Geological Society of America Bulletin

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Geological Society of America Bulletin 1984;95;618-627
doi: 10.1130/0016-7606(1984)95<618:LCSSOT>2.0.CO;2

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JAMES W. HAGGART
PETER D. WARD
Department of Geology, University of California at Davis, Davis, California 95616

ABSTRACT

The Upper Cretaceous (Coniacian–lower Campanian) Chico Formation of the northeastern Sacramento Valley, California, includes three newly defined members at the type locality: (1) cobble conglomerate of the basal Ponderosa Way Member, (2) coarse-grained conglomeratic sandstone of the overlying Musty Buck Member, and (3) fine-grained silty sandstone of the uppermost Ten Mile Member. Other outcrops of the Chico Formation exhibit the same three members plus an additional unit, the Kingsley Cave Member, composed of mudstone. The Chico Formation resulted from a transgression onto the Sierra Nevada basement in the Late Cretaceous. The Kingsley Cave Member was deposited locally in quiet-water conditions below wave base in an intrashelf basin and may represent a marine connection with regions farther northeast.

Macrofossils allow correlation of the Chico Formation with marine deposits of the Great Valley sequence exposed along the western Sacramento Valley. Strata of the Guinda and Forbes Formations represent submarine fan–channel to outer-fan deposits of a shallowing Late Cretaceous fore-arc basin. The Santonian Guinda Formation, a massive sand unit deposited in fan-channel to distal-fan turbidite environments, is correlative with the Musty Buck and Kingsley Cave Members of the Chico Formation. The Dobbins Shale Member of the Forbes Formation, a widespread mudstone unit of hemipelagic outer-fan to basin-plain deposits, is correlative with the Kingsley Cave Member of the Chico Formation and reflects a Santonian transgressive event in the northern fore-arc basin. Mudstones and turbidites of the middle of the Forbes Formation are equivalent to the shallow-marine strata of the Ten Mile Member of the Chico Formation. Correlatives of younger Forbes Formation strata have not been positively identified from the Chico Creek region but may be represented by unfossiliferous, cross-bedded, coarse-grained sandstones found above sections of the Chico Formation.

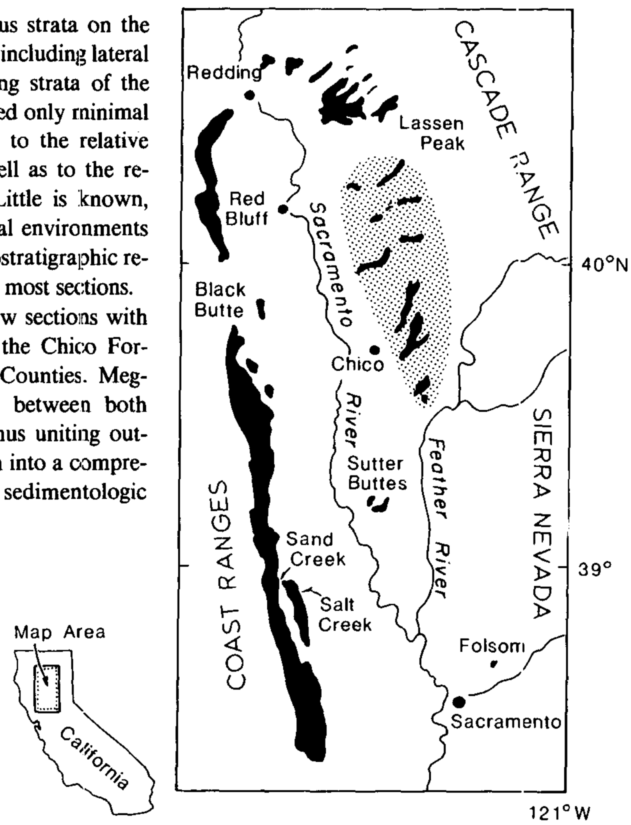
INTRODUCTION

Thick accumulations of Upper Cretaceous sedimentary deposits are found on the western, northern, and eastern margins of the Great Valley of California (Fig. 1). The search for oil and gas in northern California, as well as interest in the processes of sedimentation in fore-arc regimes, has made the Great Valley sequence, exposed along the west side of the Sacramento Valley, probably the best-studied fore-arc deposit in the world (Ojakangas, 1968; Dickinson, 1971; Ingersoll, 1978, 1979). These workers interpreted strata of the Great Valley sequence to be deep-marine slope and basin-plain deposits. Many of these rocks contain an abundant microfauna that has been utilized for correlation of diverse lithologic types (Goudkoff, 1945; Douglas, 1969).

In contrast, Upper Cretaceous strata on the eastern side of the Great Valley, including lateral equivalents of the gas-producing strata of the Sacramento Valley, have received only minimal attention. This is due, in part, to the relative paucity of a microfauna, as well as to the remoteness of most exposures. Little is known, consequently, of the depositional environments of these proximal facies, and biostratigraphic relations have not been defined in most sections.

In this paper, we describe new sections with paleontologic collections from the Chico Formation in Tehama and Butte Counties. Megafossils now allow correlation between both margins of the Great Valley, thus uniting outcrops of this depositional system into a comprehensive littoral to bathyal sedimentologic framework.

Figure 1. Distribution of Upper Cretaceous outcrop along the margins of the Sacramento Valley. Stippled area represents outcrop of the Chico Formation.



METHODS

Strata of the Chico Formation dip gently to the southwest. Sections were measured using either tape and compass or Jacob's staff. In some areas, outcrop data were plotted on U.S. Geological Survey topographic quadrangles and stratigraphic columns were determined trigonometrically. Paleontologic collections of macrofossils were made during the measuring of sections. Minor offset of bedding was observed on more southerly exposures of the Chico Formation, and such structural modification becomes more prominent farther north. These disruptions are easily recognized and the offset can be compensated for, except on Antelope Creek, where severe folding has occurred at some localities. Such areas were treated as iso-

Geological Society of America Bulletin, v. 95, p. 618–627, 11 figs., May 1984.

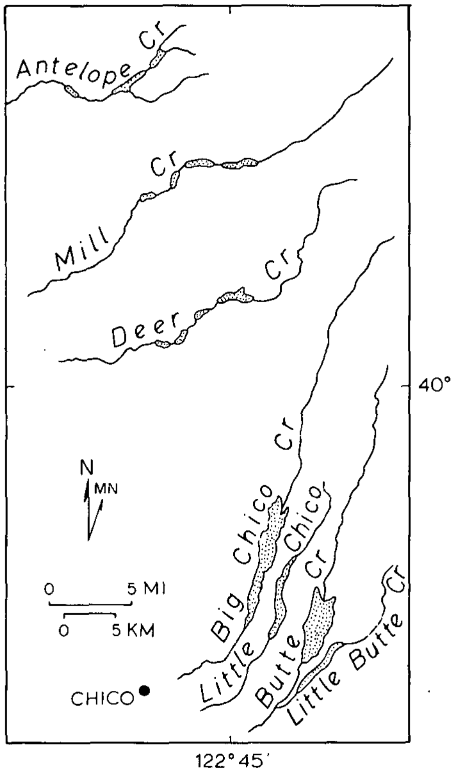


Figure 2. Outcrops of the Upper Cretaceous Chico Formation, Tehama and Butte Counties, California.

lated sections. Additionally, infilling of topographic lows in the Cretaceous surface by younger volcanics results in isolation of some of the outcrops from the rest of the section. These exposures were placed into a composite section based on the structural attitudes of the sediments bracketing them. By necessity, then, some segments of the stratigraphic sections are incomplete, resulting in local truncation of lithologic and faunal ranges.

STRATIGRAPHY

East Side: Lithostratigraphy

In the 125 years since the introduction of the name Chico for Upper Cretaceous sedimentary deposits of the Pacific Coast of North America, the term has been employed in a variety of lithologic contexts. Cretaceous strata from California, Oregon, and Vancouver Island were lumped within the Chico Group by Gabb (1869), and successive workers have argued series, group, or formational designations for the name (Anderson, 1938, 1943; Taff and others, 1940). In an effort to eliminate the confusion associated with usage of the term Chico, Peck and others (1956, p. 1982) proposed that stratigraphic application of Chico "should be abandoned as a group or series name, but that it might usefully be retained as a formational name for the rocks at and near the type locality on Chico Creek." Recent workers have, as a rule, followed this suggestion.

The overlying and extensive Tuscan Formation of Pliocene age, and locally the Eocene Lovejoy Basalt, limit exposures of the Chico Formation to narrow outcrops along only the most deeply incised drainages of the Lassen foothills region (Fig. 2). The first investigations of Chico strata were those of Trask (1856), who described ammonites from the Cretaceous deposits exposed along Big Chico Creek. Diller (1889, 1895) mapped additional Chico Formation outcrops on Deer, Mill, and Antelope Creeks and noted that Cretaceous fossils had been found in those areas. However, due to their remoteness, these outcrops have never been stratigraphically measured or collected.

North of the Chico region, Cretaceous stratigraphy and molluscan occurrences in the vicinity of Redding, California, were summarized by Popenoe (1943), who recognized six lithologic members. On the basis of macrofossils, he equated the youngest of these deposits with the base of the section exposed along Big Chico Creek. Matsumoto (1959-1960, p. 4) proposed the name Redding Formation for these strata, whereas Jones and others (1978) suggested that at least some of Popenoe's (1943) Members I–VI were of formational rank.

The type locality for the Chico Formation, Big Chico Creek, was established by Taff and others (1940) and has been the principal field area for biostratigraphic and sedimentologic studies. Saul (1959, 1961) outlined the sedimentologic units and the molluscan succession observed at the type locality. She recognized three distinctive lithologies and informally designated them the Ponderosa Way Member, the Musty Buck Member, and the Ten Mile Member. This paper follows her usage in formal presentation. Further examination of Chico Formation outcrop along Deer, Mill, and Antelope Creeks has shown the presence of these same three members, plus an additional unit, herein designated the Kingsley Cave Member. Stratigraphic relations of Chico Formation outcrops are summarized in Figure 3.

Ponderosa Way Member

The name Ponderosa Way Member is adopted for the conglomeratic lower unit observed at the base of the Chico Formation along Butte, Big Chico, and Deer Creeks. The name is taken from the foothills road, Ponderosa Way, which traverses the higher elevations of the field region. The member unconformably overlies pre-Cretaceous metamorphic rocks, this contact being obscured in most areas by a cover of erosional debris. In the extreme northeast corner of sec. 1, T. 23 N., R. 2 E., exposures on Big Chico Creek in the vicinity of the Ponderosa Way Bridge are thus arbitrarily defined as the lower-boundary stratotype for the Ponderosa Way Member. The member is approximately 200 m thick on Big Chico Creek, with the upper-boundary stratotype located in the center of sec. 1, T. 23 N., R. 2 E. The member is well exposed along Butte Creek, 8 km to the southeast, both above and below the Helltown Bridge crossing; here the stratigraphic thickness is somewhat less than on Big Chico Creek, ~180 m.

The lower part of the member consists of cobble conglomerate with local sand lenses (Fig. 4). Cobbles are poorly sorted and moderately well rounded, and they range in size from 6 to 20 cm in diameter, with some as much as 70 cm. Clasts are primarily matrix-supported and consist of chert, metavolcanics, quartzite, schist, and slate, suggesting that they were derived from the underlying metamorphics. Granitic clasts from nearby Mesozoic Sierran intrusives are absent. Clasts are embedded in a medium- to coarse-grained arkosic sandstone matrix. Rare trough cross-stratification occurs within the sandstone lenses, and there are indistinct, normal grading and cobble imbrication in some sections.

The upper portions of the member become increasingly sandy through interbedding of sandstone lenses within the massive cobble conglomerate. On Big Chico and Butte Creeks, the transition to the overlying Musty Buck Member is gradational at the localities noted above. Marine fossils (ammonites and other mollusks) have been reported from only the uppermost exposures of the Ponderosa Way Member on Big Chico Creek (Matsumoto, 1959–1960). Exposures of the member along Butte Creek lack a normal marine macrofauna.

Musty Buck Member

The Musty Buck Member rests conformably on the underlying Ponderosa Way Member on Big Chico and Butte Creeks. We place the lower-boundary stratotype of the Musty Buck Member at the uppermost occurrence of cobble conglomerate on Big Chico Creek, in the center of sec. 1, T. 23 N., R. 2 E. The upper-boundary stratotype is placed at the highest exposures of the pebbly sandstone, along Big Chico Creek at the west margin of sec. 13, T. 23 N., R. 2 E. More accessible exposures of the member are

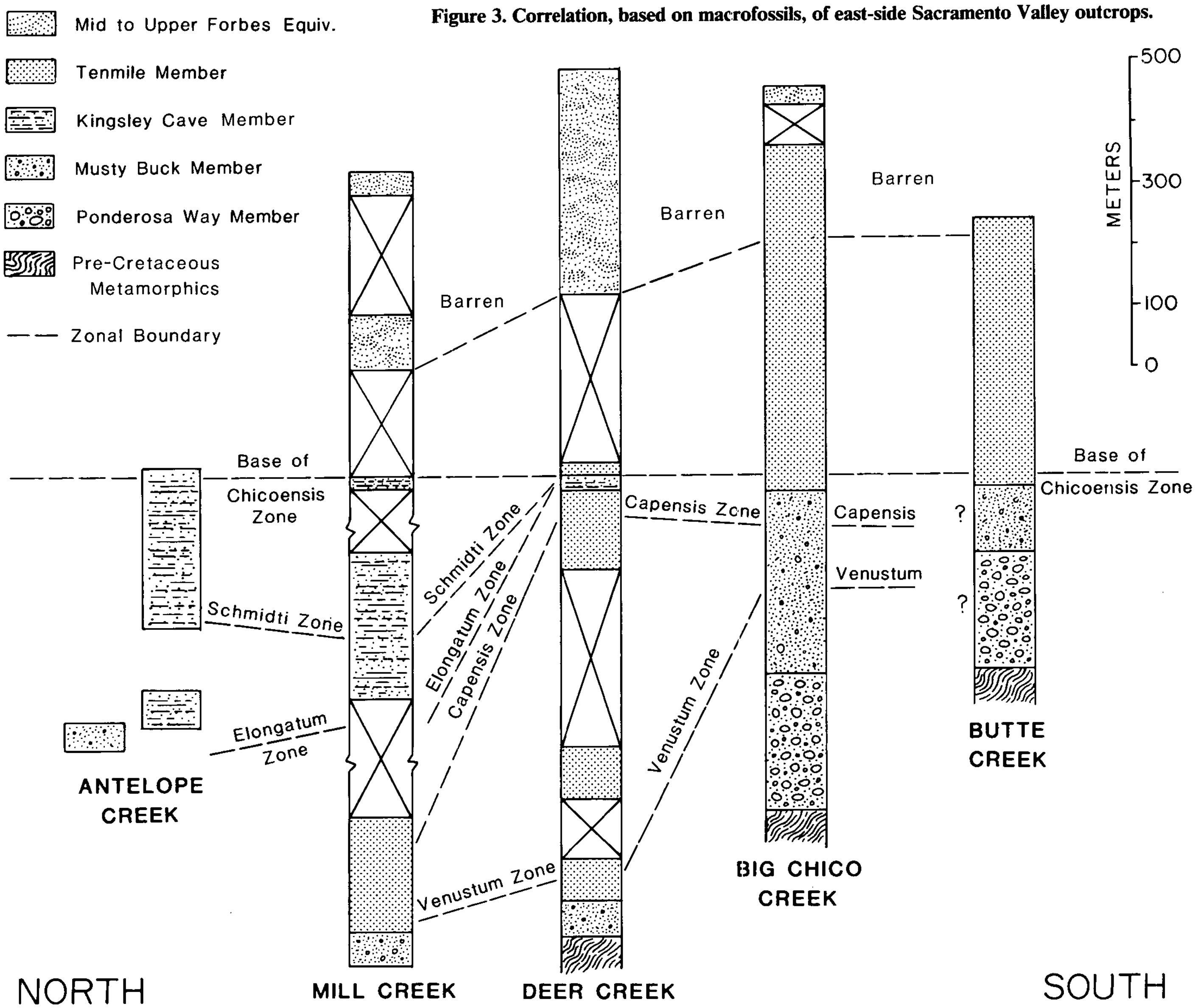


Figure 3. Correlation, based on macrofossils, of east-side Sacramento Valley outcrops.

found along Butte Creek. Here, the relative thickness of Musty Buck strata (110 m) is substantially less than found on Big Chico Creek to the northwest (215 m).

Farther north, on Deer Creek, cobble beds of the member are found directly onlapping the pre-Cretaceous metamorphic rocks. This is the only locality where we have actually observed the contact of the Chico with the underlying basement rocks. Lithologies of the member stratotype as well as the exposures on Butte Creek, Deer Creek, and Mill Creek are essentially identical. The unit consists of arkosic sandstone, greenish-gray to tan in color, containing extensive pebble beds as well as single pebbles and cobbles. Pebbles vary in size to 4 cm in diameter and include chert, quartz, and mud clasts with subordinate schist, moderately rounded to subrounded, and decreasing in diameter and occurrence upsection. The pebbles are enclosed in a medium- to coarse-grained sandstone matrix consisting of subangular to subrounded quartz with associated feldspar and biotite.

Large-scale, low-angle planar cross-stratification occurs in the Musty Buck Member along Butte and Big Chico Creeks, and the upper portions contain local associated shell-lag deposits. Bioturbation has apparently obscured many primary sedimentary structures, making bedding difficult to observe, but horizons of calcareous concretions appear to have developed along original bedding or at the base of cross sets. To the north on Deer and Mill Creeks, shell beds and concretionary horizons are less abundant, and the sands are more massive and featureless. However, pebble beds and floating pebbles are also common here. Fossils, principally bivalves and gastropods, are generally well preserved throughout the Musty Buck Member, either in concretionary lag deposits or individually in the matrix. The abundance of mollusks assignable to the families Veneridae, Mactridae, Tellinidae, and Naticidae within the member on Big Chico Creek led Saul (1961) to infer a *maximum* water

Figure 4. Exposure of the Ponderosa Way Member along Butte Creek showing interfingering of coarse sandstone lenses within conglomerate. Two-pound sledge for scale.

depth of 35 m. On Butte Creek, the abundance of wood and plant debris and the lack of a normal marine fauna suggest nonmarine, perhaps brackish-water, deposition.

Ten Mile Member

The stratigraphically highest deposits of the Chico Formation exposed along Big Chico and Butte Creeks constitute the third lithologic member recognized within the Chico Formation. The Ten Mile Member is named for the site of the "Ten Mile House" located along the old route of Highway 32, paralleling Big Chico Creek. The lower boundary of the Ten Mile Member is proposed as the last occurrence of common pebbles, either singly or in stringers, within the sandstone exposed in the SW¼ of the NW¼ of sec. 13, T. 23 N., R. 2 E., along Big Chico Creek. The full thickness of the member is obscured on Big Chico as well as all other creeks in the region; the upper-boundary stratotype is thus defined as the uppermost occurrence of the distinctive lithology making up the Ten Mile Member on Big Chico Creek. The outcrop of this member along Big Chico Creek is composed of ~575 m of discontinuous exposures.

The member, typically forming tall bluffs, consists of fine-grained silty sandstone, greenish-gray to tan in color, moderately well sorted and compositionally similar to the subjacent Musty Buck Member. Pebbles are rarely noted and are quite small and rounded where found. Large-scale, low-angle planar cross-stratification is occasionally observed within the member and bioturbation is more common than in the Ponderosa Way and Musty Buck Members. Extensively burrowed mud horizons occur at intervals within the sands, commonly in association with climbing ripples and load structures. The Ten Mile Member is quite fossiliferous, with excellently preserved wood and mollusks found both singly in the matrix or as lag deposits in concretionary horizons (Fig. 5). Saul (1961) suggested a maximum water depth of 90 m for the member, on the basis of its molluscan assemblages.

Kingsley Cave Member

The three lithologic units described above are readily observed along Big Chico and Butte Creeks and, to date, have been the only rock types recognized within the Chico Formation. Our work on drainages to the north has shown the existence of yet a fourth distinctive lithology, which is herein called the Kingsley Cave Member.

Named for the site of the near-extermination of the Yana Indians who inhabited the Lassen foothills region in recent history (Kroeber, 1961), strata of the Kingsley Cave Member crop out along Deer, Mill, and Antelope Creeks. The proposed lower boundary of the stratotype is located at the extreme northward bend of Mill Creek in the NE¼ of the NW¼ of sec. 20, T. 27 N., R. 2 E. Farther upstream, but separated by a covered interval, there are found extensive exposures of the Musty Buck and Ten Mile Members. The proposed upper boundary of the type section is located along Mill Creek at the stratigraphically highest exposures of the unit in unsurveyed land of the Lassen National Forest. This locality is just west of the SW¼ of sec. 19, T. 27 N., R. 2 E. Along Mill Creek, ~350 m of strata in discontinuous outcrop was measured.

The member consists typically of spheroidally weathered greenish-gray to bluish-gray, heavily bioturbated muddy siltstone and silty mudstone. Containing common angular quartz and biotite to 0.5 mm, these fine-grained clastics are locally interbedded with sandy horizons and lack distinctive sedimentary structures. Pebble conglomerates as much as 1 m thick are rare but interspersed throughout the member. These are typically associated with shell-lag deposits containing an abundant molluscan fauna. Gastropods, cephalopods, and disarticulated bivalves found within these lags are generally broken; many are the same species observed in the other fossiliferous members of the Chico Formation. Additionally, abundant and well-preserved mollusks, primarily ammonites and inoceramids, are found weathering out of the matrix or in calcite-cemented concretions.

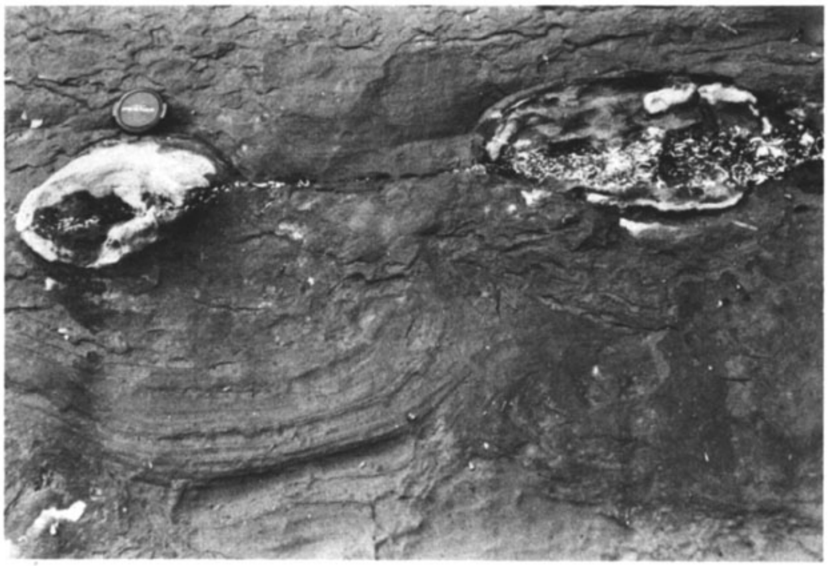


Figure 5. Concretion development around shell lags and water-escape structures in the Ten Mile Member, Big Chico Creek.

On Big Chico, Deer, and Mill Creeks, exposures of coarse-grained planar– and trough–cross-stratified sandstones are found stratigraphically above, but not continuous with, exposures of the Ten Mile and Kingsley Cave Members. These unfossiliferous, moderately well-sorted, organic-rich strata are interpreted as deltaic to shallow-marine deposits of probable mid-Campanian age, on the basis of their stratigraphic proximity to older Campanian sediments. It is possible, however, that these strata belong to the Kione Formation (upper Campanian to Maastrichtian), a nearshore-deltaic unit readily recognized in the subsurface of the eastern Sacramento Valley (Edmondson, 1962; Garcia, 1981).

East Side: Biostratigraphy

The first detailed stratigraphic study of Upper Cretaceous ammonites of California, based on modern taxonomy, was undertaken by Matsumoto and culminated in an extensive monograph and revision of the fauna (1959–1960). Matsumoto discussed the strong affinities of the California fauna with other regions of the North Pacific, notably western Canada, Alaska, and Japan. On the basis of his field work and assessment of museum specimens, he compiled a suggested ammonite and inoceramid distribution for California (1959–1960, Pt. 3, Pl. 1) and attempted correlation of Cretaceous outcrops within the region. Popenoe and others (1960) essentially followed Matsumoto's scheme in their correlation of Pacific Coast Cretaceous deposits but suggested additional, locally important molluscan species to complement the ammonite and inoceramid distributions.

Recollecting classic outcrops in the western Sacramento Valley, Ward and Haggart (1981) showed that portions of the lower Campanian ammonite-inoceramid sequence proposed by Matsumoto were in error. On the basis of detailed stratigraphic collections from the highly fossiliferous facies of the Chico Formation as well as other outcrops bordering the Sacramento Valley, the relative distribution of important ammonites and inoceramids in the Santonian and Campanian of California has been established (Haggart, in press). This distribution is summarized in Figure 6.

Recent sampling of the Chico Formation and its time equivalents elsewhere in the Sacramento Valley has shown the presence of a magnetic reversal corresponding to anomaly 33–34 observed at the base of the Campanian section at the type locality at Gubbio, Italy (Ward and others, 1983). This reversal appears to be wholly within the zone of *Baculites chicoensis* TRASK and is thus an important correlation tool when coupled with the fossil data. The presence of the reversal firmly identifies the Chicoensis zone as early Campanian in age.

West Side: Lithostratigraphy

Stratigraphic analysis of outcrops from the western margin of the Sacramento Valley, initially prompted by the search for natural gas, has resulted in a detailed understanding of these more distal fore-arc facies. Kirby (1943) described a formational succession for the west-side strata that is still in use. Kirby's Upper Cretaceous succession included the Sites, Funks, Guinda, and Forbes Formations, in ascending stratigraphic order. Kirby (1943, p. 282–283) noted the existence of a distinctive mudstone facies characterized by calcareous nodules at the base of the Forbes Formation. Emerson and Roberts (1962) called these strata the Dobbins Shale and Pessagno (1976) proposed member status for this unique Great Valley sequence unit.

More recent workers (Ingersoll and others, 1977) proposed new formational nomenclature, based on petrofacies analysis, for the Great Valley sequence. As justification for this nomenclature revision, these workers maintained that lithofacies variations, in the absence of fossils, make field mapping of Kirby's (1943) original units difficult at best. This may be true for older portions of the Great Valley sequence, but it does not hold for the Guinda and Forbes Formations, which we believe are distinctly recognizable in the field, even without fossil data. We therefore follow Kirby's (1943) nomenclature for the upper portions of the Great Valley sequence.

Ojakangas (1968) and other workers (Dickinson, 1971; Ingersoll, 1978) interpreted the western outcrop belt of the Great Valley sequence as deep-marine deposits. Basin-plain to slope environments, especially submarine-fan facies, were comprehensively analyzed by Ingersoll (1978). This work emphasized older portions of the sequence, Cenomanian through Coniacian, and did not utilize younger strata due to difficulty of access. Although detailed sedimentologic analyses of Santonian and Campanian strata of the Sacramento Valley have not been undertaken, deposition during the Late Cretaceous is considered to have occurred in a shallowing basin.

We have examined Santonian and Campanian strata along the western Sacramento Valley outcrop belt. Exposures of the Guinda and Forbes Formations, including the distinctive Dobbins Shale, can be traced from Black Butte on the north to Salt Creek and farther south (see Fig. 1). The strata maintain a remarkably similar and persistent facies pattern throughout most of their exposure; stratigraphic relations are summarized in Figure 7.

The Guinda Formation consists of alternating massive sands and thin-bedded siltstones and shales (Fig. 8). Some of the sand bodies reach 3 m in thickness and are laterally persistent over distances of hundreds of metres. Graded bedding with successive horizontal laminations, indicative of Bouma AB sequences, is locally capped with ripple laminations. Most of the sands are typified by an irregular basal surface, and some sand bodies exhibit convoluted bedding in their uppermost portions. Calcareous concretions, locally reaching 3 m in diameter, are quite common in the uppermost portions of the Guinda Formation.

Interbedded with the massive sands, there are thin beds of siltstone and mudstone, generally less than 5 cm in thickness. These, too, exhibit abundant horizontal laminations, rare ripple marks, and convoluted bedding. Such facies are most prominent in the vicinity of Putah Creek, are common at Black Butte, but notably absent in the Salt Creek region. We interpret this lower portion of the Guinda to reflect channel and proximal turbidite deposition in the mid-fan environment (Walker and Mutti, 1973).

Uppermost portions of the Guinda Formation are represented by a sequence of thin-bedded turbidite deposits. Characteristically, these flat-bottomed sand and silt interbeds rarely exceed 12 cm in thickness. Typically, Bouma A is missing, but B and, locally, C are well developed. Overlying these outer-fan facies (Walker and Mutti, 1973), we recognize hemipelagic mudstones in the Dobbins Shale Member. Throughout most of its exposure, this distinctive unit is characterized by poorly laminated to nonlaminated mudstones with abundant calcareous concretions, many fossiliferous (Fig. 9).

Massive sands that locally exhibit graded bedding, horizontal laminations, and, rarely, ripple horizons, characterize the overlying middle portion of the Forbes Formation (Fig. 10). These sands reach thicknesses of 1 m but are generally much thinner and are typified by irregular basal surfaces. Lower portions of the sands commonly contain shale clasts derived from the finer-grained interbeds. Large fragments of oysters are found in locally developed basal conglomerates. These laminated siltstones and shales are typically associated with abundant plant debris and, locally, vertical burrows. Grazing traces and some vertical burrows are also common in the massive sands. We interpret the middle portion of the Forbes Formation as mid- to outer-fan deposition in a much shallower marine setting.

West Side: Biostratigraphy

Many workers have noted the difficulty of correlating Cretaceous strata of the western out-

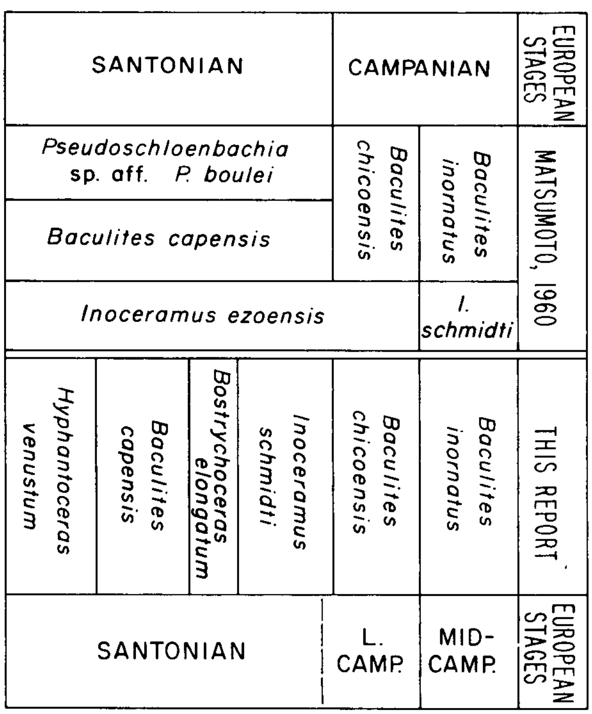


Figure 6. Comparison of ranges of important ammonite and inoceramid species in northern California, as suggested by Matsumoto (1959–1960) and Haggart (in press).

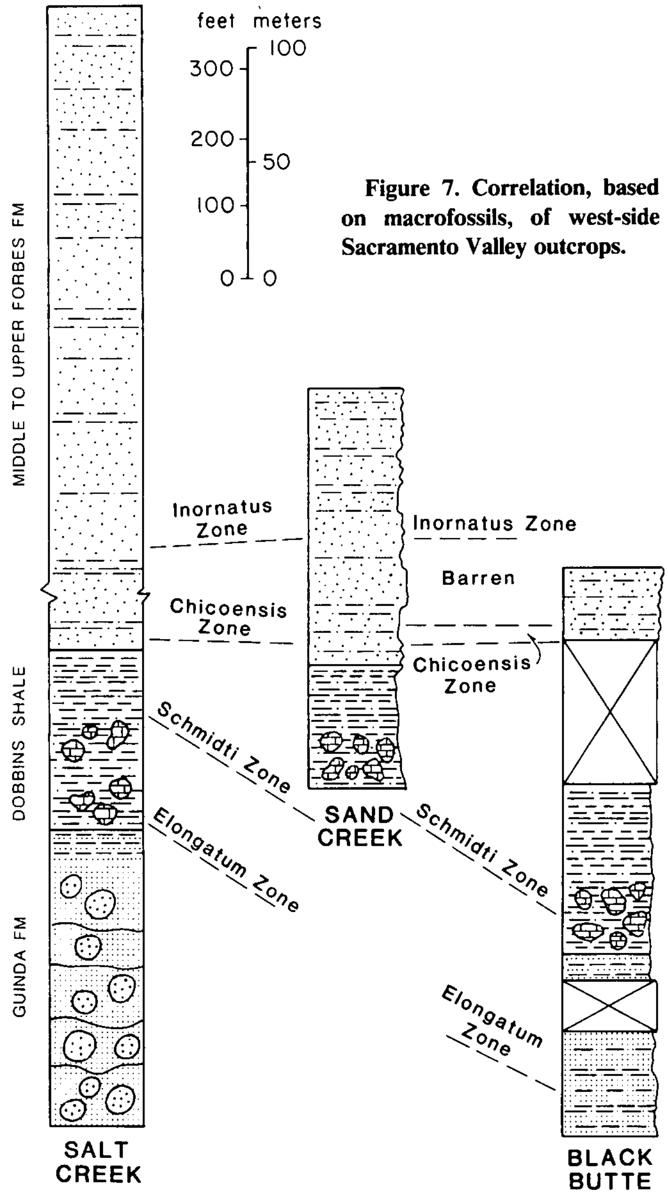


Figure 7. Correlation, based on macrofossils, of west-side Sacramento Valley outcrops.

Figure 8. Massive, mid-fan, proximal turbidites of the Guinda Formation, Black Butte. Staff in upper center of photograph is 1.6 m long.

Figure 9. Exposure of the Dobbins Shale Member of the Forbes Formation along Salt Creek showing distinctive calcareous concretions.

Figure 10. Interbedded sands and siltstones of the middle portion of the Forbes Formation, Salt Creek.

crop belt of the Great Valley sequence. Due to the paucity of megafossils and their relatively poor preservational state, most studies have relied on microfossils, principally foraminifera and radiolaria, for age dating of lithologic units. Goudkoff (1945) established a foraminiferal zonation for Great Valley strata that is in use, with some modification, today. Trujillo (1960) showed that some of Goudkoff's foraminiferal assemblages were facies- rather than time-dependent and Douglas (1969) further refined the original zonation. Still, only two planktic foraminiferal zones are recognized within the Santonian and early Campanian (Douglas, 1969, Fig. 4). It is clear that, when available, the resolution of megafossils, particularly ammonites and inoceramid bivalves, is highly desirable and a valuable correlation tool. Although some mixing of distinct faunal assemblages might be expected in the submarine-fan environment, the presence of repeated unique fossil successions strongly suggests that displacement of faunas is not an important problem here.

Ward and Haggart (1981) showed that megafossils can be successfully employed as biostratigraphic tools in at least the upper portions of the Great Valley sequence. Further collecting at additional localities in the western outcrop belt has confirmed the ammonite and inoceramid sequence observed in the arenaceous east-side Chico deposits. We have identified the Capensis, Elongatum, Schmidti, and Chicoensis zones in Santonian and Campanian strata of the Great Valley sequence and also recognize an additional zone, that of *Baculites inornatus* MEEK, superjacent to the youngest zone observed in the Chico outcrops (Haggart, in press). The recognition of these zones allows detailed correlation

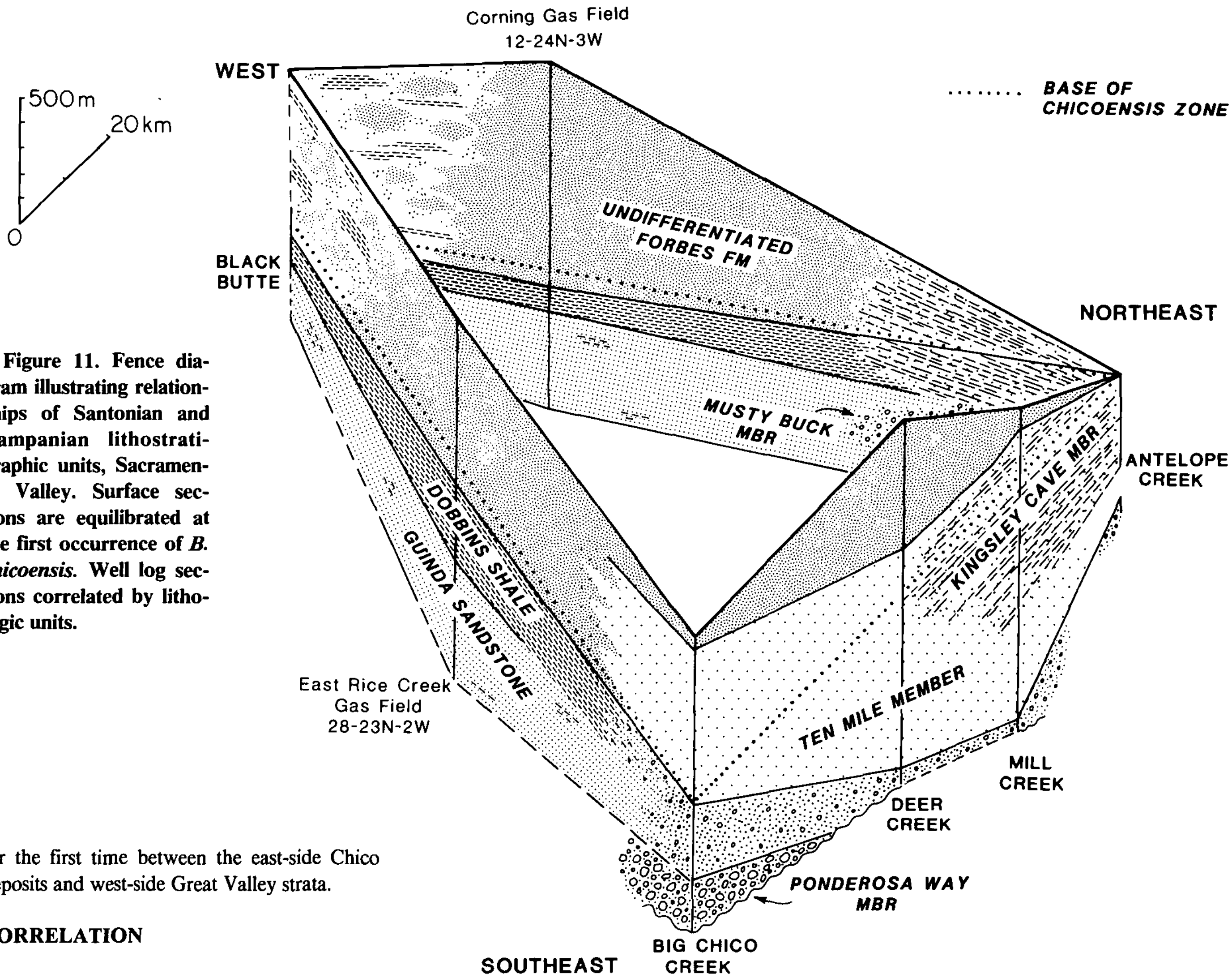


Figure 11. Fence diagram illustrating relationships of Santonian and Campanian lithostratigraphic units, Sacramento Valley. Surface sections are equilibrated at the first occurrence of *B. chicoensis*. Well log sections correlated by lithologic units.

for the first time between the east-side Chico deposits and west-side Great Valley strata.

CORRELATION

Megafossil correlations indicate that the upper portion of the Chico Formation is time-equivalent to the Guinda and Forbes Formations of Kirby (1943). Figure 11 illustrates the relationships between the various lithologic units discussed above.

Oldest strata of the Ponderosa Way Member on Big Chico Creek are unfossiliferous. However, highest exposures of the member have yielded specimens of the Coniacian form, *Baculites schencki* MATSUMOTO (Matsumoto, 1959–1960, Pt. 3). Matsumoto suggested that oldest strata of the Musty Buck Member along Big Chico Creek are Santonian, on the basis of a few juvenile ammonite specimens. However, we have recovered a fragment of *Barroisiceras* (*sensu* Matsumoto and others, 1981) sp. from lowermost exposures of the Musty Buck Member along Deer Creek. *Barroisiceras* is considered to represent Coniacian time in Japan (Matsumato and others, 1981). Additionally, LouElla Saul (1983, personal commun.) noted a species of *Cymbophora* from lowermost Musty Buck strata on Big Chico Creek that may be Coniacian in age. At this point, precise age assignments of the uppermost Ponderosa Way and lowermost Musty Buck members are difficult to make.

Uppermost strata of the Musty Buck Member contain *Baculites capensis* WOODS on Big Chico Creek. Unfortunately, unequivocal specimens of this ammonite are rare from the Great Valley sequence, but a few occurrences indicate that rocks of the basal Guinda or underlying Funks Shale are probably correlative with youngest strata of the Musty Buck Member.

An important implication of the ammonite succession shown in Figure 6 is the recognition of a previously unknown stratigraphic discontinuity at the type section of the Chico Formation as well as other nearby outcrops. Strata of the Elongatum and Schmidti zones, straddling the Santonian-Campanian boundary, are represented by a very short unfossiliferous interval in outcrops in the vicinity of Big Chico Creek. A widespread unconformity of similar age is recognized by microfossil workers in the subsurface of the Sacramento Valley (Chuber, 1962; Edmondson, 1962) and is possibly correlative with the missing interval on Big Chico Creek.

To the north, however, along Mill and Antelope Creeks, the Kingsley Cave Member represents deposition in the late Santonian, as indicated by the presence of the ammonite *Bostrychoceras elongatum* (WHITEAVES) and the overlying zonal index species *Inoceramus schmidti* (MICHAEL). Uppermost exposures of the Guinda Formation contain specimens of *B. elongatum*, and the species is well represented in the lower half of the overlying Dobbins Shale Member of the Forbes Formation. Uppermost portions of the Dobbins Shale contain abundant specimens of *I. schmidti.* We thus can correlate the uppermost Guinda beds and the overlying Dobbins Shale with the depositional hiatus observed in southerly exposures of the Chico Formation and also with the more northerly exposures of Chico, represented by the Kingsley Cave Member.

The zonal ammonite *Baculites chicoensis* allows correlation of the thick upper sequence of the Chico Formation, the Ten Mile Member, with transitional beds between the Dobbins Shale and the overlying sands of the middle portion of the Forbes Formation. Ward and Haggart (1981) demonstrated the presence of *B. chicoensis* in the stratigraphic succession at Sand Creek in Colusa County, and we have since documented this index fossil in the same transitional beds along Salt Creek to the south and at Black Butte to the north.

DISCUSSION

Integration of megafossil correlation with stratigraphic analysis of exposures of the Great Valley sequence and the Chico Formation allows the formation of hypotheses about Santonian and Campanian sedimentation across the Late Cretaceous fore-arc basin of northern California. Facies reconstruction suggests a cross-shelf transect from shallow, fluvial-deltaic deposition on the east to basinal and slope environments on the west.

The lithologic succession of the Chico Formation is highly suggestive of a transgressive sequence, from basal fluvial-deltaic deposition to offshore, but still shallow, marine sedimentation in the higher portions of the section. Howard and Reineck (1981) discussed recent high-energy shelf sedimentation off Southern California, and Bourgeois (1980) documented an Upper Cretaceous transgressive sequence in shallow-marine rocks of coastal Oregon. Lithologic successions discussed by these authors reflect the facies pattern observed in the Chico Formation. This transgressive sequence is compatible with the eastward migration of both magmatism and strandline as subduction progressed through Late Cretaceous time (Ingersoll, 1979). Transgression could be related to local basin subsidence or eustatic sea-level rise or, most likely, a combination of the two.

Within the Chico Formation, thickness variations (see Fig. 3) and common load structures, scour surfaces, and climbing ripples in the coarser facies suggest unstable, perhaps episodic sedimentation; some areas received abundant detrital influx, whereas adjoining regions were exposed to nondeposition or perhaps removal of briefly deposited sands. The few paleocurrent indicators obtained indicate westward transport, and the great thickness of accumulated clastics suggests a high rate of terrigenous input from the adjoining source regions.

Rapid sedimentation in the western fore-arc basin accompanied by slower deposition in the east was documented for the early Late Cretaceous by Ingersoll (1979). However, a comparison of relative zonal thicknesses from the eastern and western outcrop belts (Figs. 3 and 7) indicates a reversal of this pattern by the Santonian. For example, the combined thickness of Elongatum and Schmidti zones spans ~140–200 m of section at Black Butte and 80 m at Salt Creek. However, on Mill Creek, the same zones contain a minimum of 375, but less than 560 m of strata. In the western outcrop belt, the Chicoensis zone spans a maximum of 40 m at Salt Creek, 45 m at Sand Creek, and an indeterminate amount of strata at Black Butte; in contrast, on Big Chico and Butte Creeks, more than 400 m of strata occur within the zone. It is not possible at this time to confidently correlate the thick sequences of Inornatus zone strata in the western outcrop belt with the unfossiliferous upper portions of the sections exposed along the east-side creeks. The much thicker sedimentary sequences on the eastern margin of the Sacramento Valley support Ingersoll's (1979) conclusion of a decrease in sedimentation rate in the distal reaches of the Cretaceous fore-arc basin due to basin widening. Arc-derived detritus was quickly deposited in localized regions adjacent to the arc front.

In earliest Santonian time, represented by the zone of *Baculites capensis*, deposition of the Musty Buck Member was occurring in shallow-marine shoreface environments. To the west, fossil control is still poor, but deposition in deeper-marine submarine-fan complexes was occurring to produce the mid-fan to outer-fan deposits of the Guinda Formation.

The late Santonian deepening of the western fore-arc basin is well documented by the trend to distal-fan and basin-plain facies observed throughout exposures of the Dobbins Shale Member and lower portions of the middle of the Forbes. These units are characterized by the occurrence of the zonal indicators *Bostrychoceras elongatum* and *Inoceramus schmidti.*

As transgression continued eastward, sedimentation in the eastern fore-arc basin was, at least locally, reduced. The depositional hiatus observed at the type locality of the Chico Formation spans the duration of both of these upper Santonian zonal indices. However, shallow-marine deposition was occurring to the north, where silts and muds of the Kingsley Cave Member were accumulating. Apparently, Kingsley Cave deposition occurred in a localized intrashelf basin, as outcrops of this unique facies are restricted to a small geographic area. West of the outcrops of the Kingsley Cave facies on upper Antelope Creek, coarse-grained planar-cross-stratified sands and pebble conglomerates of the Musty Buck Member are noted along lower Antelope Creek. These strata contain a number of specimens of *B. elongatum* in addition to numerous other molluscan species. We postulate a topographic high to the west of the upper Antelope Creek region in the late Santonian that acted to restrict circulation in the local basin to the east, allowing fine-grained nearshore deposits to accumulate. Alternatively, these heavily faulted outcrops may be indicative of movement of fault blocks, juxtaposing highly contrasting facies and analogous to the younger California continental borderlands terrain (Nilsen and Clarke, 1975). The relatively deeper-marine nature of the Kingsley Cave Member may reflect marine deposition farther to the east and north, the postulated Lassen strait of Diller (1889). The true areal extent of Cretaceous strata in this region is not now known because of the extensive volcanic cover.

At the close of the Santonian, the trend of deepening of depositional sites in the western fore-arc basin reversed. Progradation of fan complexes occurring as mid-fan to outer-fan facies, containing the lower Campanian zonal index *Baculites chicoensis*, are found superjacent to basin-plain facies of the Dobbins Shale. Along the eastern basin margin, the deepest and thickest deposits of the Chico Formation (Ten Mile Member) were accumulating, at least in the more southerly outcrop regions. Thick deposits of Chicoensis zone strata on Big Chico Creek (595 m) suggest a return to relatively higher sedimentation rates characteristic of the early Santonian. Farther north, uppermost exposures of the Kingsley Cave Member along Mill and

Antelope Creeks contain specimens of *B. chicoensis*, suggesting that localized, quiet-basin deposition continued into the early Campanian.

Unfortunately, strata containing the mid-Campanian zonal index *Baculites inornatus* are missing from the eastern outcrop belt north of the latitude of Sacramento. However, as noted above, an apparently shallow-marine–deltaic complex is represented in unfossiliferous strata at the top of the sections along Big Chico, Deer, and Mill Creeks. This trend to shallower deposition must have preceded the development of the late Campanian to Maastrichtian Kione deltaic complex (Kione Formation), as discussed by Garcia (1981). Western basin deposits, massive mid-fan sands, and proximal turbidites of the middle Forbes indicate a continuation of fan progradation and basin shallowing into the middle Campanian.

SUMMARY

The base of the Upper Cretaceous Chico Formation onlaps steeply dipping pre-Cretaceous metamorphic rocks. Chico Formation strata reflect a transgressive sequence from coarse, fluvial conglomerates at the base to fine-grained sandstones and mudstone indicative of deeper-water deposition at the top. As indicated by macrofossils, deposition of Chico Formation sediments was sporadic, with depocenters shifting through time. The shallow-marine mudstones of the northerly Kingsley Cave Member are indicative of quiet-water deposition below wave base in a localized intrashelf basin. Alternatively, these strata may be indicative of a Late Cretaceous marine connection, around the northern Sierra Nevada, with regions to the east and north.

Strata of the Chico Formation are correlative with deeper-marine shelf and slope deposits of the western Sacramento Valley outcrop belt. Outcrops of the Guinda Formation, the Dobbins Shale Member, and the middle Forbes Formation reflect mid-fan to basin-plain environments. The succession of lithologies of both the western and eastern outcrop belts indicates a major transgressive event in the Santonian, followed by rapid shallowing of the depositional basin on the west during the early Campanian. The transgressive event appears to be of basin-wide distribution.

ACKNOWLEDGMENTS

We would like to thank Rodney Watkins and Sarah Baum for fruitful discussion. LouElla Saul, David Jones, and Ray Ingersoll provided helpful reviews of the manuscript. This work was supported in part by Geological Society of America Research Grants 263580 and 299682 to J. Haggart and National Science Foundation Grant EAR 80-19696 to P. Ward, as well as by the Atlantic Richfield Company and the Department of Geology, University of California at Davis.

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Manuscript Received by the Society March 18, 1983
Revised Manuscript Received July 11, 1983
Manuscript Accepted July 13, 1983