Downloaded from rsta.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

# Synopsis of Late Palaeozoic and Mesozoic Terrane Accretion within the Cordillera of Western North America [and Discussion]

D. L. Jones and R. M. Burt

*Phil. Trans. R. Soc. Lond. A* 1990 **331**, 479-486
doi: 10.1098/rsta.1990.0084

**Email alerting service** Receive free email alerts when new articles cite this article - sign up in the box at the top right-hand corner of the article or click **here**

To subscribe to *Phil. Trans. R. Soc. Lond. A* go to: **http://rsta.royalsocietypublishing.org/subscriptions**

This journal is © 1990 The Royal Society

Downloaded from rsta.royalsocietypublishing.org

Phil. Trans. R. Soc. Lond. A **331**, 479–486 (1990)
Printed in Great Britain



# Synopsis of late Palaeozoic and Mesozoic terrane accretion within the Cordillera of western North America

By D. L. Jones

*Department of Geology and Geophysics, University of California, Berkeley, California* 94720, *U.S.A.*

Establishing the paleogeographic origin of most of the terranes within the Cordillera remains an ellusive goal; despite more than 10 years of multidisciplinary research, the home port of any major terrane has not been identified unequivocally. Even most continental fragments that show affinities to North America cannot be repositioned confidently along the Cordilleran margin, and some continental fragments (e.g. Chulita) probably are not North American in origin. Cordilleran oceanic terranes, including island arcs, seamounts, off-ridge islands, and scraps of ocean basins, are especially difficult to reposition because Panthalassa has been destroyed. Faunal studies with emphasis on palaeobiogeographic affinities are the most useful, particularly when coupled with analyses of faunal diversity and endemism. Such studies suggest that some terranes previously thought to have formed near the Cordillerran margin were situated thousands of kilometres to the west, and were separated from the continent by broad ocean basins, rather than by a narrow marginal sea.

## Introduction

Beginning in late Permian time and continuing into the mid-Cenozoic, new continental crust was formed along the ancient rifted western margin of North America by accretion of oceanic island arcs, seamounts, pelagic and volcaniclastic sedimentary rocks, together with detached continental fragments and thick prisms of continentally derived sediments. The place of origin for most of the slivers, blocks, and fragments of accreted material remains undetermined, although several palaeomagnetic and palaeobiogeographic analyses document tectonic transport of thousands of kilometres. To emphasize the fact that great uncertainties still exist regarding palaeogeographical relations through time, the term 'terrane' (or 'suspect terrane') has been applied to these fault-bounded, displaced blocks. This uncertainty in place of origin is also reflected in uncertainty in genetic linkage between terranes, and between terranes and the continental margin. A basic tenet of terrane analysis is that mere propinquity is insufficient grounds for establishing genetic linkage in the absence of more compelling arguments.

The use of the term 'terrane' within the context of Cordilleran tectonic development has been clear and relatively straightforward. The term refers specifically to fault-bounded geologic entities of regional extent that differ in significant ways from their neighbours. Such differences between terranes imply relative tectonic dislocations sufficiently large that facies connections are broken and original palaeogeographic relations obscured. Minimum nominal displacements of a few hundred kilometres appear to be required, but in fact, most displacements probably were much larger.

Several misconceptions and complaints have recently arisen regarding terrane concepts and terminology. The most serious objections have been voiced by Dr Sengör (this symposium), and result from lack of understanding of the original terrane literature. Sengör's mistaken view



The Royal Society is collaborating with JSTOR to digitize, preserve, and extend access to
*Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences.*
www.jstor.org

Downloaded from rsta.royalsocietypublishing.org



is that terrane analysis ignores the genetic significance of lithotectonic assemblages and instead, is concerned only with simple descriptions of the rocks present without regard to their mode of origin. If such allegations were indeed true, terrane analysis long ago would have been widely rejected as a meaningless exercise. But of course, his complaints are completely unfounded because establishing the genetic significance of lithic assemblages within terranes, and discovering the genetic linkage between terranes, are now and always have been the ultimate goals of terrane analysis.

Another more trivial complaint (see, for example, W. B. Hamilton, this symposium) is that names of terranes are not genetic; that is, no clue as to the genesis of the rocks present is afforded by the name itself. This forces the reader to learn something of the internal composition of the terrane before the name becomes meaningful. In one sense, this is a legitimate complaint, but it is also founded on a lack of understanding of the nature of most terranes within the Cordillera. The basic reason why a non-genetic nomenclature was adopted from the beginning is because most terranes are polygenetic and cannot be described in simple terms. A good example of a polygenetic terrane is Chulitna, a small terrane located in southern Alaska. This terrane is of mixed oceanic and continental character that began with formation of oceanic crust in late Devonian time. Island arc volcanics and volcaniclastics covered the basal ophiolite by late Carboniferous time, to be followed in the Permian to early Triassic by shelfal carbonates and clastics. A major continental collision followed by rifting occurred in late Triassic time as evidenced by the mixture of ophiolitic and polycrystalline quartz and mica schist detritus in Triassic redbeds intercalated with basalt flows. By late Mesozoic time, this entire assemblage had subsided again and was covered by Upper Jurassic and Cretaceous radiolarian chert and flysch deposits. The specific sequence of tectonic events recorded in the sedimentary and structural record of Chulitna is unique to that terrane, but the complexity of events and the rapid change from one tectonic setting to another through time is characteristic of most of the Cordilleran terranes. This complexity precludes use of simple genetic terms to describe the entire sequence.

## Late Palaeozoic and Mesozoic tectonic development of the Cordillera

The main accretionary history of the Cordillera can be subdivided in six diachronous phases that overlap in space and time, but which generally are older to the south than to the north. These phases are summarized below and described in more detail in the following section.

1. Obduction of oceanic terranes, including Golconda, Slide Mtn, Tozitna, and Angayucham, onto the continental margin; time of emplacement ranges from probably later Permian in western Nevada (Sonoman orogeny) to early Cretaceous in the Brooks Range of northern Alaska.

2. Accretion of Asiatic (i.e. Tethyan) oceanic carbonate platform (Cache Creek terrane) in British Columbia in Middle Jurassic time.

3. Accretion of major inner Palaeozoic island arc terranes, including Stikinia, Eastern Klamath, Northern Sierra, and Black Rock, in Middle Jurassic time with resulting deformation of the Upper Triassic 'mudpile' and redeformation of Golconda terrane in northwestern Nevada.

4. Accretion of major outer Palaeozoic and Mesozoic arc terranes in late Jurassic to mid-

Downloaded from rsta.royalsocietypublishing.org

MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES
THE ROYAL SOCIETY A
PHILOSOPHICAL TRANSACTIONS OF



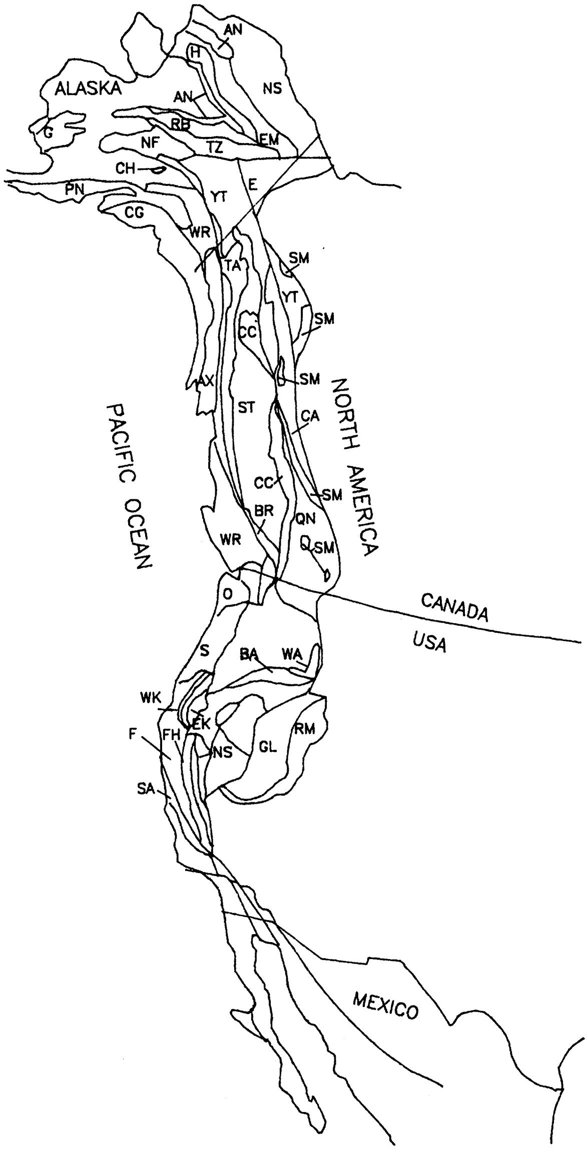


FIGURE 1. Sketch map showing selected accreted terranes in the cordillera of western North America. Symbols are as follows. Alaska: AN, Angayucham; CG, Chugach and McHugh; CH, Chulitna; E, Eagle; EM, Endicott Mountains; G, Goodnews; H, Hammond; NF, Nixon Fork; NS, North Slope; PN, Peninsular; RB, Ruby; TZ, Tozitna; WR, Wrangellia; YT, Yukon Tanana. Canada and SE Alaska: AX, Alexander; BR, Bridge River; CA, Cassiar; CC, Cache Creek; QN, Quenellia; SM, Slide Mountain; ST, Stikinia; TA, Tracy Arm; YT, Yukon Tanana. U.S.A.: BA, Baker and Izee; EK, Eastern Klamath; F, Franciscan and Great Valley sequence; FH, Foothills; GL, Golconda; NS, Northern Sierra; O, Olympic; RM, Roberts Mountain; S, Siletz; SA, Salinia; WA, Wallowa; WK, Western Klamath.

Cretaceous, including Wrangellia in British Columbia and Alaska, Wallowa, Huntinton, and Baker terranes in eastern Oregon, and Western Klamath and Foothills terranes in western Oregon and central California.

5. Development of integrated obliquely east-dipping subduction system along the entire Pacific Coast in Cretaceous time with accretion of graywacke and melange prisms from Baja California north to southern Alaska, including the Franciscan and Pacific Rim Complexes, and the Chugach and McHugh terranes.

Downloaded from rsta.royalsocietypublishing.org



6. Northward dispersal of terrane fragments by strike–slip faulting within accreted continental crust; continuous from mid-Cretaceous to present.

## Phase 1. Obuction of oceanic terranes

The first accretionary events along the continental margin consisted of obduction of vast sheets of radiolarian chert, argillite, mafic volcanic rocks, and minor volcaniclastic and siliciclastic rocks. Age-span of obducted rocks is late Devonian to late Permian in the south (Nevada) and late Devonian to early Jurassic in the north (Brooks Range), and time of emplacement varies from late Permian in Nevada to early Cretaceous in the Brooks Range. Rock assemblages are generally similar throughout, although local variations in the percentage of rock types present are notable. Abundance of mafic volcanic rocks is particulary variable, with some terranes being nearly volcanic-free, whereas others, such as Angayucham, being composed dominantly of basalt and related mafic intrusive rocks. Although many of these mafic volcanic assemblages have been referred to as 'ophiolite', geologic associations and chemical data indicate that the bulk of them represent seamounts or scraps of oceanic plateaus, rather than primary oceanic crust. Seamount volcanism in Alaska occurred in late Devonian, Carboniferous, Permian, and Triassic times, indicating that the oceanic domain in which the seamounts formed remained tectonically active (rifting?) for nearly 200 Ma.

These oceanic assemblages have been variously interpreted as having formed in a back-arc basin and to have been obducted by 'back-arc thrusting'; or to have formed in an open ocean, and to have been offscraped to form an accretionary prism above a west-dipping subduction zone into which the continental margin migrated. Despite the long record of pelagic sedimentation and associated volcanic activity found throughout the oceanic terranes, no compelling evidence has yet been presented that an active arc persisted on the west side of the oceanic basin, or that internal deformation or accretion took place during a protracted period of time. Thus neither model is very attractive in that both fail critical geologic tests. A narrow back-arc basin seems precluded by the long duration of oceanic sedimentation and by the large number of separate tectonostratigraphic environments represented within the terranes. These differing environments include continental rise and slope deposits, seamount provinces, pelagic basins free of volcanic activity, pelagic basins with arc-derived volcaniclastics, and limestone turbidite fans that lack obvious sources. Emplacement of the oceanic thrust sheets within a broadly transpressive transform system seems more probable than either 'back-arc thrusting' or offscraping above a normal subduction zone. Evidence for both left-lateral and right-lateral transpression are locally compelling, but the palaeogeography and mode of emplacement of the oceanic terranes remain as major unresolved problems.

## Phase 2. Accretion of Carbonate platform

The well-known Cache Creek terrane of northern British Columbia consists of a thick coherent sequence of shallow water carbonate rocks deposited on a basaltic substratum (seamount or oceanic plateau). Dated rocks range in age from early Carboniferous to Permian, with distinctive Asiatic (i.e. Tethyan) fusulinids characteristically occurring in the Permian part of the section. Farther south in British Columbia, the sequence is more disrupted as Permian and early Triassic limestone occurs as large blocks floating in a Triassic or early

Downloaded from rsta.royalsocietypublishing.org



Jurassic chert-argillite melange. Elsewhere, in Washington, Oregon, California, and Alaska, small blocks of limestone with Tethyan fusulinids have been identified as 'Cache Creek' terrane, although without exception, these blocks occur in Jurassic or younger melanges whose relations to the type Cache Creek terrane are not clear.

Based on the nearly total dissimilarity in Permian faunas between the Cache Creek terrane and the North American continental margin, and the strong similarity of Cache Creek fusulinids and corals to those occurring in Japan, China, and other parts of Asia, it is reasonable to propose that the Cache Creek terrane originated in an oceanic domain in the western part of Panthalassa beyond the effective range of North America faunal migrants. A minimum tectonic displacement of Cache Creek terrane comparable with the present equatorial width of the Pacific Ocean does not seem excessive.

## Phase 3. Accretion of inner arcs

The first major episode of accretion of Palaeozoic island arcs occurred in middle Jurassic time, and brought Stikinia, the Eastern Klamath (including the small scrap at Bilk Creek in northwestern Nevada), and the Northern Sierra terranes into contact with the North American margin. Convergence must have occurred on an obliquely west-dipping subduction system, as arc volcanism did not effect most of the continental margin at this time. The main results of the collision were metamorphism of the Ominica crystalline belt in Canada and widespread thrusting, metamorphism, and crustal thickening in Nevada and eastern California. Much of the previously deformed Golconda terrane of western Nevada was redeformed at this time, together with Upper Triassic and Jurassic 'overlap' deposits that are younger than the Sonoman orogeny. The relations of the Eastern Klamath terrane and the Northern Sierra terrane remain controversial. Although many authors treat the two as parts of a single arc system, geochemical data and differences in stratigraphy support their separation until at least late Triassic time.

## Phase 4. Accretion of outer arcs

Following accretion of the major Palaeozoic arc terranes to the continental margin in middle Jurassic time, another assemblage of arcs of both Palaeozoic and Mesozoic age was accreted in later Jurassic to mid-Cretaceous time. Attendant to their accretion, a complex assemblage of deep water flysch deposits were crushed between the converging terranes and the continental margin. In Alaska and British Columbia, the primary terranes accreted during the Cretaceous comprise the amalgamated super terrane composed of Wrangellia, Alexander terrane, and the Peninsular terrane. Driven northward ahead of this amalgamated massive terrane was a series of smaller scraps and fragments of mixed oceanic, island arc, and continental character, including Chulitna terrane, that finally lodged within upper Mesozoic flysch belts of southern and northwestern Alaska.

The accretionary record of Wrangellia is clearly expressed in its late Mesozoic sedimentary and structural history. The first and only period of major folding, thrust faulting, and deep erosion within Wrangellia occurred between late Jurassic and mid-Cretaceous (Albian) time. Several complicated pulses of deformation can be recognized during this interval, but the important point is that a major reorganization of the entire depositional system occurred at this time, which is believed to mark the first collision of Wrangellia with the continental margin.

Downloaded from rsta.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES



Following this collision subsidence commenced in the Albian with development of local deep basins; this subsidence continued without obvious interruption until near the end of the Cretaceous when strong uplift occurred and marine deposition was halted.

In contrast to the deformational history of Wrangellia which records an important pre-Albian collision, the surrounding flysch basins were deformed during the late Cretaceous. This difference in age suggests that the original collision of Wrangellia and its final emplacement into Alaska were separate events, the former having occurred somewhere to the south.

Accretion of outer arcs in California and eastern Oregon occurred mainly in the late Jurassic, an age broadly equated with the Nevadan orogeny. In both the Foothills and the Western Klamath terranes Upper Jurassic arc volcanics and associated epiclastic sedimentary rocks structurally overlying a complex oceanic basement were deformed and accreted to the continental margin in Kimmeridgian time. Volcanic rocks are predominantly augite porphyries, but dacitic to rhyolitic rocks are locally abundant. Relations of the volcanic rocks to underlying ultramafic to mafic to intermediate intrusive and extrusive rocks and associated sedimentary rocks of Upper Palaeozoic to middle Jurassic age are obscure, and several differing interpretations have been put forward. In the northern part of the Foothills terrane, Jurassic arc volcanics and associated plutonic rocks are interpreted to have been thrust eastward over the basement assemblage above a west-dipping subduction zone. In the central Foothills terrane, some workers interpret the arc volcanics to have been deposited above the basement rocks as a consequence of an east-dipping subduction zone that extended beneath the North American continental margin. Whatever the original disputed relations may have been, the present structural relations between the Upper Jurassic arc volcanics and the basement rocks appear to consist primarily of low-angle extensional faults of regional extent that have been folded by later compressive events associated with the terminal phases of the Nevadan orogeny. This postulated period of major extension may be partly responsible for generating large bodies of serpentinite melange that characterizes large tracts of the basement.

In eastern Oregon, the Wallowa terrane was emplaced in Cretaceous time against Mesozoic plutonic rocks intruded into Precambrian basement. Earlier accreted rocks, as well as Paleozoic miogeoclinal strata, are missing in the suture zone, implying that major truncation of the continental margin occurred before the final accretion of Wallowa terrane.

## Phase 5. Accretion of Upper Mesozoic and Cenozoic subduction complexes

By the end of Jurassic time in the south, and by the end of Cretaceous time in the north, the oceanic domains bordering North America had been swept clean of Palaeozoic and Mesozoic island arcs and other terranes with thick crustal sections. Unimpeded subduction of oceanic crust beneath the continental margin was now possible for the first time in a belt extending from Baja California north to southern Alaska. Although most earlier interpretations of this integrated subduction system emphasized normal, or head-on, convergence between oceanic plates and the continent, abundant palaeomagnetic and faunal data now show that convergence was highly oblique with a northward component that was at least comparable in magnitude with the east–west component of convergence. The result of this obliquity was the internal disruption of the fore-arc and back-arc regions by right lateral strike–slip faults that have rearranged and modified the original palaeogeographic relations within the entire region

Downloaded from rsta.royalsocietypublishing.org



of the continental margin. Well-known accretionary prisms that formed during this phase include the Franciscan terranes of California and Oregon, the Pacific Rim Complex of Vancouver Island, and the Chugach, McHugh, and Prince William terranes of southern Alaska. As is typical for Cordilleran events, accretion began earlier in the south (early Cretaceous) than it did to the North (late Cretaceous).

### Phase 6. Northward dispersal of terrane fragments by strike–slip faulting

The final phase of development of the Cordillera has been dominated by strike–slip faulting and terrane fragmentation and dispersal in a complex transform system. Minor changes in plate motions have produced alternating periods of transtension and transpression, with resulting basin formation and basin compression that have continued throughout the Cenozoic. Current strike–slip activity along the San Andreas fault in California is just one manifestation of this type of tectonic activity that has effected the entire width of accreted crust throughout the entire Cordillera at one time or another.

### *Discussion*

R. M. Burt (*University College of Wales, Cardiff, U.K.*). Dr Jones showed rocks interpreted as island or seamount in a large wide oceanic basin. These seamounts are now located inboard of a sequence identified as a volcanic arc.

Professor Dewey in his lecture included a slide of the Western Pacific. This area has abundant seamounts. He suggested that a compressional event closing the Pacific and emplacing the seamounts against a continent may lead to the defining of the seamounts as exotic terranes when in fact subduction zone parallel movement may not have been a factor in emplacement.

Does Dr Jones think that an initial westward-dipping subduction zone with seamount chains being located on the subducting plate followed by reversal of the subduction zone could not equally explain the above relationship? What are the boundaries of these terranes? Unless definite Palaeomagnetism or structural considerations prove that strike–slip subduction parallel mount these rocks can also be explained by conventional closure models and Deweygrams instead of strike–slip terrane-style movements.

It has been shown clearly along the Hawaii–Emperor chain that seamount chains young in one direction. Can the younging towards the north of this area of seamount be explained by this process. Would this younging also not imply straightforward closure, since terranes and strike–slip development result in a complex collage?

D. L. Jones. The longest chain of oceanic islands known in the Pacific Ocean (Hawaiian–Emperor chain) is about 4000 km long and spans about 70 my (= 57 km/l my). Angayucham seamounts span at least 150 my but are of unknown length. If we assume they were generated above a single hot spot with average plate velocities similar to those that generated the H–E chain, then more than 8000 km of oceanic crust passed over the hot spot from late Devonian to early Jurassic time. More complex scenarios can be envisioned that might reduce the length of oceanic crust that passed over the hot spot, such as multiple hot spots or retrograde plate motion, but it is hard for me to escape an interpretation that the oceanic realm in which these

Downloaded from rsta.royalsocietypublishing.org



seamounts formed was large and complex. In one place, Angayucham seamounts appear to young to the south, away from the continental margin on which they were obducted. But this relation has not yet been demonstrated on a regional basis, and indeed, nearby the youngest rocks are nearest the continent. Nor can it yet be shown that accretion of the seamounts occurred over a long time span, as Mesozoic rocks occur throughout the entire width of the accreted terrane. Island arcs of various and widely differing ages lie outboard of the obducted seamount-bearing terranes. Their palaeogeographic and genetic relations remain poorly understood and controversial. Despite this, it is clear that westward subduction beneath a single arc cannot explain the complexities in timing and style of emplacement of all the oceanic terranes that stretch along most of the Cordilleran margin, simply because no arc possesses the requisite characteristics in terms of timing of volcanic activity. A final point that favours transpressive emplacement of the oceanic terranes is that locally the bounding faults are clearly strike–slip in character.



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES