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Late Cretaceous Pollen from the Salinian(?) Suspect Terrane at Pigeon Point, San Mateo County, California

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Abstract

The Campanian to Maastrichtian Pigeon Point Formation is confined to southwestern San Mateo County, California; the formation is spatially isolated from similar Upper Cretaceous sedimentary rocks. The basement on which the formation rests is not exposed, but the Pigeon Point block is thought by most authors to be part of the Salinian suspect terrane. Reconstructions based on paleomagnetic data have indicated that the Pigeon Point block originated at the continental margin and was then transported some 2,500 km northward since deposition of this formation, but other studies suggest that the Pigeon Point Formation instead may have originated well within the southwestern part of the North American continent.

This report describes the flora from two samples of the Pigeon Point Formation; at least 16 angiosperm pollen species have been found, as well as several potentially significant species of spores and gymnosperm pollen. A comparison of this flora with those from Upper Cretaceous suspect terranes of California and British Columbia, and from autochthonous Upper Cretaceous sedimentary units in the Central Valley of California and the Western Interior region of New Mexico, shows that the Pigeon Point flora belongs to the continental margin floristic province, and the most similar known flora in that province is from an upper Campanian to lower Maastrichtian unit lying on the Salinian terrane in the La Panza Range of San Luis Obispo County. The Pigeon Point flora cannot be used to prove or disprove the hypothesis that the Pigeon Point Formation rests on Salinian basement, but the flora does suggest that when the formation was deposited, the Pigeon Point block did not lie at a latitude as far north as the present United States.

Introduction

The Upper Cretaceous Pigeon Point Formation is known only from the coastal area of southwestern San Mateo County, California, at the western edge of the Santa Cruz Mountains. The formation crops out in the intertidal zone and in low sea-cliffs from north of Año Nuevo Point to north of Pescadero Point (fig. 1), a distance of approximately 16 km (Hall and others, 1959).

The Pigeon Point Formation is spatially isolated from similar Upper Cretaceous sedimentary rocks, and it is the oldest sedimentary unit in the Santa Cruz Mountains west of the San Andreas fault (Lowe, 1979). This formation is thought by most authors, but has not been proven, to be part of the Salinian suspect terrane. If the Pigeon Point Formation is Salinian, then it is among the oldest sedimentary units overlying the basement of this terrane (Howell and others, 1977).

One of the most important paleomagnetic studies on sedimentary rocks in California has indicated that the Pigeon Point Formation, and the block on which it rests, have been transported some 2,500 km northward since deposition of this formation (Champion and others, 1984). Therefore, proving or disproving the validity of the paleomagnetic interpretations is critical for understanding the tectonic history of westernmost California.

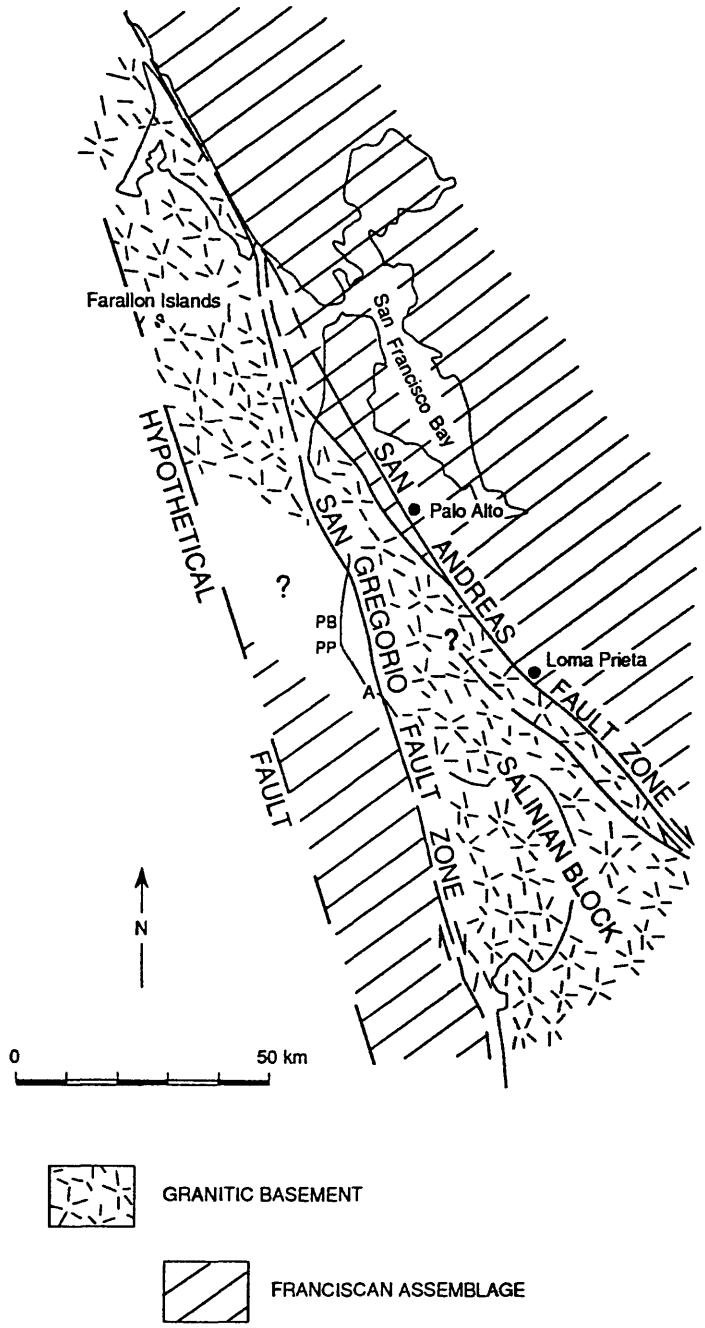

Figure 1. Simplified basement and fault map of the Pigeon Point region (modified from Howell and Joyce, 1981, fig. 1). The hypothetical fault offshore is a possible extension of the Sur-Nacimiento fault to the south (Lowe, 1979; Howell and Joyce, 1981; Dickinson, 1983). A, Año Nuevo Point; PP, Pigeon Point; PB, Pescadero Beach.

The purpose of this report is to describe the pollen flora obtained from the Pigeon Point Formation and to compare this flora with latest Cretaceous (Campanian and Maastrichtian) pollen floras (1) from suspect terranes of California and British Columbia and (2) from sedimentary units of California and New Mexico that are thought to have undergone relatively little or no tectonic transport since deposition. On the basis of these comparisons, inferences are then made about the paleogeographic position of the Pigeon Point block at the time of origin of the flora.

Pigeon Point Formation

The Pigeon Point Formation is strongly folded and faulted; therefore, it is difficult to be sure of the thickness of the preserved formation; estimates of the minimum thickness range from 2,500 m (Lowe, 1979) to 3,300 m (Howell and Vedder, 1978). Neither the base nor the top of the formation is exposed; the base is in fault contact and the top is unconformably overlain by middle and upper Tertiary rocks (Hall and others, 1959; Howell and Joyce, 1981).

Descriptions of the stratigraphy and interpretations of the depositional environments of the Pigeon Point Formation have been provided by many authors (for example, Crowell, 1957; Hall and others, 1959; Lowe, 1972, 1979; Tyler, 1972; Howell and others, 1977; Howell and Vedder, 1978; Howell and Joyce, 1981). The formation is composed of brown and light- to medium-gray sandstone, medium- to dark-gray siltstone and mudstone, and conglomerate. The lower part of the Pigeon Point is considered to have been deposited on the continental slope or even on the upper part of the continental rise as turbidites and related sediments of a submarine canyon and deep-sea fan complex; the upper part of the formation appears to represent sediments of generally decreasing water depth within the same depositional complex, and includes probable shallow-water strata of the continental shelf.

Invertebrate megafossils and protistan microfossils are not common in the Pigeon Point Formation. However, gastropods, bivalves, ammonites, and foraminifers indicate a Campanian to Maastrichtian age of the unit (Branner and others, 1909; Hall and others, 1959; Clark and Brabb, 1978; Elder and Miller, 1989).

The block on which the Pigeon Point Formation rests is bounded on the east by the San Gregorio fault system (fig. 1). Lowe (1979) and Howell and Joyce (1981) thought that the western boundary of the Pigeon Point block might be formed by an offshore extension of the Sur-Nacimiento fault system ("hypothetical fault" in fig. 1); the presence of a major fault offshore is also indicated by late Neogene to Quaternary rotation of sub-blocks of the Pigeon Point block (Holm and Verosub, 1987).

No Cretaceous strata have been found in the Santa Cruz Mountains between the San Gregorio and San Andreas faults (Howell and Joyce, 1981); in that area, Cenozoic strata apparently lie directly on Jurassic to Cretaceous granitic basement rocks (Lowe, 1972). The closest Upper Cretaceous sedimentary rocks lie on Franciscan basement east of the San Andreas fault, to the northeast and east of the Pigeon Point block, near Palo Alto and Loma Prieta, respectively (fig. 1). Near Palo Alto the Upper Cretaceous strata consist of

Campanian shale, perhaps of the Great Valley sequence (Graham and Church, 1963; Nilsen, 1979). Near Loma Prieta are turbidite sequences similar in age and lithology to the Upper Cretaceous rocks on the Pigeon Point block (McLaughlin and others, 1988).

One of the most ambiguous aspects of the Pigeon Point Formation is that the underlying basement has not been definitely determined. Most authors (for example, Lowe, 1972; Tyler, 1972; Howell and Vedder, 1978; Champion and others, 1984; Howell and Joyce, 1981) assume that the formation lies on granitic rocks of the Salinian terrane because the basement between the San Gregorio and San Andreas fault zones is Salinian, and offshore geophysical evidence links the Pigeon Point block with granitic rocks of the Farallon Islands to the north-northwest (fig. 1; Howell and Joyce, 1981). However, sandstones and conglomerates of the Pigeon Point Formation appear to be significantly different in composition from Upper Cretaceous sandstones and conglomerates of the Salinian terrane (Lee-Wong and Howell, 1977; Grove, 1989). In fact, Pigeon Point conglomerates are more similar in composition to Upper Cretaceous conglomerates of the Sur-Obispo terrane west of the Nacimiento fault (on Franciscan basement) than to conglomerates of the Salinian terrane (Grove, 1989). Furthermore, Franciscan basement apparently occurs offshore not far to the southwest of the Pigeon Point Formation (fig. 1; Howell and Joyce, 1981); thus, the Pigeon Point Formation may rest on Franciscan basement. On the other hand, volcanic rocks crop out near strata of the Pigeon Point Formation, and the possibility exists that these form the basement in the area (Clark and Brabb, 1978). However, the contact between the Cretaceous strata and the volcanic rocks is not exposed (Clark and Brabb, 1978), and the two bodies of rock appear to be in fault contact (Howell and Joyce, 1981). In short, it is possible that the Pigeon Point Formation lies above granitic (Salinian) or Franciscan basement or above a basement of undetermined affinity (Howell and Joyce, 1981).

Salinian Suspect Terrane

A very brief description of the Salinian suspect terrane is given here in order to place in context the most probable basement of the Pigeon Point Formation.

The basement of the Salinian terrane is composed of high-grade metasedimentary rocks of Precambrian(?)-Paleozoic(?) ages that were intruded by "middle" to Late Cretaceous granitic plutons emplaced in a continental arc setting (Ross, 1977, 1978; Vedder and others, 1983; Mattinson, 1984). The northeast boundary of the Salinian terrane is formed by the San Andreas fault system; the southwest boundary is formed by the Sur-Nacimiento fault system (the latter fault has not been traced as far north as the Pigeon Point block but if present would be offshore in that region). The Salinian terrane with its granitic basement lies between blocks underlain by the Franciscan subduction complex (Howell and Vedder, 1978).

The oldest sedimentary rocks on the crystalline basement of the Salinian terrane are Campanian to Maastrichtian in age (Howell and Vedder, 1978) like the Pigeon Point Formation. The Upper Cretaceous sedimentary rocks of the Salinian terrane, apparently deposited in more or less isolated basins of a continental borderland, are different in

depositional setting from the forearc strata of the Great Valley sequence that lie on Franciscan basement (Howell and Vedder, 1978).

Postulated Post-Depositional Movement of the Salinian Terrane (Assumed to Include the Pigeon Point Formation)

Paleomagnetic determinations (Champion and others, 1984; Kanter and Debiche, 1985) have been made of the Butano Sandstone (Eocene) and Point San Pedro Formation (Paleocene) of the Salinian terrane, and of the Pigeon Point Formation (Campanian to Maastrichtian). These three sets of paleomagnetic determinations appear to record a consistent northward tectonic movement of the Salinian-Pigeon Point block(s) (Kanter and Dibiche, 1985; Debiche and others, 1987). If paleomagnetic determinations of the Pigeon Point Formation are correct, the block that includes this formation was translated northward approximately 2,500 km since the end of the Cretaceous, so that the Pigeon Point Formation would have been deposited at a latitude of 21.2° plus or minus 5.3°, at the latitude of present Central America (Champion and others, 1984).

One set of reconstructions suggests the following pre-Neogene tectonic scenario for the Salinian terrane, which is assumed to include the Pigeon Point Formation (Vedder and others, 1983; Champion and others, 1984; Mattinson, 1984; Kanter and Debiche, 1985; Debiche and others, 1987): (1) In mid-Cretaceous time, the Salinian terrane was part of the continental margin at the present latitude of Central America. (2) During approximately the interval from Campanian to early Maastrichtian (70-80 Ma), at about the time the Pigeon Point Formation was being deposited, two events occurred: (a) the Salinian terrane (which has a granitic basement) was amalgamated to the Sur-Obispo terrane to its west (which has a Franciscan basement), and (b) the resultant composite allochthon began to be translated northward, on the west side of a great northwest-southeast trending right-lateral fault system. This transport was driven by the northeastward convergence of the Farallon plate and possibly in part by the northward convergence of the Kula plate. (3) The allochthon apparently became attached to the western margin of the North American plate in the Paleocene or earliest Eocene and remained attached to this plate through the early Miocene. It was probably during the Paleocene-Eocene process of attachment that some of the folding of the Pigeon Point Formation occurred (Joyce, 1981; Gibson, 1983).

However, paleomagnetic data from the Pigeon Point Formation and from sedimentary rocks of the Salinian terrane are considered by some authors to be difficult to interpret because the rocks have been diagenetically altered, strongly folded and faulted, and at least in some cases magnetically overprinted. Thus, it is not clear whether the present magnetic signature was obtained before or after regional tilting (Dickinson, 1983; Grove, 1987). This uncertainty about the paleomagnetic interpretations has allowed additional reconstructions to be proposed for the pre-Neogene history of the Salinian terrane (presumably including the Pigeon Point block). According to these alternative models, the Salinian terrane may have originated within the North American continent, at latitudes

extending from the southern Sierra Nevada to the Peninsular Ranges (Silver, 1982; Dickinson, 1983; Seiders and Blome, 1988).

Most authors agree that the Salinian terrane and Pigeon Point block have been translated northward as part of the Pacific plate since the middle Miocene, due to right-lateral movements along the San Andreas and San Gregorio-Hosgri fault systems (Graham, 1978), causing some of the folding, faulting, and tilting of the Pigeon Point block (Joyce, 1981; Champion and others, 1984).

Palynology

Nine samples were collected for this study, but only two of them contained enough well-preserved palynomorphs to be useful for this study. The samples are as follows (fig. 1):

R4151A - Stop 1 of Howell and Joyce (1981), south end of Pescadero Beach. 4 slides examined.

R4152D - Stop 3 of Howell and Joyce (1981), just north of conglomerate belt at Pigeon Point. 1 slide examined.

Sample R4151A is from the lowermost part of the exposed section of the Pigeon Point Formation, and sample R4152D is within the upper 1/4 of the exposed formation (Howell and Joyce, 1981, fig. 3).

Tyler (1972) noted that the Pigeon Point marine sediments, particularly the siltstones, are carbonaceous and include pieces of coalified wood; thus, the spores and pollen in the formation apparently were derived from a nearby vegetation. Sandstone of the Pigeon Point Formation was derived mainly from erosion of a quartz dioritic to granodioritic source (Lee-Wong and Howell, 1977), probably from a continental pluton, and the coarseness of the conglomerates suggests that the formation was not deposited at a great distance from the source area; therefore, on petrologic and sedimentological grounds, the Pigeon Point Formation should not have been isolated from the continent, and plants producing the pollen and spores of the Pigeon Point Formation are not likely to have lived in isolation from floras of the continent.

Lithic clasts are not abundant in Pigeon Point sandstones, although they are more common than in Upper Cretaceous sandstones that definitely overlie the Salinian terrane; also, shale and mudstone chips are a higher proportion of total lithic clasts in the Pigeon Point sandstones than in sandstones definitely from the Salinian terrane (Lee-Wong and Howell, 1977). Thus, a small proportion of spores and pollen recorded from the Pigeon Point Formation may possibly represent redeposited specimens.

The flora of the Pigeon Point Formation is outlined in table 1 in the form of a listing of spore/pollen taxon groups and approximate numbers of species in each group. However, table 1 does not include most species of spores and gymnosperm pollen, which are of little biostratigraphic importance. Many of the Pigeon Point species are new or at least have not been formally named. The spores and pollen are compatible with a

Table A. Spore and pollen taxon diversities in samples from (1) the Pigeon Point Formation (Campanian to Maastrichtian); (2) an unnamed late Campanian to early Maastrichtian unit lying on the Salinian terrane in the La Panza Range, San Luis Obispo County, California; (3) the Lions Gate Member of the Burrard Formation (Campanian), lying on the Wrangellia terrane and the Coast Plutonic Complex of Vancouver (City) and Vancouver Island, British Columbia; (4) Maastrichtian and (5) late Campanian to Maastrichtian strata of the Great Valley sequence, western San Joaquin Valley, California; and (6, 7) late Campanian strata from the San Juan Basin, New Mexico.

Taxonomic group	Approximate number of species by locality						
	1	2	3	4	5	6	7
Spores							
Cicatricosisporites, *Appendicisporites*	4-5	2	4	3	[a]	[b]	
Gymnosperm pollen							
Eucommiidites	1		1		[a]	1	1
Gynkgaletes	2	2			[a]		
Gymnosperm and angiosperm pollen							
Monosulcates, psilate to punctate	1			3	1		3
Angiosperm pollen							
Triporopollenites with annulus	2	4		3	2		1
Momipites, *Triatriopollenites*, *Trivestibulopollenites*		1		4	3	2	
Miscellaneous triporates		1	1			[c]	2
4- to 5-porates			3			1	1
Erdtmanipollis				1	1		
Reticulate monosulcates		2		1	6	[c]	5
Proteacidites, *Siberiapollis*							
Evenly punctate to reticulate	1-2	8	2	8	[d]	[d]	2
More coarsely reticulate near the equator	4	2		1	[d]	[d]	

	1	2	3	4	5	6	7
Siberiapollis, verrucate	1						
Miscellaneous tricolpates	2	3	4	6	31	9[c]	3
Kurtzipites						1	1
Cranwellia					1		
Cupanieidites, Duplopollis							
Psilate to punctate	2		2				
Reticulate	2	3		4	5	2	2
Miscellaneous tricolporates		2	3	7-8	24	9[c]	5
Aquilapollenites	2		[e]		5	12[c]	
Normapolles				1	3-4	2	2

[a] No data are available from locality 5 on spores or gymnosperm pollen.
[b] Number of species not indicated.
[c] Minimum number of species.
[d] *Proteacidites* (and, no doubt, *Siberiapollis*) pollen is abundant in strata of localities 5 and 6, but the number of species was not stated.
[e] Several species of *Aquilapollenites* are known from the Maastrichtian of southwestern British Columbia (A. R. Sweet, written commun., 1987).

Campanian to Maastrichtian age for the Pigeon Point Formation, but the flora does not provide a definitive age. Nine specimens of dinocysts were found while scanning the slides for pollen and spores, but they were too poorly preserved to be useful for age or paleogeographic determination (L. E. Edwards, oral commun., 1990).

Unfortunately, no Late Cretaceous spore/pollen floras have been described from Central America. However, spore/pollen diversities are provided for six comparison localities in North America (fig. 2; locality numbers are those of fig. 2 and table 1):

2. An unnamed upper Campanian to lower Maastrichtian unit lying on the Salinian terrane in the La Panza Range, San Luis Obispo County, California (Frederiksen, 1987)
3. Lions Gate Member of the Burrard Formation (Campanian), lying on the Wrangellia terrane and the Coast Plutonic Complex of Vancouver (City) and Vancouver Island, British Columbia (flora from Rouse, 1962; age and stratigraphic nomenclature from Rouse and others, 1975)

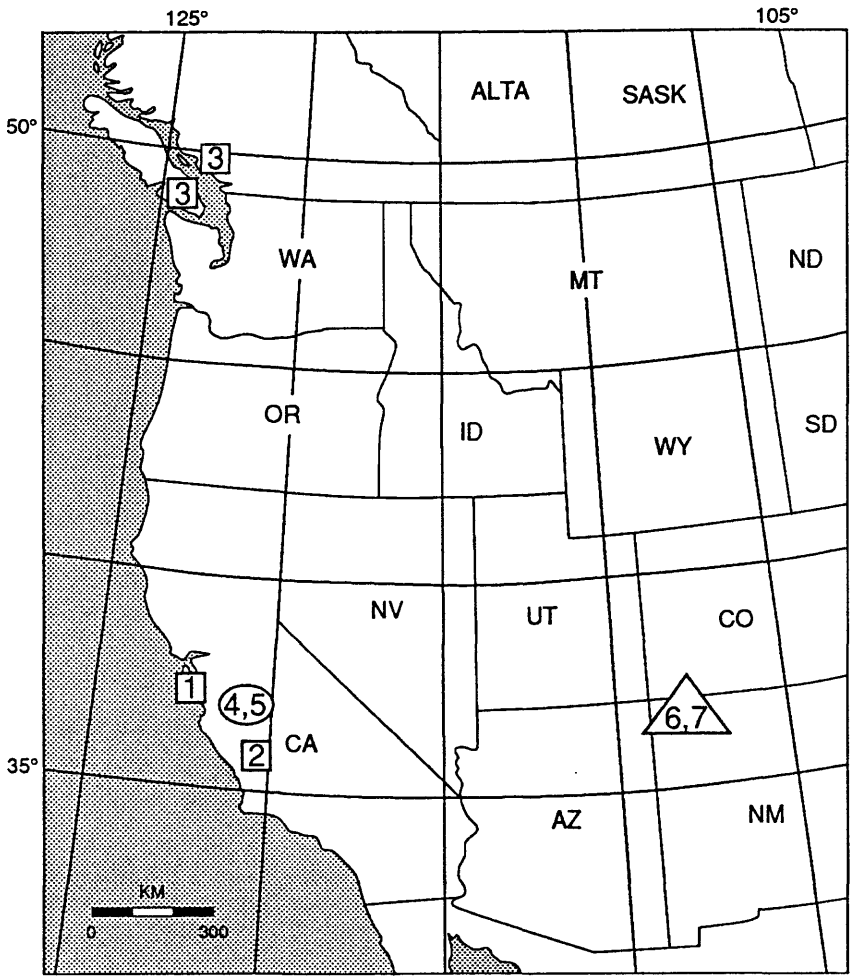

Figure 2. Map of Pigeon Point area (loc. 1) and comparison localities: 2, La Panza Range; 3, Vancouver (City) and Vancouver Island; 4, 5, western San Joaquin Valley; 6, 7, San Juan Basin (modified from Frederiksen, 1987, fig. 2). Squares = floras of the continental margin province; oval = floras transitional between those of the continental margin and *Aquilapollenites* provinces; triangle = floras of the *Aquilapollenites* province.

4. Part of the Moreno Formation (Maastrichtian), Great Valley sequence, Fresno County, western San Joaquin Valley, California (Drugg, 1967)
5. Parts of the Uhalde and Moreno Formations (late Campanian to Maastrichtian), Great Valley sequence, western San Joaquin Valley, California (Chmura, 1973)
6. Lewis Shale, Pictured Cliffs Sandstone, and Fruitland Formation (upper Campanian), Gasbuggy-1 corehole, San Juan Basin, New Mexico (Tschudy, 1973)
7. Kirtland Shale and Lewis Shale (upper Campanian), San Juan Basin, New Mexico (Anderson, 1960).

These comparison localities were chosen because the spore/pollen floras from them are well known and are approximately the same age as those from the Pigeon Point Formation; furthermore, some paleomagnetic data are available as to the latitudes at which the Campanian-Maastrichtian strata were deposited at each locality (references and discussion in Frederiksen, 1987). Late Cretaceous strata of locality 2 are thought to have been deposited at a latitude corresponding to present Central America, although that inference depends in part on the assumption that the Pigeon Point Formation lies in the Salinian terrane. Late Cretaceous strata of locality 3 may have been deposited at a latitude corresponding to some place in present California, perhaps northern California. In contrast, Late Cretaceous strata of the Great Valley sequence in the western San Joaquin Valley (localities 4, 5) apparently have moved northward only several hundred kilometers since deposition. Thus, the latest Cretaceous flora of southwestern British Columbia may represent roughly the same paleolatitude as the flora of the same age from the western San Joaquin Valley of California. The Campanian flora of the San Juan Basin apparently lived at approximately the same latitude where it is found at present (disregarding Cenozoic rotation of North America).

The floras of localities 2 and 3 of this paper are considered to belong to the Late Cretaceous continental margin floristic province, whereas the floras of localities 4 and 5 seem to be transitional between those of the continental margin province and those of the *Aquilapollenites* province (fig. 3; Frederiksen, 1987). The flora of the San Juan Basin is typical of the southern part of the *Aquilapollenites* province but is transitional to the Normapolles province (fig. 3; Tschudy, 1973; Frederiksen, 1987). "Angiosperm pollen assemblages from the continental margin province are rich in *Proteacidites* but have little or no pollen of the *Aquilapollenites*, *Callistopollenites*, Normapolles, anemophilous? porate or angiosperm monosulcate groups" (Frederiksen, 1987, p. 538). In all these features, the angiosperm pollen flora from the Pigeon Point Formation is typical of the continental margin floristic province, all known examples of which are thought to represent floras living on allochthonous terranes of western North America (fig. 3; Frederiksen, 1987).

Comparison with La Panza Range

The Pigeon Point Formation (loc. 1) is about 260 km northwest of samples from the Salinian terrane in the La Panza Range (loc. 2; fig. 2). The floras from these two localities have several significant elements in common, particularly the distinctive gymnosperm pollen genus *Gynkgaletes*, which has not been reported from any other of the comparison

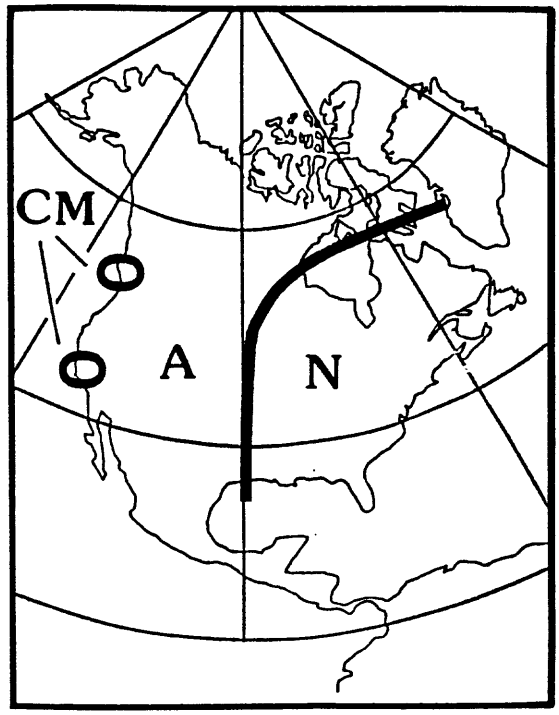

Figure 3. Latest Cretaceous floristic provinces of North America (from Frederiksen, 1987, fig. 1F). A = *Aquilapollenites* province; CM = continental margin province (sampled areas); N = Normapolles province.

localities, and the relative importance, among *Proteacidites-Siberiapollis* types, of species having a distinctly coarser reticulum at the equator than at the poles. Furthermore, no specimens of Normapolles pollen were seen in either flora; a high diversity of this pollen group is characteristic of the Campanian and Maastrichtian of eastern North America, and several Normapolles species are also found in the *Aquilapollenites* province and in the transitional area of the Great Valley sequence in the San Joaquin Valley (locs. 4 and 5, table 1; Tschudy, 1981). However, several possibly significant differences exist between the floras from the La Panza Range and the Pigeon Point Formation, for example, the presence of *Trivestibulopollenites* and two species of reticulate monosulcate pollen in

material from the La Panza Range, and the presence of the very important genus *Aquilapollenites* in the Pigeon Point Formation.

Aquilapollenites is represented by two species in the Pigeon Point Formation (both of them in sample R4151A, from the lowermost preserved part of the formation), but only one specimen of each species was found. The specimens are well preserved, and they are unlikely to be contaminants because they were found in two different slides, made from residues produced in different years. *Aquilapollenites* sp. A is new but has some similarity to *A. amicus* Srivastava 1968, *A. medeis* Srivastava 1968, *A. funkhouseri* Srivastava 1968, and *A. reticulatus* Stanley 1961, all of which are mainly or entirely known from the Maastrichtian. *Aquilapollenites* sp. B is very similar to *A. trialatus* Rouse 1957, which is known mainly from the Campanian but also from the lowermost Maastrichtian of North America (Tschudy and Leopold, 1971; unpub. work of the writer). Although the pollen genus increased in diversity northward in North America (and in Siberia), some species, known from rare specimens, have been found as far south as New Mexico (Tschudy, 1973; D. J. Nichols, written commun., 1986). Although *Aquilapollenites* has not, to my knowledge, been reported from the Upper Cretaceous of Mexico, a few species of this genus are known from the uppermost Cretaceous of northeastern Brazil, west Africa, and Egypt (references in Srivastava, 1978); thus, an extension of the known range of the genus from North America southward into Central America would not be surprising. On the other hand, it is possible that the rare specimens of *Aquilapollenites* in the Pigeon Point Formation represent long-distance transport, presumably by wind, as is suspected for rare Late Cretaceous pollen of this genus in eastern North America (Evitt, 1973; Srivastava, 1978; Frederiksen, 1989). According to models of latest Cretaceous atmospheric circulation (Parrish and Curtis, 1982), Central America probably lay in the belt of prevailing easterlies, whereas California probably lay in the belt of prevailing westerlies; thus, long-distance wind transport to the Pigeon Point block from a land area would be much more likely if the Pigeon Point Formation was deposited at the latitude of Central America than at the latitude of present California.

Comparison with southwestern British Columbia

The spore/pollen flora of the Lions Gate Member of the Burrard Formation (Campanian) in southwestern British Columbia is different in several ways from the floras of the Pigeon Point Formation and the La Panza Range. The Lions Gate flora (table 1, loc. 3) lacks *Gynkgaletes*, monosulcate pollen of both gymnosperm and angiosperm types, *Triporopollenites*, the *Momipites-Triatriopollenites-Trivestibulopollenites* group, and reticulate pollen of the *Cupanieidites-Duplopollis* group, and it has only a small diversity of *Proteacidites* and *Siberiapollis*; on the other hand, the Lions Gate flora has a larger diversity of 4- to 5-porates, tricolpates, and tricolporates than do the floras of the Pigeon Point Formation or the La Panza Range. It is difficult to evaluate the significance of these differences between the Lions Gate flora and those of the Pigeon Point Formation and the La Panza Range except that the composition of the Lions Gate flora suggests a slightly less tropical climate than the floras of the other two localities. The Lions Gate flora is

considered to belong to the continental margin floristic province (fig. 3; Frederiksen, 1987) in which *Aquilapollenites* is typically very rare or absent. The presence of several species of *Aquilapollenites* in the Maastrichtian strata of southwestern British Columbia suggests that a barrier between the Lions Gate block and the North American continent was breached toward the end of the Cretaceous.

Comparison with the Great Valley sequence

As noted previously, the late Campanian to Maastrichtian flora of the Great Valley sequence in the western San Joaquin Valley (locs. 4, 5 of table 1) probably comes from a block that has moved relatively little, with respect to the North American continent, since the end of the Cretaceous. This flora has definite affinities with those of the continent because it includes several species each of the Normapolles, *Aquilapollenites*, and *Momipites-Triatriopollenites-Trivestibulopollenites* groups, as well as such genera as *Erdtmanipollis* and *Cranwellia.* The large number of tricolpate, tricolporate, and reticulate monosulcate species undoubtedly is due in part to the unusually good preservation of the pollen from localities 4 and 5, but the large overall diversity of this flora is in contrast to the rather low diversities that seem to be characteristic of floras of the continental margin province.

Comparison with San Juan Basin

Localities 6 and 7 are in the San Juan Basin and are both late Campanian in age, but it is noticeable that fewer taxa were identified at locality 7 than at locality 6 because data from locality 7 are from an early paper (Anderson, 1960) in which some taxa (for example, *Aquilapollenites*) were not identified, and many more samples were examined from locality 6 than from locality 7. As discussed elsewhere (Frederiksen, 1987), the late Campanian flora from the San Juan Basin has a strong affinity to other latest Cretaceous floras of the Western Interior, for example, in the diversity of species of reticulate monosulcates and *Aquilapollenites* and in the presence of pollen taxa such as *Kurtzipites* and Ulmaceae (the latter family is represented among the 4- to 5-porates). The late Campanian flora of the San Juan Basin is distinctly different from floras of the continental margin floristic province (Frederiksen, 1987) including the Pigeon Point flora.

The San Juan Basin is well within the continent. Some hypotheses place the Pigeon Point Formation, at its time of deposition, in the area of present south-central or even southeastern California (Silver, 1982; Dickinson, 1983; Seiders and Blome, 1988). In that area, the Pigeon Point block would then have been separated from the San Juan Basin by the Sevier Highlands. However, these highlands apparently acted only as a partial barrier between floristic provinces because late Campanian to Maastrichtian floras of the Great Valley of California (localities 4, 5) have affinities with floras of the Western Interior as well as with the continental margin province. Thus, if the Pigeon Point flora had originated in present south-central or southeastern California, it probably would be very similar to the

Great Valley floras rather than being distinctly similar to floras of the continental margin province.

Conclusions

The flora of the Pigeon Point Formation places it in the continental margin floristic province, and the most similar flora known from that province is the late Campanian to early Maastrichtian unit lying in the Salinian terrane in the La Panza Range of San Luis Obispo County. However, the Pigeon Point flora is different in several ways from that of the La Panza Range, much as the petrography of the Pigeon Point sandstones and conglomerates differs from that of sandstones and conglomerates of the Salinian terrane. In short, the Pigeon Point flora cannot be used to prove or disprove the hypothesis that the Pigeon Point Formation lies above Salinian basement.

The Pigeon Point flora might have differed from contemporary floras of the North American continent if the Pigeon Point block lay well offshore, but this possibility seems disproved by petrographic and sedimentological evidence (Lee-Wong and Howell, 1977; Howell and Vedder, 1978; Howell and Joyce, 1981). The affinity of the Pigeon Point flora to the continental margin floristic province suggests that at the time of deposition of the formation, the Pigeon Point block did not lie at a latitude as far north as the present United States.

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