The Red Bluff Pediment—A Datum Plane For Locating Quaternary Structures in the Sacramento Valley, California

U. S. GEOLOGICAL SURVEY BULLETIN 1628

Frontispiece. High-altitude oblique aerial photograph of the northern Sacramento Valley. Sutter Buttes are in the lower center. The Red Bluff pediment is outlined along the northern valley margin.

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By EDWARD J. HELLEY and CHERYL JAWOROWSKI

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CONTENTS

FIGURES

The Red Bluff Pediment—A Datum Plane for locating Quaternary Structures in the Sacramento Valley, California

By Edward J. Helley *and* Cheryl Jaworowski

Abstract

Throughout much of the Sacramento Valley, California, we have mapped an erosion surface of low relief and great regional extent that is between 0.45 and 1.08 million years old. This surface, which is mantled by 1 to 10 meters of bright-red sandy gravel of the Red Bluff Formation, records the Quaternary expression of late Cenozoic folding and faulting. The erosion surface (the Red Bluff pediment) was formed by lateral planation, probably when through-flowing drainage was impeded during a relatively arid climate. Where it is exposed by down-cutting streams, the erosion surface can be reconstructed by contouring elevations at the base of the overlying gravel. If the surface was undeformed, we would expect a map showing smooth slopes toward the local base level, the Sacramento River. For the Red Bluff pediment to be useful as a structural datum, the original slope of the erosion surface must be determined. To approximate this original slope, the contours of the upper surface of the upper member of the Modesto Formation (14,000 to 26,000 yrs B.P.), which slopes toward the Sacramento River, were subtracted from the contours on the Red Bluff pediment. The upper surface of the Modesto shows no deformation, only a simple slope toward the Sacramento River. We contoured the Red Bluff pediment in the Corning area, where it is known to be deformed into two domes. Contours drawn on the upper surface of the Modesto in the same area were subtracted from those drawn on the Red Bluff pediment. The residual contour map shows two domes, as well as a possible northwest-trending fault that separates the domes left laterally. The deformation is very similar to that shown by contours along the subsurface gas-producing sands of the Tehama Formation. Where sufficient data points exist, we have contoured the Red Bluff pediment elsewhere, using a computer graphics system, and have found similar results: the pediment appears deformed. This deformation must postdate the erosion surface; that is, it must be younger than 0.45 million years. The deformation may reflect deeper structures, and, if so, these techniques provide a rapid, practical, and inexpensive exploration tool.

INTRODUCTION

The distinct bright-red gravels in and around the town of Red Bluff were named the Red Bluff Formation by Diller (1894). He proposed that these gravels represented evidence of late Tertiary uplift of the Coast Ranges. Later, Bryan (1923) recognized the more widespread occurrence of the Red Bluff, and he showed that it was deformed at the Corning Domes, Chico monocline, and Hungry Hollow fault, today called the Dunnigan Hills and Zamora faults. During ground-water studies in the Sacramento Valley, Olmsted and Davis (1961) recognized that the Red Bluff truncated the underlying Tehama and Tuscan Formations regionally. They also noted that the maximal soil profile developed on the Red Bluff forms hardpans which are aquicludes, preventing the percolation of surface waters into the subsurface reservoir. The hardpans form ledges which have aided in the mapping of the Red Bluff Formation. The full extent of the Red Bluff throughout the Sacramento Valley has recently been mapped by Helley and Harwood (1983).

RED BLUFF PEDIMENT

Pediments are recognized as gently sloping rock-floored erosion surfaces or plains of low relief. They may also be cut across older alluvium. They develop by subaerial agents, mostly running water in arid or semiarid regions, usually at the foot of an abrupt and receding mountain front. Pediments are commonly covered by a thin veneer of locally derived alluvium in transit across the surface.

Pediment development, today, appears confined to arid and semiarid environments with closed or impeded drainage, such as the Great Basin and parts of the Colorado Plateau (Rich, 1935; Howard, 1942; Tuan, 1959; Hunt, 1969). Most previous workers agree that a primary mechanism for development is lateral planation by streams and rills with a fixed base level (Bryan, 1922; Howard, 1942). Denny (1967) believed pediments can also develop in humid as well as arid environments and cited examples in the Eastern United States. It may be that impeded drainage is more important than climate for controlling pediplanation.

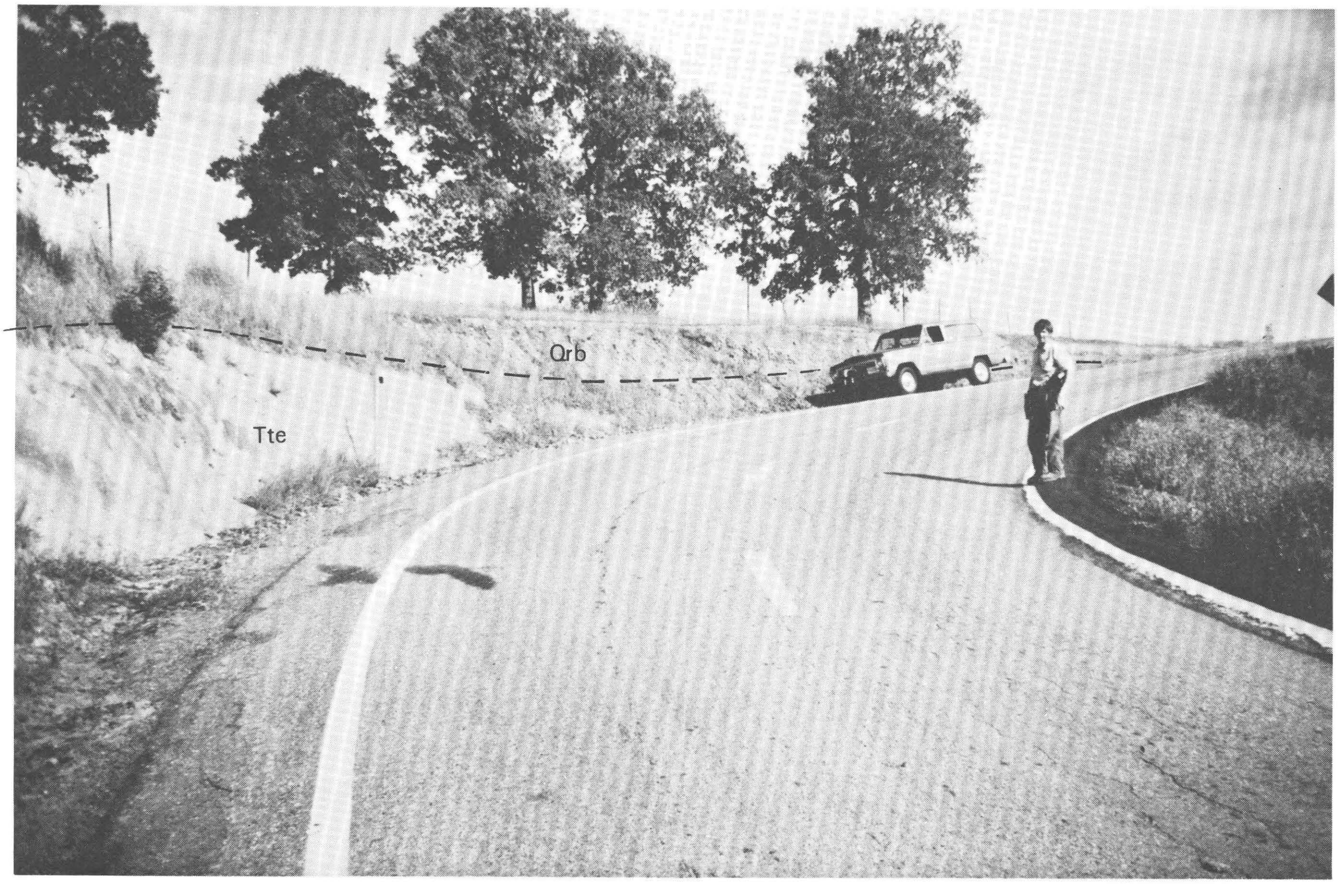

Figure 1. Outcrop of gravels of the Red Bluff Formation (Qrb) truncating the Tehama Formation (Tte), south side of State Highway 36 about 6 miles (10 km) west of the city of Red Bluff. View is to the south.

In this study we have interpreted the Red Bluff Formation as the sedimentary cover overlying a pediment. Our interpretation is based on the following field observations: (1) The Red Bluff is a thin veneer of bright-red gravels whose lower contact bevels the various underlying units (fig. 1). (2) This lower surface has very low relief and large regional extent. The coarse poorly sorted Red Bluff gravels represent an abrupt departure from the flow regimes which deposited the underlying finer grained better sorted sediments of the Tehama, Tuscan, and Laguna Formations. (3) Lithologies of Red Bluff clasts faithfully reflect local provenances. For example, the gravels west and southwest of Redding are dominantly composed of rock types exposed in the Klamath Mountains, such as metachert, polycycle siliceous grit, greenstone, and granitic rocks. Along the west side of the Sacramento Valley and in the Coast Ranges foothills the clasts are derived from the Great Valley sequence and the Franciscan Complex. Graywacke, mudstone, siltstone, and chert with visible radiolarians are common clasts. On the northeast side of the valley, east of Redding and south to Chico, the Red Bluff gravels are exclusively andesite and basalt derived from the Tuscan Formation and associated volcanic rocks, although some metamorphic rocks and vein quartz may be present. South of Chico along the east side of the valley, clasts in the Red Bluff reflect western Sierra Nevada lithologies. They consist of metamorphic and granitic rocks, resistant quartz or quartzite, and cherts of various colors usually veined and highly fractured with no distinct radiolarians; all are set in a matrix of arkosic sand.

Figure 2 shows the distribution of the Red Bluff pediment in relation to source terranes and to the major late Cenozoic structural features of the Sacramento Valley. The pediment appears best preserved on structural highs, as in the Dunnigan Hills near Cache Creek and in the area north of Willows.

The Redding and Corning soil series are characteristically developed on the Red Bluff pediment throughout the Sacramento Valley. These soils are very strongly developed xeralfs (noncalcic brown soils), similar to those forming today on Quaternary deposits throughout the valley, and attest to the semiarid climate of the past (Marchand and Allwardt, 1981). The Redding soil series is differentiated from the Corning soil series by the presence of a thick duripan that tends to impede surface-water percolation, resulting in standing water during the rainy season. The duripans aid in mapping the pediment cover, as they form a topograhically distinct ledge over the underlying sedimentary deposits (fig. 3). The surface upon which both the Redding and Corning soils are developed also

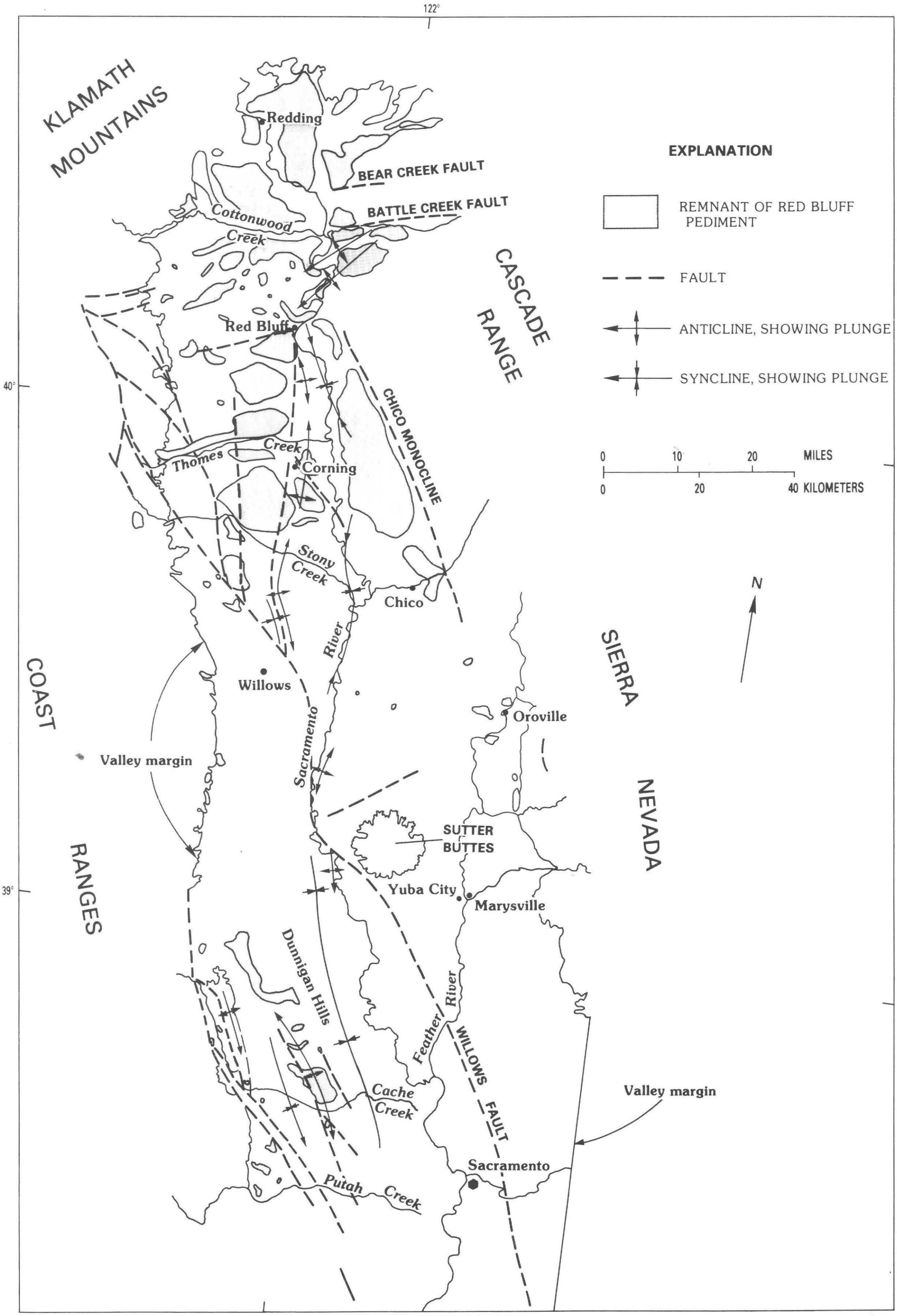

Figure 2. Sketch map of the Sacramento Valley showing the distribution of remnants of the Red Bluff pediment and the major late Cenozoic structural features known from subsurface and surface mapping (Harwood and Helley, 1982).

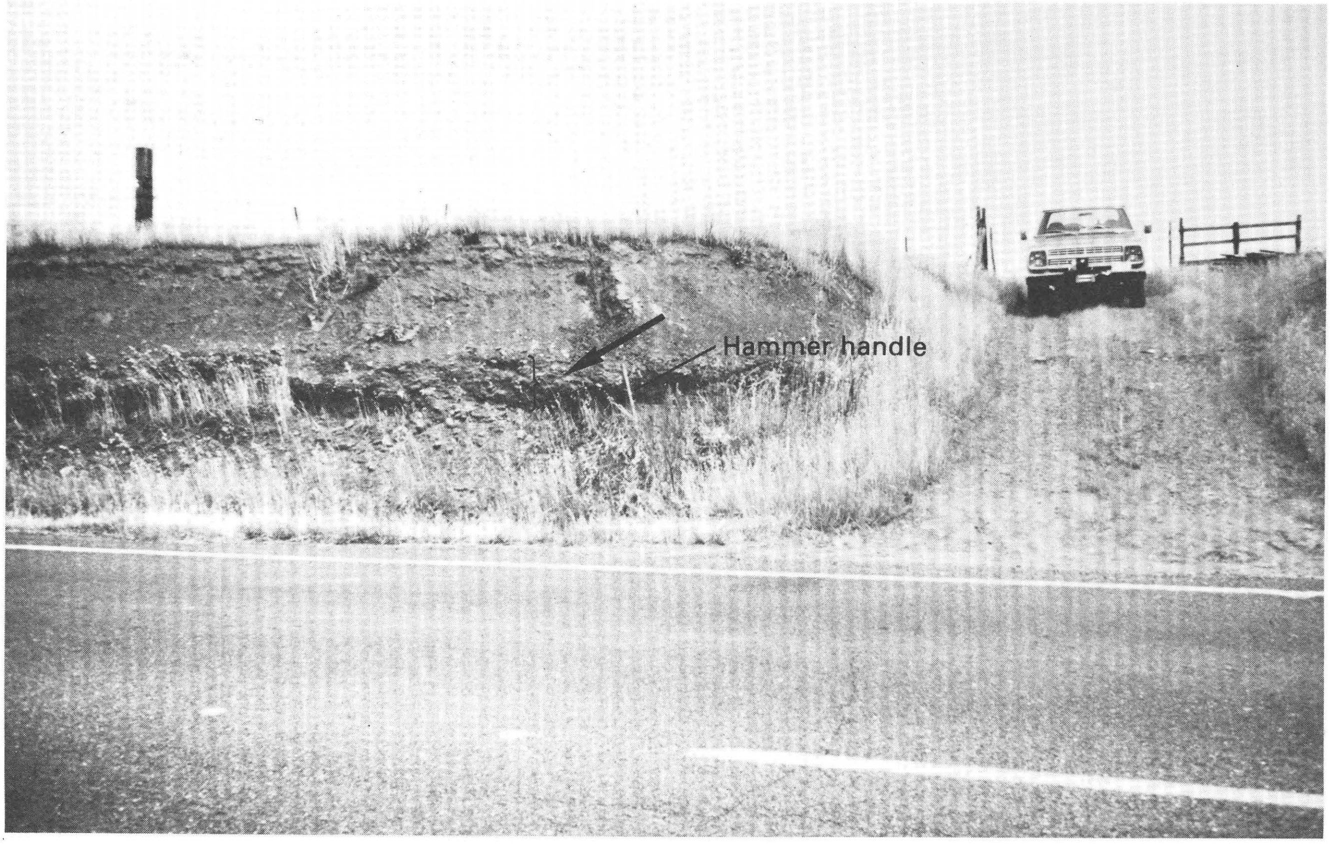

Figure 3. Pediment gravels of the Red Bluff Formation, showing hardpan (arrow). View is to north on Palermo Road south of Oroville. Here the Red Bluff truncates the Laguna Formation.

displays the unique "mima mound" or hog-wallow microrelief (fig.4; Arkley, 1962, p.28). This distinct microrelief also aided in mapping the Red Bluff pediment.

The age of the Red Bluff Formation is fairly well established on the basis of the relative positions of several formations along part of the Chico monocline (fig. 5; Harwood and others, 1981). The olivine basalt of Deer Creek, 1.08+0.16 m.y. old (Harwood and others, 1981) underlies the Red Bluff, whereas the Rockland ash bed, 0.45 m.y. old (Meyer and others, 1980; Sarna-Wojcicki and others, 1984, oral commun., 1981), overlies it in numerous places (Helley and others, 1981). Therefore, the Red Bluff Formation developed over a one-half million year interval, or less. In the San Joaquin Valley to the south, Frink and Kues (1954) interpreted the Corcoran Clay Member of the Tulare and Turlock Lake Formations to be a lacustrine deposit of regional extent that is the same age as the Red Bluff. Janda and Croft (1967) published an age of 0.6 m.y. for the Friant Pumice Member of the Turlock Lake Formation which lies conformably on the Corcoran. Page and Bertoldi (1982) described lacustrine clays in the Sacramento Valley which are identical to the Corcoran in terms of diatom flora and mineralogy. Page and Bertoldi (1982) also recovered a pumiceous ash sample from a core northeast of the Dunnigan Hills near Zamora. This ash is stratigraphically above the Corcoran-like clays and is chemically identical to the Rockland ash bed (C. E. Meyer, written commun., 1982). We tentatively correlate the clay beneath the Rockland ash bed in the Sacramento Valley with the Corcoran Clay Member of the San Joaquin Valley on the basis of similar flora and mineralogy. We conclude that the through-flowing drainage from the Sacramento Valley was impeded at this time by the presence of a large, but not necessarily deep, lake that facilitated the pediplanation process. This process probably began at the southern end of the Central Valley, progressed northward, and may have operated for the entire period from 1.08 to 0.45 m.y. ago. During that time there was no outlet through the Carquinez Straits as we know it today.

For our purposes, to assess late Cenozoic deformation, the Red Bluff pediment is the most important datum in the Sacramento Valley. We use the pediment as a structural datum because (1) pediments are relatively flat or gently sloping planimetric surfaces, (2) the age range of the pediment is well established, having developed over a reasonably short geologic time, (3) exposures are widespread and generally occupy the topographically highest part of the valley, (4) because of the strong soil profile with duripans, deposits on the pediment are resistant enough to preserve the previously deformed surface, and (5) the deformation of the pediment in the Corning and Dunnigan Hills areas is already documented.

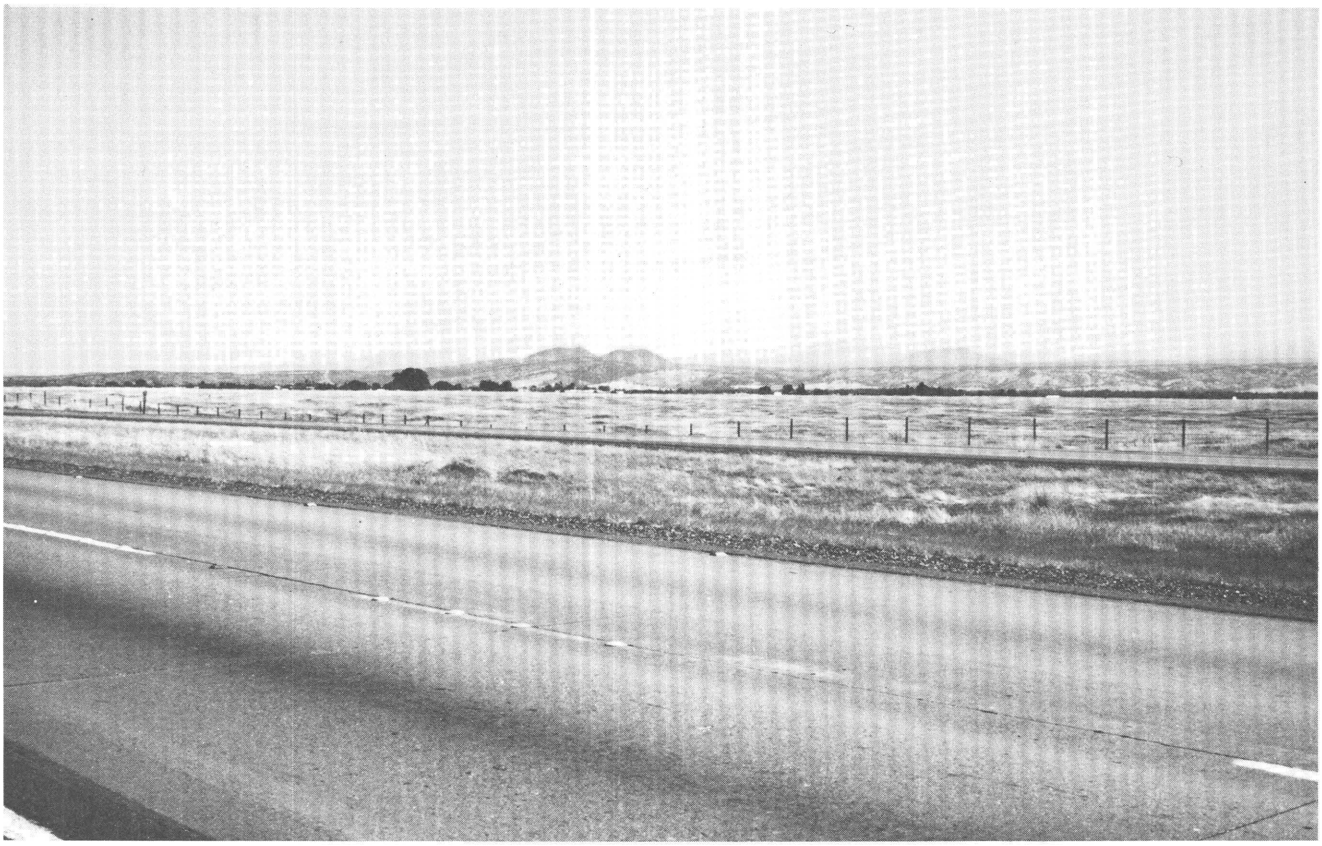

Figure 4. Red Bluff pediment surface south of Red Bluff along Interstate Highway 5. View is to northeast with Tuscan Buttes in center of photograph. Note hog-wallow microrelief on pediment surface.

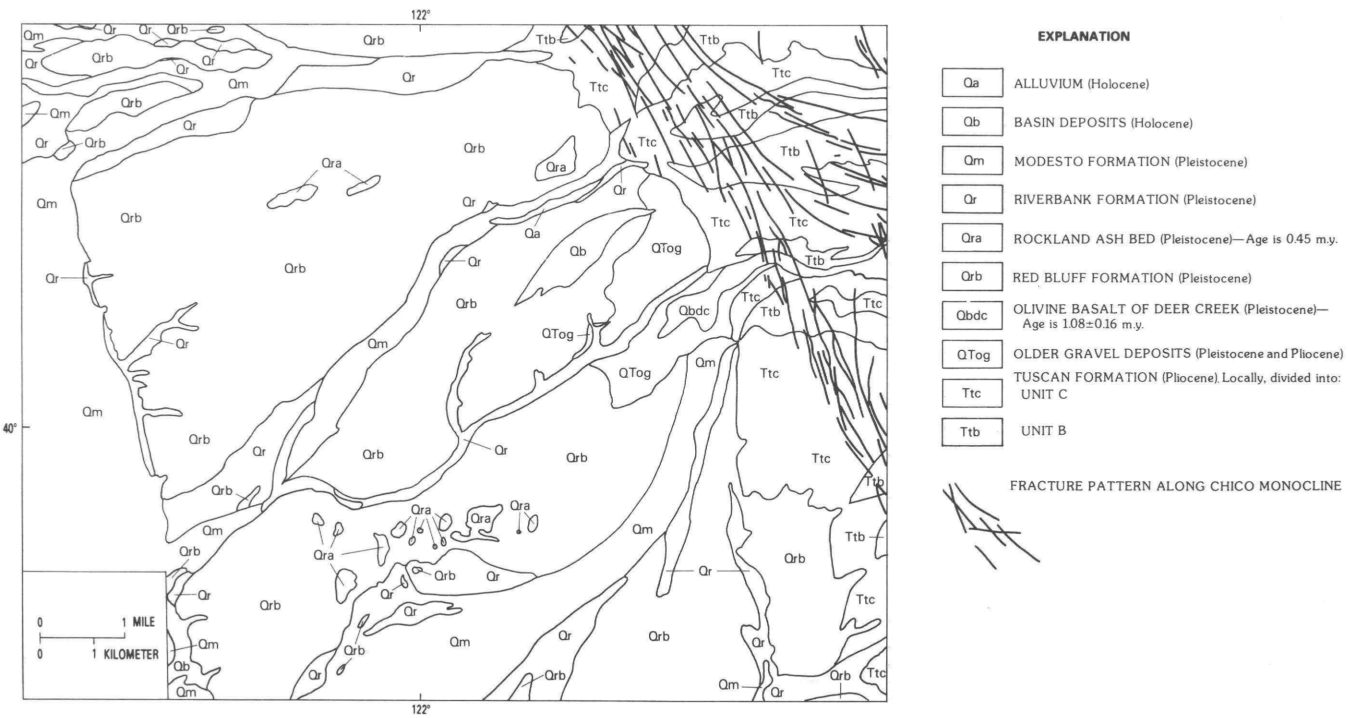

Figure 5. Geologic map of part of the Vina 7.5-minute quadrangle, California (from Harwood and others, 1981).

STRUCTURE

Structure contours on the pediment surface were generated by a collection of Fortran subroutines that produce graphic representations of three-dimensional continuous surfaces in the form of contour maps or perspective views using the Surface Display Library running under the Multics Operating System (see Mark and Newman, 1981). We began in the Corning area of the north-central Sacramento Valley because of the abundance of Red Bluff exposures as well as prior knowledge of the deformation there. Younger alluvial deposits of the Riverbank and Modesto Formations are present in cut-and-fill positions below the Red Bluff pediment and provide surfaces for comparison with the pediment. Base-level control was the Sacramento River, which flows southward through the area. A simplified geologic map of the Corning area (fig. 6) shows the Red Bluff underlying the dissected alluvial fans that originated from the area of the Chico monocline to the northeast. The Red Bluff also covers the two hills in the center of the quadrangle, known as the north and south Corning Domes (Sacramento Petroleum Association, 1962, p. 102), and the east-west-trending linear hills along the west side of the quadrangle. Dissection has produced as much as 100 feet (30 meters) of relief, thus providing the many data points necessary for machine contouring. Bugry (1981) provided a historical review of computer contour methods. He decribes two methods, one that has an intervening step of gridding the data points before contouring and the other that does not (Bugry, 1981, p. 209). We used the procedure of intervening gridding. Elevations at the base of the Red Bluff Formation were digitized using a Tektronix Graphics terminal with digitizing board.

If the Red Bluff pediment surface in the Corning quadrangle was undeformed, we would expect the resulting contour map to display subparallel lines sloping east and west toward the Sacramento River, the base level. However, the resulting map of the Corning quadrangle clearly shows the north and south Corning Domes by closed contours (fig. 7). The contours also suggest that the domes may be offset along a northwest-trending fault coincident with the linear outcrop pattern along the west edge of the north dome. Most of the contours in the northeast corner of the quadrangle show simple subparallel lines sloping toward the Sacramento River. This contour map (fig. 7) shows that the original slope of the pediment surface has been distorted. Because we did not know what the original slope was, we estimated it by preparing a contour map on the top of the upper member of the Modesto Formation (14,000 to 26,000 yrs B.P., Marchand and Allwardt, 1981). That contour map (fig. 8) shows fairly simple subparallel lines sloping toward the Sacramento River. The contours on the Modesto Formation were subtracted by computer from those on the Red Bluff pediment (fig. 7) to produce a map (fig. 9) showing the residual contours on the pediment surface.

The Corning Domes show 40 to 50 feet (12-15 m) of structural closure. Other closed contours are shown southwest of the Corning area, with similar amounts of structural closure but with an east-west orientation. Because these apparent folds were unexpected, we expanded the mapping and contouring to cover 12 adjacent 7.5-minute quadrangles (fig. 10). Again the Corning Domes stand out, but several others also appear, in the Black Butte Dam, Kirkwood, and Henleyville quadrangles. Note the courses of both Stony Creek and Thomes Creek. Stony Creek cuts through the Lovejoy Basalt at an apparent structural high at Black Butte and flows southeasterly toward its confluence with the Sacramento River. Thomes Creek, on the other hand, flows northeasterly, against the regional drainage, to the Sacramento River. The courses of both streams were apparently controlled or at least diverted by the Corning Domes. Stony Creek also appears antecedent to the structure at Black Butte, where the creek has taken its course through the resistant Lovejoy Basalt rather than cutting through the softer and easily erodible Tehama Formation. We enlarged the contouring for the northeast quarter of the Fruto NE quadrangle (fig. 11), an area near where Harwood and Helley (1982) projected the trace of the Willows fault from subsurface data and from outcrops of the Lovejoy Basalt. This map shows a good contrast between contours that show simple sloping and those that apparently reflect a small tight east-plunging fold that is probably related to drag on the Willows fault.

CONCLUSION

Erosional pediment surfaces can be used to assess late Cenozoic deformation, especially where the pediment surface has closed contours and the folds are recent. In the Sacramento Valley deformation postdates the Red Bluff pediment surface and predates the upper surface of the Modesto Formation; it is less than 0.45 m.y. old. Many of the surface folds overlie deeper subsurface structures, which suggests continuing long-term deformation. Unfortunately, the Red Bluff Formation, which overlies the pediment, has been stripped away in many places in the Sacramento Valley, leaving an insufficient number of data points to contour. We suggest that where pediments are preserved this methodology is a useful and rapid exploration tool and an inexpensive procedure for generalized mapping of regional structure.

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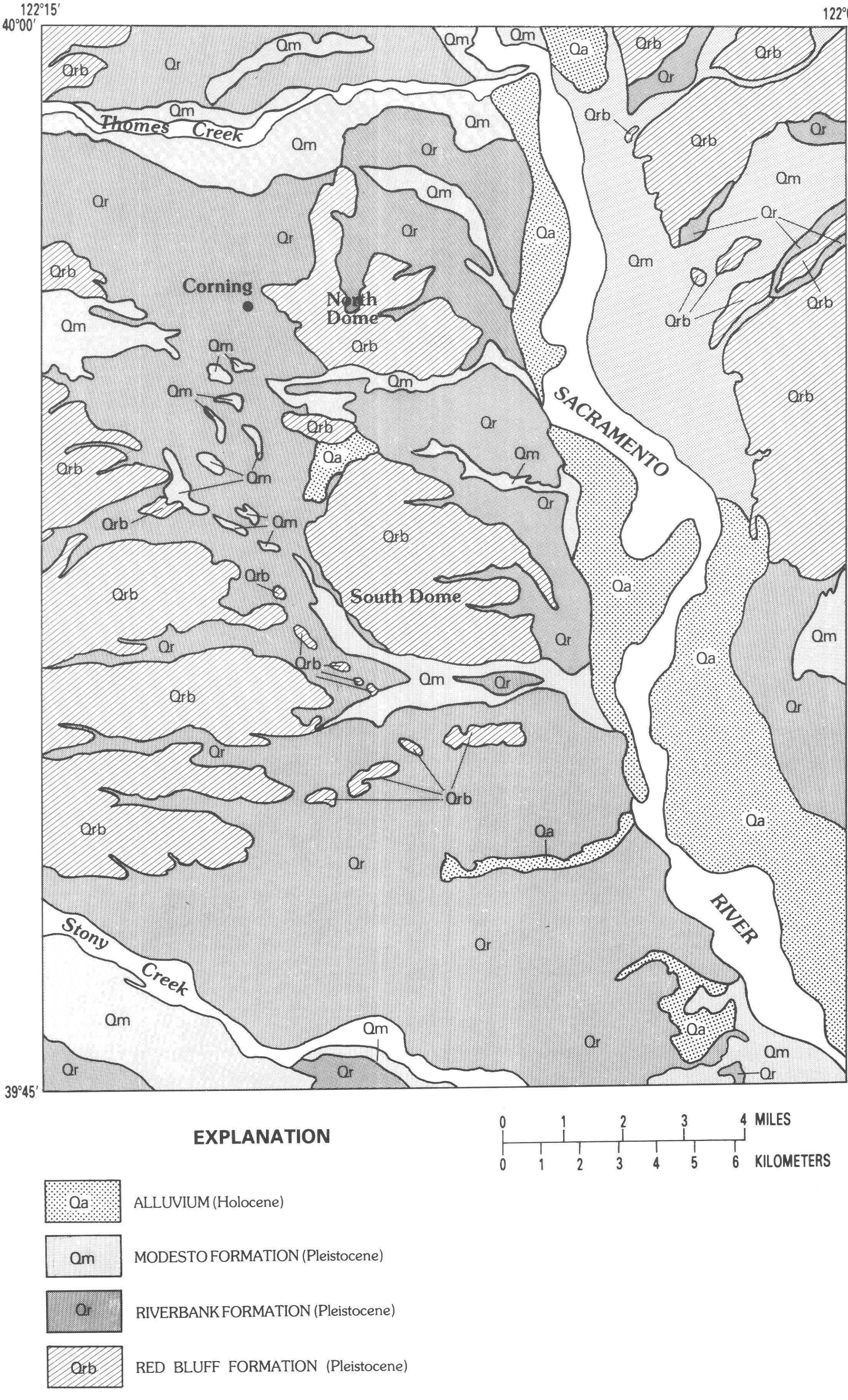

Figure 6. Simplified geologic map of the Corning 15-minute quadrangle, California, showing distribution of Quaternary deposits.

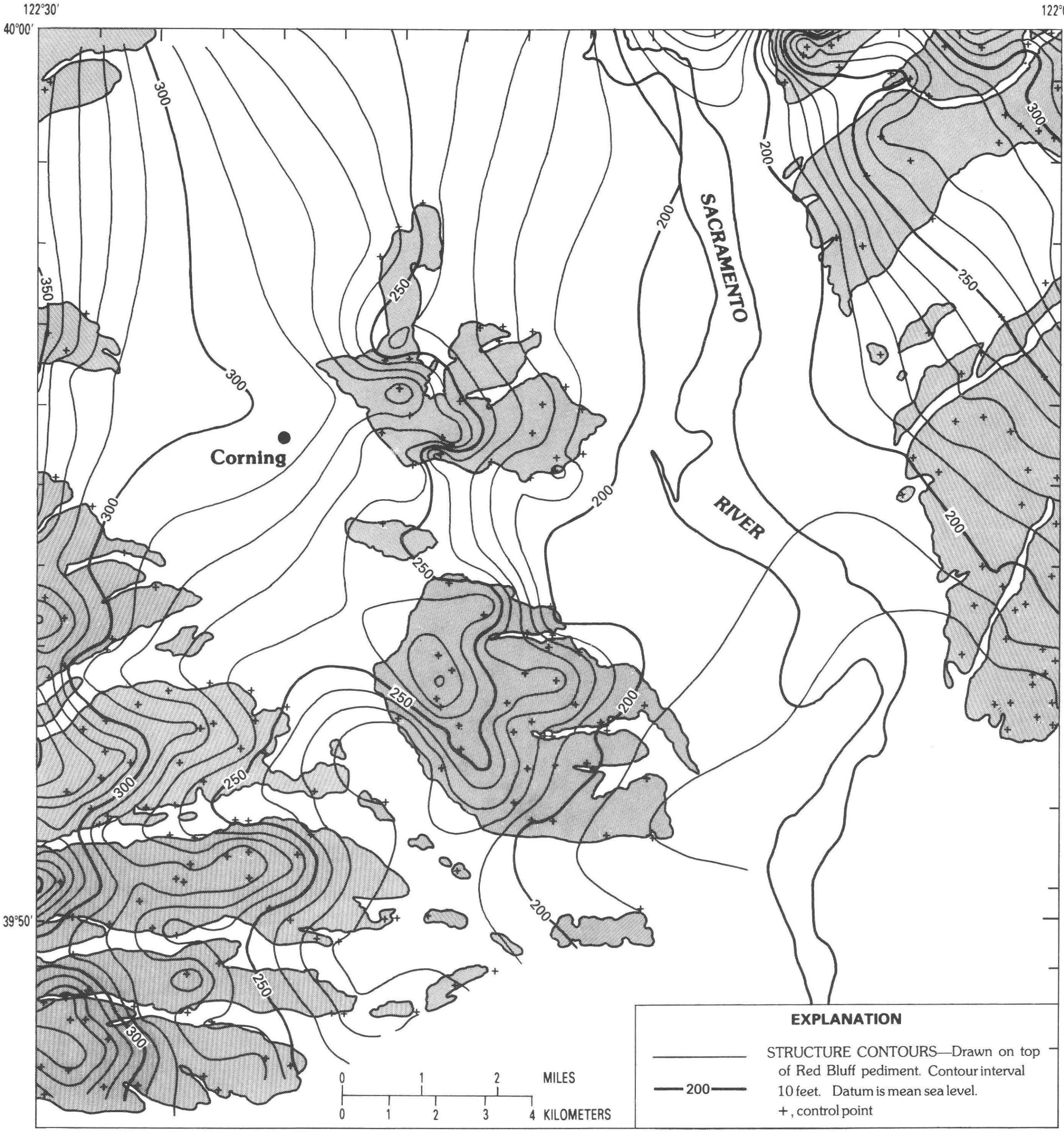

Figure 7. Structure contour map of the Red Bluff pediment in part of the Corning 15-minute quadrangle, Calif. Shaded areas show outcrop distribution of the Red Bluff Formation. The northeast side appears undeformed, but the central and western areas appear domed and folded.

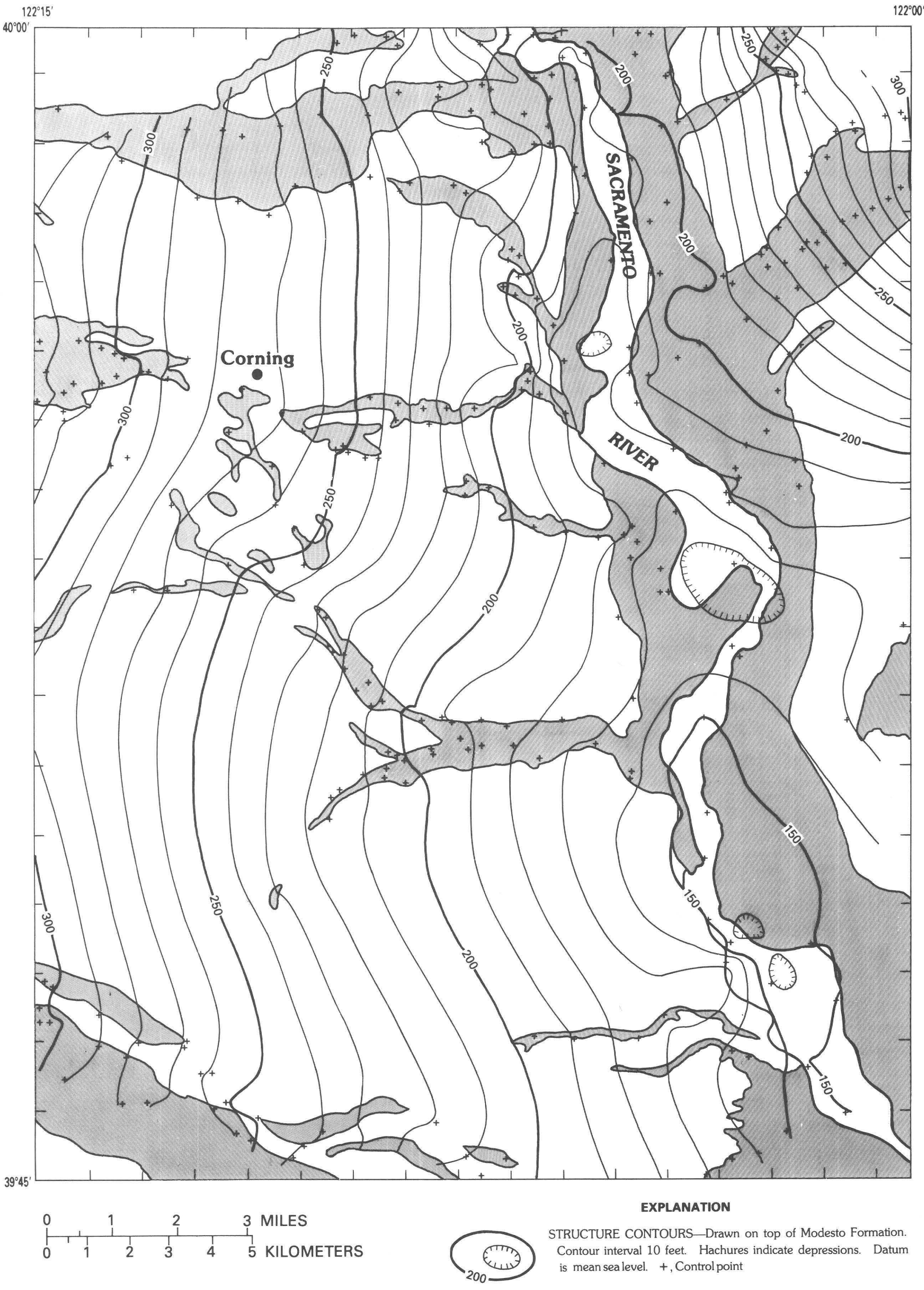

Figure 8. Structure contour map of the top of the Modesto Formation in the Corning 15-minute quadrangle, Calif. Shaded areas show outcrop distribution of the Modesto Formation.

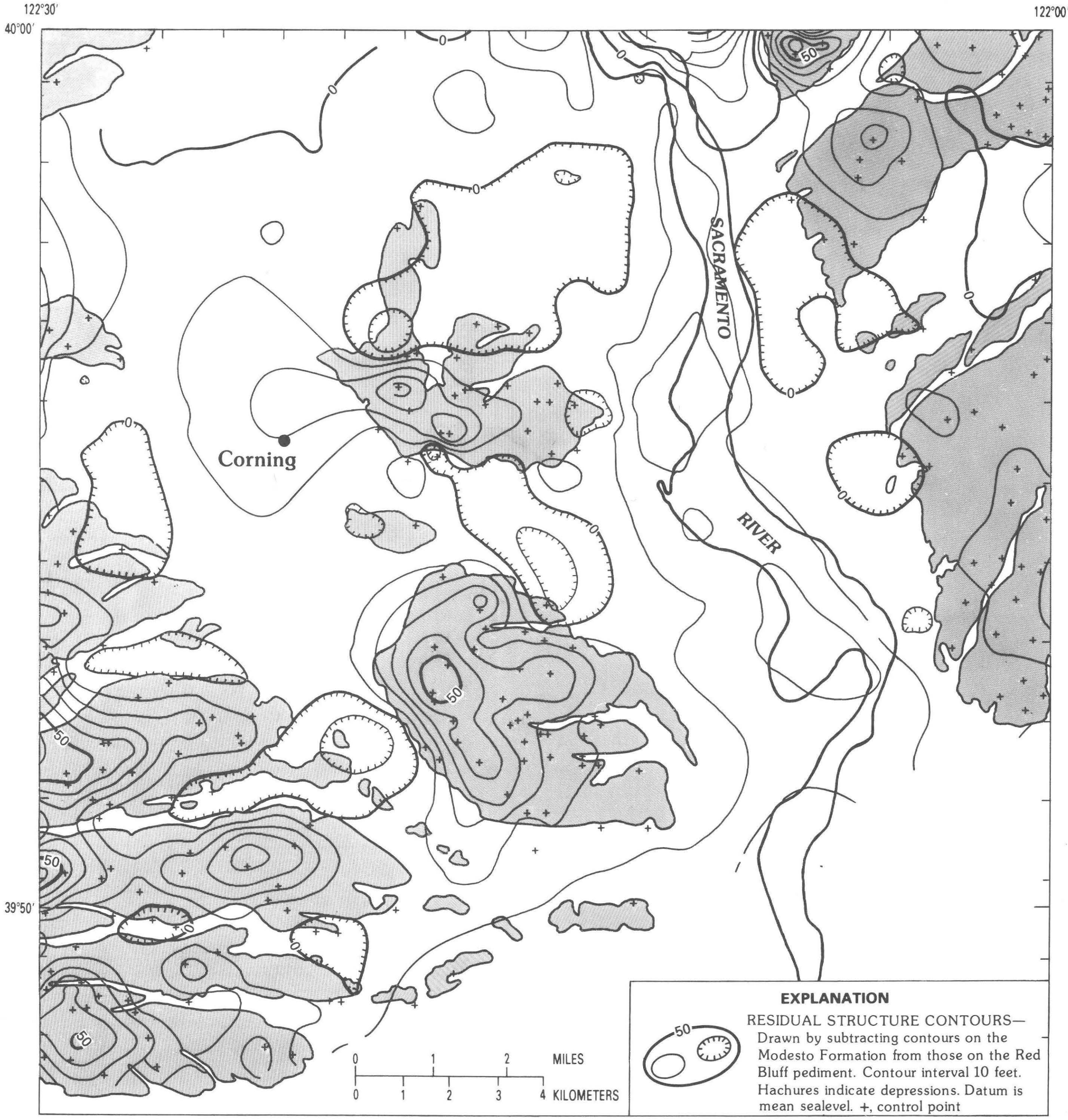

Figure 9. Residual structure contour map of the Red Bluff pediment in the Corning 15-minute quadrangle, Calif. Contours on the top of the Modesto Formation (fig. 8) were subtracted from those on the pediment (fig. 7). Shaded area shows distribution of the Red Bluff Formation. Maximum closure is about 50 feet (15.5 m).

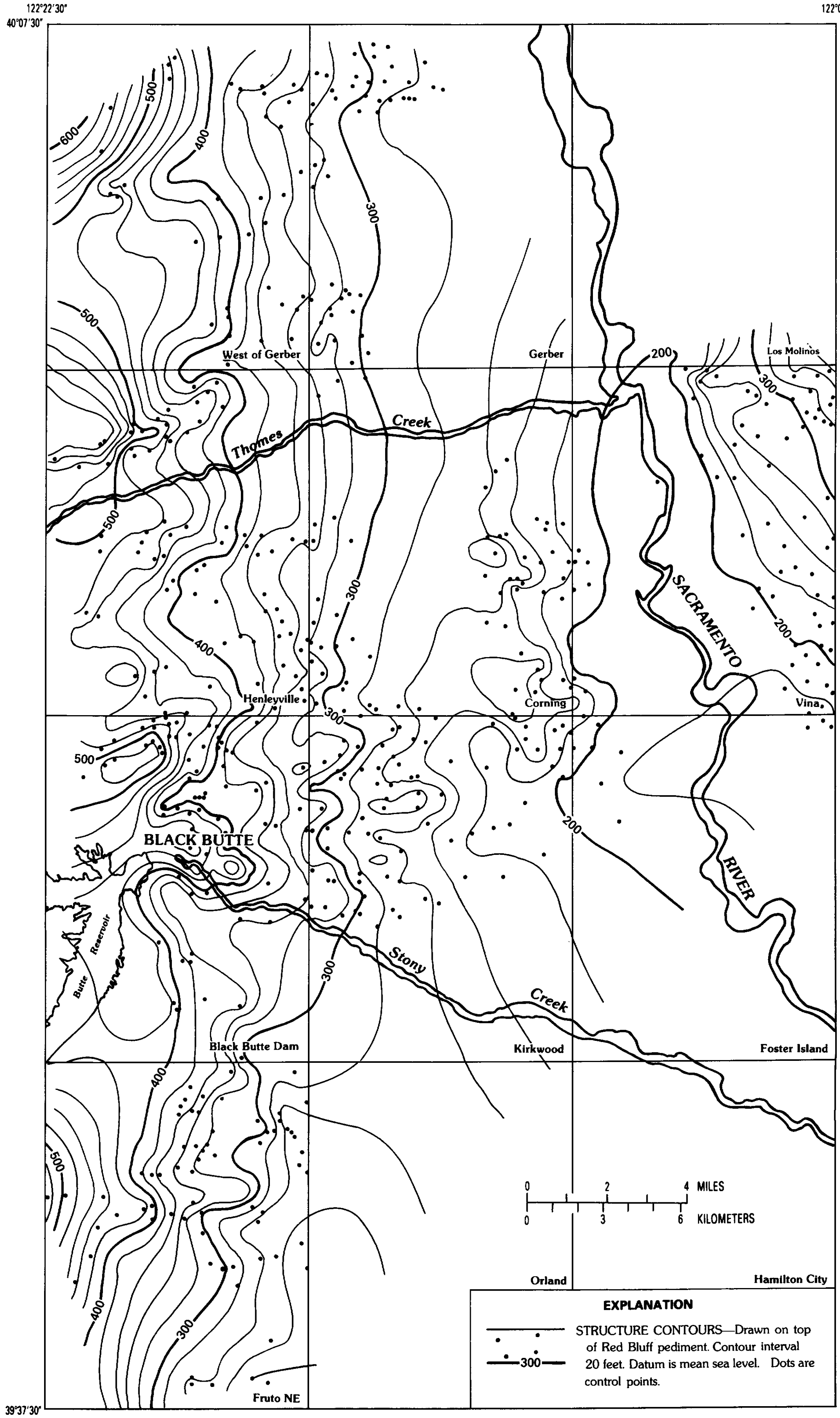

Figure 10. Structure contour map of the Red Bluff pediment, corrected for original slope, for 12 7.5-minute quadrangles in the north-central Sacramento Valley, Calif. Quadrangle name is in lower right corner of each one.

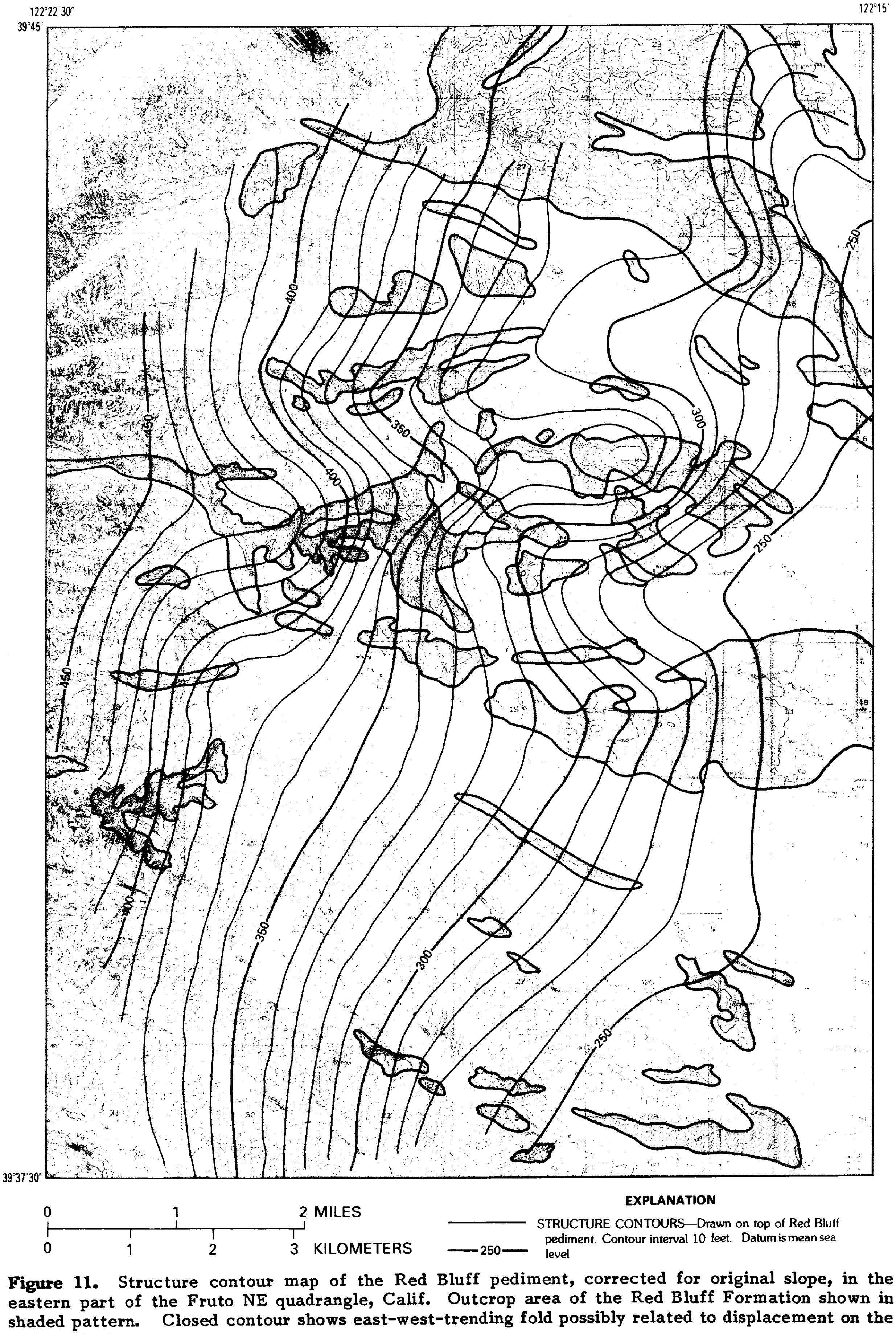

Figure 11. Structure contour map of the Red Bluff pediment, corrected for original slope, in the eastern part of the Fruto NE quadrangle, Calif. Outcrop area of the Red Bluff Formation shown in shaded pattern. Closed contour shows east-west-trending fold possibly related to displacement on the Willows fault.

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