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NORTHWARD TRANSLATION OF MESOZOIC BATHOLITS, WESTERN NORTH AMERICA: PALEOMAGNETIC EVIDENCE AND TECTONIC SIGNIFICANCE

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RESUMEN

Investigaciones paleomagnéticas indican que muchos, quizá todos, los batolitos Mesozoicos localizados en el margen occidental de Norteamérica se originaron al sur de sus localidades presentes. Dos clases de transporte tectónico han contribuido a esta migración tectónica general: (1) transporte estilo California, en el cual los batolitos son separados de la masa continental a través de fallas transformadas; y (2) transporte estilo Sunda, en el cual un fragmento de litósfera, incluyendo a los batolitos, es trasladado a lo largo del margen continental en respuesta a procesos de subducción oblicua. La interacción de la placa Norteamericana con las placas Farallón y Kula puede explicar la creación de los batolitos, así como su transporte hacia el norte.

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ABSTRACT

Paleomagnetic measurements indicate that many, perhaps all, Mesozoic batholiths currently on the western edge of North America originated far south of their present locations. Two kinds of tectonic transport probably contributed to their general northward migration: (1) California-style transport, in which the batholith belt becomes detached from the continent along a zone of transform faulting; (2) Sunda-style transport, in which a sliver of continental lithosphere including the batholith belt moves along the edge of the continent in response to oblique subduction. Interaction of North America with the Farallon and Kula plates can account for the creation of the batholiths, as well as their northward transport.

1. INTRODUCTION

Fig. 1 shows the distribution of major Mesozoic batholiths in the western Cordillera of North and Central America. Granitic material is present along the entire edge of the continent, but its concentration in the northern half of the map is unmistakable.

Figs. 2-4 show the plate-tectonic setting of western North America at 80 and 40 m.y.B.P., after Atwater (1970), Coney (1978) and Engebretson (manuscript in preparation). Although major differences are apparent between these reconstructions, they all agree in showing the Farallon and North American plates in contact for a longer period of time in the south than in the north. Although not apparent in the diagrams, all three analyses also agree that Farallon-North America interaction was convergent, involving eastward subduction during the late Mesozoic and early Tertiary, whereas Kula-North America interaction at this time was of the transform (strike-slip) type, or involved very oblique subduction.

Taken together, Figs. 1-4 suggest an enigma. If, as most investigators believe, large calc-alkaline batholiths are the product of subduction, why are most located in the north? From Figs. 2-4 one might expect just the opposite – a preponderance of Mesozoic batholiths south of about latitude 35^{o}N, reflecting continuous subduction of the Farallon plate beneath North and Central America, with fewer (and dominantly younger) plutons to the north where Kula-America interaction was the rule for most of Mesozoic time. The fact that precisely the opposite distribution is observed might mean (1) that uplift has been less in the south than in the north, and hence the batholiths of Mexico and Central America are not completely exposed, or (2) that the angle of subduction for most of late Mesozoic time was relatively shallow in the south, and thus less magma was produced here. These are *ad hoc* hypotheses which, although possible, are not particularly satisfying. In this paper we present evidence for a third hypothesis – specifically, that many of the Mesozoic batholiths now located in the north were in fact formed in the south and subsequently were transported northward by plate-tectonic processes.

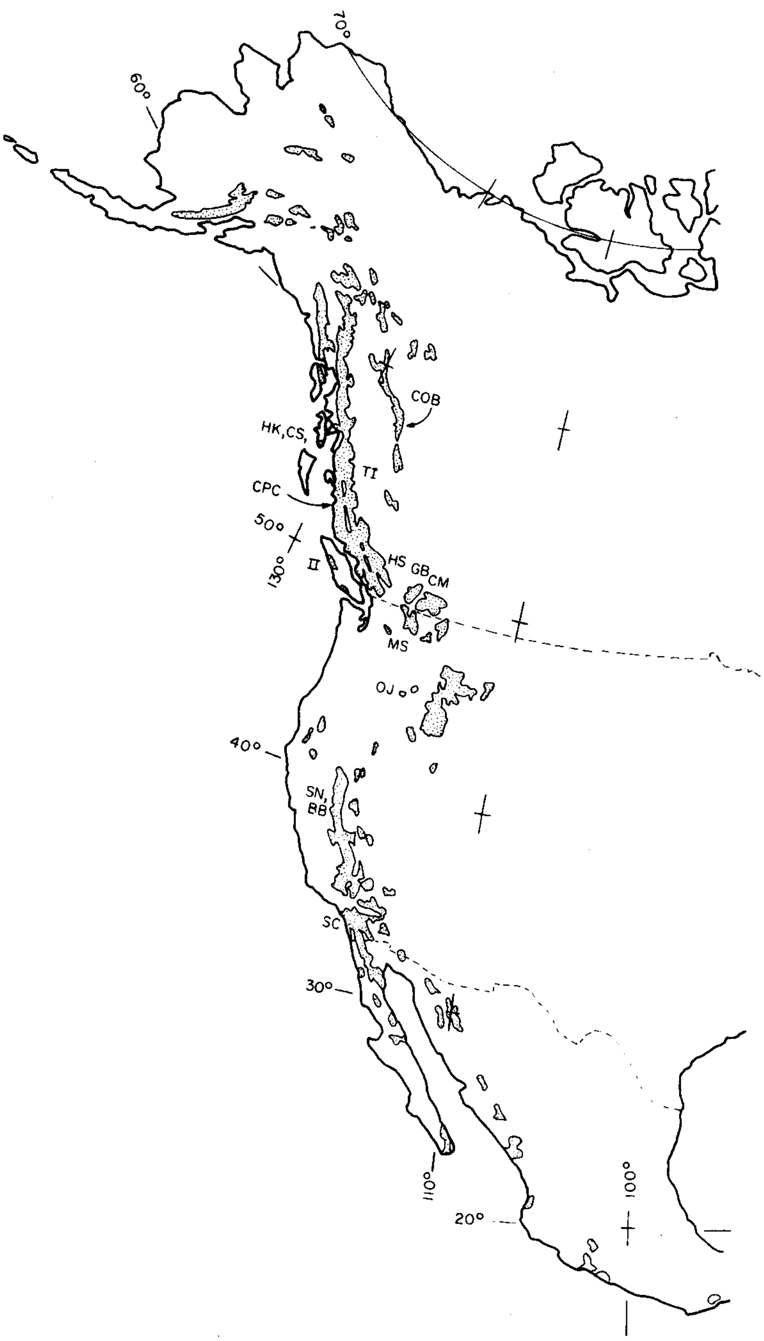

Fig. 1. Distribution of Mesozoic batholiths in western North America, taken from King and Edmonston (1972) and King (1969). Two-letter symbols designate paleomagnetic studies, keyed to Table 1. CPC, Coast Plutonic Complex. COB, Cassiar-Ominica belt.

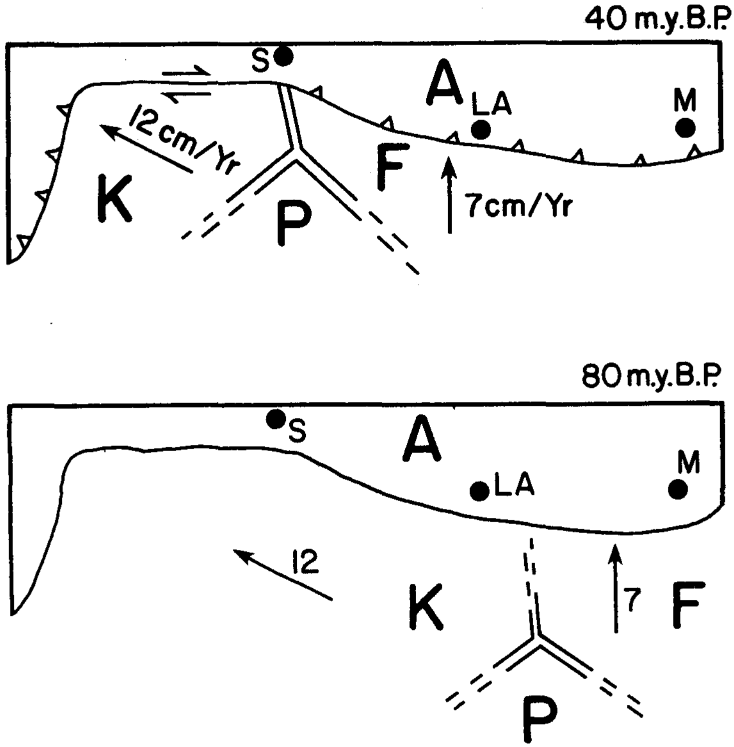

Fig. 2. Plate tectonics of western North America, after Atwater (1970). A, F, K, and P are the American, Farallon, Kula and Pacific plates, respectively. M, LA, and S are Mexico City, Los Angeles, and Seattle. Arrows indicate velocities of the Kula and Farallon plates relative to North America. Farallon-America interaction is convergent (subduction); Kula - America interaction is largely strike-slip (transform).

2. PALEOMAGNETISM OF CORDILLERAN BATHOLITHS

Beck (1980) analysed paleomagnetic data for the batholiths of the western Cordillera of North America, using data summarized by Irving *et al.* (1976a, b). In general, Mesozoic batholiths are *discordant* paleomagnetically, which means they have directions of primary remanent magnetization that are significantly different, at the 95% confidence level, from expected directions (ED) calculated from standard reference curves for stable North America (e. g., Irving, 1979). Tertiary batholiths, on the other hand, are all concordant. Tables 1 and 2 give the relevant paleomagnetic data for Mesozoic and Tertiary plutons, respectively.

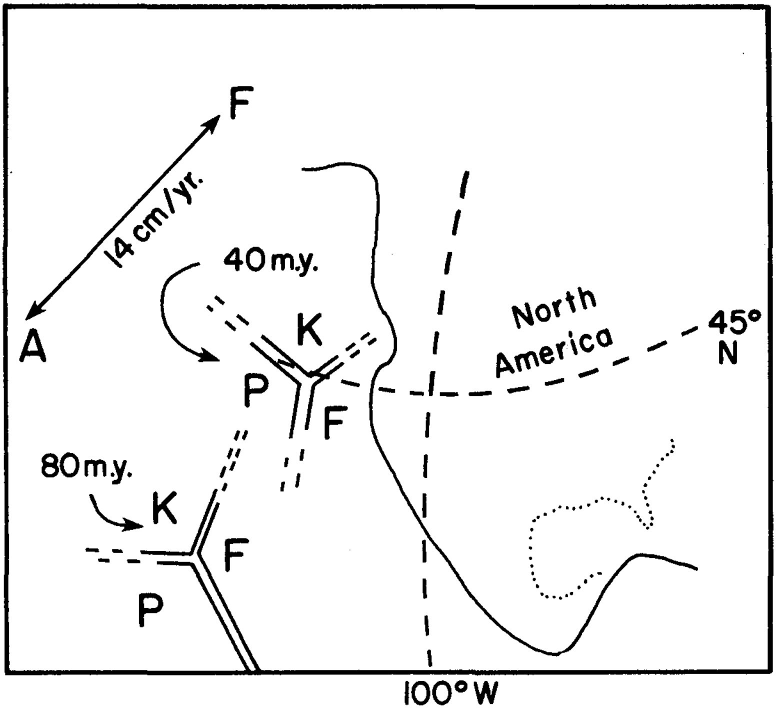

Fig. 3. Plate-tectonics of western North America, after Coney (1978). Symbols as in Fig. 2.

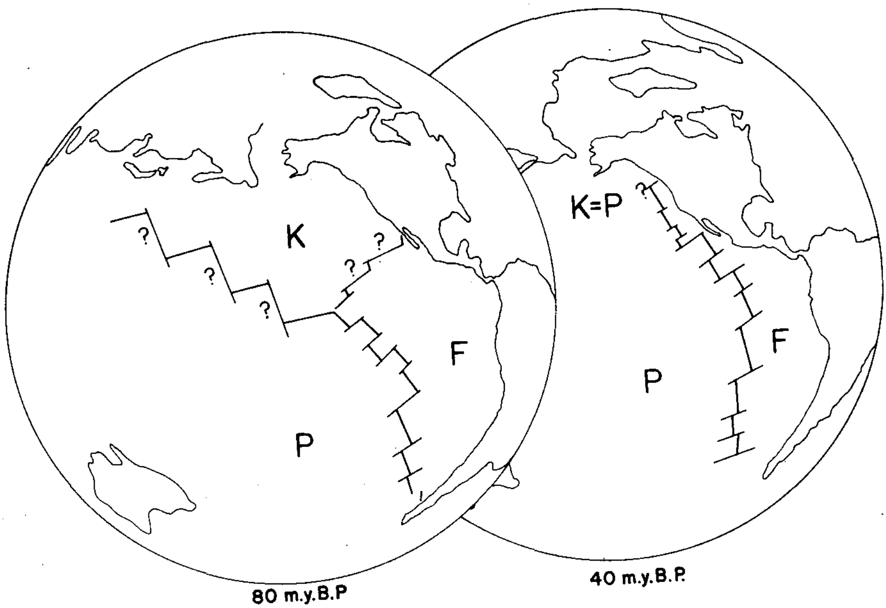

Fig. 4. Plate-tectonics of western North America, after Engebretson (manuscript in preparation). Symbols as in Fig. 2. The "equation" K-P reflects merger of the Pacific and Kula plates in the Paleocene (Byrne, 1979).

TABLE 1. Paleomagnetism of Mesozoic granitic plutons of North America.

Pluton	Age	Do/Io	Dx/Ix	R±ΔR	F±ΔF	Δλ	Reference
TI	145	332.5/63.5	330.5/68	2±28.5	4.5±14		9-154
HK*	75	26/67	327/76.5	59±21.5	9.5±5.5	13.5	Symons (1977a)
CS*	110	18/58	320/76.5	58±13	18.5±5.5	23	Symons (1977b)
GB*	200	20.5/50.5	344/49	36.5±19	-4.5±13		8-132
CM*	195	26/57.5	345.5/48	40.5±14.5	-9.5±9	-5.5	Symons (1973a)
II	160	2/74	340/64	22±29	-10±14		9-104
HS*	95	351/65	329/74	22±21.5	9±8.5	5	10-183
MS*	90	10/45.5	330.5/73	39.5±73	39.5±14	28.5	Beck *et al.* (1982)
OJ*	135	30/63	331/63	59±27.5	0±13.5		Wilson and Cox (1980)
SN	85	336/68	331.5/62	4.5±17.5	-6±8		10-28
BB	140	317/71	333.5/60.5	-16.5±24.5	-11±15		10-30
SC*	100	3/49.5	336.5/67.5	26.5±9.5	13±6	11.5	10-161

Do, Io are observed declination and inclination, respectively. Dx, Ix are expected declination and inclination, calculated from the appropriate reference pole of Irving (1979). R, F are rotation (Do-Dx) and flattening (Ix-Io), respectively; ΔR, ΔF are their 95 % confidence limits. If either $|R| > \Delta R$, or $|F| > \Delta F$, the direction is discordant with respect to stable North America; these results are starred. See Beck (1980) for further discussion of statistical techniques. Entries for which $|F| > \Delta F$ may have moved north or south; for these the change in latitude is calculated (Δλ). Numbers under "Reference" refer to Irving and others (1976a, b).

TABLE 2. Paleomagnetism of Cenozoic granitic plutons, western North America

Pluton	Age	Do/Io	Dx/Ix	R±ΔR	F±ΔF	Reference
HO	Eocene-Oligocene	358/68	349.5/68	8.5±12.5	0±6	Symons (1973b)
MB	Miocene	22/75	355.5/67.5	26.5±33.5	-7.5±9	Symons (1973b)
HT	Eocene	358/76	347/72	11±23	-4±6.5	Symons (1977a)
GS	Miocene	5.5/68.5	355.5/66.5	10±11.5	-2±5.5	11-567
GF	Eocene-Oligocene	2/67.5	348.5/67.5	13.5±16.5	0±7	11-568

See Table 1.

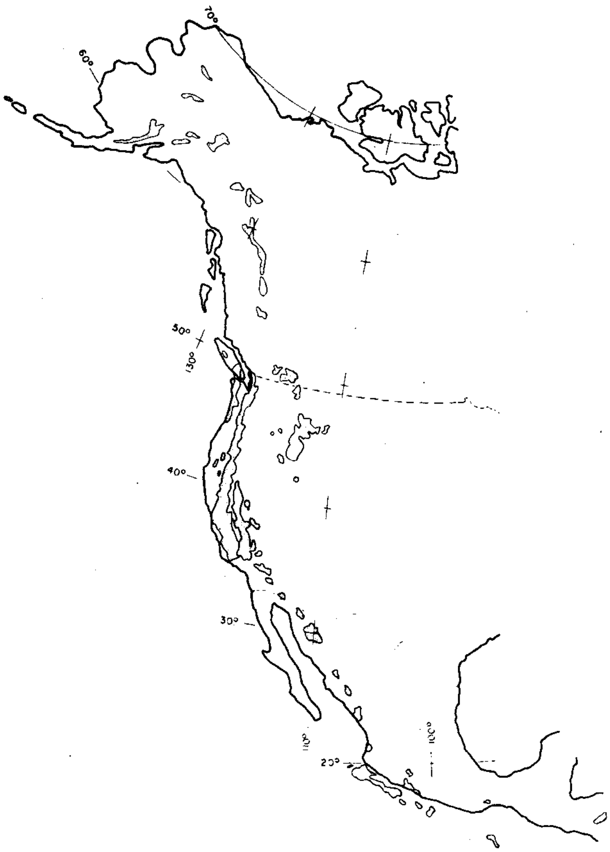

Fig. 5. Mesozoic batholiths of North America "restored" to their original locations. Restorations are made on the assumptions that (1) the batholiths originated on the western edge of North America, (2) their characteristic direction of remanent magnetism represent dipole directions acquired upon original cooling in the Mesozoic, and (3) post-magnetization tilting is negligible.

Discordant plutons are starred in Table 1. *All* of the discordant plutons have positive values for the statistic R, which means that their average direction of magnetization points clockwise, relative to the ED. This probably means that the plutons themselves have rotated (Beck, 1976, 1980). Similarly, five of the seven discordant Mesozoic plutons have positive F values, which means that their average inclinations are shallower than expected. This could imply that they have moved northward, relative to North America, since their magnetization was acquired. (As discussed below, other interpretations are possible.) Only six of the seven have discordant inclinations ($|F| > \Delta F$), since the late Jurassic-early Cretaceous plutons of the Blue Mountains (OJ) of Oregon are discordant in declination only. For these six the change in latitude implied by F is given in Table 1; most involve very large amounts of northward transport. The Mesozoic batholiths of Fig. 1 are re-plotted in Fig. 5 with their paleolatitudes "restored" according to Table 1. This creates some extremely improbable paleogeography, but the conspicuous concentration of Mesozoic batholiths in northern North America is much reduced. Accordingly, we examine the possibility that many large coastal batholiths of North America actually formed along the western edge of Mexico or California and were transported to their present positions in post-Cretaceous time.

3. METHODS OF TRANSPORT

Hamilton and Myers (1967) have argued that batholiths are relatively thin, lens-shaped bodies that crystallize at shallow depth from magma that rises diapirically from the lower crust or upper mantle. Even so, the roots of many batholiths extend to depths of some tens of kilometers, so it is unlikely that batholiths travel any significant distance as thin-skinned nappes–transport as microplates detached at the asthenosphere seems much more probable. Following Beck (1980), we consider the following mechanisms:

3.1 *Transport as a lithosphere fragment attached to a major plate.* The batholith belt of Southern California and Baja California is moving in this fashion today. It is detached from North America along the San Andreas fault zone, and is moving northward with the Pacific plate at approximately 5.5 cm/yr. In the process it is rotating slowly clockwise relative to North America, about an Euler pole located in northeastern Canada (Minster and Jordan, 1978). Thus the paleomagnetic direction for the Southern California batholith, which is discordant with positive values of R and F (Table 1), is becoming steadily more discordant in the same sense. Atwater (1970) and D. C. Engebretson (manuscript in preparation) show motion of the Kula plate approximately parallel to the continental edge, so we surmise that northward transport of batholiths at times when the American continent was in contact with the Kula plate was dominantly of this type, which might be referred to as "Californian". Californian transport involves the following steps: (1) formation of a batholith, presumably by subduction; (2) a change in the plate-margin regime from dominantly convergent to dominantly transform; (3) transfer of the batholith belt from the continental to the oceanic plate; (4) transport of the batholith belt as part of the oceanic plate. Step (2) is crucial, and will be discussed later.

3.2 *Transport as an independent microplate.* A microplate is simply a small lithospheric plate. Fitch (1972) suggested a way in which a small sliver of lithosphere might become detached from the leading edge of the over-riding plate and move independently in a zone of oblique subduction. Fig. 6, modified from Fitch (1972) and Beck (1980), shows the leading edge of the American plate moving relatively northward, in response to north-oblique convergence. In the example which inspired Fitch's original conjectures (western Sunda) the transform fault is located trenchward of the magmatic arc. However, there appears to be no reason why any zone of relative weakness within the over-riding plate might not serve to locate the transform. In particular, the thermally weakened zone within or behind the magmatic arc might so serve. This situation, shown in Fig. 6, implies northward movement of the batholith belt underlying the volcanic arc, relative to the American plate. The maximum rate of motion is given by V cos θ, where V is the relative velocity of the oceanic plate and θ is the angle between the velocity vector and the continental margin. Given the geometry illustrated by Coney (1978; Fig. 3 of this paper), transport along the American continental margin at about 3 cm/yr (30/km/m.y.) would have been possible by this mechanism during the late Mesozoic and early Tertiary. Plate reconstructions by Beck and Plumley (1979) and D. C. Engebretson (manuscript in preparation) give comparable velocities. We conclude that this type of "longshore transport" of batholith belts, which we will call the "Sundan" type after Fitch's (1972) original example, is a less powerful method for transporting batholith belts along the margin of North America than the "Californian" type discussed previously. However, it may have played a role.

Other types of transport are conceivable, of course. For instance, rifting might succeed or accompany subduction, as by back-arc spreading (Karig, 1971), and the crustal fragment so detached might later be transported elsewhere, either independently or as part of a major oceanic plate. No such complicated histories seem to be required for western North and Central America. Beck (1980) discusses some of these mechanisms.

4. ALTERNATIVE EXPLANATIONS

Paleomagnetic results from plutonic rocks are intrinsically ambiguous because of the problem of the massing "paleohorizontal". In order to be able to use a paleomagnetic direction for large-scale tectonic speculation, the effect of local tilting (by

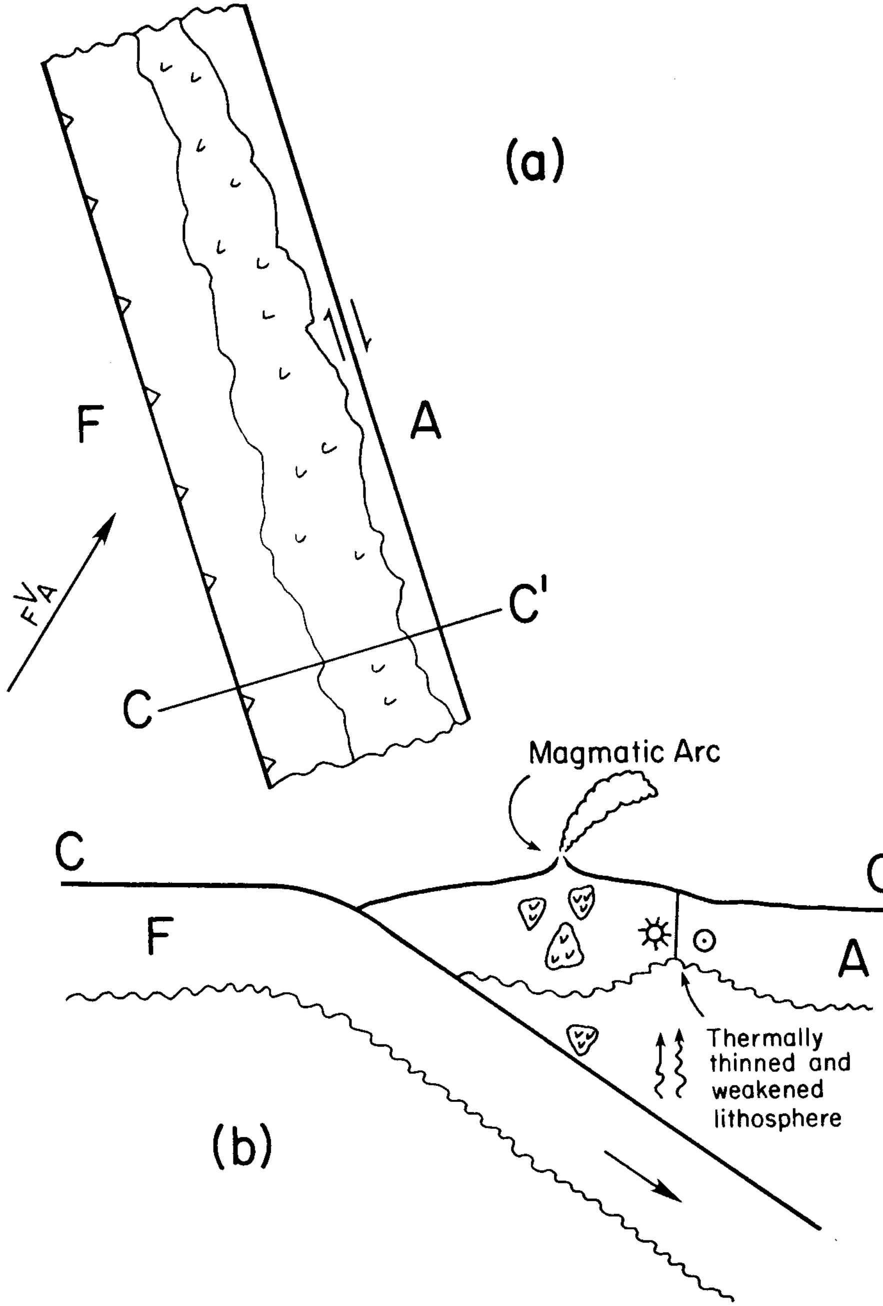

Fig. 6 Sundan-type tectonic transport of a batholith belt. F and A are the Farallon and American plates, respectively. Checked pattern indicates batholithic material. For a discussion of this model, see text.

folding or faulting) must first be determined and eliminated. This is usually easy to do for bedded rocks, but under all but the most unusual circumstances it is very difficult for plutons, because for such rocks evidence of the paleohorizontal normally is lacking. Thus, when a pluton is found to have a discordant paleomagnetic direction, it is always possible to invoke an explanation involving simple *in situ* tilt. This was done by LeCouteur and Ager (1972), for instance, who objected to an explanation involving large-scale block rotation for the Guichon Batholith and Copper Mountain Intrusions (GP and CM in Table 1). Their "tilt explanation", however, was strongly rejected by Symons (1972). Beck *et al.* (1982) discuss alternatives of tilt vs. tectonic transport for the Mt. Stuart Batholith (MS in Table 1). The problem of tilt in batholiths is important, and so we examine it briefly below.

A batholith conceivable could be tilted as a single block by very large-scale folding or block faulting, or it could be disturbed internally by closer-spaced, smaller structures. We are not interested in structural histories that produce scattered paleomagnetic directions (the Idaho Batholith is an example; Beck *et al.*, 1973), but rather in situations that would systematically deflect directions from all parts of the pluton. These include listric block faulting (Fig. 7a) or tilt as a single panel (Fig. 7b). In either case it is obvious from the illustration that tilting results in structural relief equal to w sin θ across the width of the tilted block.

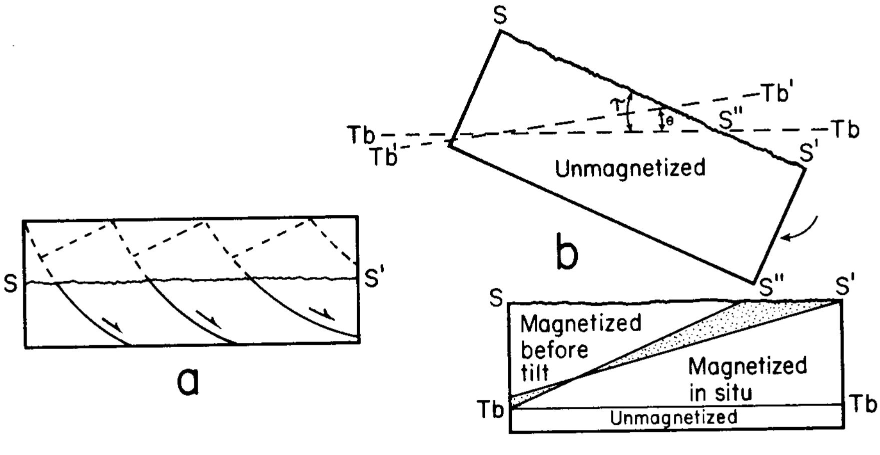

Fig. 7 Two ways to tilt a batholith. In all diagrams, S-S' is the current level of exposure. (a) shows tilting by listric block faulting. (b, upper) is a block about to undergo tilting, and (b, lower) is the same block tilted after thermal equilibrium is attained. Tb is the blocking-temperature isotherm; it is displaced to Tb' during tilting because the process of attaining thermal equilibrium is slow; the angle through which Tb is deflected away from the horizontal (θ) depends on the rate of tilting and the thermal conductivity of the rock. Only S-S" records the total amount of tilt (τ). Stippled region records tilt less than τ.

Internal listric block-faulting (Fig. 7a) could deflect the paleomagnetic direction of a large pluton and remain undetected if: (1) all blocks were tilted in the same direction, and by nearly the same amount, and (2) evidence of faulting was missing or difficult to detect. In our view both of these requirements are unlikely, at least for the examples of Table 1. Block faulting on the scale illustrated in Fig. 7a should leave geological evidence in the form of straight, parallel stream-valleys, truncated metamorphic inliers, and conspicuous parallel photolinears. All of the discordant batholiths of Table 1 have been mapped geologically, most fairly recently and at a scale clearly capable of turning up important throughgoing faults. Apparently none are block faulted. Then, too, in a real situation one would expect differential tilt between blocks, or even tilt in opposing directions, rather than the uniform tilt depicted in Fig. 7a. Block faulting in the Basin and Range Province seems to be of this type (Stewart, 1978; Eaton, 1980). Differential tilt would impose a distinctive signature on the paleomagnetic results, namely, a smallcircle (girdled) distribution with the axis of tilt as pole. Beck (1965) shows an example, for small diabase intrusions in the Appalachian Piedmont. With the possible exception of the Mt. Stuart Batholith (Beck *et al.*, 1982), none of the discordant batholiths of Table 1 have paleomagnetic results which show the slightest evidence for girdled distribution. We will not consider block faulting further.

A pluton might also have its paleomagnetic direction deflected systematically by tilt as a single coherent block, as shown in Fig. 7b. This could occur on the limb of a large fold, or as a consequence of block-faulting on a very large scale (the Sierra Nevada of California apparently has been tilted a few degrees by this method). If the clock were magnetized before tilting, it would have an *in situ* magnetic direction that would not match the reference direction, but otherwise would look (in terms of scatter, etc.) completely "normal". Such a pluton might be judged, quite erroneously, to belong to an allochthonous terrane (i. e., to have been translated a long way from its point-of-origin, or rotated through a large angle, or both). Developing large amounts of paleomagnetic discordance by simple tilt requires large rotation angles, however, and this introduces the problem of structural relief.

Beck (1980) discusses tilt of the discordant Cretaceous batholiths of Table 1 (CS, HK, HS, MS, SC). To explain their discordance by tilt, all must have been tilted toward the southwest by angles ranging from 10 to 32°; the accompaning structural relief between opposite ends of the tilted blocks ranges from 12.5 to 23.5 km. For temperature gradients in the range 20-40° C/km, this implies a temperature difference between opposite sides of the block, before tilt, of from 250 to 940° C. If the initially shallowest part of the pluton that is currently exposed was initially 2 km deep, its initially deepest part must have been at temperatures ranging from 290 to 1020°C. *before tilt began*. From work by Pullaiah and others (1975) and Storetvedt (1968) it seems unlikely that slowly-cooled igneous rock can retain remanent magnetization at temperatures above about 400°C, and perhaps not even above 200°C. Thus, for wide plutons such as those listed in Table 1, tilt, if it happens at all, probably takes place *before* the magnetization is frozen in. Beck (1980) speculates that for wide plutons (c. 50 km) no more than about 5° of post-magnetization tilt are possible. If this is so, it means that the discordances shown in Table 1 are due to large-scale tectonic dislocations; that is, that many (most?) Mesozoic Cordilleran plutons are strongly allochthonous.

One also might invoke breakdown in the dipole nature of the geomagnetic field to account for paleomagnetic discordance. Strong magnetic anisotropy could have a similar result. None of these seem to apply to the Mesozoic batholiths of western North America, however. Beck (1976) discusses these non-tectonic sources of discordance.

5. TECTONIC HISTORY OF THE CORDILLERAN BATHOLITHS

On the basis of the preceding arguments we will assume that the paleomagnetic discordance seen in Cordilleran batholiths is a result of large-scale block movements relative to North America and Central America. If so, the rudiments of a tectonic history for the larger batholith belts can be worked out.

Fig. 5 shows the Mesozoic Cordilleran batholiths of Table 1 "restored" to their most probable paleolatitudes. Error limits are not given but can be calculated from data given in Table 1; they range from 9.5 to 22.5°. The reconstruction of Fig. 5 thus is neither precise nor unique, but it is the best that can be done paleomagnetically at the moment. Note that most of the Mesozoic plutons shown in Figs. 1 and 5 have not been studied paleomagnetically; this includes large areas of batholithic rock in the Cassiar-Ominica belt of British Columbia, as well as numerous smaller plutons, particularly in Alaska and northwestern Mexico. With these limitations in mind, some speculations are possible.

(1) There was a preponderance of batholithic material south of about (present) latitude 40°N in late Mesozoic time. This probably reflects subduction of the Farallon plate; north of 40°N Kula-American interaction produced little magma.

(2) Northward transport of batholithic material in most cases took place at rates that point to the Kula plate (California-type transport) rather than the Farallon plate (Sunda-type) as a "motor". This means that at times the Kula plate must have replaced the Farallon plate opposite portions of western Mexico and California. Two possibilities suggest themselves. (1) The Kula-Farallon ridge could have undergone ridge-jumps to the south. (2) the Kula-Farallon-America triple junction could have moved alternately northward and southward, in response to slight changes in

the relative velocities of the three plates (Fig. 8). More complicated histories could be concocted, for instance by invoking a fourth (and so far undetected) plate or sudden (and also undetected) speed-ups in Farallon-America relative velocity. The data do not require such histories, however.

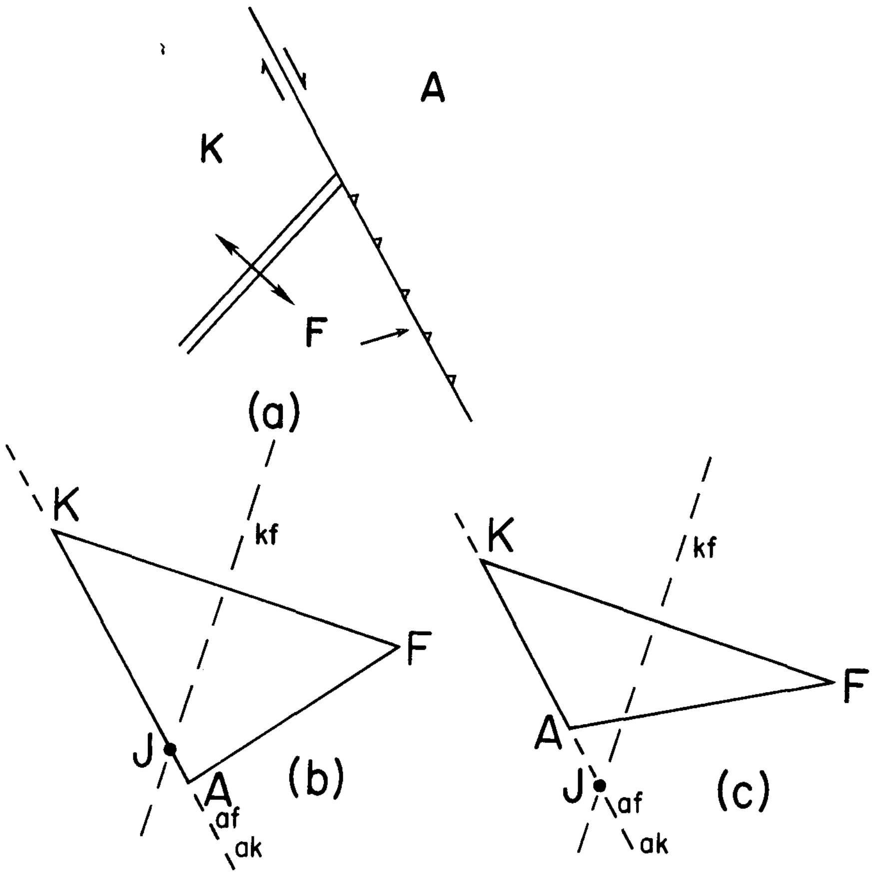

Fig. 8. Triple-junction diagrams, after McKenzie and Morgan (1969). A, F, and K as in Fig. 2. (a) shows stable geometry for a ridge-trench-fault triple junction. (b) and (c) are velocity diagrams. In each the solid lines give the relative velocities of the plates. The dashed lines show the framework in which the margin between any two plates remains stable; their intersection gives the velocity of the triple-junction (J) relative to the plates. In (b) the triple-junction moves northwest along the edge of the American plate, whereas in (c) it moves southwest. Reversals of the movement of J relative to A are brought about by slight changes in the vectors of relative plate velocity.

(3) Northward movement of the British Columbia batholith (the Coast Plutonic Complex (CPC); HK, CS, HS of Table 1) must have ended by about 40-50 m.y.B.P. because Eocene batholiths of the Prince Rupert area (HT, Table 2) are substantially *in situ*, and rocks of the Oregon-Washington Coast Range as old as 50-55 m.y.B.P. have moved northward no more than a few degrees since they formed (Bates *et al.*, 1981; Magill *et al.*, 1981). If they experienced a latitude change of 15^{o} (Table 1) in 45 m.y. they must have moved northward at least 3.5 cm/yr. Given the north-northwesterly trend of the American continental edge, minimum rates of 4-4.5 cm/yr are required. However, the Masset Formation volcanics of Queen Charlotte Island are Paleocene in age and show no latitude anomaly, although their mean declination is markedly discordant (Hicken and Irving, 1977). We probably can assume that the CPC was substantially "in place" at the time of arrival of Wrangellia (Jones *et al.*, 1977), which includes Queen Charlotte Island. In that case northward transport of the Cretaceous part of the CPC can have taken no more than about 25 m.y., and minimum velocities of 7 cm/yr are required. This suggests transport as part of the Kula plate.

Older plutons in the CPC may have even greater latitude changes (there is only one example; CS, Table 1). This could mean that the batholith belt was moving northward (Sunda-style transport) during Farallon subduction in the late Jurassic-early Cretaceous, while the belt was being built. Later passage of the Kula-Farallon-America triple junction southward past the plutons would stop subduction and initiate rapid northward transport (late Cretaceous). Still later passage of the triple junction back again, northward through the belt, would signal an end to northward movement and initiate subduction producing magma for the Tertiary plutons of the CPC (late Paleocene/early Eocene time). This of course is pure speculation, but it can be checked by additional paleomagnetic studies on plutons of different ages in the CPC.

(4) The tiny Mt. Stuart batholith of Washington State (MS) and the giant Peninsular Ranges batholith of southern California and Baja California (SC) have nearly the same paleomagnetic paleolatitude. They could be parts of the same belt. If so, time-distance considerations require that the MS batholith have been detached shortly after formation and moved at rates exceeding 10 cm/yr. This argues for California-type transport, as a crustal fragment attached to the Kula plate. If the Peninsular Ranges batholith also moved with the Kula plate it did so for a much shorter time, since its total change in latitude was less, and some of this change was acquired very recently during opening of the Gulf of California. Paleomagnetic work on Miocene basalts from southern California and Baja California suggest that much of the northward movement of the Peninsular Ranges was post-Miocene (Kamerling and Luyendyk, 1979; Erskine and Marshall, 1980; Monte Marshall, personal communication, 1981). Possibly, the Mt. Stuart block (and the surrounding North Cas-

cades terrane) was an "outboard" fragment of the Peninsular Ranges batholith belt that was torn loose and transported northward shortly after formation, by the Kula plate. Beck *et al.* (1982) speculate that the small plutons in "Salinia" (central California, at about latitude 31°N – not shown on Fig. 1) also are part of this dismembered belt. This accords well with the history recently proposed by Howell (1980).

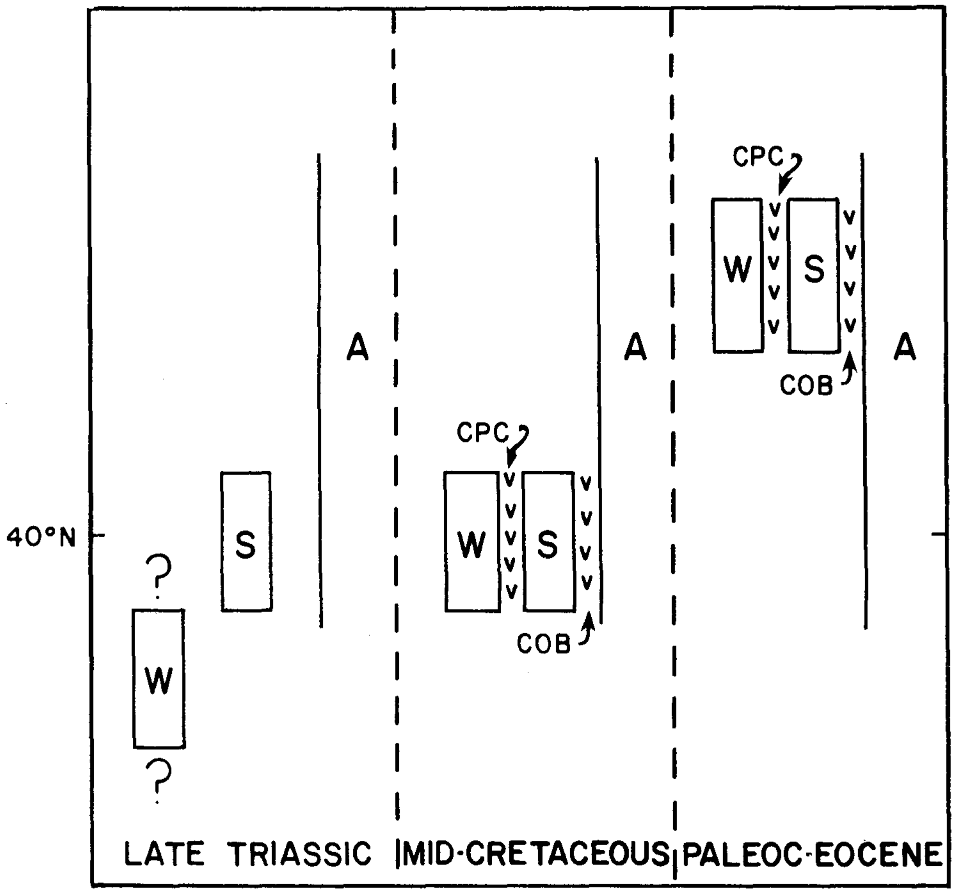

Fig. 9. Cartoon illustrating the construction of western British Columbia, taken from Irving *et al.* (1980). W, Wrangellia; S, Stikine terrane; A, American craton; CPC Coast Plutonic Complex; COB, Cassiar-Omineca crystalline belt.

6. ANOMALIES

Although several major Mesozoic batholiths appear to have moved northward since they formed, several others obviously have not. These include the Sierra Nevada batholith (SN, BB), the Late Jurassic-Early Cretaceous plutons of the Blue Mountains of Oregon (OJ), and the Guichon Batholith (GB) and Coppermine Intrusions (CM) of British Columbia. These are all located slightly inboard from the continental margin, and we speculate that they escaped northward transport because the transform fault system separating the Kula and America plates never broke inward far enough to detach them from the continent. If this is correct, the Idaho Batholith and the plutonic rocks of the Cassiar-Ominica belt also should be *in situ*. We further speculate that the westward bend at the southern end of the Sierra Nevada Batholith recently commented on by Kanter and McWilliams (1980) resulted from a process analogous to large-scale drag-folding, as more outboard batholitic material was sheared off the main belt and transported northward. The flattened inclinations reported by Kanter and McWilliams (1980) also suggest northward transport.

Two other paleomagnetic studies from Table 1 also require comment. The Jurassic Island Intrusions of Vancouver Island (II) and Topley Intrusions of British Columbia (TI) both have concordant paleomagnetic directions. The Topley Intrusions are located within the Stikine terrane of Irving *et al.* (1980), which appears on the basis of much paleomagnetic evidence to have been far south of its present location in the Jurassic. Likewise the Island Intrusions are part of Wrangellia (Jones *et al.*, 1977), which probably was even further south. Irving *et al.* (1980) conjecture that the seemingly concordant directions of Plutons II and TI represent secondary magnetizations acquired because of low magnetic stability, and we tend to agree.

7. COMPARISON WITH OTHER SCHEMES

Irving and others (1980) summarize a great deal of evidence bearing on the tectonic history of British Columbia and Alaska; Fig. 8 is a synopsis of their work. Their ideas call for the creation of the two plutonic belts of British Columbia by amalgamation of two allochthonous terranes, Wrangellis and the Stikine terrane, with each other and with North America. The crystalline belts are viewed as moving northward with the accreted terranes, as a consequence of the general northward relative movement of plates underlying the Pacific basin. We are in substantial agreement with this model, but we would emphasize the probable intermittent nature of the process–subduction producing batholiths (and, if oblique, moving them slowly northward), alternating with transform-interaction causing rapid northward movement but little if any magma.

8. SUMMARY

Paleomagnetic evidence indicates that several major Cordilleran batholith belts were translated northward along the continental margin in late Cretaceous and Paleocene time. Some evidence indicates that the movement may have commenced even earlier. Movement was probably as crustal fragments attached to the Kula plate, although north-oblique subduction of the Farallon plate may have contributed to the general northward migration. Only batholith belts on the very edge of the continent seem to have been affected; inland plutonic belts seem to have remained in place (the Sierra Nevada) or have experienced clockwise rotation only (inland batholiths of Oregon and British Columbia).

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