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PALEOGEOGRAPHIC IMPLICATIONS OF MOLLUSCAN ASSEMBLAGES IN THE
UPPER CRETACEOUS (CAMPANIAN) PIGEON POINT FORMATION, CALIFORNIA

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ABSTRACT

The Pigeon Point Formation crops out along the San Mateo County coastline in a northern and southern sequence of folded and faulted strata. Correlation of the two sequences remains somewhat equivocal, although on the basis of biostratigraphy and a reversed magnetic interval both appear to have been deposited during the early to middle Campanian. Sedimentary structures suggest that the northern sequence was deposited by turbidity currents in a continental rise setting, whereas the southern sequence primarily reflects deposition in shelf and slope environments.

Right-lateral offset on the San Andreas and subsidiary faults to the east of the Pigeon Point Formation can account for 100's of km of northward transport since its deposition. However, Champion and others (1984) suggested 2500 km of northward transport from a tropical setting of about 21°N. Molluscan assemblages in the formation argue strongly for a less tropical site of deposition. Relative abundances of warm and temperate taxa and the presence or absence of key species are similar to those of the Santa Ana Mountains Cretaceous section, and are indicative of a warm-temperate to subtropical site of deposition.

INTRODUCTION

Upper Cretaceous sedimentary rocks near Pigeon Point, California, were first recognized by Arnold (1908), who identified a number of Late Cretaceous species and named several new species from the unit. These strata were formally named the Pigeon Point Formation by Hall and others (1959), who provided molluscan evidence for a late Campanian or Maastrichtian age. Following these reports, the Pigeon Point Formation generally has been considered sparsely fossiliferous, although Saul and Popenoe (Saul and Popenoe, 1962, 1992; Saul, 1978, 1983, 1989) discussed and named a number of species from it. Continued research of existing collections and analysis of new collections by the authors indicates that approximately 100 megafossil species can be identified from the formation, making the fauna one of the most diverse known for a unit apparently confined to middle Campanian age on the west coast of North America. This paper provides a preliminary report of those taxa having paleobiogeographic implications regarding the controversy surrounding the

formation's place of deposition relative to cratonic North America.

This paleogeographic controversy was generated by paleomagnetic data reported by Champion and others (1981, 1984), which indicate that the Pigeon Point Formation was deposited as much as 2500 km south of its present latitude, or at the approximate latitude of southern Mexico in the Late Cretaceous. The formation has been considered by many to overlie basement rocks of the Salinian terrane (e.g. Howell and Vedder, 1978; Champion and others, 1984), causing speculation that that terrane is far traveled. However, other geologic and paleomagnetic evidence suggests that Salinia has had more limited tectonic transport (James and Mattinson, 1988; Lund and others, 1991; Whidden et al., 1991). In addition, sandstone petrology and conglomerate clast composition of the Pigeon Point Formation is not characteristic of Cretaceous strata underlain by Salinian basement elsewhere (Lee-Wong and Howell, 1977; Grove, 1989). Instead, conglomerate clast composition is suggestive of Late Cretaceous rocks of the Sur-Obispo terrane (Grove, 1989), which coincidentally does contain paleomagnetic evidence of substantial northward translation (Lund and others, 1991).

This paper will compare molluscan assemblage data drawn from material collected in the Pigeon Point Formation, with molluscan distributions found in rocks of similar age along the Pacific margin of North America in order to assess paleobiogeographic constraints on the tectonic transport history of the formation. However, before addressing the paleogeographic questions, we will review the geologic and lithostratigraphic settings, the age control and the paleoenvironmental implications of the assemblage distributions, since these factors play an important role in developing paleobiogeographic comparisons.

GEOLOGIC SETTING

The Pigeon Point Formation lies west of the San Andreas fault on a block that is bounded to the northeast by the San Gregorio fault (Fig. 1). Cretaceous strata have not been identified between the San Gregorio and San Andreas fault zones in the Santa Cruz Mountains, where Cenozoic strata apparently lie directly on granitic basement rocks of the Salinian terrane (Clark and Brabb, 1978; McLaughlin and others, 1988). The offshore extent of the Pigeon Point Formation is not known, but some have suggested a hypothetical

extension of the Sur-Nacimientto fault zone not far offshore (e.g. Howell and others, 1977; Lowe, 1979), which may truncate the formation to the southwest (Fig. 1).

Because of the paleomagnetically implied extensive transport of the Pigeon Point Formation since deposition (Champion and others, 1981, 1984), determination of the underlying basement rock has been paramount to analysis of terrane movements. Barring the possibility of direct investigation of the basement

through exposure or drill hole, identification of the amount of offset on the San Gregorio fault is critical in determining the basement rock and terrane to which the Pigeon Point Formation belongs. This is because the Sur-Nacimientto fault, which separates granitic basement of the Salinian terrane to its northeast from Franciscan basement of the Sur Nacimientto block to its southwest, is apparently offset by the San Gregorio fault offshore from Point Sur (Fig. 1). Franciscan basement rocks dredged from the headward part of Ascension Canyon just south of Pigeon Point (Howell and Joyce, 1981) imply at least 90 km of dextral offset of the Sur-Nacimientto fault by the San Gregorio fault system. However, if offset on the San Gregorio fault is slightly greater, on the order of 110-115 km, then the Pigeon Point Formation would lie on the southwest side of the Sur-Nacimientto fault and be underlain by Franciscan basement of the Sur-Obispo terrane (Fig. 1). Most estimates of offset on the San Gregorio-Hosgri fault system fall into the range of 105-150 km (see discussion in Griscom and Jachens, 1989). Thus, a narrow adjustment of these constraints in either direction would allow the Pigeon Point Formation to be underlain by either Salinian or Sur-Obispo basement rocks.

Cretaceous rocks nearest to the Pigeon Point Formation lie to the east of the San Andreas fault on Franciscan basement in Palo Alto and near Loma Prieta (Fig. 1). In Palo Alto, a small claystone outcrop on the Stanford University campus contains foraminifera and macrofossils of late Campanian age (Graham and Church, 1963), but exposure is too limited to make proper comparison with the Pigeon Point Formation. Upper Cretaceous rocks near Loma Prieta are turbidite deposits similar to those of the Pigeon Point Formation and are of approximately the same age, as indicated by a number of bivalves in common, including middle Campanian *Meekia bella*. However, the molluscan fauna near Loma Prieta contains turbidite transported nearshore components originating in littoral rocky coastline habitats (Elder, 1991) that are not represented by faunal components in the Pigeon Point Formation.

LITHOLOGIC AND STRATIGRAPHIC SETTING

The Pigeon Point Formation is well exposed along 16 km of coastline near Pigeon Point in San Mateo County. Neither the depositional base nor top of the formation are exposed due to burial or fault contact and erosional truncation, respectively (Howell and Joyce, 1981). Small to large scale folding, faulting, and rotation of blocks within the formation are extensive (Joyce, 1981) and inhibit precise reconstruction of the stratigraphic section. Correlation is particularly hampered by an unnamed fault 1.5 km south of Bean Hollow Beach (Fig. 2), which effectively divides the formation into northern and southern sequences of uncertain relationship. In spite of these structural difficulties, reasonably accurate large-scale stratigraphic sections through the approximately 2500-3300 m of exposed formation have been constructed by Howell and others (1977), Lowe (1979), and Howell and Joyce (1981).

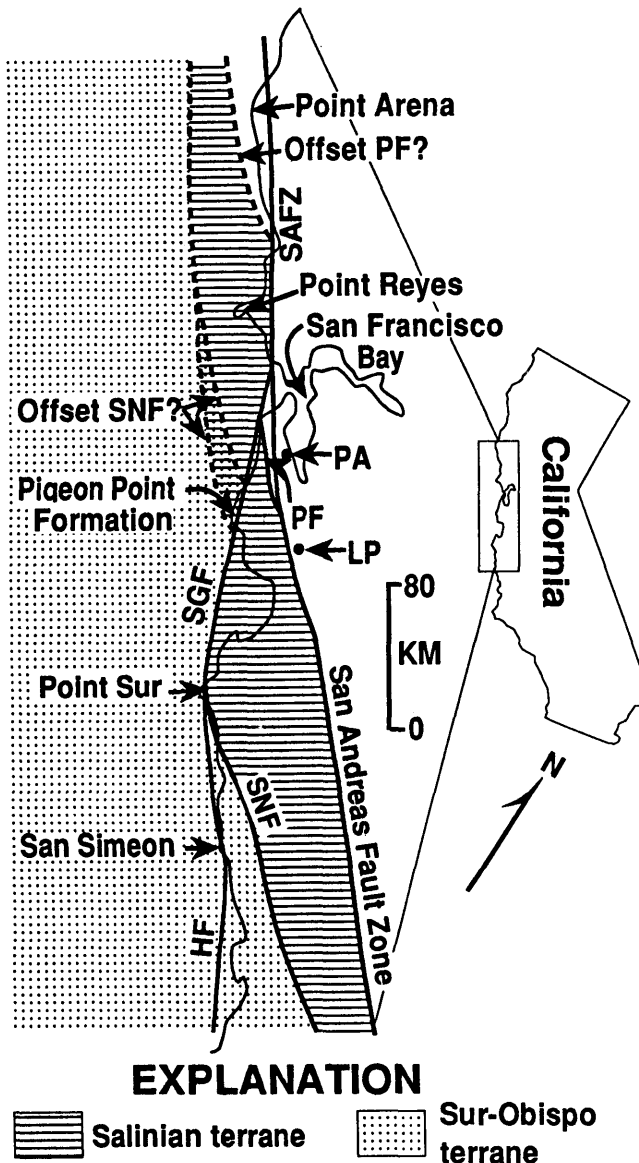


Figure 1. Map of west-central California showing the position of the Pigeon Point Formation relative to nearby localities of similar age (LP = Loma Prieta; PA = Palo Alto, Stanford University Campus) and major faults and terrane boundaries of significance to its tectonic transport history. Fault abbreviations are as follows: HF = Hosgri fault, PF = Pilarcitos fault, SAFZ = San Andreas fault zone, SGF = San Gregorio fault, SNF = Sur Nacimientto fault. Position of offset Sur Nacimientto fault and Salinian/Sur Obispo terrane boundary relative to the Pigeon Point Formation is not known.

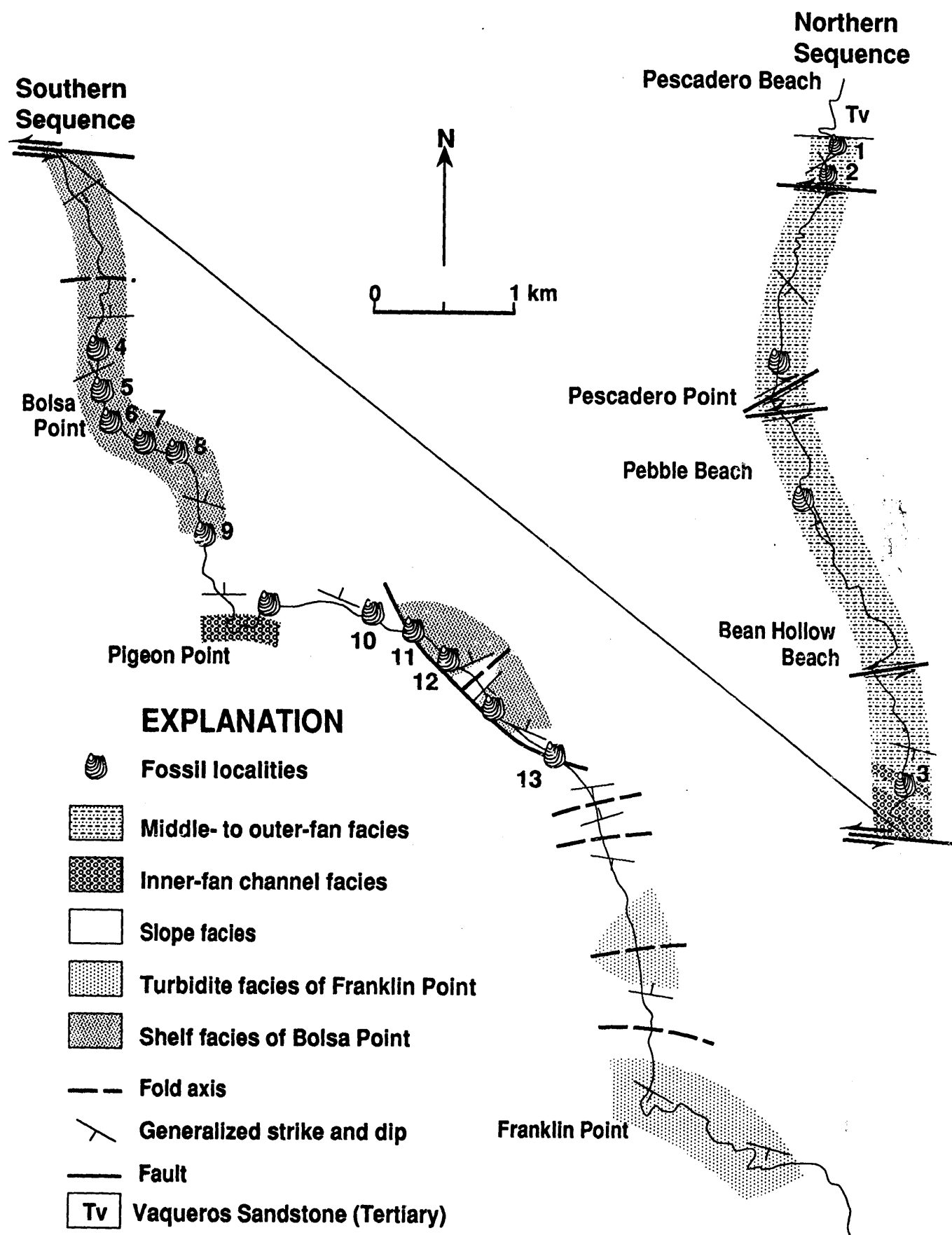


Figure 2. Map showing fossil localities, major structures, and generalized dip directions and lithofacies units of the Pigeon Point Formation. Modified from Howell and Joyce (1981).

The northern section is inferred to contain the oldest exposed rocks (Lowe, 1979; Howell and Joyce, 1981), with the section's base outcropping just south of Pescadero Beach and exposures continuing upsection to the fault 1.5 km south of Bean Hollow Beach (Fig. 2). Strata in this part of the formation have been largely interpreted as representing deep-sea fan turbidite deposits (Lowe, 1979; Howell and Joyce, 1981). The lowest part of this section is dominated by thick-bedded to massive sandstone units separated by thin intervals of thin-bedded fine-grained turbidites, suggesting deposition in the suprafan environment of the middle-fan (Walker, 1978). Macrofossils are rare in this interval except in a thinly bedded portion at the very northern end of the outcrop belt, where abundant inoceramid bivalves occur locally in a mudstone matrix, and rudist debris, solitary corals, and scattered ammonites occur in siltstone and sandstone beds (Fig. 2, locs. 1, 2).

Upsection, the formation is characterized by thinning-upward megacycles with turbidites containing all or part of the Bouma sequence (Howell and Joyce, 1981). These thinning-upward sandy cycles reflect the lateral shifting of turbidite channels characteristic of middle-fan depositional environments (Walker, 1978). Macrofossils are very rare in this facies. The uppermost part of the 2500 m thick northern section is composed of a conglomerate and sandstone unit, approximately 250 m thick, that Howell and Joyce (1981) correlated to a similar conglomeratic unit exposed at the base of the southern section near Pigeon Point (Fig. 2). This thick conglomeratic interval suggests a shift in environment to a major feeder channel in a proximal fan setting and implies a regressive trend upsection through the northern section. Few macrofossils are present in the conglomeratic interval except for scattered oysters and, in a relatively thin conglomerate bed near its base, a low diversity assemblage dominated by *Turritella* (Fig. 2, loc. 3).

The overall regressive trend is continued through the southern section, which is based by a thick conglomeratic interval that is overlain by an extensively slump-folded sequence (up to 350 m thick) of discontinuous units of mudstone, pebbly-to-cobbly mudstone, and conglomerate indicative of a transition from an inner-fan to slope setting (Howell and Joyce, 1981). Macrofossils are moderately common in this facies, where they typically occur as isolated specimens or small clusters floating in a mudstone matrix. These slope deposits are in turn overlain by the apparently youngest deposits in the Pigeon Point Formation near Bolsa Point (Fig. 2), where a 250 m thick interval of massive fine-grained sandstone containing hummocky cross-stratified beds and thin conglomerate and shell lenses is found. These features imply a shelf environment shallow enough for storm waves to impinge on the bottom, perhaps reworking shallow-water turbidite deposits (i.e. Walker, 1984). The majority of macrofossils found in the Pigeon Point Formation come from the shell lenses developed in these relatively shallow-water deposits. Howell

and Joyce (1981) correlate the cross-bedded shelf strata at Bolsa Point with fine-grained turbidites and thicker bedded sandstone units overlying the slumped slope facies to the south at Franklin Point (Fig. 2). They considered these facies to be indicative of a middle-fan environment developed offshore of the Bolsa Point deposits, but these deposits may reflect turbidites deposited on the outer-shelf below storm wave base (Walker, 1984). Macrofossils are rare in this deeper-water facies.

MOLLUSCAN ASSEMBLAGES AND DEPOSITIONAL ENVIRONMENTS

Accurate paleobiogeographic interpretations require the comparison of assemblages characterizing similar habitats because rocky shoreline or beach faunas may have a very different composition and latitudinal distribution than open-shelf or bathyal assemblages. The Pigeon Point Formation contains a fauna characteristic of the inner- to outer-shelf throughout, although in much of the formation the shells were transported to bathyal depths by turbidity currents. However, there are some notable differences in assemblage composition and taphonomy in the different facies present.

An interesting paradox found in the Pigeon Point Formation is that the only rudistid bivalves, which were nearshore taxa that required rocky or shell-rich substrates for attachment, occur near the base of the section in strata that are interpreted as being deposited in one of the most offshore, deep-water settings (Fig. 2, loc. 2). These fragmental rudists occur in sandy turbidite beds and are associated with solitary corals, serpulid worms, and *Didymoceras* ammonites. The presence of rudists in these middle-fan deposits, but not in the more fossiliferous nearshore slope and shelf facies near the top of the section, suggests that the rudist fragments bypassed those coastal regions via transport in submarine canyon systems fed from very nearshore environments.

The clay lithologies of the middle-fan facies in the basal Pigeon Point Formation contain scattered fossils which apparently are *in situ* or little transported. Just south of the fault contact at Pescadero Beach (Fig. 2, loc. 1), a zone of large, whole (to 30 cm length) and fragmented inoceramid bivalves is found within a 5 m thick interval of thinly interbedded mudstones and siltstones. This is the only place in the formation where inoceramids are abundant or even common. In addition, the only pachydiscid ammonite known from the Pigeon Point Formation came from a mudstone bed at the rudistid locality mentioned above. This specimen is quite large (>50 cm in diameter) and was crushed and highly fractured in place. The few other fossils that have been found in the middle-fan facies include rare occurrences of probable pelagic ammonites such as *Didymoceras* and *Hypophylloceras*.

The conglomerate-dominated facies interpreted to represent middle- to inner-fan channel environments generally contain very few fossils with one notable exception. This

is the type locality of *Turritella chicoensis pescaderoensis* Arnold, which is found at the base of the conglomeratic interval capping the northern section (Fig. 2, loc. 3); this is also the only locality in the Pigeon Point Formation from which this taxon is known. At this locality, several thin conglomerate beds (1-2 m thick) contain common to abundant *Turritella* as well as rare specimens of *Idonearca*, *Volutoderma*, and *Baculites*. Shale interbeds also contain *Turritella* in association with *Glycymeris*, *Acila* (*Truncacila*), and *Tessarolax*; the latter two genera are typical of fairly deep, quiet-water shelf environments. Otherwise, the conglomeratic channel facies typically yields only scattered specimens of a thin-shelled pink oyster.

The slumped and pebbly mudstone facies of the slope environment contains rare to fairly common fossils that typically occur as individual specimens floating in mudstone, or as small pockets of fossils that are commonly associated with pebbly mudstone intervals. Fossil assemblages in this depositional environment typically reflect relatively deep quiet-water habitats. Common components are *Acila* (*Truncacila*), *Tessarolax*, *Indogrammatodon*, and *Pterotrigrionia*, and less common taxa include *Glycymeris*, *Legumen*, *Calva* (*Egelicalva*), *Anomia*, *Inoceramus*, *Ampullina*, *Biplica*, *Bittiscala*, and *Lispodesthes*. Ammonites are very rare in these facies, although *Didymoceras*, *Hypophylloceras*, and *Baculites* occur.

By far, the most fossiliferous rocks in the Pigeon Point Formation are the shelf facies near Bolsa Point. Here, diverse molluscan assemblages indicative of relatively shallow water, inner-shelf habitats occur in lenses that lie at the bases of shallow scours. These shell lenses are sometimes associated with pebbly sandstones at the scour bases, but often they are not.

In general, the shell lenses are size sorted, containing either mostly large-, medium-, or small-sized shells. The large-sized shell assemblages are typified by *Glycymeris*, *Calva* (*Egelicalva*), *Idonearca*, *Pterotrigrionia*, *Cymbophora*, and sometimes *Yasadia* and *Panopea*, but also contain a number of less common elements. The most diverse faunas occur in middle-sized shell assemblages, which are dominated by *Anomia*, *Cymbophora*, *Meekia*, *Isognomon*, *Tellina*, *Nuculana*, *Biplica*, cerithiids, naticids, and acteonids, as well as many other less common taxa. *Baculites* are common in both of these size-sorted assemblages, and fragments of *Didymoceras* also are present. The small-sized shell assemblages are most commonly developed on parting surfaces between beds displaying the best developed hummocky cross-stratification. These assemblages are dominated by *Nuculana* and *Corbula*, with less common *Meekia*, *Isognomon*, and *Cymbophora*, as well as a number of rarer elements.

AGE CONTROL

Age control on the Pigeon Point Formation has been problematic, and still is to some degree, due to the lack of well pre-

served age-diagnostic ammonites. Overall taxonomic composition generally implies an early to middle Campanian age (Fig. 3). Some of the important age-indicative mollusks are shown in Plate 1. In addition to biostratigraphic control, a reversed paleomagnetic polarity interval found by Champion and others (1981, 1984) in the apparently older northern section also provides some potential age constraints. Available biostratigraphic data indicate that this reversed interval most likely reflects the early Campanian Chron 33R.

Age control on the northern sequence is based on sketchy ammonite control. Rocks near the base of the section at the south end of Pescadero Beach (Fig. 2, loc. 2), have produced a large, badly fractured pachydiscid ammonite with broad flank ribs similar to those of *Canadoceras yokoyamai* (Jimbo). If this identification is correct, then an early Campanian age is indicated, and the magnetically reversed interval in that part of the section would reflect Chron 33R. The presence of inoceramid bivalves resembling *Inoceramus subundatus* Meek and *Inoceramus* (*Endocostea*) *balticus* Böhm at localities 1 and 2 (Fig. 2) is consistent with these strata lying in the upper part of the lower Campanian Chronozone 33R (see Verosub and others, 1989). In the first modern assessment of the age of the Pigeon Point Formation, Hall and others (1959) considered the northern sequence to be of "either late Campanian, or more likely, Maastrichtian" age based on the occurrence of *Didymoceras* ammonite fragments identified from 0.4 km north? (see Saul, 1978, p. 52) of Pescadero Point. Additional fragments of *Didymoceras* have been identified from both northern and southern sequences in this study, but further classification is not possible because only the adult U-shaped hook is preserved. The body chamber of these specimens has two rows of tubercles and occasional constrictions, but the lack of preserved juvenile growth stages prohibits determination of whether the specimens belong to *Didymoceras* s.s., *Didymoceras*

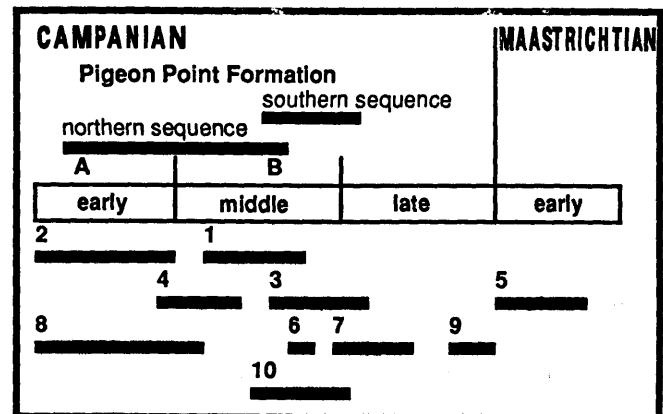


Figure 3. Relative ages of compared faunas in Table 1. In the northern sequence of the Pigeon Point Formation, A is the occurrence of *Canadoceras yokoyamai* and B is the occurrence of *Turritella chicoensis pescaderoensis*. See Table 1 and Figure 4 for other locality information.

(*Bostrychoceras*), or, for that matter, even *Nostoceras*. In general, *Didymoceras* is associated with late Campanian ammonites (*Metaplacenticeras pacificum* ammonite zone) or with early Maastrichtian ammonites (e.g. *Didymoceras hornbyense* (Whiteaves) on the west coast (Matsumoto, 1959)). However, *Didymoceras* s.s. may occur as early as the Santonian in Japan (Matsumoto, 1967). *Didymoceras* (*Bostrychoceras*) is characteristic of the Santonian and Campanian, whereas *Nostoceras* is typical of the Maastrichtian (Matsumoto, 1967).

A middle to late Campanian age is suggested near the top of the northern section by the type locality of *Turritella chicoensis pescaderoensis* Arnold (Fig. 2, loc. 3). This taxon has been considered characteristic of the late Campanian *Metaplacenticeras pacificum* ammonite zone elsewhere (Saul, 1983), but also is found with *Hoplitoplacenticeras* sp. near Punta Abrejos, Mexico, and with *Hoplitoplacenticeras? bowersi* at Dayton Canyon, Simi Hills (Fig. 4, locs. 10, 6); both occurrences lie below the *Metaplacenticeras pacificum* Zone (Alderson and Saul, 1992).

The most common ammonite in the southern sequence is a species of *Baculites* with a complex suture, oval cross-section, and general lack of ornamentation comparable to that of the late Campanian to early Maastrichtian(?) species *B. rex* Anderson, but with slightly less deeply incised saddles than typical of that species. Ward (1978) considered *Baculites rex* in the Nanaimo Group (Clapp, 1912) to be of middle late Campanian age and to have evolved from the early Campanian *Baculites chicoensis* Trask, which has a less complex and deeply incised suture than the former species. It is therefore possible that the Pigeon Point Formation *Baculites* represents a previously unrecognized middle Campanian intermediate form.

The common occurrence of the early to middle Campanian species, *Meekia bella* Saul and Popenoe, throughout the shelf deposits of the southern sequence perhaps provides the best age control for that sequence. Although the type specimen of early Maastrichtian *Yaadia hemphilli* (Anderson) was reported to have come from Pigeon Point Formation (Anderson, 1958), Saul (1978) points out problems with its locality data, and we have thus far only found specimens of *Yaadia* questionably identified as early to middle Campanian *Yaadia tryoniana* (Gabb) in the Pigeon Point Formation.

PALEOBIOGEOGRAPHY

As seen above, the bulk of evidence suggests that Pigeon Point assemblages primarily represent clastic-dominated sub-littoral to inner-shelf environments of middle Campanian age. Therefore, molluscan paleobiogeographic comparisons for the Pigeon Point Formation are best made with assemblages of similar age and habitat.

Table 1 compares the Pigeon Point fauna with 10 other west coast localities (Fig. 4) that are reasonably well known and that are

of roughly similar age (Fig. 3) and habitat. Although we have carefully chosen the localities for this comparison, there is some minor age and environmental biasing. For example, the Chico fauna has the most taxa in common with the Pigeon Point Formation even though it is of early Campanian age rather than the middle Campanian age indicated by the diverse fauna at Bolsa Point (Fig. 3). This commonality reflects the similar shallow water habitats of the mollusks and is unlikely to have been achieved by North Pacific forms following the thermocline into deeper water to the south, as the co-occurring genera *Yaadia*, *Meekia*, and *Tellina* (*Tellinella*) are constrained to shallow water habitats. In contrast, the Bell Canyon fauna, which apparently is more similar to the Pigeon Point Formation in age and water temperature than the Chico fauna (Figs. 4, 5; Table 1), has fewer species in common because its taxa represent deeper water habitats than the Pigeon Point fauna.

In spite of these minor inconsistencies in age and environment between the sites, the 49 species listed in Figure 4 provide informative comparisons of relative numbers of tropical, warm, North Pacific, and other temperate species within each fauna. In the Pigeon Point Formation, an eighth of these species are tropical and nearly a third are of North Pacific affinities. This mixing of warm and cool water species is not unexpected, however, since the Late Cretaceous was a time of broad climatic zones and wide latitudinal species ranges (Kauffman, 1973). For example, representatives of tropical groups such as the cypraeids, which today

Table 1. Pigeon Point Formation species that have been recognized at one or more of ten other Pacific slope localities. Species listed in four provincially significant groups. Relative age of Pigeon Point Formation and other localities are shown in Figure 3. See Figure 4 for geographical position of localities numbered from north to south. 1 = Nanaimo Basin, southern British Columbia and Sucia Island, San Juan Co., Washington; Cedar District Formation (Clapp, 1912). 2 = Vicinity of Chico Creek, Butte Co., California; Chico Formation. 3 = Loma Prieta, Santa Clara Co., California; Unnamed formation of the Great Valley sequence. 4 = York Mountain Quadrangle, San Luis Obispo Co., California; Atascadero Formation. 5 = Vicinity of Jalama Creek, Santa Ynez Mts., Santa Barbara Co., California; Jalama Formation (Dibblee, 1950). 6 = Bell Canyon, Simi Hills, Ventura Co., California; Chatsworth Formation. 7 = Dayton Canyon, Simi Hills, Los Angeles Co., California; Chatsworth Formation (Colburn and others, 1981). 8 = Santa Ana Mountains, Orange Co., California; upper part of Holz Shale Member of Ladd Formation. 9 = Santa Ana Mountains, Orange Co., California; Pleasants Sandstone Member of Williams Formation. 10 = Punta Abrejos, Vizcaino Peninsula, Baja California Sur, Mexico; Valle Formation. 1 - 3 lie east of the San Andreas fault; all other localities are to the west.

Pigeon Point	1	2	3	4	5	6	7	8	9	10
Tethyan & probably tropical										
<i>Corallochama</i> cf. <i>C. orcutti</i> White										
<i>Cerithium?</i> cf. <i>C. totium-sanctorum</i> White								?		?
<i>Isogognomon</i> n. sp.										
<i>Lispodesthes rotundus</i> (Waring)										
<i>Pseudoglauconia?</i> aff. <i>P. ainiktos</i> Dailey & Popenoe					aff.					
<i>Trinacria cor</i> Popenoe										
Warm but not "Tethyan"										
<i>Ampullina packardi</i> Popenoe										
<i>Anchura</i> aff. <i>A. falciformis</i> (Gabb)										
<i>Crassatella</i> aff. <i>C. conradiana</i> (Gabb)										
<i>Crassatella saulae</i> Dailey & Popenoe										
<i>Ellipsoscapha</i> cf. <i>E. nortonensis</i> (Anderson)										
<i>Euspira compressa</i> (Waring)										
"Fulgur" <i>hilgardj</i> White										
<i>Glycymeris (Glycymerita) anae</i> Smith										
<i>Glycymeris (Glycymerita) apletos</i> Dailey & Popenoe										
<i>Legumen ooides</i> (Gabb)										
<i>Laternula?</i> <i>alisoensis</i> (Packard)										
<i>Nonacteonina obesa</i> Dailey & Popenoe										
<i>Nonacteonina</i> aff. <i>N. tensa</i> Stephenson										
<i>Opis</i> cf. <i>O. rosarioensis</i> Anderson & Hanna										
<i>Pinna calamitoides</i> Shumard										?
<i>Pterotrigonina evansana</i> (Meek)										
<i>Tellina (Tellinella)</i> n. sp.										
<i>Turritella chicoensis pescaderoensis</i> Arnold										
<i>Volutoderma santana</i> Packard										
North Pacific										
<i>Ataphrus compactus</i> Gabb										
<i>Biplica obliqua</i> (Gabb)										
<i>Bittiscala tenuisculpta</i> (Whiteaves) ?										
<i>Bittiscala suciense</i> (Whiteaves) ?										
<i>Calva (Egelicalva) bowersiana</i> (Cooper)										
<i>Cymbophora popenoei</i> Saul										
<i>Cymbophora stantoni</i> (Arnold)										
<i>Cymbophora triangulata</i> (Waring)										
<i>Gyrodus (Sohlella) canadensis</i> (Whiteaves)					?					
<i>Lysis duplicosta</i> (Gabb)										
<i>Meekia (Mygallia) bella</i> Saul & Popenoe										
<i>Meekia (Meekia) peleia</i> Saul & Popenoe										
<i>Tessarolax distorta</i> Gabb	?									
<i>Willimactra (Petromactra) truncata</i> (Gabb)										
<i>Yaadia tryoniana</i> (Gabb)										
Temperate but not restricted to North Pacific										
<i>Acila (Truncacila) demessa</i> Findlay					?					
<i>Baculites</i> cf. <i>B. rex</i> Anderson										
<i>Canadoceras</i> cf. <i>C. yokoyami</i> (Jimbo)										
<i>Clisocolus dubius</i> (Gabb)										
<i>Idonearca youngi</i> (Waring)							?	?	?	
<i>Indogrammatodon?</i> cf. <i>I. vancouverensis</i> (Meek)							?	?	?	
<i>Inoceramus subundatus</i> Meek										
<i>Panopea</i> cf. <i>P. californica</i> Packard										
<i>Pholadomya subelongata</i> Meek										
Totals										
Number of species in common	19	26	14	6	14	16	18	24	19	14
Tethyan & probably tropical	0	1	0	0	3	1	2	3	2	3
Warm but not "Tethyan"	3	6	4	1	7	5	7	9	8	4
North Pacific	10	12	6	5	3	5	3	8	5	3
Temperate but not restricted to North Pacific	6	7	4	0	2	5	6	4	4	4

Table 1.

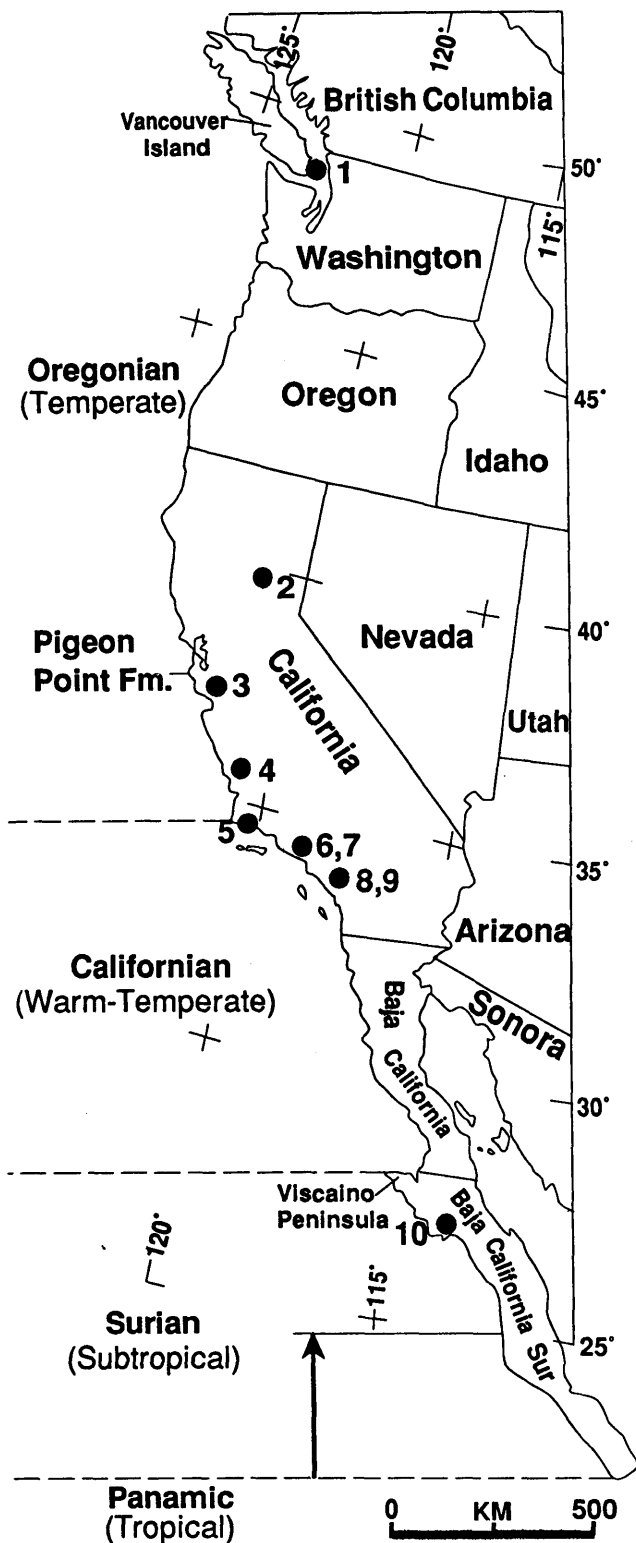


Figure 4. Map showing the geographic distribution of the ten localities compared in Table 1. See Table 1 caption for more specific locality information. Figure also shows position of modern molluscan provincial boundaries discussed in text (dashed lines), and probable northward expansion of the Campanian tropical Tethyan Province to near 25° N is shown by solid line at tip of arrow.

range on the west coast no farther north than Monterey, California, are recognized in the Campanian as far north as the Nanaimo Basin, British Columbia (Sohl, 1971; Groves, 1990). On the whole, however, California Campanian faunas were not dominated by tropical species, but rather resembled those of the modern Californian Province, which includes a single cypræid and several other species of tropical affinity but is predominantly composed of North Pacific temperate species.

If, as has been suggested, the Pigeon Point Formation was deposited approximately 2500 km south of its present latitude (i.e. near 21°N, the latitude of southern Mexico), tropical provincial affinities should be reflected in its fauna. However, the only clearly Tethyan Pigeon Point species listed in Table 1 under "Tethyan and probably tropical" is the rudistid bivalve, *Coralliochama*. In contrast, Tethyan bivalves such as *Trigonarca*, *Quadratrigonia*, and *Roudairia*, and Tethyan gastropods including *Nerinea*, *Wood-salia*, and actaeonellids are present in California faunas of other Cretaceous stages, primarily the Albian through Turonian. Post-Turonian cooling of the Pacific coast may explain the absence of these taxa from autochthonous California Campanian rocks (Saul, 1986), but if the Pigeon Point Formation was deposited at the latitude of southern Mexico, these groups should be well represented. This would be especially true if the northern boundary of Campanian Tethyan assemblages was near 25°N, as suggested by Sohl (1971); that is 2° north of the present Panamic boundary on the west coast of Baja (Fig. 4). Although there are no Campanian molluscan faunas from the Pacific coast of southern Mexico with which to test this assumption, Olsson (1934, 1944) has documented these Tethyan mollusks in Senonian faunas of Peru. Thus, we do know that these tropical groups inhabited the tropical eastern Pacific when the Pigeon Point Formation was deposited.

There is some possible biasing of these paleobiogeographic comparisons that should be noted, however. One conceivable bias is potential upwelling along the Pacific coast (Barron, 1985). If upwelling occurred, it may have depressed the northern boundary of Tethyan assemblages further south than the 25°N suggested by Sohl (1971), who primarily based this latitude on Caribbean distributions. Also, protected bays in the present Surian Province contain more diverse and tropical components than open coastal areas, which have more Californian style faunas (Brusca, 1980). Therefore, the Pigeon Point fauna might appear anomalously cool if it originated in an area of upwelling or an open coastal environment. On the whole, however, it would be remarkable for the Pigeon Point Formation to have so many species in common with Sucia Island and Chico Creek (Table 1, Fig. 4) if it were deposited at the latitude of southern Mexico, but this commonality would be expected if the formation was deposited north of 25°N.

Although the Pigeon Point Formation does not appear to have originated in the tropics, there are faunal indications that it was de-

posited south of its present position. About half of the species listed in Table 1 are indicative of warm water, whereas more than half of the species in the northern areas (Fig. 4, locs. 1-4) are North Pacific or temperate water indicators. For example, the major difference between the Pigeon Point fauna and that of the Chico Formation is the fewer warm and tropical forms present in the latter. Additionally, there are some biogeographically significant species in the Pigeon Point Formation that differentiate it from the northern faunas. Plate 2 shows some of these taxa. *Anchura falciformis* Gabb is common in the northern faunas but is not found in the Santa Ana Mountains, where two undescribed Campanian species occur. One of these, listed as *Anchura* aff. *A. falciformis* on Table 1, is a species of more southern occurrence than *Anchura falciformis* and therefore suggestive of warmer water. Another such species is *Volutoderma santana* Packard, which otherwise has not been found north of the Santa Ana Mountains. The less strongly shouldered *Volutoderma averilli* (Gabb) is common at Chico Creek and in the Nanaimo basin and is also present in the Santa Ana Mountains but has not been recovered from the Pigeon Point Formation. Other Pigeon Point species listed in Table 1 that have not been found in northern faunas are *Isognomon* n. sp., *Lispedesthes rotundus* (Waring), *Latur-nula? alisoensis* (Packard), and *Ceritium? totium-sanctorum* White. In addition, the rudist *Coralliochama* is only found west of the San Andreas fault in California.

In conclusion, Table 1 indicates that warm water faunal elements increase from north to south in the compared area, and that the warm water components of the Pigeon Point Formation ally it most closely to the more southern localities (Fig. 4, locs. 5-10). Molluscan temperature indicators of the Pigeon Point Formation are most similar to those in middle to late Campanian faunas from the Peninsular Ranges terrane of southern and Baja California and correspond particularly well with those of the Santa Ana Mountains. These Santa Ana rocks have been inferred to have been deposited near the paleolatitude of 26°N (see data in Lund and others, 1991), and, therefore, north of the Tethyan Province, whose northern boundary may have been near 25°N. This inferred paleolatitude for the Pigeon Point formation of near 26°N does not clearly indicate the terrane in which the Pigeon Point Formation might lie. Lund and others (1991) have projected the Sur-Obispo terrane to be further south than this in the Campanian (although largely based on the Pigeon Point paleomagnetism of Champion and others, 1984), and the Salinian terrane to be further north than the molluscan assemblages in the Pigeon Point Formation imply.

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