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DAVID BLOOM

Cordilleran suspect terranes

Peter J. Coney

Department of Geosciences, University of Arizona, Tucson, Arizona 85717

David L. Jones

US Geological Survey, Menlo Park, California 94025

James W. H. Monger

Canadian Geological Survey, Vancouver, British Columbia, Canada

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Over 70% of the North American Cordillera is made up of 'suspect terranes'. Many of these geological provinces are certainly allochthonous to the North American continent and seem to have been swept from far reaches of the Pacific Ocean before collision and accretion into the Cordilleran margin mostly in Mesozoic to early Cenozoic time.

RECENT tectonic studies and a new geological and geophysical data base support earlier theories[1-3] that much of the North American Cordillera is a vast mosaic or collage[4,5] of what are here termed 'suspect terranes'[6]. The terranes are suspect because we cannot be certain of their palaeogeographical setting with respect to North America through much of Phanerozoic time. Most are truly allochthonous and seem to have collided and accreted to the North American cratonic margin mostly during Mesozoic and early Cenozoic time[7]. Large-scale concurrent and post-accretionary horizontal translations of hundreds of kilometres[8] and significant rotations around vertical axes[9,10] are also indicated, both of which are continuing to the present.

Distribution and character of terranes

The distribution of the major Cordilleran suspect terranes is shown in Fig. 1. More than 50 terranes are recognized some of which are here grouped for simplicity and designated composite terranes. Some terranes are too small to show at the scale of this map.

Once the Palaeozoic miogeocline is identified in the geology of western North America all geological terranes outside it are inherently suspect in that their palaeogeographical distribution or their palaeotectonic setting with respect to North America is uncertain. The reason is based on a simple plate tectonic concept. During most of latest Precambrian through early Palaeozoic time the western margin of North America was a passive continental margin across which was draped a growing miogeoclinal terrace[11] as some proto-Pacific Ocean opened. Brief periods of convergence and collision are inferred during mid-Palaeozoic time[12], but the progressive out-building of the terrace was almost uninterrupted for at least 700 Myr. This regimen changed in latest Triassic to middle Jurassic time[13] and since then the margins of the Pacific Ocean have been convergent or transform. Subduction related to convergence consumed all of the vast Palaeozoic Pacific Ocean[12] and it follows that all Palaeozoic terranes now found outside the edge of the original Palaeozoic passive continental margin must have somehow accreted against that margin during Mesozoic–Cenozoic time. It also follows that all younger geological terranes outside that margin (many of which sit on older Palaeozoic rocks) are also suspect, until proved otherwise, and may have been accreted against that margin.

The terranes shown in Fig. 1 are characterized by internal homogeneity and continuity of stratigraphy, tectonic style and history. The boundaries between terranes are fundamental discontinuities in stratigraphy that cannot be explained easily by conventional facies changes or unconformity. Most boundaries separate totally distinct temporal or physical rock sequences[15,19], and many juxtapose different faunas[16]. Some terranes carry palaeomagnetic records that differ strongly from those of cratonal North America[9,10]. These data suggest large displacements and/or rotations between the terranes themselves and between the terranes and stable North America.

Note that identification of a terrane is based primarily on its stratigraphy[14] and need not carry any genetic or even plate tectonic implication. At the start of investigations, the identified terranes are simply considered as domains in the descriptive sense. Their identification and description has provided great insight into Cordilleran geological and tectonic history.

In support of the concept of terranes and their suspect character it is important that most of them display sedimentary and volcanic rock sequences that are of oceanic affinity rather than continental. It is also significant that rocks proved to be older than middle Palaeozoic are not common in the larger suspect terranes[15]. Most contain only upper Palaeozoic and/or Mesozoic sequences and most seem to have formed far removed from any continental influence, or at best at the most distal reaches of continental influence.

Most of the boundaries between terranes are known or suspected faults that usually display complex structural history (for example, see ref. 19). Many of the boundaries are certainly sutures, now largely cryptic, and most have been reactivated by concurrent and post-collisional large-scale, right-lateral strike-slip movements. High-pressure mineral assemblages of the blueschist facies from some of these boundaries have yielded Mesozoic radiometric ages[5]. Also, several boundaries are marked by thick and highly deformed Mesozoic sequences of turbidite flysch[7].

The allochthonous terranes are of several types. A few are, or contain, pieces of oceanic crust (Ch, Cl, Br, SJ, BL, Trp, C) and represent last vestiges of large late Palaeozoic–early Mesozoic oceans now trapped well within the Cordillera far from the present Pacific margin[15]. The Permian Tethyan faunas characteristic mainly of the Cache Creek terrane are totally distinct from coeval faunas found on both sides[16]. Other terranes contain fragments of oceanic arcs subsequently swept against the Cordilleran margin (R, I, G, YT, W, P, St, E, Ca, BL, KL, S, Si). A significant proportion of these arcs are late Palaeozoic in age, many are late Triassic to Jurassic in age, but at least one (the Gravina–Nutzotin belt)[17] is as young as early Cretaceous. The major Palaeozoic and Mesozoic arcs (St, P, W) have no known basement other than presumed oceanic crust. Some of the arcs, although submarine in character, rode passenger on older basement terranes. Other terranes seem to be fragments or slices off distal parts of unknown continental edges (E, NF, PM, YT, Ax, Sa, RM) and they possess what might be termed a

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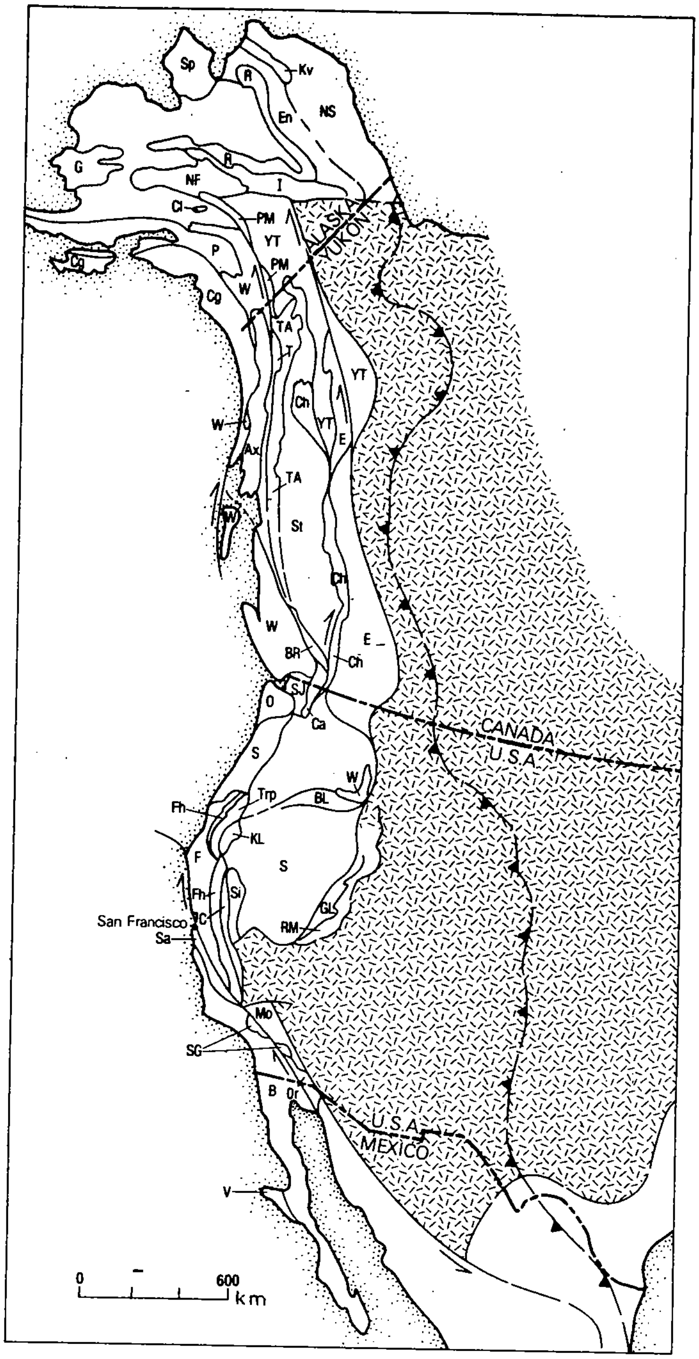

Fig. 1 Generalized map of Cordilleran Suspect Terranes. Dashed pattern, North American autochthonous cratonic basement. Barbed line, eastern limit of Cordilleran Mesozoic-Cenozoic deformation. Barbed arrows, direction of major strike-slip movements. Terranes are described below.

Alaska

(for further information on the distribution and character of terranes in Alaska, see refs 14, 17–20, 53)

Sp, Seward Peninsula—structurally complex assemblage of Precambrian metamorphic and sedimentary rocks, and Palaeozoic carbonate rocks.

Ns, North Slope—Precambrian, Palaeozoic, and Mesozoic clastic and carbonate sequence—part of North America, but may have moved from original position.

Kv, Kagvik—Thin sequence of radiolarian chert, argillite, shale, and minor volcanics, Mississippian to Triassic in age.

En, Endicott—metamorphosed Lower to Upper Palaeozoic clastic and carbonate rocks intruded by Palaeozoic granitic rocks.

R, Ruby—composite terrane comprising at least three separate units, including Precambrian metamorphic rocks, mid to Upper Palaeozoic volcanic and sedimentary rocks, and thick piles of Lower Mesozoic basalt and chert.

I, Innoko—structurally deformed sequence of Upper Palaeozoic to early Mesozoic chert, argillite, graywacke, and basic to intermediate volcanics.

NF, Nixon Fork—Precambrian metamorphic rocks overlain by Palaeozoic and Mesozoic carbonate, clastic, and cherty rocks.

G, Goodness (composite)—includes three terranes: (1) a complex assemblage of deformed Upper Palaeozoic volcanics, chert, and graywacke with blocks of older limestone; (2) Precambrian gneisses and schist; and (3) Mesozoic arc-derived volcanic flows, tuff, and graywacke, with interbedded chert.

Cl, Chulitna (composite)—includes three terranes: (1) Devonian ophiolite overlain by Palaeozoic chert, volcanic conglomerate, limestone, and flysch, and Mesozoic limestone, redbeds, flysch, and chert; (2) Mesozoic chert, argillite, crystal tuff, and conglomeratic sandstone; (3) Upper Palaeozoic tuff, and chert, volcanic graywacke, with blocks of Lower Palaeozoic limestone.

PM, Pingston & McKinley (composite)—includes three terranes: (1) Upper Palaeozoic phyllite and Triassic thin-bedded limestone and sooty black shale; (2) Upper Palaeozoic chert, Triassic pillow basalt, and Upper Mesozoic flysch and conglomerate; (3) Lower Palaeozoic limestone; tuff and flysch of unknown ages.

YT, Yukon–Tanana (composite)—includes regionally mĕtamorphosed schist and gneiss of Precambrian(?) age, Devonian limestone, Upper Palaeozoic silicic metavolcanic rocks, Permian ophiolite, and foliated granitic rocks of unknown age.

W, Wrangellia—Upper Palaeozoic arc complex composed of flows, breccias, and volcaniclastic rocks overlain by limestone, clastics, and chert, and Mesozoic pillowed and subaerial basalt flows succeeded by limestone, cherty limestone, and clastic rocks.

P, Peninsular—rare Palaeozoic limestone, Triassic basalt, argillite, and limestone, Lower Jurassic volcanic and volcaniclastic rocks, younger clastics.

Cg, Chugach (composite)—includes (1) deformed Upper Mesozoic flysch and melange units, and (2) deformed Lower Cenozoic flysch and volcanic rocks.

Ax, Alexander—complex terrane of Precambrian(?) and Palaeozoic volcanic rocks, clastics, and limestone, and Mesozoic volcanics, limestone, and clastic rocks.

T, Taku—structurally complex assemblage of Upper Palaeozoic volcaniclastics, limestone, flysch(?), and Lower Mesozoic basalt, limestone, and flysch.

TA, Tracy Arm—structurally complex assemblage of marble, pelitic gneisses, and schist of unknown ages.

Canada

(for further information on distribution and character of terranes in Canada, see refs 2, 5, 8, 15, 16, 19, 25, 33)

Ch, Cache Creek terrane—Mississippian to Middle (Upper?) Triassic, highly disrupted radiolarian chert, argillite, basalt, alpine-type ultramafics, large shallow-water carbonates, and local blueschist metamorphism.

BR, Bridge River terrane—Middle Triassic to Lower Middle Jurassic, highly disrupted radiolarian chert, argillite, basalt, alpine-type ultramafics and minor carbonate.

St, Stikine terrane—Mississippian and Permian volcaniclastics, basic to acidic volcanics and carbonates, locally deformed and intruded in middle to late Triassic time, overlain by Upper Triassic to Middle Jurassic volcanogenic strata.

E, Eastern assemblage (composite)—includes possible late Precambrian–early Palaeozoic metamorphic terranes, of possible continental affinity, together with Mississippian to Triassic basalt, ultramafics and chert and volcaniclastics and carbonates, overlain unconformably by Middle Triassic to Lower Jurassic volcanogenic strata.

Washington and Oregon

SJ, San Juan (composite)—includes highly deformed Mesozoic chert, argillite, graywacke, and volcanic rocks, partly in melanges, with blocks of lower Palaeozoic plutonic rocks, Palaeozoic chert, carbonates, and volcanic rocks. Permian limestone blocks contain Tethyan fusulinids (see ref. 54).

Ca, Northern Cascades (composite)— includes crystalline and pelitic gneisses, and thrust sheets composed of (1) Upper Palaeozoic andesitic volcanics and associated sedimentary rocks; (2) green schist and blue schist; and (3) Jurassic ophiolite (see ref. 55).

O, Olympic—Lower Cenozoic volcanic rocks and associated deep and shallow water sedimentary rocks. Basement unknown, but presumed to be oceanic (see ref. 56).

S, Lower Cenozoic volcanic and sedimentary rocks lying west of the Cascade Range. Palaeomagnetic data imply post-Eocene clockwise rotation of 70° (see refs 35, 36).

BL, Blue Mountains (composite)—includes melange with blocks of Palaeozoic ophiolite, limestone, and chert, and Mesozoic chert and sandstone, structurally overlain by Triassic and Jurassic volcanic sandstone, conglomerate, and argillite (see refs 57, 58).

California

Fh, Foothills—Upper Jurassic andesitic volcanic and volcaniclastic rocks associated with phyllite, slate, and graywacke, and Upper Jurassic ophiolite (see refs 59, 60).

Trp, Triassic and Palaeozoic of Klamath Mountains (composite)—includes a structurally complex assemblage of Lower Mesozoic ophiolite, chert, basalt, Jurassic andesitic rocks, and associated sedimentary rocks (see refs 61, 62).

KL, Eastern Klamath Mountains—Middle to Upper Palaeozoic clastic, volcanic, and carbonate rocks, overlain by Triassic and Jurassic volcanics and minor limestone (see refs 63, 64).

Si, Northern Sierra—Lower Palaeozoic clastic sedimentary rocks, Upper Palaeozoic and Lower Mesozoic volcanic and associated sedimentary rocks (see ref. 65).

C, Calaveras (composite)—including a western belt of melange with ophiolite and Mesozoic chert, and an eastern belt of quartzose clastic rocks, argillite, and minor Permian limestone (see ref. 66).

F, Franciscan (composite)—includes Upper Mesozoic Great Valley sequence with ophiolite at base, and structurally underlying disrupted and partially metamorphosed rocks of the Franciscan Complex (see ref. 67).

Sa, Salinia—includes metamorphosed pelitic rocks, marble, and graywacke of unknown ages, intruded by Cretaceous granite plutons (see ref. 68).

SG, San Gabriel (composite)—two structurally complex and juxtaposed Precambrian crystalline terranes intruded by Mesozoic plutons (see ref. 69).

OR, Orocopia—metagraywacke and mudstone and minor chert and basic volcanic rocks, age unknown. No known basement (see ref. 70).

Mo, Mohave (composite)—juxtaposed and disrupted Palaeozoic sedimentary sequences, Lower Mesozoic sedimentary and volcanic rocks intruded by Mesozoic plutons (see ref. 71).

Mexico

B, Baja—includes scattered localities of Upper Palaeozoic limestone and Lower Mesozoic clastic rocks, overlain by a thick pile of Upper Mesozoic volcanic and volcaniclastic rocks, capped by latest Cretaceous quartzofeldspathic sandstone (see ref. 72).

V, Vizcaino (composite)—includes Triassic basalt, chert, and limestone, Upper Jurassic arc-derived volcanic and volcaniclastic rocks, Upper Jurassic and Cretaceous clastic rocks, ophiolite, and structurally underlying Upper Mesozoic blue schist and disrupted rocks similar to the Franciscan Complex (see ref. 73).

Nevada

S, Sonomia (composite)—includes Upper Palaeozoic volcanics in the south, and Lower Mesozoic volcanics in the north. Si and KL terranes originally included in Sonomia (see ref. 74).

GL, Golconda—structurally deformed assemblage of chert, argillite, minor limestone, and volcanics of Mississippian to Permian age (see ref. 75).

RM, Roberts Mountains—structurally complex assemblage of chert, argillite, sandstone, basalt, and minor limestone of Cambrian to latest Devonian or early Mississippian ages (see ref. 76).

'quasi-continental' character. A few terranes are of uncertain origin. A significant number of the terranes have basalt or gabbroic rocks, particularly of late Triassic age (I, PM, W and so on) suggesting they are fragments from rifting events, intraplate volcanism, or oceanic plateaus of unknown origin or setting[18].

In a few cases it can be shown by stratigraphical and structural controls that disparate terranes amalgamated before final accretion against the North American margin[18,19]. One of the largest and best documented cases is the amalgamation of Wrangellia[20] with the Alexander terrane. Wrangellia everywhere comprises a late Palaeozoic submarine arc assemblage, with no known basement, overlain by a distinctive and very thick (up to 6,000 m) partly submarine, partly subaerial Upper Triassic basalt, overlain in turn by sedimentary rocks which extend into the early Jurassic. Palaeomagnetic data from identical Upper Triassic basalt sequences in eastern Oregon (J. Hillhouse, personal communication), Vancouver Island in western Canada[21], and from southern Alaska[22] all record the same low Triassic palaeolatitudes with respect to Triassic North America. The Alexander terrane is a complex assemblage of volcanosedimentary rocks of Palaeozoic age[17]. Somewhere on route from its equatorial origins, Wrangellia amalgamated with the Alexander terrane[3,19], as demonstrated by the overlapping Upper Jurassic and Cretaceous strata of the Gravina–Nutzotin belt, and with the Lower Jurassic arc of the Peninsular terrane[18]. Once amalgamated the resulting super-terrane was the site of variably distributed Jurassic to Lower Cretaceous Gravina–Nutzotin[17] arc activity before its final consolidation into the Cordilleran orogen. Since accretion Wrangellia has been fragmented by major horizontal translations and rotations so that its pieces are now scattered over almost 2,000 km of the Cordilleran margin from Oregon to Alaska[20].

Some terranes are very small (most are not shown on Fig. 1) and have no known counterparts in the Cordillera. A remarkable example is in the Chulitna terrane[23] in southern Alaska. It lies with other small, but totally distinct, terranes embedded in a mass of late Jurassic to early Cretaceous flysch north of the Wrangellia terrane in the Central Alaska Range. Only several tens of kilometres long, the terrane is a nappe-like structure exposing in continuous sequence late Devonian ophiolite, Mississippian chert, Permian volcanic conglomerate and breccia, flysch, chert and limestone, Lower Triassic limestone, Upper Triassic red beds and basaltic to silicic volcanics, Jurassic sandstone and chert, and Cretaceous argillite, chert, sandstone and coquinoid limestone. No other stratigraphic section such as this is known anywhere in the Cordillera. Lower Triassic ammonites from this terrane are of equatorial affinity[24] and indicate a southern origin.

Not shown in Fig. 1 are some overlap assemblages termed superjacent terranes. These terranes are sedimentary and volcanic sequences deposited on the basement terranes shown in Fig. 1 and tie together previously disjunct terranes. The Gravina-Nutzotin belt[17] is an example. Analyses utilizing basement and superjacent stratigraphy, biostratigraphy and palaeomagnetic data combined with consideration of belts of dated cross-cutting plutonic rocks provide critical data for unraveling the pre-, syn-, and post-accretionary history of these complex structural units.

Accretionary history

A full understanding of the history of accretion and post-accretionary consolidation of Cordilleran suspect terranes into the North American Cordillera is incomplete. Although we review here what is known or suspected for the assembly as a whole, much of what we say is preliminary as additional complexities continue to unfold.

Southern Alaska is made up of several large terranes with numerous smaller ones scattered along the margins and between the larger ones[18,23]. The Yukon–Tanana terrane is largely made up of heterogeneous gneiss and schist, scattered deformed plutons, and high-level sheets of chert, basalt and ultramafic rock. The terrane is probably composite with nappes of upper Palaeozoic oceanic assemblages thrust across a quartzo–feldspathic and silicic volcanic-rich protolith of probable Precambrian to known Palaeozoic age and of unknown continental affinity. The time of final emplacement of the composite terrane against North America is not known, but may have been as recent as Cretaceous time with earlier amalgamation in the Triassic[25]. Subsequently, in post-Early Cretaceous time Wrangellia, already amalgamated with the Lower Jurassic Peninsular arc terrane and Alexander terrane, collided with the Yukon–Tanana terrane entrapping many smaller terranes of unknown origin (including Chulitna terrane) within a flysch-filled suture zone[18,26]. The successive accretions must have caused subduction systems to step southward and from late Cretaceous to early Tertiary time, the Chugach and younger accretionary flysch prisms were emplaced against the newly formed North American margin[27]. Concurrent and post-accretionary convergence has caused translation and intra-plate deformation with reactivation of old sutures. This has resulted in northwestward strike-slip displacements of hundreds of kilometres along the Tintina, Denali and other faults in Alaska and adjacent Canada[25,28–30].

The largest allochthonous terrane in Canada is the Stikine terrane[15]. It has a basement of upper Palaeozoic submarine arc rocks overlain by Upper Triassic to Middle Jurassic submarine and subaerial volcanic and sedimentary rocks (Takla–Hazelton assemblage)[15] and intruded by coeval granitic plutons. This major block seems to have accreted between early Triassic and mid-Jurassic time[25,31] entrapping between itself and the North American margin Tethyan ocean floor (Ch) and a collage of Palaeozoic 'oceanic' arcs and possible distal fragments of the Cordilleran continental terrace (E). The late Jurassic and Cretaceous Bowser Basin[32] overlap assemblage is deposited on Stikine terrane and records the first clear sediment source to the east, of both continental and oceanic (Ch) character. Final stages of the accretionary process were emplacements of nappes eastwards and westwards from the suture zone and on to the former continental margin. This eastern accretion was followed by the arrival of Wrangellia[7], which, from Vancouver Island north, seems to have been in middle Cretaceous time. In eastern Oregon, its arrival time may be earlier. The northern part of Wrangellia had already amalgamated with the Alexander terrane, as explained above, and arrived bearing a Jurassic arc and the Gravina–Nutzotin late Jurassic to early Cretaceous submarine arc terrane on it. Subsequent thrusting and northward translation on intra-plate strike-slip faults[8,33] largely during late Cretaceous to early Tertiary time, have disrupted the original relationships, but left a detached fragment of Wrangellia isolated in eastern Oregon. Once again, subduction zones must have stepped outboard through successive accretions, for by late Cretaceous–early Tertiary time the trench was on or near the present Pacific margin[8].

Much of the central western part of the Cordillera in the US is underlain by several terranes (S, BL, KL, Si, Trp, C) whose very poorly exposed relationships to one another are still imperfectly understood[34]. Certainly the Permian Tethyan fauna-bearing terranes of Oregon and California are important and which move to positions much closer to the Pacific margin as they are tracked southward from their more internal position in Canada. No Tethyan fauna-bearing terranes are known south of central California. The Roberts Mountain allochthon of west-central Nevada is probably a distal continental terrace or marginal oceanic assemblage emplaced across the Cordilleran miogeocline in middle Palaeozoic time[12]. This is the oldest known example of accretion in western North America. Most of the remaining suspect terranes in the northern Sierra Nevada, Klamath Mountains and western Nevada are Palaeozoic to Mesozoic volcanic and sedimentary sequences of oceanic and arc-trench affinity which were swept against the Cordilleran margin in late Palaeozoic to middle Mesozoic time[7]. By mid-Cretaceous time the Franciscan accretionary assemblage was forming on the outboard margin of North America. Siletzia, a submarine basalt province of early Tertiary age in western Oregon certainly rotated clockwise over 70° since Eocene time[35,36] and was only finally emplaced in mid-Tertiary time.

In southwestern North American Precambrian basement extends nearly to the present coastline in southern California and northwestern Mexico. This precludes major large accretionary masses there, but several smaller displaced terranes (Sa, SG, Or) of both oceanic and quasi-continental character are known along this margin. Another important relationship is that some Jurassic magmatic arc terranes were intruded into, or deposited on, North American cratonic basement in northwestern Mexico and the southwestern US. This is in direct contrast to arcs of similar age north of central California which are ubiquitously found outside confirmed North American basement and intruded into or deposited on the suspect terranes themselves. As stated earlier, this makes the northern Mesozoic arc terranes as suspect as the terranes they sit on until it is proved otherwise. How all these Upper Triassic to Jurassic arcs relate to one another along strike and which way they faced are problems currently under much discussion and investigation. Note that major low-angle thrusting in southern California and southwestern Arizona is emerging from recent work and large-scale emplacement of allochthons in this region is not precluded[37,38].

The major displaced terrane in southwestern North America so far proposed is of totally different character from those described northwards in the Cordillera. This terrane is that part of the North American craton which is supposed to have moved up to 800 km southeastwards relative to stable North America along the Mojave–Sonora megashear[39] or transform fault. This movement is said to have taken place in late Jurassic time and was kinematically linked to the opening of the Atlantic Ocean and the Gulf of Mexico as Africa–South America separated from North America.

Conclusions

The collisions and accretions in western North America discussed above have profound implications for Cordilleran tectogenesis[25,40]. The mechanical process of these accretions and their effect on the accreted masses themselves and on the Cordilleran margin are poorly understood. Certainly thrust faulting has played a dominant part and if the thrust faulting within the accreted terranes is linked to the thrust belts[41,42] along the eastern Cordilleran margin as has been suggested[25], the resulting telescoping is unprecedented in Cordilleran tectonic thought. Concurrent and post-accretionary telescoping and consolidation apparently took place by major intra-plate thrusting and strike-slip translations[25]. The entire process seems to have endured over a period of at least 120 Myr or from mid-Jurassic well into early Tertiary time. Much northward translation and clockwise rotation occurred which suggest oblique convergence from a general northward Pacific 'mega-drift'[7], as implied by palaeomagnetic data.

The analogy with the Himalayan orogen and the internal disruption of Asia[43] is striking, but there are major differences. Unlike India, a large continental mass which remains coupled to the Indian Ocean plate as the subcontinent indents Asia, the comparatively smaller accreted terranes in western North America became uncoupled from Pacific Ocean plates by formation of subduction zones near the present Pacific margin in late Mesozoic time. Much of the telescoping and translation continued inside the marginal subduction zones well into Tertiary time. During the late Cretaceous to early Tertiary period of Laramide deformation[6] possible elevated convergence rates between North America and the Farallon and Kula plates combined with variably dipping subducting slabs[44] may have produced deep-seated Laramide tectonism and complex shifting magmatic patterns across the Cordilleran foreland as a final stage to consolidation of the Cordilleran mosaic and its cratonic foreland. Also North America's generally northwestward and westward motion over the mantle against the generally northward-moving accretions may have been dynamically important[41,42,45]. It is not accidental that Cordilleran telescoping on the foreland only began after the Middle Jurassic initiation of opening of the Central Atlantic Ocean which sent the North American plate northwestward then westward over the Pacific Ocean[41,8]. Post-middle Tertiary successive overriding of Pacific spreading centres by North America has produced the complex transform regimen which has affected North America's western edge down to the present[46].

The numerous upper Palaeozoic and lower to middle Mesozoic arcs that so characterize the allochthonous terranes are of special interest. None of these can be confirmed to have stood on the North American cratonic margin. They may have stood offshore in the manner of the present western Pacific Ocean arcs, but if they did we still do not know which way they faced. In any event they would have to have eventually collapsed against the North American margin by subduction of various sorts of small ocean basins caught behind them. This view is attractive because of the example of the western Pacific Ocean, but it does present some difficulties. The principal difficulties are the scraps of Tethyan ocean floor caught inside these arcs and preliminary palaeomagnetic evidence[9,10,47,48] which suggest large northwards translations of some of these arcs before final accretion. All this presents the possibility that the arcs may indeed be far travelled and totally unrelated to North America and thus exotic fragments from far reaches of the Pacific Ocean[7]. It is not until Cretaceous time that a semi-continuous magmatic arc along the Cordilleran margin can be substantiated by plutonic, volcanic and stratigraphical data[6,52].

Either of these models is consistent with possible plate palaeogeographies of the time. During late Palaeozoic and early Mesozoic time two-thirds of our planet's surface was paved with a single enormous ocean[49]. The other third was Pangea. Assuming that lengths and spacings of spreading centres were similar then to that now, a single large ocean would statistically favour more percentage area of old ocean crust lying around ready to be subducted than at any other time before or since the Phanerozoic. If offshore and/or intra-oceanic arcs correlate with subduction of cold and dense old oceanic crust, as has been suggested[50], large parts of the late Palaeozoic–early Mesozoic palaeo-Pacific Ocean could have been festooned with magmatic arcs[51]. As Pangea began to break up and North America began to advance over that Ocean, the arcs could have been swept northwards against large sectors of North America's margin to produce much of the Cordilleran mosaic which has been considered here. During this process, the Pacific was cleared of older arcs, oceanic plateaus and continental fragments, leading thus to the creation of the simple plate configuration that characterizes the present eastern Pacific.

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Voltage-dependent translocation of the asialoglycoprotein receptor across lipid membranes

Robert Blumenthal, Richard D. Klausner & John N. Weinstein

Section on Membrane Structure and Function, LTB, DCBD, National Cancer Institute, National Institutes of Health, Bethesda, Maryland 20205

A membrane receptor protein for asialoglycoproteins induces voltage-dependent increases in ion conductance across a lipid bilayer, probably reflecting penetration of the protein into the bilayer towards an electrically positive pole. In the presence of specific ligand for the receptor, this penetration leads to a 'translocation' of the receptor from one side of the bilayer to the other. These observations suggest a mechanism by which biological membranes might regulate the disposition of their proteins, and a way in which membrane receptors involved in endocytosis might be spared lysosomal destruction in order to be recycled to the plasma membrane.

BOTH the lipid and the protein components of biological membranes seem to be asymmetrically distributed[1]. A key question is whether the biosynthetic process determines once and for all the orientation of a given membrane component, or whether later processes can affect the component's disposition. At least some membrane lipids do seem to redistribute between

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