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NORTH AMERICAN APPARENT POLAR WANDER, PLATE MOTION, AND LEFT-OBLIQUE CONVERGENCE: LATE JURASSIC-EARLY CRETACEOUS OROGENIC CONSEQUENCES

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Abstract. The North American apparent polar wander (APW) path indicates an episode of unusually rapid absolute northward motion of western North America between 150 and 135 Ma. During this time the northward component of absolute motion of points along the Washington-Oregon-California coast was in excess of 150 km/m.y. and perhaps as high as 230 km/m.y. We believe that such high absolute northward velocity for North America probably ensures that relative motions of oceanic plates and terranes influenced by them were to the south at this time.

The inception of rapid northward motion and left-oblique convergence was abrupt and should be recorded in the geology of the western Cordillera. It is tempting to correlate this period of unusual Pacific basin-North American interaction with the "Nevadan orogeny" in the Klamath Mountains as well as with left-lateral strike-slip structures such as the Pine Nut fault and Bear Mountains fault zone. Significant differences exist between North American plate motion recorded by the Late Jurassic-Cretaceous APW path and that predicted by a fixed hotspot model. We believe that this discrepancy reflects uncertainty associated with pre-Late Cretaceous hotspot tracks and poorly constrained relative plate motions during the Cretaceous normal polarity superchron.

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INTRODUCTION

Apparent polar wander (APW) paths record the motion of plates with respect to the spin axis of the Earth (i.e., geographic north and south poles). Estimates of plate velocity from APW paths are necessarily minimum values because the longitudinal component of plate motion cannot be directly determined from paleomagnetic data. Nevertheless, the latitudinal and azimuthal components of plate motion contained within an APW path can be used to evaluate the relationship between plate motion and intraplate tectonics including deformation, basin formation, and magmatism.

Gordon et al. [1984] and May and Butler [1986] demonstrated that APW paths can be successfully modeled as a series of small circle segments (tracks) separated by sharp corners or cusps. Tracks are interpreted as the record of plate motion about a single Euler pole with constant angular velocity while cusps represent distinct changes in direction and velocity of plate motion (i.e., plate reorganization events). The logical hypothesis tested in this paper is that plate margin deformation, magmatism, and terrane displacement is a direct consequence of relative and/or absolute plate motion and therefore the timing of plate motion events described by an APW path should correspond to tectonic history.

SOME UNDERLYING PRECONCEPTIONS

Orogenic belts are the result of plate tectonic processes that act on convergent or transform plate margins [e.g., Dewey and Bird, 1970; Coney, 1972]. (We use the term "orogeny" in a general sense to refer to tectonism including both deformation and magmatism. No particular style of deformation is implied. Accordingly, an "extensional orogen" is just as meaningful a concept as a "compressional orogen.") Such margins tend to remain active for periods of the order of 10^7-10^8 years, so orogenic belts should be active for comparable periods. Historically, estimates of the duration of orogeny vary widely. For instance, Stille [1936] believed that individual orogenies lasted only about 0.5 m.y. or less, punctuating long periods of quiescence. At the other extreme, Gilluly [1963] thought that orogeny within individual orogenic belts was essentially continuous for many hundreds of millions of years. The estimated duration of active orogeny in a single belt in the plate tectonic model falls somewhere between these extremes. Nothing, however, in the plate tectonic model requires that orogeny be particularly steady state; if orogeny is caused by plate interactions, then important changes in plate interaction should be highlighted in the geologic record as episodes of conspicuous tectonic activity. During the life of an orogenic belt (say 10^8 years) it would be normal to encounter pulses (perhaps 10^7 years) of "unusual" orogenic activity, reflected in "new" structures and perhaps by changes in the amount or type of igneous rock being produced; these would form the separate orogenies of classical tectonic literature. Thus the Nevadan, Sevier, and Laramide orogenies represent different episodes of intraplate deformation that may have been associated with changes in plate interactions (direction and velocity) within a period of essentially continuous Cordilleran tectonic activity that has lasted since early Mesozoic time.

In the plate tectonic model we might expect to find orogenic pulses or phases associated with the following: (1) the inception of subduction (along a margin that had previously been passive), (2) collision of a continental margin with a large fragment of crust too buoyant to subduct, (3) a large increase in rate of convergence, (4) a dramatic change in the direction of convergence (as from right oblique to left oblique), and (5) a rapid decrease in the age of subducting lithosphere (as when a ridge approaches and is extinguished against a trench).

Obviously this is not an exhaustive list. Many of these theoretical "orogeny-producing" events involve abrupt first-order changes in relative plate motions. For this reason, plate motion studies are very useful for orogenic modeling. The Laramide orogeny, for instance, has been correlated with a rapid shallowing of subduction angle of Farallon or Kula plates beneath North America. Both increased convergence rate and younging of the subducting slab were likely responsible [Coney, 1972; Coney and Reynolds, 1977; Jones et al., 1982; Engebretson et al. 1985; etc.]. In this paper we suggest that Late Jurassic-Early Cretaceous deformation and magmatism (in part the "Nevadan orogeny") may be the intraplate response to such an event as 4 above. During this time, plate convergence relative to western North America became strongly left oblique.

Recent analysis of the North American Jurassic APW path [May and Butler, 1986] suggests a distinct episode of very rapid plate motion between about 150 and 135 Ma. This interval of poleward motion is represented by the J2-K track of APW shown in Figure 1 and contrasts markedly with the older J1-J2 track (Early to Late Jurassic) and with the Cretaceous "stillstand" during which no significant APW is observed from 135 to 75 Ma. We believe that this interval of high-velocity latitudinal motion correlates with deformation in the western Cordillera characterized by collapse of marginal arc terranes and left-oblique structures. The rate of

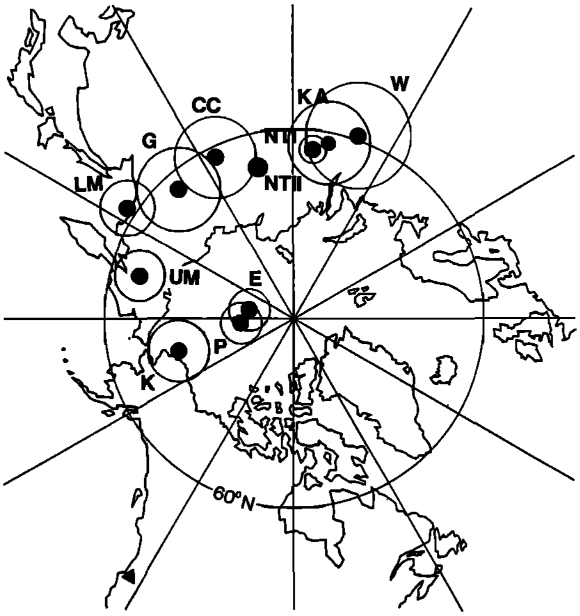

Fig. 1a. Apparent polar wander path for the North American craton [from May and Butler, 1986; Globerman and Irving, 1988; and Diehl et al., 1983]. Solid triangle is "observation site" (42°N, 124°W) discussed in text. Some pre-Cretaceous poles have been corrected for 3.8° clockwise rotation of the Colorado Plateau [Bryan and Gordon, 1986; May and Butler, 1986]. W, Wingate Formation [Reeve, 1975]; KA, Kayenta Formation [Steiner and Helsley, 1974]; NTI, Newark Trend I [Smith and Noltimier, 1979]; NTII, Newark Trend II [Smith and Noltimier, 1979]; CC, Corral Canyon rocks [May et al., 1986]; G, Glance Conglomerate [Kluth et al., 1982]; LM, lower Morrison Formation [Steiner and Helsley, 1975]; UM, upper Morrison Formation [Steiner and Helsley, 1975]; K, mean Cretaceous "stillstand" pole [Globerman and Irving, 1988]; P, mean Paleocene pole [Diehl et al., 1983]; E, middle-early Eocene pole [Diehl et al., 1983].

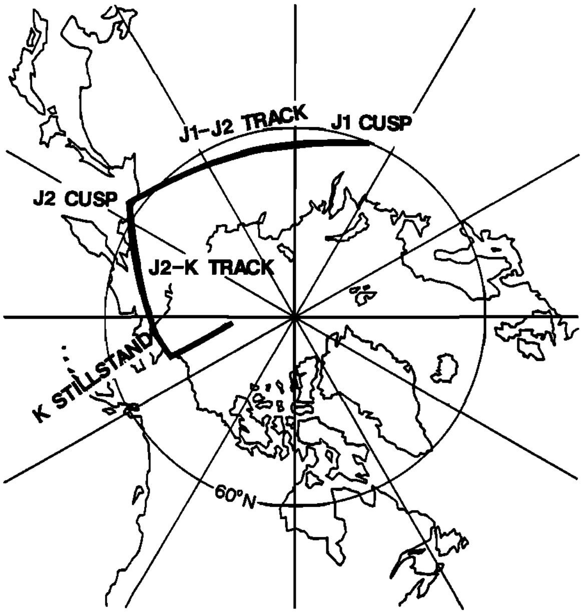

Fig. 1b. APW track and cusp terminology [after May and Butler, 1986].

northward absolute motion for the western margin of North America calculated from the APW path is extraordinarily high. In turn this suggests that, unless Farallon or Kula absolute northward velocities were greater than about 15 cm/yr, relative plate motion along western North America must have been left oblique. In part, this phase of deformation and associated magmatism includes the "Nevadan" orogeny in the Klamath Mountains of California and Oregon [Harper and Wright, 1984; Ingersoll and Schweickert, 1986, and references therein].

We accept the plate tectonic view of orogenic deformation as a long-continued process affecting active plate margins, beginning with the inception of convergence and evolving as the mode and intensity of plate interaction evolves. However, as discussed above, it should be possible to recognize major pulses or transitions in tectonic activity related to major changes in plate interactions [see Beck, 1984]. Two such changes or pulses are recorded in the North American APW path in the Late Jurassic and Early Cretaceous.

NORTH AMERICAN APPARENT POLAR WANDER AND IMPLICATIONS

Figure 1a shows the APW path for the North American craton for Jurassic through Eocene time [after May and Butler, 1986; Globerman and Irving, 1988; and Diehl et al., 1983]. Four episodes of APW are evident. Because we are interested in the tectonic implications of APW on the western margin of North America, these episodes will be described from the point of view of an observer on the continental margin (42°N, 124°W for the purposes of our calculations).

1. For much of the Jurassic, the observation site changed its orientation relative to the paleomeridian by rotating clockwise. It also moved gradually northward. This is the J1-J2 small-circle track of May and Butler [1986] (Figure 1*b*) reflecting North American motion about a single Euler pole with constant angular velocity from about 200 to 150 Ma.
2. At about 150 Ma there was a major change in both the direction and rate of North American plate motion such that from 150 to 135 Ma the observation site moved almost directly toward the pole at high velocity. This represents the J2-K small-circle track of May and Butler [1986] (Figure 1*b*).
3. During most of the Cretaceous (135-75 Ma) the observation site appears to have remained stationary with respect to the pole. (Of course, it may have been moving rapidly westward at that time, but this cannot be determined from the paleomagnetic record.)
4. Beginning in the Late Cretaceous and continuing into the Early Tertiary, the observation site rotated counterclockwise and receded gradually from the pole into lower latitudes.

For our purposes Figure 1 is important chiefly because it provides a chronology of changes in paleolatitude. Figure 2 shows the paleolatitude of the observation site as a function of time, calculated from the reference poles shown in Figure 1 using the dipole formula [Irving, 1964] (Table 1). The slope of the plot of paleolatitude versus time measures the northward component of absolute velocity for our point near the center of the western North American Cordillera (42°N, 124°W present coordinates). The significant deduction from Figure 2 is that the observation site had a northward component of absolute motion that exceeded 15 cm/yr for a relatively brief interval from about 150 to 135 Ma.

This account obviously relies on the correctness of the APW path shown in Figure 1. Other paths have been suggested [e.g., Irving and Irving, 1982; Gordon et al., 1984], but they also show an episode of rapid poleward motion for western North America during the Late Jurassic-Early Cretaceous, although not so dramatically and with less temporal resolution. In addition, some of the Jurassic poles shown in Figure 1 have been corrected for clockwise rotation of the Colorado Plateau [Bryan and Gordon, 1986; May and Butler, 1986], and the exact amount of rotation, if any, is in dispute [Steiner, 1986, 1988; Bryan and Gordon, 1986]. However, it is clear that any reasonable amount of correction for rotation will leave the 150-135 Ma episode of rapid

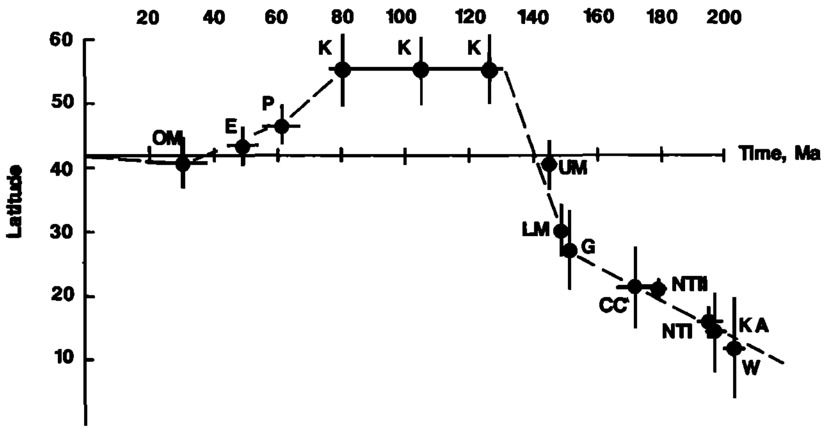

Fig. 2. Paleolatitude of "observation site" (42°N, 124°W) as a function of time, calculated from reference poles shown in Figure 1. Note the rapid increase in paleolatitude during the Late Jurassic-Early Cretaceous. Symbols as in Figure 1.

northward motion of western North America essentially unaffected.

Because our arguments are based on a close temporal coincidence between different data sets, it is important to review the age constraints on the J2 cusp and the J2-K APW track. The age of the J2 cusp, and therefore the time of initiation of rapid northward motion of our observation site, is constrained by the Glance Conglomerate pole of Kluth et al. [1982] and the lower Morrison Formation pole of Steiner and Helsley [1975]. The Glance pole (formerly called the Canelo Hills pole) was derived from welded ash flow tuffs which have yielded a Rb-Sr whole rock isochron age of 151±2 Ma.

The age of the Morrison Formation is somewhat more enigmatic. May [1985] reviewed arguments for the age of the Morrison and assigned absolute ages using the Harland et al. [1982] time scale of 149 Ma and 145 Ma for the Salt Wash and Brushy Basin members, respectively (i.e., lower and upper Morrison at the Norwood, Colorado, locality of Steiner and Helsley [1975]). Recently, Kowalis and Heaton [1987] published fission track dates from the Morrison Formation in central Utah. Their results suggest that at this locality most of the Morrison is Late Jurassic and perhaps Early Cretaceous in age with dates ranging from 130 to 157 Ma. Fission track dates from zircons in the lower part of the

TABLE 1. Latitudinal History of a Point on the Western Edge of North America Near the Oregon-California Border (42°N, 124°W Present Coordinates)

Paleopole Symbol	Age, Ma	Calculated Latitude	Paleopole Name	Reference
OM	22-38	40.7±4.1	composite	Diehl et al. [1983]
E	44-54	43.4±3.0	composite	Diehl et al. [1983]
P	55-67	46.7±3.2	composite	Diehl et al. [1983]
K	135-75	54.9±4.9	composite	Globerman and Irving [1988]
UM	145	40.5±3.9	upper Morrison Formation	Steiner and Helsley [1975]
LM	149	30.3±4.2	lower Morrison Formation	Steiner and Helsley [1975]
G	151±2	27.0±6.3	Glance Conglomerate	Kluth et al. [1982]
CC	172±6	21.3±6.2	Corral Canyon rocks	May et al. [1986]
NTII	179±3	21.1±1.4	Newark Trend II	Smith and Noltimier [1979]
NTI	195±4	15.9±2.3	Newark Trend I	Smith and Noltimier [1979]
KA	194-200	14.4±6.3	Kayenta Formation	Steiner and Helsley [1974]
W	200-206	11.7±8.0	Wingate Formation	Reeve [1975]

For composite poles, age indicates age range of poles included in average; other ages from May and Butler [1986]. Error limits on paleolatitudes are radii of 95% confidence circles about mean poles.

Morrison (Salt Wash member in part] range from 142±6 to 157±7 Ma, which is consistent with the 149 Ma age suggested by May [1985]. Kowalis and Heaton [1987] report 130±7 to 144±7 Ma zircon ages from the lower part of the Brushy Basin member. However, the upper part of this member yields very young dates ranging from 99±5 to 123±7 Ma. As discussed by these authors, the anomalously young age determinations probably reflect problems associated with stratigraphic relationships between the upper Morrison and Cedar Mountain formations. The upper Morrison pole of Steiner and Helsley [1975] (Figure 1) clearly predates the Cretaceous stillstand, which is at least 126±6 Ma (see below) and probably as old as 130-135 Ma, requiring that the age of the Brushy Basin member be somewhere between 130 and 150 Ma. Alternatively, one might interpret the Morrison to be severely time transgressive across its regional outcrop extent, but we are unaware of any strong evidence in this regard. Given available constraints, the 149 and 145 Ma dates for the lower and upper Morrison poles are still considered as most likely, but small adjustments to these ages will not affect our arguments about North American plate motion. (If the Morrison horizons sampled are in fact younger than we believe, then the rate of northward motion implied by the J2-K track is even greater.)

The age of the young end of the J2-K track is even less well constrained than is the J2 cusp. The oldest pole included in the Cretaceous stillstand pole of Globerman and Irving [1988] is the Monteregian Hills pole [Larochelle and Black, 1963] with a published age range of 118-136 Ma. The average Cretaceous pole calculated from rocks with ages ranging from ~136 to 85 Ma is located at 71°N, 196°E, $\alpha_{95} = 4.9°$. Paleomagnetic Euler pole analysis by May and Butler [1986] suggested that a stillstand position would likely have been achieved by about 135 Ma. Clearly, more reference poles are needed from Late Jurassic and Early Cretaceous rocks from cratonic North America.

Acknowledging a certain absolute age uncertainty associated with the Morrison poles, the pattern and timing of the J2-K APW track is still unambiguous and requires unusually rapid northward motion of western North America during Late Jurassic and Early Cretaceous time (approximately 150 Ma to 135 Ma).

TRANSPORT DIRECTION OF ALLOCHTHONOUS TERRANES

It is well established that many crustal blocks within the Cordilleran "collage" have moved a significant distance along the continental margin since they formed. Evidence of strike-slip faulting parallel to the margin [Gabrielse, 1985], or latitudinally displaced faunal assemblages [Newton, 1983], are examples of the kind of geological observations that support this statement. However, most of the quantitative support comes from paleomagnetism. Paleomagnetic inclinations reflect paleolatitude, and comparison of observed and "expected" inclinations can indicate whether or not a crustal fragment has moved with respect to the craton to which it is now attached. This method is well established and yields internally consistent results; see reviews by Beck [1980, in press] and Irving [1979].

Displacements of the order of several thousand kilometers have been inferred. However, recent revision of Late Triassic and Jurassic North American reference poles [Gordon et al., 1984; May and Butler, 1986] has shown that long-distance latitudinal transport previously proposed for some terranes (e.g., Quesnellia and Stikinia) is no longer required by paleomagnetic data. Beck [in press] has suggested that a statistically insignificant bias toward slightly near-sided poles indicates that net motion of these terranes may actually have been southward. If so, their southward displacement most likely occurred during the Late Jurassic-Early Cretaceous episode of left-oblique convergence.

As stated above, most of the recognized displacements seem to have been northward relative to North America [e.g., Hillhouse, 1977; Beck et al., 1981; Champion et al., 1984; Hagstrum et al., 1985]. However, it seems likely that much of this displacement took place during the period from Late Cretaceous to Eocene. "Coastwise transport" of terranes probably operates in a direction determined by the sense of relative motion of continental and oceanic plates; for the Cordillera, right-oblique convergence and/or dextral transform interaction produce relative northward transport and vice versa. Engebretson et al. [1985] show an episode of unusually rapid north-oblique convergence (between North America and both Kula and Farallon plates) during the Late Cretaceous to Eocene interval. Transport of these oceanic plates with respect to North America "ought" to have been rapidly northward during this time.

The story from pre-Late Cretaceous evidence may be different. Plate motion models are significantly less reliable for times during and before the Cretaceous normal polarity superchron (83-118 Ma), although reconstructions by Engebretson et al. [1985] do suggest a difference; relative motion before mid-Cretaceous time includes intervals of left-oblique convergence. Avé Lallemant and Oldow [1988] have documented kinematic interpretations of structural data from western North America to suggest a complex history of alternating left-oblique and right-oblique convergence through the Mesozoic and Cenozoic. They consider the interval from 165 to 120 Ma to be one dominated by left-oblique convergence and southward translation of Cordilleran forearc terranes. Relying exclusively on paleomagnetic data, we believe that the interval from 150 to 135 Ma should be associated with left-oblique relative plate motion and plate margin tectonism.

SUPPORTING GEOLOGICAL EVIDENCE

A drastic change in North American plate motion at 150 Ma corresponds very closely in time with the age of the Nevadan orogeny in the Klamath Mountains. At 145-150 Ma the Josephine-Galice back arc basin collapsed, and the Late Jurassic Rogue-Chetco arc terrane was accreted to the western margin of North America [Harper and Wright, 1984]. Collapse of such a back arc basin can easily be envisioned as a consequence of major plate reorganization. The Nevadan orogeny in its type area, the Sierra Nevada, appears to be somewhat different than in the Klamath Mountains and perhaps slightly older. Relationships in the northern Sierra Nevada discussed by Ingersoll and Schweickert [1986] indicate that the classical Nevadan is 155-158 Ma. On the other hand, Bogen et al. [1985] argue that the Nevadan is 153±3 Ma in the Sierra Nevada and therefore not significantly older than in the Klamath Mountains, nor older than the J2 APW cusp. Furthermore, Bogen et al. [1985] report paleomagnetic data from three Jurassic formations in the Sierra Nevada concluding that all record a secondary magnetization attributable to a Nevadan metamorphic overprint. Their mean pole position shown in Figure 3 is identical to the 145 Ma upper Morrison pole on the J2-K APW track. This suggests a close temporal relationship between Nevadan metamorphism and the unusually rapid northward North American plate motion evident in the APW path.

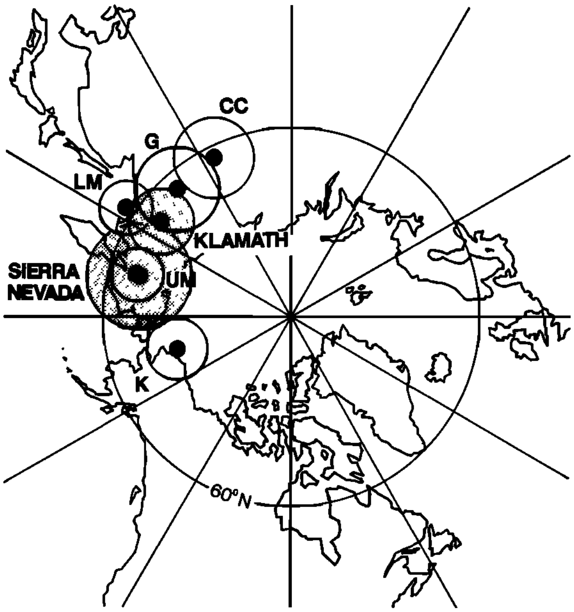

Fig. 3. Paleomagnetic poles from Bogen [1986] and Bogen et al. [1985] interpreted to be "Nevadan" remagnetizations in the Klamath Mountains (vertical axis rotation removed) and the Sierra Nevada. Note both poles fall on the J2-K track. Symbols for reference poles as in Figure 1.

Similarly, Bogen [1986] reported paleomagnetic results from the Galice Formation in the northern Klamath Mountains. He interprets the secondary magnetization observed in these rocks as a Nevadan remagnetization which had subsequently been rotated 99±10° clockwise. Removal of this rotation yields an intersection with the J2-K track concordant with the 151 Ma Glance Conglomerate pole and the 149 Ma lower Morrison pole (i.e., directly on the J2 cusp) (Figure 3). Although these arguments may be construed as somewhat circular, we think that the observed and interpreted correspondence between poles ascribed to Nevadan remagnetization and the J2 cusp suggests a significant temporal tie between a tectono-metamorphic event and APW geometry.

The Ingersoll and Schweickert [1986] model for Nevadan tectonics involves an arc-continent collision at approximately 158 Ma followed by back arc rifting and then subsequent collapse of the back arc basin at 150 Ma. At present it seems possible to correlate only the 150 Ma Klamath event directly with the J2 APW cusp, and we find this correlation compelling. As discussed above, Avé Lallemant and Oldow [1988] believe that left-oblique relative convergence began at approximately 165 Ma, suggesting that relative motion may have been dominated by Farallon (or Kula) absolute motion from 165 to 150 Ma rather than by North American absolute motion, as we suggest for 150-135 Ma.

Evidence for left-oblique convergence reviewed by Avé Lallemant and Oldow [1988] includes the Late Jurassic-Early Cretaceous, southeast vergent, Luning-Fencemaker fold and thrust belt of western Nevada. The Pine Nut fault located along the western margin of the Luning-Fencemaker system records sinistral strike-slip displacement and separates domains of differential crustal shortening [Oldow, 1983, 1984]. Oldow [1983] cites evidence for the timing of motion on the Pine Nut from K-Ar dates of 145-165 Ma on a syntectonic pluton and 100 Ma dates on posttectonic plutons. The magnitude of displacement and associated shortening is believed to be of the order of hundreds of kilometers.

The Bear Mountain fault zone in the Sierran foothills is another left-lateral strike-slip structure cited by Avé Lallemant and Oldow [1988], whose age is constrained by U-Pb and K-Ar dates between 151 and 123-110 Ma. Newton [1986, p. 706] describes a Kimmeridgian-Tithonian Nevadan orogeny in the southern Foothills terrane of the Sierra Nevada as due to "sinistral oblique convergence between the Farallon and North American plates." This relative plate motion is considered to be responsible for left-lateral transpressional deformation accommodated along NW-striking left-lateral oblique- and strike-slip faults [Newton, 1986]. The Bear Mountains fault zone is described as a major shear zone associated with a NNW-SSE stretching lineation and left-lateral kinematic indicators.

Paterson et al. [1987] recognize a southern continuation of the Bear Mountains fault zone along which they believe eastern and western Jurassic volcanic arc sequences of the Foothills terrane were amalgamated during and after Nevadan deformation. These authors argue that structural data and timing relations in the southern Foothills area are not consistent with a "short-lived" Nevadan orogeny but suggest significant deformation probably continued into the Cretaceous. The timing on the Bear Mountains fault zone corresponds quite closely with the age of the J2-K APW track.

In the southern Cordillera the Jurassic magmatic arc which had stretched across southern Arizona ceased activity at about 150 Ma, and a similar although less dramatic decline in magmatism is documented in the Sierra Nevada batholith of California from about 150 Ma to 120 Ma [Chen and Moore, 1982]. The 151 Ma volcanic rocks associated with the Glance Conglomerate in SE Arizona [Bilodeau et al., 1987] are directly associated with the earliest evidence for significant extension in the Bisbee Basin, an area that had previously been the site of arc magmatism throughout much of the Jurassic.

A WORD ABOUT REFERENCE FRAMES

On the basis of APW path shown in Figure 1 there is little doubt that the paleolatitude of the Cordillera increased very rapidly during the Late Jurassic to Early Cretaceous. More paleomagnetic data may change some of the details of the shape of the J2-K track, but the fact that the paleomagnetic pole approached western North America during this time interval will almost certainly survive. If Figure 1 is substantially correct, then so is Figure 2, assuming that the axial geocentric dipole hypothesis (i.e., a fundamental hypothesis in paleomagnetism) is correct. However, Figure 2 can be true and our main deduction from it be false. This would require an episode of true polar wander (TPW) during the Late Jurassic-Early Cretaceous. If this were the case, then the North American APW path could not be simply used to infer relative plate motions along the Cordilleran margin.

TPW has been studied recently by Andrews [1985] and Livermore et al. [1984]. In both studies, displacements of selected paleomagnetic poles by plate motion were eliminated using the fixed hotspot model of Morgan [1983]. Repositioned poles were then compared to the spin axis. Both studies found that the repositioned paleopoles were systematically offset from the spin axis for certain time intervals; this was interpreted as evidence for TPW. Both studies relied on the same hotspot model of Morgan [1983], and objections can be raised as to details of the paleomagnetic poles used. Nevertheless, both studies suggest the existence of episodes of significant TPW, with velocities as high as 100 km/m.y. Jurassic TPW is more difficult to recognize than later episodes because Jurassic hotspot tracks become quite ambiguous. However, both studies concluded that the Late Jurassic was a time of fairly insignificant TPW; less than 20 km/m.y.

Our comparison of the recently published and popular hotspot-based plate motion model of Engebretson et al. [1985] with plate motions predicted by the paleomagnetic data suggests significant differences. We believe that these differences are the result of poorly constrained Late Jurassic-Early Cretaceous hotspot tracks, poorly constrained relative plate motion during the Cretaceous normal polarity superchron (118-83 Ma), and the simple fact that hotspots do not provide a truly consistent fixed reference frame [Chase and Liu, 1985; Molnar and Stock, 1987]. Until these problems can be resolved, TPW during the Jurassic-Early Cretaceous cannot be evaluated, and paleomagnetic poles in conjunction with marine magnetic anomalies must be considered the most reliable reference frame for modeling plate motion.

SUMMARY

The APW path for the North American craton shows an interesting pattern of abrupt changes in velocity and direction that appear to have major tectonic significance. In particular, during Late Jurassic-Early Cretaceous time (roughly 150-135 Ma) the APW path requires the western edge of North America to have moved northward at a speed of at least 150 km/m.y., perhaps exceeding 200 km/m.y. Terranes during this interval may have moved southward with respect to North America. Evidence for plate margin deformational response at this time includes the collapse of a back arc basin during the Nevadan orogeny in the Klamath Mountains, left-lateral strike-slip faulting in western Nevada and California, possible relative southward transport of terranes along the western continental margin, and a west-sweeping arc in the southern Cordillera. It is suggested here that the J2-K APW interval (150-135 Ma) correlates with this major tectonic episode affecting much of the western edge of North America and was associated with left-oblique rather than right-oblique convergence.

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