QUATERNARY STREAM TERRACES IN THE NORTHWESTERN SACRAMENTO VALLEY, GLENN, TEHAMA, AND SHASTA COUNTIES, CALIFORNIA

By

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ABSTRACT

Stream terraces in Glenn, Tehama, and Shasta Counties, in the northwestern Sacramento Valley, California, were mapped and analyzed quantitatively. The morphology and pedology of the terraces were delineated in order to develop quantitative methods for identification of the different terrace levels and to determine their possible origin and age relationships.

Six stream terraces were differentiated. From youngest to oldest, these terraces are informally designated as: the Orland high floodplain, the Yolo, Arbuckle, and Perkins terraces, the Corning terrace sequence, and the Redding high floodplain. The Orland high floodplain, generally a topographically low fill deposit preserved on the slip-off slopes of meander loops or upstream from major valley constrictions, is 4,000 years old and is probably coeval with either the Recess Peak stadia and(or) the Matthes stadia in the Sierra Nevada. The Yolo terrace, a slightly dissected terrace remnant along major creeks, is about 10,000 years old and is contemporaneous with the upper member of the Modesto Formation of the San Joaquin Valley and the Tioga stadia of the Sierra Nevada. The Arbuckle terrace, a slightly dissected, wide continuous terrace prominent along most creeks, is about 30,000 years old and is perhaps equivalent to the lower member of the Modesto Formation and the Tahoe stadia in the Sierra Nevada. The Perkins terrace, a highly dissected discontinuous terraces along many creeks, is about 130,000 years old and is coeval with the upper member of the Riverbank Formation in the Great Valley. The

Corning terrace sequence consists of several terraces intermediate in age between the Perkins terrace and the Redding high floodplain, and is between 250,000 and 1,250,000 years old. This time interval includes the middle and lower members of the Riverbank Formation, the upper part of the lower member of the Fair Oaks Formation, and the Turlock Lake Formation of the San Joaquin Valley. The Redding high floodplain, made up of long, continuous, highly dissected terrace remnants with hummocky microrelief along drainage divides, is about 1,250,000 years old and corresponds to the upper part of the Red Bluff Formation, which is coeval with the Arroyo Seco gravel surface, the lower member of the Fair Oaks Formation, and the North Merced pediment gravel along the foothills of the Sierra Nevada.

Local and regional correlations were made with morphologic, pedologic, and lithologic data; however, soil color was used to more clearly differentiate terrace levels. Present stream terraces are characterized by a distinct gray hue (5Y dry); Yolo and Arbuckle terraces by yellowish brown colors (10YR 6/2 to 10YR 6/4 dry); and older terraces by yellowish red colors (5YR 4/6 to 5YR 5/8 dry).

The relationship between the most probable maximum and minimum possible areal extents of the terraces usually is helpful to distinguish one terrace level from another. A maximum/minimum ratio of less than 2 is usually indicative of the Yolo or Arbuckle terrace levels; greater than 8.5 of the Corning terrace sequence; and between 2.0 and 8.5 of the Perkins terrace. This measure of the probable amount of erosion may be useful for tentative identification of terraces in the Great Valley where only one level is preserved. The ratio of maximum areal extent between different terrace levels is useful in identifying terraces in the Great Valley where multiple terraces are present.

Estimates of terrace ages, based on volumes of material eroded, closely correspond to absolute ages obtained from fluvial and fluvioglacial deposits elsewhere in California.

A three-stage cyclic pattern of landscape change appears to have occurred. First, a period of intense soil formation during interglacial time; second, a period of degradation probably during glaciation; and third, a period of erosion during glacial recession.

INTRODUCTION

Purpose and scope

The geology of the northwestern Sacramento Valley has been studied and interpreted by many workers; however, their major emphasis was placed on stratigraphic description and correlation of the pre-Quaternary sequences of sedimentary rocks. The few previous reports which contain systematic studies of the late Cenozoic history of the region commonly considered only small segments of single drainage systems; however, these studies contributed materially to this work and are referenced where appropriate.

One of the objectives of this study was to analyze thoroughly the Quaternary terraces along the northwestern margin of the Sacramento Valley. This analysis included field mapping of the terraces, and determining the morphology and establishing the stratigraphic identity of the terraces. The second major objective was, by the use of these features, to develop quantitative methods for identification of the different terrace levels, and to determine the age and possible origin as a means to a better understanding of the Quaternary tectonic history and climatic effects in the northwestern Sacramento Valley and the relationship of these terraces to other Quaternary deposits in California.

Several factors and fortuitous circumstances have made this study of the Quaternary history in the northwestern Sacramento Valley a fruitful undertaking:

1. few published or unpublished reports embody a definitive or sys-

tematic account of the Quaternary geology and geomorphology of the northwestern Sacramento Valley;

2. each of the major streams that drain the eastern flank of the Coast Ranges and Klamath Mountains between the latitudes of the towns of Willows (sec. 9, T. 19 N., R. 3 W.) and Anderson (sec. 22, T. 30 N., R. 4 W.) has well-preserved fluvial terrace assemblages;
3. the pre-Quaternary geology of the northwestern margin of the Sacramento Valley has been mapped in sufficient detail to permit concentration on the Quaternary geology without the necessity of mapping a prohibitively large area;
4. large scale topographic maps and aerial photographs are available for nearly the entire region; and
5. recently published U.S. Department of Agriculture soil surveys of Glenn, Tehama, and Shasta counties, California (Begg, 1968; Gowans, 1967; and Klaseen and Ellison, 1974), provide data suitable for stratigraphic interpretation of the unconsolidated deposits.

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Regional physiography and geology

The area studied (figs. 1 and 2) is within Glenn, Tehama, and Shasta Counties, California. The southern boundary is defined by Stony Creek, the northern boundary by Cottonwood Creek, and the western boundary by the east front of the Coast Ranges and Klamath Mountains. The eastern boundary roughly coincides with the present course of the Sacramento River.

The late Mesozoic geology of the western margin of the Sacramento Valley reflects plate tectonic deformation (Hamilton, 1969; Dickinson, 1970; Ernst, 1970; Bailey and others, 1970; Dickinson, 1971). The Coast Ranges, which border the Sacramento Valley on the west, are composed largely of the Franciscan Assemblage (Bailey and others, 1964), a complex assemblage of imbricate thrust faults, blueschist, and melanges of graywacke, shale, conglomerate, mafic igneous rock, chert, and metamorphic rock, which are presumed to represent structures and deposits associated with the late Mesozoic subduction (Ernst, 1970).

Structurally overlying the Franciscan Assemblage, is an ophiolite sequence (Bailey and others, 1970), which is exposed along the eastern front of the Coast Ranges and is locally separated from the rocks farther to the east by the Coast Ranges - Stony Creek - Elder Creek - South Fork Mountain fault systems. The fault systems, although usually thrust

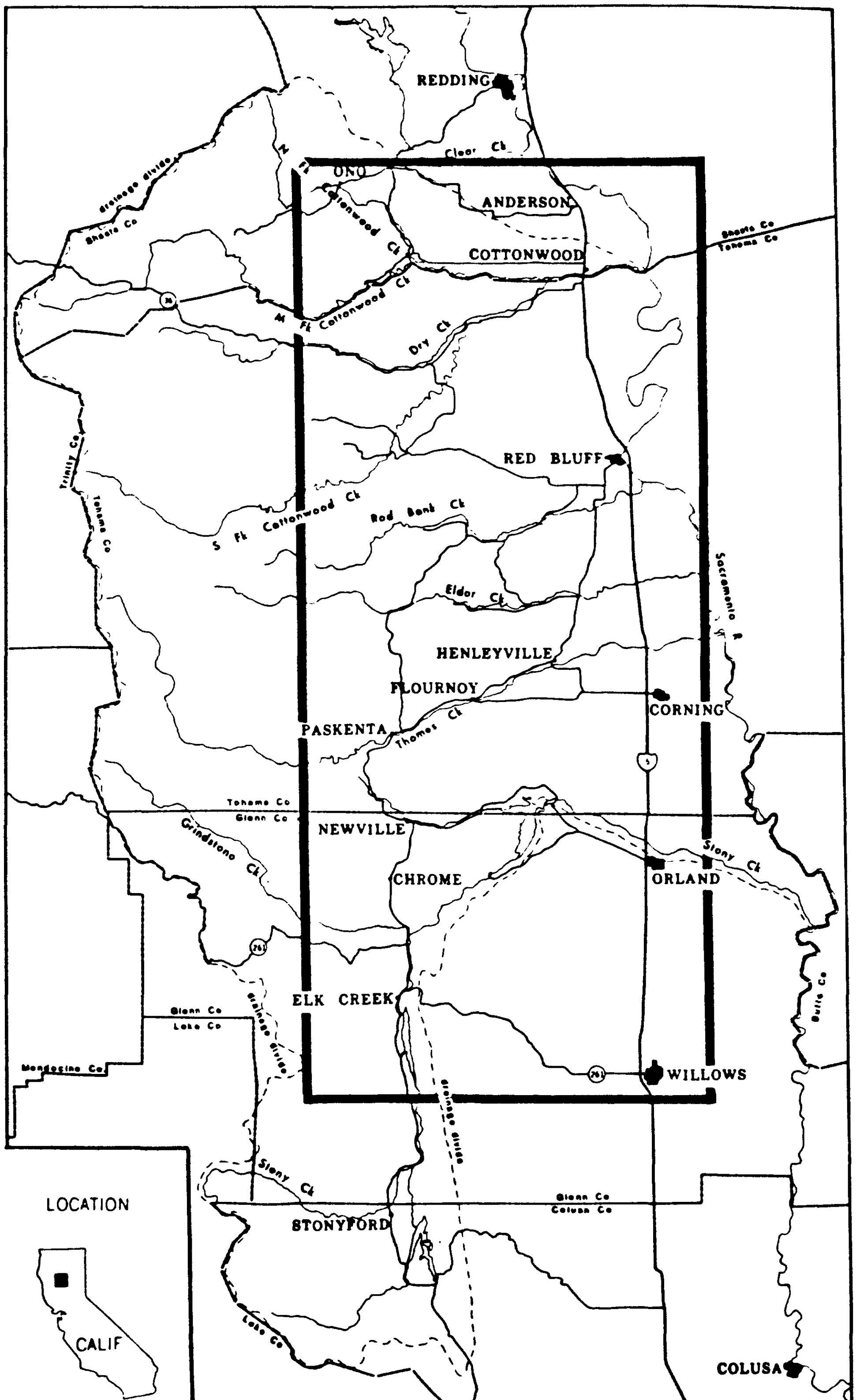

Figure 1. Index map showing study area and major geographic features. Area studied delineated by heavy line. Scale approximately 1:800,000.

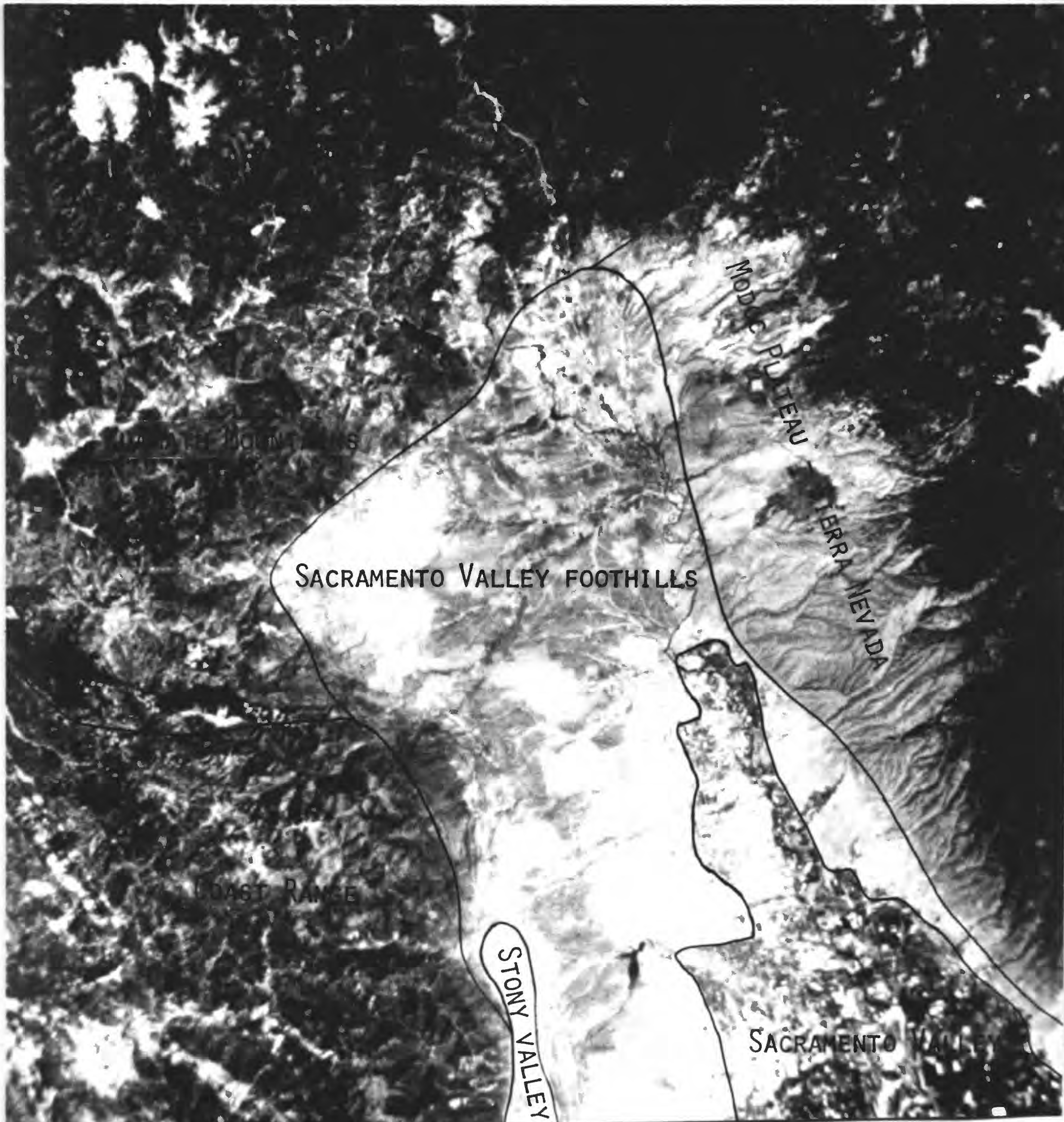

Figure 2. Annotated Landsat image of the northwestern Sacramento Valley area showing the major physiographic subdivisions of northern California. Heavy lines correspond to approximate boundaries of provinces. Scale approximately 1:1,000,000.

faults, exhibit 100 km or more left lateral offset along the Elder Creek section (Jones and Irwin, 1971; Dickinson and Rich, 1972).

East of the fault system, the Great Valley Sequence forms the western foothills of the Sacramento Valley (Bailey and others, 1964). The Great Valley Sequence, which is coeval with the Franciscan Assemblage, is thought to have been deposited mostly as deep-marine turbidites in a fore-arc basin associated with the late Mesozoic subduction (Dickinson, 1971; Dickinson and Rich, 1972; Ingersoll, 1976; Ingersoll and others, 1977) consists of interbedded graywacke, feldspathic sandstone, shale, and conglomerate (Dickinson and Rich, 1972; Ingersoll, 1976).

To the north and northwest, the Great Valley Sequence was deposited on the Klamath Mountains. The Klamath Mountains have been subjected to a more complicated tectonic evolution than have the Coast Ranges. The rocks underwent several periods of structural modification between the Ordovician and Late Jurassic; the modifications resulted in a complex imbricate thrust and metamorphic succession (Ernst, 1974). Granitic plutons were intruded during Late Jurassic time, and the entire Klamath Mountains area essentially became part of the continental margin (Ernst, 1974) although some Eocene and later deformation may have occurred.

The duration of tectonic activity in the northwestern Sacramento Valley is uncertain. Depositional patterns and sandstone petrology of the Great Valley Sequence suggest that clastic sedimentation in the arc-trench gap continued into the late Cretaceous (Dickinson and Rich, 1972; Rich and Brown, 1972; Ingersoll, 1976), and structural and depositional changes, represented by unconformities between the Great Valley Sequence and early Tertiary (Eocene?) rocks, indicate deformation may have continued into the early Tertiary (Page, 1966).

Two basalt flows at Orland Buttes (sec. 8, T. 22 N., R. 4 W.) represent the only post-Cretaceous - pre-Pliocene units which crop out in the study area although rocks of Eocene age are known in the subsurface and along the eastern margin of the Sacramento Valley. These flows are 20 m thick, dip about 5 degrees to the east (Anderson and Russell, 1939), and are bounded on the west by a normal fault with about 800 m of vertical displacement (U.S. Army Corps of Engineers, 1963).

The nonmarine Tehama Formation (Russell, 1931; Russell and VanderHoof, 1931) rests unconformably on the gently undulating surface of the upturned edges of the Great Valley Sequence (Bryan, 1923; Harrington, 1942). The Tehama Formation is a clastic wedge of fluvial sediments which is thinnest on the west and thickens, due to subsidence during deposition (Russell, 1931), toward the center of the Sacramento Valley. The approximate age of the top of the Tehama Formation is late Pliocene to early Pleistocene based on vertebrate fossils identified by VanderHoof (1933), Anderson and Russell (1939), and Olmsted and Davis (1961). Deposition of fluvial sediments ceased before about 1.2 ± 0.7 my (Sarna-Wojcicki, 1976) because the rhyolite flows, which directly overlie the Tuscan Formation (Diller, 1892) along the east side of the Sacramento Valley are composed chiefly of volcanic debris which is coeval with the Tehama Formation (Russell and VanderHoof, 1931; Russell, 1931; Anderson, 1933; Anderson and Russell, 1939; Olmsted and Davis, 1961; Lydon, 1968). The Nomlaki tuff member (Russell and VanderHoof, 1931) of the Tehama Formation, a pinkish ash-flow pumice lapilli tuff (Russell, 1931; Sims and Sarna-Wojcicki, 1975), crops out near the base of the Tehama Formation. The tuff was deposited over much of the northern Sacramento Valley about 3.3 ± 0.4 my ago (Evernden and others, 1964) (KA 587) and is the only marker bed within the formation. The part of the Tehama Formation above the Nomlaki tuff member (fig. 3) consists of as much as 650 m of poorly sorted fluvial sand, silt, and clay with lenses of crossbedded sand and gravel (Russell and VanderHoof, 1931; Donderville, 1958; Redwine, 1972; Page, 1973). These sediments represent floodplain deposits similar to those being deposited today along the western margin of the Sacramento Valley. A northwestern source for the Tehama sediments was inferred by Anderson and Russell (1939) because of an abundance of minerals and rock types derived from the Coast Range and Klamath Mountains, data from pebble imbrications and foreset beds, and a general eastward decrease in grain size. Within the study area the Tehama Formation commonly dips between 2 and 4 degrees toward the east (Harrington, 1942; Donderville, 1958; Young, 1958; Olmsted and Davis, 1961), which might represent an initial depositional dip. A Pleistocene orogeny (Taliaferro, 1951, Olmsted and Davis, 1961; Hackel, 1966; Oakshott, 1971) uplifted and gently folded the western part of the study area, and appears to have terminated deposition of the Tehama Formation (Russell and VanderHoof, 1931; Anderson and Russell, 1939; Russell and Anderson, 1939).

The Red Bluff Formation (originally defined by Diller, 1894; redefined by Russell, 1931) was deposited on the eroded surface of the Tehama Formation. The formation is locally as much as 30 m thick, but generally is less than 15 m thick, and consists of poorly sorted gravels with a reddish silty to sandy matrix (Olmsted and Davis, 1961). The Red Bluff

Figure 3. The lenses of crossbedded sand and gravel in the Tehama Formation are similar to floodplain deposits being formed along the western margin of the Sacramento Valley today. Roadcut (sec. 30, T. 28 N., R. 5 W.). Shovel is 71 cm long.

Formation can commonly be differentiated from the Tehama Formation by its much redder color and coarser grain size (Russell, 1931; Anderson and Russell, 1939); however, the two formations are indistinguishable in several areas. The deposits within the Red Bluff Formation decrease in maximum clast size both from north to south and from west to east (Olmsted and Davis, 1961). They contain boulders near Redding and only pebble- and cobble-size clasts near Stony Creek.

After deposition of the Red Bluff Formation, during late Pleistocene, renewed uplift, folding, and erosion occurred (Bryan, 1923; Russell, 1931; Olmsted and Davis, 1961; Hackel, 1966). The entire Sacramento Valley region north of Stony Creek was uplifted (Olmsted and Davis, 1961), as evidenced by the rapid change from a valley south of Stony Creek to a rolling, dissected, elevated terrain north of Stony Creek and exposures of the Red Bluff Formation in cliffs as much as 60 m above the Sacramento River. Deformation is also evidenced by folding of the Red Bluff Formation into an anticlinal fold near the town of Corning (sec. 22, T. 24 N., R. 3 W.) and the Red Bluff arch (Diller and others, 1916; Bryan, 1923; Olmsted and Davis, 1961), an east-west trending anticline between the town of Red Bluff and Cottonwood Creek. Bryan (1923) estimated the uplift to be about 15 m in the northern region near the Sacramento River, increasing to between 70 and 100 m near the Klamath Mountains on the west. The evidence for this uplift and deformation are discussed further in the section on "Reconstruction of the Redding high floodplain." Thus, the post-Red Bluff Formation orogeny and the post-Tehama Formation - pre-Red Bluff Formation orogeny determined the present configuration of the landforms along the west side of the Sacramento Valley.

The western extent of fluvial deposition within the northwestern Sacramento Valley has changed greatly since the deposition of the Tehama Formation. Deposition of the Tehama Formation began as far west as the Coast Range - Klamath Mountains mountain front. Deposition of the Red Bluff Formation, however, appears to have been no closer to the mountains than 20 km, except at the extreme northern end of the Sacramento Valley. Present alluviation is occuring even farther east. The largest depositional area at present is the Stony Creek alluvial fan, which has an apex approximately 4 km east of the westernmost exposure of the Red Bluff deposits. Each fan head for the major streams north of Stony Creek appears to have shifted farther and farther east, approximately to a line between Orland Buttes and the town of Red Bluff.

Terrace studies in northern California

Terraces in the northwestern Sacramento Valley were first discussed by Diller (1914). He described the terraces along Clear Creek, just north of the study area; however, he did not designate the number of terrace levels, postulate an origin, or estimate their ages. Climatic and(or) tectonic origins for two terrace levels were postulated from regional studies by Bryan (1923). Later, Russell (1931) found four terrace levels. Young (1958) delineated terraces near Paskenta; Rodda (1959) mapped, but did not distinguish, different terrace levels along Cottonwood Creek. Similar local studies which included terrace mapping were by Donderville (1958), who found two terrace levels in the Watson Creek area; Chuber (1961), who identified at least five terrace levels in the Stony Creek drainage basin. Brown and Rich (1961) and Brown (1964), mapped several undifferentiated terrace levels in the southern part of the Stony Creek drainage basin. Gould (1962) identified but did not map three terrace levels along Thomes and Elder Creeks and Willis (1962) mapped more than two terrace levels along Thomes Creek. Bailey and Jones (1973b) mapped terraces along part of the South Fork of Cottonwood Creek.

Three recent studies include a more detailed analyses of the terraces. Murphy and others (1969) mapped six terrace levels in the Cottonwood Creek drainage basin; all the terraces are younger than the Red Bluff Formation. Shlemon and Begg (1972, written commun., 1974) delineated five ages of channel systems on Stony Creek downstream from Black Butte Reservoir. Huston (1973) described five strath terrace levels in the Stony Creek drainage basin.

Most of the work on terraces elsewhere in the Great Valley has been along the east-central margin of the valley. In the American River area, Olmsted and Davis (1961) found three periods of erosion and deposition which are younger than the Arroyo Seco pediment (pl. 3), Shlemon and Hansen (1969) identified six periods of soil formation, and Shlemon (1972) found four terrace forming cycles that occurred during the last 600,000 years and suggested there may have been three more cycles older than 600,000 B.P. Shlemon (1971) and Shlemon and others (1973) found evidence for four periods of channel-filling in the Sacramento-San Joaquin Delta area. Shlemon (1971) described three gravel-filled channels and terraces in the Mokelumne River area and Janda and Croft (1967) identified several cycles of incision and filling in the northeastern San Joaquin Valley, although they did not specify the number of cycles.

Analyses of terraces to the west of the study area were started by Hershey (1902, 1903a, 1903b) who studied river terraces in the Klamath Mountains and described a sequence of terraces which are similar to those found in this study. Multiple terrace levels were also mapped by Irwin (1963) in the Trinity River drainage basin.

These previous studies indicate that numerous terrace forming episodes have occurred throughout much of the Great Valley and in other areas in northern California. Discrepancies in the number of terrace forming episodes is usually a function of the different time spans considered in the studies and in the degree of preservation of the deposits studied. Inferred correlations between terraces in several of these previous studies and terraces in the northwestern Sacramento Valley indicate regional, not local, events have resulted in the formation of many of these terraces.

Principal terrace levels

The northwestern Sacramento Valley contains six regionally correlative levels which occur as a series of nested terraces incised into older rocks or semi-consolidated sediments. From youngest to oldest these levels are informally designated as: (1) the Orland high floodplain; (2) the Yolo terrace, a slightly dissected terrace level; (3) the Arbuckle terrace, a slightly dissected terrace level; (4) the Perkins terrace, a moderately dissected terrace level; (5) the Corning terrace sequence, an assemblage of several poorly preserved terrace levels; and (6) the Redding high floodplain, a widespread erosional surface. The names are derived from the dominant soil associated with the various terrace levels (see table 1). Several minor terrace levels exist along individual drainages.

The Orland high floodplain is generally a topographically low fill deposit, which is preserved on the slip-off slopes of meander loops or upstream from major valley constrictions. It is sparsely tree-covered and generally consists of multiple levels, some or all of which may be within the present floodplain. It is characterized by a soil assemblage of minimally developed Orland loam, Yolo loam, and Cortina gravelly loam (table 1).

The Yolo terrace is generally, although not always, identifiable along major creeks. The terrace remnants are continuous and slightly dissected and are characterized by a soil assemblage of minimally developed Cortina gravelly loam, Yolo loam, and Wyo loam, and medially developed Arbuckle gravelly loam.

The Arbuckle terrace is prominent along most creeks. The terrace is characteristically continuous, wide, and only slightly dissected. It is characterized by a soil assemblage of medially developed Arbuckle gravelly loam, Hillgate gravelly loam, Churn gravelly loam, Hillgate loam, and Tehama loam. The Arbuckle terrace remnants are locally and regionally more extensive than the Yolo terrace remnants.

The Perkins terrace is the uppermost terrace level along many creeks. Its highly dissected discontinuous remnants are commonly separated by valleys of small streams. The Perkins terrace is characterized by a soil assemblage of maximally developed Perkins gravelly loam, Kimball gravelly loam, and Corning gravelly loam.

The Corning terrace sequence is defined as all terraces intermediate in age between the Perkins terrace and the Redding high floodplain. The sequence is commonly represented by only one main level, although multiple levels occur along some streams. The Corning remnants are geomorphically similar to the Perkins remnants although horizontally they are more widely separated than the Perkins remnants. The soils which characterize these terrace levels are maximally developed Corning gravelly loam and maximally developed Redding and Red Bluff gravelly loams with a hardpan. Because of the general scarcity of terrace remnants, small areal dimensions of the terrace remnants, and a soil assemblage which is difficult to separate further, additional subdivisions of the terraces between the Perkins terrace and Redding high floodplain are impractical.

The Redding high floodplain is the topographically uppermost surface in the area. It is restricted to the the upper surface of the Tehama and

Red Bluff Formations and is characteristically found as long, continuous, highly dissected remnants along drainage divides. This surface is characterized by Corning and Redding gravelly loam soils, but within some areas a Red Bluff gravelly loam is present. The remnants usually have a distinct hummocky (mima mound, prairie mound, or hog wallow) microrelief. These mima mounds were apparently initally formed by pocket gophers and later modified by a variety of processes (Arkley and Brown, 1954; Page and others, 1977). These features appear to be common on soils that have a shallow hardpan or claypan, such as the Redding soil series.

METHODS FOR ANALYZING STREAM TERRACES

Criteria for identifying, correlating, and dating stream terraces

The term "terrace," as used in this study, describes a steplike, relatively flat, or gently sloping abandoned floodplain paralleling a presently existing stream which is bounded on the landward side by an ascending slope and on the stream-ward side by a descending slope (figs. 4 and 5). The terrace surface, in a cross-valley profile, need not be flat, but it must be nearly horizontal or slope only very gently toward the descending slope. This requirement avoids complications caused by valley-flanking pediments and alluvial fans. The term "strath terrace" refers to stream terraces cut into bedrock that may be covered by a veneer of stream deposits. The veneer seldom exceeds a thickness equal to the depth of flood scour (figs. 6 and 7). The term "fill terrace" refers to preserved stream terraces cut into older unconsolidated alluvial fill along a stream. A "floodplain" is defined as an area likely to be flooded by stream flow equivalent to a 100-year flood. "High floodplains" are either (1) features near the maximum elevation of the 100-year flood (fig. 8) or (2) features that were once terraces but that have since had the ascending slope eroded so that they are now ridge tops (figs. 4, 8, and 9). The loose sediment that was in the floodplain at the time of stream rejuvenation and is now a veneer over the bedrock is referred to as a terrace "gravel." Individual particles that are greater than sand size are referred to as "pebbles" (0.2-6.4 cm), "cobbles" (6.5-25.6 cm), or "boulders" (greater than 25.6 cm). All particle diame-

Figure 4. Arbuckle terrace (middle level) and Perkins high floodplain (upper level) on south bank of Grindstone Creek.

Figure 5. Yolo terrace (foreground and minor level), Arbuckle terrace (middle level), and Perkins high floodplain (upper level) on north bank of Grindstone Creek.

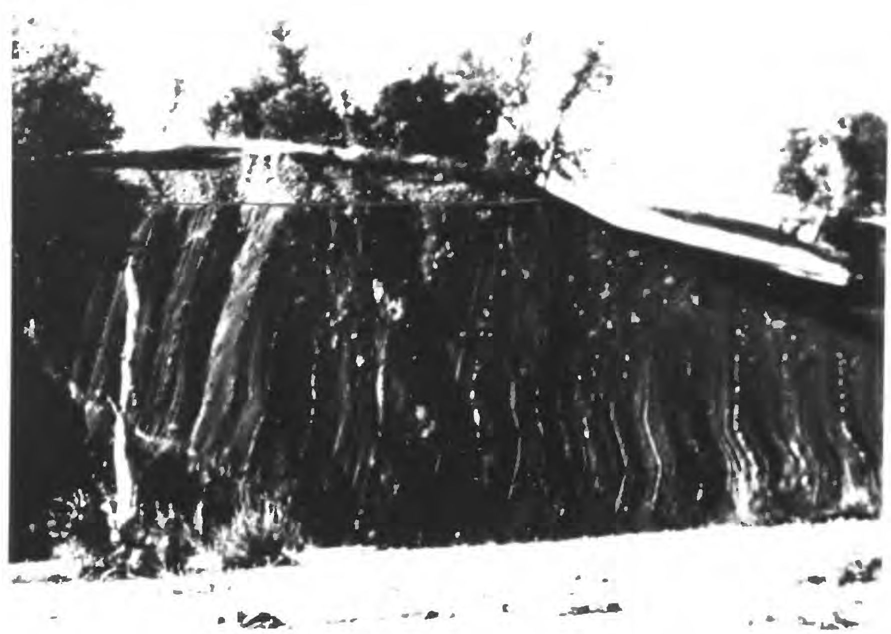

Figure 6. Perkins strath terrace, cut across upturned Great Valley Sequence. South side of Grindstone Creek.

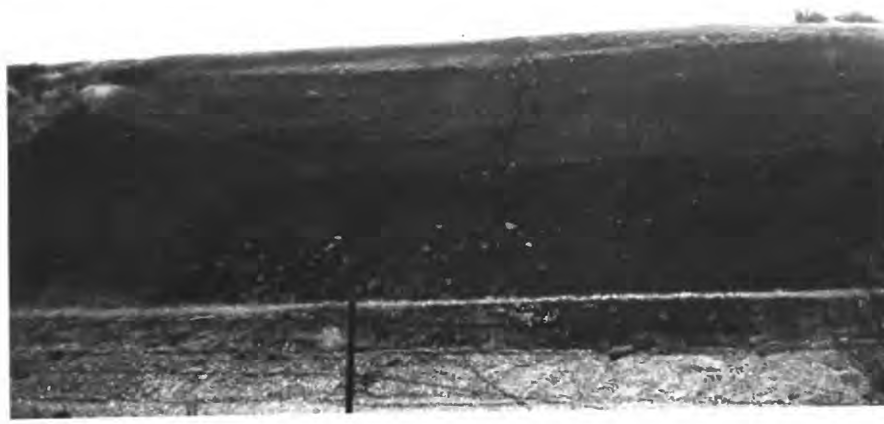

Figure 7. Perkins strath terrace (uppermost level) near Grindstone Rancheria. Thickness approximately 2 meters. Lowest horizontal feature is a road, middle horizontal feature is berm in roadcut.

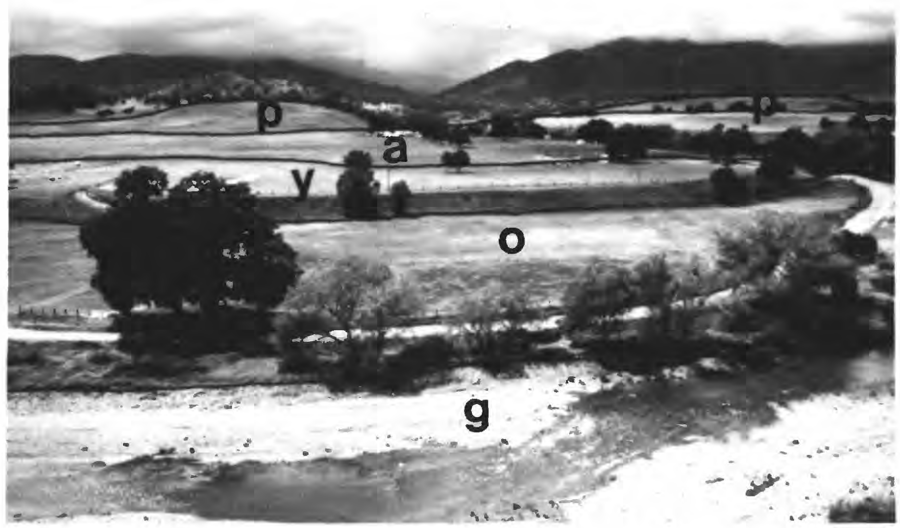

Figure 8. Terraces near Grindstone Rancheria, looking west. Grindstone Creek (g), Orland high floodplain (o), Yolo terrace (y), Arbuckle terrace (a), and Perkins high floodplain (p).

Figure 9. Perkins high floodplain north of Grindstone Creek. Perkins high floodplain is emphasized by heavy concentration of trees. View looking south. Grindstone Creek is south of the Perkins level.

ters, unless otherwise stated, refer to the maximum diameter.

Most of the features studied were terraces; therefore, the different age levels are classified as terraces (for example: Arbuckle terrace), even though some features may be intermediate in form between terraces, alluvial fans, rock fans, and pediments.

The major drainages of the northwestern Sacramento Valley contain fluvial terraces and alluvial fans which reflect a complex fluvial history. Because of the absence of paleontologic, archeologic, or isotopic material suitable for relative or absolute age dating, morphologic, pedologic, and lithologic criteria were used to make the correlations. Best correlations were obtained from an integrated approach combining all three criteria. No single criterion proved totally adequate although some techniques proved more useful than others.

The morphologic criteria of absolute elevation, relative elevation, slope, amount of dissection, continuity, and association with other features proved useful along single streams. The morphologic criteria are less diagnostic, however, between drainage systems or between widely separated parts of the same drainage system. In these two cases, supporting pedologic and lithologic data are needed for reasonable correlation.

The pitfalls of fluvial terrace correlation have been discussed by several authors (Cotton, 1940; Johnson, 1944; Frye and Leonard, 1954; and Ritter and Miles, 1973). Several major correlation problems found in many terrace systems and discussed by the above authors are avoided in the northwestern Sacramento Valley, however, because essentially all the terraces in the study area are strath terraces, and therefore are erosional features. No evidence was found upstream from the fan heads

(Black Butte Dam, sec. 29, T. 23 N., R. 4 W.; Henleyville, sec. 4, T. 24 N., R. 4 W.; etc.) to indicate major episodes of regional aggradation although local regional aggradation has occurred in a few areas. Older terraces, therefore, are generally higher, more dissected, locally less extensive, and less continuous than younger terraces. In the alluvial fan areas and in the main part of the Sacramento Valley where fields are plowed or leveled and drainageways otherwise altered, some of the morphologic characteristics which are useful upstream are of only limited value.

Terrace correlation is also complicated by tributary streams which may either dissect, flow across, or build alluvial fans onto the terrace surfaces. Erosion by the major streams and their tributaries, and natural surface relief combine with slopewash to alter the surface continuity. The natural surface relief (the relief due to minor channels, bars, levees, etc.) along present streams is usually less than 1 m and seldom exceeds 2 m. Field evidence indicates little reason to suspect that past surface relief was much different than at present. Care was taken in correlations to avoid errors due to younger overburden on terraces.

Although the most accurate longitudinal profiles are based on the bedrock alluvial contact, this approach proved impractical for this study because of the large size of the study area and time limitations. Longitudinal profiles in this study, therefore, are based on the upper surface of the terrace deposit. Because considerable care was taken to avoid using data where there was overburden and because the vertical separation of the terrace is usually several times the thickness of the deposit, the upper surface profile is a reasonably accurate reflection of the alluvium-bedrock profile (figs. 10 and 11).

The amount of terrace dissection, although generally useful, can be inadequate as a measure of relative terrace age for individual terrace remnants. This is particularly true for those terraces that are protected from erosion by younger suprajacent alluvial fans and slopewash.

Lithologic characteristics of the terrace deposits were of little value in correlations. The lithologic differences between terrace levels along a single stream are generally nondiagnostic although differences between various drainage systems may be pronounced. Intrabasinal terrace gravel lithologic changes, brought about by incision through time into different types of bedrock, were not detected. The lithologic changes between terrace levels along an individual stream is negligible, largely because the location of the drainage basin boundaries have remained nearly constant. Stream captures by the west and northwest flowing Eel River drainage system and the resulting changes in basin dimensions have occurred; however, these basin changes appear to be minor and were not detected in lithologic changes.

Soil stratigraphy provided the chief method of correlation of terraces between drainage basins. Each soil association has an orderly distribution and is characterized by the relative amount of soil development. The soils reflect at least six periods of fluvial erosion and terrace formation during late Pleistocene to recent time.

Figure 10. Arbuckle terrace on Elder Creek showing relatively uniform thickness of terrace deposit. Arbuckle terrace in foreground and mid-distance with tree. Elder Creek is in valley between the terrace remnants. Terrace deposit is dark horizontal band overlying the bedrock in valley scarp below tree.

Figure 11. Arbuckle terrace on South Fork of Cottonwood Creek showing relatively uniform thickness of terrace deposit.

Soil analyses

Relative soil development - differences in thickness, structure, consistency, color, pH, clay content, and other soil variables - is a useful means of correlation and is based on the assumption that if climate, vegetation, topography, and parental material (Jenny, 1941) are nearly constant, then the amount of soil profile development is a function of time (Morrison, 1967). Climatic, topographic, and parental material differences between points within the study area are minor. Vegetative differences are present between north-facing slopes and south-facing slopes, but are minor between slopes facing the same direction within the study area. Because these factors are nearly constant at any given time, a soil chronosequence whose differing characteristics are primarily or entirely the result of differences in their age will develop (Harden and Marchand, 1977). This soil chronosequence is exceedingly useful in correlating the northwestern Sacramento Valley terrace deposits between drainage basins and with other areas in California.

Soil scientists have observed that certain Great Valley soil assemblages have an orderly spatial distribution (Storie and Harradine, 1958; Gowans, 1967; Shlemon, 1967a, b; and Begg, 1968). Birkeland (1964), Janda (1966), Marchand and Harden (1976), Harden and Marchand (1977), Marchand and Allwardt (1977), and Marchand (1977a, b) have used these soil assemblages in mapping, correlating, and dating alluvial deposits within the Great Valley.

Evaluation of soil assemblages in the northwestern Sacramento Valley, although not totally definitive, provided the chief means of correlation between drainage basins and as a means of determining relative ages of terraces along a single drainage. The terrace levels are characterized by a distinctive sequence of soils that have diagnostic amounts of soil profile development (tables 1 and 2). These soils are particularly useful also for recognizing and correlating other Quaternary features in the study area.

The soils are principally Non-Calcic Brown soils, a great-soil group common in California's interior valleys. Tinsley (1975) has summarized the previous work and described the characteristics of this soil group. Generally, however, the Non-Calcic Brown soils are characterized by a thin, hard A horizon with a low organic content and by the lack of carbonate concentrations in the B and C horizons (Agricultural Experiment Stations of the Western Land Grant Universities and Colleges, 1964). The results of the Glenn, Tehama, and Shasta county soil surveys (Begg, 1968; Gowans, 1967; and Klaseen and Ellison, 1974) were very useful during this study in establishing terrace correlations.

Soils indicate an age for the ground surface, not the deposits on which the soil has formed; hence, the soils are assumed to represent minimum ages. Misleading soil profiles may occur, however, because the soil profiles are gradually removed or altered by more recent erosion and because the remnant terrace gravels are covered by younger material, hence less well developed soils. Gradual erosion is seldom a problem on the larger terrace remnants because the coarse texture and permeable characteristics of the gravel combine to prohibit overall surface lowering. On smaller terrace remnants, however, erosion must be considered.

Table 1: Principal soil series of the Quaternary deposits in the northwestern Sacramento Valley, California

Quaternary deposits	Major soil series	Soils	Characteristic profile development
Recent alluvium Orland high floodplain	Orland, Yolo, Cortina	Alluvial	Undeveloped to minimally developed
Yolo terrace	Cortina, Yolo, Wyo, Arbuckle	Relict	Minimally to medially developed
Arbuckle terrace	Arbuckle, Hillgate, Churn, Tehama	do.	Medially developed
Perkins terrace	Perkins, Kimball, Corning	do.	Maximally developed
Corning terrace sequence	Corning, Redding, Red Bluff	do.	Maximally developed, with hardpan
Redding high floodplain	Do.	do.	Do.

Table 2: Typical characteristics of the soil series of the Quaternary deposits in the northwestern Sacramento Valley, California

(from Gowans, 1967; Begg, 1968; Klaseen and Ellison, 1974)

Series	Great soil group	Order	Subgroup	Family	Prevalent terrace	Hardpan and(or) claypan	A-horizon thickness and color	B-horizon thickness and color	Typical color of subsoil	Typical pH
Orland	Alluvial	Entisol	Typic Xerorthent	Coarse-loamy, mixed, thermic	Orland	--	0-18" (2.5YR 5/1)	--	Grayish-brown	7-7.5
Cortina	Do.	do.	Typic Xerofluvent	Loamy-skeletal, mixed, non-acid, thermic	do.	--	0-3" (10YR 5/3)	--	Grayish-yellowish-brown	6.5-7
Yolo	Do.	do.	Typic Xerorthent	Fine-silty, mixed, non-acid, thermic	do.	--	0-34" (10YR 5/3)	--	Pale brown	6.5-7.5
Wyo	Noncalcic Brown	Alfisol	Mollic Haploxeralf	Fine-loamy, mixed, thermic	do.	--	0-11" (2.5YR 5/2)	11-42" (2.5YR 5/2)	Grayish-brown	6.5-7
Arbuckle	Do.	do.	Typic Haploxeralf	do.	Arbuckle	--	0-14" (10YR 5/4)	14-59" (10YR 5/4)	Yellowish-brown	6-7
Churn	Do.	do.	Ultic Haploxeralf	do.	do.	--	0-9" (10YR 6/4)	9-60" (10YR 6/4)	do.	6
Tehama	Do.	do.	Typic Haploxeralf	do.	do.	--	0-19" (10YR 6/3)	19-60" (2.5YR 6/3)	do.	6.5-7
Hillgate	Do.	do.	Typic Palexeralf	Fine, montmorillonitic, thermic	do.	--	0-17" (10YR 6/4)	17-70" (10YR 5/4)	do.	6-7
Perkins	Do.	do	Mollic Haploxeralf	do.	Perkins	--	0-9" (7.5YR 5/4)	9-60" (5YR 5/4)	Reddish-brown	5-6.5
Kimball	Do.	do.	Mollic Palexeralf	do.	do.	Claypan	0-6" (7.5YR 5/5)	6-55" (5YR 5/4)	do.	6-6.5
Corning	Do.	do.	Typic Palexeralf	do.	Corning	do.	0-21" (5YR 5/6)	21-36" (5YR 5/6 to 2.5YR 5/6)	do.	5-6.5
Red Bluff	Do.	do.	Ultic Palexeralf	Fine, kaolinitic, thermic	Redding	do.	0-20" (5YR 4/4)	20-72" (2.5YR 4/6)	do.	5-6
Redding	Do.	do.	Abruptic Durixeralf	do.	do.	Claypan and hardpan	0-13" (5YR 5/6)	13-23" (5YR 4/6)	do.	Do.

Young material that covers terraces and that is covered by younger soils usually is a result of slope wash or alluvial fans. The younger deposits generally are readily distinguished in the field by their association with present topography and by the disruption of the continuity of the terrace surface. The overlying deposits of intermediate age are more difficult to recognize in the field, but they generally stand out as anomalously young soils on topographically high features. The cessation of deposition of the intermediate age deposits was often due to either (1) differential erosion of the less resistant source area to a level below the more resistant terrace gravels (for example, the north side of Grindstone Creek, sec. 16, T. 21 N., R. 6 W.), or (2) incision of a drainage system on a terrace near the base of a hill which isolates the terrace (for example, Thomes Creek west of Flournoy).

The soils in the area studied are relict soils, not exhumed or buried soils, and, therefore, they have been subjected to climatic changes since they began forming. Although the soils have undergone continuous pedogensis, they have probably not done so at a uniform rate. Figure 12a shows the relative rate and amount of profile development for soils under uniform climatic conditions, and figure 12b shows the effect of superimposed climatic changes. These diagrams indicate that relict soils formed at different times in similar environments will be distinguishable until maturity, despite climatic changes. This condition appears to prevail in the northwestern Sacramento Valley. The amount of development of each soil profile has been affected by a different number of climatic changes, yet until each soils become well-developed, they are distinguishable and the distinction most likely reflects differences in age.

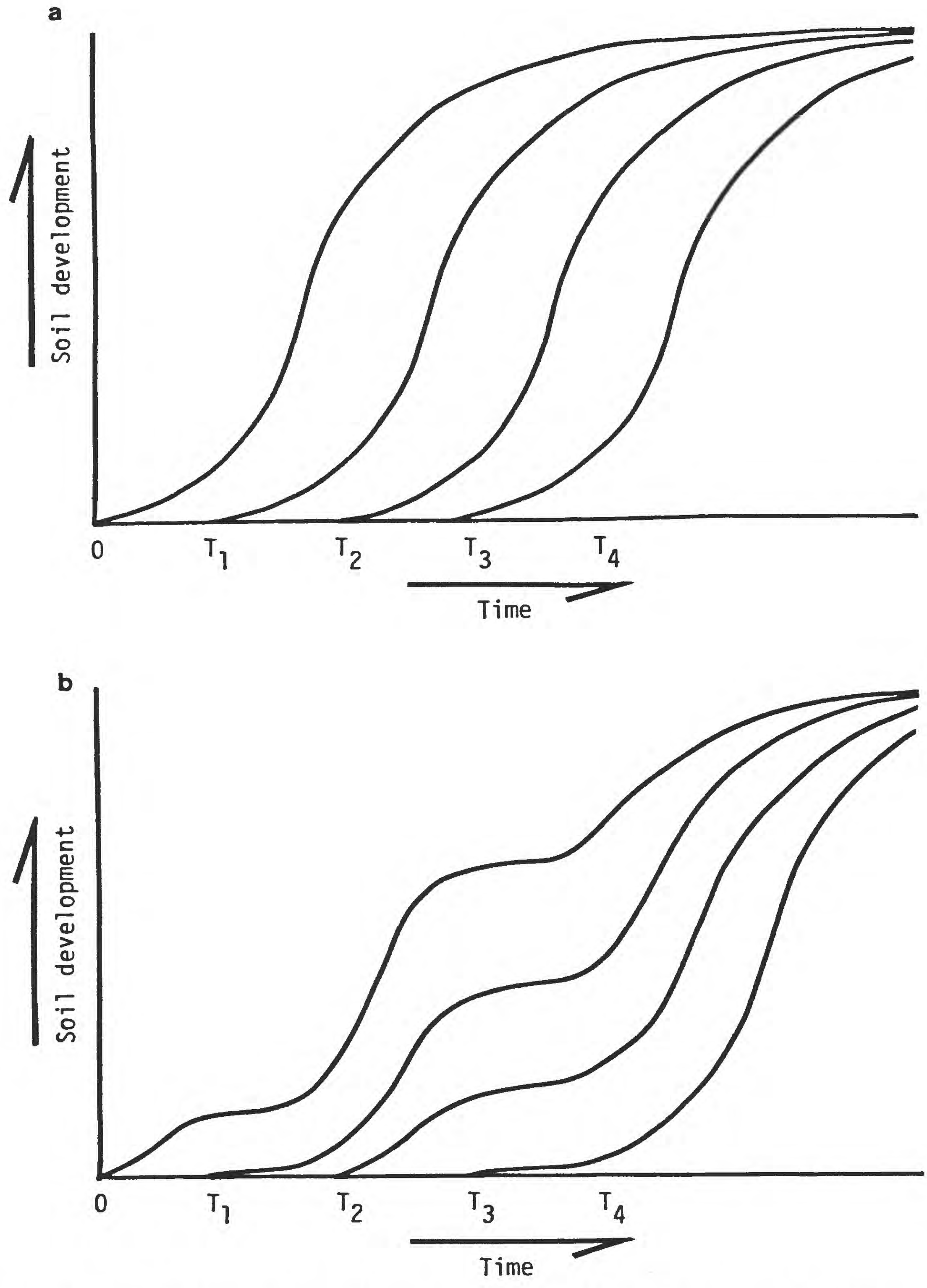

Figure 12. Relative rate and degree of profile development for soils under uniform (a) and fluctuating (b) climatic conditions (after Jenny, 1941; Shlemon, 1967a). Under uniform climatic conditions morphologic change effectively ceases following attainment of a maximally developed profile despite further passage of time. Under fluctuating climatic conditions soils of different ages are morphologically unique despite climatic changes until the soils attain a maximally developed profile.

The age of a specific Non-Calcic Brown soil is chiefly expressed by the relative amount of profile development. Good indicators of the stage of profile development are the vertical distribution of the clay and the changes in acidity within the profile (Tinsley, 1975; Marchand and Harden 1976; Harden and Marchand, 1977); however, in the northwestern Sacramento Valley the color of the oxidized B horizon is more useful and more readily recognizable for correlation than the clay distribution because the soils are usually formed on coarse gravel in which clay is a minor constituent (fig. 13).

Marchand and Harden (1976) and Harden and Marchand (1977) found soil color one of the most useful indicators of soil age in the northeastern San Joaquin Valley. They also determined that soil color could be used to date soil as much as three million years old and, in some cases, to date even older, moderately eroded soil profiles. In the northwestern Sacramento Valley, the dominant spectral color, hue, generally is redder and the strength of the color, chroma, generally is brighter with increasing age of the soil. All references to soil colors in the northwestern Sacramento Valley are to dry soils because this is their most common condition. Moist soil colors are usually one to three value steps, lightness, higher and zero to two chroma steps higher. Hues usually remain constant for moist or dry samples, except for older and redder soils which become redder when moistened.

The amount of profile development has been classified as "minimal," "medial," "maximal," or "maximal with a hardpan" by county reports (Gowans, 1967; Begg, 1968; and Klaseen and Ellison, 1974) and this terminology has been successfully used by Harradine (1963), Janda and Croft

Figure 13. Arbuckle terrace deposit showing typical particle size for terraces in the northwestern Sacramento Valley. Terrace deposit near Steuben Bridge on Stony Creek. Shovel head is at the base of the deposit.

(1967), and Tinsley (1975). For this study, therefore, the following definitions are used: (1) a "minimally developed soil" is a soil with only an A-C profile (no B horizon) and with color values close to those of the fresh material; (2) a "medially developed soil" is a soil with an A-B-C profile, with thin textural clay films, and with a yellowish and(or) brownish hue; (3) a "maximally developed soil" is a soil with thicker B and C horizons than in medially developed soils, thicker clay films than in medially developed soils, more clay in the B horizon than in medially developed soils, and of slightly redder hue than the medially developed soils; and (4) a "maximally developed soil with a hardpan" is a soil similar to maximally developed soils but with a slightly redder hue and a hardpan.

DETAILED DESCRIPTIONS OF QUATERNARY STREAM TERRACES

The Stony Creek drainage basin was selected as the type area for the stream terraces in the northwestern Sacramento Valley and, therefore, will be described in detail. Only cursory descriptions of the other drainage basins are given below.

Stony Creek Drainage Basin

Grindstone Creek section of Stony Creek drainage

Grindstone Creek (pl. 1), a major tributary of Stony Creek, emerges from the mountain front in a 750 m deep V-shaped canyon, flows across the east dipping Great Valley Sequence in the Stony valley area (fig. 1), turns south along the east margin of the valley, and joins Stony Creek at the Grindstone Rancheria (sec. 15, T. 21 N., R. 6 W.). Three paired strath terraces, Yolo, Arbuckle, and Perkins, border the creek, but no evidence could be found that they ever extended upstream beyond the mountain front (fig. 14). The lack of terraces in the mountains, however, may be due to the steeper terrain and narrow valleys so that any terraces that may have existed have been removed by mass wasting.

The youngest surface along Grindstone Creek is the Orland high floodplain (fig. 8). The only sizable remnant is near the Grindstone Rancheria and, according to local residents, it is flooded about every

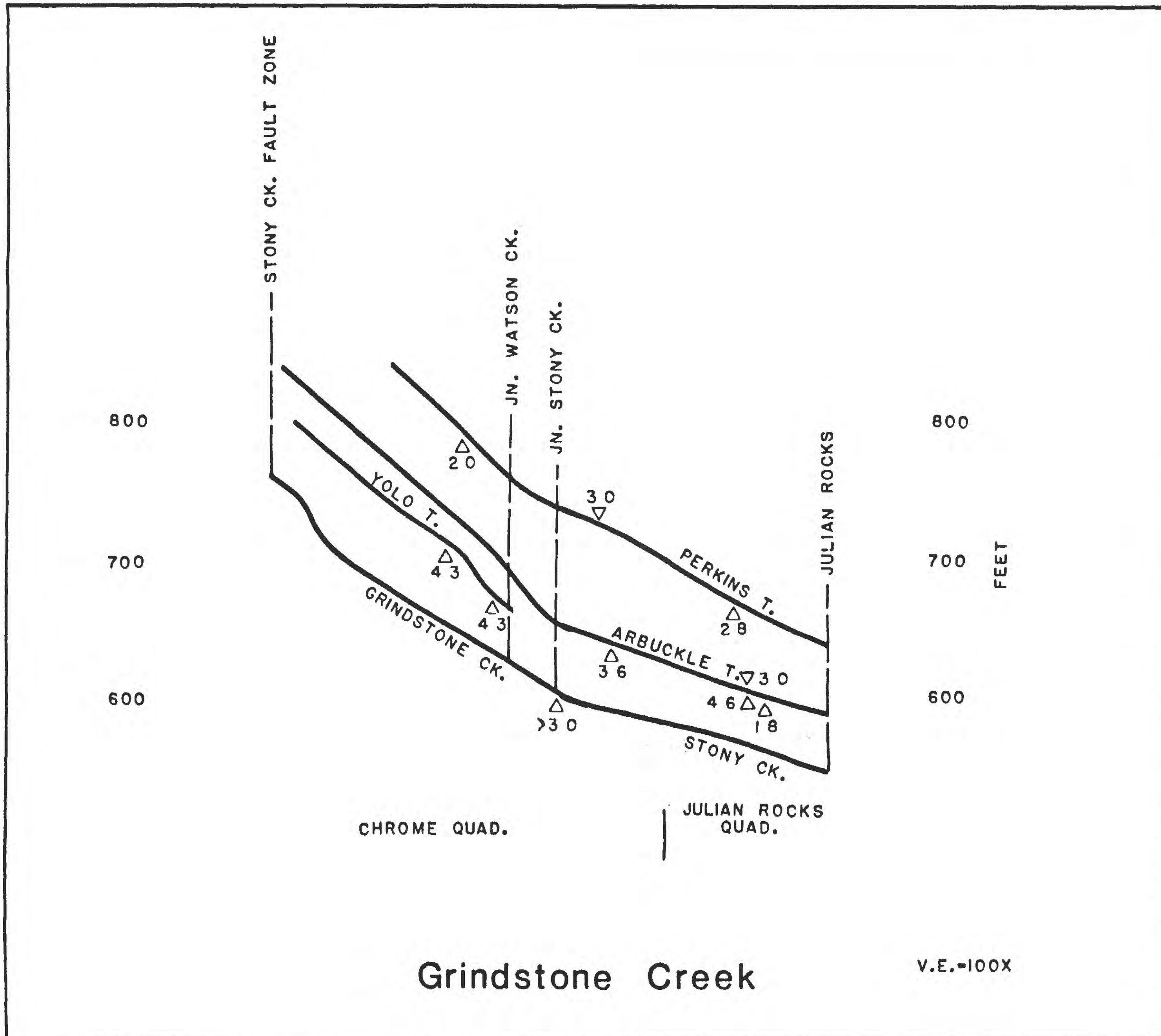

Figure 14. Longitudinal profiles and maximum gravel sizes of Grindstone Creek. Location and maximum gravel size (cm) indicated by triangles with numbers.

ten years. The floodplain may be the result of deposition from floodwaters ponding upstream from a valley constriction at a resistant Cretaceous sandstone unit near the Grindstone Rancheria.

The Yolo terrace along Grindstone Creek is a paired terrace which includes several minor levels near the confluence with Watson Creek (fig. 8). This paired terrace is one of the few terrace sets which shows these minor levels because slopewash obscures these features on most of the other terrace remnants. The Yolo terrace along Grindstone Creek corresponds to the Stony Creek strath terrace of Huston (1973).

The Arbuckle terrace is a paired strath terrace which corresponds to the Elk Creek strath terrace of Huston (1973) (fig. 8). As with the Yolo terrace, minor terrace levels, meander scars, and abandoned channels are evident near the confluence with Watson Creek.

Paired remnants of the Perkins terrace are preserved as a pair of gravel-capped ridges (fig. 8) above the Arbuckle terrace. This surface corresponds to the Salt Creek strath terrace of Huston (1973) along Grindstone Creek. The preservation of former floodplains as ridges is apparently due to the gravel cap. The gravel deposits deterred erosion while the flanking valley sides, which are mostly shale, are more susceptible to erosion.

Watson Creek section of Stony valley area

Near the mountain front, Watson Creek, a tributary to Grindstone

Creek, enters the Stony valley area near the drainage divide between Stony Creek and the North Fork of Stony Creek (pl. 1 and fig. 15). The terraces form a fan-shaped assemblage (sec. 32, T. 22 N., R. 6 W.) that indicates that Watson Creek flowed at various times into either Grindstone Creek or the North Fork of Stony Creek. A complex terrace assemblage, which was mapped as Arbuckle terrace, forms much of the valley between the town of Chrome (sec. 28, T. 22 N., R. 6 W.) and Grindstone Creek. No terrace remnants were identified west of the mountain front.

The Perkins terrace, which here corresponds to part of the Heifer Camp Creek strath terraces of Huston (1973), is preserved as a channel extending from the mountain front northeast through Chrome and northward along the east side of the Stony valley area. A bench has been cut into a conglomerate ridge near the mountain front; this level may correspond to the Perkins terrace, but no gravel is preserved. Only small gravel-capped remnants occur along the south-draining part of Watson Creek although several unmapped ridges without a gravel cap have nearly the same elevation. These ridges may indicate that the Perkins terrace was once much more extensive south of Chrome than is shown by the minor remnants preserved today (fig. 16). Several similar nongravel-capped levels are present throughout most of the Stony valley area.

The Corning terrace sequence consists of remnants which form a fan-shaped assemblage with an apex at the place where Watson Creek debouches from the mountain front. These levels correspond to the Watson Creek strath terrace and to several remnants of the Heifer Camp Creek strath terrace of Huston (1973).

Watson Creek has undergone an unusual evolution. During the late

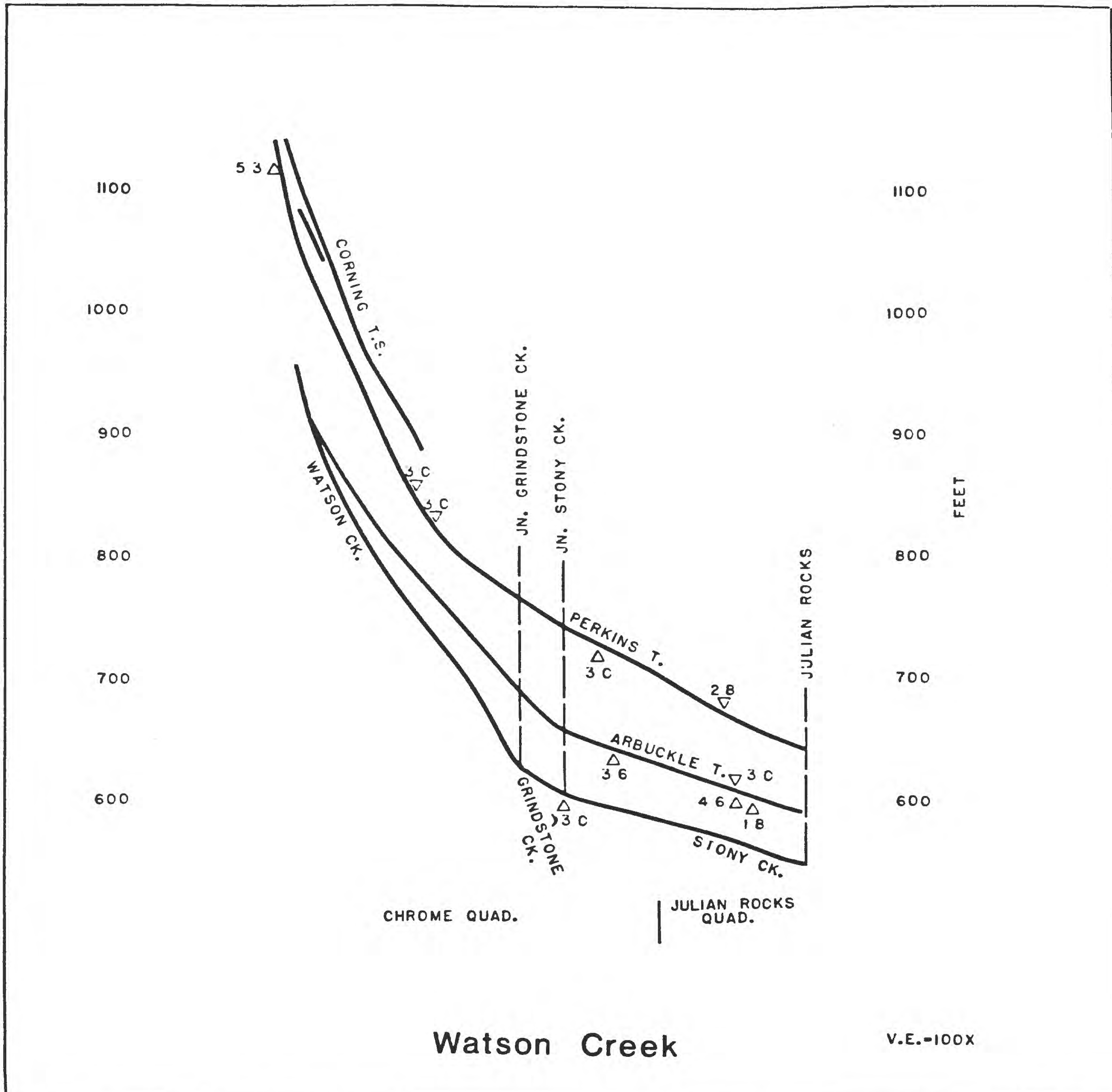

Figure 15. Longitudinal profiles and maximum gravel sizes of Watson Creek. Location and maximum gravel size (cm) indicated by triangles with numbers. Terrace level without a name was not correlated with any of the six regional terraces.

Figure 16. Perkins high floodplain along Watson Creek showing non-gravel capped hill (foreground) which probably is a highly dissected remnant of the Perkins level in the distance.

Tertiary, Watson Creek debouched from the Coast Ranges onto the rocks of the Great Valley Sequence, as did Grindstone Creek to the south and the North Fork of Stony Creek to the north. Presumably the drainage divides at this time were about midway between the streams although no supporting or contradictory evidence is now present. The three streams deposited alluvial fans (the Tehama Formation), that were similar to features now represented elsewhere in the study area by several sets of radiating streams incised into the Tehama Formation. Post-Tehama Formation orogenesis induced stream incision near the mountains, eventually removing all of the Tehema Formation deposits that may have existed in the Stony valley area. Grindstone Creek and the North Fork of Stony Creek, because of their larger drainage areas, downcut more rapidly than Watson Creek and were able to maintain their courses across the newly exposed rocks of the Great Valley Sequence. Because the adjacent creeks were lower in elevation and because Watson Creek was not able to maintain its course eastward across the rocks of the Great Valley Sequence, tributaries in parts of the Stony valley area north and south of Watson Creek were captured by the adjacent creeks. The area surrounding Watson Creek eroded rapidly; however, Watson Creek, partly because of stream capture and partly because its own coarse-grained deposits resisted erosion, was left near the drainage divide. The creek flowed into either the North Fork of Stony Creek or into Grindstone Creek at various times during the development of the Corning and Perkins terraces. This shifting between drainage basins could have been due to either piracy oscillating between the adjacent streams or by lateral migration, erosion, and breaching of its banks by Watson Creek. However, stream shifting is not likely to have been caused by piracy because it would require Grindstone Creek and the North Fork of Stony Creek, alternately to have erosional advantage, one over the other. A more plausible explanation is that Watson Creek, by lateral migration, alternately breaching one flanking floodplain or terrace and then another. Near the end of the period of drainage shifting, Watson Creek was flowing in a northeast-trending channel; this channel is now preserved near the present community of Chrome. The subsequent and final shift could have been due to either breaching of a flanking terrace or piracy by a tributary to Grindstone Creek. During, or after, the period of Perkins terrace formation but before the period of Arbuckle terrace formation, Grindstone Creek had a distinct elevation advantage over Watson Creek, as indicated by the Perkins terrace longitudinal profiles. Subsequent incision, prior to the formation of the Arbuckle terrace, was sufficient to prevent Watson Creek from shifting to the north again and to prevent the North Fork of Stony Creek from capturing Watson Creek. This sequence of events also accounts for the absence of terraces younger than the Perkins terrace in the area between Watson Creek and Heifer Camp Creek.

Elk Creek to Grindstone Rancheria section of Stony Creek

In this stream section, Stony Creek is a subsequent stream which flows north from the town of Elk Creek (sec. 9, T. 20 N., R. 6 W.) to the confluence of Stony Creek and Grindstone Creek at the Grindstone Rancheria (pl. 1). The location of the stream has remained nearly constant since the Perkins terrace was formed. The stream shifted little because its migration in the downdip direction has been limited by a massive sandstone unit in the Great Valley Sequence. Stony Creek and its tributaries have developed both strath and fill terraces upstream from the town of Elk Creek (Rich and Brown, 1972; Huston, 1973).

The Arbuckle terrace, the principal terrace along this reach of the stream, corresponds to the Elk Creek strath terrace of Huston (1973). The terrace gravel was deposited on a nearly planar surface. The gravel clasts have a negligible to slight "glossy" sheen which may be due to a thin coating of silicon dioxide, ferric oxide, and(or) manganese dioxide. Marchand and Harden (1976) and Marchand (1977b) found these compounds to be a common cement in terrace gravels in the northeastern San Joaquin Valley. This "glossy" sheen appears to be a function of time, with a higher sheen on older terrace deposits; therefore, it was used, with caution, as additional evidence for terrace correlations.

The uppermost surface along this section (Diamond M and Ivory Mill strath terraces of Huston (1973)), is here referred to as the Perkins terrace.

Grindstone Rancheria to Julian Rocks section of Stony Creek

Downstream from its confluence with Grindstone Creek, Stony Creek trends east across the Cretaceous sandstone and shale beds of the Great

Valley Sequence and is deflected to the north by a massive conglomerate unit at Julian Rocks (pl. 1 and fig. 17). The creek continues to flow north for 2 km before it breaches the conglomerate unit at Julian Rocks (sec. 1, T. 21 N., R. 6 W.).

In this stream reach, floodwaters ponding upstream from Julian Rocks have apparently been the cause of another segment of the Orland high floodplain which is largely a deposit of laminated sand and silt. The paired, nearly continuous, Arbuckle terrace is the most extensive terrace along this section of Stony Creek. The uppermost terrace, the Perkins terrace, is also a paired terrace; clasts in the terrace gravel show a definite "glossy" sheen.

Julian Rocks to Steuben Bridge section of Stony Creek

Stony Creek, between Julian Rocks and Steuben Bridge (sec. 27, T. 22 N., R. 5 W.), flows east-northeast and is incised into an early Pleistocene channel formed on the Tehama Formation - Stony Creek alluvial fan (pl. 1 and fig. 17). The creek has gradually shifted south since the formation of the Perkins terrace. The shift may be due to insolation of the north facing slope from the sun which increases sedimentation from the north. No field evidence could be found to suggest that the shift might have resulted from tilting or migration in a down-dip direction.

Paired benches are carved into the Julian Rocks conglomerate unit at the level of the Arbuckle terrace although no terrace gravels are pre-

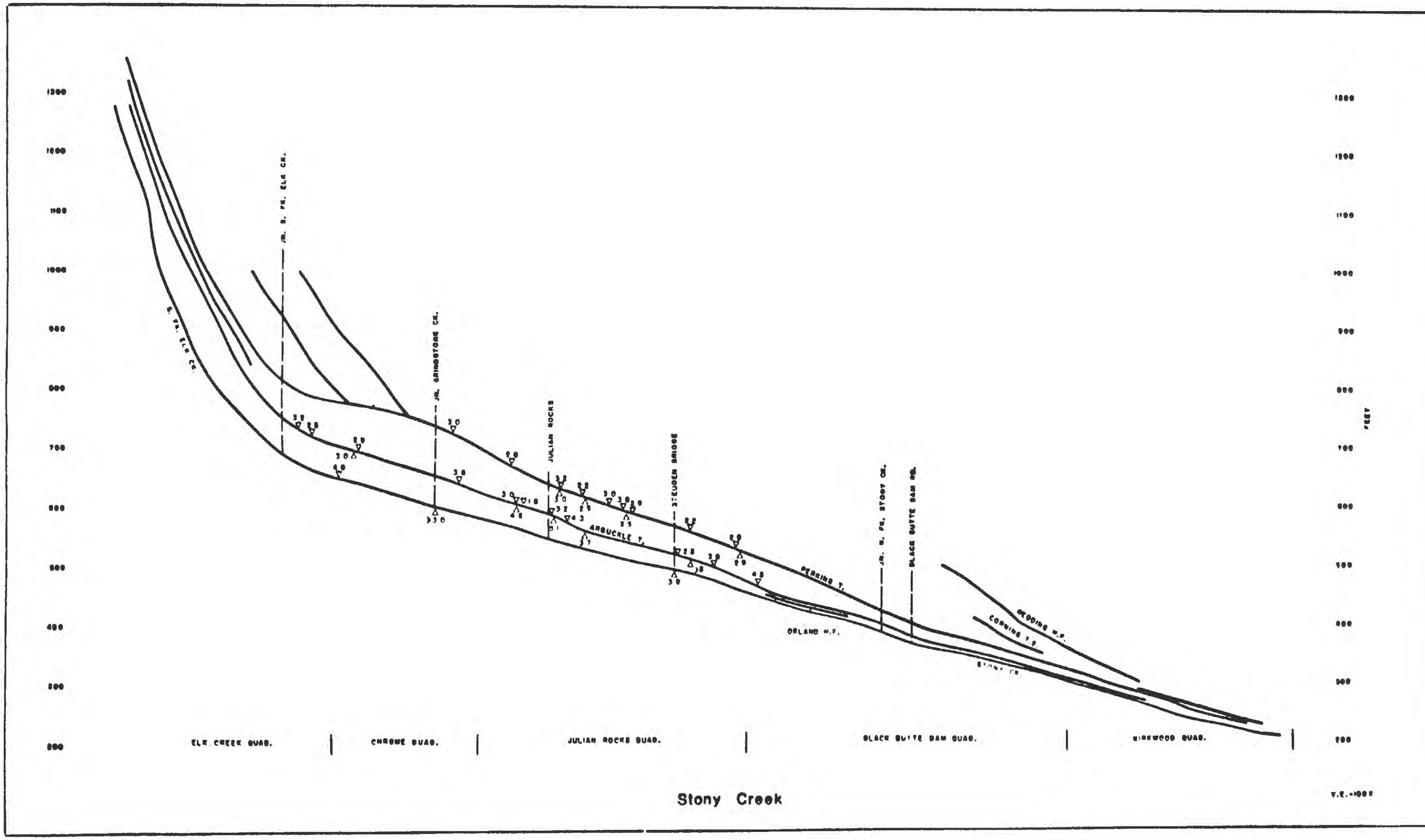

Figure 17. Longitudinal profiles and maximum gravel sizes of Stony Creek. Location and maximum gravel size (cm) indicated by triangles with numbers. Terrace levels without a name were not correlated with any of the six regional terraces.

served on the bare bedrock. The Arbuckle terrace forms a paired strath terrace downstream from Julian Rocks and the clasts in the terrace gravel are well rounded, have a very slight brown stain, are imbricated, and some have a slight "glossy" sheen.

The Perkins terrace, along this stretch of the creek, is represented by dissected discontinuous remnants that flank the north side of the valley. The surface phenocrysts of porphyritic andesite clasts are deeply weathered. This pitting is most prominent on the Perkins terrace, but it is present also on lower terraces. The amount of phenocryst weathering appears to be a function of time; therefore, it was used, with caution, as an additional tool for terrace correlation. The cobbles and boulders have a high "glossy" sheen, are well rounded, and show a higher sphericity than clasts in the younger terrace deposits.

Steuben Bridge to Black Butte Dam section of Stony Creek

Stony Creek flows northeast across the gently dipping Tehama Formation through this section, is deflected north by the fault-bounded Orland Buttes (sec. 8, T. 22 N., R. 4 W.), and then crosses the Orland Buttes volcanic units to debouch into the Sacramento Valley at the Black Butte Dam (sec. 29, T. 23 N., R. 4 W.; pl. 1; and figs. 17 and 18). Although most of this stretch is now flooded by the water of Black Butte Reservoir, large seasonal water-level changes (approx. 12 m) allowed detailed mapping of the terraces during the late summer low-water levels. Topo-

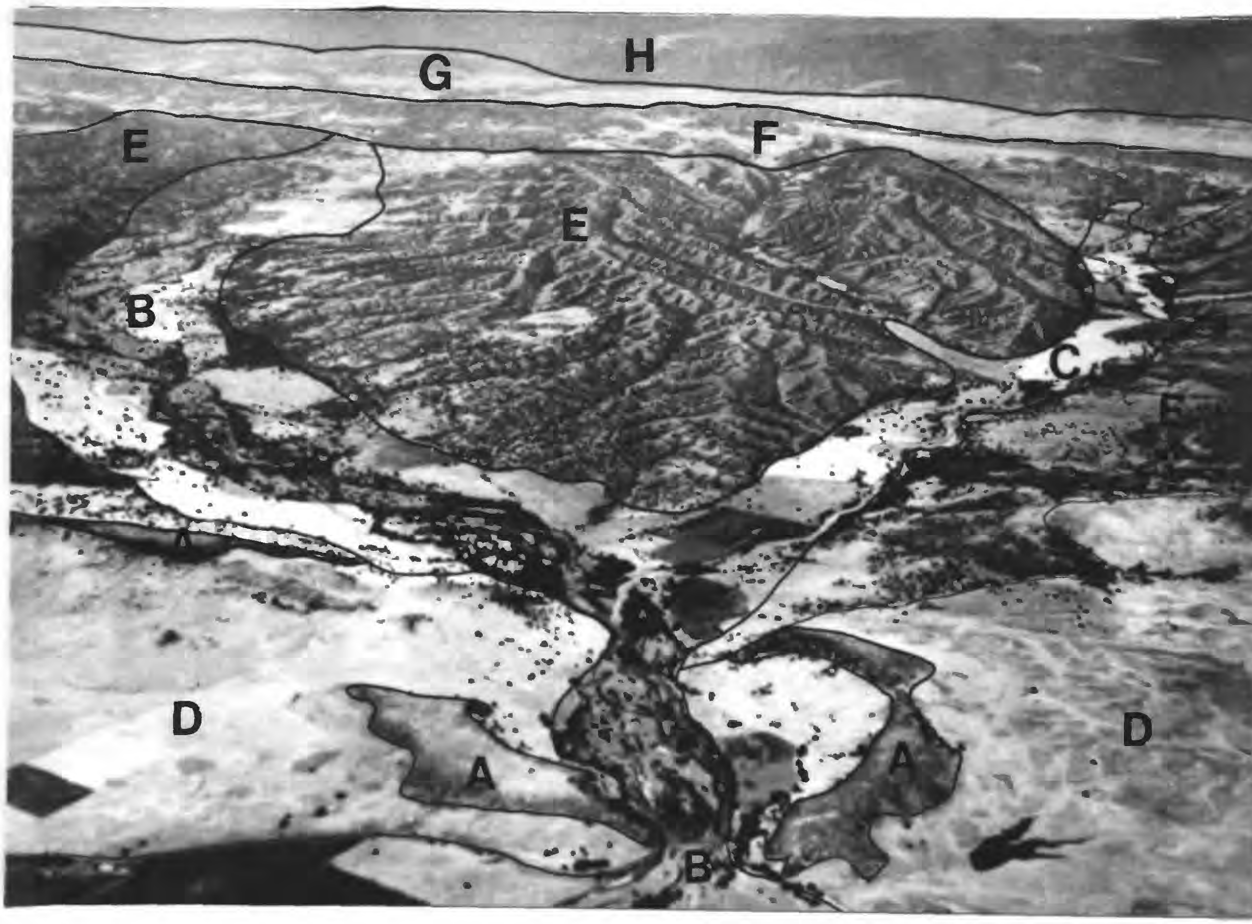

Figure 18. Stony Creek drainage basin prior to construction of Black Butte Dam. View looking west. Orland Buttes (A), Stony Creek (B), North Fork of Stony Creek (C), complex of Tehama Formation, Red Bluff Formation, and Redding high floodplain, with mima mounds often developed on the surface (D), Tehama Formation (E), Great Valley Sequence (F and G), Stony valley area (G), and Coast Ranges (H). Southward stream shifting by both streams is evidenced by the markedly assymetric valleys upstream from Orland Buttes. Most readily apparent terrace is the Arbuckle terrace. It appears essentially as a treeless, farmed area west of the confluence of the two streams. Much of the stream valley area upstream from the closest part of the Orland Buttes is presently overlain by Black Butte Reservoir. Photo taken by U.S. Army Corps of Engineers at 6800 ft on July 17, 1959.

graphic maps, aerial photographs, and soil surveys (Begg, 1968; Gowens, 1967) made before the construction of the dam, were available to the author and they are the only source of information for terrace mapping between the 430 foot (131 m) contour and the dam. The terraces that are seasonally covered by the reservoir are still morphologically well defined, although they are now overlain by approximately 70 cm of fine-grained lacustrine deposits.

Two large areas of the Orland high floodplain are preserved upstream from Orland Buttes. They are paired, and as is typical of much of the Orland high floodplain, they are upstream from a major constriction in the creek. Local residents indicated the terrace remnants were flooded frequently before the construction of Black Butte Dam. Downstream from Steuben Bridge, the continuity of the Arbuckle terrace is only interrupted by three large tributaries on the northwest side of the creek; however, only a narrow remnant exists for a short distance downstream from the bridge along the southeast side of the creek. This relationship may be a manifestation of the down-dip eastward migration of Stony Creek. The cobble and boulder clasts in the terrace gravels have no "glossy" sheen and, although well rounded, they are nonspherical. The Arbuckle terrace can be traced in the field from Stony Creek to the confluence with the North Fork of Stony Creek, and headward along the North Fork. At the confluence is one of the few places where correlation, on the basis of continuity, is possible between two major streams in the study area.

The Perkins terrace, although highly dissected, is a moderately well preserved assemblage of terrace remnants and also may be traced from

Stony Creek to the North Fork of Stony Creek.

Black Butte Dam to Sacramento River section of Stony Creek

Stony Creek, after crossing the fault bounded Orland Buttes, flows east-southeast across an alluvial fan (pl. 1 and fig. 17). The stream has cut into and deposited alluvial fan material on the Red Bluff Formation and on younger alluvial sediments. The alluvial fan sediments are sheets and lenses, as much as 40 m thick (Olmsted and Davis, 1961), of clean, well-sorted gravels. Terraces mapped downstream from Orland Buttes have been reconstructed principally from well log and soil analyses by Shlemon and Begg (1972; written commun., 1974). All of the principal surfaces are preserved within this stream section, and the more recent levels may reflect a northward shifting of the creek. This direction of shifting is opposite to the direction along most of the rest of the Stony Creek drainage area. Because there is no other known data which would indicate northward stream shifting, this anomalous direction of shifting may be more apparent than real.

Large areas of the Orland high floodplain are present along both sides of the stream; these areas generally correspond to Shlemon and Begg's (1972; written commun., 1974) channel number 1. Based on the amount of soil profile development, Shlemon and Begg inferred the age to be less than 10,000 years old.

An extensive area of the Yolo terrace is preserved south of the present stream; it corresponds to Shlemon and Begg's (1972; written commun., 1974) number 2 level (10,000-30,000 B.P.).

The Arbuckle level is represented by a north-trending distributary system which interfingers toward the south with basinal deposits of the Sacramento River. The level is bounded on the west by the alluvial fans of streams draining from the foothills. Several south-trending channels (not shown on pl. 1) are represented by the soil distribution. Shlemon and Begg (1972; written commun., 1974) inferred the age of this level, their number 3 level, as 30,000-80,000 B.P.

The Perkins level is preserved on the flanks of the Stony Creek alluvial fan and as small remnants within the younger alluvium. Arbuckle and Kimball gravelly loam soils have developed on the terrace gravel. Although these soils often occur together, either one or the other is more pronounced locally. The Arbuckle soils are probably ancient stream channels; these channels cut 1 or 2 m into the Kimball soil. Shlemon and Begg (1972; written commun., 1974) have dated this level as older than 80,000 years.

The Corning terrace sequence and Redding high floodplain are present on the north side of the creek. This is the southernmost remnant of the Redding level within the study area. The prominent dendritic outline of the preserved remnants is characteristic of the Redding high floodplain.

North Fork of Stony Creek

North of Watson Creek, the Stony valley area (pl. 1 and fig. 19) is nearly twice as wide as it is south of Chrome. The terraces in this section are rather poorly developed, partly because of an increase in the valley relief as a result of a larger number of resistant sandstone and conglomerate units in the Mesozoic section and partly because of the relatively minor drainages in this area. Although the North Fork of Stony Creek (sec. 33, T. 23 N., R. 6 W.), Salt Creek (sec. 4, T. 22 N., R. 6 W.), and Heifer Camp Creek (sec. 9, T. 22 N., R. 6 W.) have developed the most extensive terrace assemblages in this area, several tributaries also have terraces developed along them. Three terrace levels - Arbuckle, Perkins, and Corning - are preserved along the North Fork of Stony Creek.

The Arbuckle terrace, in this part of the drainage basin, is about 8 m above the present stream. The terrace merges upstream with the present floodplain (fig. 19). This upstream convergence, which is unique within the study area, may be due to Watson Creek's final shift to Grindstone Creek. The Perkins terrace is rather extensively preserved in this area and corresponds to the Heifer Camp Creek strath terrace of Huston (1973). The terrace converges downstream towards the present stream and towards the Arbuckle terrace. The elevation of the terrace above the present stream is about 28 m near the mountain front and about 22 m near the town of Newville (sec. 3, T. 22 N., R. 6 W.). The Corning terrace sequence is best preserved along Heifer Camp Creek. The terrace sequence corresponds to the Watson Creek strath terrace of Huston (1973). Near the mountain

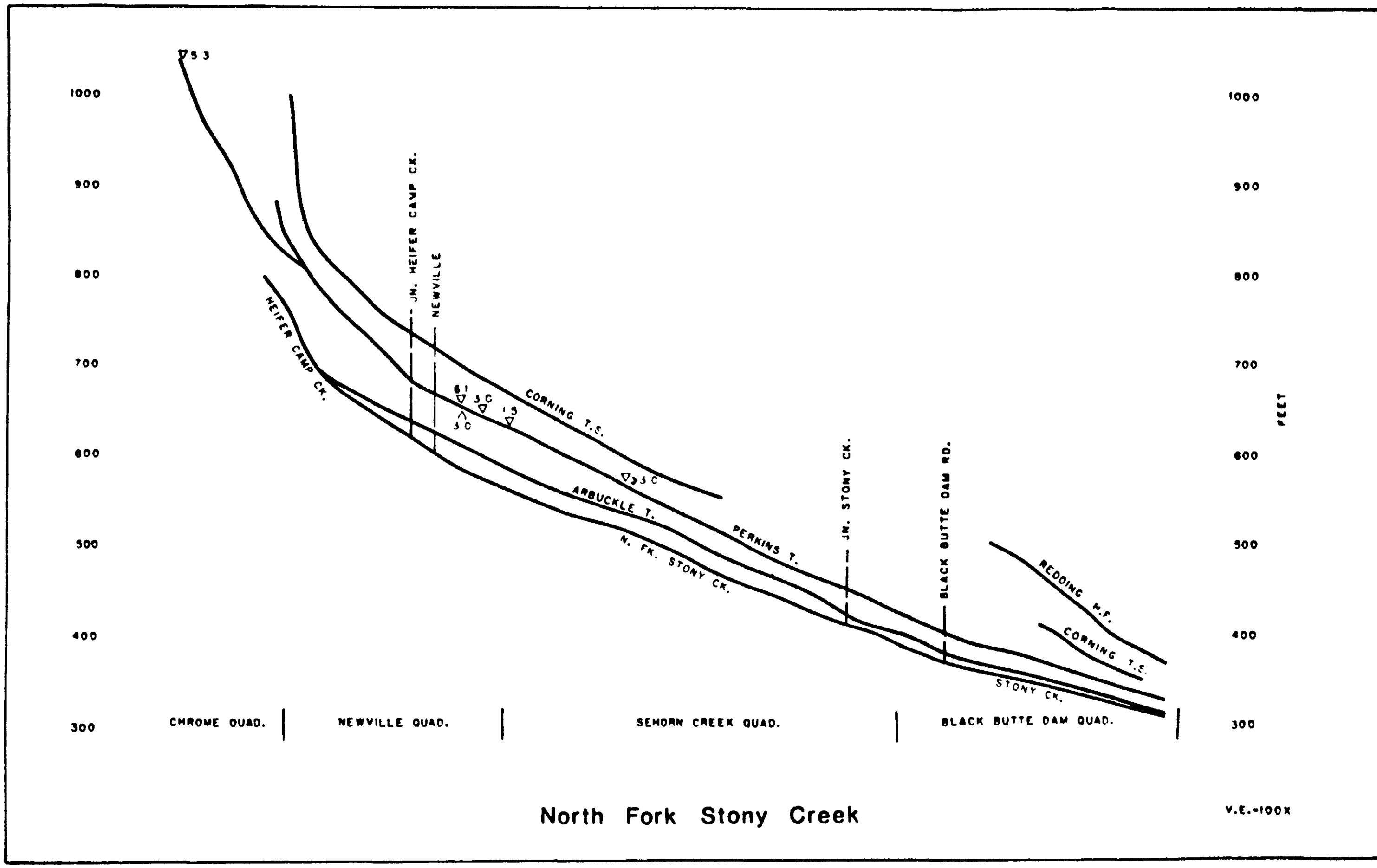

Figure 19. Longitudinal profiles and maximum gravel sizes of the North Fork of Stony Creek. Location and maximum gravel size (cm) indicated by triangles with numbers. Two Perkins terrace profiles upstream are due to profiles along different tributaries (Heifer Camp Creek, steeper profile; paleo-Watson Creek through Chrome, shallower profile).

front, the terrace is 50 m above the present stream. Downstream, near Newville, it converges to about 40 m above the present stream.

The valley of the North Fork of Stony Creek between Newville and Black Butte Dam (pl. 1 and fig. 19) contains several fill terraces. The creek flows across about 6 km of steeply dipping Great Valley Sequence and then intersects the Tehama Formation. From this intersection downstream to the the main branch of Stony Creek, the creek has shifted to the south, causing the removal of nearly all but the lowest terrace, the Arbuckle terrace, from the south side of the creek.

The Arbuckle terrace, the primary terrace level along the North Fork of Stony Creek, is a paired fill terrace which has as much as 5 m of debris cover. The present creek is flowing across Cretaceous rocks at about the contact between the fill and the bedrock. The terrace surface is more irregular than most Arbuckle terrace surfaces, and a distinct abandoned channel has been preserved on it. Local residents suggest that this channel on the Arbuckle terrace was abandoned within the last 100 years (Carpenter, 1967). It appears the channel was a tributary stream channel, not the North Fork of Stony Creek, because the soils on the terrace have a medial degree of profile development and therefore have been forming for several thousands of years.

Paired remnants of the Perkins terrace are preserved only near Newville and near the confluence with the main branch of Stony Creek. Elsewhere, southward shifting of the creek has removed all traces of the terrace on the south side of the valley. The Perkins terrace, where it was cut into the Tehama Formation, is now poorly preserved, highly dissected, and largely covered by slopewash. Morphologically, these remnants are essentially identical to the Perkins terrace remnants in the Steuben Bridge to Black Butte Dam section of Stony Creek. Few remnants of the Corning terrace sequence are preserved along the North Fork of Stony Creek. The remnants are morphologically similar to the Perkins terrace, except that they occur at a higher elevation.

Thomes Creek Drainage Basin

Thomes Creek (pl. 1 and fig. 20) is the first major stream north of the Stony Creek drainage basin. Thomes Creek emerges from the Coast Ranges at The Gorge (sec. 17, T. 23 N., R. 7 W.), west-southwest of the town of Paskenta (sec. 4, T. 23 N., R. 6 W.). Upstream from The Gorge, Thomes Creek has eroded an asymmetric V-shaped canyon. Aside from the asymmetry, the deep canyon, with its relatively uniform slopes and straight channel, is similar to the canyon formed by Grindstone Creek. Downstream from The Gorge, Thomes Creek crosses a shaly section of the Great Valley Sequence, and the creek changes from its nearly straight channel to one with well-developed ingrown meanders. The creek continues to meander until it passes through a major constriction at Williams Butte (sec. 7, T. 23 N., R. 6 W.) formed by sandstone and conglomerate units. Although several minor terraces are preserved on the meander slip-off slopes, some of the terrace remnants may be equivalent to the regionally correlative terraces. The youngest terrace along this stream reach is the Yolo terrace. It is usually preserved as the lowest level on the

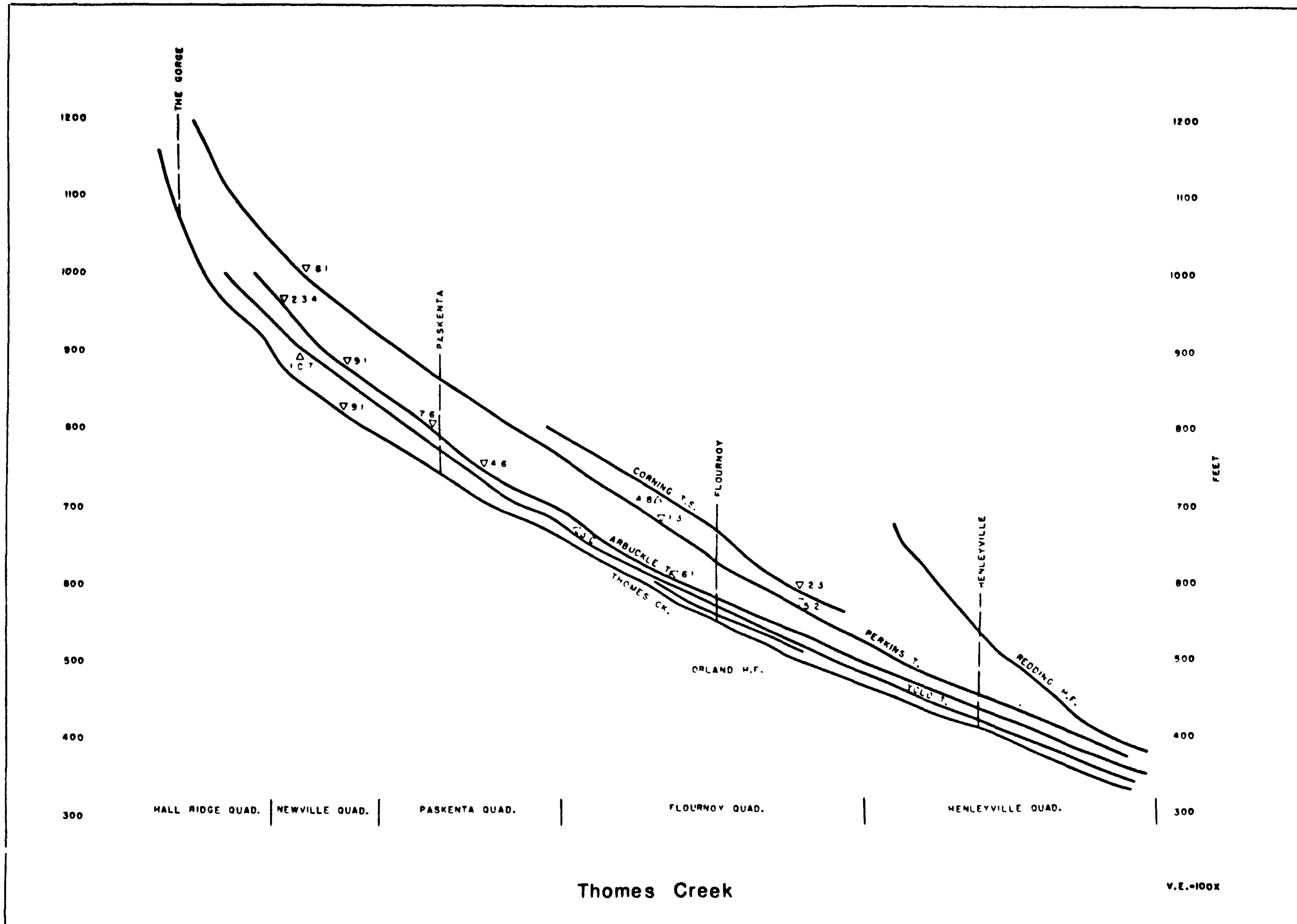

Figure 20. Longitudinal profiles and maximum gravel sizes of Thomes Creek. Location and maximum gravel size (cm) indicated by triangles with numbers.

inside of meander loops on a nearly planar bedrock surface. The Arbuckle terrace is characterized by multiple minor terrace levels (for example: sec. 11, T. 23 N., R. 7 W.) through most of this stream section, and the Perkins terrace, the uppermost terrace, is best preserved on the south side of the stream.

Downstream from Williams Butte, Thomes Creek is in a nearly straight east-northeast trending valley (pl. 1 and fig. 20). The channel form changes from a meandering channel, upstream from Williams Butte, to a braided channel downstream. The stream flows across the Great Valley Sequence for approximately 7 km before intersecting the Tehama Formation (sec. 35, T. 24 N., R. 6 W.). The valley is over twice as wide downstream from this point and it has a well-developed assemblage of terraces. This part of the drainage basin is asymmetric - the southern tributaries seldom exceed 0.5 km in length and the tributaries on the north are as much as 10 km long. The asymmetry appears to have been caused by a combination of a shifting of the creek down the dip of the Tehama Formation and by solar insolation which results in a greater sediment input from streams entering from the north. The three largest tributaries, Digger Creek (sec. 4, T. 23 N., R. 6 W.), McCarty Creek (sec. 25, T. 24 N., R. 6 W.), and Mill Creek (sec. 7, T. 24 N., R. 4 W.) all enter Thomes Creek from the north and also have assemblages of terraces along them. All six terrace levels are preserved through this stream section. The paired Yolo terrace is continuous and well preserved, and has an irregular, meander scarred surface. The Arbuckle terrace, the uppermost terrace still preserved along the south side of the creek, is continuous and many of the cobbles show a slight "glossy" sheen, similar to the gravel deposits of the Arbuckle terrace on Stony Creek. The Perkins terrace is preserved only on the north side of the creek and is most extensive where it has been cut into the Tehama Formation.

The Thomes Creek alluvial fan has its apex near the town of Henleyville (sec. 4, T. 24 N., R. 4 W.; pl. 1; and fig. 20). The terraces are lower in relative elevation and broader in surface extent downstream from Henleyville. The Thomes Creek alluvial fan is irregular in outline due to pre-terrace folding and faulting of the Tehama and Red Bluff Formations (Sacramento Petroleum Assoc., 1962) in the vicinity of the Corning Gas Field (Corning Hills, secs. 1 - 13, T. 24 N., R. 3 W.). The Yolo, Arbuckle, and Perkins terraces and the Redding high floodplain are preserved through this stream reach. The Arbuckle terrace, downstream from Henleyville, is preserved only on the south side of the creek. The terrace can be traced to a point about midway between the towns of Orland and Corning (sec. 13, T. 23 N., R. 3 W.), as well as between the Corning Hills. The Perkins terrace is preserved on both sides of the creek downstream from Henleyville, but it is particularly extensive north of the creek. The Redding high floodplain occurs on both sides of the creek. Although highly dissected, the Redding high floodplain is continuous, and its surface is characterized by hummocky mima mounds.

Elder Creek Drainage Basin

The next major drainage basin to the north is the Elder Creek drainage basin. Only minor terraces are developed along Elder Creek (pl. 2 and fig. 21) upstream from the place where it crosses the Tehama Formation. The creek emerges from the mountains, has formed an ill-defined assemblage of terraces, crosses the Great Valley Sequence, and then flows through a narrow canyon near Gleason Peak.

Elder Creek crosses onto the Tehama Formation downstream from Gleason Peak (pl. 2 and fig. 21) where the valley widens to about 1 km. A slight southward shifting of the stream through time is suggested by the terrace locations. Tributaries, such as Government Gulch (sec. 23, T. 25 N., R. 5 W.) and Digger Creek (sec. 13, T. 25 N., R. 6 W.), also have assemblages of terraces developed along them although the terraces are poorly defined. The gravel clasts in the present Elder Creek are platy, as are some Thomes Creek sediment clasts, although, this characteristic is generally absent in other stream deposits in the study area. The Orland high floodplain and Yolo terrace form small remnants along the present stream. The Arbuckle terrace is the chief terrace along Elder Creek. The boulders in the Arbuckle terrace deposit are as much as 35 cm in diameter, and the deposit is usually about 2 m thick. The Perkins terrace is preserved as dissected remnants on the valley flanks. A slight shift of the stream to the south may be indicated by the lack of Perkins remnants, except near Gleason Peak, on the south bank of the stream. The Corning terrace sequence is preserved only as highly dissected remnants on the north side of the stream.

The apex of the Elder Creek alluvial fan (pl. 2 and fig. 21) is just downstream from Gallatin Road, where the valley widens and the terrace remnants become more extensive. Terraces between the Arbuckle and Red-

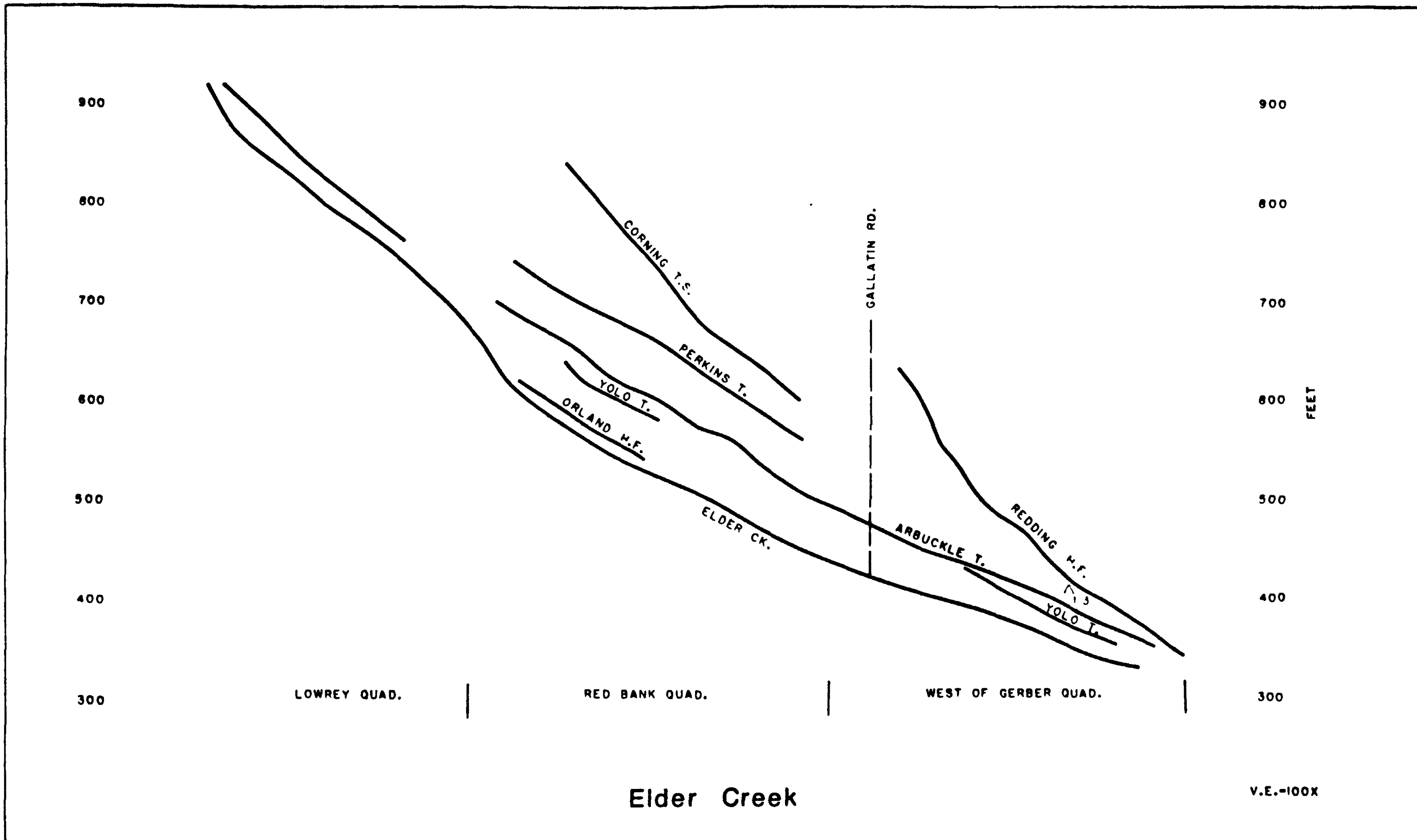

Figure 21. Longitudinal profiles and maximum gravel size of Elder Creek. Location and maximum gravel size (cm) indicated by triangle with number. Terrace level without a name was not correlated with any of the six regional terraces.

ding levels are usually not preserved. The Orland high floodplain is preserved as small remnants adjacent to the present stream, and the Yolo terrace is preserved as extensive remnants adjacent to the present creek. The Arbuckle terrace is the main terrace level along the creek, and the Perkins terrace is only preserved in the alluvial fan area. The Redding high floodplain is preserved on both sides of the creek as the highest interfluvial levels. Exposures of the Redding high floodplain have a pronounced hummocky topography and contain considerable amounts of pea-sized white quartz pebbles, a characteristic feature of the Redding high floodplain in several parts of the study area.

Red Bank Creek Drainage Basin

Red Bank Creek, the next major creek north of Elder Creek, flows across the Great Valley Sequence through this section (pl. 2 and fig. 22). Near the mountain front the terraces are generally small in extent and poorly defined.

Red Bank Creek crosses onto the Tehama Formation (pl. 2 and fig. 22) about 1 km downstream from The Narrows (sec. 16, T. 26 N., R. 6 W.). At this point the valley is 2 km wide and contains a complex assemblage of at least ten different terrace levels - the greatest number of terraces at any one location within the study area. The Yolo terrace is a continuous paired strath terrace throughout this reach. It has an irregular surface on which several channels and meander scars are preserved. The

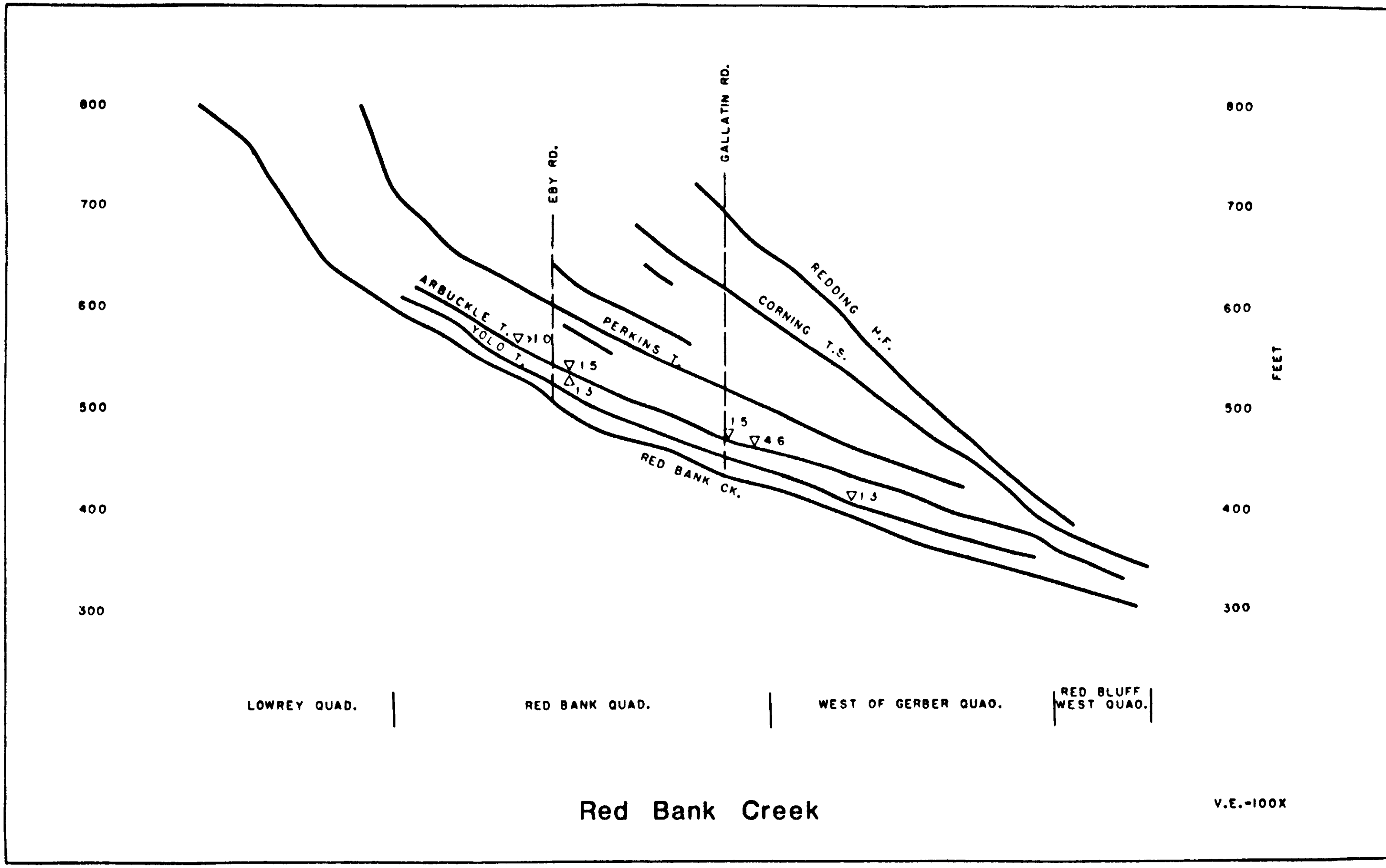

Figure 22. Longitudinal profiles and maximum gravel sizes of Red Bank Creek. Location and maximum gravel sizes (cm) indicated by triangles with numbers. Terrace levels without a name were not correlated with any of the six regional terraces.

Arbuckle terrace also forms a nearly continuous, paired strath terrace, and has the largest remnants in the area. The terrace deposit is typically 2 m thick and the clasts, which are as much as 15 cm in diameter, are finer-grained than most stream deposits in the study area. The Perkins terrace, which has about 2 m of gravel, is separated from the Arbuckle terrace by two intermediate terraces that have formed on the meander slip-off slope. The Corning terrace sequence consists of three terrace levels on the north side of the stream, the uppermost of which can be correlated with more extensive remnants downstream. The Redding high floodplain, which is very dissected, is preserved as the uppermost level.

The apex of the Red Bank Creek alluvial fan is approximately 3 km downstream from Gallatin Road (pl. 2 and fig. 22). The Orland high floodplain is preserved along most of this reach, and the Yolo terrace is preserved in the upper half of this section at an intermediate level on meander slip-off slopes. The Arbuckle terrace is the most extensive terrace remnant, and the Perkins terrace is preserved as dissected remnants. The remnants of the Corning terrace sequence are large enough to show a hummocky relief. The drainage divides on both sides of the creek are the Redding high floodplain. The mima mounds are more pronounced on the Redding high floodplain than on the Corning levels, and the high floodplain deposits are at least 4 m thick.

Cottonwood Creek Drainage Basin

South Fork of Cottonwood Creek

The Cottonwood Creek drainage basin drains approximately one-third the study area. Cottonwood Creek has three main forks: South, Middle, and North. The South Fork of Cottonwood Creek, between the mountain front and Cold Fork Creek, flows across the Great Valley Sequence; it has formed narrow, although distinct, terrace remnants along the sides of the valley (pl. 2 and fig. 23). The stream crosses from the Great Valley Sequence onto the Tehama Formation in the vicinity of Oxbow Bridge (sec. 21, T. 27 N., R. 6 W.) where the terraces become more extensive, both laterally and vertically. Five terrace levels, Orland, Arbuckle, an uncorrelated level, Perkins, and Corning, border the creek and the distribution of the terraces indicate a slight north-northwest shifting of the stream through time. The paired Arbuckle terrace, the principal level in this section, is separated from the Orland high floodplain by an uncorrelated terrace level which can be traced along most of the South Fork of Cottonwood Creek. The Perkins terrace is preserved on the south side of the creek and is represented by several dissected remnants.

One and one-half km east of Oxbow Bridge at Table Mountain (sec. 15, T. 27 N., R. 6 W.), the Redding high floodplain reaches a maximum elevation of 350 m. This maximum elevation is near the apex of a Plio-Pleistocene alluvial fan built by the South Fork of Cottonwood Creek. The alluvial fan is bounded on the north by Little Dry Creek and on the

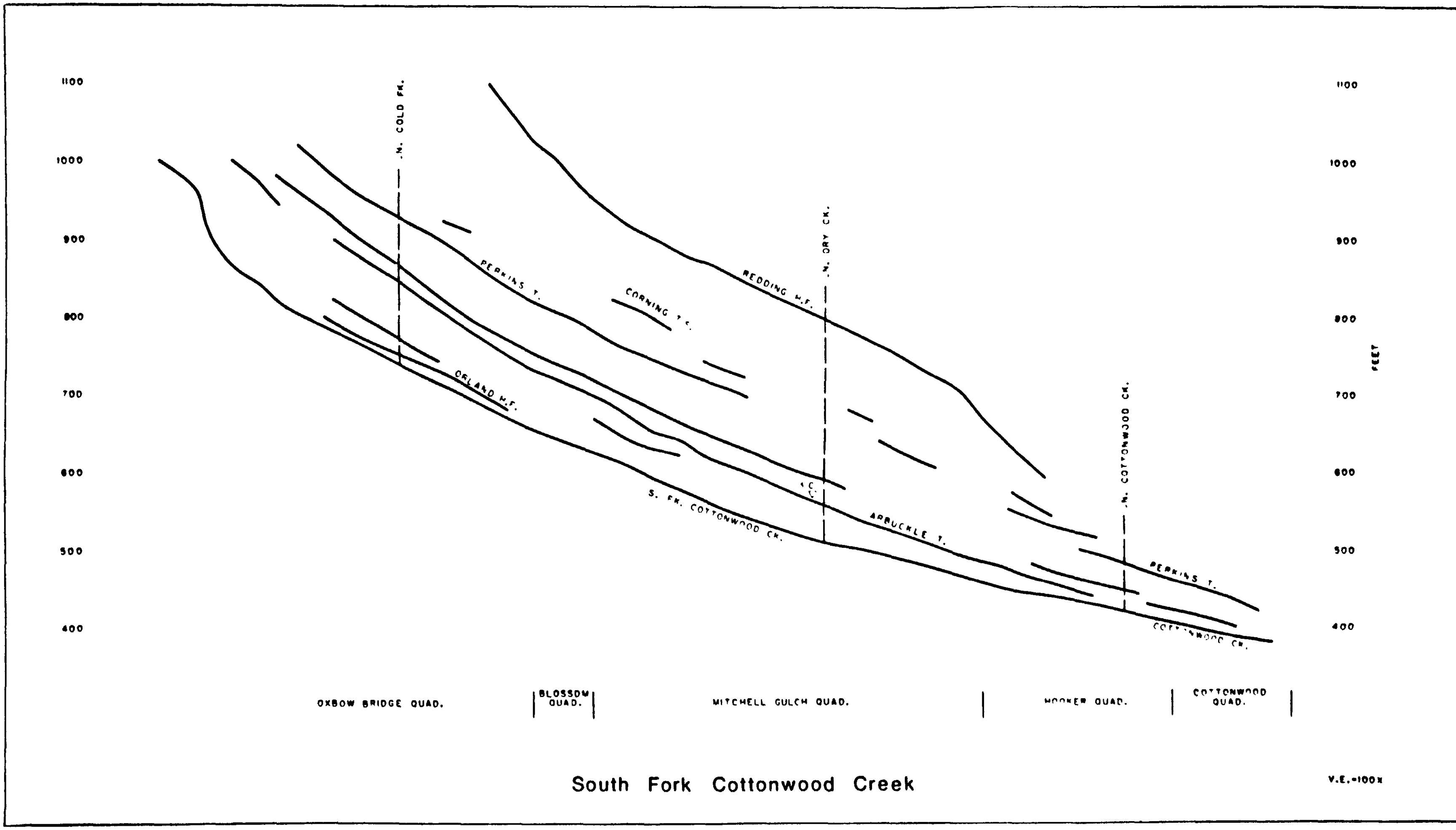

Figure 23. Longitudinal profiles and maximum gravel size of the South Fork of Cottonwood Creek. Location and maximum gravel size (cm) indicated by triangle with number. Terrace levels without a name were not correlated with any of the six regional terraces.

south by parts of the Red Bank Creek drainage system.

Cold Fork Creek is an eastward flowing tributary to the South Fork of Cottonwood Creek (pl. 2 and fig. 24). Small terrace remnants are preserved in the area where the creek crosses the Great Valley Sequence; however, where the creek has well developed assemblages of terraces, it is on the Tehama Formation. The Arbuckle terrace contains the largest remnants along this stretch and is mostly preserved on the north side of the creek. The Perkins terrace along Cold Fork Creek has been separated from other terraces by Red Bank Gulch (sec. 8, T. 27 N., R. 6 W.), which is an incised creek that once flowed as a Yazoo stream on the Arbuckle terrace at the base of the Perkins terrace.

The South Fork of Cottonwood Creek, between Cold Fork Creek and Dry Creek (pl. 2 and fig. 23), has formed ingrown meanders which have apparently also undergone episodic periods of downcutting similar to the upper section of Thomes Creek. The downstream half of this creek section has shifted to the southeast, and the upstream half has shifted to the north. The Orland high floodplain is present on most meander slip-off slopes; in several localities, multiple levels are present. The Arbuckle terrace is the main level along this section. The clasts in the Arbuckle terrace deposit have a medium "glossy" sheen, and are as much as 30 cm in diameter. The Perkins terrace is preserved as dissected elongate remnants, and the terrace deposit is usually 2 m thick. A remnant of the Corning terrace sequence is preserved north of the stream, and it is morphologically similar to, but topographically lower than, the Redding high floodplain to the southeast.

Dry Creek (T. 28 N., R. 6 W.) is a northeasterly flowing tributary

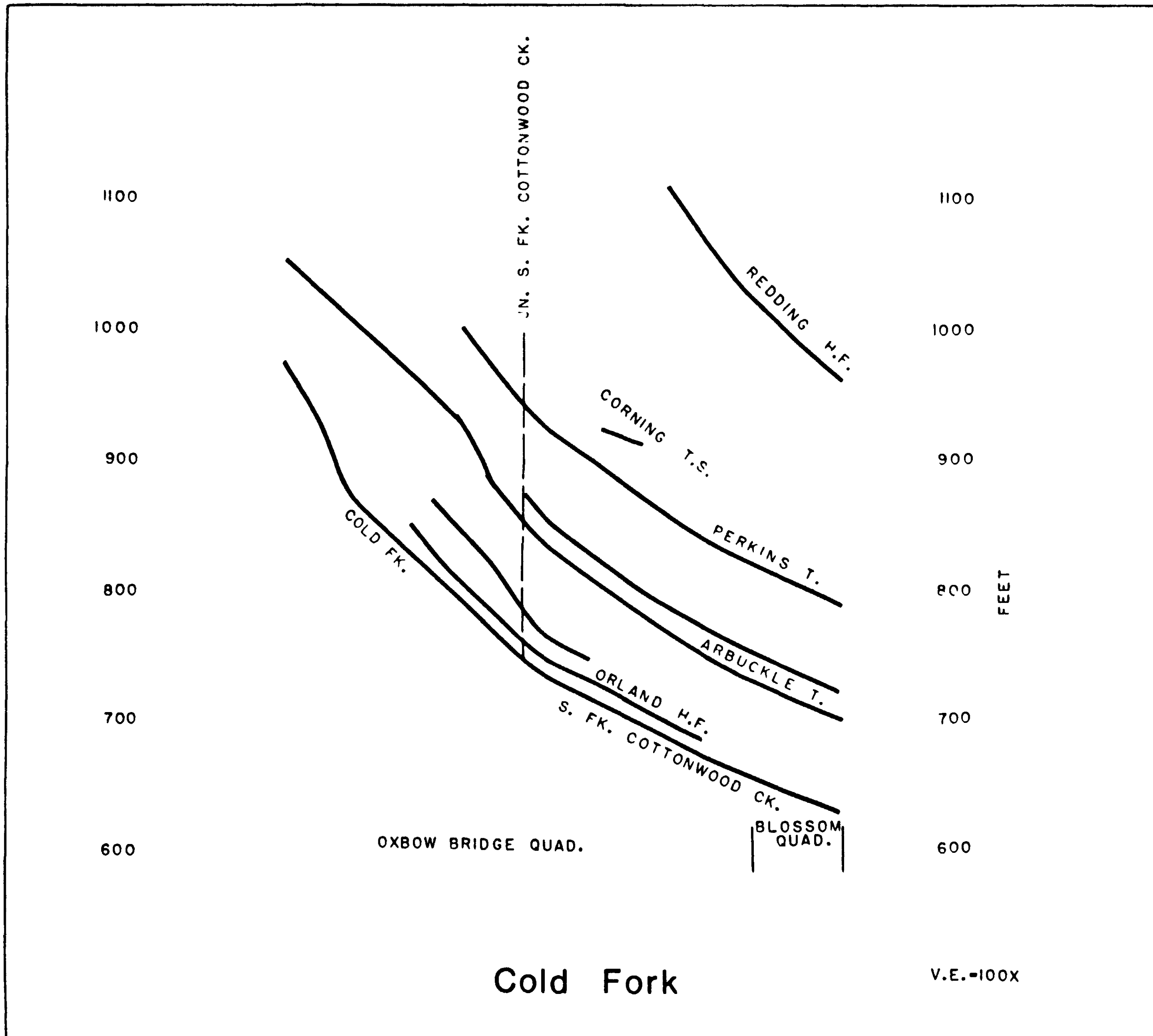

Figure 24. Longitudinal profiles of the Cold Fork of Cottonwood Creek. Terrace levels without a name were not correlated with any of the six regional terraces.

to the South Fork of Cottonwood Creek (pl. 2 and fig. 25). In contrast to the nearby South Fork of Cottonwood Creek, which has shifted to the southeast, Dry Creek has shifted in the opposite direction. Terrace correlations and locations west of lat. 122° 30' are based on those of Murphy and others (1969). Orland high floodplain and Arbuckle and a few small remnants of the Perkins terrace are preserved along the creek.

From Dry Creek downstream to the confluence with the main branch of Cottonwood Creek, the South Fork of Cottonwood Creek has shifted as much as 3 km to the north-northwest (pl. 2 and fig. 23). Four terraces, Yolo, Arbuckle, Corning, and Redding, are preserved along this stream stretch. The Arbuckle terrace is the main level and has a terrace deposit that is about 3 m thick. The Corning terrace sequence, along the south side of the creek, consists of several different levels. The Redding high floodplain is preserved along both sides of the creek; however, the remnant to the north is probably more closely related to Little Dry Creek (T. 29 N., R. 5 W.) than it is to the South Fork of Cottonwood Creek.

Little Dry Creek section of the Cottonwood Creek drainage

The location of terrace remnants along Little Dry Creek, a tributary to the main branch of Cottonwood Creek, indicate that the stream has shifted as much as 3 km to the north-northwest (pl. 2 and fig. 26). Orland, Arbuckle, Corning, and Redding terrace remnants are preserved in this area. Several Corning terrace sequence levels are preserved on a

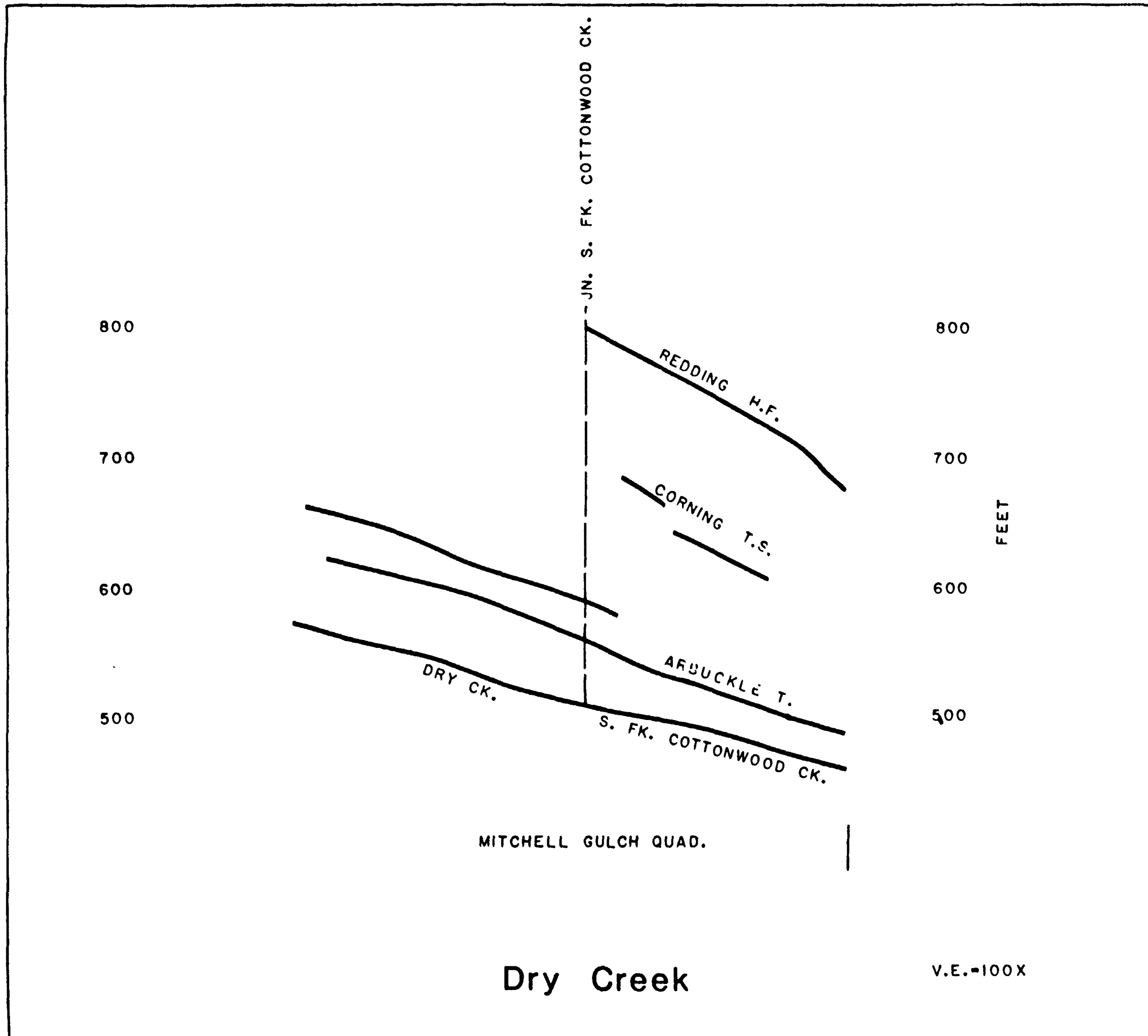

Figure 25. Longitudinal profiles of Dry Creek. Terrace level without a name was not correlated with any of the six regional terraces.

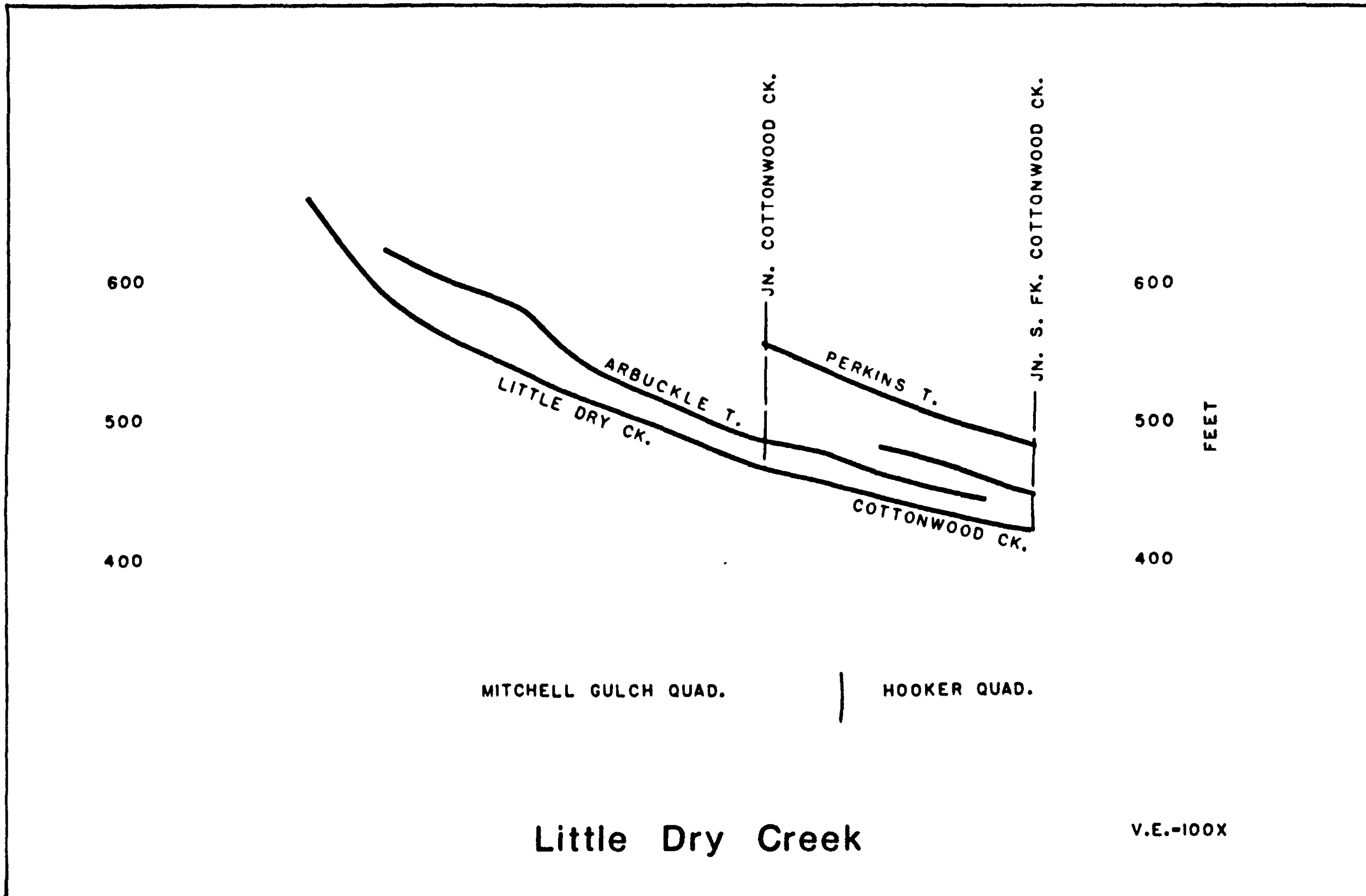

Figure 26. Longitudinal profiles of Little Dry Creek. Terrace level without a name was not correlated with any of the six regional terraces.

large slip-off slope south of the stream.

Middle Fork, North Fork, and main branch sections of Cottonwood Creek

The Middle Fork of Cottonwood Creek flows northeast and terrace remnants indicate that the stream has shifted to the southeast since deposition of the Red Bluff Formation (pl. 2 and fig. 27). The creek is flowing across the Great Valley Sequence throughout most of the study area. Terrace locations and correlations are partly based on work done by Murphy and others (1969). Gold dredging has destroyed several remnants near the confluence with the North Fork of Cottonwood Creek; however, Arbuckle and Perkins terrace remnants are preserved upstream from the confluence and on the north side of the creek. The terraces are more extensive where they cut into the Tehama Formation than where they cut into the Great Valley Sequence.

The North Fork of Cottonwood Creek (pl. 2 and fig. 28), after debouching from the mountain front, is a southeast flowing stream which crosses the Great Valley Sequence, abuts against the western part of the Happy Valley alluvial fan (sec. 15, T. 30 N., R. 6 W.), is deflected southward, and then crosses onto the Tehama Formation. The stream has formed a much more extensive assemblage of terraces in the area where it cuts into the Tehama Formation. A general southeastward migration of both the North and Middle Forks of Cottonwood Creek is indicated by the assemblage of terraces. Terrace locations and correlations are based

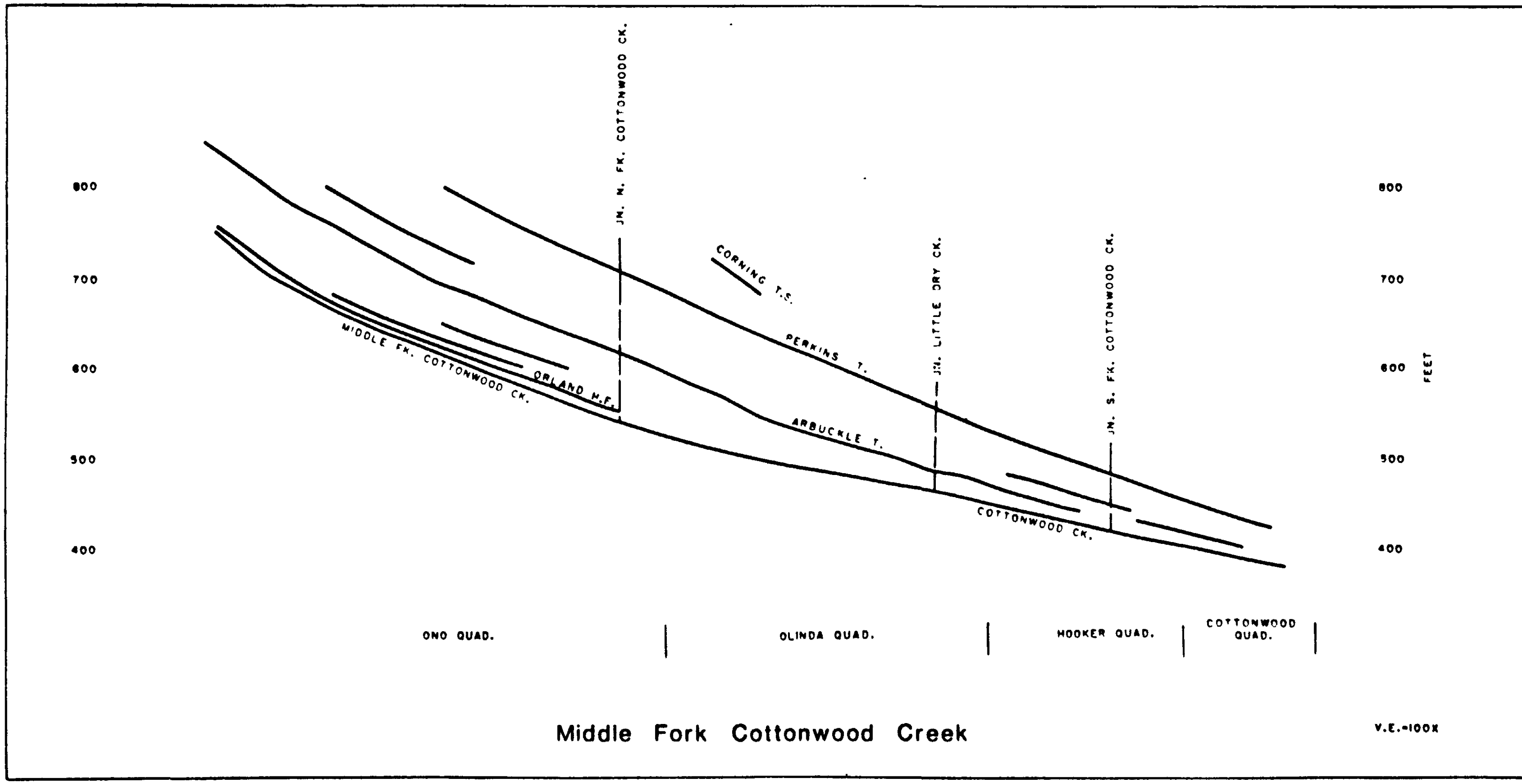

Figure 27. Longitudinal profiles of the Middle Fork of Cottonwood Creek. Terrace levels without a name were not correlated with any of the six regional terraces.

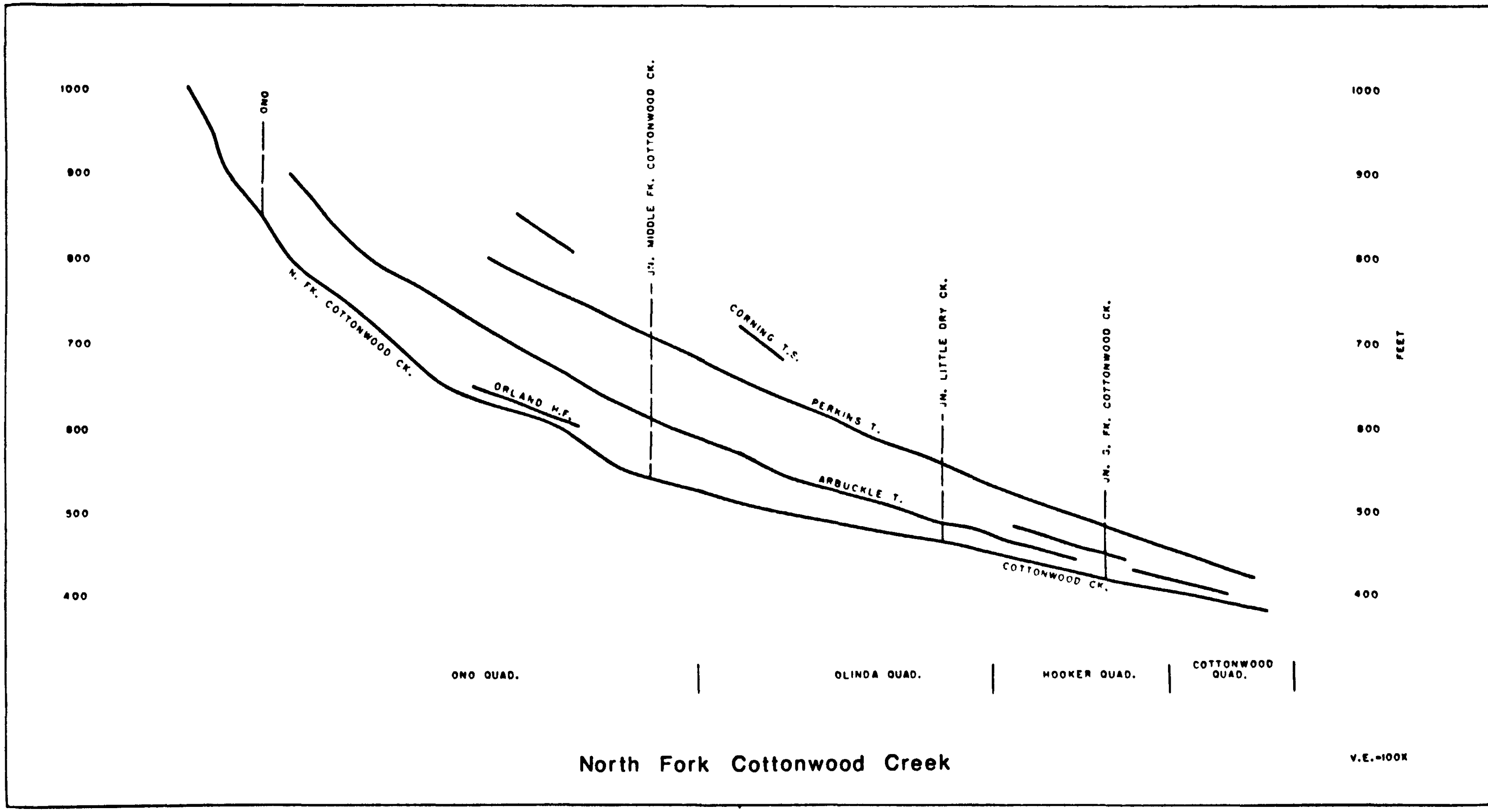

Figure 28. Longitudinal profiles of the North Fork of Cottonwood Creek. Terrace levels without a name were not correlated with any of the six regional terraces.

partly on work of Murphy and others (1969). Arbuckle and Perkins terrace remnants are common throughout the stream reach. A Redding high floodplain remnant, which is preserved to the northeast of the stream, was probably formed by Clear Creek (sec. 36, T. 31 N., R. 6 W.), a stream which lies north of the study area.

Cottonwood Creek, downstream from the confluence of its Middle and North Forks, flows east to the Sacramento River (pl. 2 and fig. 28). Arbuckle, Perkins, Corning, and Redding terraces are preserved along this stream reach. The main level, the Arbuckle terrace is as much as 2 km wide and is dissected only by the larger tributary streams. The Perkins terrace gravel is commonly about 2 m thick and is well exposed in several roadcuts west of the town of Cottonwood. The Red Bluff Formation - Happy Valley alluvial fan, the upper surface of which is the Redding high floodplain - is north of the stream. The alluvial fan, which now drains mostly into Cottonwood Creek, was probably formed by Clear Creek.

ANALYSES OF QUATERNARY STREAM DEPOSITS

Sedimentary analyses

The terrace deposits were sampled in order to evaluate their characteristics and variations (table 3). Previous workers in the study area have not reported sedimentary analyses of the terrace deposits and it was hoped that variations in size distribution, lithology, and heavy mineral content might be related to differential weathering and selective transport.

Sieve analyses

Sediment samples from the terrace deposits were collected and dry sieved (table 4, figs. 29-32). The +3ø and -5ø sizes shown on the figures were extrapolated from plots on phi probability paper. The sediment size distribution curves are arranged on each figure such that the age of the deposits increase toward the bottom of the figure, each column contains samples from approximately the same area, and the sample locations generally range from downstream on the left to upstream on the right. Generally, the sediment size distributions are so variable, both within and between terrace levels, that any systematic changes with time, if present, were not detected. Stony Creek deposits downstream from Grindstone Rancheria (fig. 29, cols. 1-3) have size distributions which are sufficiently unique and consistent to permit differentiation of the pre-

Table 3: Sediment sample locations

Sample	Location	General Description
7237401	sec. 16, T. 21 N., R. 6 W.	Yolo terrace on Grindstone Creek (upstream)
8167402	sec. 12, T. 21 N., R. 6 W.	Arbuckle terrace on Stony Creek (midstream)
8167403	sec. 16, T. 21 N., R. 6 W.	Yolo terrace on Grindstone Creek (downstream)
8167405	sec. 21, T. 22 N., R. 2 W.	Present Stony Creek (near Sacramento River)
8167406	sec. 28, T. 23 N., R. 4 W.	Present Stony Creek (downstream)
8167408	sec. 24, T. 22 N., R. 5 W.	Tehama Formation on Stony Creek (upstream)
8167409	sec. 27, T. 22 N., R. 5 W.	Present Stony Creek (midstream)
8177412	sec. 21, T. 24 N., R. 5 W.	Arbuckle terrace on Thomes Creek (midstream)
4087520	sec. 20, T. 23 N., R. 4 W.	Tehama Formation on Stony Creek (downstream)
4087521	sec. 21, T. 23 N., R. 4 W.	Redding high floodplain on Stony Creek
4087522	sec. 33, T. 25 N., R. 4 W.	Tehama Formation on Thomes Creek (downstream)
4087524	sec. 34, T. 24 N., R. 4 W.	Redding h. f. between Henleyville and Black Butte Dam
4087525	sec. 33, T. 25 N., R. 4 W.	Redding high floodplain on Thomes Creek
917750A	sec. 23, T. 22 N., R. 5 W.	Perkins terrace on Stony Creek (downstream)
918750B	sec. 1, T. 21 N., R. 6 W.	Arbuckle terrace on Stony Creek (downstream)
918750C	sec. 1, T. 21 N., R. 6 W.	Arbuckle terrace on Stony Creek (downstream)
6147601	sec. 3, T. 20 N., R. 6 W.	Arbuckle terrace on Stony Creek (upstream)
6147602	sec. 3, T. 20 N., R. 6 W.	Perkins terrace on Stony Creek (upstream)
6147604	sec. 27, T. 22 N., R. 5 W.	Perkins terrace on Stony Creek (midstream)
6157601	sec. 24, T. 28 N., R. 6 W.	Corning terrace sequence on S. Fork of Cottonwood Creek
6157602	sec. 24, T. 28 N., R. 6 W.	Perkins terrace on South Fork of Cottonwood Creek
6157603	sec. 19, T. 28 N., R. 5 W.	Arbuckle terrace on South Fork of Cottonwood Creek
4307701	sec. 4, T. 26 N., R. 3 W.	Present Red Bank Creek (downstream)
4307702	sec. 4, T. 26 N., R. 3 W.	Redding high floodplain on Red Bank Creek (downstream)
4307703	sec. 4, T. 26 N., R. 3 W.	Tehama Formation on Red Bank Creek
4307704	sec. 12, T. 28 N., R. 4 W.	Redding high floodplain between Cottonwood and Red Bluff
4307705	sec. 11, T. 29 N., R. 4 W.	Present main branch of Cottonwood Creek
4307706	sec. 11, T. 29 N., R. 4 W.	Perkins terrace on Cottonwood Ck. (downstream)
4307707	sec. 29, T. 30 N., R. 4 W.	Redding h. f. on main branch Cottonwood Ck. (downstream)
4307709	sec. 9, T. 30 N., R. 6 W.	Redding high floodplain on Cottonwood Creek (upstream)
4307710	sec. 16, T. 30 N., R. 6 W.	Arbuckle terrace on North Fork of Cottonwood Creek
4307711	sec. 34, T. 30 N., R. 6 W.	Present North Fork of Cottonwood Creek
4307712	sec. 9, T. 29 N., R. 6 W.	Perkins terrace on Middle Fork of Cottonwood Creek
4307713	sec. 9, T. 29 N., R. 6 W.	Arbuckle terrace on Middle Fork of Cottonwood Creek
4307714	sec. 7, T. 29 N., R. 5 W.	Arbuckle terrace on main branch of Cottonwood Creek
4307715	sec. 1, T. 29 N., R. 5 W.	Perkins terrace on Cottonwood Creek (upstream)
4307716	sec. 17, T. 29 N., R. 4 W.	Present South Fork of Cottonwood Creek (downstream)
4307717	sec. 17, T. 29 N., R. 4 W.	Corning terrace sequence on Little Dry Creek
4307718	sec. 32, T. 29 N., R. 5 W.	Arbuckle terrace on Dry Creek
4307719	sec. 32, T. 29 N., R. 5 W.	Present Dry Creek
4307720	sec. 30, T. 28 N., R. 5 W.	Present South Fork of Cottonwood Creek (upstream)
4307721	sec. 30, T. 28 N., R. 5 W.	Arbuckle terrace on South Fork of Cottonwood Creek
4307722	sec. 30, T. 28 N., R. 5 W.	Tehama Formation on South Fork of Cottonwood Creek
4307723	sec. 30, T. 28 N., R. 5 W.	Tehama Formation on South Fork of Cottonwood Creek
4307724	sec. 5, T. 27 N., R. 5 W.	Redding h. f. on South Fork Cottonwood Ck. (downstream)
4307725	sec. 15, T. 27 N., R. 6 W.	Redding h. f. on South Fork Cottonwood Ck. (upstream)
5017701	sec. 3, T. 26 N., R. 4 W.	Redding high floodplain on Red Bank Creek (midstream)
5017702	sec. 8, T. 26 N., R. 4 W.	Arbuckle terrace on Red Bank Creek
5017703	sec. 16, T. 26 N., R. 5 W.	Present Red Bank Creek (upstream)
5017704	sec. 5, T. 26 N., R. 4 W.	Redding high floodplain on Red Bank Creek (upstream)
5017705	sec. 11, T. 25 N., R. 4 W.	Arbuckle terrace on Elder Creek (downstream)
5017706	sec. 11, T. 25 N., R. 4 W.	Present Elder Creek (downstream)
5017707	sec. 24, T. 25 N., R. 5 W.	Arbuckle terrace on Elder Creek (upstream)
5017708	sec. 18, T. 25 N., R. 4 W.	Present Elder Creek (upstream)
5017709	sec. 8, T. 24 N., R. 4 W.	Present Thomes Creek (downstream)
5017710	sec. 5, T. 24 N., R. 4 W.	Perkins terrace on Thomes Creek (downstream)
5017711	sec. 21, T. 24 N., R. 5 W.	Present Thomes Creek (midstream)
5017712	sec. 20, T. 24 N., R. 5 W.	Perkins terrace on Thomes Creek (upstream)
5017713	sec. 22, T. 24 N., R. 5 W.	Tehama Formation on Thomes Creek (upstream)
5017714	sec. 4, T. 23 N., R. 6 W.	Arbuckle terrace on Thomes Creek (upstream)
5017715	sec. 4, T. 23 N., R. 6 W.	Present Thomes Creek (upstream)
5017716	sec. 3, T. 22 N., R. 6 W.	Present North Fork of Stony Creek
5017717	sec. 28, T. 22 N., R. 6 W.	Corning terrace sequence north of Watson Creek
5017718	sec. 15, T. 21 N., R. 6 W.	Present Grindstone Creek
5017719	sec. 15, T. 21 N., R. 6 W.	Perkins terrace on Grindstone Creek
5017721	sec. 3, T. 20 N., R. 6 W.	Present Stony Creek (upstream)

Table 4: Sieve analyses weight percentages for eight size fractions

(All samples except those with high clay content were dry sieved.)

Sample	Weight percent of sample							
	≤-4φ	-3φ	-2φ	-1φ	-0.25φ	1.25φ	>1.25φ	
7237401	16.08	7.50	10.14	18.84	11.53	16.05	19.87	
8167402	13.33	22.95	16.44	11.12	7.08	15.25	13.83	
8167403	24.62	21.26	17.64	13.36	7.80	8.21	7.11	
8167404	39.95	10.95	9.86	14.77	9.97	8.81	5.70	
8167405	35.18	16.91	14.74	11.71	5.68	11.17	4.71	
8167406	31.86	15.53	13.50	10.73	5.98	12.96	9.44	
8167408	39.97	16.99	14.20	5.69	5.94	9.32	7.89	
8167409	37.14	14.34	9.99	8.67	9.54	8.91	11.42	
8177412	33.37	17.40	11.56	11.44	7.26	10.35	8.61	
8177413	0.00	0.00	5.93	34.14	23.90	23.35	12.68	
8177415	60.07	23.65	8.24	1.70	0.97	1.26	4.10	
4087520	6.34	13.16	23.62	25.63	11.11	14.01	6.13	
4087521	2.51	3.88	14.86	25.08	15.07	20.72	17.88	
4087522	8.76	18.20	20.19	18.45	11.62	16.67	6.10	
4087524	41.06	13.22	21.20	12.45	4.19	4.98	2.91	
4087525	20.93	13.12	9.91	14.64	13.96	18.82	8.62	
917750A	0.00	4.55	10.57	14.38	10.15	19.24	41.10	
918750B	0.33	0.00	9.24	23.85	15.88	27.83	22.86	
918750C	1.16	8.18	25.07	24.21	12.45	13.44	15.49	
	≤-4.25φ	-4φ	-2φ	-1φ	-0.5φ	1φ	2φ	>2φ
6147601	19.23	6.37	38.44	14.35	5.81	10.97	3.66	1.18
6147602	31.56	5.74	26.10	14.66	6.82	11.65	2.56	0.90
6147604	48.07	1.51	10.90	9.45	4.08	8.06	8.35	9.58
6157601	11.45	0.72	26.55	17.84	7.09	12.89	9.97	13.50
6157602	16.97	22.65	37.79	9.50	2.76	4.77	3.09	2.46
6157603	0.00	0.00	15.05	32.04	10.26	18.22	10.91	13.52
4307701	17.13	5.35	27.26	12.27	5.78	16.92	13.55	1.74
4307702	28.94	6.52	25.73	15.36	5.48	11.10	4.01	2.86
4307703	0.00	0.00	0.00	0.00	0.00	27.46	25.22	47.31
4307704	9.07	3.68	23.60	19.59	10.68	22.45	7.30	3.64
4307705	36.97	9.94	24.11	8.12	6.08	12.87	1.64	0.28
4307706	14.22	4.19	24.46	14.73	8.03	22.28	8.63	3.47
4307707	18.63	3.95	20.58	11.88	6.55	19.30	10.46	8.65
4307710	40.77	5.13	15.62	16.49	6.21	7.75	5.85	2.17
4307711	24.49	9.55	25.85	10.43	6.39	15.72	5.21	2.35
4307712	30.47	6.25	13.59	15.33	6.22	15.21	7.88	5.06
4307713	62.73	2.16	10.08	5.69	2.54	5.93	5.71	5.17
4307714	32.88	9.26	22.33	7.31	3.74	13.03	7.73	3.72
4307715	25.98	4.48	13.54	3.41	1.83	6.36	9.80	34.59
4307716	15.15	10.06	45.29	12.38	4.03	5.32	4.64	3.13
4307717	20.39	3.86	22.60	16.16	8.25	19.31	6.09	3.34
4307718	18.35	13.87	40.19	10.04	4.43	7.96	3.22	1.94
4307719	26.91	10.30	25.80	8.44	4.73	12.12	6.44	5.27
4307720	33.71	9.41	20.40	6.23	3.36	11.55	9.73	5.62
4307721	8.58	2.64	41.09	12.52	5.27	12.19	10.55	7.15
4307722	0.00	0.00	0.00	0.00	0.00	20.78	32.29	46.94
4307723	14.47	4.32	22.09	13.11	6.59	23.93	12.02	3.46
4307724	9.84	1.67	20.69	18.72	7.77	18.00	11.76	11.53
4307725	16.02	4.18	25.55	15.19	7.17	14.44	6.91	10.53
8017701	15.73	11.49	29.54	14.25	6.61	12.57	4.91	4.90
8017702	15.18	6.74	34.95	13.08	5.93	12.68	5.73	5.71
8017703	29.48	11.16	27.29	11.93	5.79	7.72	2.90	3.74
8017704	38.53	2.05	26.93	10.08	4.21	9.34	4.14	4.73
8017705	1.58	1.97	38.70	26.57	9.23	15.86	4.34	1.74
8017706	23.95	11.66	31.30	11.61	5.27	10.87	3.42	1.92
8017707	24.58	14.20	30.50	5.52	1.47	3.43	5.94	14.35
8017708	36.17	8.02	23.88	10.14	4.75	10.37	4.29	3.38
8017709	29.46	9.94	24.48	9.61	4.96	12.22	5.11	4.22
8017710	10.13	3.04	29.49	18.42	7.35	12.76	6.80	12.01
8017711	24.96	9.69	33.74	10.97	4.48	10.46	4.57	1.13
8017712	35.33	11.12	20.27	9.83	4.14	10.11	6.14	3.05
8017713	0.00	0.00	0.00	0.00	0.46	1.16	4.11	94.28
8017714	27.16	6.61	21.86	9.55	5.23	14.79	8.74	6.05
8017715	16.69	14.88	46.24	7.40	1.87	2.80	5.08	5.04
8017716	36.98	12.66	31.69	8.36	2.90	3.73	2.36	2.31
8017717	19.02	7.52	34.87	13.60	5.49	11.53	5.21	2.76
8017718	27.82	9.90	34.91	8.75	2.97	4.43	5.74	5.48
8017719	16.70	7.08	36.59	13.08	5.71	15.22	3.85	1.75
8017721	23.95	14.72	36.21	9.52	3.01	4.31	3.95	4.33

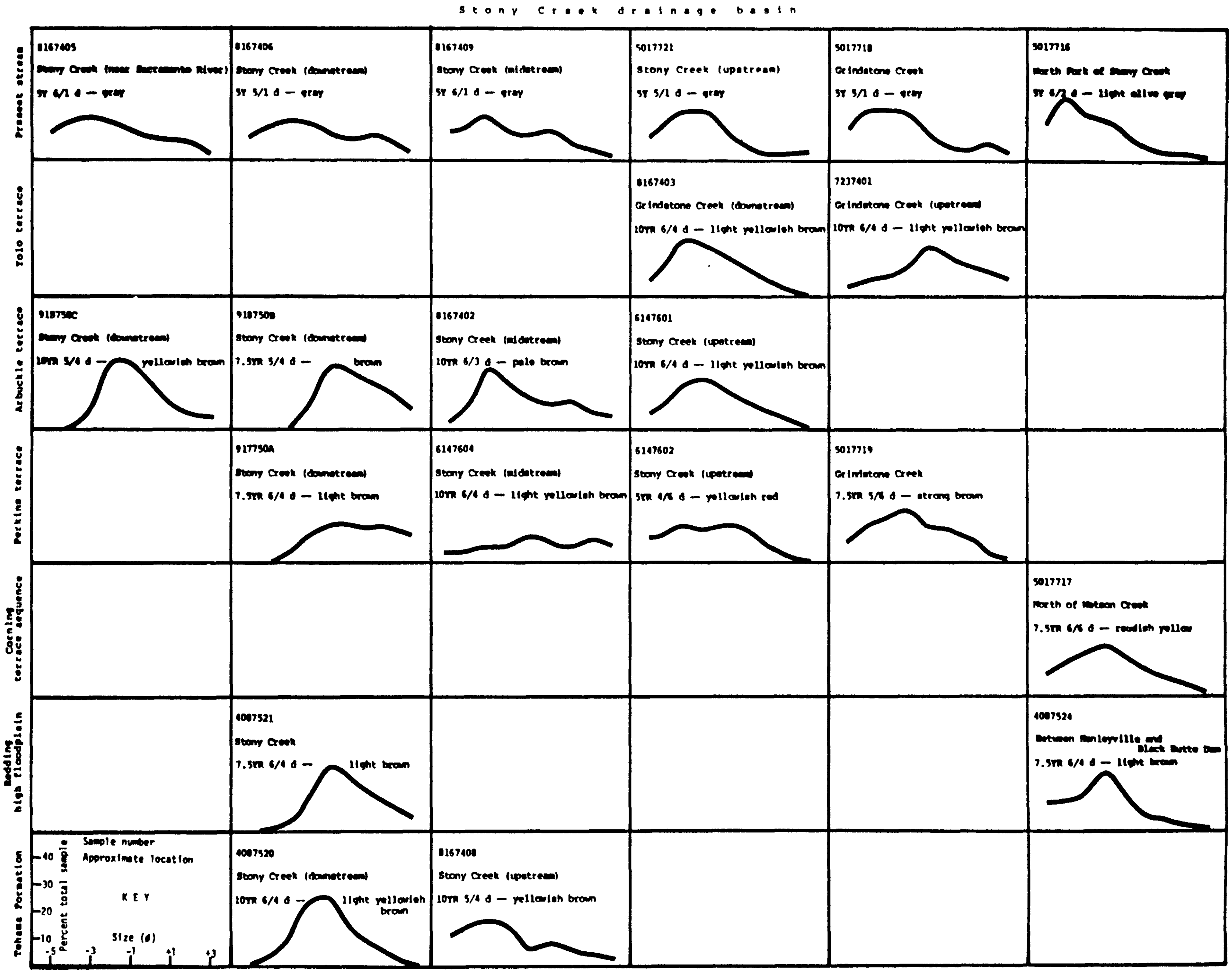

Figure 29. Sediment distribution curves and soil colors for the Stony Creek drainage basin. Key is in lower left box.

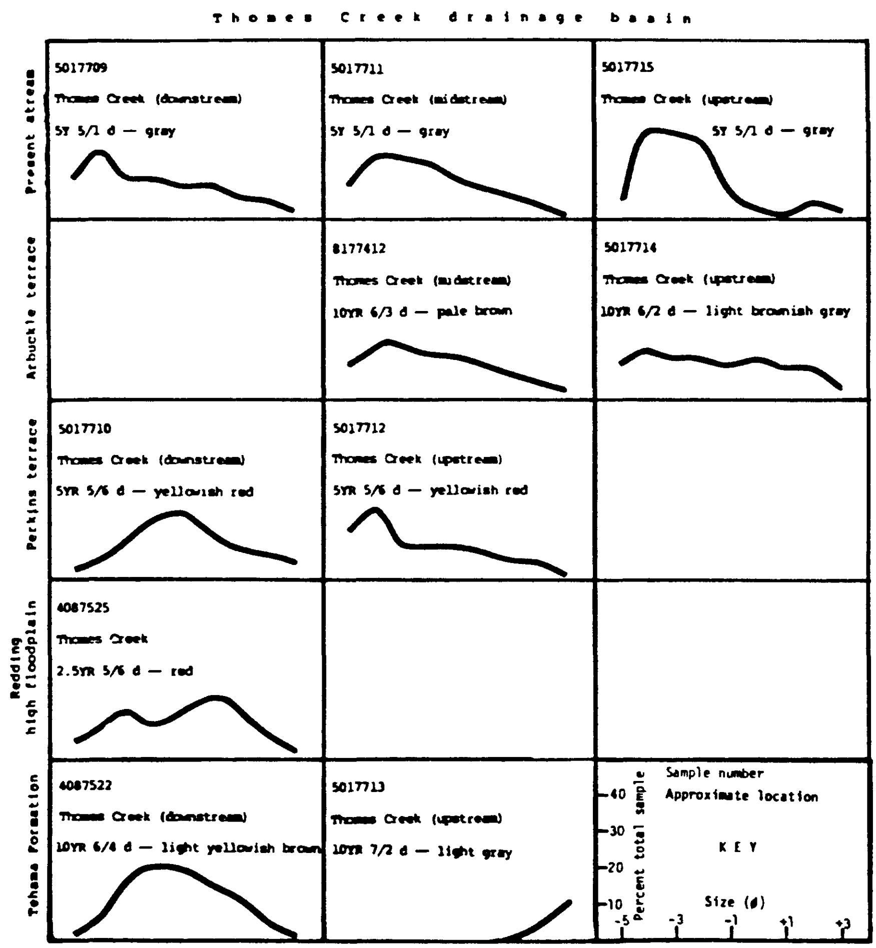

Figure 30. Sediment distribution curves and soil colors for the Thomes Creek drainage basin. Key is in lower right box.

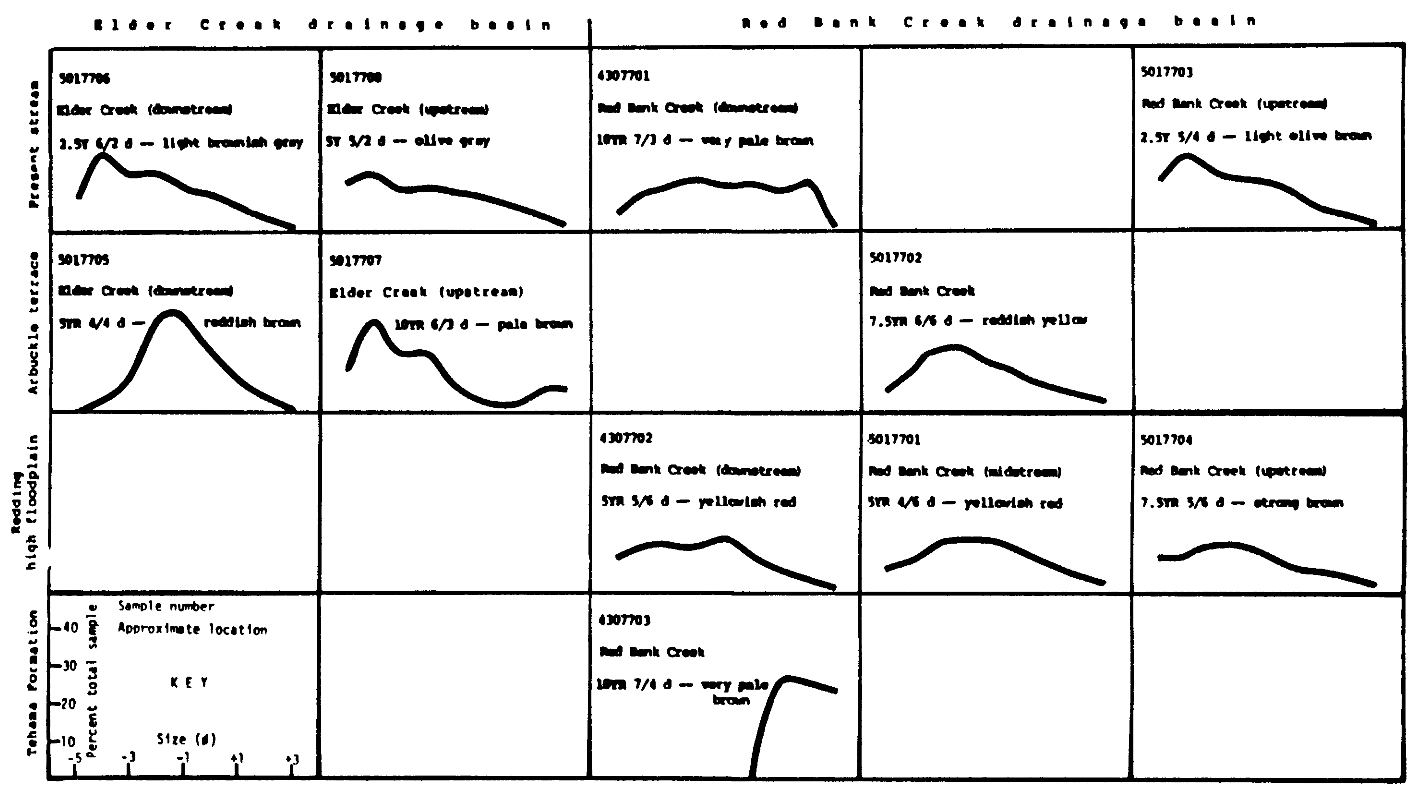

Figure 31. Sediment distribution curves and soil colors for the Elder and Red Bank Creek drainage basins. Key is in lower left box.

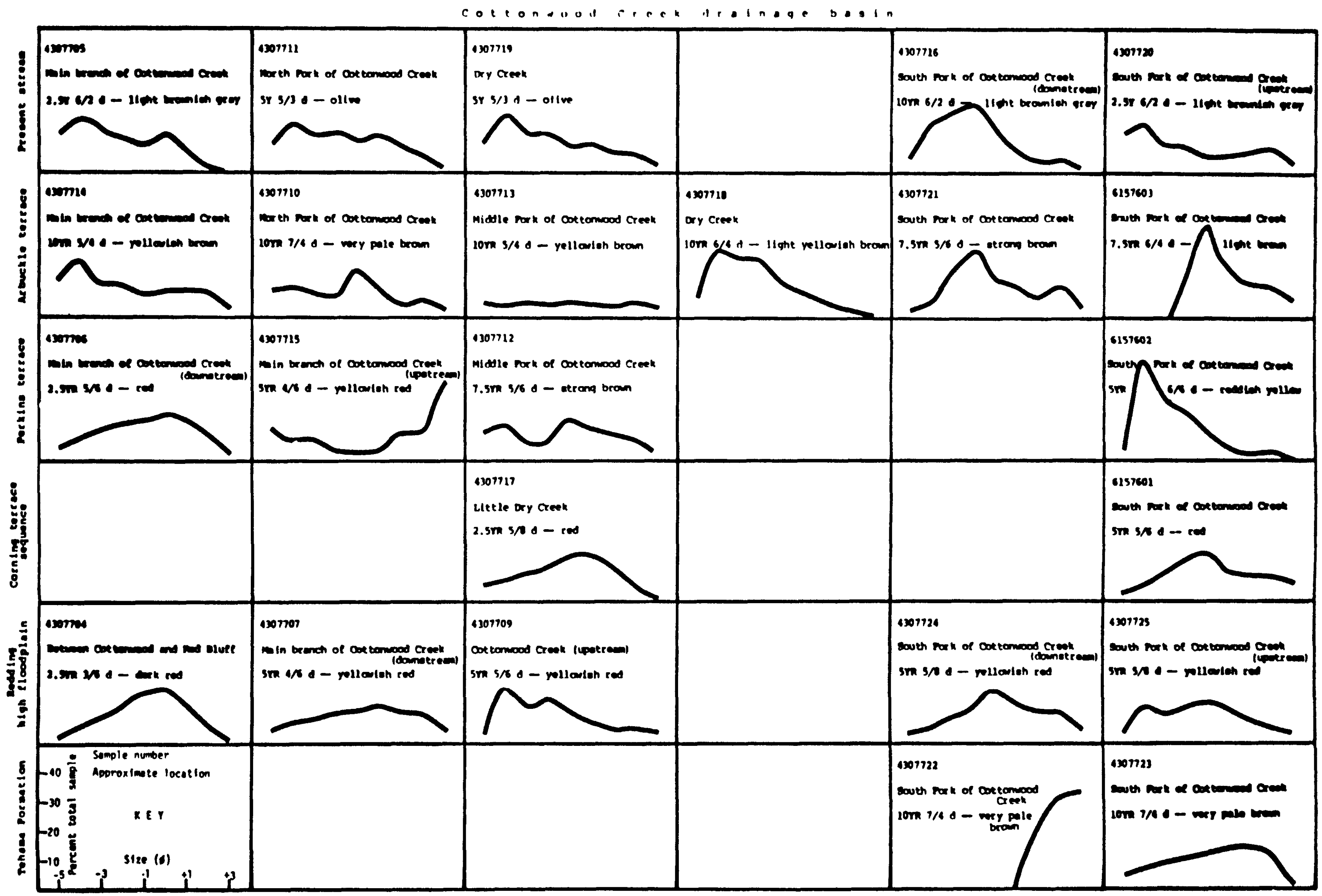

Figure 32. Sediment distribution curves and soil colors for the Cottonwood Creek drainge basin. Key is in lower left box.

sent stream, Arbuckle terrace, and Perkins terrace deposits. Stony Creek deposits upstream from Grindstone Rancheria, however, have no distinguishing size distributions which aid in differentiating them from deposits along Grindstone Creek or the North Fork of Stony Creek (fig. 29, cols. 4-6). Furthermore, the distinct size distributions relative to the age of the deposits downstream are essentially absent in the upstream parts of the drainage basin. Thomes Creek deposits (fig. 30) show no distinguishing characteristics with respect to size distribution. Present Elder Creek deposits (fig. 31, cols. 1 and 2) appear to have poorer sorting, a more even distribution, than the Arbuckle terrain deposits; however, the sparcity of samples makes such a conclusion very tentative. Red Bank Creek deposits (fig. 31, cols. 3-5), with the exception of the Tehama Formation sample, have similar size distributions. In particular the samples from the Redding high floodplain have almost identical distributions. The Tehama Formation sample (#4307703), as indicated by the lack of coarse particles, was probably deposited in a low energy environment, perhaps a lake or as overbank deposits. Deposits in the Cottonwood Creek drainage basin (fig. 32) also show no distinguishing characteristics with respect to size distributions. Similarly, changes or consistencies between deposits of the same age in different drainage basins was not discerned by visual comparison of the size distribution curves. Therefore, the size distributions of terrace deposits were not found to be an aid in differentiating or correlating terraces in the study area.

All the Quaternary terrace deposits and present stream deposits have similar skewness and sorting values (table 5, fig. 33). Most samples have a range of skewness values from approximately -0.2 to 0.4 and a

Table 5: Sieve analyses statistical parameters

(As defined by Inman, 1952.)

Sample	Mean (ϕ)	Median (ϕ)	Sorting (ϕ)	Skewness	Kurtosis
7237401	-1.125	-1.10	2.875	-0.0087	0.7478
8167402	-1.425	-2.20	2.425	0.3196	0.5464
8167403	-2.375	-2.75	2.125	0.1765	0.7882
8167405	-2.825	-3.10	2.575	0.1068	0.5825
8167406	-2.450	-2.80	2.900	0.1207	0.5862
8167408	-2.900	-3.45	2.850	0.1930	0.6316
8167409	-2.625	-3.10	3.125	0.1520	0.6880
8177412	-2.550	-3.05	2.650	0.1887	0.6226
4087520	-1.550	-1.75	1.650	0.1212	0.7424
4087521	-0.400	-0.75	1.900	0.1842	0.6447
4087522	-1.625	-1.80	1.875	0.0933	0.5733
4087524	-3.825	-3.35	2.425	-0.1959	0.8041
4087525	-1.950	-1.60	2.500	-0.1400	0.5700
917750A	0.775	0.50	2.725	0.1009	0.5505
918750B	0.075	-0.20	1.725	0.1594	0.5072
918750C	-0.725	-1.40	1.925	0.3506	0.7143
6147601	-2.650	-2.70	2.150	0.0233	0.7093
6147602	-3.300	-3.00	2.750	-0.1091	0.5818
6147604	-11.775	-3.95	12.975	-0.6031	-0.2563
6157601	-0.950	-1.40	2.700	0.1667	-1.3333
6157602	-2.925	-3.50	1.625	0.3538	0.9077
6157603	-0.100	-0.85	1.850	0.4054	0.5811
4307701	-1.850	-2.00	2.750	0.0545	0.4000
4307702	-2.925	-2.90	2.675	-0.0093	0.8224
4307703	1.875	1.90	1.475	-0.0169	0.6610
4307704	-1.550	-1.30	2.100	-0.1190	0.9762
4307705	-3.250	-3.80	2.600	0.2115	0.4519
4307706	-1.850	-1.55	2.500	-0.1200	0.5900
4307707	-1.800	-1.45	3.050	-0.1148	0.6148
4307709	-1.175	-2.25	3.175	0.3386	0.6142
4307710	-3.925	-3.50	3.425	-0.1241	0.6204
4307711	-2.500	-2.75	2.550	0.0980	0.4804
4307712	-2.625	-2.00	3.275	-0.1908	0.4885
4307713	-7.900	-7.40	7.600	-0.0658	0.5000
4307714	-2.550	-3.35	2.950	0.2712	0.4237
4307715	-0.600	-0.45	4.900	-0.0306	-0.2653
4307716	-2.625	-2.90	1.775	0.1549	0.9155
4307717	-2.375	-1.75	2.725	-0.2294	0.6697
4307718	-2.700	-3.15	1.900	0.2368	0.6711
4307719	-2.350	-3.05	2.750	0.2545	0.4909
4307720	-2.275	-3.35	3.275	0.3282	0.3664
4307721	-1.300	-2.10	2.400	0.3333	0.5938
4307722	1.875	2.85	1.075	-0.9070	0.6047
4307723	-1.650	-1.30	2.650	-0.1321	0.5094
4307724	-0.975	-1.05	2.525	0.0297	0.6139
4307725	-1.625	-1.75	2.875	0.0435	0.6783
5017701	-2.400	-2.50	2.600	0.0385	0.6923
5017702	-2.025	-2.40	2.425	0.1546	0.6186
5017703	-2.925	-3.35	2.325	0.1828	0.6667
5017704	-3.350	-3.35	3.150	0.0000	0.6667
5017705	-1.525	-1.75	1.475	0.1525	0.6949
5017706	-2.700	-3.05	2.200	0.1591	0.5682
5017707	-1.550	-3.30	3.300	0.5303	0.5379
5017708	-3.025	-3.45	2.775	0.1532	0.5856
5017709	-2.650	-3.10	2.700	0.1667	0.5926
5017710	-1.175	-1.60	2.575	0.1650	0.7670
5017711	-2.750	-3.10	2.250	0.1556	0.6222
5017712	-2.775	-3.70	2.725	0.3394	0.5229
5017713	4.900	4.90	1.850	0.0000	0.6622
5017714	-2.275	-2.50	3.075	0.0732	0.4715
5017715	-2.725	-3.25	1.525	0.3443	1.3279
5017716	-3.525	-3.95	1.975	0.2152	0.8608
5017717	-2.425	-2.70	2.325	0.1183	0.6129
5017718	-2.850	-3.30	2.350	0.1915	0.8085
5017719	-2.350	-2.55	2.200	0.0909	0.5568
5017721	-2.925	-3.40	1.925	0.2468	0.9351

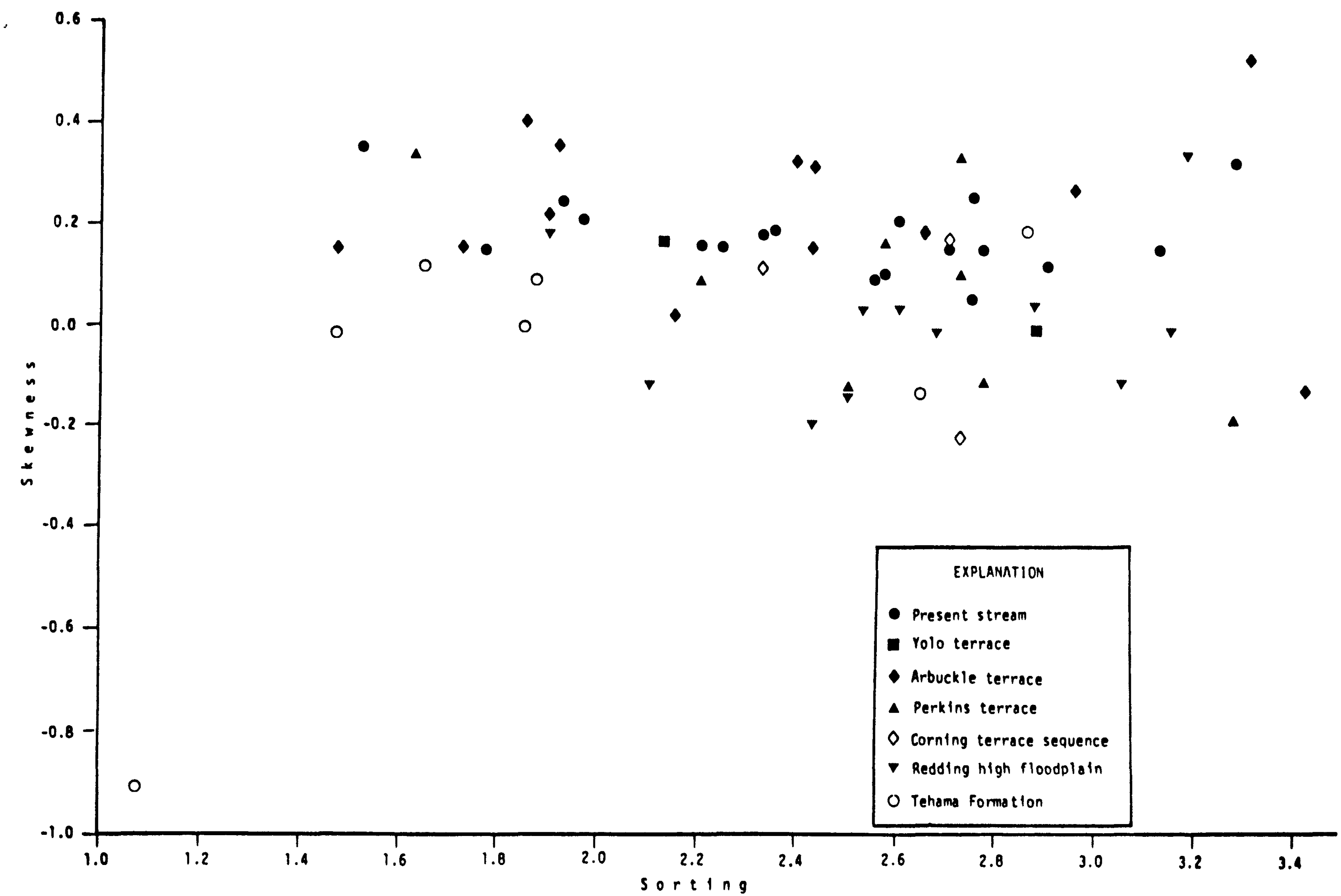

Figure 33. Sorting - skewness scater diagram of sediment samples from throughout the study area.

range of sorting values from 1.4 to 3.4. Because the domains for specific terrace levels are not unique, similar environments of deposition may be indicated.

Composition analyses

Analyses of terrace deposit compositions were conducted to determine if terrace levels could be differentiated using the percentage of different rock types that are present (table 6, fig. 34). The samples were divided into five groups: vein quartz, chert, graywacke and metagraywacke, schist and gneiss, and greenstone and serpentine. The samples shown on figure 34 are arranged with Stony Creek drainage basin deposits in columns 1-3, with Thomes Creek drainage basin deposits in column 4, and with the Stony Creek deposits that are furthest downstream in column 1 and those furthest upstream in column 3.

There was no unique or distinguishing characteristic of the composition curves which aided in differentiating terrace levels. The major components are usually graywacke and quartz, which together comprise about 95 percent of most samples, and the chert, schist, gneiss, greenstone, and serpentine clasts present are not characteristically in a specific level.

Because terrace levels in the Stony Creek and Thomes Creek drainage basins were not distinguishable using sediment compositions, similar analyses were not done on other sediment samples.

Table 6: Composition analyses of selected sediment samples

Sample number	Vein quartz	Chert	Graywacke	Schist and gneiss	Greenstone and serpentine
		(percentage)			
7237401	27	1	71	0	1
8167402	25	1	73	1	0
8167403	19	3	76	0	2
918750C	33	6	61	0	0
918750B	0	9	87	4	0
917750A	56	3	40	0	1
8167405	26	2	74	0	0
8167409	17	3	80	0	0
8167408	12	4	83	1	0
4087508	37	10	48	3	2
8177412	19	12	57	12	0
4087525	25	8	67	0	0
4087521	59	9	32	0	0
4087522	24	6	70	0	0
4087524	18	11	70	1	0
8167406	27	1	72	0	0

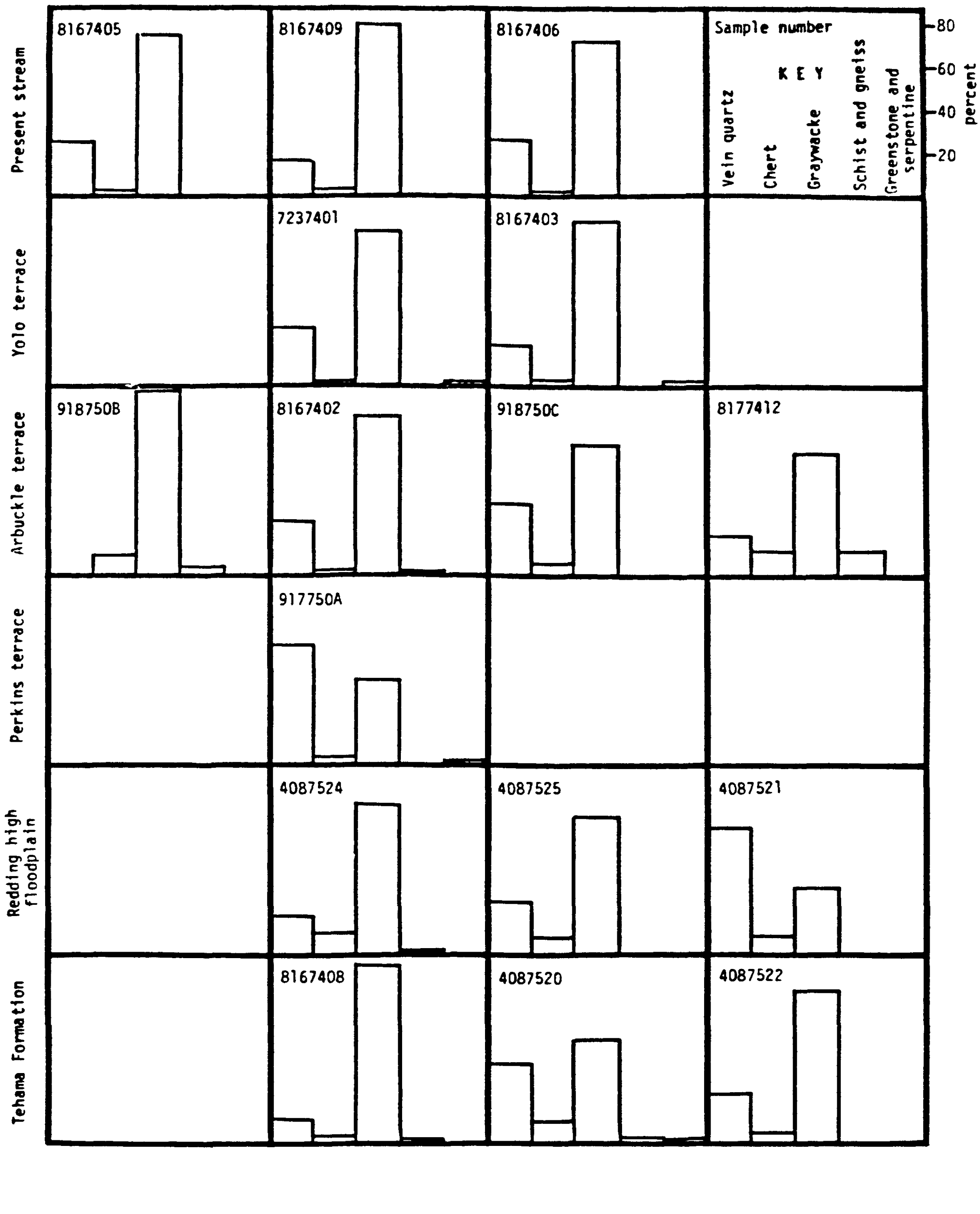

Figure 34. Lithologic variations for selected sediment samples.

The lack of differences between deposits of various ages indicates that the types of rocks upstream and the approximate outcrop area of each rock type have not changed significantly since deposition of the Tehama Formation.

Mineral analyses

Heavy mineral separations of each sample were made and analyzed for composition and weight percentage of the total sample. The total percentage of heavy minerals in the terrace deposits generally decreases with age (table 7, fig. 35) and can apparently be attributed to weathering of the mineral grains. Variations in percentages between the drainage basins exist; however, these changes are probably due to different rock types in the drainage basins. Specific uses of the total percentage of heavy minerals as a means of differentiating terrace levels between drainage basins were not apparent.

The heavy minerals in each sample were studied with an X-ray diffractometer and the diffraction patterns were analyzed for 80 minerals or mineral groups. Comparison of specific heavy minerals in samples with respect to drainage basin (table 8, fig. 36) yielded information relative to differences in source area rock types. These data, however, were of little use in this study because the changes in rock types within a single drainage basin relative to the differences in rock types between drainage basins appear to be negligible.

Table 7: Heavy mineral percentages found in sediment samples

Sample number	Percentage	Sample number	Percentage
7237401	0.06	4307713	4.68
8167402	0.43	4307714	5.26
8167403	1.40	4307715	1.49
8167405	7.27	4307716	5.12
8167406	12.73	4307717	0.53
8167408	2.23	4307718	1.51
8167409	4.49	4307719	11.42
8177412	3.50	4307720	3.94
4087520	0.14	4307721	1.48
4087521	0.05	4307722	0.18
4087522	0.58	4307723	4.21
4087524	1.50	4307724	0.09
4087525	0.34	4307725	0.09
917750A	0.55	5017701	0.64
918750B	0.24	5017702	3.69
918750C	0.60	5017703	6.58
6147601	0.05	5017704	0.85
6147602	0.08	5017705	2.98
6147604	3.95	5017706	19.48
6157601	8.55	5017707	12.49
6157602	0.37	5017708	21.24
6157603	0.76	5017709	3.72
4307701	3.47	5017710	1.27
4307702	0.71	5017711	6.84
4307703	0.05	5017712	0.27
4307704	0.51	5017713	0.06
4307705	9.62	5017714	2.01
4307706	0.20	5017715	1.31
4307707	0.05	5017716	2.69
4307709	0.11	5017717	2.26
4307710	1.41	5017718	0.53
4307711	9.15	5017719	0.23
4307712	2.07	5017721	1.53

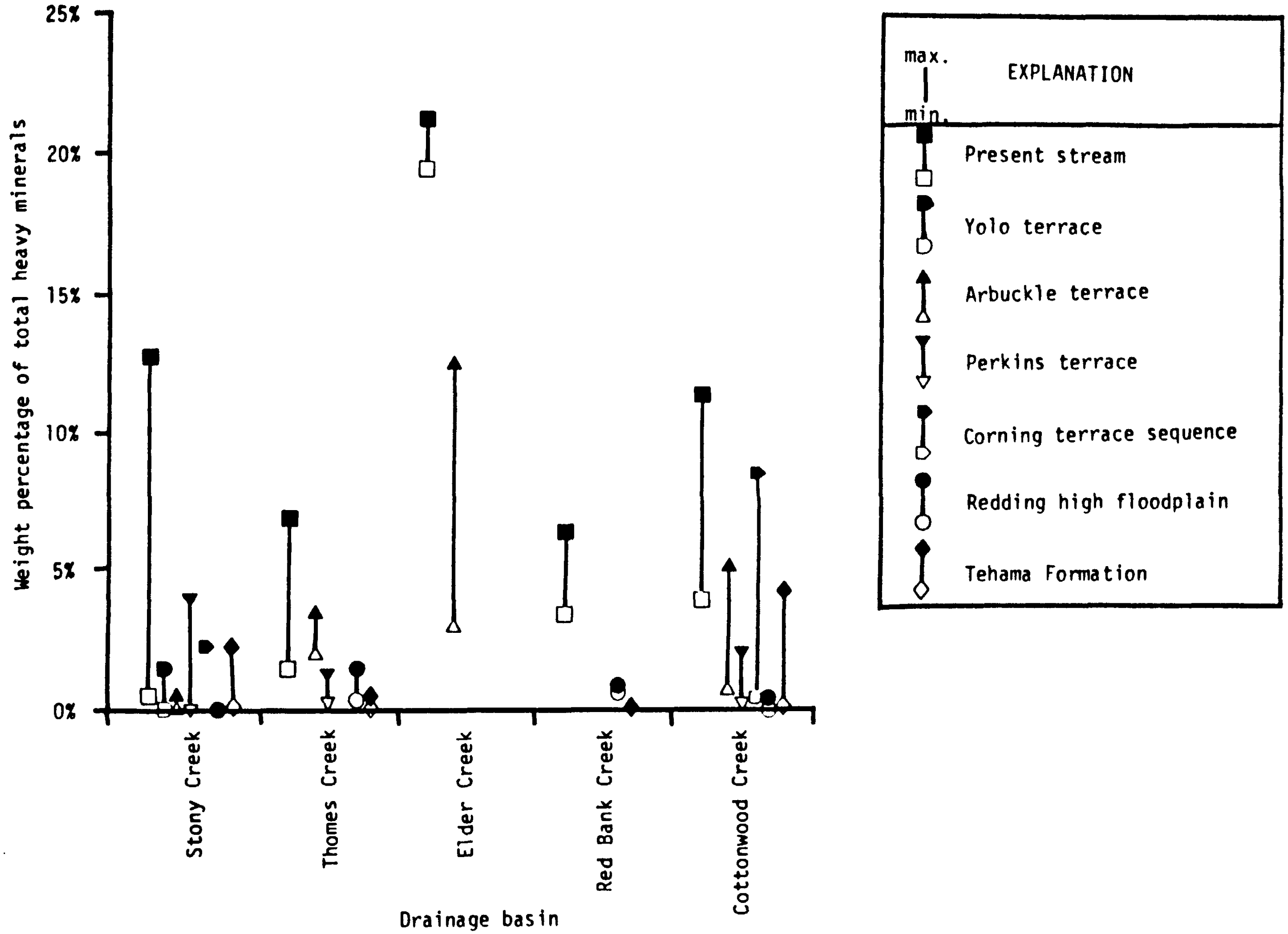

Figure 35. Ranges of heavy mineral percentage for the various terraces within the major drainage basins.

Table 8: Heavy minerals found in sediment samples

(■=found, m=minor, ?=possibly present, i=insufficient sample but probably present. The heavy minerals from each sample were studied with an X-ray powder diffractometer. The diffraction patterns were then analyzed for over 80 minerals or mineral groups.)

Sample number	Andradite	Apatite	Augite	Chlorite	Chromite	Enstatite	Feldspars	Glaucophane	Hedenbergite	Hematite	Hornblende	Hypersthene	Ilmenite	Magnetite	Mica	Pumpellyite	Quartz	Tourmaline
7237401														i			i	
8167402				■						■	?			■	■		■	
8167403	■			■				■						■		■	■	?
8167405	■	?		■			■							■	?	■	■	?
8167406	?		■	■	■	?	?				■	?		■	■	■	■	m
8167408		?		■						■				■		?	■	?
8167409	■		?	■		■						■		■	■	■	■	m
8177412		■		■	■		?	■		■				■	■		■	?
4087520								■			■			i		■	■	
4087521														i			■	
4087522				■			?	■		■				■	■	■	■	?
4087524	■	?	■	■			■	■			■			■			■	
4087525				■				?						■	■	?	■	
917750A				■				?		?	■			■		■	■	
918750B				m						■				■	?		■	
918750C				■				■			■			■	■	■	■	
6147601	■	?	■	■										■	m	■	■	?
6147602				■				?						■			■	
6147604				■						■				■		■	■	
6157601														■			■	
6157602		?		■			■	■			?			■	■		■	
6157603		?						■						■			■	
4307701			■	■	■	■		?			?			■		■	■	
4307702		■						■			■			■	m		■	
4307703								?			?			i			i	
4307704				■						■	■			■			■	
4307705		■	■	■		■					■			■			■	
4307706														■			■	
4307707											?			i	■		■	■
4307709							■				■			i	■		■	
4307710				■							■			■			■	
4307711				■			m				■		■	■	■		■	
4307712				■			■				■			■		■	■	■
4307713		■	■	■			■				■			■	m		■	
4307714		■		■		■	?							■			■	
4307715		■					m				■		■	■			■	
4307716		■	■	■			■	■			■			■	m		■	
4307717				m									■	■	m		■	
4307718		■	■	■							■			■			■	
4307719		■	■	■			■							■		■	■	
4307720		■	■	■			■	■						■	■	■	■	
4307721		?		■				m		■				■		?	■	
4307722		■		■	■						■			■			■	
4307723		■		■		?	■					■		■	■	■	■	
4307724													■	■			■	
4307725							■	■						i			■	
5017701				m				■						■			■	
5017702					■			■			■			■			■	
5017703		■		■				■		?	■			■			■	
5017704				m	■			■		■	■	■		■			■	
5017705	■	■		■				■			■			■		■	■	
5017706		?	■	■	?		?	■	■		■			■		■	■	?
5017707			■	■	■	■	■		■		■			■	■	■	■	
5017708			■	■				■	?		■			■	■	■	m	
5017709		■	■	■	■					■				■	■	■	■	
5017710				m	■			■			?			■		■	■	
5017711			■	■		?		m			■	■		■	■		■	
5017712				■							■			i			■	
5017713				■										i	?		i	
5017714				■	■			■			■			■	■	■	■	
5017715			■	■			?				■	■		■	■	■	■	
5017716			■	■	■	■					m			■			?	?
5017717				■	■									■			■	
5017718				■		■								■			?	
5017719				■				?			?			■			■	
5017721				■			?	■			■			■	m	■	■	

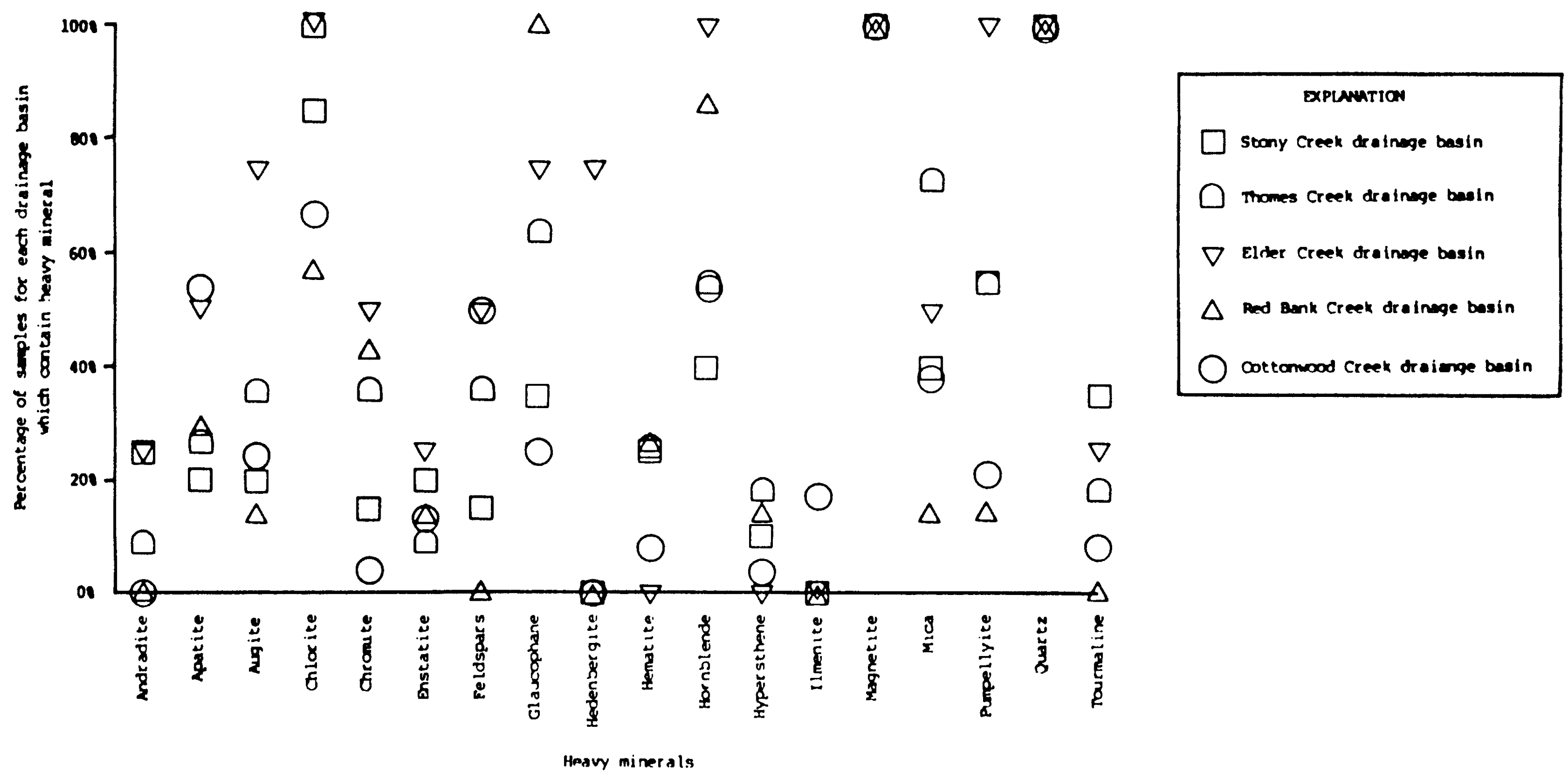

Figure 36. Distribution of heavy minerals in the major drainage basins.

The presence of specific heavy minerals may be broadly useful in distinguishing terrace levels (fig. 37). In general the total percentage of all heavy minerals is less as the age of the deposit increases. Heavy minerals from the Tehama Formation do not follow this pattern, however, because weathering of the minerals perhaps is inhibited by the thicker deposits. Assemblages of heavy minerals on individual terrace levels are not sufficiently unique to permit classification.

The clay mineralogy, although not studied in this report, was analyzed for Glenn County soils by Begg (1968). He found the mineralogy to be directly related to composition of the parent material and that there was no relationship between the kind of clay or the relative amount of each kind of clay with vegetation, climate, or age.

Soil color analyses

One of the most obvious and readily obtainable characteristics of soils is color. At essentially all field stations the soil color was determined by comparison to a Munsell color chart (tables 9-11). The present stream sediments have a distinct gray hue (5Y) which is different from soils on even the youngest terrace, the Yolo terrace (10YR) (figs. 29-32). The Yolo and Arbuckle terrace levels can usually be distinguished from older levels by their hue (10YR) and chroma (2 to 4), as compared with the older level hues (5YR) and chromas (6 to 8). The Yolo and Arbuckle terraces cannot, however, be distinguished from each other

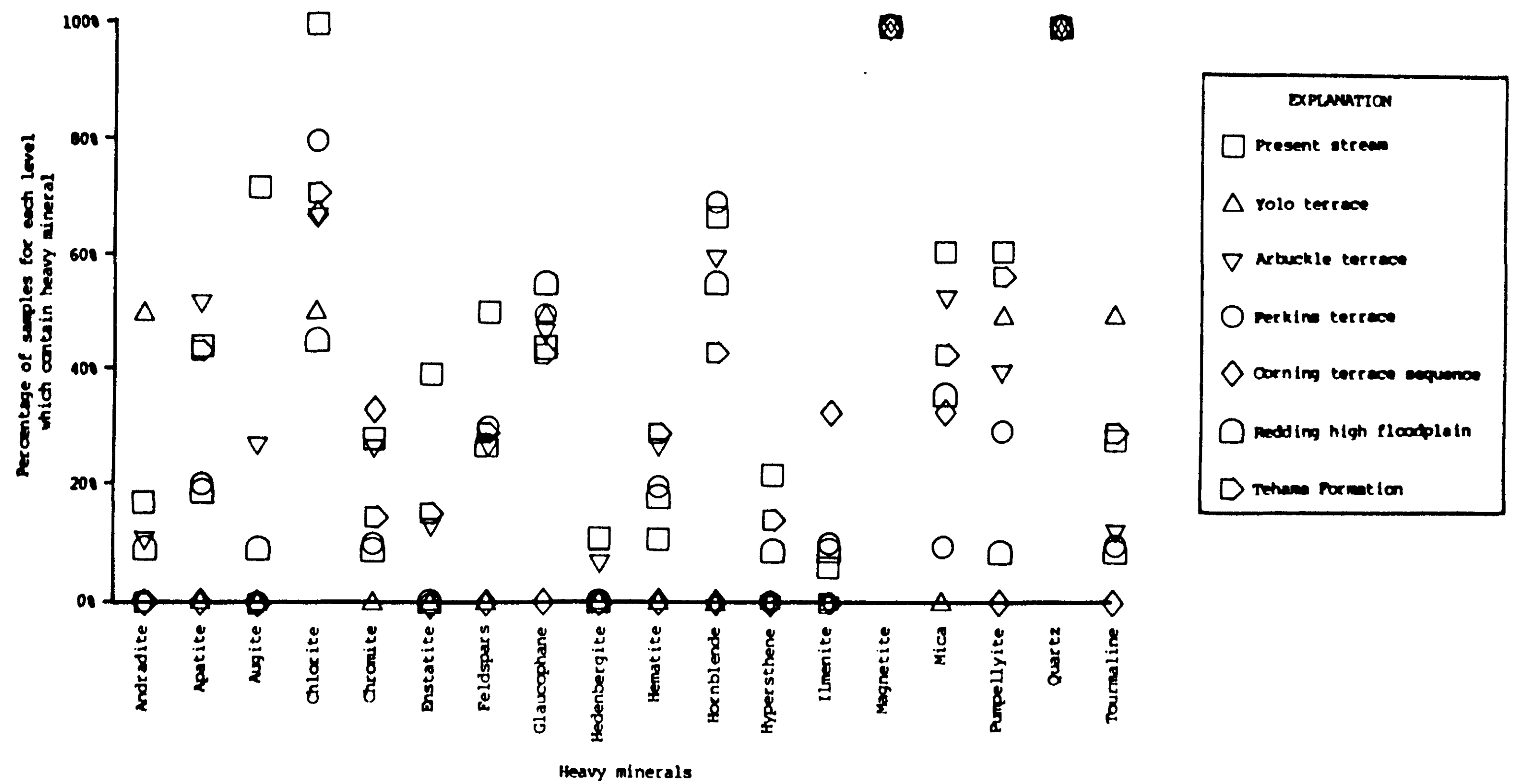

Figure 37. Distribution of heavy minerals in the various levels.

Table 9: Characteristic soils and soil colors on terraces in the Stony Creek drainage basin

(l.=loam, gl.=gravelly loam, d=dry)

	terrace					
Location	Orland	Yolo	Arbuckle	Perkins	Corning	Redding
Grindstone Creek	Orland l.	Arbuckle gl. Hillgate gl. (10YR 6/4 d)	Arbuckle gl. Hillgate gl. Hillgate l.	Perkins gl. (7.5YR 5/6 d) - (2.5YR 3/6 d)		
Stony Creek, Elk Creek to Grindstone Rancheria			Tehama l. Arbuckle gl. Hillgate gl. (10YR 6/4 d)	Perkins gl. Corning gl. (10YR 6/4 d) - (5YR 4/6 d)		
Stony Creek, Grindstone Rancheria to Julian Rocks	Orland l.		Hillgate gl. Arbuckle gl. (10YR 6/3 d) - (7.5YR 5/4 d)	Kimball l. Kimball gl. (7.5YR 5/4 d) - (2.5YR 3/6 d)		
Stony Creek, Julian Rocks to Steuben Bridge			Hillgate gl. Arbuckle gl. Hillgate l. (10YR 5/4 d)	Corning gl. (5YR 5/4 d)		
Stony Creek, Steuben Bridge to Black Butte Dam	Cortina gl. Orland l.		Arbuckle gl. Hillgate l. (10YR 6/4 d) - (7.5YR 6/6 d)	Arbuckle gl. Corning gl. (5YR 5/3 d)		
Stony Creek, Black Butte Dam to Sacramento River	Orland l. Cortina gl.	Wyo l. Cortina gl.	Arbuckle gl. Tehama l. Hillgate gl.	Kimball gl. Arbuckle gl.	Corning gl.	Corning gl. Redding gl. (7.5YR 6/4 d)
Watson Creek			Hillgate l. Hillgate gl.	Arbuckle gl. Hillgate gl. Kimball gl. Corning gl.	Corning gl. (7.5YR 6/6 d)	
Stony Creek, North Fork, Stony Valley			Wyo l. Arbuckle gl.	Corning gl.	Redding gl. Corning gl. (7.5YR 6/6 d)	
Stony Creek, North Fork, Newville to Black Butte Dam			Wyo l. Hillgate gl.	Hillgate gl. Corning gl. Perkins gl.	Corning gl.	

Table 10: Characteristic soils and soil colors on terraces in the Thomes, Elder, and Red Bank Creek drainage basins

(l.=loam, gl.=gravelly loam, d=dry)

Location	terrace					
	Orland	Yolo	Arbuckle	Perkins	Corning	Redding
Thomes Creek, The Gorge to Willaims Butte		Arbuckle gl. (10YR 6/3 d)	Arbuckle gl. Hillgate l. (10YR 5/3 d)	Kimball gl.		
Thomes Creek, Willaims Butte to Henleyville	Cortina gl. Orland l.	Arbuckle gl. Cortina gl. Orland l. Yolo l. Wyo l. (10YR 6/2 d)	Arbuckle gl. Hillgate l. Tehama l. (10YR 6/2 d) - (10YR 6/3 d)	Kimball gl. Perkins gl. Corning gl. (5YR 5/6 d)	Corning gl. (2.5YR 5/6 d)	
Thomes Creek, Henleyville to Sacramento River		Orland l. Wyo l. Arbuckle gl. Cortina gl.	Tehama l. Arbuckle gl. Hillgate l.	Kimball l. Hillgate l. Perkins gl. Kimball gl. Arbuckle gl.		Corning gl. Redding gl.
Elder Creek, Gleason Peak to Gallatin Road			Arbuckle gl. Hillgate gl. Tehama gl. (10YR 6/3 d) - (5YR 5/3 d)	Perkins gl. Kimball gl. (5YR 6/6 d)	Redding gl. Red Bluff gl. Corning gl.	
Elder Creek, Gallatin Road to Sacramento River		Arbuckle gl. Cortina gl. Zamora l. Yolo l.	Tehama l. Wyo l. Hillgate gl. Arbuckle gl. (5YR 4/4 d)	Kimball l. Perkins gl. Kimball gl.		Redding gl. Corning gl.
Red Bank Creek, The Narrows to Gallatin Road		Arbuckle gl. Tehama l.	Hillgate l. Tehama l. Arbuckle l. (10YR 6/6 d)	Kimball gl. Perkins gl.	Corning gl. Redding gl.	Redding gl.
Red Bank Creek, Gallatin Road to Sacramento River	Cortina gl.	Arbuckle gl.	Arbuckle gl. Hillgate gl. Tehama l. Hillgate l. (10YR 6/6 d) - (7.5YR 5/6 d)	Perkins gl. Kimball gl.	Redding gl. Corning gl. Red Bluff gl.	Redding gl. Corning gl. Red Bluff gl. (7.5YR 5/6 d) - (5YR 4/6 d)

Table 11: Characteristic soils and soil colors on terraces in the Cottonwood Creek drainage basin

(l.=loam, gl.=gravelly loam, d=dry)

	terrace					
Location	Orland	Yolo	Arbuckle	Perkins	Corning	Redding
Cottonwood Creek, South Fork, mountain front to Cold Fork	Cortina gl. Yolo l.		Arbuckle gl.	Perkins gl.		
Cottonwood Creek, Cold Fork			Perkins gl. Hillgate gl.	Corning gl.		
Cottonwood Creek, Cold Fork to Dry Creek	Cortina gl. Yolo l.		Arbuckle gl. Tehama gl. Hillgate l. Tehama l. (10YR 4/3 d) - (7.5YR 6/6 d)	Perkins gl. (5YR 4/4 d) - (5YR 6/6 d)	Redding gl. Red Bluff gl. (5YR 3/4 d) - (5YR 5/6 d)	Red Bluff gl. Redding gl. (5YR 5/8 d)
Dry Creek	Cortina gl.		Hillgate l. Arbuckle gl. (10YR 6/4 d)	Kimball gl.		
Cottonwood Creek, South Fork, Dry Creek to main branch		Arbuckle gl. Cortina gl. Yolo l.	Arbuckle gl. Hillgate l. Tehama l.		Red Bluff gl.	Corning gl. Redding gl.
Little Dry Creek			Perkins gl. Arbuckle gl.		Redding gl. Red Bluff gl.	
Cottonwood Creek, Middle Fork			Hillgate l. Churn gl. (10YR 5/4 d)	Redding gl. Red Bluff l. (7.5YR 5/6 d)		
Cottonwood Creek, North Fork			Churn gl. Perkins gl. Tehama l. (10YR 7/4 d)	Red Bluff l. Redding gl.		Redding gl.
Cottonwood Creek, main branch			Tehama l. Hillgate l. Arbuckle gl. Churn gl. Tehama gl. (10YR 5/4 d)	Perkins l. Perkins gl. (5YR 4/6 d) - (2.5YR 5/6 d)		Red Bluff l. Redding gl. Red Bluff gl. (2.5YR 5/6 d)

on the basis of dry soil color. Similarly, the Perkins terrace, Corning terrace sequence, and Redding high floodplain cannot be distinguished from each other on the basis of soil color. The Tehama Formation can be distinguished from terraces older than the Arbuckle by its hue (10YR). Soil color values, which usually are either 5 or 6, proved to be of little use in differentiating terrace levels. The soil color may, therefore, be used with considerable confidence to differentiate terraces into one of three groups of terrace levels.

ANALYSES OF STREAM TERRACES

Areal analyses

The geomorphology of the terraces was analyzed quantitatively to determine terrace interrelationships as an aid in correlation, to identify anomalous relationships, and to aid in correlation with features in other areas of California. Two measurements of area, the minimum and maximum possible areal extents, were used. The maximum possible areal extent was defined as the surface area of a terrace level if the present valley could be filled to that level. The minimum possible extent was defined as the surface area of the present remnants of a given level plus a typical stream width connecting the remnants. The significance of these values is not the actual area but the consistency of the ratios between the areal extents.

One measure of the amount of erosion is based on the relation between the maximum and minimum possible areal extents of the terraces (table 12, fig. 38). Yolo and Arbuckle terrace levels have similar amounts of erosion using this method; apparently because the terrace ages are more nearly the same. A maximum/minimum extent ratio of less than 2.0 is usually indicative of Yolo or Arbuckle terrace levels. Ratios between 2.0 and 8.5 usually correspond to Perkins terrace remnants and a ratio greater than 8.5 is usually indicative of the Corning terrace sequence. This measure of the amount of erosion could be particularly useful in future studies for tentative terrace identification in areas where only one level is preserved.

Another measure of the amount of erosion, the ratio of maximum areal extents between different terrace levels (table 12, fig. 39), is particularly useful as an aid in terrace identification in areas where multiple terrace terrace levels are present. The maximum terrace areas are used because the actual terrace extent was probably closer to the maximum values than to the minimum values. Arbuckle and Perkins terraces can be distinguished by a Perkins/Arbuckle maximum area ratio which is usually less than 1.9, as opposed to the Arbuckle/present stream ratio which is usually greater than 1.9. Similarly, Yolo and Arbuckle terraces can be differentiated because the Yolo terrace extent is less than 2.6 times the present stream extent, and the Arbuckle terrace extent is greater than 2.6 times that of the present stream.

Table 12: Maximum and minimum areal extents of terrace levels and volumes of sediments on the terraces

(Height refers to the thickness of material removed since formation of the next oldest level.)

Location and level	Area Minimum (Km^2)	Area Maximum (Km^2)	Length (Km)	Width (Km)	Height Minimum (m)	Height Maximum (m)	Volume (Km^3)
Grindstone Creek, present stream	--	1.52	6.40	0.24	15.2	25.9	0.031
, Arbuckle terrace	3.5	3.58	6.40	0.56	20.7	21.3	0.075
, Perkins terrace	3.8	4.70	--	--	--	--	--
Stony Creek, Elk Creek to Rancheria, present stream	--	2.26	6.10	0.37	15.2	16.8	0.036
, Arbuckle terrace	4.4	4.57	6.10	0.75	21.3	25.9	0.108
, Perkins terrace	1.7	4.80	--	--	--	--	--
, Rancheria to Julian Rocks, present stream	--	2.27	5.79	0.39	12.8	15.2	0.032
, Arbuckle terrace	4.1	4.18	5.79	0.72	15.2	25.9	0.086
, Perkins terrace	2.4	5.80	--	--	--	--	--
, Julian Rocks to Steuben Bridge, present stream	--	2.68	6.71	0.40	7.9	12.8	0.028
, Arbuckle terrace	4.3	4.98	6.71	0.74	14.0	15.2	0.073
, Perkins terrace	0.7	6.30	--	--	--	--	--
, Steuben Bridge to Confluence, present stream	--	9.81	10.67	0.92	4.0	7.9	0.058
, Arbuckle terrace	6.5	13.16	10.67	1.23	6.7	14.0	0.136
, Perkins terrace	2.1	15.20	--	--	--	--	--
, North Fork, present stream	--	2.20	14.17	0.15	3.0	6.7	0.011
, Arbuckle terrace	7.7	7.79	14.17	0.55	9.1	12.8	0.086
, Perkins terrace	4.6	10.70	--	--	--	--	--
Thomes Creek, upstream, present stream	--	3.91	15.24	0.26	5.5	13.7	0.038
, Yolo terrace	7.5	9.85	15.24	0.65	5.5	11.6	0.084
, Arbuckle terrace	14.7	18.99	15.24	1.25	20.7	22.9	0.414
, Perkins terrace	6.8	24.72	15.24	1.62	8.5	8.5	0.211
, Corning terrace sequence	3.3	28.70	--	--	--	--	--
, downstream, present stream	--	11.19	23.77	0.47	3.7	5.5	0.051
, Yolo terrace	16.4	23.14	23.77	0.97	3.7	5.5	0.106
, Arbuckle terrace	21.6	34.57	23.77	1.45	4.6	20.7	0.437
, Perkins terrace	11.6	49.84	23.77	2.10	3.0	8.5	0.289
, Corning terrace sequence	2.2	51.60	--	--	--	--	--
Elder Creek, present stream	--	3.38	22.25	0.15	6.1	18.9	0.042
, Yolo terrace	5.6	8.05	22.25	0.36	3.7	7.6	0.045
, Arbuckle terrace	23.9	25.40	22.25	1.14	4.6	15.2	0.252
, Perkins terrace	2.7	27.61	22.25	1.24	3.0	38.1	0.568
, Corning terrace sequence	3.2	32.30	--	--	--	--	--
Red Bank Creek, present stream	--	6.08	23.16	0.26	3.0	4.6	0.023
, Yolo terrace	6.3	10.50	23.16	0.45	6.1	6.1	0.064
, Arbuckle terrace	20.5	24.30	23.16	1.05	7.9	21.3	0.355
, Perkins terrace	10.3	36.20	23.16	1.56	10.7	36.6	0.856
, Corning terrace sequence	4.8	43.20	--	--	--	--	--
Cottonwood Creek, South Fork, upstream, present stream	--	7.08	15.24	0.46	16.8	36.6	0.189
, Arbuckle terrace	15.3	17.01	15.24	1.12	25.9	29.0	0.467
, Perkins terrace	3.8	23.40	--	--	--	--	--
, downstream, present stream	--	2.02	15.24	0.13	6.1	16.8	0.023
, Yolo terrace	4.1	4.50	--	--	--	--	--
, Arbuckle terrace	14.9	15.30	15.24	0.30	16.8	24.4	0.093
, Middle Fork, present stream	--	3.61	14.63	0.25	21.3	29.0	0.091
, Arbuckle terrace	9.6	11.80	--	--	--	--	--
, North Fork, present stream	--	1.63	15.24	0.11	21.3	30.5	0.042
, Arbuckle terrace	7.4	8.09	15.24	0.53	30.5	30.5	0.246
, Perkins terrace	8.1	15.00	--	--	--	--	--
, main branch, present stream	--	4.59	18.90	0.24	3.0	21.3	0.056
, Arbuckle terrace	35.0	49.13	18.90	2.60	9.1	30.5	0.973
, Perkins terrace	21.2	70.20	--	--	--	--	--

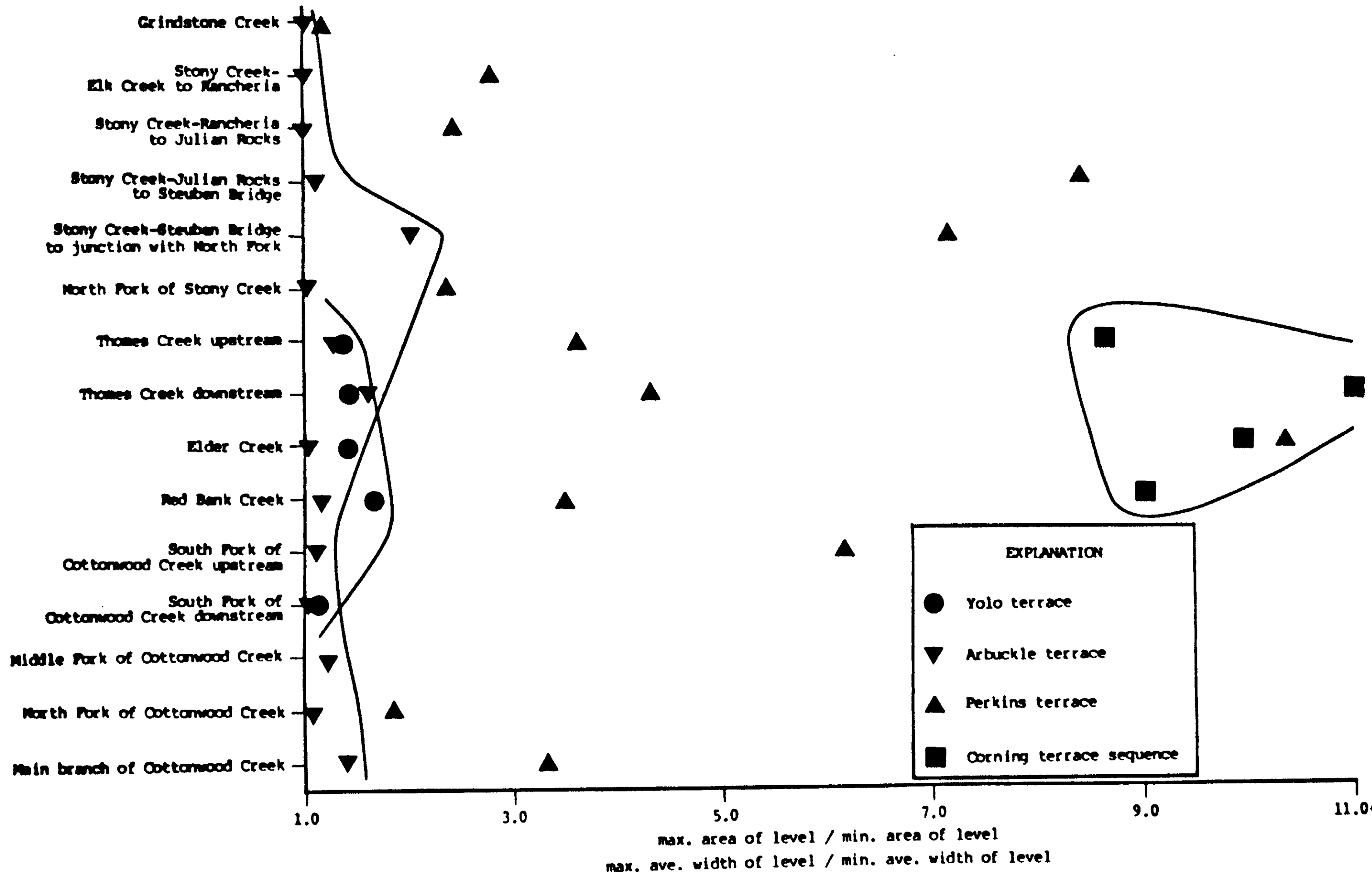

Figure 38. Amount of erosion of various levels based on the relationship between maximum and minimum possible extents.

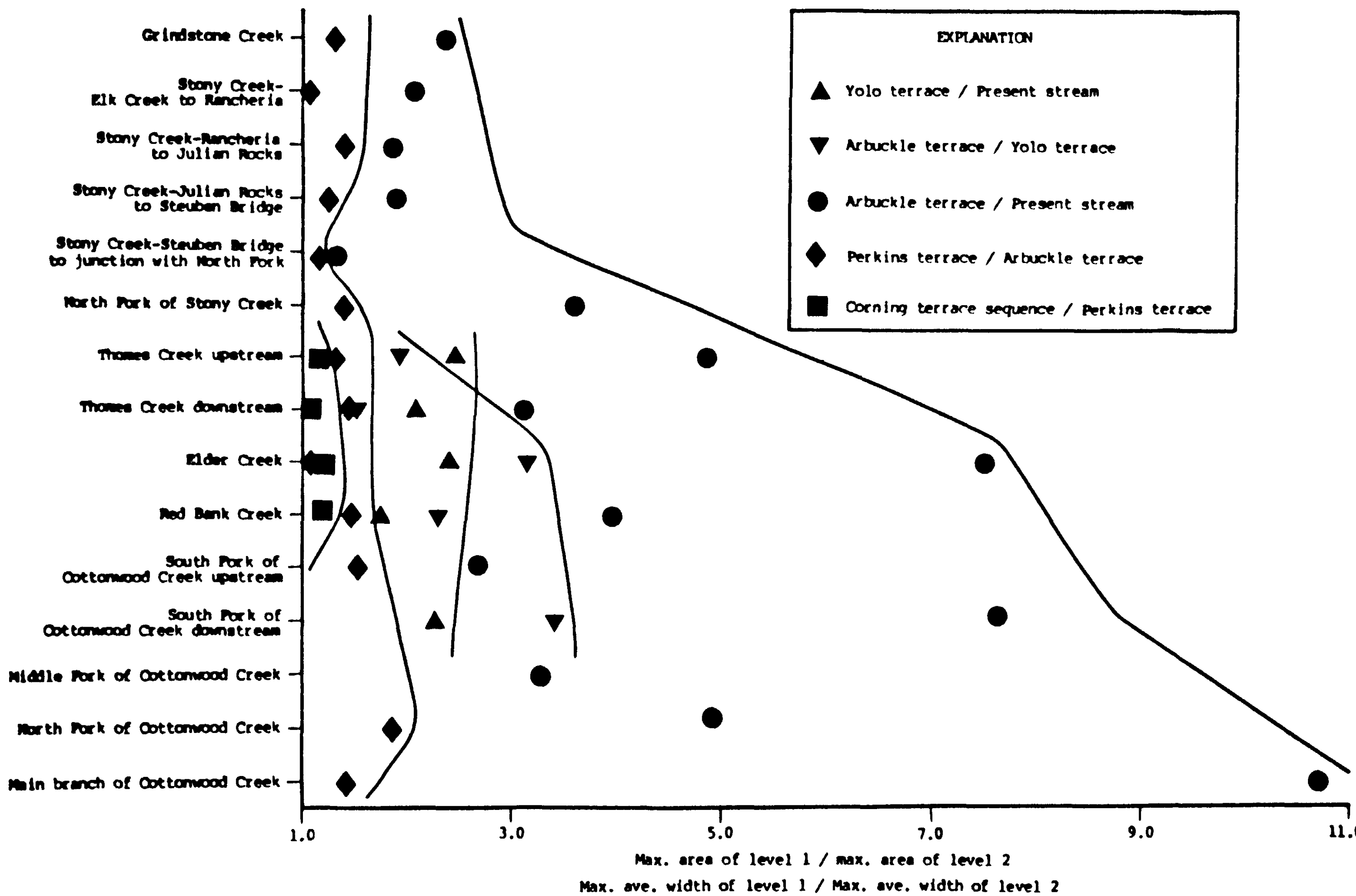

Figure 39. Amount of erosion of various levels based on the relationship between maximum possible extents.

Volumetric analyses

The volume of material removed between stages of terrace formation can be used to tentatively differentiate terrace levels (table 12, fig. 40) even though the domains are often unique. This technique is tentative because there is no single value at which one terrace can be distinguished from others. The volume of material removed may be visualized as a truncated prism or wedge (fig. 41). The heights of the lower and upper ends of the wedge are determined from the stream longitudinal profiles (figs. 14, 15, 17, 19-28). Therefore, the volume (V), is

$$V = (\text{Amax} \times \text{Hl}) + \frac{\text{Amax} \times (\text{Hu} - \text{Hl})}{2}$$

where

Amax is the maximum possible areal extent,

Hl is the lower difference in elevation between adjacent terrace levels, and

Hu is the upper difference in elevation between adjacent terrace levels.

Comparison between these "volumetric" rates of erosion and absolute terrace ages from correlations with features elsewhere in the Great Valley shows that the rate of erosion, by volume, for any given stream has been relatively constant over the last 200,000 years at least. The Perkins terrace is used as a common reference in subsequent calculations because it is centrally located in the Quaternary stratigraphic section, because the level is usually preserved in all stream reaches, and because the correlation of this level with features outside the study area are

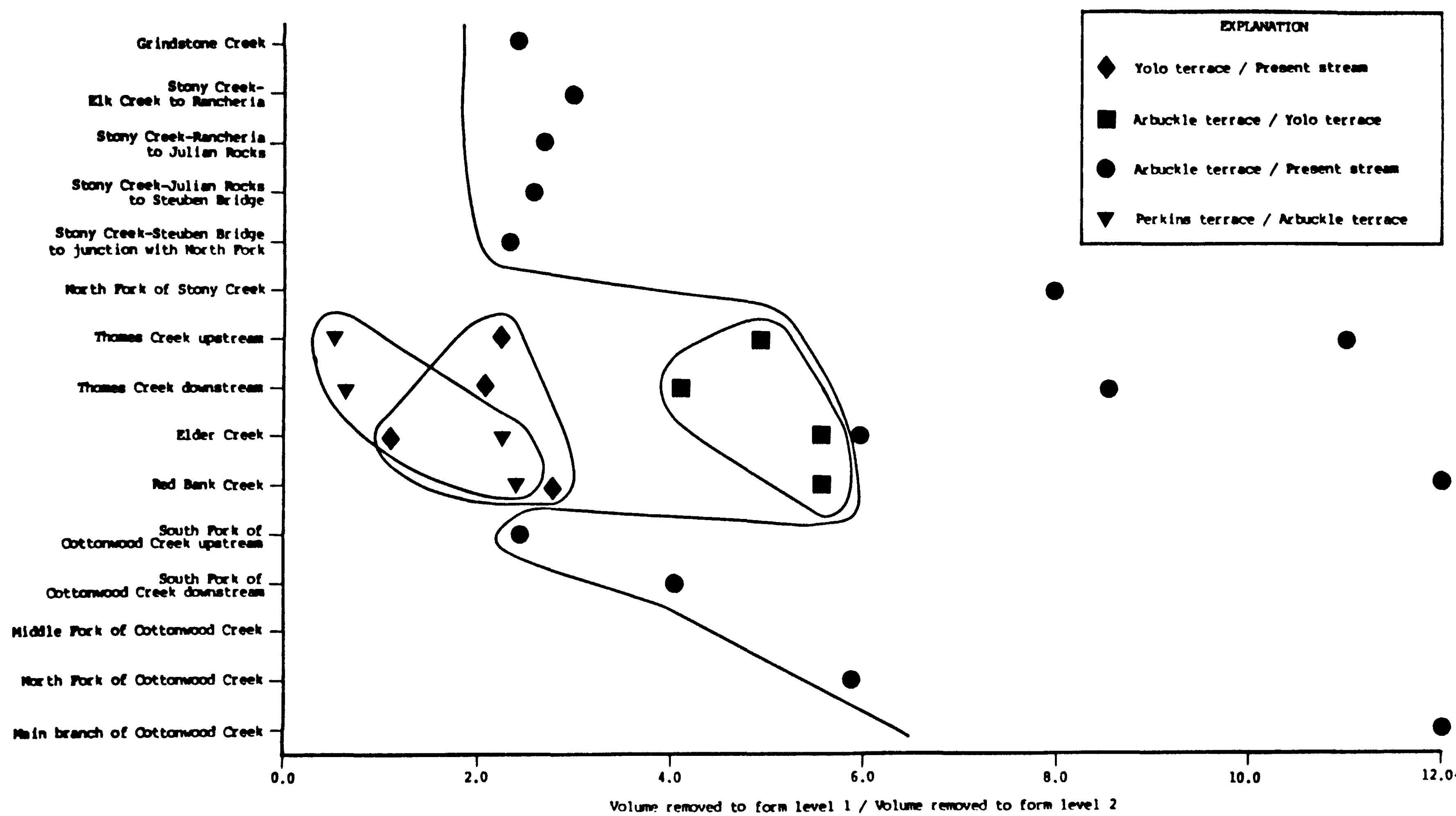

Figure 40. Relationship between volumes of material removed to form the terraces and present stream valleys.

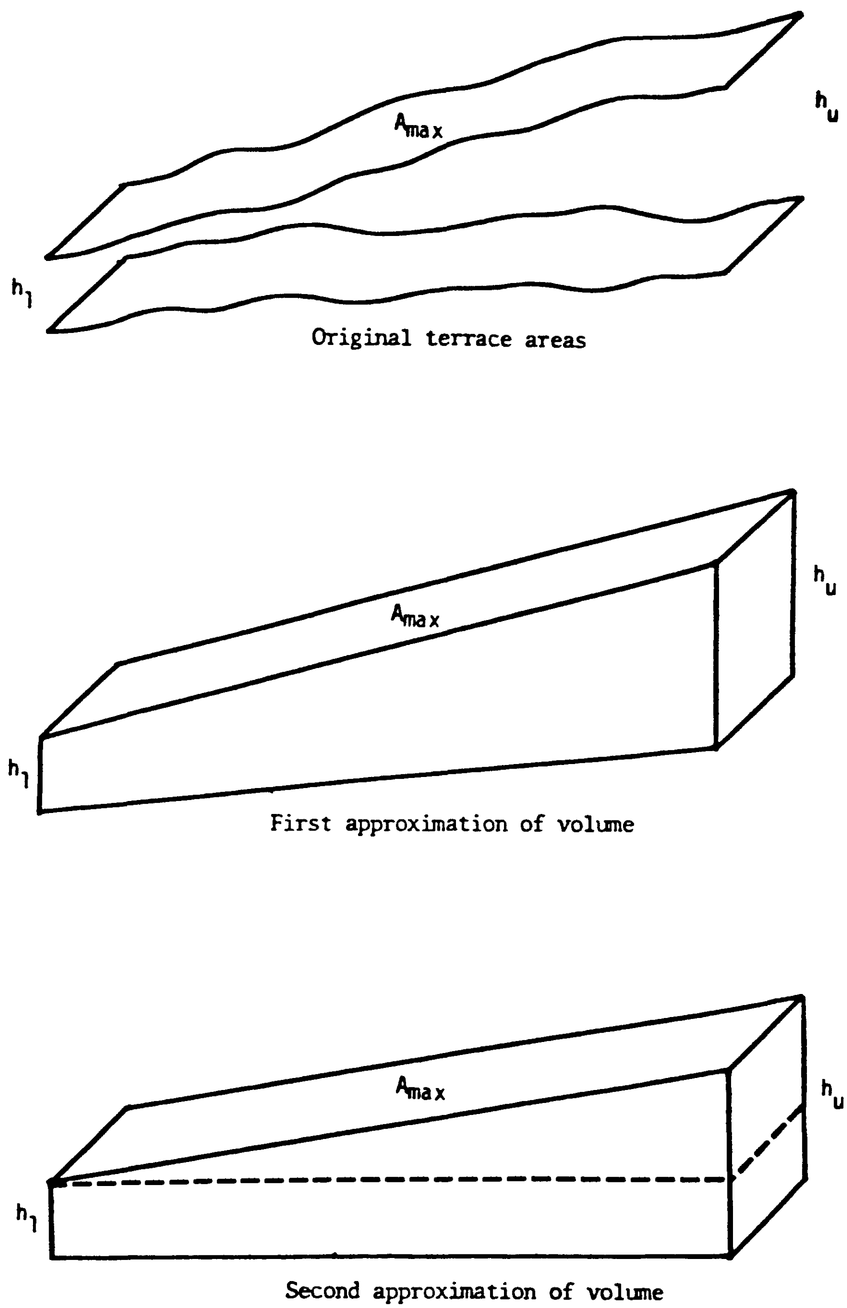

Figure 41. Diagram showing solid figure used in volumetric calculations.

probably the most accurate. If the volume of material that is eroded from a stream valley (table 12) since the formation of the Perkins terrace is set as unity, then the volume of material eroded within the valley since the formation of the Arbuckle terrace is about 26 percent of the Perkins terrace volume (table 12 and fig. 42). Similarly, the volume of material removed since the formation of the Yolo terrace is about 8 percent of the Perkins terrace volume. Along Elder Creek and Red Bank Creek, approximately 2.75 times the Perkins terrace volume of material has been eroded since the formation of the Corning terrace sequence. The erosion along Thomes Creek since the Corning terrace sequence formed, however, is about 1.44 times the Perkins terrace volume. This disparity in volumes between the Corning terrace sequence formed along Thomes Creek, and along Elder and Red Bank Creek is probably due to preservation of different levels within the Corning terrace sequence.

Reconstruction of Redding high floodplain

The Redding high floodplain has a remarkably regular upper surface (pl. 4) which may be the highly dissected remains of a pediment. Generallized contours of the surface were drawn connecting the valley-ward extent of elevations to restore the landscape to its predissected form. Only elevations on remnants were used to construct these generalized contours. Areas lower than the Redding remnants were omitted because they are probably areas where the Redding high floodplain has been eroded.

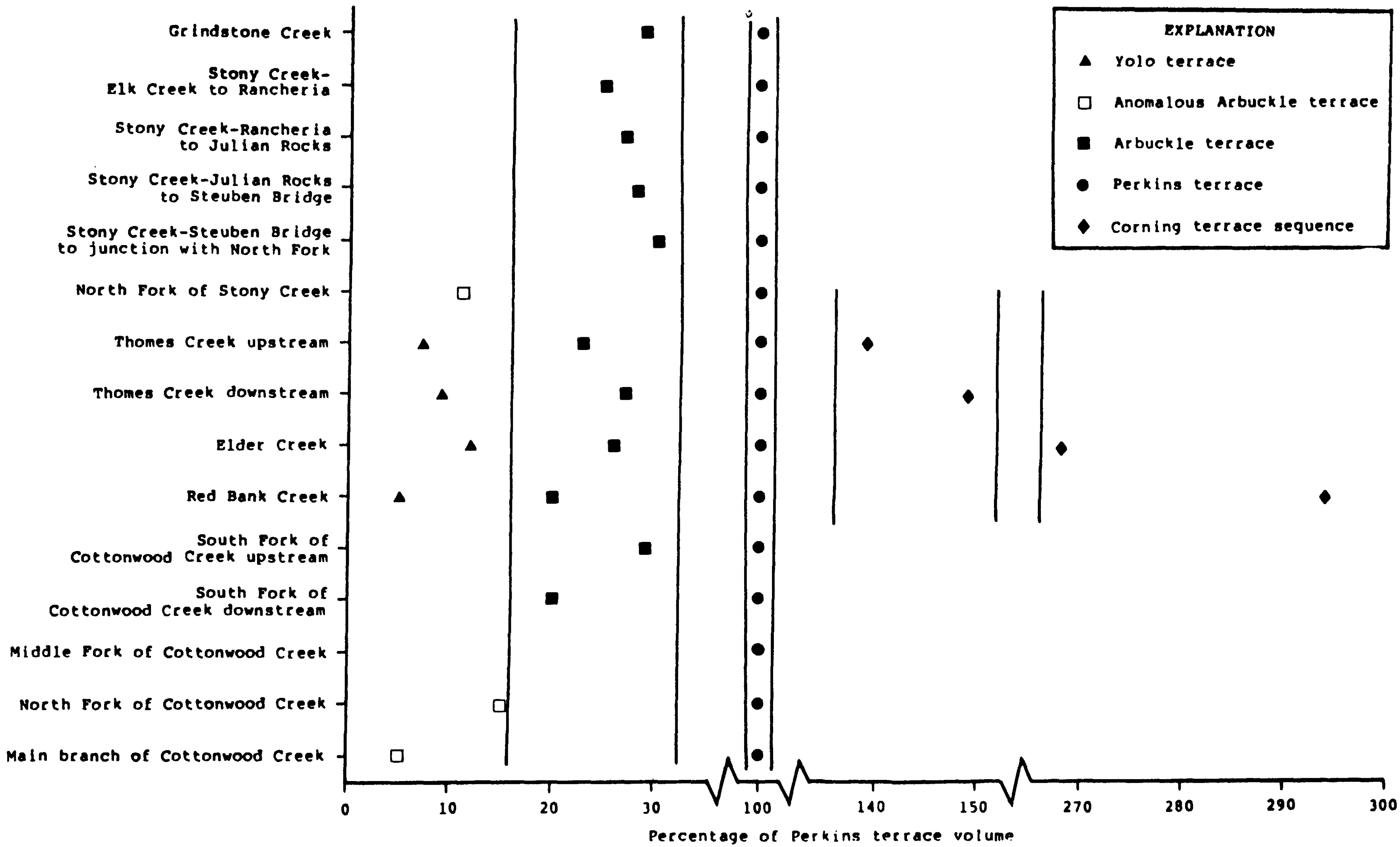

Figure 42. Relationship betweeen volumes of material removed to form various terraces with respect to the Perkins terrace volume.

There are no present features topographically higher than the Redding high floodplain in areas where the Redding level is best preserved.

The surface of the Redding high floodplain between Stony Creek and Red Bluff trends north-south and slopes to the east at approximately 10 m per km (50 ft/mi). Many remnants of the Redding surface exist throughout this area; therefore, the control on the contouring is very good. North of Red Bluff, however, the remnants are less common, perhaps because of increased erosion due to folding and faulting. Due to the sparsity of control points, these folds and faults (Madsen and Johnson, 1960) are only broadly defined by the Redding high floodplain.

The general 10 m per km (approx. 0.5^{o}) slope of the Redding high floodplain, although much steeper than present stream gradients, does not in itself confirm tilting of the region to the east. One-half degree slopes are typical of both erosional and depositional features.

Between Red Bluff and Cottonwood, the Redding high floodplain reflects tilting toward the west. The amount of uplift since the formation of the Redding high floodplain is approximately 140 m (450 ft). This figure was obtained from the difference in elevations of (1) the present highest remnants (800 ft) and the nearby Sacramento River (350 ft), and (2) the present highest remnants and a northward extension of the north-trending generalized contours beyond Red Bluff. This hypothesis of tilting toward the west is supported by:

1. folds which plunge west (Madsen and Johnson, 1960), are mostly confined to the area between Cottonwood and Red Bluff, and were not detected west of the intersection with the east sloping part of the Redding level;

2. ingrown meanders, which are often indicative of upwarping, occur only along this stretch of the Sacramento River;
3. the location of the Sacramento River on the east side of this west sloping feature (a condition which is discussed below); and
4. the deflection of the north-south trending generalized contours.

The location of the Sacramento River on the east side of the uplift between Cottonwood and Red Bluff can best be explained by uplift on the east following formation of the Redding high floodplain. If the warping did not occur and the present slopes of the Redding level are original, then the Sacramento River would need to either (1) form in this location by stream capture, or (2) be superimposed from a level higher than the Redding high floodplain, a level which has since been completely removed. Both these conditions are unlikely.

A second major deflection of the generalized contours occurs in the region between the South Fork of Cottonwood Creek and the main branch of Cottonwood Creek. The amount of downwarping is approximately 30 m (100 ft), based on the extension of contours along the north-south trend. Faults (Madsen and Johnson, 1960) coincide with this feature; however, offsets along the contours cannot be detected because of the lack of a sufficient number of control points.

Because the Redding high floodplain in the area along Cottonwood Creek and in the area between Cottonwood and Red Bluff coincides with mapped structures (Madsen and Johnson, 1960), deformation appears to have occurred since the formation of the Redding level, deformation which would have occurred within the last 1 million years.

The final major deflection of generalized contours is in the area north of Cottonwood Creek. No structural features have been mapped here by Madsen and Johnson (1960); however, the contour deflection appears too great to be on the original surface. This deflection may coincide with previously undetected faulting. Although folding cannot be ruled out, faulting is more likely because the deflection of the generalized contours is similar to the Cottonwood Creek deflection, which is related to faulting. In this area, generalized contour deflections related to folding, which plunge westward, all close to the west.

CORRELATION AND AGES OF QUATERNARY STREAM TERRACES IN NORTHWESTERN SACRAMENTO VALLEY

No dateable material could be found in the study area; therefore, inferred correlations (pl. 3) between the late Cenozoic geologic features of the northwestern Sacramento Valley and features in other areas have been established. These ages are based chiefly upon: (1) absolute ages obtained by other studies; (2) correlations established or postulated by Wahrhaftig and Birman (1965), Shlemon (1967a, b), Marchand (1977a, b), and Marchand and Allwardt (1977); and (3) similarity of soil development.

The Orland high floodplain is inferred to be approximately 4,000 years old and to be coeval with either the Recess Peak stadia and(or) the Matthes stadia in the Sierra Nevada (pl. 3). Shlemon and Begg (written commun., 1974) suggest that the Orland high floodplain, Stony Creek alluvial fan level 1 of their report, is less than 10,000 years old. They based their age on the amount of soil profile development on the floodplain. There is evidence for a period of Holocene soil formation elsewhere in the Sacramento Valley. Shlemon and Bell (1972) dated by ^{14}C methods a buried soil along Putah Creek as 3890 ± 220 and 4330 ± 180 B.P. (GX-2127 and GX-2128) which they believe may have formed during deglaciation following the Recess Peak stadia. Most other authors have not discriminated divisions for units less than 10,000 years old.

The Yolo terrace is inferred to be approximately 10,000 years old and to correspond to the upper member of the Modesto Formation of the San Joaquin Valley and to the Tioga stadia (pl. 3). Shlemon and Begg (written commun., 1974) suggest that their Stony Creek alluvial fan level 2, the level which is correlative with the Yolo terrace, is between 10,000 and 30,000 years old based on the amount of soil profile development. This time span corresponds to the period of deposition of the upper member of the Modesto Formation (Marchand and Allwardt, 1977). Birkeland (1967) found that weakly developed soils, a characteristic soil development on the Yolo terrace, formed on the younger (upper) member of the Modesto Formation in the San Joaquin Valley and on coeval Tioga stadia deposits in the eastern Sierra Nevada. Considering topographic expression and relative soil profile development, Shlemon (1967a, 1972) suggests that the upper member of the Modesto Formation was deposited during the Tioga glacial advance. Wood (1975) determined the age of a period of soil formation in the Sierra Nevada to be between 10,185 ± 105 B.P. and 8,705 ± 90 B.P. Absolute ages for the upper member of the Modesto Formation and for deposits correlated with it include ^{14}C dates of 9,150 ± 650 B.P. (Shlemon and Bell, 1972) (GX-2129) for a buried soil along Putah Creek, 10,690 ± 300 B.P. (Shlemon and others, 1973) (USGS W-744) for buried organic silt and clay in the Sacramento - San Joaquin Delta, and 9,040 ± 300 B.P., 13,350 ± 500 B.P., 14,060 ± 450 B.P., and 14,100 ± 200 B.P. (Marchand and Allwardt, 1977) for wood fragments obtained from the upper member of the Modesto Formation.

The Arbuckle terrace is inferred to be approximately 30,000 years old and is thought to correspond to the lower member of the Modesto Formation and the Tahoe stadia (pl. 3). Shlemon and Begg (written commun., 1974) suggest that the Stony Creek alluvial fan, level 3, is between 30,000 and 80,000 years old; the age is based on soil profile development. Birkeland (1967) found moderate to weakly developed soils on the older (lower) member of the Modesto Formation and the coeval Tahoe stadia deposits. Similarly, Shlemon (1967a, 1972) suggested that the lower member of the Modesto Formation was deposited during the Tahoe glacial advance. He based his conclusion on topographic expression and soil profile development. Shlemon (1972), by radiometric methods, bracketed the age of the lower member of the Modesto Formation between 27,000 B.P. and 103,000 B.P. Marchand (1977b) and Marchand and Allwardt (1977) correlated the lower member of the Modesto Formation with the isotope stage 4 of the marine record (70,000 B.P.), and they dated, by ^{14}C methods, the boundary between the upper and lower members of the Modesto Formation at 26,780 ± 600 B.P.

The Perkins terrace is inferred to be approximately 130,000 years old and to correspond to the upper member of the Riverbank Formation (pl. 3). Birkeland (1967) found strongly to very strongly developed soils on the Riverbank Formation and on the Donner Lake stadia deposits. Shlemon and Begg (written commun., 1974) suggest that the Perkins terrace, levels 4 and 5 on the Stony Creek alluvial fan, is more than 80,000 years old, based on soil profile development. Hansen and Begg (1970) dated, by a uranium-actinium series, an assemblage of fossil camel (Camelops hesternus), mammoth (Mammuthus), and horse (Equus), from sediments immediately above the Riverbank Formation as 103,000 ± 6,000 B.P. Shlemon and Hansen (1969) used an ionium-uranium age dating technique to date fossil ground sloth (Paramylodon harlani), camel (Camelops hesternus), and horse (Equus) bones found within the Riverbank Formation at 105,000 to 180,000 B.P. Marchand (1977b) dated the upper member of the Riverbank Formation as isotopically equivalent to stage 6 of the marine record (130,000 B.P.). Perkins soils are commonly characteristic of the top of the Riverbank Formation (Shlemon, 1967a, b).

The Corning terrace sequence is inferred to be between 250,000 and 1,250,000 years old (pl. 3). The age of the sequence is bracketed between the Perkins terrace and the Redding high floodplain. These terraces are, respectively, 130,000 years old and 1,250,000 years old. A more accurate bracketing of the time interval is not possible because of the general absence of potasium-argon dateable materials in the Sacramento Valley area. This interval includes the middle and lower members of the Riverbank Formation, upper member and the upper part of the lower member of the Fair Oaks Formation, and the Turlock Lake Formation. The Corning soil series caps the upper member of the Fair Oaks Formation along the American River (Shlemon, 1967a, b). Birkeland (1967) found very strongly developed soils (as are the Corning soils) on top of the Turlock Lake Formation, pre-Donner Lake stadia deposits, and Hobart stadia deposits. Janda (1965) correlated the Fair Oaks Formation with the Turlock Lake Formation and Friant Pumice member which were dated at 600,000 ± 20,000 B.P. using Potassium-Argon dating.

The Redding high floodplain is inferred to be approximately 1,250,000 years old (pl. 3). The Redding level is coeval with the top of the Red Bluff Formation, which in turn is perhaps equivalent to the Arroyo Seco gravel (surface), the lower member of the Fair Oaks Formation, and the North Merced gravel (pediment). Begg (1968) indicated that soils on this level are older than 500,000 B.P., based on soil profile development and Marchand and Harden (1976) estimated the age of the Redding soil series as 1,250,000 B.P. Louderback (1951) gave an age of 1.1 ± 0.5 my for the age of an erosion surface on the northeast side of the Great Valley. A pediment gravel which is probably correlative with the North Merced Gravel cuts part of the Tuscan Formation on the east side of the Sacramento Valley (Marchand and Allwardt, 1977). The pediment gravel may be correlative with the Redding high floodplain.

Comparison of the terraces with Hershey's terraces in the Cecilville-Trinity Alps area

Hershey (1903b) describes six channel (terrace or floodplain) levels in the Cecilville-Trinity Alps area. These six levels, which he labels A (oldest) through F (youngest), bear a remarkable physical similarity to the six terrace levels described in this study. This study is significant because it is one of the few studies in northern California which contains a sufficient amount of descriptive information for comparisons with the present study.

Hershey's youngest level, F, was described as being "buried under gravel and boulders of the present river bed"; it may correspond to the Orland high floodplain. His next two levels, E and D, are characterized by dark brown and light brown soils, respectively, while his upper three levels, C, B, and A, have red colored soils. These descriptions correspond to the breaks in soil color between the yellowish-brown soils of the Yolo and Arbuckle terraces and the reddish soils of the Perkins, Corning, and Redding levels of this study. Hershey (1903b) also describes level D as a broad level which corresponds to the "lower terrace" and "broad valley floor" found along the lower Klamath and lower Trinity Rivers. This is the typical geomorphic expression of the Arbuckle terrace in the northwestern Sacramento Valley. Hershey also characterizes his upper level, A, as having a "peculiar rolling topography" and that it "dates back at least as far as the Red Bluff epoch." This topography is similar to that of the Redding high floodplain in the northwestern Sacramento Valley which is characterized by mima mounds developed only on the upper surface of the Red Bluff Formation. The C level has been described as about twice as high above the present stream as the D level; this is also a common relationship between the Arbuckle and Perkins terraces. These relationships between Hershey's (1903b) study and the terraces in the northwestern Sacramento Valley help substantiate the subdivisions identified in the present study and support the hypothesis that the terrace forming episodes are not only a local phenomena.

Comparison of erosion rates and absolute terrace ages

Terrace ages, based on the volumes of material eroded, closely corresponds to absolute ages, based on correlations with features elsewhere in California. If the rate of sediment erosion has been constant or has been uniform when averaged over a glacial - interglacial cycle, then the "volumetric" percentages should reflect the age of terrace formation. Using the Perkins terrace age (130,000 B.P.) as a reference, the Arbuckle terrace age should be 26 percent of 130,000 years. This age, 33,800 B.P., compares favorably to the approximate age of 30,000 B.P., which was derived from inferred correlations (pl. 3). The Yolo terrace age should be 8 percent of 130,000 years (10,400 B.P.), an age which corresponds closely to the 10,000 B.P. derived from inferred correlations. Similarly, using this technique, the Corning terrace sequence ages are 195,000 B.P. for the Thomes Creek remnants and 390,000 B.P. for the Elder and Red Bank Creek remnants. The age obtained from correlations established by earlier studies is between 200,000 B.P. and 1,000,000 B.P. The 195,000 B.P. "volumetric" age corresponds to the 200,000 B.P. "correlation" age and the 390,000 B.P. level tentatively corresponds to the age of the boundary between the Turlock Lake and Riverbank Formations (pl. 3).

Anomalous values for the relative amount of erosion since the formation of the Arbuckle terrace exist along the North Fork of Stony Creek (11 percent) and the main fork of Cottonwood Creek (5 percent). Both these percentages are near the relative values for erosion since the formation of the Yolo terrace, not the formation of the Arbuckle terrace. It appears, therefore, that little or no erosion occurred following the formation of the Arbuckle terrace; and the lack of erosion resulted in the Arbuckle and Yolo terraces merging in these stream reaches. The merging of terraces along the North Fork of Stony Creek may have been due to the loss of discharge following the most recent shifting of Watson Creek into the Grindstone Creek drainage system. The merging of the two levels along the main fork of Cottonwood Creek was apparently due to a local change because the other parts of the drainage basin responded normally. This local change may have been a period of minor folding; it would have occurred between 30,000 and 10,000 B.P. The folding, if it occurred, probably followed previous fold trends, and, based on calculations using volumes eroded, require only about 2 m of downwarping of the valley to cause the two terrace levels to merge. It should be emphasized that terrace profiles and soils neither confirm nor contradict this hypothesis.

Differences in surface elevation of terrace levels were analyzed at several locations along each major drainage and the mean relative elevation changes between levels were determined from the longitudinal profiles (figs. 14, 15, 17, 19-28). If essentially uniform vertical erosion had occurred, then there should be a direct relationship between the amount of downcutting between levels and the length of time between levels. Although a wide variation between specific locations for all terrace levels exists, the elevation of the Yolo terrace is about 20 percent of the Perkins terrace elevation above the present stream, the Arbuckle terrace elevation is about 59 percent of the Perkins terrace elevation, and the Corning terrace sequence elevation is about 141 percent of the Perkins terrace elevation. If a uniform rate of downcutting had occurred and if the Perkins terrace did form at 130,000 B.P., then the Yolo terrace age should be 20 percent of 130,000 years, or 26,000 years. Similarly, the age of the Arbuckle terrace should be 76,700 B.P. and the age of the Corning terrace sequence should be 183,300 B.P. These "vertical erosion" ages do not correspond to the ages based on correlations with adjacent areas, which are 10,000 B.P. for the Yolo terrace, 30,000 B.P. for the Arbuckle terrace, and 200,000 B.P. for the Corning terrace sequence. It appears, therefore, that vertical erosion has not been at a constant rate because these ages do not correspond.

Formation of stream terraces

Stream profile analyses

Gradients of essentially all levels associated with the Quaternary deposits decrease with decreasing age, and essentially all levels converge downstream (figs. 14, 15, 17, 19-28). Possible explanations for this downstream convergence of erosional features include:

1. episodic lowering of base level,
2. episodic raising of the headwaters,

3. episodic changes in effective stream discharge,

4. episodic changes in detritus available, and

5. combinations of the above.

Subsidence of the Sacramento Valley is probably not the cause of terrace formation; although essentially the entire Great Valley south of Stony Creek has been subsiding since the Eocene and perhaps earlier (Redwine, 1972; Marchand, 1977b) and the part north of Stony Creek has been uplifted during the Pleistocene (Olmsted and Davis, 1961). However, similar assemblages of terraces have developed throughout the study area. Therefore, if eastward tilting caused formation of the terrace levels, then the movement involved uplifting of the Coast Ranges and Klamath Mountains, not downwarping of the Sacramento Valley.

Episodic deformation alone as a possible explanation for the successively higher and older terraces is improbable because the terrace soils correlate with features that have been related to glacial-interglacial episodes (pl. 3). The probability that periods of deformation occurred during each climatic episode is unlikely. This is not meant to imply that episodic deformation could not have occurred, only that it is an unlikely unique method for terrace formation in the northwestern Sacramento Valley. Continuous tilting toward the east causing elevation of the terraces combined with periods of climatic change which helped to form the terraces is a much more plausible explanation for terrace formation.

Changes in effective stream discharge are difficult to detect; therefore, the causes for the changes are essentially impossible to discover. However, possible causes and effects can be hypothesized.

Increases in effective stream discharge can be brought about by increased precipitation, less uniformly distributed rainfall throughout the year, and glacial climates with summer floods due to the melting of the snow and ice (Russell, 1931). Both increased precipitation and less uniformly distributed precipitation might be reflected in vegetation changes. Unfortunately, little has been done concerning these changes, largely because the mountainous terrain and coarse-grained deposits are not conducive to such studies.

Areas of stream capture are minor, so they probably had little effect on changes in the discharge. There appear to be only four areas, besides Watson Creek which was discussed above, that may have undergone stream capture. These areas include:

1. a barbed drainage into Corbin Creek (sec. 32, T. 20 N., R. 7 W.) of the Eel River drainage basin, which would have reduced the Stony Creek drainage basin by 3 km^2;
2. a capture of a Grindstone Creek tributary by Cold Creek (sec. 6, T. 21 N., R. 8 W.) which added 23 km^2 to the Middle Eel River drainage basin;
3. a possible capture of several Eel River drainage tributaries by the Middle Fork of Stony Creek (sec. 19, T. 18 N., R. 8 W.) which added 6 km^2 to the drainage basin; and
4. the possible capture of Knob Gulch (sec. 26, T. 30 N., R. 10 W.), a tributary to the Middle Fork of Cottonwood Creek which drains 14 km^2, by Brown's Creek in the Trinity River drainage basin.

Only the Stony Creek and the Cottonwood Creek drainage basins have changed, yet similar assemblages of terraces have developed in all drainage basins. Changes in stream regimes due to stream capture, therefore, are not thought to be the cause of the formation of the terraces in the northwestern Sacramento Valley.

Effects of climatic changes

Chronologies based on fish scales (Casteel and others, 1977), pollen analyses (Adam, 1967; Sercelj and Adam, 1975), meadow development (Wood, 1975), glaciations (Birman, 1964; Curry, 1969, 1971; Sharp, 1972), tree-line fluctuations (LaMarche, 1973), tree-rings (LaMarche, 1974), and archaeology (Moratto and others, 1978) show that Holocene climatic events are generally synchronous throughout California (Moratto and others, 1978). Late Pleistocene and Holocene oak pollen frequency curves for Clear Lake (Sims and others, in press) strongly resemble deep-sea oxygen isotope curves in the Pacicif Ocean (Shackleton and Opdyke, 1973) and the Caribbean Sea (Emiliani, 1966, 1972). It appears, therefore, that climatic changes in California for at least the last 130,000 years are generally synchronous with worldwide climatic events.

Comparison of the terrace ages with an oxygen isotope curve for the Pacific Ocean shows that the Arbuckle and Perkins terrace ages coincide with major cold periods (fig. 43). Similarly, the Yolo terrace and Orland high floodplain ages appear to coincide with minor cooling periods. The youngest level in the Corning terrace sequence, which was estimated by the volume of material eroded to be about 195,000 B.P., also

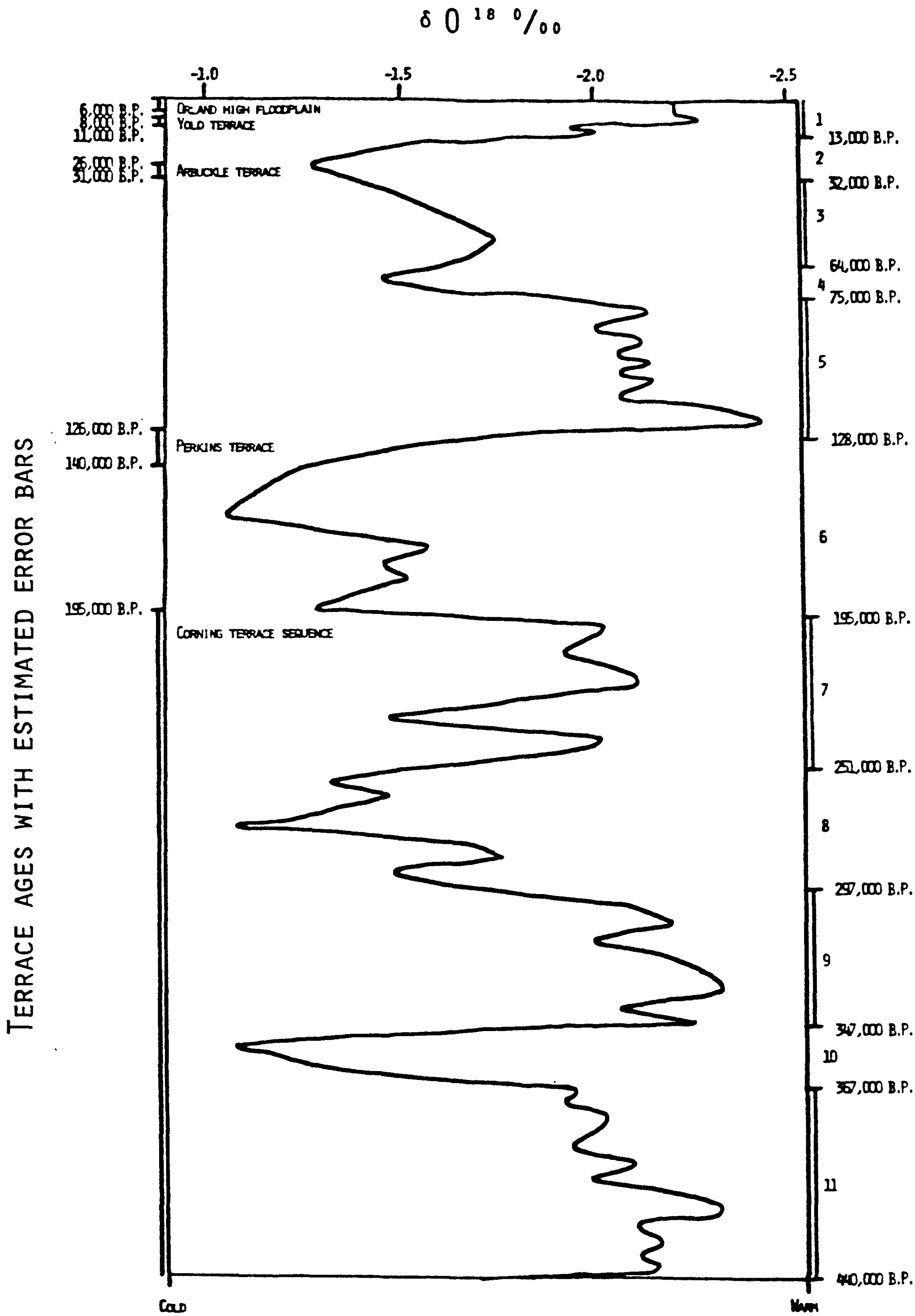

Figure 43. Relationship between postulated ages of the terraces in the northwestern Sacramento Valley and the oxygen isotope and paleomagnetic records from Pacific Ocean deep-sea core V28-238 (Shackleton and Opdyke, 1973).

coincides with a colder period. Although these terrace ages coincide with worldwide climatic events the exact characteristics of the climatic changes in the northwestern Sacramento Valley can only be hypothesized.

Sea-level changes during glacial periods had an indeterminant effect on stream intrenchment in the study area. Evidence in the San Francisco Bay area indicates that streams were able to erode bedrock to about 50 m below present sea-level (Louderback, 1951) and that during the last post-glacial rise the sea-level extended to 3 m above present sea-level (Shlemon, 1971). Channel incision due to sea-level lowering has been postulated in the Great Valley for the American River (Shlemon, 1972); however, Janda and Croft (1967) concluded that incision in the San Joaquin Valley was not eustatically controlled because the same alluvial sequences also occur in the internally drained Tulare Lake basin. Other studies in the Great Valley usually mention eustatic changes as possible causes for erosion and(or) deposition although there is usually little evidence supporting these changes. Similar conclusions must be drawn for the northwestern Sacramento Valley, unfortunately; although eustatic changes probably had no effect on the area there is no unequivocal evidence to support this belief. The problem is that climatic and tectonic changes appear to have occurred simultaneously and that either could produce features similar to those expected by eustatic changes alone.

Ages of lacustrine deposit are too recent and the deposits reflect such subtle and detailed changes that they have limited use as climatic indicators for episodes of terrace formation and(or) erosion in the northwestern Sacramento Valley. In Searles Lake, California, Smith (1970) found five pluvial episodes with interspaced soil forming periods between 24,000 and 10,500 B.P. This time span, however, is only represented by the Yolo terrace level in the northwestern Sacramento Valley. An early and middle Holocene temperature increase, which began about 10,000 B.P. and ended about 2,800 B.P., has been documented for Clear Lake, California (Casteel and others, 1977), the Sierra Nevada (Adam, 1967), and the White Mountains in the Basin and Range province (LaMarche, 1973). The geographic range of this climatic change suggests that a similar change may have occurred in the northwestern Sacramento Valley, although again the data are too recent and covers only the time period for the formation of the Orland high floodplain.

Evidence of glaciers within the drainage basins studied occurs in:

1. the Stony Creek drainage basin at Snow Mountain (sec. 28, T. 18 N., R. 8 W.) (Holway, 1911, 1914; Davis, 1958; Rich and Brown, 1971);
2. the Grindstone Creek drainage basin near Black Butte (sec. 27, T. 22 N., R. 9 W.) (Holway, 1914; Davis, 1958) and at Anthony Peak (sec. 15, T. 23 N., R. 10 W.) (Davis, 1958);
3. the South Fork of Cottonwood Creek drainage basin at the South Yolla Bolly Mountains (sec. 10, R. 25 N., R. 9 W.) (Wahrhaftig and Birman, 1965); and
4. the Middle Fork of Cottonwood Creek drainage basin at the North Yolla Bolly Mountains (sec. 10, T. 27 N., R. 10 W.) (Davis, 1958; Blake, 1965).

Because only a total area of about $5 km^2$ (Davis, 1958) was occupied by all the glaciers and because only some drainages were glaciated, whereas all drainages developed similar terrace assemblages, it appears that the glaciers per-se had negligible effect on the development of erosional and(or) depositional features within the study area. It is worth noting, however, that those drainages which were partially glaciated and were probably most affected by climatic change are the drainages with the best developed terrace sequences.

Although glaciers within the drainage basins were limited and probably represent the southern extent of glaciation within the Coast Ranges (Davis, 1958), glaciers were much more extensive in the Klamath Mountains (Hershey, 1900, 1903a, b; Hinds, 1952; Irwin, 1960; Sharp, 1960; Aune, 1970; and Lee, 1973) and dates from the more recent studies (pl. 3) are probably applicable to climatic changes in the study area.

Increased precipitation, which may have accompanied decreasing temperatures during glacial periods in the northwestern Sacramento Valley, resulted in erosion and subsequently in the formation of the terrace levels.

Bryan (1923) postulated that glacial periods in the Sierra Nevada should be periods of erosion. Periods of incision during glacial periods have also been proposed by Shlemon and Hansen (1969) and Shlemon (1971) for the east side of the Sacramento Valley. This erosion occurs because of the increased snow cover which decreases sediment input into streams and because of the subsequent spring thaws which increase flooding. Increased precipitation during the glacial period would simply accentuate the erosion by increasing runoff (Bryan, 1923; Langbein and others, 1949 Langbein and Schumm, 1958; Schumm, 1965).

On the west side of the Sacramento Valley, however, most of the mountain area is more arid than in the Sierra Nevada. Therefore, if no change in precipitation accompanied the glacial periods on the west side of the Sacramento Valley, the lack of snow cover would allow increased frost action. As a consequence, stream sediment would be increased, resulting in aggradation during the glacial periods; this effect would be opposite to the effects produced by glacial periods in the Sierra Nevada. Because both the east and west sides of the Sacramento Valley have similar terrace sequences, which are apparently about the same age, it appears that aggradation due to frost action during glacial periods was more than offset by erosion due to an increase in precipitation. Langbein and Schumm (1958) and Schumm (1965), in studies of the interaction of precipitation and vegetation on runoff and erosion, published graphs which are applicable to the present climate of the northwestern Sacramento Valley. For mean annual temperatures of approximately 61^{o} F (16^{o} C) and mean annual precipitation of approximately 20 in. (51 cm) (Elford, 1970), Schumm's (1965) curves indicate that the northwestern Sacramento Valley is presently at a maximum mean annual sediment yield. This conclusion is supported by the present subdued rates of downcutting and(or) valley-widening along streams in the area. According to the model of Langbein and Schumm (1958), a change from a warm, interglacial climate, like the present, to a cool, glacial climate would decrease the evaporation rate. The decreased evaporation rate and cooler temperatures would result in denser vegetation, which in turn would decrease the stream sediment. The decreases in stream sediment should induce erosion of the valleys. Any increase in precipitation which might accompany the glacial period would increase runoff and increase the rate of erosion. Marchand (1977b) has reached similar conclusions regarding the incision of pre-existing features during the onset of glacial periods in the Sierra Nevada.

General cycle of terrace formation

Shlemon (1972) proposed a five-stage cycle of landscape changes for the American River area. A modified three-stage version of these cycles may be more applicable to the formation of individual terrace levels in the northwestern Sacramento Valley. Fewer stages are proposed because stratigraphic evidence supporting a greater number of subdivisions was not found. Generally, the repetition of this three stage cycle has resulted in the assemblage of terraces in the northwestern Sacramento Valley.

The first stage (fig. 44), a period of relative landscape stability during interglacial or interstadial time, may constitute the longest period of time, and it was a period of intense soil formation. It was probably similar to the present climatic and hydraulic regimes. Shlemon (1967a, 1972), Janda and Croft (1967), and Marchand (1977b) proposed a similar period of soil formation along the east side of the Great Valley during interglacial periods.

The second stage, a period of degradation, probably occurred during glaciation. Because of the increased discharge during the glaciation, the capacity of the streams also increased, causing stream incision and(or) valley widening both in the upstream sections of the streams and

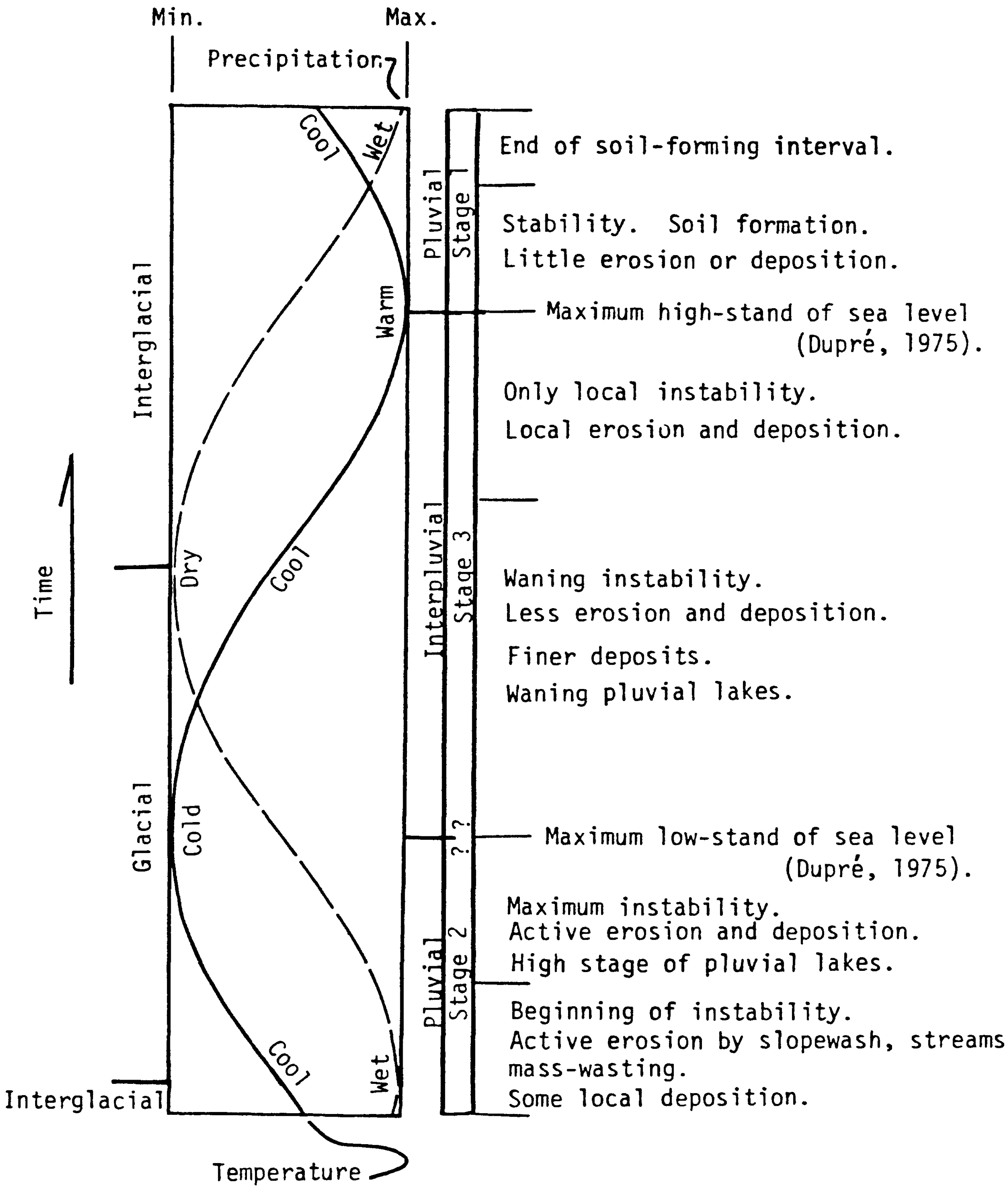

Figure 44. Possible climatic relationships and effects on erosion, deposition, and soil formation. After Frenzel (1973) and Morrison (1967).

on the alluvial fans. Shlemon and Hansen (1969) and Shlemon (1971) proposed similar periods of incision for the Mokelumne River and Sacramento areas.

A third stage, a period of transportation and deposition during a glacial recession, may have occurred. During this stage the discharge was reduced to volumes similar to those produced at the beginning of stage 1 and, where glaciers existed, they supplied only glacial flour to the streams. Because few glaciers existed in the northwestern Sacramento Valley, their contribution of sediment to the streams was probably minor, and only fine material was deposited. Aggradation in the Great Valley during this stage has also been postulated by Shlemon and Hansen (1969) and Shlemon (1972).

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