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Review of the Great Valley sequence, eastern Diablo Range and northern San Joaquin Valley, central California

by

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ABSTRACT

The Great Valley sequence of the eastern Diablo Range and northern San Joaquin Valley consists of a thick accumulation of marine and nonmarine clastic rocks of Jurassic to early Paleocene age deposited in a forearc basin that was situated between the Sierran magmatic arc to the east and the Franciscan subduction complex to the west. In the western part of the basin, the sequence rests conformably on the Jurassic Coast Range Ophiolite or is faulted against the structurally underlying Franciscan Complex. Beneath the eastern San Joaquin Valley, the sequence unconformably onlaps igneous and metamorphic rocks of the Sierran magmatic arc. The sequence generally thickens westward to as much as 8-9 km in the Diablo Range, where it is unconformably overlain by late Paleocene and younger strata.

The stratigraphy of the Great Valley sequence has been the subject of much work, but problems, particularly nomenclatural, remain. Lithostratigraphic subdivisions of the sequence have not gained widespread acceptance because of the lenticularity of most sandstone bodies, abrupt facies changes in subsurface and outcrops, and the lack of detailed subsurface information from closely spaced or deep wells. Although microfossils provide the best means of regional correlation, their locally sparse distribution, together with post-depostional dissolution in outcrop sections, limits their usefulness. Sequence stratigraphy, in conjunction with well-log correlations, has great potential for stratigraphic analysis.

Five outcrop sections in the Diablo Range between Del Puerto Creek on the north and the Avenal Ridge-Reef Ridge area on the south, and a representive subsurface columnar section from the northern San Joaquin Valley, illustrate the diversity of stratigraphic nomenclature, depositional facies, and thickness variations of the Great Valley sequence. Although rocks as old as Tithonian (Late Jurassic) and as young as Danian (early Paleocene) are present locally, the greatest outcrop thickness of Great Valley sequence strata is of Cenomanian to Maestrichtian (Late Cretaceous) age. Although there is, in a general sense, some correlation between plate-tectonic events and changes in forearc basin sedimentation, specific causes for unconformities in the sequence remain unclear.

Outcrops of the Great Valley sequence in the Diablo Range consist mostly of submarine-fan, basin-plain, and slope deposits; the upper part of the sequence contains significant shelf and deltaic deposits. More extensive slope, shelf, and deltaic deposits underlie the San Joaquin Valley to the east. Paleocurrent data from outcrops, facies distribution patterns, and provenance information suggest predominantly westward or southwestward transport of sediments from the Sierran magmatic arc source area. The petrofacies generally reflect the petrologic evolution of the arc terranes and unroofing of Sierran batholiths in the late Mesozoic.

INTRODUCTION

The Great Valley sequence consists of a thick accumulation of mostly marine clastic rocks that was deposited in the southern part of a forearc basin situated between the Sierran magmatic arc to the east and the Franciscan subduction complex to the west (Dickinson, 1976; Dickinson and Seely, 1979). This late Mesozoic and early Tertiary basin was approximately coincident with the present Great Valley of California and adjacent parts of the Coast Ranges; however, the basin has been overprinted by a variety of Cenozoic structural styles including features related to right-lateral slip on the San Andreas fault, which cuts obliquely across the southwestern part of the forearc basin (Fig. 1). The present Great Valley is an north-northwest-trending asymmetric structural trough with a steeply dipping southwest limb and a gently dipping northeast limb (Fig. 2). The former forearc basin can be divided into the Sacramento basin in the north and the San Joaquin basin in the south by the buried west-trending Stockton arch, a former structural high that is located between Stockton and Modesto (Fig. 1). The northern flank of the Stockton arch is defined by the south-dipping Stockton reverse fault that forms the boundary between the

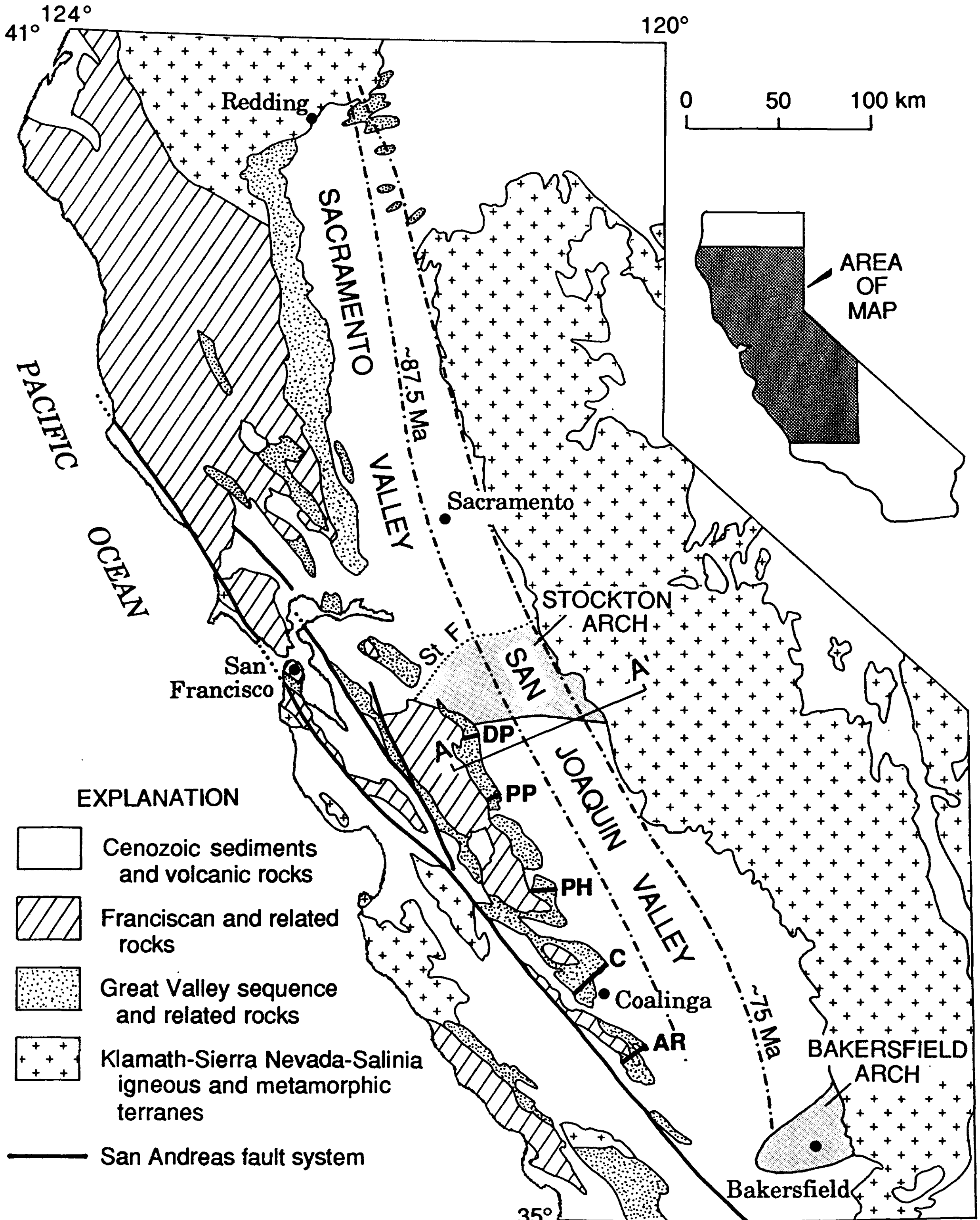

Figure 1. Index map of northern and central California showing principal components of the late Mesozoic arc-trench system and geographic locations. Approximate eastern limit of Great Valley sequence deposition, from Ingersoll (1982, Fig. 4), shown for about 75 Ma and 87.5 Ma. Abbreviations for locations of stratigraphic columns (Figs. 3, 4, 5, 6): DP, Del Puerto Creek; PP, Pacheco Pass quadrangle; PH, Panoche Hills; C, Coalinga area; AR, Avenal Ridge-Reef Ridge area. Other abbreviations: StF, Stockton fault. Cross-hatching indicates area of Stockton and Bakersfield arches.

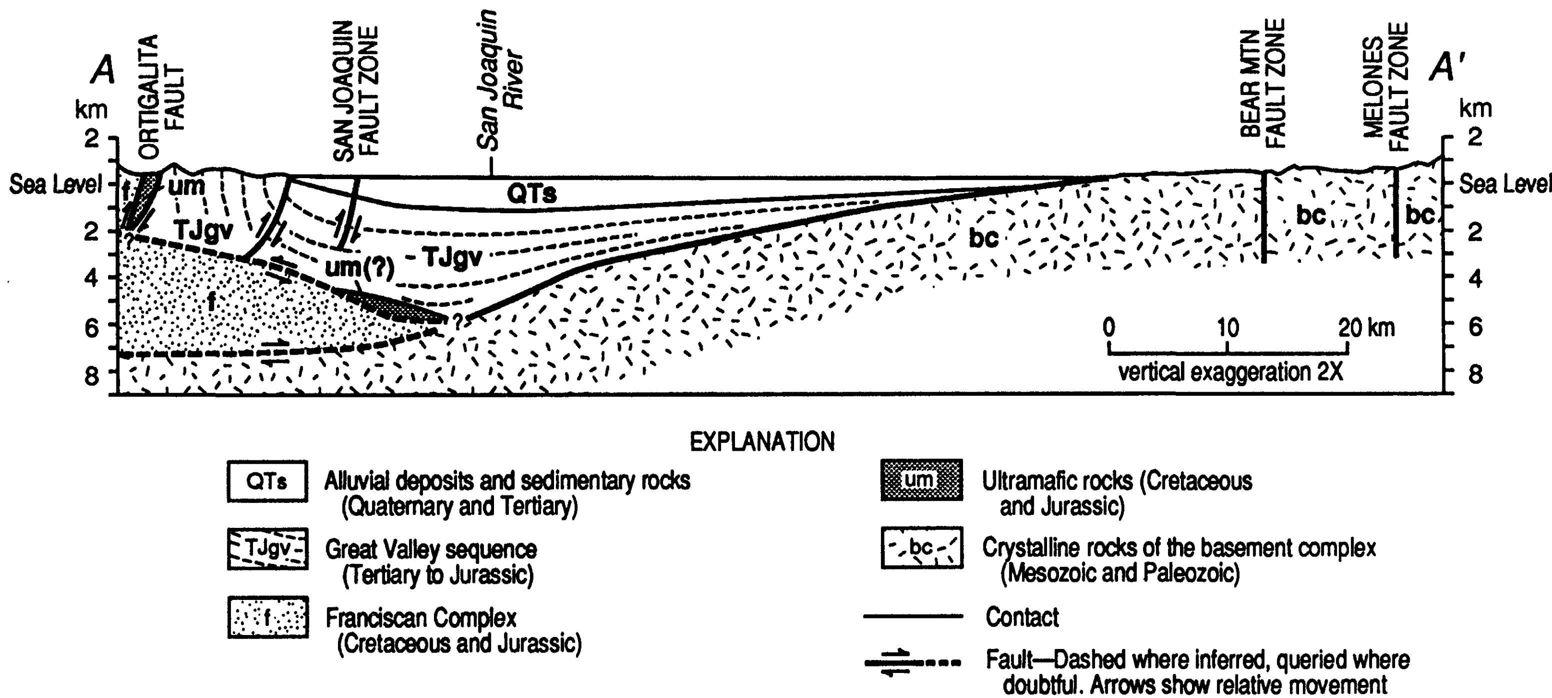

Figure 2. Generalized structure section of the northern San Joaquin Valley, modified from Bartow (in press, Plate 1). Subsurface wedge of Franciscan rocks based on interpretation of Wentworth and others (1984, Fig. 4). Location of section shown on Figure 1.

Sacramento and San Joaquin basins (Fig. 1). The Great Valley sequence crops out as far south as the northern Temblor Range and has been reported to be present beneath the Elk Hills oil field in the southwestern San Joaquin Valley (Fishburn and McJannet, 1989); the sequence also crops out along the west side of the Diablo Range (Fig. 1). The discussion herein, however, is limited to the northern San Joaquin Valley and eastern Diablo Range south of the western projection of the Stockton fault.

The sedimentary rocks of the Great Valley sequence rest concordantly on the Middle to Upper Jurassic Coast Range Ophiolite (Bailey and others, 1970; Hopson and others, 1981) in Diablo Range outcrops and beneath the western part of the valley in the subsurface. Small fragments or slivers of the ophiolite crop out in the Diablo Range along high-angle faults, such as the Tesla-Ortigalita fault, that presently separate the sequence from the Franciscan Complex to the west (Fig. 2). Upper Cretaceous strata of the Great Valley sequence unconformably onlap Sierran igneous and metamorphic rocks beneath the eastern San Joaquin Valley.

In a longitudinal southeast-trending section down the middle of the San Joaquin Valley, the Great Valley sequence thins southward from about 3 km or more thick at the Stockton fault and pinches out against the north side of the west-trending Bakersfield arch (Bartow, in press). The sequence thickens markedly westward, however, to an aggregate thickness in outcrop northwest of Coalinga of more than 9 km. As this thickness is a total of individual unit maximums, the actual stratigraphic thickness at any one point is almost certainly somewhat less. The thickness beneath the west side of the valley near the trough axis is not exactly known because the top of the sequence commonly lies at depths of 6 km or more and the base has neither been reached by drilling, nor have seismic data been published (Fig. 2).

Despite the abundance of sandstone and the great lateral extent of the Great Valley sequence, little oil and gas have been discovered in the unit in the northern San Joaquin Valley in comparison to the Sacramento Valley. Oil-prone Eocene and Miocene shale from the deeper Tertiary basin to the south and southwest appear to be the principal source rocks for the small quantities of oil discovered in the southern part of the area. McGuire (1988b), however, reports that shale of the Moreno Formation near Coalinga is a favorable oil source rock. Cretaceous shale of the upper Great Valley sequence is generally gas prone, and the gas fields of the Sacramento and northernmost San Joaquin Valleys appear to have derived gas from the thick accumulation of Cretaceous and Paleocene strata that underlie the Sacramento-San Joaquin delta (Zieglar and Spotts, 1978; Callaway and Rennie, in press). Jenden and Kaplan (1989) present chemical and stable isotope data that suggest the presence of multiple sources for Sacramento Valley gas, including indigenous gas, dry thermogenic gas, and nitrogen-rich gas possibly originating in metasedimentary rocks of the Franciscan Complex. These observations may also apply to the San Joaquin Valley.

FOREARC BASIN EVOLUTION

The Great Valley forearc basin formed subsequent to the Nevadan orogeny in the Late Jurassic. Schweickert and Cowan (1975) proposed that after an east-facing island arc and trench system collided with the ancestral Sierran arc in the Late Jurassic, causing the Nevadan orogeny, a new west-facing subduction zone developed to the west of the suture zone, thereby trapping part of an older backarc basin, represented by the Coast Range Ophiolite, in the new arc-trench gap. This model has been further developed by Ingersoll (1978c), Ingersoll and Dickinson (1981), and Ingersoll and Schweickert (1986).

Sedimentation in the forearc basin began in latest Jurassic time and continued with only local interruption through the Cretaceous and into the early Paleocene. A basin-wide unconformity separates the Great Valley sequence from late Paleocene or younger strata. Paleogene marine and fluvio-deltaic sedimentation continued in the forearc basin until the emergence of the Stockton arch in the late Paleogene separated the Sacramento basin from the San Joaquin basin (Bartow, in press). Sedimentation in the Sacramento and northern San Joaquin basins since the Oligocene has been almost entirely nonmarine. The thick and complex Neogene marine basin in the southern San Joaquin Valley, sometimes referred to as the "San Joaquin basin," is not, strictly speaking, part of the Great Valley forearc basin, but is a younger successor basin that developed in response to transform tectonics accompanying the northward migration of the Mendocino triple junction during the Neogene (Bartow, in press).

The Great Valley forearc basin widened during the Cretaceous as a result of two processes. The trench-slope break migrated westward as a result of accretion at the east-dipping trench, while the Sierran magmatic front migrated eastward, followed by eastward transgression onto the western part of the arc (Ingersoll, 1978c, 1979) (Fig. 1). Eastward migration of the locus of arc magmatism during the Late Cretaceous to Eocene Laramide orogeny was a result of shallowing of the angle of subduction (Coney and Reynolds, 1977; Cross and Pilger, 1978; Dickinson and Synder, 1978). Subsurface seismic and well data show that Late Cretaceous strata resting on Sierran basement rocks young eastward (Schilling, 1962a), thereby documenting an eastward onlap of the Cretaceous onto the eroded Sierran arc rocks beneath the cover of Cenozoic strata in the eastern San Joaquin Valley. This eastward transgression over the magmatic arc was probably due to a combination of thermal subsidence as the arc rocks cooled (Moxon and Graham (1987) and sediment loading.

Moxon (1988) discussed the evolution of the forearc basin in relation to plate-tectonic events. A rapid subsidence that began in the late Albian or Cenomanian appears to correlate with a marked increase in the rate and obliquity of convergence between the North American and Farallon plates (Page and Engebretson, 1984). Major uplift along the west side of the basin that began in the Campanian correlates with the onset of the Laramide orogeny (Page and Engebretson, 1984). Shoaling and basin filling continued through the late Campanian and Maestrichtian as the basin axis was shifted eastward by the uplift of the subduction complex to the west.

The petrologic evolution of the Sierran magmatic arc and its forearc basin can be traced through study of petrologic variations in sandstone of the Great Valley sequence. Eight petrofacies based on sandstone detrital modes reflect changes in provenance (Dickinson and Rich, 1972; Ingersoll, 1978a, 1983; Mansfield, 1979). Within the southern (San Joaquin) part of the forearc basin, vertical changes in petrofacies from volcanic-rich sediment to the more arkosic sands derived from plutonic rocks reflect dissection of the Sierran magmatic arc as the locus of arc magmatism migrated eastward (Ingersoll, 1978a). Areal variations indicate a more continental provenance for the southern forearc basin relative to a more oceanic arc-magmatic provenance for the northern forearc basin (Ingersoll, 1978a).

STRATIGRAPHY

The name "Great Valley sequence" was introduced by Bailey and others (1964) for the rocks cropping out along the west side of the Great Valley of California that are coeval with the Franciscan rocks of the Coast Ranges. The name "Great Valley Group" was proposed by Ingersoll (1982) to replace the informal "Great Valley sequence," but because of remaining uncertainties about the definition of the group, including problems raised by the presence of units like the Panoche Group of Payne (1960, 1962) in the so-called Great Valley Group, the name "Great Valley sequence" is retained herein. Strata of the Great Valley sequence range in age from Late Jurassic (Bailey and others, 1964) to early Paleocene (Goudkoff, 1945; Payne, 1951) (Fig. 3). There is a difference between the northern and southern Great Valley forearc basin in the age range of the outcropping strata. The top of the sequence may originally have been the same age throughout the basin, although strata younger than Campanian have generally been stripped by later erosion in the northern (Sacramento) part of the forearc basin. Late Jurassic and Early Cretaceous age strata, however, are much thicker and more extensive in the northern part than in

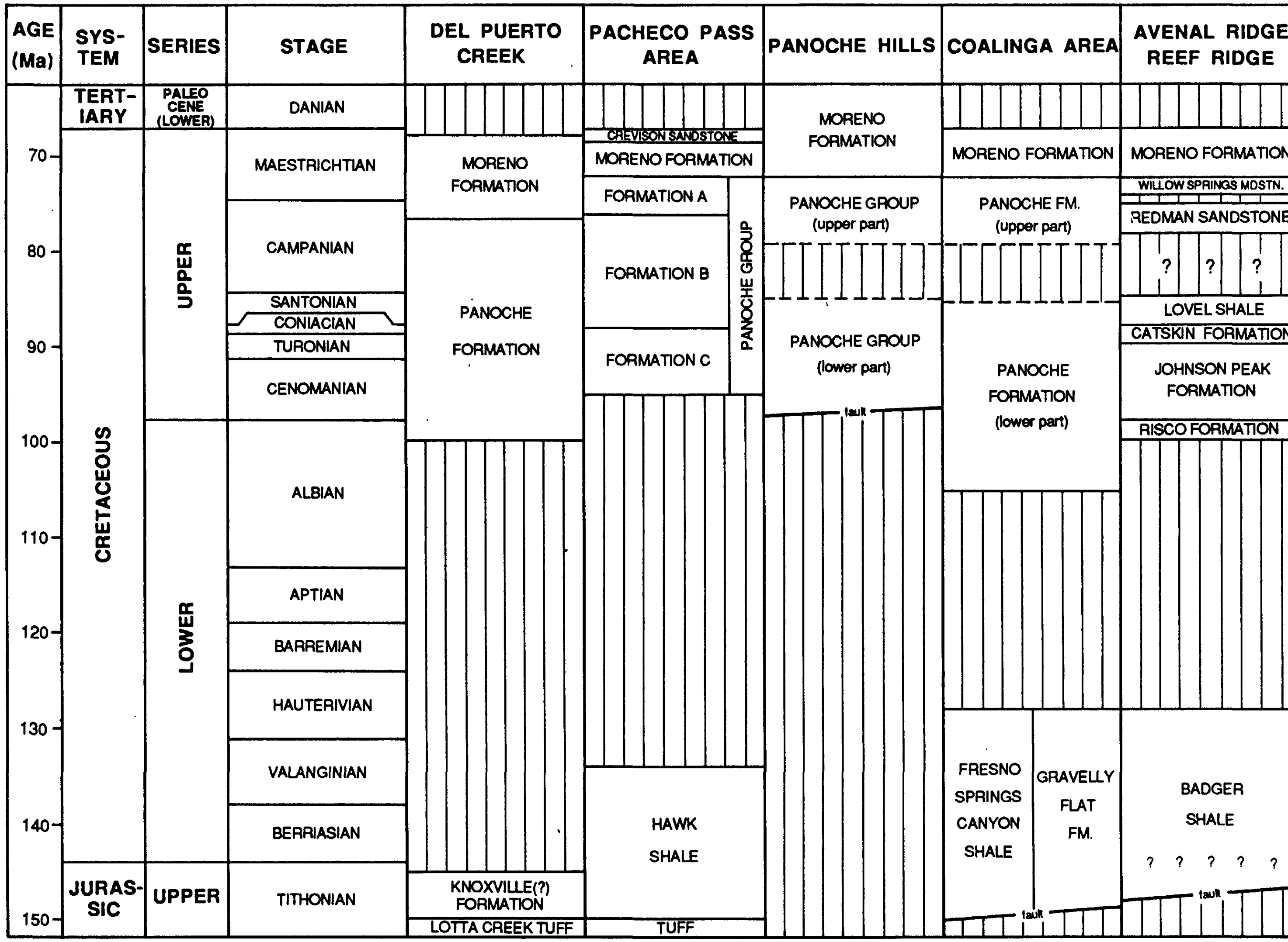

Figure 3. Generalized correlation chart for Upper Jurassic to lower Paleocene strata of the Diablo Range showing the age range of units included in the Great Valley sequence. Del Puerto Creek section from Bishop (1970) with additions from Maddock (1964); Pacheco Pass quadrangle from Schilling (1962b); Panoche Hills from Payne (1951, 1960, 1962) and Almgren (1986); Coalinga area from Anderson (1972) and Almgren (1986); Avenal Ridge-Reef Ridge area from Tamesis (1966), and Marsh (1960) with additions from Dibblee (1973). Time scale from Kent and Gradstein (1985) and Berggren and others (1985). Locations of the columns shown on Figure 1; see Figure 5 for subdivisions of upper part of sequence.

the southern part of the forearc basin, due in part to uplift and erosion in the central Diablo Range, and perhaps in part because of oblique truncation of the southwestern part of the basin by the San Andreas fault.

Problems

One of the principal problems in working with the Great Valley sequence is the plethora of lithostratigraphic names--some valid and useful, others not. Names such as Knoxville Series, Shasta Series or Group, and Chico Series or Group, which have been widely applied in the past, are based mainly on faunal criteria and are not acceptable as lithostratigraphic names. Most formational names that have been applied to outcropping parts of the sequence are useful only for local sections because of the lack of continuity of mappable units. Briggs (1953a, p. 421) made the point quite clearly:

> Eight formational units of Bennison [unpub] within the late Cretaceous section in the region immediately north of Pacheco Pass could not be recognized beyond Origalita Creek, approximately 10 miles south of the pass. M.B. Payne's (1951) eight divisions of the Moreno Shale are not distinctive units north and south of the Panoche Hills, the type area. J.Q. Anderson [unpub, 1972] distinguished eleven members in the southern part of the Diablo Range; but these have never been successfully traced north of that area, and of more than fifty cartographic units mapped by the writer between Little Panoche and Los Banos Creeks (Briggs, 1953[b], pl. 1) none is certainly continuous across the 17 miles between these creeks.

Similar observations were made by Bailey and others (1964, p. 136):

> Detailed mapping, particularly by Schilling (1962[b]) in the Pacheco Pass quadrangle, has emphasized the striking lateral facies changes exhibited by these rocks. Thick, massive, sandstone bodies grade laterally into siltstone and shale, and thick lenses of conglomerate pass over a short distance into sandstone. Few lithologic units can be traced continuously from one end of a 15-minute quadrangle to another.

This situation is understandable in light of the complex facies architecture of the sequence, which consists, basically, of a thick succession of mudrock enclosing lenses of sandstone or conglomerate (Ingersoll and Dickinson, 1981). These lenses may be submarine-fan complexes in the outcrop, where exposure trends are transverse to fan trends, or deltaic complexes in the subsurface, where lack of closely spaced deep wells hinders correlation. In either case, many sandstone bodies tend to lens out in all directions. Furthermore, the major outcrop units, such as the Moreno and Panoche Formations, as well as many of their local subdivisions, have not been systematically recognized in the subsurface. Because the Panoche includes most of the Upper Cretaceous, it is of little use in subsurface correlations; the different sets of names used in the subsurface are mostly a result of the different depositional systems represented in the outcrop and subsurface.

Biostratigraphy offers the best means of regional correlation, but it also has its limitations. This is largely because of the sparseness of fossils at some localities or in restricted stratagraphic intervals of the sequence. Outcrop sections have been correlated to stage level or better using megafossils, mostly ammonites (Matsumoto, 1959a,b, 1960; Kusnick, 1981; Ward and Haggart, 1981; Haggart, 1984,1985; Haggart and Ward, 1984). Calcareous microfossils have also proven very useful in outcrop sections where fresh materal can be obtained by augering or trenching. Normally, however, post-depositional dissolution and locally sparse distribution (due to unfavorable facies) limits their usefulness. The benthic foraminiferal zonations of Goudkoff

(1945), modified by Almgren (1986), and Berry (1974) provide the best means of correlation, especially in the subsurface. The benthic faunas are facies controlled which makes correlation between widely disparate depositional facies more difficult; however, benthic foraminiferal faunas representing similar environments of deposition within the Great Valley sequence can be correlated regionally with a fair degree of certainty. Planktonic foraminifers (Douglas, 1969), calcareous nannoplankton, dinoflagellates, and radiolaria also have potential for dating and correlation of unweathered material. Filewicz (1986) has demonstrated the usefulness of calcareous nannofossils from western Sacramento Valley outcrops, but published data on these fossils is very limited. Siliceous microfossils, especially radiolaria, have also been used for dating and correlation upper Mesozoic strata. Most of the radiolarian work has been with Franciscan cherts, although there is potential for application to the Great Valley sequence (Pessagno, 1977a,b; Murchey and others, 1983). Although work to date has been limited, magnetostratigraphy also has potential application to the Great Valley sequence (Ward and others, 1983).

Sequence stratigraphy, based on seismically definable units, but utilizing good biostratigraphic control, has great potential for sorting out the present stratigraphic morass. Depositional systems can be organized into a framework of systems tracts and sequences (definitions of Van Wagoner and others, 1988); the resulting stratigraphic sequences could form the basic units of Great Valley forearc basin stratigraphy. Past work utilizing electric logs to define depositional systems (Drummond and others, 1976; Garcia, 1981; Cherven, 1983) form a starting point for outlining systems tracts, and Moxon (1988) has defined seven sequences which are at least locally bounded by unconformities. Although sequence stratigraphy based on seismically defined units has initial application only to the subsurface, it could probably be extended to the outcrop, given sufficient biostratigraphic control.

Diablo Range

Five outcrop sections from the Diablo Range are correlated on Figure 3. These sections, extending from Del Puerto Creek on the north to Avenal Ridge on the south (see Fig. 1 for locations), illustrate the diversity of stratigraphic names applied to the Mesozoic rocks of the southern (San Joaquin) part of the Great Valley forearc basin. Payne (1962) asserted that most of the units that he defined in the Panoche Hills could be traced for more than 120 km northwestward, but as noted above, there really is little continuity from one section to another for any units other than the Panoche and Moreno Formations. These two formations were originally defined by Anderson and Pack (1915) and were mapped from the Coalinga area northward to the Tracy area. The Panoche consists mostly of a series of alternating sandstone and siltstone layers but includes a complete range of lithologies from claystone to boulder conglomerate; the conformably overlying Moreno consists predominantly of brown shale.

Despite the diversity in nomenclature, a few general observations can be made. Most of the Great Valley sequence is in fault contact with rocks of the Franciscan Complex; two sections, at Del Puerto Creek and the Pacheco Pass area, are conformable on volcanic rocks of the Coast Range Ophiolite. The Upper Jurassic tuff at the base of these sections is generally considered part of the Great Valley sequence, although it is genetically related to the ophiolite (Hopson and others, 1981).

The oldest part of the Great Valley sequence consists mostly of monotonous dark shale of latest Jurassic to Early Cretaceous age. These shale units are very thin (Fig. 4) considering the relatively long time span represented. The Tithonian-Valanginian Hawk Shale of the Pacheco Pass quadrangle, for example, is only about 90 m thick (Schilling, 1962b); the Gravelly Flat Formation of the Coalinga area, which is possibly as young as Hauterivian, is as much as 700 m thick (Rose and Colburn, 1963). There is a major hiatus between this older part of the sequence and the younger (mostly Late Cretaceous) part. The cause of this major unconformity is uncertain, but it

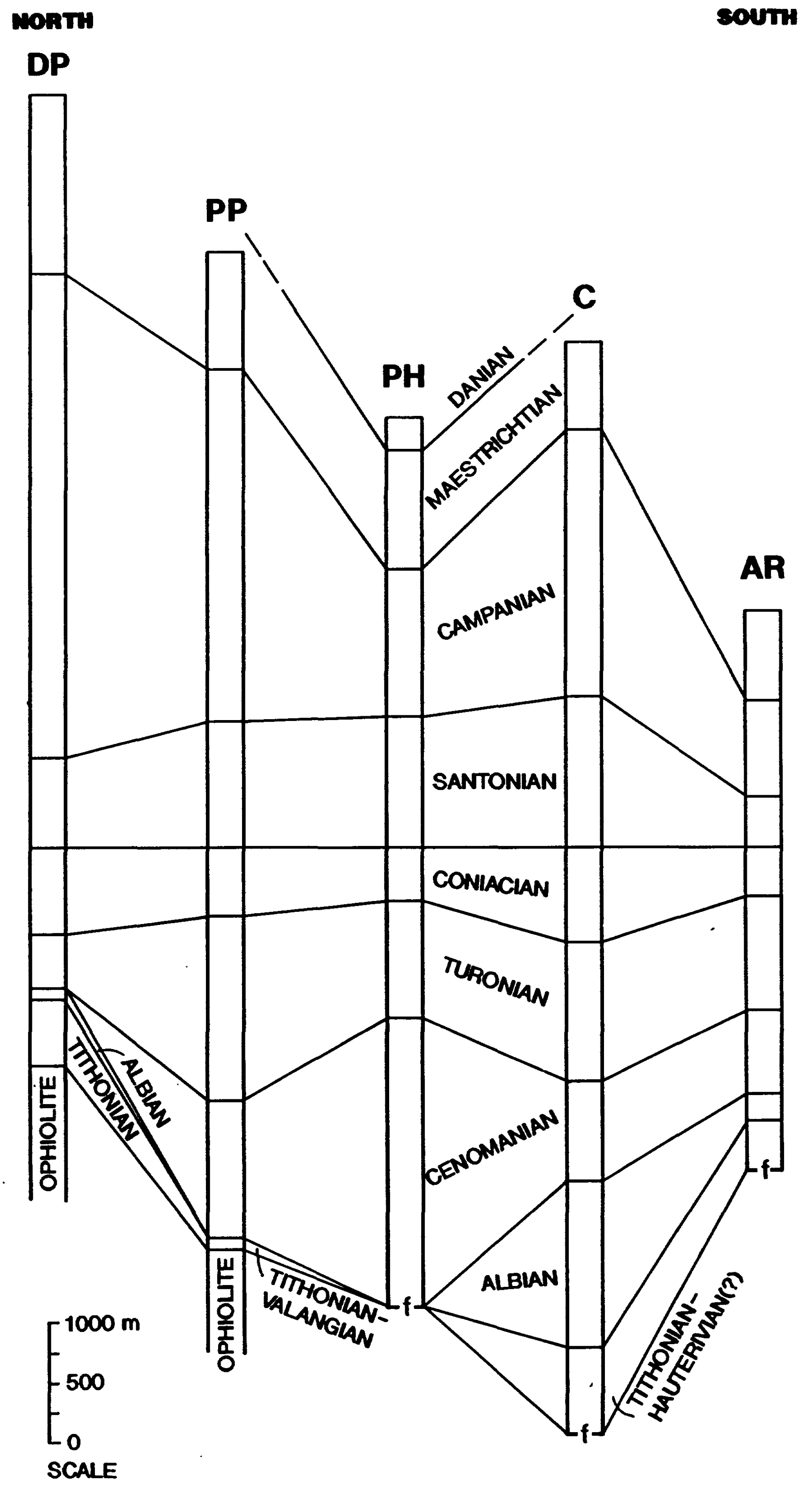

Figure 4. Correlation diagram for stratigraphic columns of Figure 3 showing thickness variations by stage, using base of Santonian as datum. Abbreviations as in Figure 1.

has been suggested that it may be a result of tectonic activity associated with sinistral strike-slip along the continental margin (Ingersoll, 1988).

The younger part of the Great Valley sequence, which constitutes the bulk of the unit (Fig. 4), is mostly Cenomanian and younger, although it locally includes strata as old as late Albian (Early Cretaceous) (Fig. 5). The Cenomanian thins between the Pacheco Pass quadrangle and Del Puerto Creek (Fig. 4) and may not even be present in the Del Puerto Creek area. Turonian through Santonian strata show only minor thickness variations; however, the Campanian and Maestrichtian sections thicken northward (Fig. 4). Although nomenclature varies, the younger part of the sequence has been divided by most workers into the Panoche and Moreno Formations. The lower part of the Panoche consists mostly of shale or mudstone containing lenses of sandstone and conglomerate and grades upward into a sandstone-rich section (Fig. 6). This increase in sand may be due to an increase in coarse-grained quartz and feldspar derived from Sierran plutonic rocks as dissection of the magmatic arc progressed (Ingersoll, 1982).

Almgren (1986) called attention to the apparent absence of the F zones of Goudkoff (1945) (approximately the lower Campanian) in the Panoche Hills and Coalinga area. This hiatus may be present throughout the southern Diablo Range; Tamesis (1966) recognized a probably correlative unconformity at the base of his Redman Sandstone in the Avenal Ridge area (Fig. 5). For the most part, however, there is no apparent physical break in sedimentation and the tectonic significance of the hiatus is not really known, although it may be related to the shallowing of the subduction angle at the inception of the Laramide orogeny (Coney and Reynolds, 1977; Cross and Pilger, 1978; Dickinson and Synder, 1978).

The Moreno Formation, as mapped in the Diablo Range, is progressively older northward from its type section in the Panoche Hills (Fig. 5). Strata equivalent to the upper part of the type section has been stripped by erosion in the northern sections and the base (or the top of the conformably underlying Panoche Formation) is demonstrably older stratigraphically in the northern Diablo Range sections, as illustrated by Payne (1951) and Stein (1983). Some workers (Bishop, 1970; Dibblee, 1981, 1982a,b; Bartow and others, 1985) have adhered to the original formation boundaries of Anderson and Pack (1915), resulting in an older Moreno in the northern sections, whereas others (Payne, 1951; Schilling, 1962b; McGuire, 1988a,b) suggest that strata older than that of the type section is not part of the Moreno Formation. Schilling's (1962b) solution was to create a separate formation, Formation A, between the Panoche Formation and what he considered to be true Moreno (Fig. 5).

One of the more intriguing aspects of the Diablo Range outcrops of the Great Valley sequence is the presence in the type Moreno of the Cretaceous-Tertiary boundary. The exact stratigraphic position of the boundary has been elusive, but McGuire (1988b) has narrowed the position to an interval about 2 m thick located a few meters above the top of the Marca Shale Member. No attempt has yet been made to sample that interval in detail in search of an iridium-bearing boundary clay.

Northern San Joaquin Valley

Stratigraphic nomenclature in the subsurface of the northern San Joaquin Valley has little in common with that in the outcropping rocks to the west (Fig. 5), although the Coalinga nomenclature of Anderson (1972) has been applied, in part, in the southern part of the basin. The Cretaceous section is only partially known here, because few, if any, wells penetrate deeper than the upper part of the F zone (lower Campanian). The subsurface units are, therefore, correlative with the upper part of the Panoche Formation and the Moreno Formation. The name "Panoche" has been difficult to apply uniformly in the subsurface because the unit includes most of the Upper Cretaceous section and the Moreno is present locally only as thin interbeds between thick sandstone units that are apparently not fully present in the outcrop. Bishop (1970, Fig. 15)

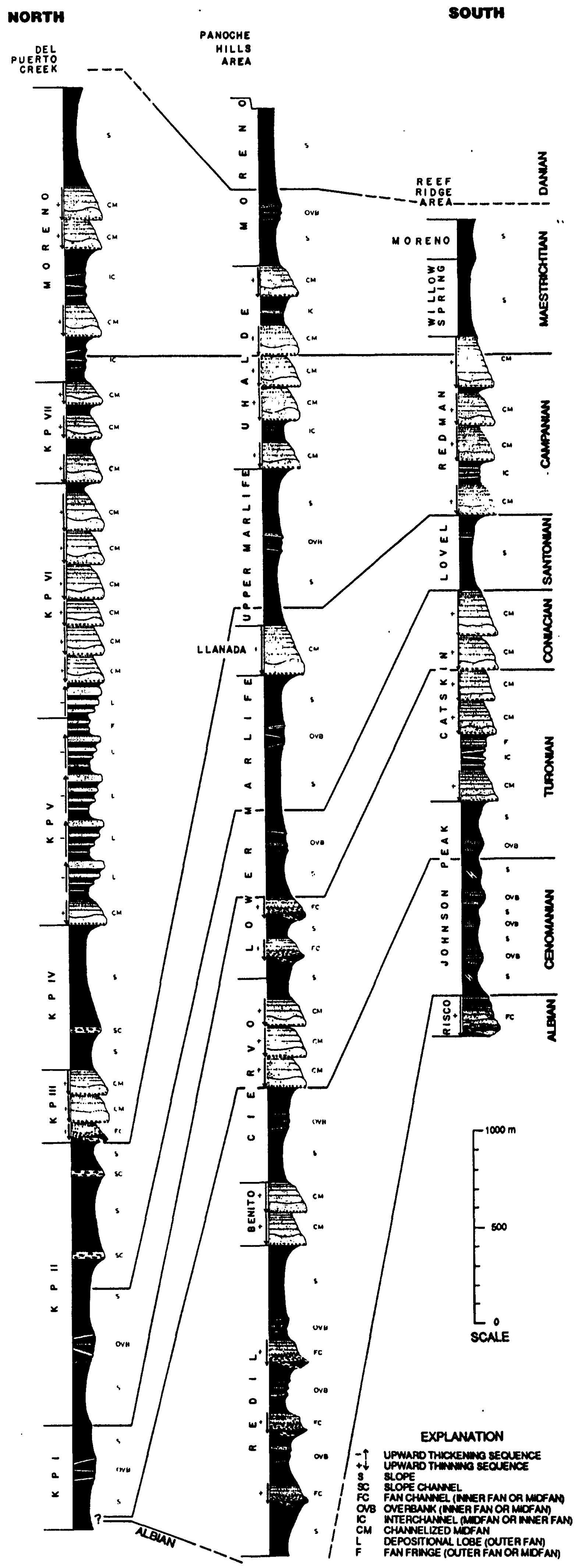

Figure 6. Schematic stratigraphic sections of the Upper Cretaceous part of the Great Valley sequence in the Diablo Range showing depositional facies, generalized lithostratigraphy, and correlations. Modified from Ingersoll and others (1977).

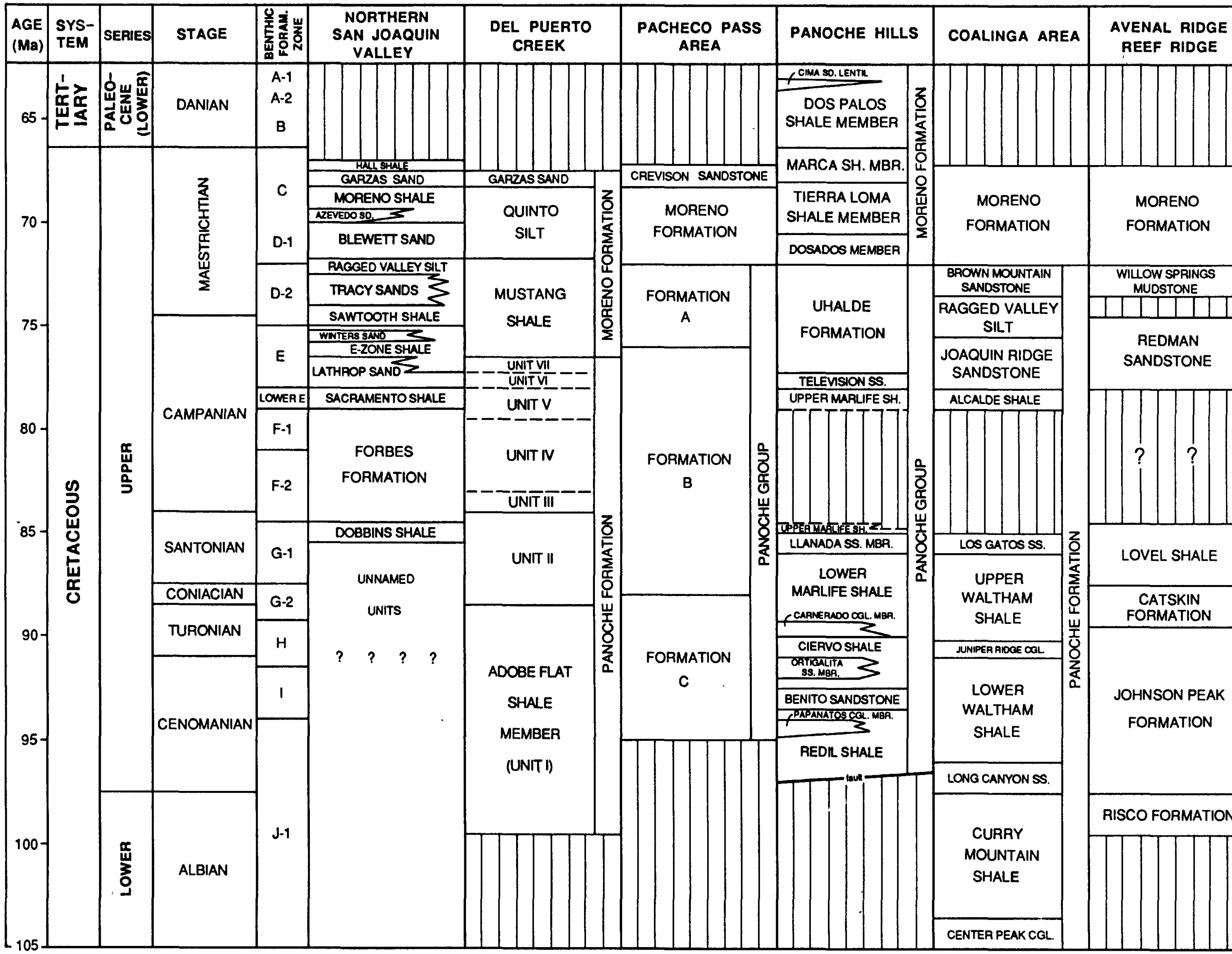

Figure 5. Correlation chart for the upper part of the Great Valley sequence. Northern San Joaquin Valley column from Edmondson and others (1964) and Almgren (1986), other sources and time scale as in Figure 3.

illustrated a close correspondence between outcrop and subsurface stratigraphy in the Del Puerto Creek area (Fig. 7), even though the nomenclature is different. An west-east cross section (Fig. 8) (Hoffman, 1964, Fig. 5), using the same well at the west side of the valley (Shell "Elfers" 36X-28), shows the stratigraphic changes eastward across the valley. The section is predominantly sandstone from the E zone (upper Campanian) upward, and represents a variety of depositional systems, as discussed in the next section. The names "Panoche" and "Moreno" have little relevance here.

SEDIMENTATION

Depositional systems

Sedimentary rocks of the Great Valley sequence were formerly interpreted to be shallow-marine deposits of the shelf and possibly of the slope, and were commonly thought of in a geosynclinal context. Bailey and others (1964) considered the Great Valley sequence to be the miogeosynclinal counterpart of the eugeosynclinal Franciscan rocks. The miogeosynclinal sandstone, shale and conglomerate, partly shelf deposits and partly deep-water turbidites, were contrasted with the eugeosynclinal assemblage of graywackes, volcanic rocks, bedded chert, and ultramafic rocks. With the fuller development of the turbidite concept and the evolution of facies models for deep-sea fans, has come a better understanding of Great Valley sequence outcrops in the Coast Ranges as consisting principally of deep-sea-fan and slope deposits (Ingersoll and others, 1977; Ingersoll, 1978b). Similarly, plate-tectonic analyses have led to reinterpretation of the eugeosyncline and miogeosyncline as subduction accretion complex and forearc basin, respectively (Dickinson and Seely, 1979).

The evolving interpretation of the outcropping Great Valley sequence, has been accompanied by a fuller understanding of the variety of facies present in the subsurface. These rocks are now seen to consist of a complex of fluvio-deltaic, shelf, submarine slope, deep-sea fan and basin-plain deposits (Figs. 9, 10) (Drummond and others, 1976; Garcia, 1981; Cherven, 1983). The fluvio-deltaic systems are best developed and thickest in the subsurface and, along the eastern margin of the southern forearc basin, supplied sediment to submarine canyons and deep-sea fan systems to the west and southwest. Sandstone body trends vary with the facies; delta-front sandstone bodies generally have a northwest trend, and submarine-canyon and deep-sea-fan sandstone bodies generally have a southwest trend .

Deep-sea-fan facies associations in the Great Valley sequence include both prograding (coarsening and thickening upward) and retrograding (fining and thinning upward) sequences. In Diablo Range outcrops, retrograding sequences appear to be most common (Fig. 6) (Ingersoll, 1978b, 1979). Upper Cretaceous strata in the Diablo Range generally shallow upward from basin-plain and deep-sea-fan deposits to slope, shelf, and deltaic deposits at the top. The Upper Jurassic and Lower Cretaceous rocks are reported to consist chiefly of either basin plain to lower fan deposits (Mansfield, 1979) or, alternatively, slope deposits (R.V. Ingersoll, in Mansfield, 1979). The northern (Sacramento) forearc basin outcrops have been reported to generally include more distal environments, such as lower fan and basin plain, than the southern (San Joaquin) outcrops (Ingersoll, 1978b; Ingersoll and Dickinson, 1981). The more proximal nature of the southern outcrops is believed to be a consequence of their oblique trend relative to the basin trend; more distal facies having been uplifted and eroded (Ingersoll, 1979; Ingersoll and Dickinson, 1981). Great Valley sequence outcrops along the west side of the Diablo Range may represent remnants of the more distal facies, but little is known about the stratigraphy or depositional facies of these rocks.

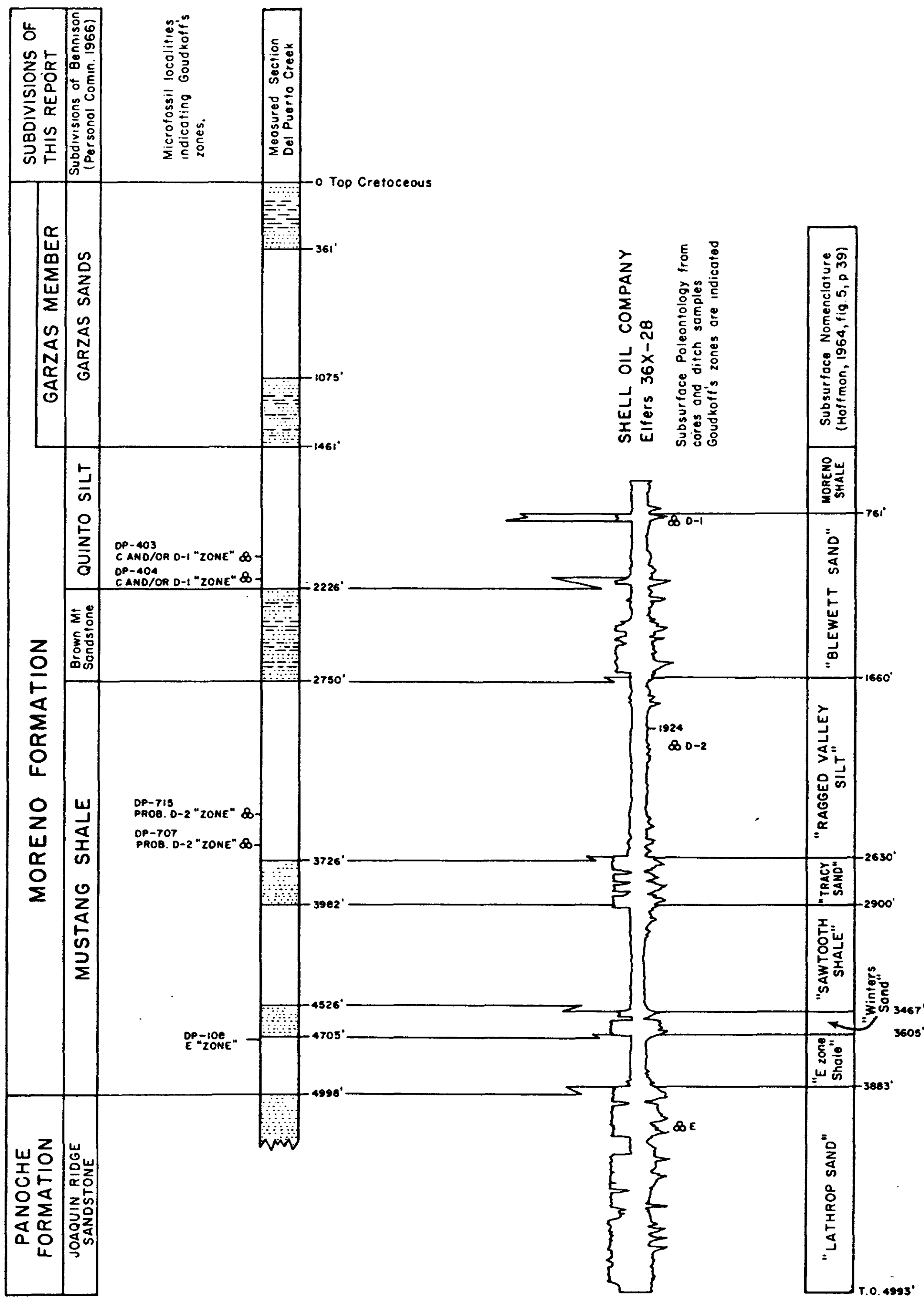

Figure 7. Correlation of Del Puerto Creek section of the Diablo Range with San Joaquin Valley subsurface to the east from Bishop (1970, Fig. 15), showing differences in stratigraphic nomenclature. Shell "Elfers" 36X-28 was spudded in the Garzas Sand about 1.5 km south of Del Puerto Creek.

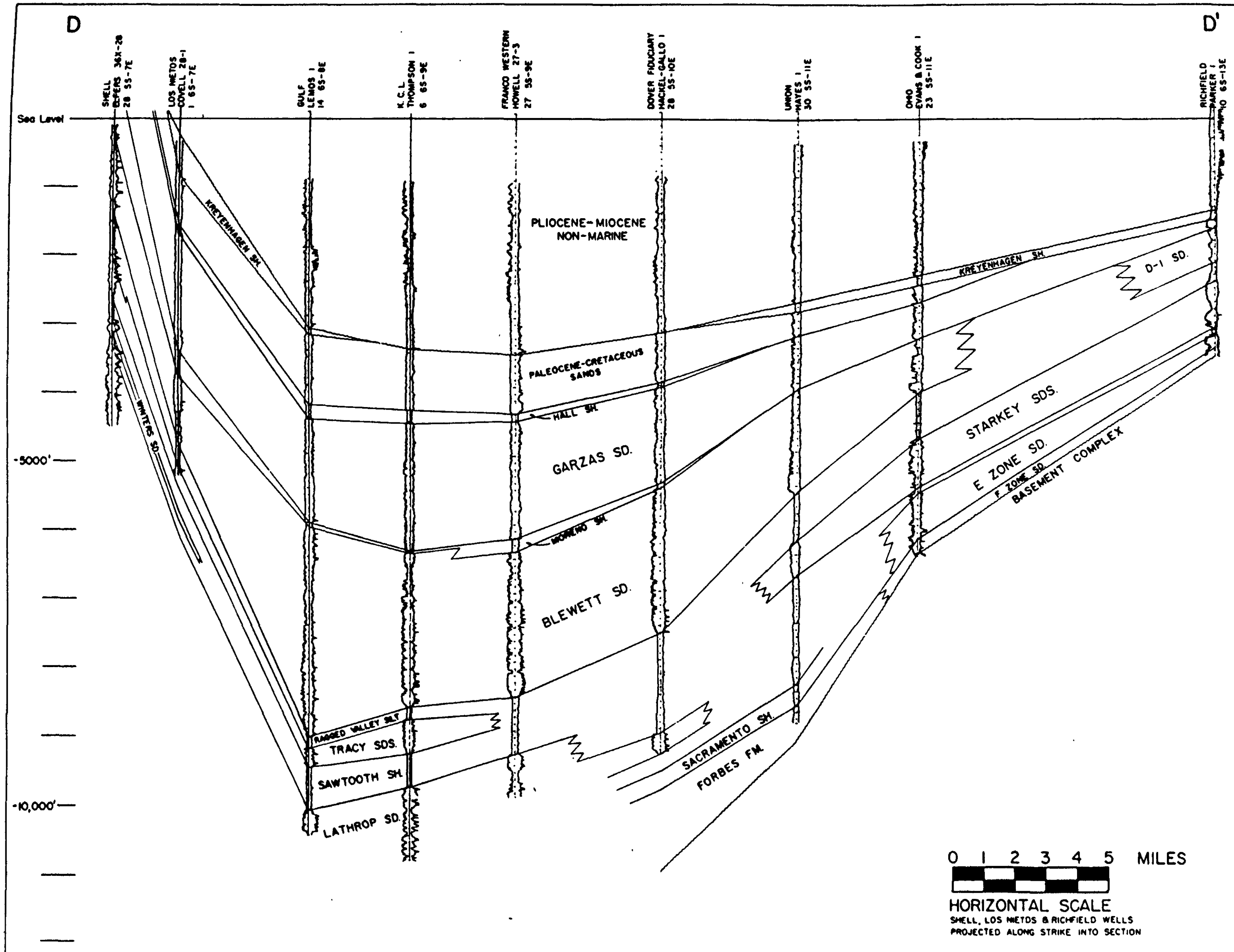

Figure 8. Correlation section eastward across the northern San Joaquin Valley from the Del Puerto Creek area in the Diablo Range, from Hoffman (1964, Fig. 5). Location is approximately the same as section A-A' (Fig. 1).

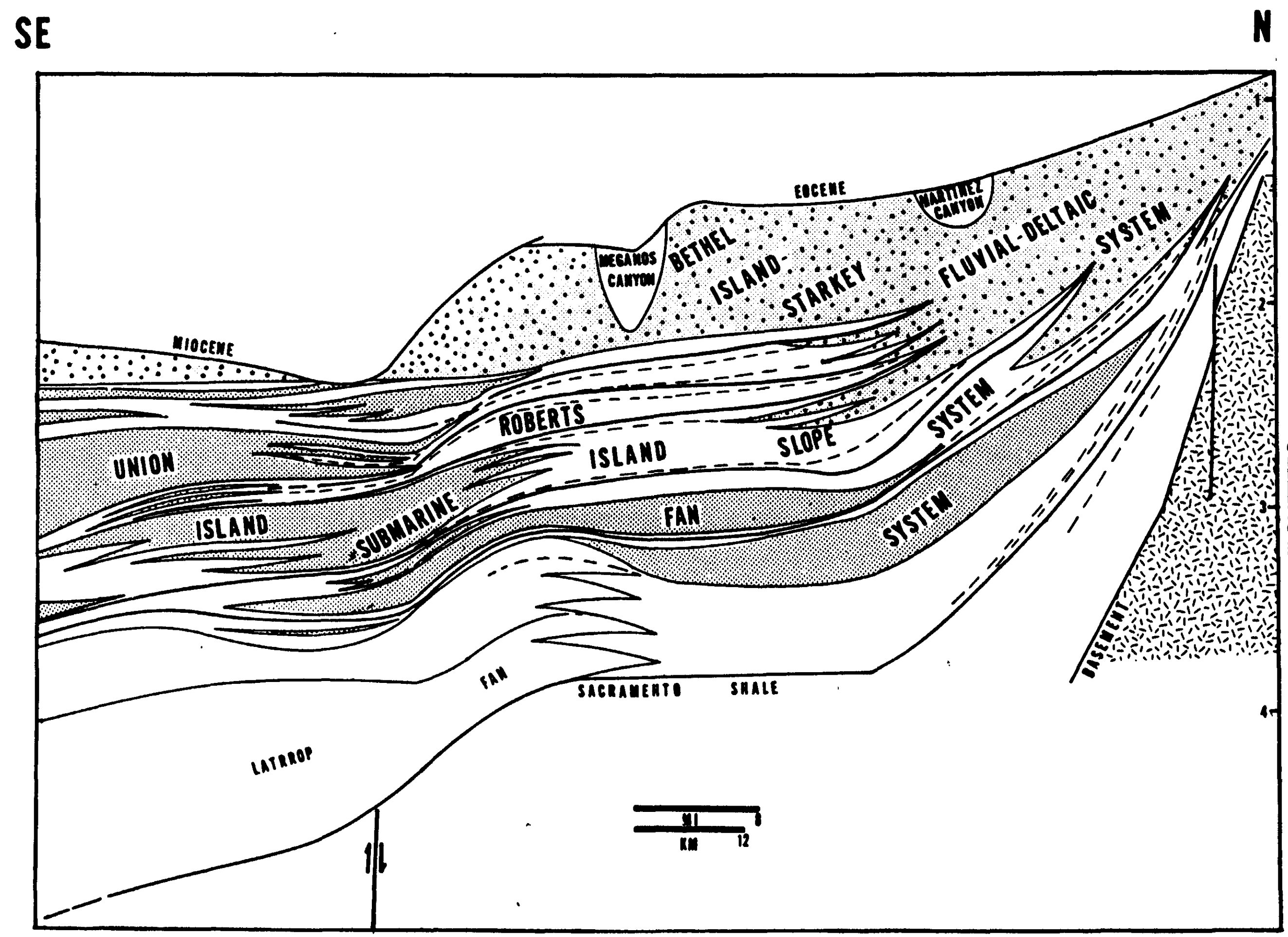

Figure 9. Schematic cross section of the southern Sacramento and northern San Joaquin basins showing interpretation of depositional systems, from Cherven (1983, Fig. 4, reprinted by permission). Stippling, submarine-fan sand; shaded heavey stippling, delta-front and delta-plain sand and prodelta shale; random dash, Sierran basement; blank, shale. (Lithology of Lathrop fan not shown.)

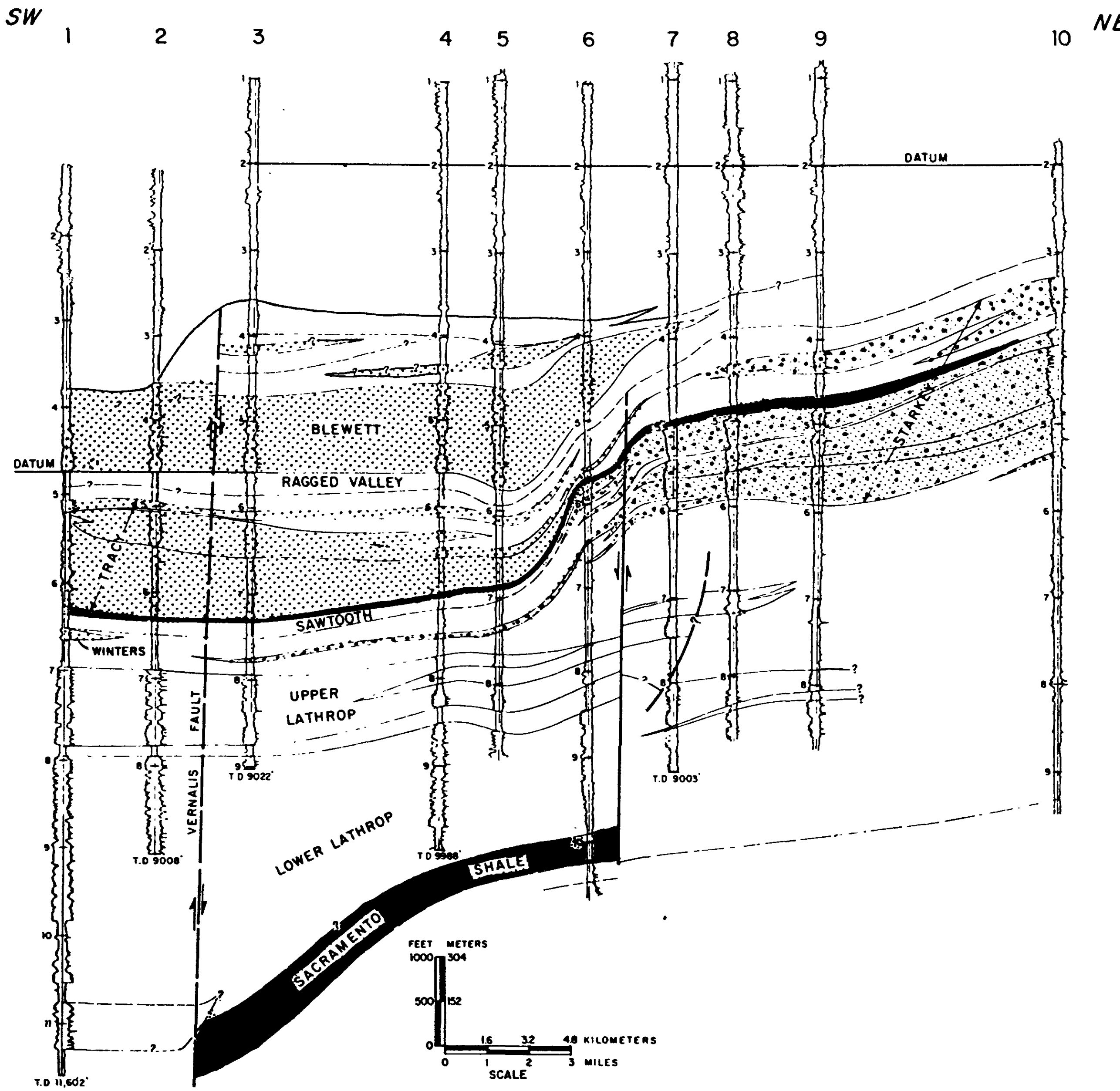

Figure 10. Northeast-southwest correlation section of Upper Cretaceous rocks in the northern San Joaquin Valley from Cherven (1983, Fig. 23, reprinted by permission), showing onlapping of submarine fans against slope deposits,. Offset restored on Vernalis fault. Heavy stippling, submarine-fan sand; mixed stippling, delta-front sand; black, transgressive shale; blank, shale. Wells: (1) Young "Navarra" 1, sec. 29, T3S, R6E; (2) Sesnon-Great Basins "Mohawk-Boltzen-Hunter" 76-16, sec. 16, T3S, R6E; (3) Exxon "McCleod" 1, sec. 11, T3S, R6E; (4) Great Basins "Signet-Whiting" 66X-23, sec. 23, T2S, R6E; (5) Great Basins "Christiana-Palmer" 1-13, sec. 13, T2S, R6E; (6) Exxon "Oliverra" 1, sec. 7, T2S, R7E; (7) Occidental-Great Basins "Clevenger-Frazier" 1, sec. 4, T2S, R7E; (8) Reynolds-Great Basins "Unit 32" 1, sec. 32, T2S, R7E; (9) Reynolds "Manteca Unit" 26-3, sec. 26, T1S, R7E; (10) Shell "Simms" 1, sec. 9, T1S, R8E.

Sediment source and transport

Sandstone provenance data indicate that most of the sediments of the Great Valley sequence were transported predominantly westward into the forearc basin from the Sierran magmatic arc. Paleocurrent measurements from outcropping Upper Cretaceous rocks indicate transport directions predominantly toward the south in the northern (Sacramento) part of the forearc basin and toward the west in the southern (San Joaquin) part (Ingersoll, 1979). The southward-directed currents suggest longitudinal flow controlled by a bathymetric high, the trench-slope break or outer arc ridge. This high, located between the forearc basin and the trench, was probably part of the subduction complex. Most of the southward-directed paleocurrent data are reported by Ingersoll (1979) to be from sole markings of thin-bedded distal turbidites that are most common in basin-plain and outer fan facies associations, which he considered not to be generally present in the Diablo Range.

Although there is no direct data on paleocurrents from the subsurface of the northern San Joaquin Valley, the facies reconstructions of Cherven (1983) suggest sediment transport consistently toward the west or southwest. Some delta lobes, however, suggest southward transport.

Previous workers, on the basis of various types of data, have suggested a possible western source for part of the sequence. Although an assumed western landmass was considered to be a major source by some workers (Briggs, 1953a; Callaway, 1964) there is no direct evidence from paleocurrent data, models of depositional systems, or petrology to support this concept. The presence of the confining bathymetric ridge of subduction complex material on the west flank of the forearc basin, however, is permissive of minor contributions from that direction. Bishop (1970) concluded that some conglomerate in the Del Puerto Creek area was derived from the west and McGuire (1988b) provides evidence from sandstone petrology of a western source at one locality at the top of the Panoche Formation in the Panoche Hills.

SUMMARY

1. The Great Valley sequence consists of the latest Jurassic to early Paleocene deposits in an elongate forearc basin located between the Sierran magmatic arc and the Franciscan subduction complex. Strata in the Diablo Range outcrops and in the subsurface of the northern San Joaquin Valley represet the southern part of the forearc basin.

2. Great Valley sequence deposits consist of a complex of depositional systems ranging from fluvial-deltaic in the east to deep-sea fan and basin plain in the west.

3. Changes in sandstone petrology, describable in terms of a set of petrofacies, reflect the evolution of the magmatic arc and the unroofing of the Sierran plutons.

4. The many sets of lithostratigraphic names currently in use in various parts of the forearc basin may be more a hindrance to understanding Great Valley sequence stratigraphy than they are help. Sequence stratigraphy, based on seismically defined units and utilizing good biostratigraphic and magnetostratigraphic control, will most likely lead to better understanding of the Great Valley sequence in the future.

5. Although there has been considerable gas production from the Great Valley sequence in the Sacramento Valley, gas and oil discoveries, to date, in the Great Valley sequence of the San Joaquin Valley have been minimal.

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