the Breckenridge fault to the White Wolf it is improbable that such a long and important fault zone would terminate only a few miles from an intersection with another important fault." The distribution of earth ruptures and epicenters on figures 2 and 3 show this overlap. Furthermore, figure 3 shows several aftershocks of $M \geqslant 5$ that are close to the mapped trace of the Breckenridge fault.

South of Caliente, where extensive damage was done to the railroad line, Kupfer and others (1955) observed "broken and crushed rock" (p. 68) and "a gouge zone 1 foot to 3 feet wide and a much wider breccia zone" (p. 70) in a zone of faulting and fracturing, as much as 180 m wide, that trends almost east-west. They suggested a deformational pattern of compression that was relieved by reverse faulting (south block up relative to north block) in the White Wolf fault zone. This compression was immediately followed by relaxation and settling along normal faults.

Webb (1955) discussed whether or not the White Wolf fault is connected to "onstrike" faults farther north. He referred to the "Kern Canyon lineament," which, to him, consisted of the following separate and distinct faults: the Kern Canyon, Hot Spring Valley, Havilah Valley, Breckenridge, and White Wolf. He asserted that no published work justified calling this a single fault or connecting the separate faults into a master structure. Even though Webb (1955, p. 36) suggested abandoning the concept of a single structure, he asserted that "*** if such superficial evidence as slickensides and epidotized joints is accepted, faulting can be demonstrated in segments between recognized faults." Furthermore, he speculated that the presently exposed faults "*** may be remnants of an ancient, and originally continuous fault, developed in the cover rocks of the ancient Sierra Nevada." Although his speculation would probably be unacceptable to most present-day structural geologists, it does show that Webb was searching for some way to relate these "separate" faults, as their alignment seems to call for. Indeed, that Webb knew how to solve the problem is shown by his statement that "Understanding of this lineament *** rests, like all other geologic problems, on completion of detailed geologic mapping."

Hill (1955, p. 40), on the basis of subsurface data, noted that "*** the eastern edge of lower Miocene sands appears to be offset several miles [16 km on his fig. 2] in a left lateral sense by the White Wolf fault." Hill suggested an even farther left-lateral shift in Eocene sedimentary rocks. Dibblee (1955, p. 30), however, observed that "*** the total overall lateral displacement must be small, probably not over 2,000 feet. The easterly pinchout of the [Miocene] Santa Margarita sand is in about the same position on either side of the fault and therefore is not appreciably offset."

Cisternas (1963) made a detailed study of selected aftershocks from the 1952 Arvin-Tehachapi earthquake and found that most of these aftershocks indicated left-lateral slip, although a few indicated dip slip or right-lateral slip. Cisternas' data suggested a 50° SE. dip for the White Wolf fault and additional southeast-dipping planes to the northwest of the main fault (fig. 4*A*). M.G. Bonilla (oral commun., 1980) indicated that more precisely located aftershocks from 1976 to 1978 show the dip of the White Wolf fault plane to be about 60° SE.

If the aftershocks that Cisternas (1963) used (fig. 4*A*) are plotted without the influence of Cisternas' faultlines, these aftershocks could as well define a zone some 10 km wide, essentially centered on the White Wolf fault and dipping 75° SE. (fig. 4*B*). An even more pronounced trend is evident if only the 1952 main shock and aftershocks of the

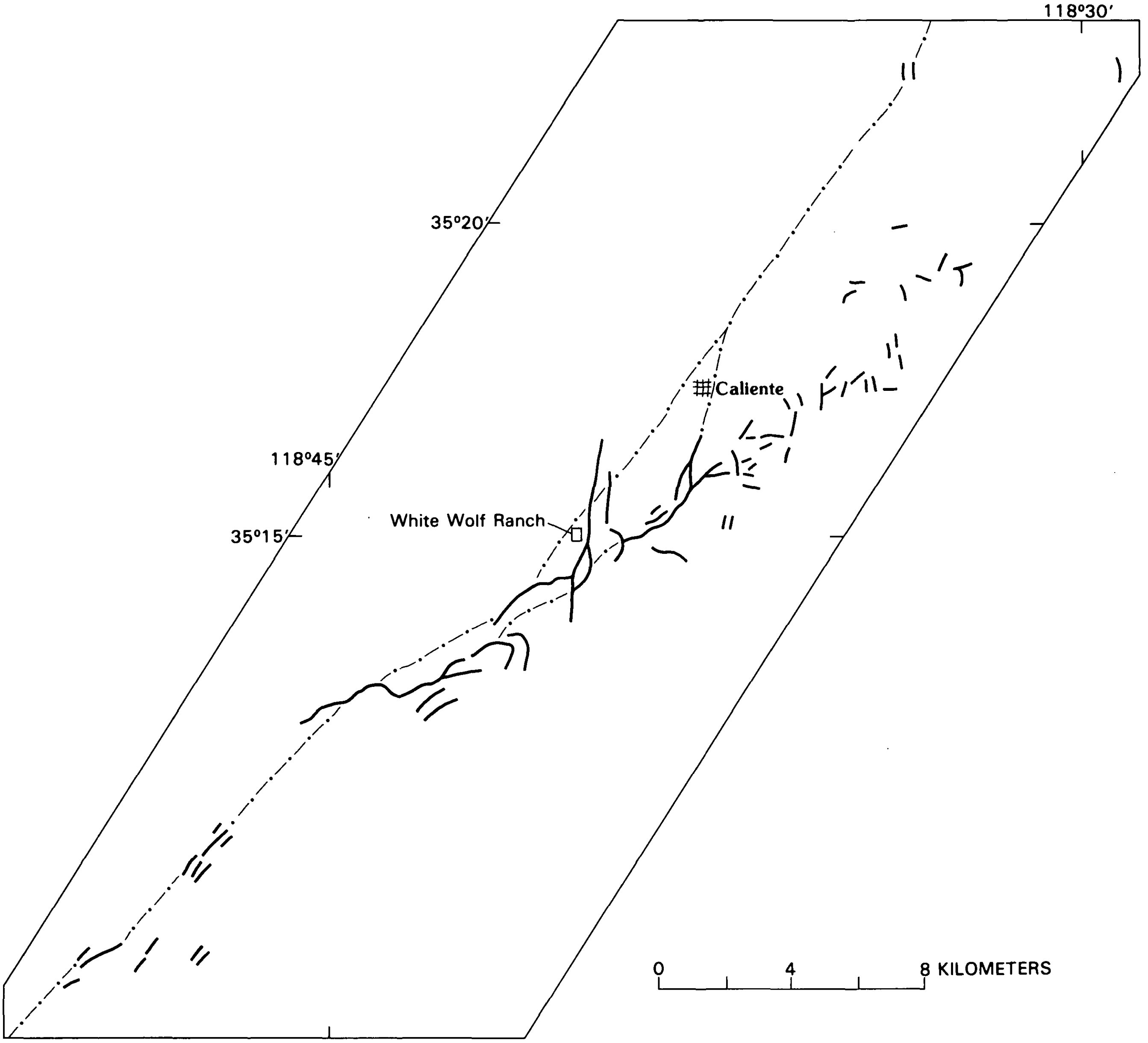


Figure 2. Caliente, Calif., area, showing locations of earth ruptures (heavy lines) caused by July 21, 1952, earthquake on the White Wolf fault zone. Ruptures somewhat generalized from Buwalda and St. Amand (1955). Thin dash-dotted lines denote generalized trace of the White Wolf fault and southern section of the Breckenridge fault (see pl. 1).

first 2 days are plotted (fig. 4*C*). In addition, this new, "steeper" interpretation has the advantage of including the main shock within the White Wolf fault zone. Cisternas (1963) also showed an interesting northeast-trending alignment of epicenters about 20 km to the northwest of the White Wolf fault (fig. 4*A*). Movement on this zone (which included three events of $M \geqslant 5$) caused the Bakersfield earthquake ($M = 5.8$, about 10 km east of Bakersfield, fig. 3) 1 month after the Arvin-Tehachapi event. Focal mechanisms for these aftershocks indicate right-lateral slip and a fault plane dipping 70° NW. However, no surface geologic expression of this zone has been noted.

Stein and Thatcher (1981) estimated that the late Quaternary reverse-fault displacement (west side down) on the White Wolf fault was between 3,600 and 5,100 m during the interval 1.2–0.6 Ma. This age range is based on the assumption that an ash deposit found in several oil wells northwest of the fault is correlative with one of several ash deposits in the Western United States that have been dated at 0.6 to 1.2 Ma. The estimated displacement is based on the probable range in the reconstructed original position of this same ash deposit on the southeast side of the fault.

Stein and Thatcher (1981, p. 4919) noted that the strike of the White Wolf fault is "* * * continuous with the N. 70° E.

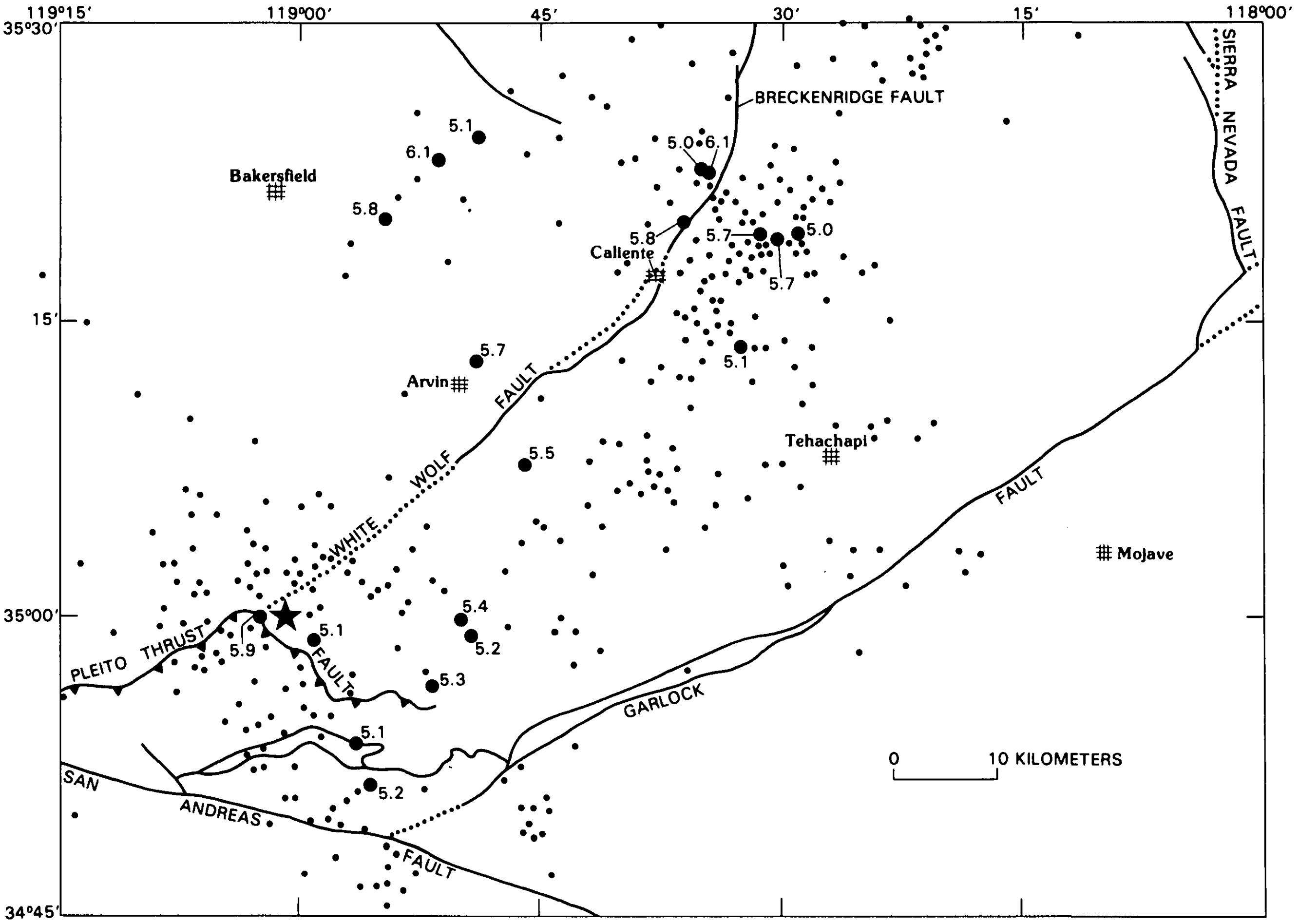


Figure 3. Southernmost Sierra Nevada, showing locations of earthquake epicenters for the period 1932–79. Star denotes location of the $M=7.7$ event of July 21, 1952 (Arvin-Tehachapi earthquake). Large dots, events of $M>5$ (magnitude shown); small dots, events of $M<5$. Data from Southern California Cooperative Seismic Network catalog (California Institute of Technology, Pasadena).

striking Pleito fault to the southwest, and the N. 30° E. striking Breckenridge fault to the northeast. Both adjacent faults extend into the 1952 aftershock zone. Horizontal shear strains also confirm the presence of a significant left-lateral slip component that decays to the northeast."

Structure contours on a conspicuous electric-log marker (N Point) and on correlative neritic and continental rocks to the southeast in the upper Miocene of the southern San Joaquin Valley (Webb, 1981) show a significant disruption across the White Wolf fault (fig. 5). I estimate that the vertical contrast across this fault is between 12,000 and 14,000 ft (as much as 4,000 m). The syncline shown by these structure contours can also be interpreted as offset about 5 km in a left-lateral direction by the White Wolf fault (fig. 5). Stein and Thatcher (1981), using these structure contours, estimated a slightly greater vertical offset of about 5 km, but the same left-lateral offset of 5 km. They used these Miocene offset data, coupled with their offset data from the upper Quaternary ash deposit, to suggest that offset rates on the White Wolf fault have increased significantly from the late Quaternary to the present, relative to the period from the upper Miocene to the late Quaternary.

The bulk of evidence indicates that the latest movement on the White Wolf fault has been left lateral and reverse along a somewhat steeply dipping reverse fault. Evidence of earlier offset is sparse, but left-lateral offset is suggested by subsurface Tertiary units.

Breckenridge fault

Lawson (1906a, p. 398) noted that the east side of Breckenridge Mountain "* * * is a very precipitous mountain front overlooking Walker Basin. The mere inspection of the profile suggests immediately that the mountain is a tilted orographic block and that its eastern front is a fault-scarp."

Dibblee and Chesterman (1953) mapped the Breckenridge fault in their study of the Breckenridge Mountain 15-minute quadrangle. They showed the fault extending along

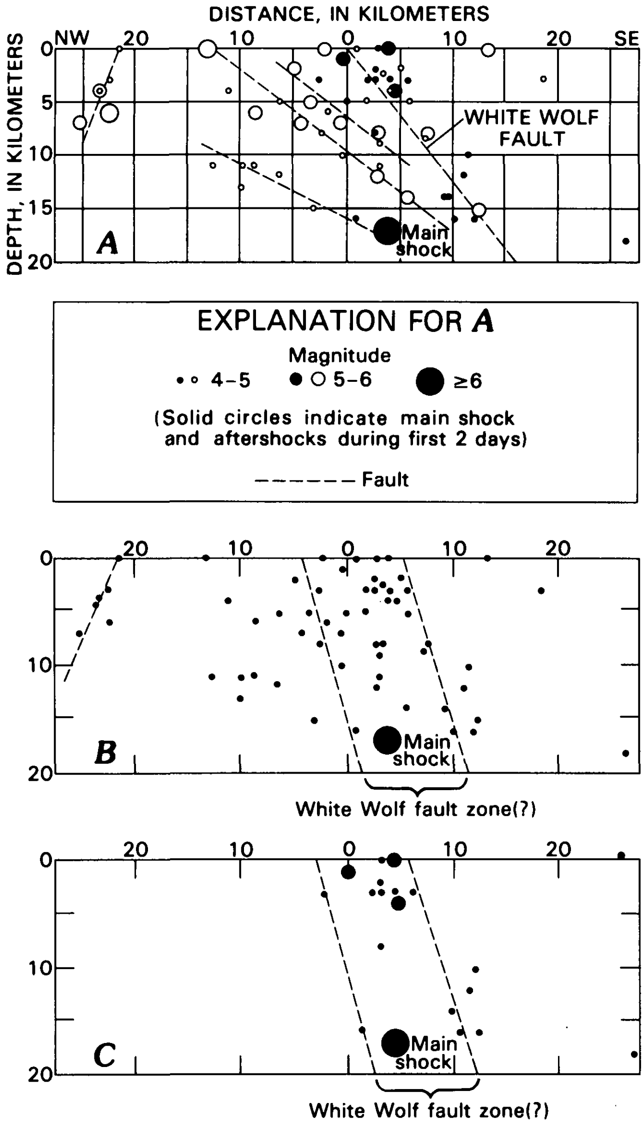


Figure 4. Vertical cross sections across the White Wolf fault. *A*, Cross section from Cisternas (1963), based on locations of selected aftershocks of 1952 Arvin-Tehachapi earthquake. *B*, Alternative interpretation of the White Wolf fault zone, using all the aftershock locations of Cisternas (1963). No magnitude indicated. *C*, Alternative interpretation, using only those aftershocks that occurred during the first 2 days after the main shock.

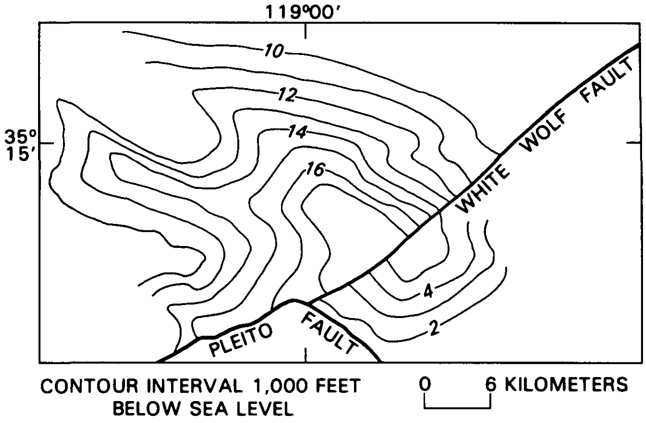


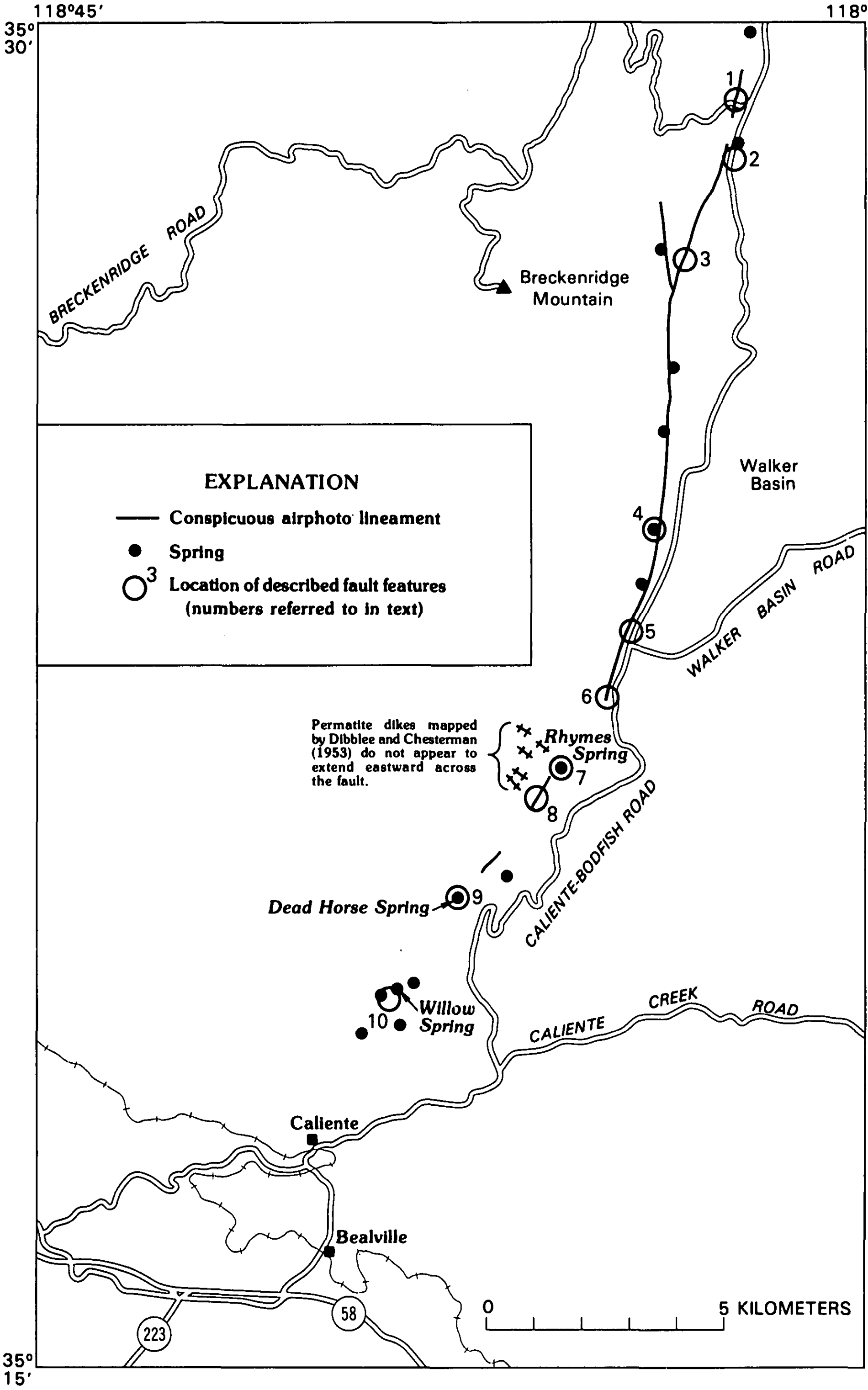
Figure 5. Structure on N Point marker, near top of upper Miocene chert and the Stevens sandstone of local usage (extrapolated southeastward into neritic and continental rocks). Modified from Webb (1981, fig. 3).

the straight west side of the Walker Basin (pl. 1) for about 10 km, and as "approximately located" for an additional 3 km, to the north quadrangle boundary. Dibblee and Chesterman (1953, p. 45) spoke of this fault as "a member of the Kern Canyon fault zone" and further noted that the west block is elevated more than 1,200 m relative to the east side. They indicated (p. 46) that "Movement on the fault is mainly if not entirely vertical" and that the fault was not found exposed.

Buwalda and St. Amand (1955) examined the Breckenridge fault after the 1952 Arvin-Tehachapi earthquake. They found no ground ruptures or scarplets on the Breckenridge fault at the base of the Walker Basin scarp. They did, however, describe several ruptures in and near a small borrow pit west of the highway at the south end of the Walker Basin (loc. 6, fig. 6); the largest ground rupture was about 38 m long. These ruptures all appeared to be tension cracks, and there was no suggestion of vertical or horizontal movement on them. Buwalda and St. Amand (1955) gave no indication of the orientation of the larger cracks in their text, but their map compilation of earth ruptures shows two lines trending just slightly west of north. They mention a 12-m-long crack about 120 m east of the highway that trends N. 5° E., and also noted several small north-south-trending cracks nearby.

Smith (1964) showed an approximately located fault extending southward from the Breckenridge fault, but not quite connected to the White Wolf fault. This extension, added to the compilation of Dibblee and Chesterman (1953) and credited to A.R. Smith and C.W. Jennings (Smith, 1964), is approximately the same faultline as the southern extension of the Breckenridge fault (from the Walker Basin to the Caliente area) that I propose in this report.

The present-day physiography and the mapping by Dibblee and Chesterman (1953) show that the Breckenridge fault on the west side of the Walker Basin resembles a classic normal fault that in another setting could be called a basin-and-range fault. There presumably was no sympathetic movement on this fault segment during the 1952 earthquake. One can only speculate on whether sympathetic movement may have occurred on the "new southern extension" of the Breckenridge fault, as I propose in this report. However, it is interesting to note that three $M \geqslant 5$ aftershocks occurred along or near that extension (fig. 3).



EXPLANATION

1. Contact between the granodiorite of Mount Adelaide and the tonalite of Bear Valley Springs is marked by altered and sheared granitic rocks with mortar structures and splotchy to anastomosing zones of calcite and strung-out chlorite layers. Hydrothermally altered microbreccia. Dibblee and Chesterman (1953) mapped a fault at this locality.
2. North-south-trending vertical shear zone in the Mount Adelaide body. Granitic fragments in gouge of the shear zone are red stained, show mortar structure, and contain epidote and bleached biotite. Hydrothermally altered microbreccia with incipient fluxion structure. Probably a subsidiary shear zone east of the main fault.
3. A several meter-wide zone (N. 25° E., 50°-90° SE.) of gouge and sheared granitic rock at contact of the tonalite of Bear Valley Springs on the west with metasedimentary rocks of Walker Basin on the east. Anastomosing fabric of shattered quartz and plagioclase crystals, with wavy layers of calcite and chlorite. Hydrothermally altered microbreccia with incipient fluxion structure.
4. Tonalite float at base of slope is granulated, and dark minerals are altered to chlorite and bleached biotite. Hydrothermally altered microbreccia.
5. Green shear zones and cataclastic deformation in the generally fresh looking, but strongly hydrothermally altered, tonalite of Bear Valley Springs. Hornblende and biotite are altered to chlorite, actinolitic amphibole, and epidote. Some prehnite veins. Plagioclase in part is strongly saussuritized and contains bent to wavy and fractured crystals (as shown by twin-plane distortion). Flamboyant extinction is common in quartz. Thin section suggests a fabric approaching fluxion structure.
6. Strong directional fabric (fluxion structure) in granitic rocks (N. 25° E., 80° SE.). Quartz in intensely slivered and anastomosing layers and lenses. Also lenses and layers of angular mortared fragments. Dark minerals are altered to chlorite and epidote. Hydrothermally altered mylonite. Buwalda and St. Amand (1955, p. 53) noted "tension cracks" here with "no suggestion of vertical or horizontal offset" in their investigation of the effects of the 1952 Arvin-Tehachapi earthquake.
7. Sheared tonalite with anastomosing fabric striking generally N. 25° E. and near-vertical (fluxion structure, but not so strong or pervasive as at the locality just to the north). Granulation locally intense; elongate slivered undulatory quartz crystals and many bent and shattered plagioclase crystals. Both hornblende and biotite are considerably bleached and altered. Travertine present in stream gully (presumably from Rhymes Spring—no surface evidence of marble). Hydrothermally altered protomylonite.
8. Aligned swales strewn with float of small sheared and altered granitic fragments and one poor roadcut with N. 25° E.-trending vertical shear planes. Bands, streaks, and zones of strongly mortared material, as well as flamboyant quartz and bent and broken plagioclase crystals. Almost complete alteration of mafic minerals to chlorite, epidote, and calcite. Hydrothermally altered microbreccia with local weak fluxion structure.
9. Dead Horse Spring is on contact between the Bear Valley Springs and Mount Adelaide granitic units. Near the spring, gougelike material in low cuts and hydrothermally altered granitic float with minor granulation suggest that contact is faulted, but the evidence is weak.
10. Dark shear zone (N. 20° E., vertical), about 7 m thick, with associated bleached and less sheared rocks on both sides of the zone, makes a total thickness of about 20 m. Shear zone strikes toward Willow Spring, where shattered and sheared granitic rocks strike N. 30° E. and dip steeply east. Fresh Bear Valley Springs rocks crop out 100 m east of the faultline, and fresh Mount Adelaide rocks crop out 200 m west of the faultline. Rocks in the shear zone are strongly granulated and brecciated and contain anastomosing mica-rich zones. Only very incipient fluxion structure is visible.

Figure 6. Sketch map summarizing evidence for faulting at selected localities along the Breckenridge fault and connecting south end of the Kern Canyon fault.

Kern Canyon fault

Lawson (1904) first described the Kern Canyon fault in the upper Kern Basin (fig. 7). The physiography of the strikingly straight river valley there suggested to Lawson a grabenlike rift valley analogous to the African rift valleys, and the then-prevalent theory of their origin. In other early explorations, Lawson (1906a) noted the longitudinal valley in which Havilah is situated, and postulated a fault scarp. He also suggested that the straight steep wall on the west side of the pass between Havilah and Hot Spring Valley is a degraded fault scarp (pl. 1).

Webb (1936) made probably the first field study of the Kern Canyon fault and traced it northward from Kernville (whose prereservoir site was near present-day Wofford Heights) as far as the mouth of Golden Trout Creek (fig. 8), a distance of some 65 km. He noted that only weak physiographic evidence of a fault exists south of Kernville but that the fault might extend as far as the south end of Hot Springs Valley. He mapped the fault as a single trace, discounting the suggestion by Lawson (1904) of a grabenlike crustal rift. Webb (1936, p. 635) very briefly noted: "In several places, however, zones of extreme brecciation are found along the fault, grading into complex shear zones and highly altered recrystallized rocks." Although Webb did not describe any mylonite, the heading of his brief discussion of deformed rocks is titled "Breccias and Mylonites." Presumably, his "complex shear zones" included mylonite. He was thus the first person to note evidence for strong compressive deformation along the Kern Canyon fault.

Miller and Webb (1940), in their reconnaissance geologic study of the Kernville 30-minute quadrangle, showed the Kern Canyon fault extending from the north boundary of the quadrangle southward to South Fork Valley. They showed

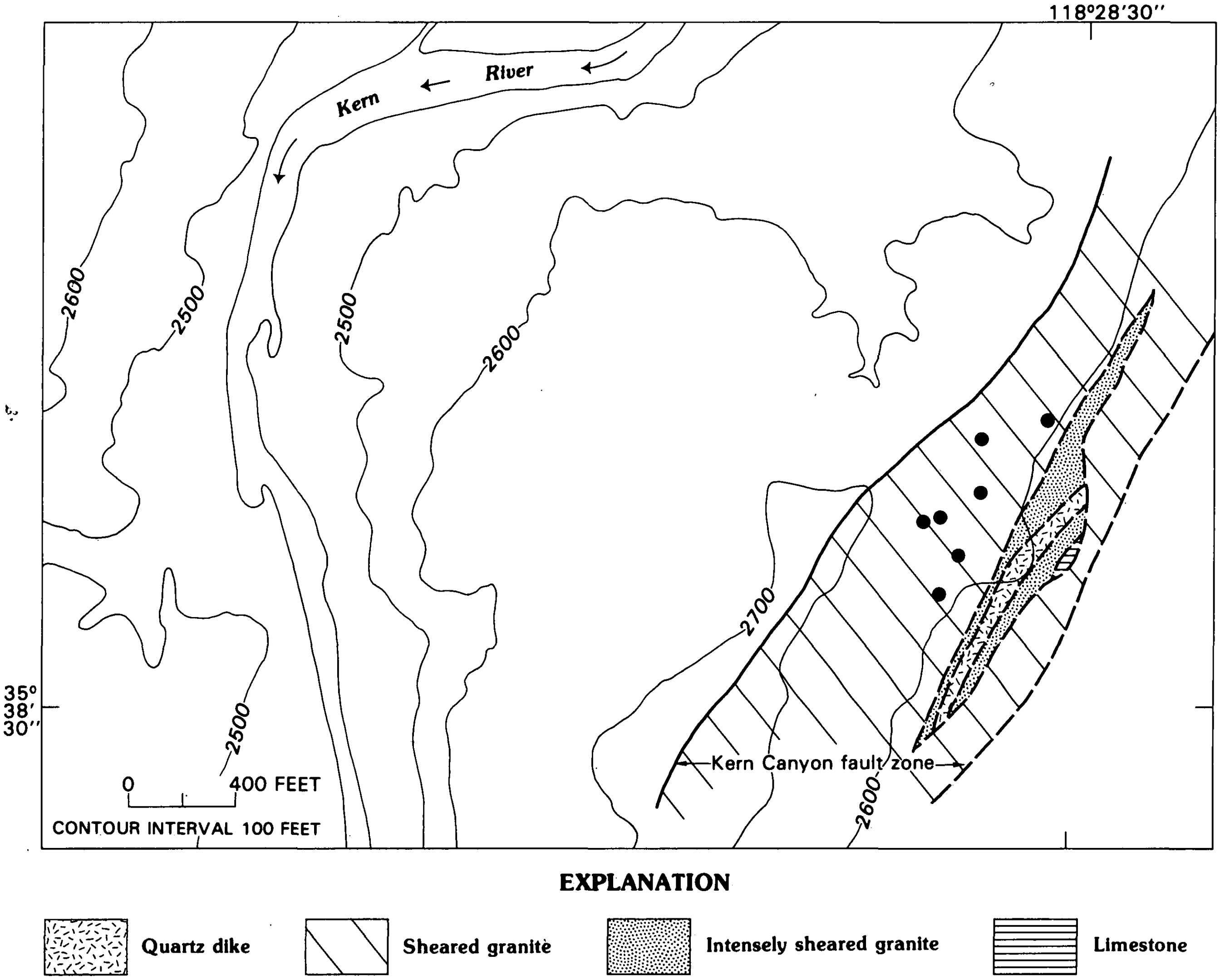


Figure 7. Geologic map of the Kern Canyon fault zone at west abutment of the Isabella auxiliary dam, based on an intensive study of drill cores and trench exposures (simplified from Treasher, 1948, pl. 2). Dots denote locations of drill holes in sheared granite.

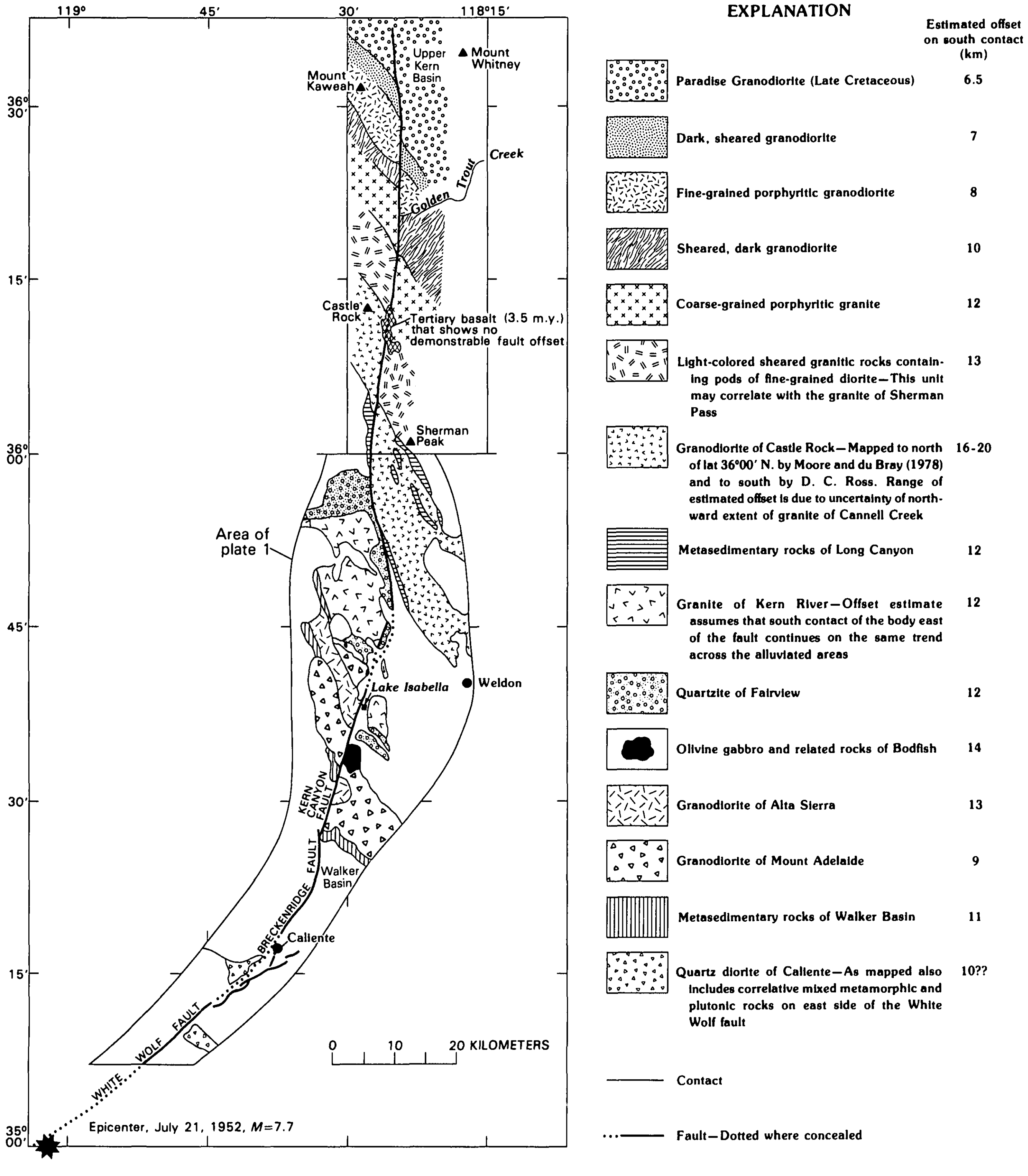


Figure 8. Generalized geologic map of basement-rock units that show right-lateral offset on the White Wolf-Breckenridge-Kern Canyon fault zone. Data north of lat 36°00′ N. from Moore and du Bray (1978).

the southern section of the fault as a dashed line at the contact between the units I now call the granite of Kern River and the metavolcanic rocks of French Gulch east of Isabella Lake, where I alternatively consider the contact to be intrusive. Miller and Webb (1940, p. 361) considered the Kern Canyon fault to be "*** a very old fault, produced probably during the development of the ancestral Sierra Nevada, whose roots only are now visible, but which, as a line of weakness, offers erosion easy work in sculpturing special land forms. The nature of the movement on the fault is not known."

Treasher (1948) compiled a considerable body of data on the Kern Canyon fault as part of investigations for the siting of the Isabella dams, to make this surely the most extensively studied segment of the Kern Canyon fault. Detailed surface study, drilling, and trenching indicate that the fault zone there is at least 800 ft (244 m) wide (fig. 7). Treasher (1948), on the basis of geologic field studies, reported that the fault continues southward along the east side of the median ridge that separates Hot Spring Valley from the Kern River, passes through the Bodfish tunnel of the Borel Canal (about 1 km northwest of Bodfish), and continues southward over Havilah Pass into Havilah Valley (pl. 1). He also stated that reconnaissance studies indicate that the fault continues through the Walker Basin to the vicinity of Caliente. Treasher (1948, pl. 7) presumably also considered the White Wolf fault to be part of the Kern Canyon fault zone because he labeled the whole zone the "Kern Canyon fault," although he did not discuss the White Wolf segment in his text. At the damsite, Treasher (1948) noted that a zone of intensely sheared granite and quartz, as much as 90 m wide, is surrounded by less intensely deformed granite which is sheared into narrow plates that are now badly weathered. He noted that hydrothermal alteration is common in the fault zone and that it "continues to the present day." At the damsite, the Kern Canyon fault strikes N. 10° E. and dips about 70° W. To the south, the dip is steeply to the east. Treasher (1948) considered the fault to be a "reverse or thrust fault with the west side up" at the damsite, but he noted that "*** no estimate is made of horizontal displacement." Treasher (1949) later stated that evidence of recent seismic activity along the Kern Canyon fault is contradictory but that a significant grouping of epicenters occurs along the fault north of Kernville.

Dibblee and Chesterman (1953) showed the Kern Canyon fault continuing southward from Havilah Valley and dying out in the metasedimentary pendant just north of the Walker Basin. My alternative interpretation, that the Kern Canyon fault bends westward and blends into the Breckenridge fault, is discussed below in the section entitled "Subsidiary Faults to the Kern Canyon Fault."

Engel (1963) observed highly crushed and decomposed granitic rocks at the divide between the Walker Basin and Havilah Canyon (probably near loc. 1, fig. 6). He also described highly crushed granitic rocks at Havilah Pass that exhibited slickensided and grooved surfaces in the vertical fault which suggested left-lateral oblique slip, with dip slip dominating. About a mile farther north he also saw slickensides and mullions that indicated, to him, left-lateral movement.

Moore and du Bray (1978) provided the first concrete evidence of the sense of movement on the northern section of the Kern Canyon fault with their mapping that demonstrated right-lateral offset on seven granitic units in the interval lat 36°00′–36°40′ N. (fig. 8). Thus, some 70 years after the fault's "discovery," someone finally did the obvious—mapped the rocks on both sides of the fault and found out what they showed! More detail on the distribution of the units offset by the northern section of the Kern Canyon fault from lat 36°15′ N. to 36°40′ N. can be seen on geologic maps of the Mount Whitney and Kern Peak 15-minute quadrangles (Moore, 1981; Moore and Sisson, 1984).

North of Kernville, the existence and location of the Kern Canyon fault as a major throughgoing fault have generally been agreed upon. South of Kernville, however, the location and even the existence of the Kern Canyon fault as a major throughgoing fault (Webb, 1955) have been variously interpreted. The sense of major movement (right lateral) on the northern part of the fault has only very recently been established. The sense of major movement for the southern section of the Kern Canyon fault is also well established in the present report as right lateral (fig. 8). Nevertheless, there have been references to other styles of movement—for example, reverse dip slip at the Isabella dams (Threasher, 1948) and oblique left-lateral and dip slip at Havilah Pass and south of Havilah (Engel, 1963).

Big Blue fault

Prout (1940), in his study of the Big Blue mine area southwest of Kernville, described a well-defined shear zone, as thick as 30 m, that strikes N. 20°–30° E. and dips 70° W..I have taken the liberty of calling this unnamed fault the "Big Blue fault" (pl. 1). Prout noted crushed and brecciated rocks in the shear zone, and "heavy gouge." His description of the foliated and wavy appearance of minerals in alaskite of the mine area suggests that he observed fluxion structure in the fault zone. Prout (1940, p. 391) considered the fault through the Big Blue mine area to be "*** more or less parallel to the Kern River fault, which follows in a general direction the waters of the Kern River from Isabella to Fairview." Several other workers, including Treasher (1948), Engel (1963), and Smith (1964), considered the Big Blue fault to be part of the main trace of the Kern Canyon fault. Basement-rock distribution suggests that Prout's earlier interpretation is more nearly correct and that the Big Blue fault is a subsidiary fault of the Kern Canyon fault "system."

Cook Peak fault

Treasher (1948) postulated a Cook Peak fault, which he called the eastern branch of the Kern Canyon fault. It presumably trends north-south along the east side of the northern arm of Isabella Lake, across South Fork Valley and along the east face of Cook Peak, to die out against a fault along Erskine Creek. Although Treasher did not so state, I would speculate that the existence of this fault is based almost solely on physiographic evidence. Basement-rock distribution does not require the fault where Treasher proposed it, and, in fact, the segment of the "Cook Peak fault" along the east face of Cook Peak is an intrusive contact, where the granite of Kern River sends apophyses into the metavolcanic rocks of French Gulch to the east.

A compilation by Smith (1964) showed the Cook Peak fault farther east and "approximately located" south of Isabella Lake. The fault as shown on the compilation is a strike fault paralleling the foliation within the metavolcanic rocks of French Gulch; the fault was located by L.E. Weiss and M.G. Best (unpub. data, 1964). Inspection of aerial photographs along the suspected fault trace reveals an approximately aligned series of topographic lows in the metavolcanic pendant rocks. This alignment could merely reflect differential erosion of the various metavolcanic layers, or a shear zone could be present, which would not be unusual in this region. I observed no noticeable offset of the metavolcanic rocks in the field. Faulting parallel to the foliation in the metavolcanic rocks could conceal small offsets, but faulting, if it has occurred, has not significantly affected the basement-rock distribution.

Fault compilations on small-scale geologic maps

I examined several small-scale geologic maps to see how various compilers portrayed the relation between the White Wolf, Breckenridge, and Kern Canyon faults. Figure 9 shows pertinent parts of the various compilations chosen. Possibly reflecting the equivocality of the available literature (and the problem), I found no clear consensus—almost every option was used by the following compilers.

Cohee (1962), on his 1:2,500,000-scale tectonic map of the United States, showed the White Wolf-Kern Canyon fault as one continuous fault zone, but with an overlapping "gap" between the Kern Canyon and Breckenridge faults (fig. 9*A*).

Bayley and Muehlberger (1968), on their 1:2,500,000-scale basement-rock map of the United States, connected all three faults and called the whole zone the "White Wolf fault." They also tied the Pleito thrust fault to their zone and continued the entire zone to the San Andreas fault (fig. 9*B*).

King (1969), on his 1:5,000,000-scale tectonic map of North America, followed the compilation of Cohee (1962) and did not connect the Kern Canyon and Breckenridge faults (fig. 9*C*).

King and Beikman (1974), on their 1:2,500,000-scale geologic map of the United States, showed the Kern Canyon and Breckenridge faults smoothly joined, but showed the White Wolf fault separately (fig. 9*D*).

Jennings (1975), on his 1:750,000-scale fault map of California, showed more detail and delineated the White Wolf, Breckenridge, and Kern Canyon faults separately (fig. 9*E*). The White Wolf fault is somewhat "disjointed" because his compilation relies mostly on historical (1952) fault breaks. Nonetheless, Jennings' (1975) compilation clearly shows the continuity of trend of the three faults.

DATA FROM PRESENT STUDY

Evidence for the position of the Kern Canyon fault, based on airphoto interpretation

West of the Caliente-Bodfish road is a conspicuous break in the slope and well-aligned topographic notches that produce a good airphoto lineament from locality 1 (fig. 6) northward to Havilah (airphotos 2–137, 2–138, GS–VCML, April 1970). About 3 km north of Havilah, the strikingly linear west side of the small valley is aligned with a topographic swale that strikes toward Havilah Pass. A parallel lineament on the east side of the valley may mark a subsidiary fault, but it does not appear to affect the basement-rock distribution (airphotos 2–161, 2–162, GS–VCML, April 1970).

Havilah Pass is a distinctive topographic notch aligned with the linear topographic break that extends continuously northward from the valley north of Havilah. Northward from Havilah Pass, this sharp topographic break can easily be traced about 3 km to the linear topographic notch where the Borel Canal (4 km south-southwest of Lake Isabella) crosses the fault. A less conspicuous and somewhat less continuous lineament is most clearly visible east of the Bodfish-Caliente road just north of Havilah Pass. This lineament marks the major basement fault break between granitic rocks on the west and gabbroic rocks on the east. There, the fault zone is about 500 m thick but narrows much more both north and south of Havilah Pass (airphotos 2–252, 2–253, GS–VCML, April 1970).

North of the Borel Canal topographic notch, a knife-sharp lineament angles across the outskirts of Bodfish and strikes into the faultline scarp that marks the straight-line west margin of Hot Spring Valley. This lineament through Bodfish is a low but distinctive topographic contrast and a sharp vegetation contrast (airphotos 2–206, 2–207, GS–VCML, April 1970). The peninsula between the two Isabella dams has a remarkably straight east side that aligns with the west wall of Hot Spring Valley (airphotos 2–270, 2–271, GS–VCML, April 1970).

From north of the peninsula between the two Isabella dams to a short distance north of Kernville, the trace of the Kern Canyon fault, whose presence is virtually demanded by

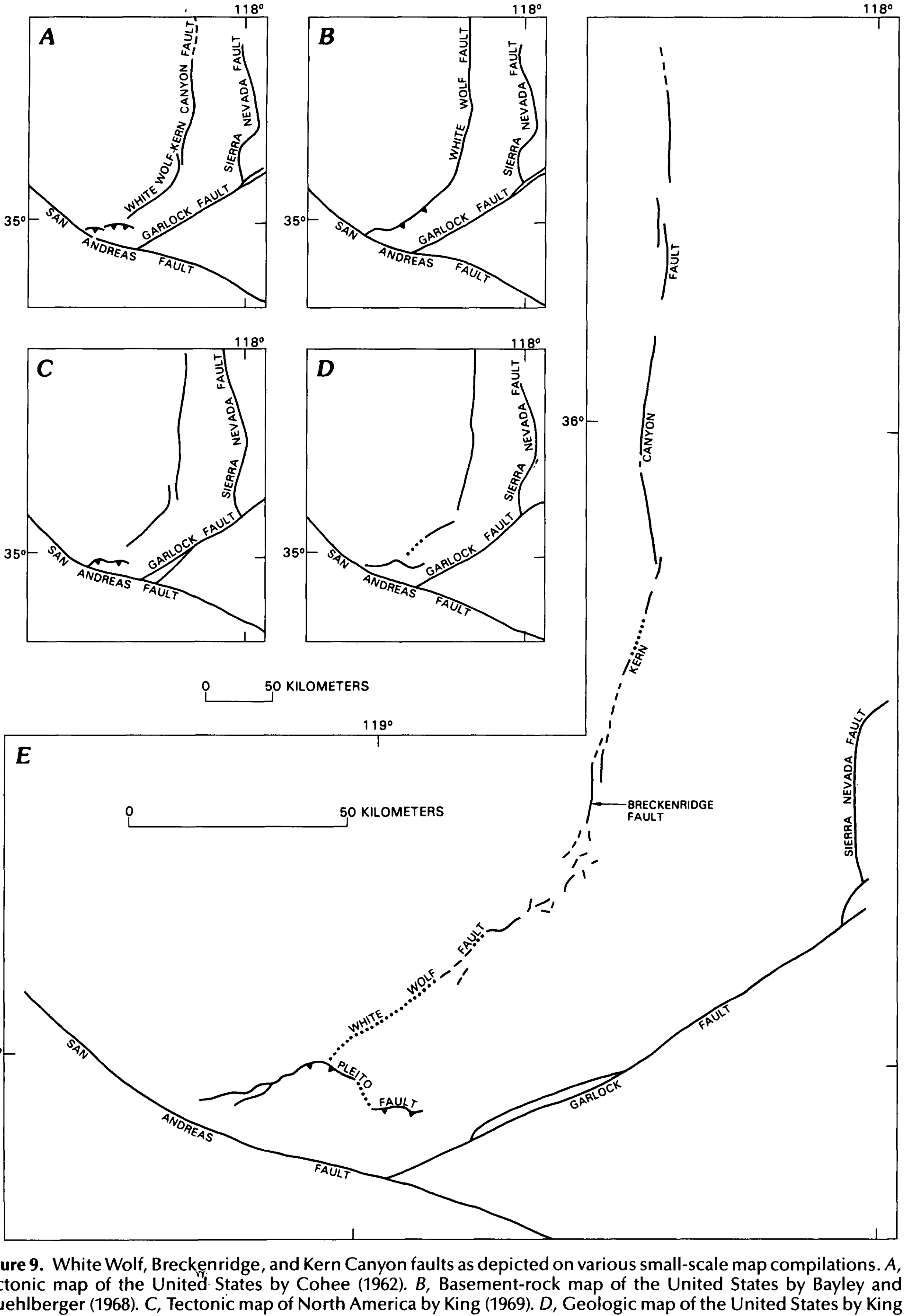


Figure 9. White Wolf, Breckenridge, and Kern Canyon faults as depicted on various small-scale map compilations. *A*, Tectonic map of the United States by Cohee (1962). *B*, Basement-rock map of the United States by Bayley and Muehlberger (1968). *C*, Tectonic map of North America by King (1969). *D*, Geologic map of the United States by King and Beikman (1974). *E*, Fault map of California by Jennings (1975).

the basement-rock distribution, lies beneath the waters of Isabella Lake. Between Wofford Heights and Kernville, however, is a good airphoto alignment of topographic saddles that mark the Big Blue fault, which is probably a subsidiary fault west of the trace of the main Kern Canyon fault (airphotos 2–228, 2–229, GS–VCML, April 1970).

North of Kernville, a distinct linear color contrast, between light-colored granitic rocks on the east and dark-colored metamorphic rocks on the west, marks the faultline. Topographic notches also accentuate this alignment, which becomes increasingly more obvious and well defined to the north. These aligned topographic lows and saddles are called the Rincon on the Kernville 15-minute quadrangle. Near the north margin of the map, this airphoto lineament is accentuated by a truncation of metamorphic layers (particularly light-colored marble) by the fault (airphotos 6–22, 6–24, 6–28, 6–29, GS–VDYM, July 1976).

Airphoto stereopairs (2–161 and 2–162; 2–251 and 2–252; 2–206 and 2–207; 2–270 and 2–271) of the four "youngest looking" segments of lineaments or scarps(?) between Havilah and the Isabella dams were somewhat more closely examined by R.E. Wallace (written commun., 1980) for interpretations of recency and sense of movement. He concluded that the fault is so nearly linear that it probably is strike slip and that the scarp features are so subdued that very recent movement—at least in major amounts—seems unlikely. Microgeomorphology, particularly offsets of streams and gulches, generally suggests no lateral offset or, in some places, possible left-lateral movement. Larger scale aerial photographs, however, would be necessary to document offset microgeomorphology. Wallace concluded that any strike slip on these segments is of considerable antiquity and is pre-Quaternary.

Field evidence of deformation within the Kern Canyon fault zone

In the following discussion and throughout this report, descriptive terms for cataclastically deformed rocks generally conform to the classification of Higgins (1971), as follows: (1) fault breccia—coarse-grained noncoherent or coherent fault material; (2) fault gouge—fine-grained noncoherent fault material; (3) microbreccia—coherent rocks that show granulation and crushing, but no fluxion structure; (4) protomylonite—coherent rocks that show some fluxion structure, but still preserve, in part, their original structure and texture; and (5) mylonite—coherent rocks dominated by fluxion structure, but containing fragments of remnant rock.

Evidence for deformation along the Breckenridge fault in the Breckenridge Mountain 15-minute quadrangle is documented in figure 6. Specific localities are noted, and somewhat detailed descriptions of the deformed rocks are given to indicate what kinds and how much evidence I had available to extend the Breckenridge fault southward toward Caliente, and to document my interpretation of the join between the Breckenridge and Kern Canyon faults. To the north, the presence and general position of the Kern Canyon fault are much less controversial (Smith, 1964); and the following, more generalized discussion of well-exposed fault evidence should suffice to document the degree and style of deformation.

Northward from the Havilah Pass area to the north boundary of the map area (pl. 1), sheared rocks are widespread along the Kern Canyon fault zone. Hydrothermal alteration, particularly of the granitic rocks, is also widespread in the deformed rocks. The style (intensity) of deformation generally ranges from microbreccia to protomylonite. True, finely milled down mylonite is much less common. Many of the deformed granitic rocks show a well-developed fluxion structure, but quartz, though slivered and in elongate masses, still retains local coherence. Nevertheless, there is at least local evidence of strong compressive deformation in which massive coarse-grained granitic rocks were converted into virtual "schist" and "paper shale."

Roadcuts on both sides of Havilah Pass exhibit strongly deformed granitic rocks. There, the zone of deformation is as much as 500 m thick, probably the widest development of shearing along the entire Kern Canyon fault zone. The east limit of this zone, the contact between granitic rocks on the west and gabbroic rocks on the east, is marked, at least locally, by a several-meter-thick zone of much deformed rocks, and is the zone of major fault movement. To the west, the limit of shearing is somewhat harder to define. Within the wide shear zone are numerous anastomosing slickensided shear planes, commonly marked by green-smeared surfaces. In most granitic specimens from this shear zone, the mafic minerals and plagioclase are strongly hydrothermally altered, and sericite, chlorite, calcite, and epidote are abundant. The green-smeared shear planes represent concentrations of these hydrothermal-alteration products. In addition, the green alteration material locally appears to have intruded the brecciated rocks. The shear planes define a well-developed foliation, and fluxion structure is present or incipiently developed, but mylonite is uncommon.

Along the west side of Hot Spring Valley southwest of Lake Isabella, the face of a conspicuous faultline scarp(?) exposes brown, hackly, sheared granitic rocks with slickensides and drawn-out, deformed quartz. Although most of these rocks are too friable to sample, locally coherent samples show strong brecciation, with granulated to slivered quartz. Strong hydrothermal alteration is reflected by green-smeared shear zones and irregular patches in the outcrop.

The peninsula between the two Isabella dams is one of the best places to see the sheared granitic rocks of the fault zone. Although the high water level of the lake at times turns the northern parts of the peninsula into islands, the southern part between the two dams is always accessible. The zone of shearing is as much as 200 m wide and is marked by a conspicuous anastomosing network of shear planes. Much of the shattered granitic rocks are barely cohesive, and alteration is abundant. These deformed rocks range from fault gouge and fault breccia to cohesive microbreccia and protomylonite. Thin sections show drawn-out, shattered, and granulated quartz, as well as broken and bent plagioclase crystals containing local zones of strong fluxion structure. Hydrothermal alteration has converted virtually all the original mafic minerals to muscovite, chlorite, and calcite.

East of the Corral Creek campground (about 10 km north of Kernville), the granite of Cannell Creek is strongly mylonitized in and near the fault zone. Quartz is in slivered elongate bands, and dark minerals are smeared out and extensively altered to chlorite, epidote, and muscovite.

About 3 km north of the Corral Creek area, strongly deformed granite that, in part, resembles "schist" or "paper shale" crops out in an alluviated flat near Gold Ledge Creek. These variously yellow-, orange-, and red-weathering, hydrothermally altered and deformed rocks in part are mylonite, with strongly drawn out bands of quartz bent around residual fragments of feldspar. Other rocks are protomylonite showing considerable fragmentation but only incipient alignment of quartz. It is unclear what granitic unit is the protolith of these strongly deformed rocks. The local abundance of coarse K-feldspar fragments, and the scarcity of mafic minerals and their hydrothermal-alteration products, suggest derivation from the granite of Cannell Creek.

Near Salmon Creek (north of the ovoid patch of alluvial material about 10 km south of the north boundary of pl. 1), strongly deformed granitic rocks and minor metasedimentary rocks are present along the fault zone. Some of these rocks are also mylonite containing impressively drawn out and segregated quartz layers. Remnant hornblende and large pinched-off biotite books suggest that the protolith for the deformed granitic rocks is the granodiorite of Castle Rock. Strongly deformed metasedimentary rocks (N. 10° W., about 70° E.) just north of this alluviated area but south of the deformed granitic rocks may be the strung-out end of a pendant that separates the Cannell Creek and Castle Rock granitic bodies in the Gold Ledge Creek area. If so, then the presence of these metasedimentary rocks would suggest that the right-lateral offset of the south contact of the granodiorite of Castle Rock is about 16 km (lower offset in fig. 8).

Selected samples of these deformed rocks north of Salmon Creek were analyzed for ^{18}O to help identify their protoliths (Ross, 1983). One sample identified in the field and in thin section as a mylonitized metasedimentary rock is strongly enriched ($\delta^{18}O = 16.6$ permil standard mean ocean water [SMOW]). Another sample from the same outcrop that was somewhat less deformed was thought to be a mylonitized granitic rock: this sample is somewhat enriched ($\delta^{18}O = 11.6$ permil SMOW). Although this enrichment is high for a primary igneous rock, its texture does not fit with that of other metasedimentary rocks of the area—the ^{18}O enrichment may reflect alteration. Just to the north, a protomylonite sample containing remnant hornblende and biotite was considered certainly a deformed granitic rock: the $\delta^{18}O$ of this sample (9.9 permil SMOW) supports this interpretation. However, a more mylonitized sample from the same outcrop that I interpreted to be derived from the granodiorite of Castle Rock (as is the above sample) is considerably enriched ($\delta^{18}O = 13.3$ permil SMOW). This sample, which, in my opinion, clearly had a granitic protolith, may also be enriched because of alteration. In summary, the ^{18}O data clearly identify one metasedimentary rock and one granitic rock, but show anomalous enrichment for two other deformed granitic rocks.

Near the north boundary of the map area (pl. 1), cataclastically deformed granitic rocks ranging from microbreccia to protomylonite, showing some fluxion structure, are well exposed along the fault zone. One microbreccia sample contains abundant fine-grained blue-black tourmaline. There, the main fault plane is sharply defined by dark-colored metasedimentary rocks striking into the fault at a low angle that are cut off abruptly against light-colored granitic rocks on the east. East of the main fault, which appears sharp and well defined on airphotos and on cursory examination in the field, the porphyritic granodiorite of Castle Rock is sheared for at least 1 km east of the fault along the Brush Creek road (about 2 km south of north boundary of pl. 1). A sample about 300 m east of the fault zone is a strong protomylonite with well aligned bands of quartz that form an anastomosing pattern through remnant feldspar crystals. About 1 km east of the main faultline, a coarsely porphyritic sample of granodiorite contains strongly deformed quartz drawn out in slivered layers that are pinched between resistant feldspar crystals. Even at this distance from the fault, a definite fluxion structure is overprinted on the granitic rocks.

The wide zone of compressive deformation of the granodiorite of Castle Rock near the north boundary of the map area (pl. 1) poses a special problem, as does the widespread compressive deformation throughout the outcrop of the granite of Cannell Creek to the south. Moore and du Bray (1978) observed that north of lat 36°00′ N. the fault zone is less than 100 m wide but that secondary, subparallel faults and shears with the same displacement sense are common within a zone as much as 1 km wide on both sides of the master fault. This zone of shearing is as much as 500 m wide south of Isabella Lake, but generally its east limit is well defined. North of Kernville, the west side of the fault zone is rather tightly defined, the east limit of deformation is harder to define, and, from here to the north, the thickness of the zone of deformation exceeds 1 km.

The west margin of the granodiorite of Castle Rock may be a protoclastic margin against an "older" fault, or faulting and deformation occurred together, or the granodiorite may have been deformed along a wide zone by later movement of the Kern Canyon fault. A sample of granodiorite from 1 km east of the faultline that shows strong quartz deformation also contains an undeformed K-feldspar phenocryst, 3 cm long. The presence of this phenocryst suggests that the deformation occurred in a still partially plastic intrusive rock.

The pervasively deformed granite of Cannell Creek has a strong cataclastic fabric (mylonite in part) that follows the trend of the Kern Canyon fault. The granite body grossly resembles a large dike that may also have intruded along the east side of the Kern Canyon fault while deformation was in progress.

Subsidiary faults to the Kern Canyon fault

A conspicuous zone of shearing and alteration associated with fissure-filling quartz, south of Kernville, was first studied by Prout (1940). I have named this zone the "Big Blue fault" after the Big Blue mine. Brecciated granitic and metasedimentary rocks are present, as are slickensided granitic rocks and, locally, mylonite that was derived from siliceous metasedimentary rocks. Locally, the breccia contains abundant fine-grained, pale-brown tourmaline. Although this shear zone has been considered (Treasher, 1948) to be the main Kern Canyon fault, with Prout (1940) I interpret it as a subsidiary fault west of the main Kern Canyon fault. The basement rocks are definitely offset by this fault, but the amount of offset is difficult to determine.

Other possible subsidiary shears have also been noted near the Kern Canyon fault that do not measurably offset the basement rocks. At locality 2 (fig. 6), a probable subsidiary fault to the main Kern Canyon fault has been described near its join with the Breckenridge fault. Three other shear zones, which are isolated from the main fault trace, were noted farther north. These shear zones, in otherwise massive and relatively fresh granitic outcrops, generally parallel, and are close to, the main Kern Canyon fault zone. All three zones show significant compressional deformation; they are not merely altered joints. No sense of movement has been determined for these presumably subsidiary faults, but the amount of movement must be relatively small because similar rocks are present on both sides of all three shears.

Mylonite zones, a few centimeters thick, that strike N. 20° E., dip about 70° W., and extend only a few meters on strike are present on the small promontory east of Wofford Heights. These mylonite zones are in felsic granitic rocks that resembles the granite of Bodfish Canyon.

A shear zone (N. 20° E., 80°–90° E.), about 2 m thick, whose strike length was not determined, is present in the fresh massive granite of Kern River on the east shore of Isabella Lake about 700 m NW. of Rocky Point (3 km south of Wofford Heights). The sheared granitic rocks have a pronounced fluxion structure and can best be described as protomylonite. Another shear zone that trends N. 10 W. and dips 70° to the east is present about 500 m to the north in the granite. The rocks here are also protomylonite but are not quite so "milled down" as in the more southern shear zone.

A conspicuous brown altered and sheared zone, tens of meters thick, cuts the massive, undeformed granodiorite of Mount Adelaide in a large roadcut along California Highway 178 about 1.5 km southwest of the Lake Isabella Junction. This zone, which trends N. 15° E. and dips about 80° E., contains strongly deformed granitic rocks with good fluxion structure that range from protomylonite to mylonite. The sheared rocks strongly resemble the deformed rocks along the peninsula between the two Isabella dams.

Tufa and travertine deposits

Tufa and travertine were seen at four localities in the map area (pl. 1). About 2 km south of the Walker Basin, small cappings of tufa and travertine are found along the small creek near Rhymes Spring (loc. 7, fig. 6). The source of these calcareous deposits is not known, but because there are no marble outcrops nearby, the tufa and travertine probably were deposited from circulating water from the Breckenridge fault zone. Three small tufa and travertine outcrops along Cannell Creek (about 4 km north of Kernville) were first mapped by Jenkins (1961), who noted that these deposits had been locally mined for "onyx" as building material. Marble is present in the metamorphic rocks east of these calcareous deposits, but their position, essentially capping the Kern Canyon fault zone, suggests that this material may also have been deposited from fluids from the fault zone.

Two other tufa and travertine deposits in the northern part of the map area (pl. 1) are definitely not connected to Kern Canyon fault circulation. On the east side of the Sierra Highway, east of the Limestone Cliff Campground (about 4 km south of the north boundary of pl. 1), calcareous deposits drape a steep slope that is underlain by the dark quartzite of Fairview. Upslope, several marble bodies supply a ready source for this secondary carbonate capping. A much smaller tufa and travertine mound is found about 4 km farther southwest, at the foot of an elongate marble body on the west side of the Kern River. There, the local source is obvious, and fault circulation is not evident. These latter two localities suggest some caution in considering the secondary carbonate deposits at Cannell Creek and Rhymes Spring to be fault related.

BASEMENT-ROCK CORRELATIONS

Airphoto lineaments, aligned saddles and swales, and other topographic evidence identify a probable line of faulting from Comanche Point northward to lat 36°00′ N. Widespread evidence of cataclastic deformation along this line leaves no doubt that compressive deformation and faulting have occurred. The amount and sense of the fault movement are controversial for at least some parts of this 200-km-long faultline. Certainly the southern segment (the White Wolf fault) moved a few meters in a left-lateral and reverse sense during its most recent activity in 1952. Also, the topography strongly suggests that some of the most recent activity on the central segment (the Breckenridge fault) has been normal-fault displacement of more than 1,000 m. In general, the best measure of total displacement on the fault zone as a whole and of the sense of that displacement is the distribution of basement rocks across the fault. The basement rocks along the Kern Canyon fault provide several tie points for determining the total offset and sense of movement; however, basement-rock units along the Breckenridge and White Wolf faults offer much less chance of determining the sense and amount of total offset.

Offset of seven basement-rock units in a right-lateral sense was documented north of lat 36°00′ N. by Moore and du Bray (1978). South of lat 36°00′ N., similar right-lateral offset of several other basement-rock units has also been documented (fig. 8).

The plutonic-rock units that best illustrate the offset south of lat 36°00′ N. are the granite of Kern River, the gabbro of Bodfish, and the granodiorites of Mount Adelaide and Alta Sierra. The granite of Kern River is a distinctive, relatively dark colored rock containing abundant mafic minerals and numerous small inclusions and centimeter-size clots of mafic minerals, with a surprising abundance of K-feldspar. The lithologic similarity of the body east of Lake Isabella (east of the fault) to the body north of Wofford Heights (west of the fault) is striking. Probably the single most distinctive feature of this unit is the abundance of small mafic mineral clots, which earned this rock the field name of "the clotty granite."

The olivine gabbro and related rocks of the Bodfish unit include outcrops containing abundant small olivine and pyroxene crystals, mantled by alteration products that produce a diagnostic spotty weathered surface. These mantled rocks also characteristically weather to distinctive piles of spheroids ("cannonballs"). The same unusual mantled rocks with spheroidal weathering are found in the mafic rocks south of the Wofford Heights marina. At one time, I considered the tonalite of Wofford Heights also to be correlative with the Bodfish mafic rocks, but further work showed that the Wofford Heights unit, though deceptively dark locally, generally contains considerable quartz and, on the whole, differs significantly. However, a small inclusion of mafic rocks near the west end of the tonalite of Wofford Heights contains mantled olivine that resembles mafic rocks of the Bodfish unit; this inclusion is probably a preserved remnant of the Bodfish body.

One of the best basement-rock correlations across the Kern Canyon fault is provided by the granodiorites of Mount Adelaide and Alta Sierra. The granodiorite of Mount Adelaide may be the easiest rock to recognize in the region, with its abundant coarse discrete and, in part, euhedral crystals of biotite and hornblende. It is intruded by the much finer grained granodiorite of Alta Sierra, which, because it locally coarsens to resemble somewhat the Mount Adelaide rocks, I consider to be a younger magma pulse related to the Mount Adelaide body. The two belts of Mount Adelaide rocks straddling the dikelike mass of Alta Sierra rocks can be matched up across the Kern Canyon fault to make a reconstruction compatible with the offsets of the Kern River and Bodfish bodies (fig. 10).

Farther south, the basement-rock distribution does not permit any firm correlations to be made across the faultline. Further detailed work might permit subdividing the large area of the tonalite of Bear Valley Springs and provide possible correlative tie points, but no obviously mappable variations showed up in my reconnaissance studies. The large Mount Adelaide body northwest of Caliente appears to end at the faultline; no correlative rocks have been found on the east side of the fault. Early in my studies, I tentatively correlated the Mount Adelaide body by Caliente with the body east of the fault to the north. The southern mass, the type area of the Mount Adelaide unit, is a true tonalite containing only minor K-feldspar. The northern mass on the east side of the fault contains much more K-feldspar and is a granodiorite, which, though texturally similar to the southern mass, is truly a separate pluton (and probably should eventually have a name other than "Mount Adelaide"!). Thus, a correlation of those two Adelaide bodies would seem to be ruled out on lithologic grounds alone. Furthermore, such a basement-rock correlation would contradict numerous other firm basement-rock correlations across this faultline.

I here tentatively propose a correlation between the quartz diorite of Caliente and the gneissic and granitic mixed rocks near Comanche Point. The Caliente rocks are a mixture of quartz diorite, tonalite, various types of gneiss, amphibolite, and small bodies of gabbro and ultramafic rocks. In essence, the Caliente rocks have affinities to both the tonalite of Bear Valley Springs and the gneiss, amphibolite, and granulite of San Emigdio-Tehachapi Mountains. The rocks near Comanche Point on the east side of the fault are a somewhat similar mixture of these same Bear Valley Springs and San Emigdio-Tehachapi units. The isolated bedrock hill on the north side of California Highway 223, about 7 km from the junction with California Highway 58 (fig. 1), is composed of somewhat fine grained tonalite marked with swarms of mafic inclusion and slivers of quartzofeldspathic gneiss. Though tentatively mapped as the tonalite of Bear Valley Springs, this tonalite sharply contrasts with the coarse, relatively homogeneous tonalite immediately across the fault to the southeast. This correlation is admittedly tentative in comparison with those of the Kern River, Bodfish, Mount Adelaide, and Alta Sierra units to the north. The correlation is plausible and consistent, however, with the right-lateral offset reflected by many other basement rocks farther north on this fault trend.

Some of the metamorphic-rock units can also be matched across the fault zone with an offset reconstruction,

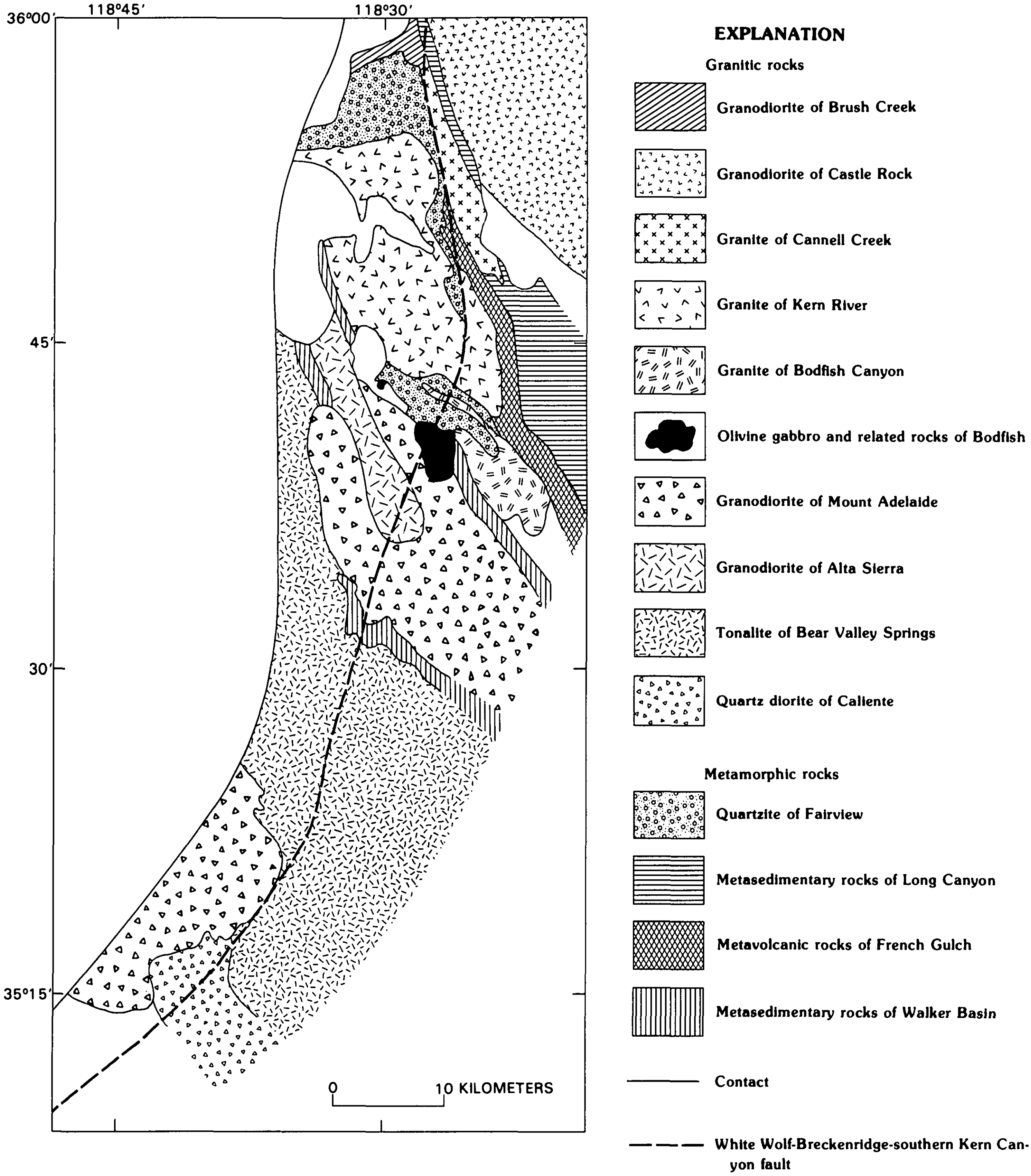


Figure 10. Generalized reconstruction of basement-rock units across the White Wolf-Breckenridge-southern Kern Canyon fault zone northward to lat 36°00' N. West of the fault zone, basement-rock units are shown as on plate 1; east of the fault zone, units are "adjusted."

comparable to the previously described plutonic-rock units (fig. 8). The pendant of metasedimentary rocks of Long Canyon that separates the Cannell Creek and Castle Rock bodies on the east side of the fault can be correlated with the metasedimentary rocks at the north margin of the map area (pl. 1) on the west side of the Kern Canyon fault. Both metamorphic bodies are dominantly well layered sequences of schist, impure quartzite, and calcareous rocks, and both have comparable strikes and dips.

The quartzite of Fairview south of Lake Isabella on the east side of the fault is also a good match for the Fairview body west of Wofford Heights. Both of these dominantly quartzite sequences are relatively dark colored and feature distinctive coarse to pebbly, angular, unsorted sand grains. The west-northwestward trend of both masses is somewhat anomalous to the general north-northwest-trending regional grain. Moreover, the north-southward strike of beds at the east end of the Wofford Heights mass and at the west end of the two quartzites south of Lake Isabella indicates that both the shapes and attitudes of these two quartzites bodies are compatible and permissive of correlation.

The metasedimentary-rock belt just north of the Walker Basin on the east side of the fault matches well, both in lithology and attitude, with the metasedimentary-rock belt across the fault northwest of Havilah. The reconstructed map pattern (fig. 10) shows two discontinuous, but approximately parallel, belts of metasedimentary rocks of the Walker Basin, with general northwestward trends striking right across the faultline. These two belts may be parts of one original metasedimentary-rock belt, now split apart by the Mount Adelaide and Alta Sierra masses. In any event, these northwest-trending belts of metasedimentary rocks suggest a tie point for fault offset.

CORRELATION PROBLEMS

Many plutonic- and metamorphic-rock units can be confidently correlated across the Kern Canyon fault zone, and one less firm basement-rock correlation is suggested across the White Wolf fault. The crossfault match is not perfect, however, and even the reconstruction of figure 10 requires a little "fudging"; the resulting "match" points out units that do not correlate across the fault.

Two granitic units, which are presumably cut off by the Kern Canyon fault, do not appear on the opposite side of the fault. The elongate, highly sheared felsic granite of Cannell Creek is transected at a low angle by the Kern Canyon fault, but no counterpart of this distinctive and easily recognized unit has been seen west of the fault. The Cannell Creek body may be a relatively narrow, dikelike body emplaced between relatively north-south trending metamorphic rocks, and a relatively straight west boundary of the granite body served as a weak zone along which the Kern Canyon fault later propagated. Alternatively, the granite body could have intruded and butted against the already-formed Kern Canyon fault. Neither interpretation is particularly attractive, but either would permit the granite of Cannell Creek to be restricted to one side of the fault.

The granodiorite of Brush Creek butts against the west side of the Kern Canyon fault near the north edge of the map area (pl. 1), and no counterpart was found east of the fault. This granodiorite appears to pinch out rapidly between bounding metasedimentary rocks, and there may have been very little, if any, of it to the east to be sheared off. Also, the ground-up eastern part could be spread out along the fault and thus not easily recognizable.

The tonalite (body) of Mount Adelaide northwest of Caliente also is abruptly terminated along the west side of the Breckenridge fault, on the basis of my reconnaissance. No counterpart of this distinctive rock type has been found to the east, and, almost surely, one does not exist. Therefore, I conclude that this linear fault contact is "inherited" from a generally linear intrusive contact. The northwest boundary of this tonalite body (beyond the area of pl. 1), which is unquestionably intrusive, also is generally linear and trends northeast and subparallel to the Breckenridge fault. Evidence is suggestive, but certainly not compelling, that the blocky-shaped tonalite body was forced in along some preexisting northeast-trending structure—fault, joint, or metamorphic trend.

The reconstruction (fig. 10) shows that the belt of the metavolcanic rocks of French Gulch strikes north-southerly into dominantly quartzitic rocks of the Fairview unit across the Kern Canyon fault. This contrast is not so drastic as the map pattern suggests. Metavolcanic rocks are rather widespread and locally common in the Fairview rocks, and I have always considered the French Gulch and Fairview rocks to be closely related and in sharp contrast to the more schistose rocks, both to the east and west (the Long Canyon and Walker Basin metamorphic units).

In summary, the present distribution of basement-rock units can be realigned with a reconstruction of right-lateral movement on the White Wolf-Breckenridge-Kern Canyon fault, although some basement-rock units do not neatly fit with this reconstruction. I have proposed a justification, or a rationalization, for each "nonfitting" unit. Nevertheless, the correlation problems still perplex me and leave a clear-cut fault reconstruction elusive.

EDISON FAULT PROBLEM

The east-west-trending Edison fault, as mapped by Dibblee and Chesterman (1953), cuts across the northeastward extension of the White Wolf fault as proposed in this report (fig. 11). West of the White Wolf fault near the west boundary of the Breckenridge 15-minute quadrangle, Dibblee and Chesterman (1953) noted normal displacement of more than 1,500 m on the Edison fault. Immediately east of the pro-

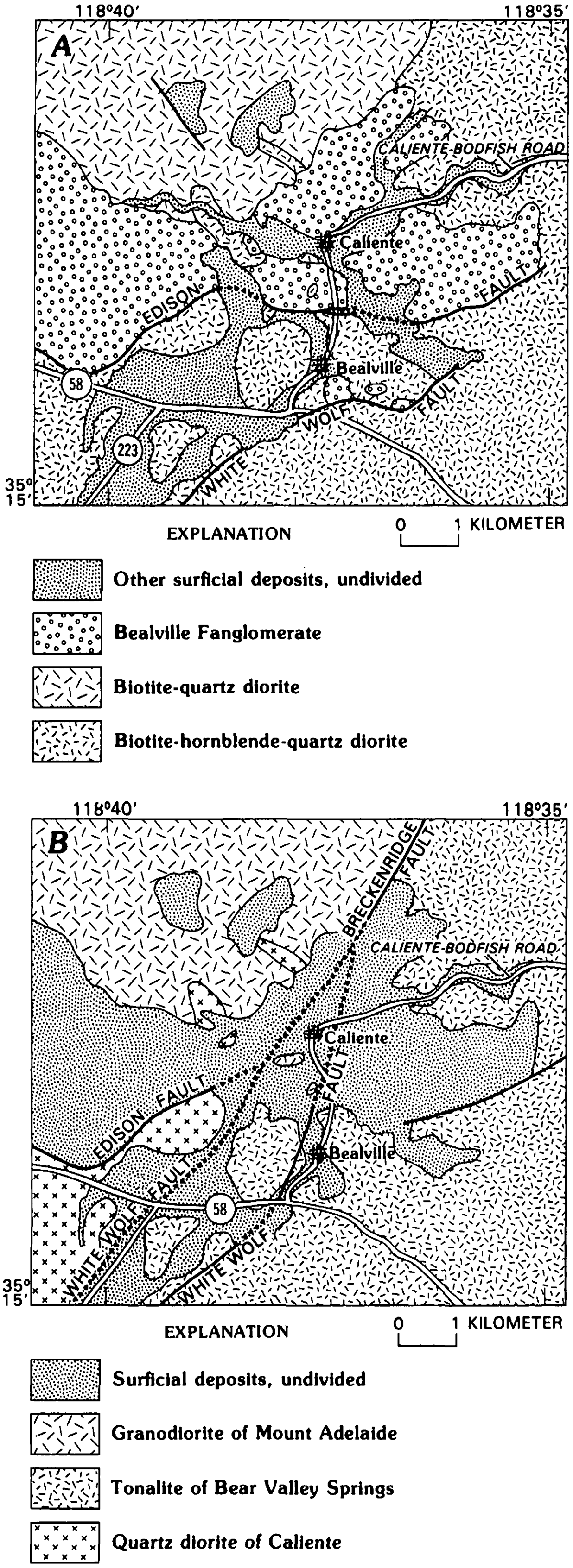


Figure 11. Alternative interpretations of the Edison fault in the Caliente, Calif., area. *A*, Dibblee and Chesterman (1953). *B*, This report.

posed extension of the White Wolf fault, granitic basement is exposed on both sides of the Edison fault, which appears to die out within the granitic basement. The Edison fault may be cut off by the White Wolf fault, and the more eastern segments are White Wolf strands (as shown on pl. 1). Note that the eastern segment nearly parallels the line of recent (1952) breakage on the White Wolf fault (fig. 2) that splays off eastward away from what I consider to be the main fault trend. The plot of aftershock epicenters (fig. 3) suggests that the White Wolf fault extends considerably northward of the Edison fault.

I examined the segment of the Edison fault along and west of the Bodfish-Caliente road (between Bealville and Caliente, fig. 11*A*) and found that, along this road, the fault zone is masked by a covered interval of about 70 m. About 0.3 km west of the road, where Dibblee and Chesterman (1953) show an attitude on the fault, poor exposures of both granitic rocks and the Bealville Fanglomerate are present in a steep, narrow gully. To me, the relations there are equivocal, and I was unable to decide whether the contact is a fault or a depositional contact with the fanglomerate lapping over the granitic rocks. Dibblee and Chesterman's interpretation that two small hills of granitic rocks north of the gully locality are depositionally overlapped by fanglomerate suggests that this same relation may pertain along the "fault segment" near the Bodfish-Caliente road. Therefore, I propose, as an alternate interpretation, the relations shown in figure 11*B* for the fault segment in question. The Edison fault, by this interpretation, would be cut off by the White Wolf fault. If, however, Dibblee and Chesterman's interpretation (fig. 11*A*) is correct, then a serious obstacle exists to any connection of the White Wolf and Breckenridge faults.

AGE OF FAULTING

The age of inception of faulting or, at least, the age of the earliest recorded evidence of faulting on the Kern Canyon fault south of lat 36°00' N. is probably provided by the wide zone of cataclastic deformation near the north margin of the map area (pl. 1). There, the granodiorite of Castle Rock is deformed over a width of at least 1 km along its west margin, which abuts the Kern Canyon fault. Textures in the granodiorite suggest that the deformation occurred during emplacement of the granodiorite. If this relation is true, then the intrusive age of the granodiorite is at least a minimum age on the inception of the Kern Canyon fault. Presently, there are two Rb-Sr whole-rock ages of 86±5 Ma (R.W. Kistler, written commun., 1983) and 90 Ma (Kistler and Peterman, 1978), and one K-Ar age on biotite of 81±2 Ma (Bergquist and Nitkiewicz, 1982) for the Castle Rock body. Thus, the present data suggest that the Kern Canyon fault was active about 85 to 90 Ma.

Burnett (1976) mapped a felsic pluton that he interpreted to be intrusive into the Kern Canyon fault zone. Near the Chagoopa Falls Ranger Station (about 50 km north of the map area, pl. 1) he obtained a K-Ar age on plagioclase of 77 ± 15 Ma (insufficient biotite and hornblende were present to date those minerals). Moore and du Bray (1978) interpreted Burnett's felsic pluton as oxidized and otherwise altered granitic rocks in the fault zone, and suggested that no young pluton intrudes the Kern Canyon fault zone near the Chagoopa Falls Ranger Station.

I suggested earlier in this report that the granite of Cannell Creek may be a dikelike mass intruding along an already-existing Kern Canyon fault, or that the granite might have been deformed by fault movement during its emplacement. A review of all the thin sections and stained slabs from the granite of Cannell Creek showed that strong cataclastic deformation is limited to the northern part of the body (fig. 12). Samples near Corral Creek and Cannell Creek are strongly deformed to protomylonite and mylonite. Nothing in the samples studied suggested protoclastic or syntectonic deformation. If the deformation is connected to Kern Canyon fault movement, which seems likely, this granite predates the deformation. The dashed contact in figure 12 separates samples in the southern part of the granite body that are less intensely deformed and even locally undeformed. These less deformed rocks also do not show any obvious evidence of protoclastic or syntectonic deformation. The present sparse dates would then suggest that the shearing episode postdates the probable intrusive age of about 110 Ma based on the Rb-Sr data. I have no ready explanation for the "young" K-Ar biotite ages of 50 and 55 Ma for this granite reported by Jenkins (1961) and Evernden and Kistler (1970). Jenkins suggested that this is a deformation age, which is certainly possible, because no intrusive bodies of that age are known in the area.

A whole-rock age of 3.5 ± 0.1 Ma (Dalrymple, 1963) on basalt east of Castle Rock (see fig. 8) is widely cited as a younger age limit on the Kern Canyon fault, because the dated flow is considered to cap the fault. Certainly the basalt postdates any significant movement on the fault. A rubbly basalt weathering surface could easily obscure small fault displacements, and a study of the lower contact of the basalt with the fault zone is needed to confirm that no movement has occurred in the past 3.5 Ma.

A cursory study of the youngest-appearing scarplines from Isabella Lake to Havilah suggested to R.E. Wallace (written commun., 1980) that any movement was pre-Quaternary. Thus, present data suggest deformation and right-lateral strike-slip faulting along the Kern Canyon fault zone about 90–80 Ma, another possible, but doubtful, deformational event about 55–50 Ma, and much later and different styles of deformation on the White Wolf and Breckenridge segments of the fault zone. The later and seemingly contradictory movements on the Breckenridge and White Wolf segments of the fault zone were responses to much more recent stress patterns on this old line of right-lateral strike-slip breakage.

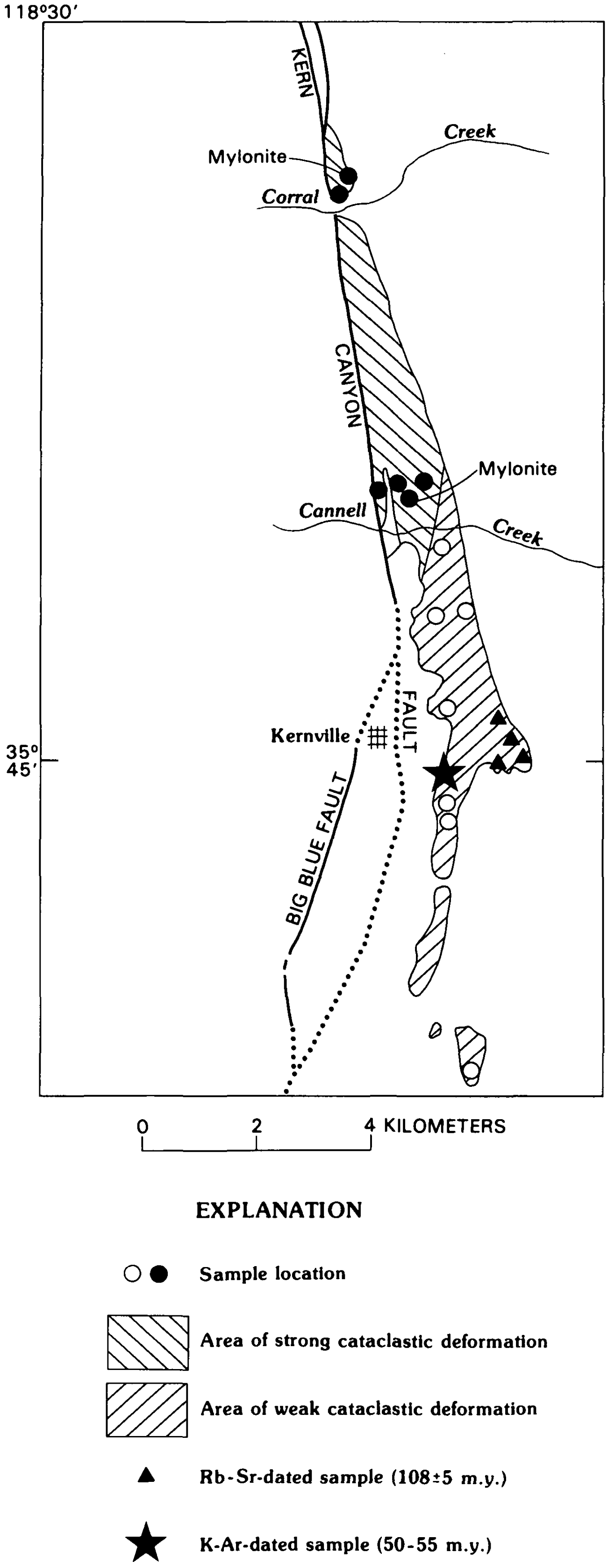


Figure 12. Kernville, Calif., area, showing locations of samples of the granite of Cannell Creek.

SEISMICITY

Current active seismicity on the White Wolf fault is unquestionable. Since the $M = 7.7$ event of April 1952, there has been a constant murmuring of aftershocks. These aftershocks follow a rather consistent pattern in which one node of activity lies near the original epicentral area and another, broad node of activity, some 60 km to the northeast, straddles the north end of the White Wolf fault and the Breckenridge fault (fig. 3). Notable also on figure 3 is the almost complete absence of epicenters along or near the central section of the White Wolf fault. This double-nodal pattern was still evident in 1983 in a plot of southern California earthquakes (Allen, 1983). The same plot also shows a scattering of small ($M < 4$) shocks along and near the Breckenridge and Kern Canyon faults northward to lat 36°00′ N.

The Kernville area was rattled by a series of earthquakes that started in fall 1983; the largest event was $M = 4.7$ (L.M. Jones, written commun., 1984). These shocks, which were centered near Big Meadow (pl. 1), were not connected with the Kern Canyon fault. To associate these tremors with the Kern Canyon fault would require a rather low dip on the fault, which the map pattern, field studies, and the focal mechanisms of these events do not support.

Chester Marliave (in Treasher, 1948, pt. 2, p. 17) stated: "During the year 1868 there were many severe earthquakes in this region, six of which, including many associated aftershocks, very probably occurred on the Kern Canyon fault. The most severe shock occurred in October, which was reported to have an intensity of 10 on the Rossi-Forel scale. This corresponds to about 8.5 on the Mercalli scale ***." Although it is extremely chancy to assign a magnitude to that event, Barosh (1969, fig. 7) suggested that the best estimate would be about $M = 6.5$. In a tabulation of earthquake shocks in the Kern Canyon area, Treasher (1948) listed a modified Mercalli intensity 9 event in 1868, which he stated was located along the upper Kern River and was accompanied by more than 500 aftershocks. Although the 1868 events were assumed to be on the Kern Canyon fault, it now seems more likely that they were located near the present activity. The early newspaper accounts of the 1983–84 events suggested that this activity was on the Kern Canyon fault, but instrumental locations showed it to be at least 10 km east of the fault.

Although Treasher (1948) listed other earthquakes in the Kern Canyon area and plotted some epicenters on and near the Kern Canyon and Breckenridge faults, there is no hard evidence of any significant historical seismicity along these faults. A compendium of seismic events in the southern California region from 1932 through 1972 (Hileman and others, 1973) reports several events whose epicenters plot relatively close to, but generally a few kilometers east of, the Kern Canyon fault zone. The error circles of these events indicate that they could have occurred in the Kern Canyon fault zone. However, the rather closely monitored seismic swarm east of the Kern Canyon fault zone that occurred in 1983–84 (Jones and others, 1984) suggests that these earlier seismic events are more likely related to other seismic swarms near the Kern Canyon fault zone which define a rather conspicuous linear trend about 10 km east of the Kern Canyon fault zone (fig. 13).

SUMMARY AND SPECULATIONS

The Sierra Nevada batholith is broken by a conspicuous zone of faulting that extends from the headwaters of the Kern River southward to the north flank of Wheeler Ridge. If some discontinuous, but onstrike, faults north of the Kern River headwaters are added, the strike length of the fault is about 200 km. From its north limit southward to Kernville, the fault trend is essentially north-southward or slightly west of north. From Kernville to the Walker Basin the fault trend is about N. 20° E., and farther southwest the fault bends around, so that at its south end the trend is about N. 65° E. No other fault of this extent is known within the Sierra Nevada batholith. Either significantly or, possibly, only coincidentally, this line of faulting approximately parallels the trend of the combined Sierra Nevada and Garlock faults. The northern part of the fault zone was first described in the very early 1900's, and since then, numerous investigations have been made of various parts of the fault zone. Few of these studies, generally of specific parts of the fault zone, have addressed the question whether this is a single major fault zone or several separate and distinct, fortuitiously aligned faults. The continuity of this 200-km-long fault zone appears to be incontrovertible on any small-scale map compilation. Nevertheless, some disquieting contradictions suggest caution in assuming that it is, indeed, one master fault.

Firm evidence exists for the right-lateral offset of numerous basement-rock units by as much as some 15 km from the north end of the fault zone southward to the Walker Basin (fig. 8; Moore and du Bray, 1978). The right-lateral fault displacement progressively increases southward to about lat 36°00′ N., but farther south the offset appears to decrease, although the evidence there is less conclusive. South of the Walker Basin, only one tentative basement-rock correlation has been suggested—a match of gneissic and plutonic rocks between the areas near Caliente and Comanche Point. This correlation suggests that right-lateral offset of the basement rocks extends at least as far southward as Comanche Point.

The most recent activity on the White Wolf fault was left-lateral and reverse-fault displacement, as documented convincingly by the 1952 Arvin-Tehachapi earthquake. Left-lateral and reverse-fault movements are also indicated by displacements of Eocene, Miocene, and upper Quaternary deposits, on the basis of subsurface data (Hill, 1955; Stein

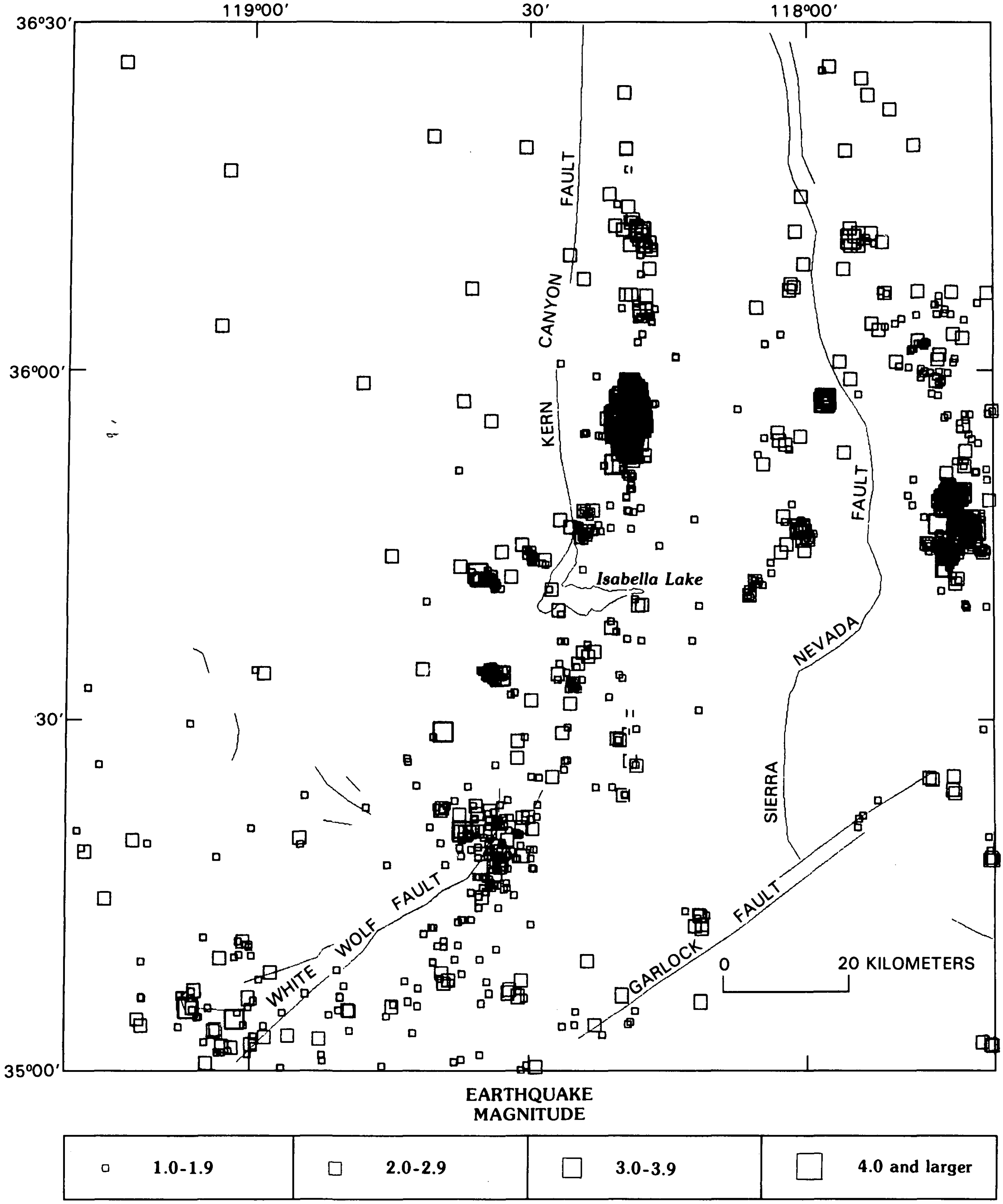


Figure 13. Southern Sierra Nevada, showing locations of earthquake epicenters for the period January 1, 1983, through June 1984. Data from L.M. Jones (written commun., 1984).

and Thatcher, 1981; Webb, 1981). If the basement-rock correlation is valid, then the sense of movement has changed on the White Wolf fault sometime since its inception.

Stein and Thatcher (1981) observed that the left-lateral offset on the White Wolf fault has increased significantly during the late Quaternary and that the left-lateral component is "decaying" to the northeast. These fairly recent changes in both rate and style of deformation reflect the increasing influence of a new stress regime imparted by the northward-pushing Big Bend section of the San Andreas fault, on an old basement break. The generally east-west trending Pleito thrust fault, near the south end of the White Wolf fault, probably reflects this same stress pattern, and speculation suggests that these two faults are related and, possibly, connected.

Burchfiel and Davis (1980, p. 249) suggested that the southern Sierra Nevada was involved in a "major right-lateral intraplate oroclinal bend," which can be dated no closer than "pre-late Cenozoic." Such an oroclinal flexure could have provided the force that cracked the southern part of the Sierra Nevada batholith and produced the White Wolf-Breckenridge-Kern Canyon fault. If, as I suggested earlier, the granodiorite of Castle Rock is syntectonic, then the inception of oroclinal flexing could have been about 80 to 90 Ma. If an oroclinal flexure of this age is acceptable, then not only is there a plausible cause for a tear in the batholith, but also the curved south end of the tear from this flexural event might have been suitably oriented to be later affected by the San Andreas stress regime.

If the basement fault is, in fact, a result of oroclinal bending of the batholith, then the amount of right-lateral offset might be expected to have increased progressively southward as the degree of bending increased. Offset on the fault does increase rather systematically southward to about lat 36°00′ N., but then farther to the south the offset appears to decrease. This southward decrease may be a reflection of the "cancelling out" of some of the original right-lateral movement in the newer faulting regime, which favors left-lateral offset.

Earlier discussion has suggested that the Breckenridge fault is continuous with the Kern Canyon fault to the north and with the White Wolf fault to the south. The most recent movement on the Breckenridge fault appears to be normal dip-slip displacement, with the east side down more than 1,000 m, which is contradictory to the inferred original right-lateral basement displacement on this fault. The Breckenridge fault, taken alone, resembles a basin-and-range normal fault; it might be considered analogous, on a small scale, to the frontal fault on the east side of the Sierra Nevada. Physiographic evidence of east side down, which is so conspicuous in the Walker Basin, also is discontinuously evident northward to about the latitude of Kernville. Within this same interval, the fault trends relatively straight at about N. 20° E., in rather marked contrast to the north-south-trending segment to the north and the more east-westerly trending segment to the south. Although the explanation for this relation is unclear, a fairly recent increase in the basin-and-range pattern of extensional tectonics may have permitted a sag in the basement along this particular orientation. The north-southerly aligned seismic activity of 1983–84, north of Isabella Lake and east of the Kern Canyon fault (fig. 13), most probably also reflects similar basin-and-range extension (focal-plane solutions for these small earthquakes indicate normal-fault movement, with the east side down).

In conclusion, I tentatively submit that the White Wolf-Breckenridge-Kern Canyon fault zone is one continuous right-lateral tear in the Sierra Nevada batholith. It may have originated some 80 to 90 Ma during the last great magmatic pulse of the Sierra Nevada batholith, in response to simultaneous oroclinal folding of the batholith. Nevertheless, perplexing contradictions in the recent history of the fault remain that, despite my attempts at resolution, require more explanatory powers than I have been able to muster here.

REFERENCES CITED

Allen, C.R., 1983, Southern California seismic arrays, *in* Jacobson, M.L., compiler, Summaries of technical reports, volume XVII: U.S. Geological Survey Open-File Report 83–918, p. 197–198.

Barosh, P.J., 1979, Use of seismic intensity data to predict the effects of earthquakes and underground nuclear explosions in various geologic settings: U.S. Geological Survey Bulletin 1279, 93 p.

Bayley, R.W., and Muehlberger, W.R., compilers, 1968, Basement rock map of the United States, exclusive of Alaska and Hawaii: Washington, U.S. Geological Survey, scale 1:2,500,000.

Bergquist, J.R., and Nitkiewicz, A.M., 1982, Geologic map of the Domelands Wilderness and contiguous roadless areas, Kern and Tulare Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map, MF–1395–A, scale 1:48,000.

Burchfiel, B.C., and Davis, G.A., 1981, Mojave Desert and environs, *in* Ernst, W.G., ed., The geotectonic development of California (Rubey volume 1): Englewood Cliffs, N.J., Prentice-Hall, p. 217–252.

Burnett, J.L., 1976, Kaweah Peaks pluton and its relationship to the age of the Kern Canyon fault, Tulare County, California: California Division of Mines and Geology Map Sheet 35, 7 p., scale 1:62,500.

Buwalda, J.P., and St. Amand, Pierre, 1955, Geological effects of the Arvin-Tehachapi earthquake, [chap.] 5 *of* Geology, pt. 1 *of* Oakshott, G.B., ed., Earthquakes in Kern County, California, during 1952: California Division of Mines Bulletin 171, p. 41–56.

Cisternas, Armando, 1963, Precision determination of focal depths and epicenters of local shocks in California: Seismological Society of America Bulletin, v. 53, no. 5, p. 1075–1083.

Cohee, G.V., chairman, 1962, Tectonic map of the United States, exclusive of Alaska and Hawaii: Washington, U.S. Geological Survey, scale 1:2,500,000, 2 sheets.

Dalrymple, G.B., 1963, Potassium-argon dates of some Cenozoic volcanic rocks of the Sierra Nevada, California: Geological Society of America Bulletin, v. 74, no. 4, p. 379–390.

Dibblee, T.W., Jr., 1955, Geology of the southeastern margin of the San Joaquin Valley, California, [chap.] 2 *of* Geology, pt. 1 *of* Oakeshott, G.B., ed., Earthquakes in Kern County, California, during 1952: California Division of Mines Bulletin 171, p. 23–34.

Dibblee, T.W., Jr., and Chesterman, C.W., 1953, Geology of the Breckenridge Mountain quadrangle, California: California Division of Mines Bulletin 168, 56 p.

du Bray, E.A., and Dellinger, D.A., 1981, Geology of the Golden Trout Wilderness, southern Sierra Nevada, California: U.S. Geological Survey Miscellaneous Field Studies Map MF–1231–A, scale 1:48,000.

Engel, Rene, 1963, Kern River area, *in* Guidebook for Seismological Study Tour, 1963 meeting of the International Union of Geodesy and Geophysics: China Lake, Calif., U.S. Naval Ordnance Test Station, p. 49–56.

Evernden, J.F., and Kistler, R.W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 42 p.

Fox, L.K., 1981, Compositional variations and implications of petrogenesis of the Kernville pluton, southern Sierra Nevada, California: Princeton, N.J., Princeton University, senior thesis, 77 p.

Higgins, M.W., 1971, Cataclastic rocks: U.S. Geological Survey Professional Paper 687, 97 p.

Hileman, J.A., Allen, C.R., and Nordquist, J.M., 1973, Seismicity of the southern California region, 1 January 1932 to 31 December 1972: Pasadena, California Institute of Technology, Seismological Laboratory, 487 p.

Hill, M.L., 1955, Nature of movements on active faults in southern California, [chap.] 4 *of* Geology, pt. 2 *of* Oakeshott, G.B., ed., Earthquakes in Kern County, California, during 1952: California Division of Mines Bulletin 171, p. 37–40.

Hoots, H.W., 1930, Geology and oil resources along the southern border of San Joaquin Valley, California, *in* Contributions to economic geology (short papers and preliminary reports), 1929. Part II.—Mineral fuels: U.S. Geological Survey Bulletin 812, p. 243–332.

Jenkins, S.F., 1961, A structural study of a portion of the Kernville Series: Berkeley, University of California, M.A. thesis, 83 p.

Jennings, C.W., compiler, 1975, Fault map of California with locations of volcanoes, thermal springs, and thermal wells: California Division of Mines and Geology California Geologic Data Map Series Map 1, scale 1:750,000.

Jones, L.M., Johnson, C.E., and Dollar, R.S., 1984, Swarms in the southern Sierra Nevada: Earthquake Notes, v. 55, no. 1, p. 22.

King, P.B., compiler, 1969, Tectonic map of North America: Washington, U.S. Geological Survey, scale 1:5,000,000.

King, P.B., and Beikman, H.M., compilers, 1974, Geologic map of the United States, exclusive of Alaska and Hawaii: Washington, U.S. Geological Survey, scale 1:2,500,000.

Kistler, R. W., and Peterman, Z.F., 1973, Variations in Sr, Rb, K, Na, and initial Sr^{87}/Sr^{86} in Mesozoic granitic rocks and intruded wall rocks in central California: Geological Society of America Bulletin, v. 84, no. 12, p. 3489–3512.

———1978, Reconstruction of crustal blocks of California on the basis of initial strontium isotopic compositions of Mesozoic granitic rocks: U.S. Geological Survey Professional Paper 1071, 17 p.

Kupfer, D.H., Muessig, Siegfried, Smith, G.I., and White, G.N., 1955, Arvin-Tehachapi earthquake damage along the Southern Pacific railroad near Bealville, California, [chap.] 7 *of* Geology, pt. 1 *of* Oakeshott, G.B., ed., Earthquakes in Kern County, California, during 1952: California Division of Mines Bulletin 171, p. 67–74.

Lawson, A.C., 1904, The geomorphogeny of the Upper Kern Basin: University of California Publications, Department of Geology Bulletin, v. 3, no. 15, p. 291–376.

———1906a, The geomorphic features of the Middle Kern: University of California Publications, Department of Geology Bulletin, v. 4, no. 16, p. 397–409.

———1906b, The geomorphogeny of the Tehachapi Valley system: University of California Publications, Department of Geology Bulletin, v. 4, no. 19, p. 431–462.

Miller, W.J., and Webb, R.W., 1940, Descriptive geology of the Kernville quadrangle, California: California Journal of Mines and Geology, v. 36, no. 4, p. 343–378.

Moore, J.G., 1981, Geologic map of the Mount Whitney quadrangle, Inyo and Tulare counties, California: U.S. Geological Survey Geologic Quadrangle Map GQ–1545, scale 1:62,500.

Moore, J.G., and du Bray, Edward, 1978, Mapped offset on the right-lateral Kern Canyon fault, southern Sierra Nevada, California: Geology, v. 6, no. 4, p. 205–208.

Moore, J.G., and Sisson, T.W., 1984, Geologic map of the Kern Peak quadrangle, Tulare County, California: U.S. Geological Survey Geologic Quadrangle Map GQ–1684, scale 1:62,500.

Prout, J.W., Jr., 1940, Geology of the Big Blue group of mines, Kernville, California: California Journal of Mines and Geology, v. 36, no. 4., p. 379–421.

Ross, D.C., 1983, Generalized geologic map of the southern Sierra Nevada, California, showing the location for which K-Ar radiometric age data and Rb/Sr data have been determined: U.S. Geological Survey Open-File Report 83–231, scale 1:250,000.

Saleeby, J.B., Goodin, S.E., Sharp, W.D., and Busby, C.J., 1978, Early Mesozoic paleotectonic-paleogeographic reconstruction of the southern Sierra Nevada region, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 2: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 311–336.

Sams, D.B., Saleeby, J.B., Ross, D.C., and Kistler, R.W., 1983, Cretaceous igneous, metamorphic, and deformational events of the southernmost Sierra Nevada, California [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 294.

Smith, A.R., compiler, 1964, Bakersfield sheet *of* Geologic map of California: California Division of Mines and Geology, scale 1:250,000.

Stein, R.S., and Thatcher, Wayne, 1981, Seismic and aseismic deformation associated with the 1952 Kern County, California, earthquake and relationship to the Quaternary history of the White Wolf fault: Journal of Geophysical Research, v. 86, no. B6, p. 4913–4928.

Treasher, R.A., compiler, 1948, Definitive project report, Isabella project, Kern River, California; part IV, Dam and appurtenances; appendix A, Geology: U.S. Army Corps of Engineers, Sacramento District, 2 v.

———1949, Kern Canyon fault, Kern County, California [abs.]: Geological Society of America Bulletin, v. 60, no. 12, pt. 2, p. 1957–1958.

Webb, R.W., 1981, Stevens and earlier Miocene turbidite sandstones, southern San Joaquin Valley, California: American Association of Petroleum Geologists Bulletin, v. 65, no. 3, p. 438–465.

———1936, Kern Canyon fault, southern Sierra Nevada: Journal of Geology, v. 44, p. 631–638.

———1955, Kern Canyon lineament, [chap.] 3 *of* Geology, pt. 1 *of* Oakeshott, G.B., ed., Earthquakes in Kern County, California, during 1952: California Division of Mines Bulletin 171, p. 35–36.