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Structural aspects of suspect terranes and accretionary tectonics in western North America

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Abstract—The regional structural relationships between the Cordilleran suspect terranes and cratonic North America, and within the suspect terranes themselves, are reviewed for eastern Alaska, western Canada and United States and northern Mexico. A distinctive characteristic of the relationships between the suspect terranes and the North American craton is that although much modified by post-accretionary strike-slip faulting, thrust faulting and extensional detachment faults, the generally more distal and/or oceanic terranes are frequently found as rootless nappes or thin thrust sheets sitting upon more 'inboard' terranes or upon the craton itself. The amount of tectonic transport implied is large. Strike-slip faulting has been a very significant aspect of the structural evolution of the North American Cordillera with total distributed displacements of over 2000 km documented on geologic relationships alone and much more implied by paleomagnetic evidence. At least since later Mesozoic time to the present, movements were such that the terranes moved northward. Post-accretionary intraplate telescoping along thrust faults, transpressional strike-slip faulting, and delamination at mid- to upper-crustal levels were important processes in Cordilleran tectonic evolution.

INTRODUCTION

REGIONAL structural analysis within the context of accretionary tectonics in the North American Cordillera is a new endeavor and by necessity must follow the regional stratigraphic and biostratigraphic studies implicit in the concept of terrane analysis. For this reason most maps published to date portraying distribution of tectonostratigraphic terranes have lacked regional structural information. However, regional structural observations made during broad stratigraphic studies and more recent detailed studies have provided a basis for some preliminary observations on the exposed and inferred structural geometries associated with accretionary tectonics in western North America. These studies also provide a basis for some remarks on the kinematic and dynamic implications of these geometries on our perceptions of the tectonic evolution of western North America. The purpose of this contribution is to review these matters, although it is to be emphasized that conclusions are preliminary. The discussion can be followed on Figs. 1–3: see also Coney & Campa (1987), Jones *et al.* (1987), Monger & Berg (1987) and Silberling *et al.* (1987).

THE METHOD OF TERRANE ANALYSIS AND ITS TERMINOLOGY

Some of the terminology surrounding accretion tectonics will be reviewed here (see Coney *et al.* 1980, Jones *et al.* 1983, Saleeby 1983) since there has been some confusion as to what is meant or implied by certain frequently used terms.

Tectonostratigraphic terrane

A terrane is a geologic entity of regional extent characterized generally by a coherent stratigraphic sequence in which depositional continuity can be established. By definition, the distinctive lithologic sequence represents a geologic history different to some degree from that of adjacent terranes or a nearby cratonic interior. A 'basement' may or may not be preserved or known. If the original lithologic sequence has been destroyed by intense deformation and metamorphism, the resulting fabrics and lithologies may in themselves define the terrane. By definition all terranes are fault bounded. In fact, operationally, limits of terranes are major discontinuities in stratigraphy or lithology and a fault is either proven or suspected. Some workers have interpreted terrane boundaries as minor faults along zones of rapid facies change, or sometimes simply zones of rapid facies change. If a fault is accepted by all workers, the discussion usually surrounds the amount of displacement on the fault. Since this is usually not known, it is subject to interpretation. The terrane concept simply emphasizes the uncertainty, and the resulting paleogeographic implications of that uncertainty. In fact, it is the uncertainty principle that is the most fundamental aspect of the method of terrane analysis. The definition of a 'suspect' terrane does not imply that the terrane came from China. It simply means there is uncertainty as to the original paleogeographic relationships between one terrane and another or between a terrane and an adjacent craton. Terrane boundaries may range from horizontal to vertical.

Terranes are of several types. *Stratigraphic terranes* are terranes with an observable stratigraphic succession.

Disrupted terranes are those that lack coherent stratigraphy due to internal shearing or faulting. Many 'melange' terranes are of this type. *Metamorphic and/or plutonic terranes* are crystalline complexes defined by their particular fabrics or lithologies. *Composite terranes* may be the result of the amalgamation, or joining together, of two or more terranes prior to final accretion at a continental margin. The resulting 'amalgam' has sometimes been referred to as a 'super terrane' which is thus made up of two or more 'sub-terranes'. The term composite terrane has also been used to describe a terrane with poorly understood internal complexity where a number of sub-terranes are suspected but not proven.

Overlap assemblages

Terranes and their boundaries may be overlapped by sedimentary or volcanic assemblages that tie the terranes together by the time of overlap. This may be demonstrated by either direct lateral continuity across terrane boundaries or by provenance linking. Plutons intruding across terrane boundaries serve a similar purpose. Obviously, structures that effect overlap assemblages must postdate amalgamation and/or accretion.

Accretion

There is much confusion about the term accretion as used, for example, in the phrase "accretionary tectonics" or "continental accretion". All the term should mean is an addition of rock material to an original continental 'nucleus'. Tectonic accretion takes many forms and would include the collision of near or far travelled objects with a continental margin and their welding into that continent. The assumption is that to some degree oceanic lithosphere which originally lay between a terrane and a continent has been disposed of in some way, usually by subduction. The tectonic accretion of oceanic arcs, plateaus, etc., to a continental nucleus is, of course, a net addition to the global budget of continental crust while the accretion of 'exotic' continental fragments is simply a redistribution of existing continental crust.

The off-scraping of trench fill and/or sedimentary and volcanic veneer (layer 1) from oceanic crust against a continental margin to produce 'accretionary wedges' typical of some subduction zones is another form of tectonic accretion. Similarly, material carried down subduction zones and underplated beneath a continental margin is tectonic accretion. There is also the theoretical possibility of construction of a magmatic arc, all or a part of which is on oceanic crust directly adjacent to a continental margin. Subsequent tectonic telescoping could consolidate this arc terrane into the continent and add to it.

We also have evidence of tectonic wedging and delamination where thin slices, or flakes, are detached from underlying continental or oceanic lithosphere to be obducted onto a continental margin. Often the exact plate tectonic setting of such emplacements is obscure.

Dispersal of already accreted terranes may occur by margin parallel strike-slip faulting to cause re-accretion somewhere else. Commonly terranes are slivered and fragmented in this way and there is considerable evidence of rotation about vertical axes along with the translation. Finally, the North American Cordillera gives ample evidence of considerable post-accretionary intraplate consolidation of the original collages. Large-scale and long-enduring thrust faulting, strike-slip faulting and even extensional normal faulting are well documented, as we will see, and have served to fragment and rearrange the terranes overprinting the original accretionary structures.

Concept of terrane-specific tectonic elements

This concept is of importance and rests on the need to determine if a lithologic, stratigraphic or structural feature is confined or not to a terrane, or if it crosses a terrane boundary. In other words, is the feature *terrane specific?* Many terranes have their own structural style. This may suggest these structures formed before accretion and represent tectonic events that have nothing to do with the orogenic belt they are now found in. On the other hand, the structures may simply represent a particular structural response during or after accretion due to inherited lithology or stratigraphy. Since structural features are often hard to date, it could be difficult to distinguish the above two cases. Similarly, the same is true for so-called overlap sequences that are thought to cap or unconformably overlie major periods of deformation. If these overlaps are terrane specific, they are as suspect as the terrane they sit on until proven otherwise. The same is true for volcanic and plutonic belts which are often correlated across large regions. If they cannot be shown to directly overlap or intrude terrane boundaries, the belts are as suspect as the terranes they intrude or sit upon.

Faults and accretionary tectonics

Since terranes are defined by their bounding faults, it would be well to review briefly some aspects of faulting and accretionary tectonics. Faults that bound terranes are obviously *terrane boundary faults* and those faults which cut through terranes or across terrane boundaries are *non-terrane boundary faults*. In reality, however, few terrane boundary faults seem to represent original accretionary terrane boundary structures. In western North America there are examples of terrane bounding faults that today are thrust, strike-slip, and even extensional normal faults whose movements are clearly younger than the age of accretion. Most of these structures record very complex and prolonged histories. One special type worth mentioning because it is so common in the Cordillera is a strike-slip fault where the amount of movement is very large. The Tintina and Denali faults of Canada and Alaska are examples of this type. On these faults there has been so much lateral displacement that terranes have been fragmented and dispersed into now separated pieces.

THE CORDILLERAN FORELAND THRUST BELT AND ITS WESTERN MARGIN WITH ACCRETED TERRANES

General statement

The Cordilleran foreland thrust belt extends along the eastern margin of the orogen from Alaska to southern Mexico (Figs. 1 and 2) and consists of a belt of folds and thrust faults and associated foreland depositional basins (Armstrong 1968, Burchfiel & Davis 1972, Dickinson 1976, Price 1981). From northwestern Canada south to northwestern Mexico the foreland thrust belt formed in miogeoclinal or shelf sequences of late Precambrian to early Mesozoic age that were deposited upon or across the edge of the North American cratonic basement. In Alaska the belt formed within the suspect terranes of Arctic or northern Alaska (Coney & Jones 1985), but these terranes have continental margin affinity and could be displaced fragments underlain by North American basement. In Mexico (Campa & Coney 1983) the belt formed in mainly Mesozoic overlap assemblages, deposited over suspect terranes probably mostly accreted or rearranged during late Paleozoic convergence and early Mesozoic divergence between South America and North America. The deformation that produced the Cordilleran fold and thrust belt took place mainly between Middle to late Jurassic and earliest Cenozoic time.

From the Alaska–Canada border south through Canada, down the northern Rocky Mountains into western Wyoming, and southwestward across western Utah and eastern Nevada, the belt is made up of what are usually termed 'thin-skinned' eastward-vergent folds and low-angle thrust faults. These structures preferentially evolved in the thick, late Precambrian to early Mesozoic Cordilleran miogeocline. West of the foreland folds and thrust faults is a series of crystalline culminations of uplifted, poly-deformed, metamorphic core complexes (Coney 1980, Armstrong 1982) which have in part been exposed and in part formed during post-compressional extensional detachment faulting of early to mid-Cenozoic age. East of the thin-skinned belt, on the cratonic shelf of interior North America (in central and southwestern United States) are the distinctive late Cretaceous to early Tertiary Laramide central and southern Rocky Mountains and Colorado Plateau (Tweto 1975). These are characterized by generally arcuate basement-cored thrust and monocline-bounded uplifts surrounded by intermontane basins.

The eastern margin of the suspect terranes between the Alaska–Canada border and northern Mexico lies close to the belt of metamorphic culminations that marks the western part of the fold and thrust belt. In western United States the suspect terranes lie for the most part just west of the metamorphic hinterland. In Canada, on the other hand, inliers of the suspect terranes occur east of the metamorphic culminations. Since the structural geology of this important juncture separating the suspect terranes from the North American craton is of considerable interest, we will review some of the known relations in more detail.

Northern Canadian Cordillera

In the Canadian Cordillera (Figs. 1, 4 and 5) the boundary marking the interface of suspect terranes and the North American craton is structurally very complex. On the cratonic side, rocks associated with the Cordilleran miogeocline can be traced westward through the fold and thrust belt where they are known to be detached structurally from the ever descending Precambrian basement along a basal décollement (Price 1981). Nearing the western margin of the foreland, ramp-style thrusts bring up more distal miogeoclinal facies, and in metamorphic culminations, the Precambrian basement itself. The metamorphic culminations, of which the Shuswap metamorphic core complex is the prime example, are now viewed as crustal duplex structures formed during Mesozoic–early Cenozoic compression modified by Cenozoic extension (Coney & Harms 1984). Of particular interest here is the fact that roof-thrusts of the duplex systems carry suspect terranes up to 100 km east of present exposures and/or subsurface projections on balanced structure sections of the North American Precambrian basement.

The entire boundary zone between the suspect terranes and the Cordilleran foreland has been complicated by large-scale strike-slip faulting along the Tintina fault and related systems (Gabrielse 1985). The sense of offset is consistently right lateral and may total 800 km or more. Much of the movement is apparently of late Mesozoic to early Cenozoic age. These faults have so disrupted structural relationships between terranes, and between the terranes and North America, that original accretionary geometries are very obscure. The amount of movement on these faults is so large that today they are in fact the terrane boundaries over large distances. Furthermore, as was mentioned above, large-scale low-angle mid-Cenozoic extensional detachment faulting, particularly in southern reaches, has brought deeper structural levels to the surface and considerably modified the original Mesozoic compressional structures (Parrish *et al.* 1988).

The suspect terranes found in this region can be grouped for our purposes into three types (Monger & Berg 1987). The first, which includes Cassiar, Kootenay and Yukon Tanana terranes, are mostly of continental affinity and are now considered by many to be probable displaced fragments of the Cordilleran miogeocline, or at best distal equivalents. A second, which generally lies west of the first group and is called Quesnel terrane, is made up of Triassic to Jurassic submarine volcanic and sedimentary rocks in places overlying Upper Paleozoic rocks of oceanic affinity. The third, a very distinctive

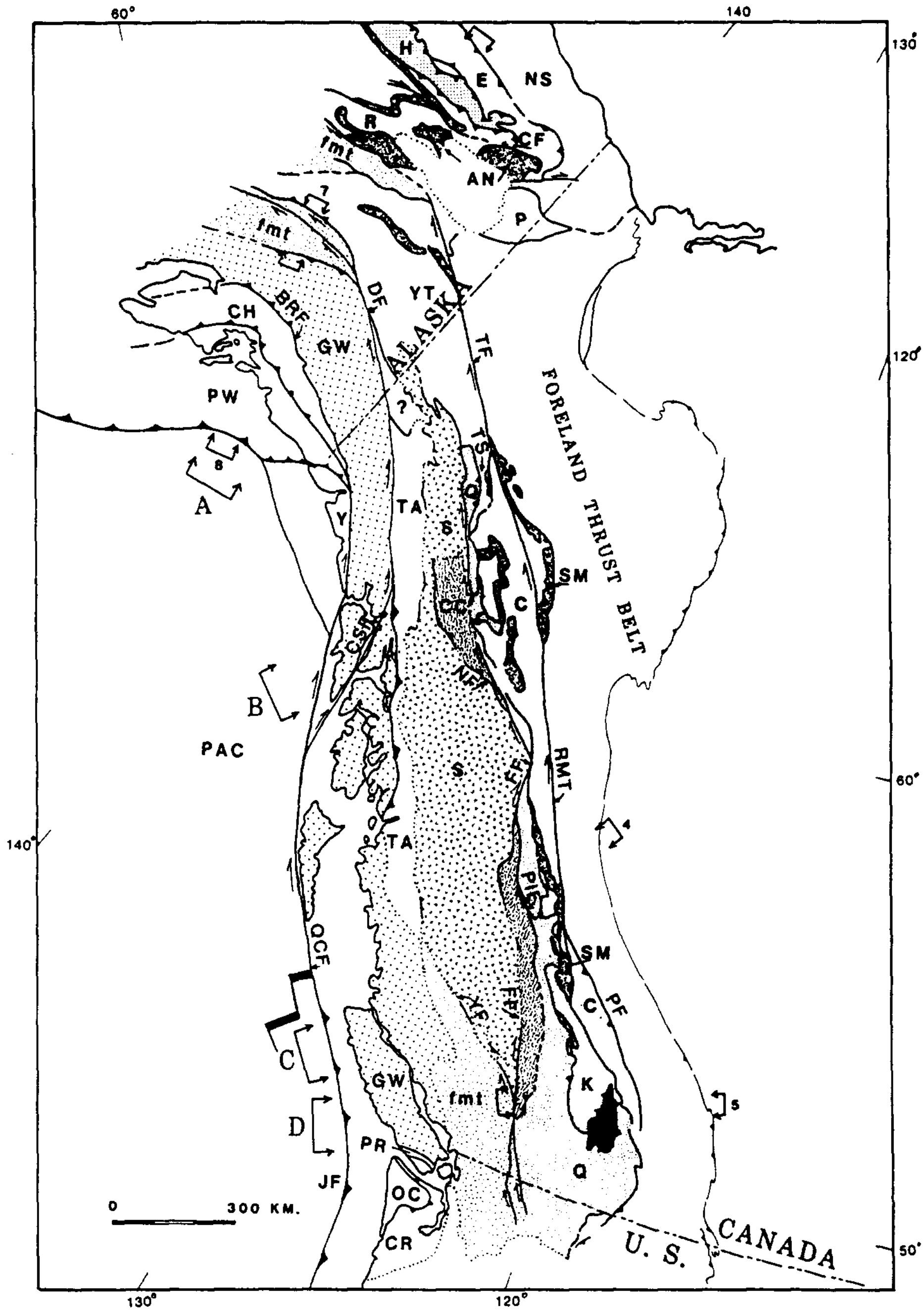

Fig. 1. Generalized tectonostratigraphic terrane and structural map of eastern Alaska and western Canada. Only those terranes and structures germane to the discussion are shown. For complete descriptions of terranes see Jones *et al.* (1987) and Monger & Berg (1987). Faults labeled: BRF, Border Ranges fault; DF, Denali fault; TF, Tintina fault; TS, Teslin suture; CSF, Chatham Strait fault; NF, Nahalin fault; QCF Queen Charlotte fault; FF, Finley–Fraser faults; PiF, Pinchi fault; RMT, Rocky Mountain trench; PF, Purcell fault; YF, Yalokam fault. Terranes labeled (from north to south): AO, Arctic Ocean; NS, North Slope; E, Endicott; H, Hammond; CF, Coldfoot; AN, Angayucham; R, Ruby; P. Porcupine; YT, Yukon Tanana; SV, Seventy Mile; GW, Greater Wrangellia; CH, Chugach; PW, Prince William; PAC, Pacific plate; JF, Juan de Fuca plate; Y, Yakatat; TA, Tracey Arm; S, Stikine; CC, Cache Creek; Q, Quesnel; C, Cassiar; SM, Slide Mountain; K, Kootenay; PR, Pacific Rim; CR, Crescent; OC, Olympic core. Crushed flysch basins and enclosed microterranes are labeled 'fmt'; and selected metamorphic core complexes are labeled 'm'. The shaded area labeled 'Foreland Thrust Belt' is that part of the orogen known to be anchored on cratonic North America. The Sylvester allochthon is the fine stipple area of Slide Mountain terrane at 60°N. Locations of generalized structure sections on Fig. 3 are labeled A–E. Locations of structural sections of Figs. 4, 5, 7 and 8 are indicated by respective numbered brackets

sequence of pillow basalt, gabbro, some ultramafic rock, minor carbonate, radiolarian cherts and argillite yielding fossils which range in age from Devonian to Permian, is called the Slide Mountain terrane. This very oceanic appearing assemblage now sits structurally as rootless nappes and klippen on top of the eastern North American margin related group of terranes, and locally apparently even on the North American margin itself. These structurally highest exotic sheets are the easternmost of the truly 'oceanic' suspect terranes and they are now known to occur intermittently over a distance of 2000 km from Alaska to southern British Columbia. The Slide Mountain terrane, as presently mapped, is everywhere either below or east (inboard) of Quesnel terrane.

In the northern Canadian Cordillera, about 500 km of

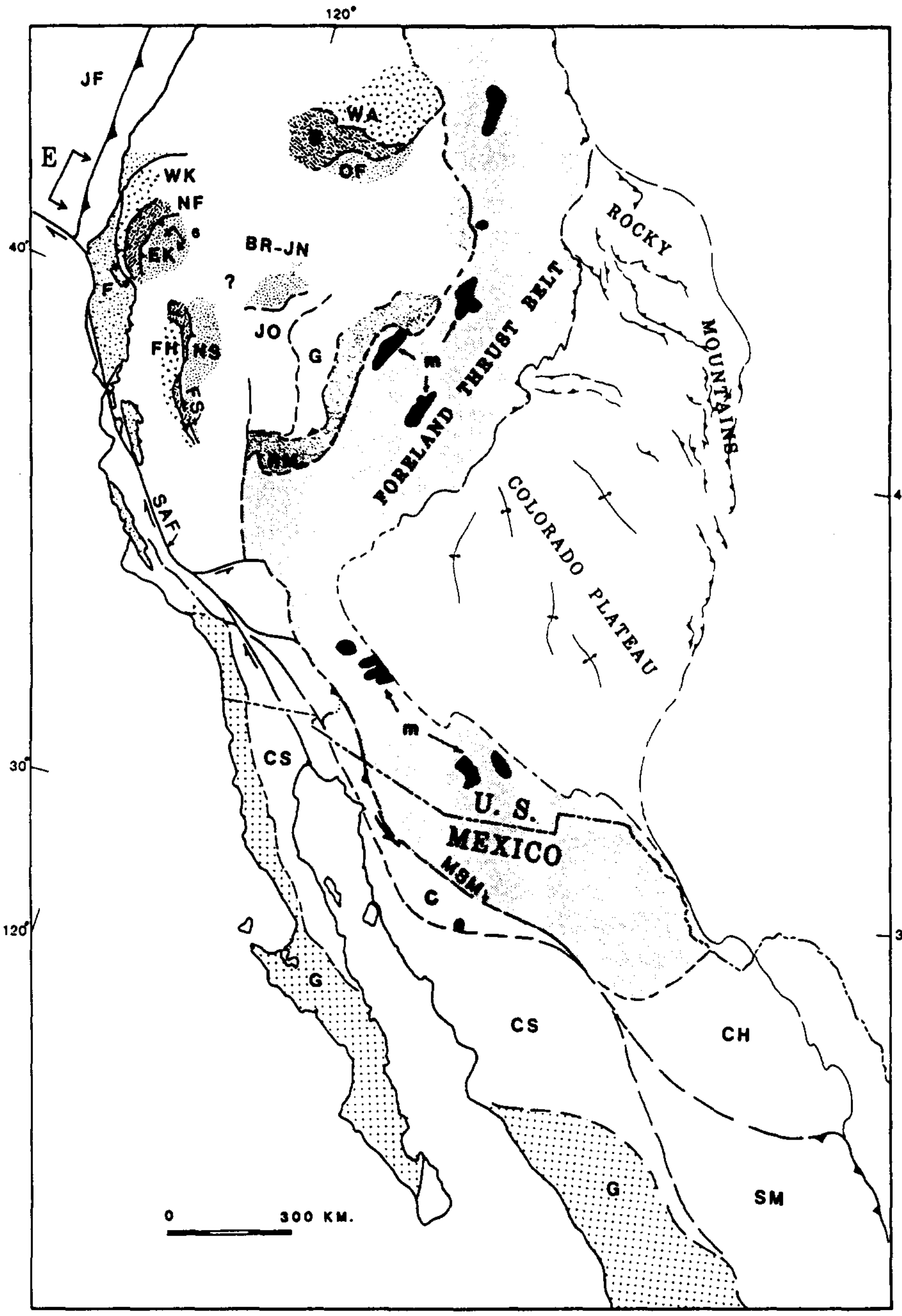

Fig. 2. Generalized tectonostratigraphic terrane and structural map of western United States and northern Mexico. Only these terranes and structures germane to the discussion are shown. For detailed descriptions of terranes see Silberling *et al.* (1987) and Coney & Campa (1987). Faults labeled: SAF, San Andreas fault; FS, Foothills suture; MSM, Mojave–Sonora megashear. Terranes labeled: WA, Wallowa; B, Baker; OF, Olds Ferry; F, Franciscan; WK, Western Klamath; NF, North Fork–Fort Jones–Hayford; EK, Eastern Klamath; BR–JN, Black Rock and Jackson; FH, Foothills; C, Calaveras–Kaweah; NS, Northern Sierra; JO, Jungo; G, Golconda; RM, Roberts Mountain; G. Guerrero; CS, Cortes; C, Caborca; CH, Coahuila; SM, Sierra Madre. Other symbols as on Fig. 1.

right-lateral movement on the Tintina fault (Fig. 1 and Fig. 3, section B) has displaced northward: (1) a slice of distal carbonate platform of the Cordillera miogeocline known as the Cassiar terrane and (2) a highly metamorphosed and deformed, originally more distal, mostly detrital part of possible North America's margin known as the Yukon Tanana terrane (Tempelman-Kluit 1979, Mortensen & Jilson 1985). The amount of movement is such that both have overstepped a fragment of the Yukon Tanana terrane east of the Tintina fault where it is in tectonic contact with very distal facies of the miogeocline in the Selwyn Basin–McKenzie Mountains salient. Large klippen and nappes of the oceanic Slide Mountain terrane sit structurally on top of the Cassiar terrane. They seem to be caught in the fault zones separating Yukon Tanana terrane from North America east of the Tintina fault, and to lie upon Yukon Tanana terrane as well.

The Yukon Tanana terrane is characterized by widespread subhorizontal mylonitic and gneissic fabrics superimposed upon a complex lithologic succession (Mortensen & Jilson 1985). Lowest parts of the terrane are quartz–feldspathic–mica schists that are thought to represent late Precambrian to early Paleozoic distal detrital equivalents of the Cordilleran miogeocline. Higher parts of the terrane are more heterogeneous and

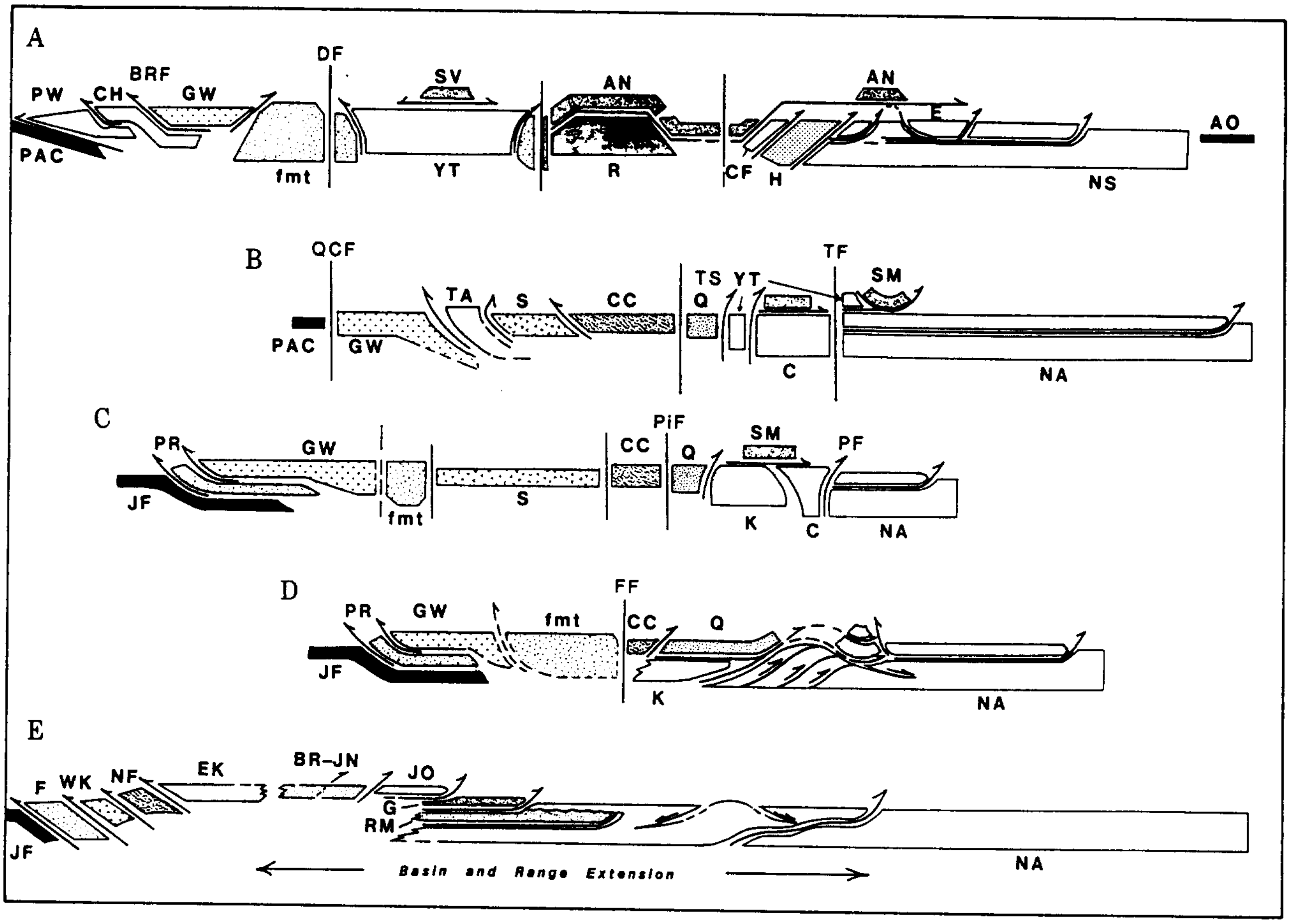

Fig. 3. Generalized structural diagrams. The objective here is to show the general structural relationships between the terranes and cratonic North America as they are perceived at the surface today. They should not be taken necessarily as indicative of deep crustal structure or of original accretionary relationships. The idea for this method of presentation was suggested by a diagram in Struik (1986) reproduced in part as the eastern end of section C. Symbols and labels as in Figs. 1 and 2.

include metamorphosed mafic and felsic volcanics, orthogneiss, chlorite schists and still higher marbles and quartzites, all thought to be Upper Paleozoic in age. There are metaplutonic rocks that yield Mississippian ages. Late Triassic sedimentary rocks apparently sit unconformably on the metamorphic rocks, but are cut by important regional scale flat thrusts which often involve generally unmetamorphosed ultramafic and mafic rocks as well as generally undeformed Jurassic mafic to intermediate plutons. The mafic–ultramafic rocks may be relatives of the Slide Mountain terrane which would have been thrust over the metamorphosed Yukon Tanana terrane after the Triassic, but before Cretaceous plutons stitched the amalgam together. The Cretaceous plutonic suite also intrudes North America.

The interesting thing about all these relationships from the perspective of tectonostratigraphic terranes is that, although there have been several conflicting tectonic interpretations of how the various pieces accreted into North America, and although most workers agree that certainly the Cassiar terrane and most likely the Yukon Tanana terrane are pieces of the Cordilleran miogeocline, the original paleogeography of these terranes is very uncertain. This is particularly the case for Yukon Tanana terrane. In spite of the fact that some of its assumed protolith stratigraphy resembles that of the North American margin, none of the pre-Triassic metamorphism, plutonism, and volcanism typical of the

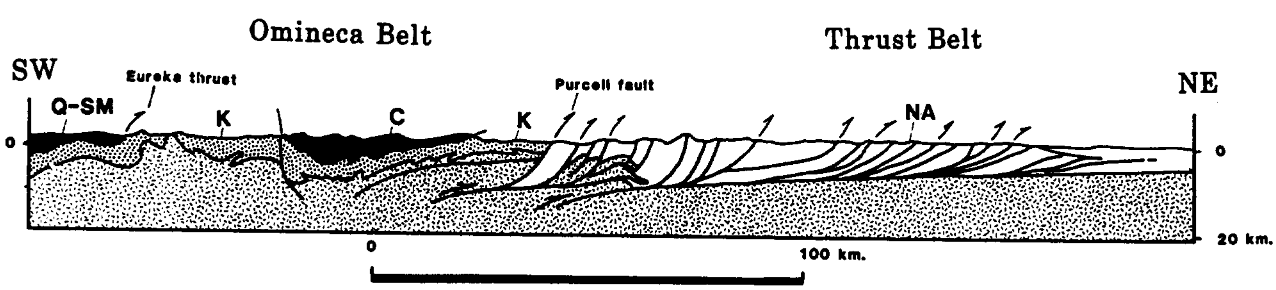

Fig. 4. Structural section across the Cariboo Mountains, south-central Rocky Mountains of Canadian Cordillera, after Struik (1988, fig. 4). NA, North American miogeocline; K, Kootenay terrane; C, Cassiar terrane; Q–SM, Quesnel and Slide Mountain terranes. Dashed pattern is North American Precambrian basement.

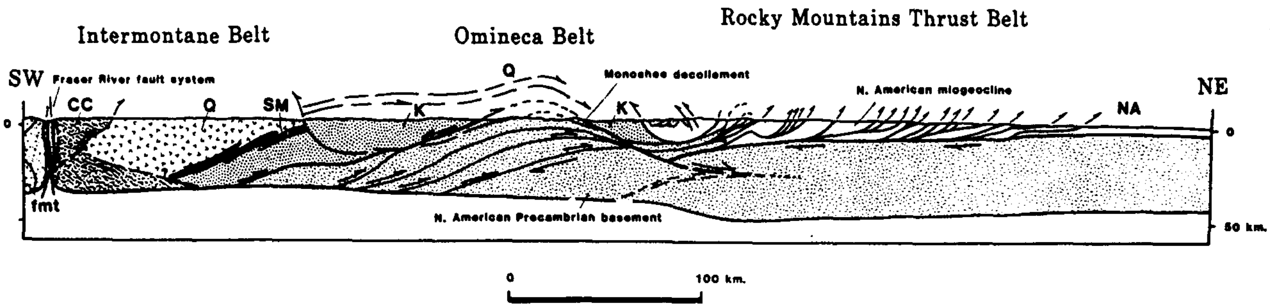

Fig. 5. Structural section across the eastern Intermontane belt, the Omineca belt and the southern Rocky Mountains of Canadian Cordillera, after Monger *et al.* (1985). NA, North American miogeocline; K, Kootenay terrane; Q, Quesnel terrane; SM, Slide Mountain terrane; CC, Cache Creek terrane; fmt, flysch basin and micro-terranes. Fine dash pattern is North American Precambrian basement.

Yukon Tanana is known anywhere within rocks of the North American cratonic margin. In other words, the mid-Paleozoic plutonism, metamorphism and deformation in Yukon Tanana is terrane specific, but later larger-scale flat thrusting and cataclasis is not, in that it affects the Cassiar terrane and the North American margin as well.

The boundary between the Quesnel terrane and Yukon Tanana–Cassiar terranes is the so-called Teslin suture (Tempelman-Kluit 1979, Hansen 1987). This vertical to steeply W-dipping shear zone has intense mylonitization. Within the zone are shredded large lenses of what appear to be Yukon Tanana protoliths, Slide Mountain protoliths and possible Quesnel terrane. The Yukon Tanana terrane is here reduced to narrow selvages and the Quesnel terrane is nearly in contact with the Cassiar terrane. Some combination of oblique right strike-slip and dip-slip convergence is inferred from kinematic indicators (Hansen 1987). Northward the zone widens and becomes ill-defined, and fabrics become more horizontal as the Yukon Tanana terrane widens to several hundred kilometers. Just east of the Teslin boundary, fabrics become flat and there are sub-horizontal thrusts and nappes of Slide Mountain terrane and occasional possible Quesnel terrane interleaved with Yukon Tanana slices. These structures, and presumably much of those of the Teslin suture zone, are the post-Triassic to pre-Cretaceous deformation mentioned above. South of the Yukon–British Columbia border for up to 600 km there is no equivalent of Yukon Tanana terrane and Quesnel terrane is juxtaposed directly against Cassiar terrane, probably in part on steep strike-slip faults of later Mesozoic age (Gabrielse 1985).

Southeastward in northern British Columbia the Tintina fault merges into what is usually termed the northern Rocky Mountain trench (Gabrielse 1985). This feature is also considered a strike-slip fault but its trend is several degrees more northerly than the Tintina trend. Here Cassiar terrane, almost 150 km wide, is juxtaposed directly against the North American foreland and is laced with NW-trending faults sub-parallel to the northern Rocky Mountain trench. Many of these faults are known to be right lateral strike-slip faults. Sitting structurally on top of the Cassiar terrane, about equidistant from its northeast and southwest margins, is a narrow, 25 km wide, and almost 200 km long, klippen of the Slide Mountain terrane, here termed the Sylvester allochthon (Fig. 1).

The Sylvester allochthon (Harms 1984, 1985, 1986) is 'oceanic' in that it includes pillowed and massive basalt, gabbro, ultramafic rocks, banded radiolarian chert, some carbonate, argillite and minor arenite. Fossils from the allochthon range from late Devonian to Triassic. The internal structure of the allochthon is complex and characterized by interleaved tectonic slices bounded by sub-horizontal layer-parallel faults. There is a persistent NW–SE lineation in the allochthon formed from pencil cleavage, mullions, fold axes, etc., more westerly-trending than, but roughly parallel to, regional structural trends and the elongate trend of the allochthon itself. Of considerable interest is evidence that at least some of the internal structure of the Slide Mountain terrane formed in several phases during final periods of deposition of the Sylvester sequence in latest Paleozoic to early Mesozoic time. This evidence is based on cross-cutting relationships between dated small tonalite and other plutons and flat thrust faults affecting fossiliferous horizons. The basal Sylvester fault is a regional sub-horizontal structure which separates the klippen from thick Lower Paleozoic miogeoclinal carbonates of the Cassiar terrane. The actual faulting itself seems to have utilized Devonian-Mississippian argillites of the miogeoclinal sequence, below which are probable NE-dipping duplex panels of Lower Paleozoic carbonate rocks. The basal Sylvester fault thus has the character of a roof-thrust. Near it are NE-vergent minor structures presumably related to the emplacement of the allochthon some time between late Triassic and Cretaceous time. The Cassiar terrane, the basal fault and the Sylvester allochthon are all intruded by the Cassiar batholith, one of the numerous 90–100 Ma mid-Cretaceous plutons common to the region.

Southern Canadian Cordillera

For almost 800 km southward, the tectonic elements described above narrow considerably and in places the Quesnel terrane lies within 25 km of the North American miogeocline. Much of this narrowing is probably due to 'necking' related to significant strike-slip faulting.

Further south, the boundary zone between suspect terranes and the North American miogeocline widens in southern British Columbia and northernmost United States into the sprawling massive structural culmination of the southern Omineca belt (Brown *et al.* 1986, Carr *et al.* 1987, Parrish *et al.* 1988). The Omineca belt (Figs. 1 and 5) is over 400 km wide and lies nested behind a prominent salient in the southern Canadian Rocky Mountain foreland thrust belt to the east. This region is very complex and still subject to some controversy. In essence it is a vast northward elongate domal culmination of originally sub-horizontal crustal-scale thrust sheets and duplexes. Precambrian continental basement rocks are exposed in its core and are successively overlain by nappes of Kootenay, Slide Mountain and Quesnel terrane. The entire structural array is much obscured by widespread metamorphism, pre-, syn- and post-nappe emplacement plutonism, prolonged telescoping which began in the mid-Jurassic and continued into early Cenozoic, and finally Eocene denudational extensional faulting which may have brought much of the system to present levels of exposure.

At the north end of the Omineca culmination (Figs. 1 and 4) in the Cariboo Mountains (Struik 1986, 1988), the Quesnel terrane is thrust eastward over the Kootenay terrane on a gently W-dipping fault marked by intense ductile deformation. The base of the Quesnel terrane is a persistent, up to 300 m thick, amphibolite with lesser ultramafics and serpentinite. The Quesnel terrane here consists of Triassic and Jurassic shale and basaltic to andesitic volcanics and is largely unmetamorphosed. The Kootenay terrane is made up of metamorphosed and deformed late Precambrian(?) to late Paleozoic grits, shale, lesser limestone and conglomerate. The Kootenay terrane is in contact with the Cassiar terrane along a moderate to low-angle E-dipping thrust fault. The Cassiar terrane is also metamorphosed and includes protoliths of late Precambrian to late Paleozoic age. Sitting on top of the Kootenay and Cassiar terranes is the Slide Mountain terrane. The basal fault here is the flat Pundata thrust, generally a zone of shearing several meters thick. The thrust actually appears to truncate the bounding fault between the Kootenay and Cassiar terranes. The internal structure of the Slide Mountain terrane is very similar to that described above for the Sylvester allochthon. That is to say, sub-horizontal imbricate thrusts have scrambled the original oceanic stratigraphy. The eastern boundary of Cassiar terrane is the southern extension of the northern Rocky Mountain trench where it merges into the E-vergent Purcell thrust.

Southward into the main mass of the Omineca belt (Figs. 3D and 5) the grade of metamorphism increases and all the terranes and structural relationships described above transform into flat nappes and sub-horizontal ductile shear zones arched across ductile duplex cores (Brown *et al.* 1986). Rocks equated with Quesnel terrane extend several hundred kilometers structurally east of their positions further north such that they overlap by several hundred kilometers exposures of Kootenay terrane and assumed North American Precambrian basement. In fact, Quesnel terrane lies within a few kilometers of North American foreland rocks just north of the United States–Canadian border.

The details of the structural complexity of this region cannot be fully discussed here. The salient aspects, however, can be summarized from Brown *et al.* (1986), Carr *et al.* (1987), and Parrish *et al.* (1988), as follows. Oceanic rocks of the Quesnel terrane and possibly Slide Mountain terrane must have been emplaced eastward over equivalents of Kootenay terrane and its presumed floor of Precambrian basement, starting in mid-Jurassic time. The nappes may have included large batholiths of Jurassic age. The present overlap is almost 300 km, and accounting for mid-Cenozoic extension, must have been at least 200 km originally. Nappes of Kootenay terrane became detached from the basement as movement progressed such that a structural stack of Quesnel (above) and Kootenay (below) formed a roof-thrust over the evolving crustal duplex below. This entire structural flat stack is sometimes referred to as the Selkirk allochthon which rode on the Monoshee décollement. As telescoping progressed into late Jurassic and Cretaceous time, the accreting mass came above sea level to shed debris onto the Cordilleran foreland. As the foreland collapsed in imbricate thrust systems detaching from the Precambrian basement, the entire geometry of the Omineca–Kootenay hinterland continued to telescope but was locally much modified by considerable back thrusting and W-vergent structures overprinting the original E-vergent structures. This deformation continued into late Cretaceous and early Cenozoic time. Finally, the entire edifice collapsed in a siege of Cenozoic extension, presumably driven in some way from the effects of the previous considerable tectonic thickening. This denuded the duplex cores, reactivated original thrusts into detachment faults, arched the complex, and exposed rocks metamorphosed and deformed at depths of 20 km or more.

United States and Northern Mexico Cordillera

The relationships discussed above can be followed southward into the State of Washington in northwestern United States, but they are soon abruptly buried by the Miocene flood basalts of the Columbia Plateau (Fig. 2). The boundary between North America and the suspect terranes reappears south of the plateau, and can be followed southward across western United States and into northwestern Mexico. Throughout this region the accretionary structural relationships are much obscured by Cenozoic tectonics, particularly late Cenozoic Basin and Range extensional block faulting and also by strike-slip faulting related to the San Andreas transform.

The first occurrence of the boundary between the suspect terranes and North American rocks is in northeastern Oregon where the Wallowa terrane is apparently juxtaposed against North American rocks and the western edge of the Idaho batholith along a much discussed N-trending steeply E-dipping metamorphic shear zone (Hamilton 1963, Lund & Snee in press). The original relationships are much obscured by intense deformation and recrystallization, and most of the North American side of the boundary is engulfed in granitic rocks of the Idaho batholith. The Wallowa terrane is a Permian to Lower Jurassic volcanic and sedimentary sequence of island arc or oceanic plateau affinity which has been traditionally correlated with Wrangellia terrane (Jones *et al.* 1977). If it is part of Wrangellia, all of the terranes found between North American rocks and Wrangellia further north in Canada are missing here. More recently the Wallowa terrane has been generally correlated with Stikinia or possibly even Quesnel terrane (Mortimer 1986, Miller 1987). In any event, recent detailed studies here (Lund & Snee in press) suggest the juxtaposition is late Cretaceous in age and involved convergent transcurrent movements, probably right lateral.

Southwards from here, starting in southern Idaho and extending across Nevada into southern California, the boundary seems to lie west of the metamorphic culminations analogous to the Omineca belt and the character of the terranes is somewhat different.

The foreland fold and thrust belt in this region is known as the Sevier orogenic belt (Armstrong 1968) and it formed in the thick miogeoclinal prism just as it did in Canada. Several metamorphic culminations occur in the western part of the belt and they, like those in Canada, seem to record Mesozoic deep-seated deformation subsequently tectonically denuded by mid-Cenozoic extensional detachment faulting (Coney 1980, Armstrong 1982). West of the metamorphic complexes the first suspect terranes occur and here they are the Roberts Mountain and Golconda allochthons (Figs. 2 and 3E).

The Roberts Mountain terrane (Silberling *et al.* 1987) is a tectonic stack of Lower Paleozoic distal turbidites, radiolarian chert, graptolitic pelitic rocks and lesser pillow basalt that is clearly thrust up and over the North American miogeocline. The original emplacement is widely accepted as Devonian to early Mississippian in age based on the fact that a distinctive detrital wedge shed from the allochthon spreads out east of it and is interbedded in the miogeocline. There is also evidence, however, that much of the present distribution of outcrops is the result of younger Mesozoic deformation. Sitting on top of the Roberts Mountain terrane is a shelf carbonate sequence of Upper Paleozoic age which overlaps the allochthon and is presumed to tie it to the North American miogeocline. Just west of the Roberts Mountain terrane is the younger Golconda terrane.

The Golconda terrane (Speed 1979, Silberling *et al.* 1987) is an internally deformed stack of imbricated, Upper Paleozoic, deep-marine pelagic and turbiditic sedimentary rocks and pillow lavas. It is overlain unconformably by a distinctive early Triassic lava, Middle Triassic limestone, and Upper Triassic to early Jurassic fine-grained terrigenous clastic rocks. The Golconda allochthon sits structurally on top of the late Paleozoic carbonate overlap which covers the Roberts Mountain terrane. As in the case of the Roberts Mountain terrane, Mesozoic thrusting and Cenozoic extensional faulting have complicated original structural relationships.

When the Golconda allochthon was emplaced is still a topic of some debate. The usual interpretation is that it was thrust over the North American margin in late Permian–early Triassic time before the Triassic overlap assemblage was deposited. If it was, no widespread detrital wedge formed in front of the allochthon on the miogeocline as did during Devonian–Mississippian emplacement of the Roberts Mountain allochthon. If this scenario is accepted, the intense shearing and imbricate thrusting seen below the Triassic unconformity would record the emplacement. Part of the problem is that the Triassic overlap sequence is terrane specific to the Golconda terrane. That is to say, the overlap does not cross the Golconda thrust; thus the allochthon and its unconformable cover could have been emplaced in post-Triassic time. On the other hand, some argue that in spite of the lack of overlap across the Golconda thrust the Upper Triassic to Lower Jurassic fine-grained basinal to deltaic terrigenous deposits that are part of the Triassic sequence above the unconformity can be fitted into a widespread depositional scheme of similar deltaic to basinal clastic rocks that are part of the last stages of the North American miogeocline (Lupe & Silberling 1985). Nevertheless, all seem to agree Mesozoic thrusting has considerably modified the original geometry.

At the southern end of this belt in south central Nevada, the Roberts Mountain and Golconda terranes swing from N-trending to more westerly trends until they are truncated by a NW-trending fault system near the California border. Northwest of this concave arcuate trend there is an enclave of stacked thrust sheets of mostly Triassic to early Jurassic siliciclastic rocks known as the Jungo and Walker Lake terranes (Silberling *et al.* 1987), which form the upper plate of the Fencemaker and Luning thrusts (Oldow 1983). This deformational belt verges generally to the east and southeast, placing the Jungo and Walker Lake terranes over the Roberts Mountain and/or Golconda terranes. Just what lies below the Triassic basinal deposits is not clear, but latest Paleozoic volcanic and sedimentary rocks occur here and there, usually below thrust faults associated with the base of the terranes. These late Paleozoic volcanic rocks are interpreted by some to underlie the entire enclave, representing a subsided late Paleozoic arc (Speed 1979). The Upper Triassic basinal rocks are correlated by some with those that overlie the Golconda terrane, despite there being no known record of overlap of the critical terrane boundaries.

In northwestern Nevada there are scattered outcrops of Upper Paleozoic oceanic basin and volcanic rocks and Upper Triassic to mid-Jurassic volcanogenic sediments, volcanics and shallow plutonic rocks. The relationship of these rocks to the Jungo terrane is not known, but they have been suggested to be similar to the Quesnel group of terranes discussed above in Canada.

At the California border, all the northeast structural trends are truncated by northwest faults which are generally parallel to the regional structure of the entire Pacific margin. Even the Cordilleran miogeocline seems to be truncated and the NE-trending structures of the foreland thrust belt swing 90° to northwest as they enter Arizona from southern California (Burchfiel & Davis 1972, 1975). In southeastern California and adjacent southwestern Arizona, Paleozoic rocks typical of interior cratonic North America well inboard of the miogeocline occur within 100–150 km of the present Pacific margin and are juxtaposed against diverse terranes of uncertain origin. This entire region has been much obscured by possible late Paleozoic left-lateral stike-slip faulting (Walker 1988), massive Mesozoic plutonism, widespread Cenozoic extensional tectonics, and strike-slip faulting related to the late Cenozoic San Andreas system.

In northwestern Sonora, Mexico (Fig. 2), very thick Paleozoic sections identical with the Cordilleran miogeocline last seen in California reappear. Their position has been considered anomalous in that facies and thickness comparisons would suggest up to 800 km of left-lateral offset from California (Stewart *et al.* 1984). Combined with an apparent similar offset of Precambrian age provinces, this has led to the concept of the Caborca terrane as an assumed displaced fragment of North American miogeoclinal cratonic margin. These relationships have been interpreted to be the result of mainly Jurassic strike-slip faulting along the Sonora–Mojave 'megashear' thought to have been a large left-lateral transform fault connecting spreading centers in the Gulf of Mexico with the Pacific margin (Anderson & Schmidt 1983), but some of the displacement could be late Paleozoic (see Walker 1988). The relationships are thus similar to the Cassiar terrane in Canada, but the sense of offset is opposite and the movement earlier. The Caborca terrane, however, is apparently a composite terrane, with Paleozoic distal to deep water deposits ranging in age from lower Paleozoic to Permian age apparently thrust northeastward onto the carbonate banks of the assumed miogeoclinal fragment. These emplacements appear to be overlapped by Upper Triassic continental red-bed sequences (Stewart in press).

Where last seen in northwestern Mexico, the North American cratonic margin is striking nearly due east before being buried by extensive Mesozoic and Cenozoic rocks which cover most of northern Mexico. How these trends and structural relationships project into the SE-trending late Paleozoic Appalachian–Ouachita Mountains of the Atlantic and Gulf of Mexico margins is obscure, and currently in considerable debate.

STRUCTURAL GEOLOGY WITHIN THE ACCRETED TERRANES

The structural geology within the accreted terranes is complicated by the fact that the Cordillera has been subjected to nearly continuous deformation in varying plate tectonic regimens for most of Mesozoic and Cenozoic time. Much of this activity has obviously superimposed structures on original accretionary structures, whatever they might have been. As a result, early critical relationships are masked.

The most 'outboard' of the suspect terranes discussed in the previous section was the so-called Quesnel group, which seems to have been a generally submarine volcanic domain of Triassic to early Jurassic age which perhaps sat upon an oceanic substrate of late Paleozoic age. These rocks are interpreted as being juxtaposed against terranes of probable North American margin origin in various ways, usually involving flat thrusts, steeper transpressional structures, or strike-slip faults. The fact that volcanic and plutonic rocks of similar late Triassic to Jurassic age are known to intrude or sit upon the North American craton in southeasternmost California and adjacent Arizona and Sonora, Mexico, has led to the suggestion that the Quesnel group of terranes was tied to the North American miogeoclinal margin in the south, and lay close to it northward. This, of course, is an interpretation, but not necessarily an unreasonable one. Evidence in British Columbia (Klepacki & Wheeler 1985) is interpreted to show that Quesnel and Kootenay terranes are depositionally tied together. In any event, the early Mesozoic paleogeography is very uncertain. Outboard of the Quesnel group of terranes, however, the relationships are even more uncertain and suspect terranes found as far west as the present Pacific margin are more generally agreed to be in some sense 'exotic'.

The Cache Creek group of terranes

The first terrane found outboard of the Quesnel group of terranes at many localities from northwestern Canada southward to the west flank of the Sierra Nevada in California is a disrupted sequence of oceanic sedimentary and volcanic rocks including argillite, radiolarian chert, pillow basalt, reefoid limestones and Alpine-type ultramafic rocks (Monger 1977, Miller 1987). These sequences are often described as displaying melange-like characteristics and, locally, blue-schists yielding late Triassic isotopic ages (Davis *et al.* 1978). Fossils from these sequences are late Paleozoic to early Mesozoic in age, and more important, include Permian fusilinids, corals and conodonts similar to coeval faunas from Japan, China and the Himalayan region. For this reason, these faunas are usually described as 'Tethyan' (Monger & Ross 1971). The type terrane of the group is the Cache Creek terrane in Canada, but somewhat similar terranes would be the Baker terrane of the Blue Mountains of Oregon, the Fort Jones, North Fork and Hayfork terranes of the Klamath Mountains, and the Kaweah or Calaveras terrane of the Sierra Nevada foothills of California.

In Canada the structural boundary between the Quesnel group and the Cache Creek terrane is almost everywhere a major dislocation usually described as a right-lateral strike-slip fault (Fig. 1 and 3B & C). These faults are part of a vast system that runs the length of the Canadian Cordillera (Gabrielse 1985). The faults seem

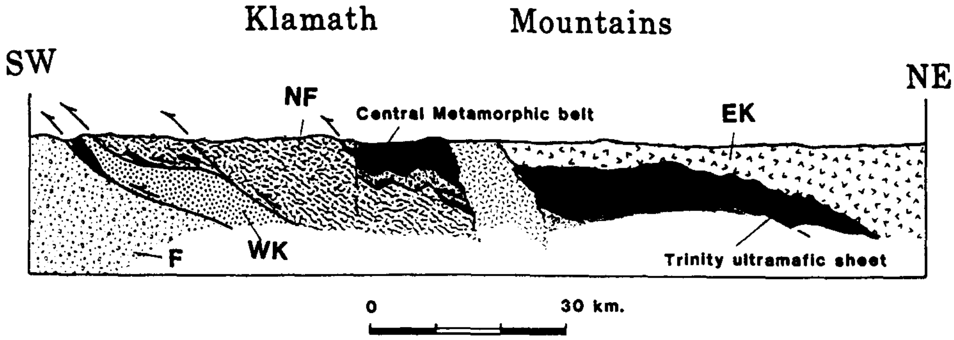

Fig. 6. Structural section across the Klamath Mountains, after Irwin (1981, figs. 2–4). EK, Eastern Klamath terrane; NF, North Fork–Fort Jones–Hayfork terranes; WK, Western Klamath terrane; F, Franciscan terrane.

to be of several overlapping ages with more northerly-trending ones offsetting more northwesterly-trending structures. The principal earlier faults are the Semenof–Teslin–Kutcho system in the north and the Pinchi fault in the south. These faults are characterized by mylonite, complex penetrative deformation, scales and slices of serpentine, and occasional blueschist minerals. There is much evidence of a prolonged and perhaps variable movement history ranging from Triassic to Cretaceous time. The total right-lateral movement is certainly several hundred kilometers. The main younger fault is the Finlay fault, apparently a part of the Fraser fault system. These younger faults have clear physiographic manifestation, display much evidence of brittle brecciation and shattering, and have been active into Cenozoic time. They offset all terranes and only locally form the boundary between Cache Creek and more inboard terranes. The total right-lateral movement on these younger faults seems to be about 100–150 km. The total movement on the older system is largely unknown. In other words, for most of the distance in Canada, the present contact between Cache Creek and Quesnel terranes is a strike-slip fault. One exception occurs in southern British Columbia where Cache Creek is mapped as thrust eastward over Quesnel (Travers 1978).

In the United States (Fig. 2) the structural relationships between terranes similar to those discussed above for Canada are quite different. In Oregon the Baker terrane, or Central melange terrane (Dickinson & Thayer 1978, Silberling *et al.* 1987), is juxtaposed against the 'more inboard' Olds Ferry terrane. The Baker terrane is extremely disrupted late Paleozoic to Triassic argillite, ophiolitic rocks, radiolarian chert with limestone blocks carrying both 'Tethyan' and North American faunas. The Olds Ferry terrane is mostly volcanoclastic sediments and volcanic rocks of Upper Triassic to Jurassic age. The juxtaposition is very complex; where seen, the melange belt usually is thrust southward over the Olds Ferry volcanic–sedimentary belt, but the melange is assumed to also underlie at least the northwestern edge of the Olds Ferry terrane. The relationship between the Olds Ferry terrane and the North American craton or miogeocline is unknown since they are nowhere in contact. North of the Baker terrane is the Wallowa terrane. As discussed earlier, the Wallowa terrane continues eastward where it is juxtaposed directly against assumed North American rocks along the west side of the Idaho batholith.

In the Klamath Mountains (Figs. 2, 3E and 6), rocks often correlated with the Cache Creek–Baker terranes form a complex arcuate band of disrupted, sheared and variably metamorphosed oceanic rocks which are thrust eastward beneath the massive Trinity 'ophiolite' and the Eastern Klamath terrane (Burchfiel & Davis 1981, Irwin 1981). The entire vergence of the Klamath Mountains is westward (Davis 1968) and structural sections always show this region as a stack of shallow E-dipping rooted thrust sheets. Some of the deformation must be post-early Jurassic because of cross-cutting plutons of that age and since radiolarians in the melange-like terranes are that young, but blueschist isotopic ages are Triassic.

In the western Sierra Nevada (Saleeby 1981) the equivalent boundary is best described as a zone known as the Foothills suture (Fig. 2). Considerable discussion (Schweickert 1981, Schweickert & Snyder 1981) still surrounds this region, but disrupted sequences of late Paleozoic to early Mesozoic oceanic rocks with several occurrences of 'Tethyan' faunas lie juxtaposed against the Northern Sierra or Kings terranes along a steeply E-dipping fault. The Northern Sierra terrane has been related to other volcanic belts such as the Eastern Klamath and Quesnel group of terranes to the north (Davis 1969, Mortimer 1986, Miller 1987).

In summarizing this important boundary, it is to be remembered that the current consensus is usually that the Tethyan-bearing melange-like terranes described from northern Canada south to California are a subduction complex related to the Quesnel group of terranes. The Quesnel group of terranes are usually interpreted as an arc-like assemblage which faced away from North America and lay adjacent to, or at some distance offshore from, North America's miogeoclinal margin (Mortimer 1986). Some paleogeographic linkage is in fact supported by lithologic, faunal and facies similarity, and provenance linkage (Miller 1987). This model is thought to be supported by evidence that the southern end of the arc may tie to North America itself. This interpretation may be correct, but today something approaching 80–90% of the present boundary is either a major zone of strike-slip faulting or locally, thrust faults which place the melange terranes eastward over the 'arcs'. Only in the Klamath and Sierran regions is any semblance of a consistent geometry found, but here some of the relationships are of younger age than the requisite subduction-arc age, and are thus uncertain.

The Stikine group of terranes

Before embarking on a discussion of remaining structural relationships within the accreted terranes, it would perhaps be helpful to contemplate the Cordilleran-wide distribution of some of the entities involved from the perspective of existing terrane maps (Jones *et al.* 1987, Monger & Berg 1987). The terrane grouping of Kootenay–Yukon Tanana extends from southern British Columbia northward into central Alaska (Fig. 1). As presently portrayed, the terrane widens northward such that as it enters Alaska it attains a width of over 300 km (Jones *et al.* 1987). In Alaska (Figs. 1, 3A, 7 and 8) the major discontinuity southwest of the Yukon Tanana terrane is a crushed flysch basin with fossils ranging from late Jurassic to mid-Cretaceous. Southwest of the flysch basin is the Wrangellia superterrane or Greater Wrangellia. Although much disrupted by strike-slip faults, it appears that the crushed flysch basin separating the Wrangellia superterrane from more inboard terranes can be traced southward through southeastern Alaska and western Canada into northwestern United States. In central westernmost Canada and southeastern Alaska, Greater Wrangellia is separated from Kootenay–Yukon Tanana by almost 400 km. This space is filled mostly by the Stikine terrane, which happens to be the largest suspect terrane in western North America, and a long narrow strip of metamorphic and plutonic rocks along the western margin of Stikine known as Tracey Arm terrane. Southward Stikine terrane narrows or perhaps terminates such that in Washington and southwestern British Columbia Wrangellia is separated from Quesnel terrane only by a micro-terrane laden flysch basin of late Mesozoic age. As discussed earlier, Quesnel terrane appears to be thrust eastward over several hundred kilometers of Kootenay terrane in the southern Omineca Mountains of British Columbia.

The Stikine terrane mostly exposes Triassic to Middle Jurassic submarine volcanic and associated sedimentary rocks and related granitic plutons. At several very restricted localities on both the northeast and northwest sides of Stikine terrane the Mesozoic volcanic sequences are known to depositionally overlie Devonian through Permian submarine volcanic and sedimentary rocks. There is at present no real evidence of any cratonic substrate of Stikine terrane and it seems to be 'oceanic' in origin (Samson *et al.* 1987). At one locality, however, Stikine may be tied to underlying metamorphic rocks correlated with Tracey Arm terrane by presumed Triassic dikes similar to Stikine lithology (Monger & Berg 1987).

The relationship between Stikine terrane and Cache Creek terrane is very problematical (see discussion in Monger & Berg 1987). At many places in the Canadian Cordillera the Cache Creek is thrust southwestward over the Stikine terrane, principally along the Nahlin fault. This fault certainly moved in part at least after the Middle Jurassic; thus, to what degree it represents the original juxtaposition geometry is uncertain. Furthermore, there is evidence that the Cache Creek and Stikine terranes were amalgamated by late Middle Jurassic time, since detritus from Cache Creek is found in lower horizons of the Jurassic–Cretaceous Bowser basin which is depositional on Stikine. Interbedded detrital sequences may link the two by late Triassic time, and large areas presently included in Stikine terrane, such as the late Triassic to Jurassic Whitehorse trough, appear to be depositional on Cache Creek terrane, although a sub-horizontal fault contact is not precluded. Thus, early Jurassic, or even late Triassic amalgamation is possible, but there are recently reported early Jurassic radiolarians in the western parts of the Cache Creek terrane in southern British Columbia (Cordey *et al.* 1987).

More important for our purposes is the peculiar map pattern at the north end of Stikine terrane where it is bounded on the northeast by Yukon Tanana terrane and on the northwest by the northernmost reaches of what is assumed to be Tracey Arm terrane. Both Tracey Arm and Yukon Tanana are relatively high-grade metamorphic terranes. The boundary between them, if any, is totally unknown. The Cache Creek terrane participates in this northward projection as do the Quesnel and Slide Mountain terranes. Furthermore, outliers of Stikine terrane are mapped into Alaska where they are thought to lie structurally on top of Yukon Tanana terrane as klippen. Proven Cache Creek terrane terminates near Whitehorse in Yukon Territory unless it correlates with undated similar lithologies which extend into Alaska as the Windy terrane. If this correlation is accepted, Cache Creek ends up jammed into the north margin of the Cretaceous suture along the southern margin of Yukon Tanana that separates Yukon Tanana from Greater Wrangellia. This then leads to the somewhat outrageous hypothesis that Cache Creek and Stikine terranes are stacked nappes thrust over almost the entire width of Yukon Tanana in northern Canadian Cordillera and into central Alaska. The original relationship between Stikine and Cache Creek terranes remains a mystery as it did so long ago when the anomalous position of Cache Creek between two belts of Triassic and Jurassic volcanic rocks was first recognized (Monger *et al.* 1972).

The Stikine terrane does not extend into the United States, but there are Upper Triassic to early Jurassic submarine volcanic and sedimentary rocks of similar composition to Stikine rocks found outboard of the melange packages discussed earlier in the Blue Mountains of Oregon, in the Klamath Mountains and in the Sierran foothills (Mortimer 1986). The Oregon example has recently been correlated with Stikine terrane, but traditionally it has been considered to be a part of Wrangellia terrane. In the Klamath Mountains and Sierran foothills the volcanic and sedimentary

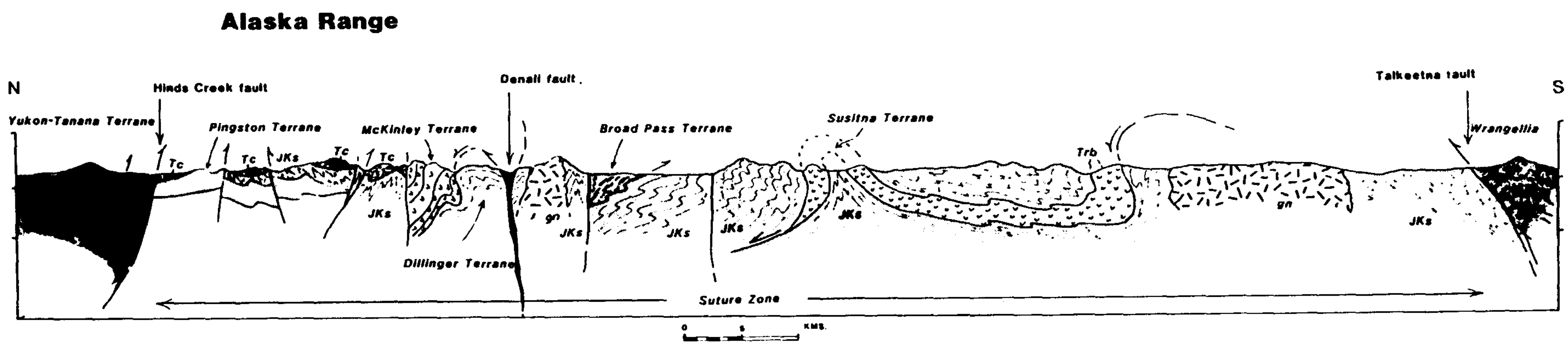

Fig. 7. Structural section across the crushed flysch basin and micro-terranes of the Alaska Range, southern Alaska; from a section by the author used as fig. 3-C in Jones *et al.* (1982). The crushed Jurassic–Cretaceous flysch (JKs) and enclosed micro-terranes lie between Wrangellia terrane on the south and Yukon Tanana terrane on the north. The micro-terranes are: Pingston terrane: Pennsylvanian–Permian phyllite and radiolarian chert, Triassic sooty argillite, thin-bedded silty limestone and minor quartzite, and gabbro sills and dikes; McKinley terrane: late Paleozoic flysch, thick Triassic pillow basalt and gabbro, late Paleozoic to late Triassic chert and argillite; Dillinger terrane: thick Lower to Middle Paleozoic silty carbonate turbidites; Broad Pass terrane: disrupted Carboniferous tuff and chert with blocks of Silurian–Devonian limestone; Susitna terrane: Triassic pillow basalt. Tc is the overlapping late Cretaceous–early Cenozoic continental sandstones and conglomerates of the Cantwell Formation. The plutons labeled gn are early Cenozoic granites.

sequences are probably depositional on, or at least associated with, Triassic serpentinized ultramafic rocks and they are found in the footwall of complex E-dipping shear zones that juxtapose the volcanic assemblages with the melange packages to the east (Burchfiel & Davis 1981, Saleeby 1981, 1983). There is, however, no particular reason to suppose that these sequences were once part of Stikine terrane.

The Wrangellia group of terranes

The next outboard suspect terrane grouping in the Cordilleran collage can be characterized by three elements, the relationships between which are not entirely clear. Included would be the Wrangellia superterrane in southern Alaska and Canada, the Franciscan terrane of California and southwestern Oregon, and the Guerrero terrane of western Mexico (Figs. 1 and 2). The relationship that binds them together is that they were apparently all accreted to North America in the period from late Jurassic to late Cretaceous time, and are all either composed of (the Franciscan terrane) or have on their inboard margins (Wrangellia and Guerrero terranes) vast amounts of variably deformed deep marine late Jurassic to late Cretaceous flysch.

The Wrangellia superterrane, or Greater Wrangellia, is made up of the classic terrane of Wrangellia (Jones *et al.* 1977), the Alexander terrane (Jones *et al.* 1972) and the Peninsular terrane (Jones & Silberling 1979). These varied terranes apparently began to amalgamate as early as late Paleozoic time, continuing into the Mesozoic before they can be accounted for along the North American margin in middle to late Cretaceous time. It is still unclear where the amalgam first accreted, but subsequent dispersal by major right-lateral strike-slip and transpressional deformation has sliced the superterrane into fragments which are now scattered along the Cordilleran margin from at least Vancouver Island in southwestern British Columbia north to southern Alaska. This process continues to the present day.

In the Alaska Range of southern Alaska (Figs. 3A and 7) the inboard boundary of the Wrangellia superterrane is a westward-widening flysch-filled, micro-terrane laden, suture zone separating the terrane from the Yukon Tanana to the north (Coney & Jones 1985). Near Mount McKinley, the late Jurassic to Cenomanian flysch-filled suture zone is over 100 km wide and the Denali fault, one of the major active strike-slip faults of the northern Cordillera, slices through the flysch. Eastward, the flysch-filled suture zone narrows until Wrangellia and Yukon Tanana terranes are juxtaposed across only the Danali fault with selvages of flysch and micro-terranes streamed along the vertical fault zone.

The structural geology of the westward widening suture zone is rather complex. The leading, or northern, edge of Wrangellia is thrust northward over the crushed and disrupted flysch on moderately S-dipping imbricate thrust faults (Coney *et al.* 1979, Csejtey & St. Aubin 1981). Eastward, as the suture zone narrows, the fault steepens and eventually dips northward at its juncture with the Denali fault. The northern boundary of the flysch-filled suture zone is a complex system of arcuate, concave south, steep faults that bring Yukon Tanana terrane and narrow micro-terrane slices structurally up and over the flysch.

Deformation within the flysch is intense and characterized by internal thrust faults, much shearing, tight isoclinal folds and abundant stratal disruption. Cleavage is locally well developed and at the eastern end of the trough, faulting has brought up deeper levels which are metamorphosed to amphibolite grade. In general, however, metamorphism in the flysch is of low grade. Within the flysch are an astonishing variety of small terranes, some with geologic histories extending back into the Lower Paleozoic, displayed today as long slivers and rootless nappes. One of these long disrupted slivers, the Windy terrane, is found for several hundred kilometers along the northern boundary of the suture and extends into Canada; it was mentioned earlier as a possible correlative of the Cache Creek terrane.

A major angular unconformity of latest Cretaceous age suggests the main accretion took place between Cenomanian and latest Cretaceous time. The unconformity and overlying continental deposits display concentric folds and steep thrusts trending E–W. Still younger Cenozoic volcanic rocks are much less deformed.

Slicing through all of this is the still active Denali fault which has further disrupted and dispersed the chaos of the suture zone. The total dextral movement on the fault is certainly hundreds of kilometers and it may have had its origin as the main terrane boundary fault in late Cretaceous time. Most of the present-day dramatic relief

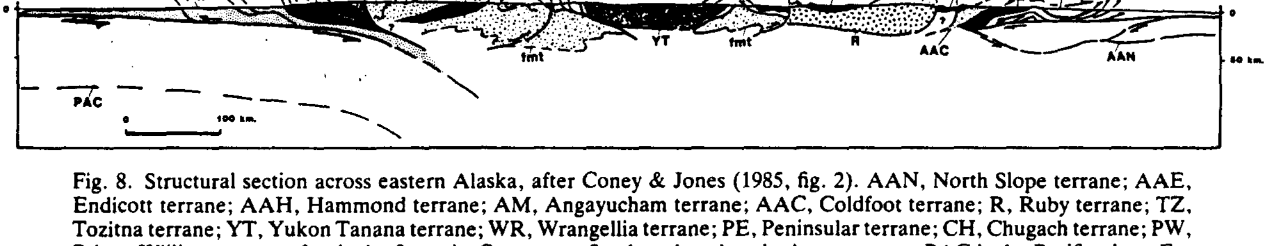

Fig. 8. Structural section across eastern Alaska, after Coney & Jones (1985, fig. 2). AAN, North Slope terrane; AAE, Endicott terrane; AAH, Hammond terrane; AM, Angayucham terrane; AAC, Coldfoot terrane; R, Ruby terrane; TZ, Tozitna terrane; YT, Yukon Tanana terrane; WR, Wrangellia terrane; PE, Peninsular terrane; CH, Chugach terrane; PW, Prince William terrane. fmt is the Jurassic–Cretaceous flysch and enclosed micro-terranes. PAC is the Pacific plate. For descriptions of terranes not discussed in text, see Coney & Jones (1985).

of the Alaska Range is no doubt due to massive transpressive intraplate stress and resulting deformation along the Denali fault system. In fact, the Denali fault probably turns into a steeply S-dipping thrust fault as it turns more southwestward along the north side of Mount McKinley.

In the eastern Alaska Range and southeast into Canada the Denali fault continues as the boundary between the Wrangellia superterrane and Yukon Tanana terrane with narrow slivers of micro-terranes along it as discussed above. Near Haines, in southeastern Alaska, the active right-lateral Chatham Strait strike-slip fault truncates these features and the inboard boundary of Greater Wrangellia changes in character southward through southeastern Alaska and western Canada.

Along the inboard margin of the Wrangellia superterrane in southeastern Alaska (Berg *et al.* 1978, Coney & Jones 1985, Crawford *et al.* 1987, Gehrels & Saleeby 1987), distal late Jurassic to mid-Cretaceous flysch and associated submarine volcanic rocks of the Gravina–Nutsotin assemblage and variable slices of what has been termed Taku terrane, fill the suture zone. These rocks become progressively metamorphosed toward the northeast with a strong SW-vergent structural style and fabric. Two major deformations are observed. The first is characterized by nearly E–W-trending recumbent ductile isoclinal folds that verge southward and are oblique to the NW-trending suture zone. As one moves northeastward, the early structures are overprinted by steeper and more brittle structures parallel to the trend of the suture zone and which eventually transpose the early fabrics into a steeply NE-dipping foliation with a near vertical penetrative lineation. The metamorphism reaches amphibolite grade and the suture zone itself is marked by a remarkable similarly foliated and lineated tonalite sill.

The terrane found across the suture zone has been termed the Tracey Arm terrane. It is a metamorphic–plutonic complex characterized by high-grade, somewhat granulitic gneiss, schist, granitic plutons, with minor marble and ultramafic rocks. Some of the plutons, including the tonalite sill, are latest Cretaceous in age. Just what the main metamorphic mass of the Tracey Arm terrane represents, however, is very uncertain. It could be a metamorphic–plutonic overprint, and thus not a terrane at all, or it could be the upturned edge of Stikine terrane which lies just to the northeast. Parts of the terrane, particularly the northern reaches, could possibly be the southwestern feather edge of Yukon Tanana terrane here reemerging from beneath the structural stack of Stikine and Cache Creek terrane discussed earlier. In any event, it seems clear that the northeastern margin of the Wrangellia superterrane dips steeply northeast against, and presumably beneath, the tipped-up or overfolded edge of Tracey Arm terrane. The boundary between the Tracey Arm and Stikine terranes does not seem to be well known, but in places the metamorphic rocks of Tracey Arm are known to be in fault contact over unmetamorphosed Stikine terrane. On the other hand, in one locality Stikine lies over Tracey Arm on a NE-dipping fault.

In southern British Columbia, Stikine terminates and the inboard margin of Wrangellia crosses the western Cordillera to lie close to Quesnel terrane. Between the two are Jurassic–Cretaceous flysch basins and a myriad of micro-terranes of uncertain origin. This zone passes into northwestern United States as the Jurassic–Cretaceous Methow trough and North Cascade Mountains of northwestern Washington.

The flysch basins described above are the same age as most of the Franciscan terrane (Blake & Jones 1981) in California (Figs. 2 and 3E). The Franciscan is now considered to be a variable complex of melanges, ocean floor rocks, submarine arc sequences, and a great deal of deep marine graywacke and shale, brought together in a transform to compressional setting. These rocks are thrust eastward beneath the ophiolitic floor or the Great Valley along the generally E-dipping Coast Range thrust, beneath which are found blueschist-bearing metamorphic rocks. Understanding of this classic 'subduction' system has been recently clouded by discovery that youngest movement on the Coast Range thrust was upper plate down to the east as a detachment fault (Jayko *et al.* 1987), suggesting tectonic denudation of the overthickened accretionary mass.

Southward, the poorly known Guerrero terrane (Campa & Coney 1983) appears to underlie most of western Mexico (Fig. 2). It is made up mostly of late Jurassic and mid-Cretaceous submarine volcanic rocks and associated sedimentary rocks with no presently known basement. There is some evidence that deep-water facies of flysch and related materials were entrapped in a generally E-vergent boundary zone that tends to place Guerrero rocks eastward over the Cretaceous carbonate shelf typical of interior Mexico. The terrane was consolidated into North America in late Cretaceous time. Whether it simply grew as a slightly offshore arc or accreted from some distance is still a topic of considerable discussion.

Structures on the Pacific margin

The present Pacific margin of the North American Cordillera displays a considerable variety of tectonic settings typical of the Cenozoic history of the orogen. Parts of the margin are actually 'decretionary', for example Baja California, while two long segments, the San Andreas system and the Queen Charlotte faults, are transform dominated. Accretionary tectonics are still taking place, however, off the southern Mexican coast, in northern California–Oregon–Washington and southwest British Columbia, and in the Gulf of Alaska. Recent studies in the latter two regions are briefly summarized here, since they are instructive.

In both regions recent seismic studies have revealed that the geometry of the subduction accretionary process is subhorizontal (Figs. 3A & D). Certain evidence has been interpreted to suggest that accreting material is underplated to the upper plate of the convergent system far inboard of the present margin. In the case of the Gulf of Alaska (Page *et al.* 1986) the Chugach and Prince William terranes represent mostly Cenozoic graywacke and argillite once spread over much of the nearby northeast Pacific floor and now accreted against the southern margin of the Wrangellia superterrane. The boundary is the Border Ranges thrust, which steepens northward, then flattens to sole into a major detachment at about 8 km depth which extends northward far beneath the Wrangellia superterrane. Below the detachment is interpreted another 30 km of underplated accretionary material. Similar sections have been drawn across the Olympic Mountains and Vancouver Island in southwestern British Columbia and northwestern Washington (Clowes *et al.* 1987).

CONCLUDING REMARKS

It would be inappropriate, and probably premature, to try to interpret all the regional structural relationships discussed in this paper. Several observations, however, can be made which might help put what has been discussed in a more general perspective, thus making what has been described more useful for those concerned with other orogenic systems.

It will have become apparent that a distinctive characteristic of the structural relationships between the accreted terranes and the North American craton is that, although much modified by strike-slip faulting and post-accretionary 'back thrusting', more distal and/or 'oceanic' terranes are frequently found as relatively thin thrust sheets sitting upon more 'inboard' terranes and/or on the miogeocline itself. The regional structural vergence is toward the craton. This regional cratonward vergence holds true, of course, on the Cordilleran foreland as well.

The amount of tectonic transport and telescoping implied is large. The structural overlap of terranes, such as oceanic Quesnel over North American cratonic basement and its miogeoclinal cover, is several hundred kilometers at least in British Columbia, and if Stikinia and Cache Creek terranes (which lie outboard of Quesnel terrane) have been thrust across Yukon Tanana throughout much of the northern Cordillera, the total structural overlap is even more. Furthermore, since the majority of the terranes seem to be composed of only supercrustal sedimentary and/or volcanic veneer and since evidence for presence of deeper crustal material is generally lacking, particularly in the more oceanic terranes, one has to conclude that the terranes represent thin slices or flakes somehow detached from whatever substrate they once sat upon. How the deeper crustal layers, let alone original lithosphere, were disposed of during the process of accretion is unclear, but some process of tectonic wedging and delamination at crustal scales seems necessary. Classic plate tectonic signatures recording these processes are not obvious and those tectonic signatures that do exist record plate tectonic interactions that predate the accretion across the Cordilleran margin.

One final structural relationship quite typical of the boundary zone between the North American rocks and the suspect terranes, particularly in Canada and Alaska, is the widespread occurrence of thin tectonic sheets of generally unmetamorphosed 'oceanic rocks' sitting directly on relatively high-grade metamorphic rocks of more 'continental' affinity (Tempelman-Kluit 1979, Coney & Jones 1985, Mortensen & Jilson 1985, Struik 1986). This relationship has been described at numerous places where the 'oceanic' Slide Mountain terrane and its probable relatives in Alaska, such as Angayucham terrane, sit structurally on top of such metamorphic complexes as Kootenay, Yukon Tanana and Ruby terranes, and along the south flank of the Brooks Range in northern Alaska. The contact is generally very abrupt with subhorizontal foliations, mylonite fabrics and much telescoping of metamorphic isograds evident in the lower plate. One possible explanation is that the relationship is due to massive syn- to post-metamorphic simple shear as the 'oceanic' sheets were obducted over the more 'continental' sheets below. If true, the process is on an extraordinary scale. An alternative solution would be post-obduction denudational extensional detachment faults similar to those described in the Cordilleran metamorphic core complexes (Coney 1980, Armstrong 1982) which have similar characteristics of juxtaposition of unmetamorphosed rocks on foliated and lineated metamorphic cores. There is clearly much research yet to do in North American Cordilleran geology.

The regional structural styles associated with Greater Wrangellia, the Franciscan terrane, and the Guerrero terrane in Mexico are more variable. In southern Alaska Wrangellia seems to be thrust northward over the wide flysch basin, but in southeastern Alaska and Canada the Wrangellia superterrane seems to be thrust against and below Tracey Arm terrane. In other words, the regional structural vergence here is westward with a strong element of right oblique convergence. The vergence in the Klamath Mountains and in the Franciscan dominated Coastal Ranges of California is generally perceived as westward. Regional structural style in the Guerrero margin in Mexico is not sufficiently well known to comment on, but it has been noted to be E-vergent at several localities. Most of the Cenozoic to recent accretionary structures along the present Pacific margin verge away from North America, or are dominated by transform to rifting geometry.

Although various types of tectonic activity, including amalgamation, have been well documented within the accreted terranes back into early Mesozoic and even late Paleozoic time, there is no evidence of any large-scale regional source areas west of the miogeocline until late Jurassic time. This is recorded in the near Cordilleran-wide reversal of sedimentary polarity in the miogeocline from generally eastern source areas to western source areas in late Jurassic to early Cretaceous time. This must mean that either the pre-late Jurassic tectonic activity of the accreted terranes took place below sea level or the terranes were removed from North America. The exceptions, of course, are the evidence of emplacement of the Roberts Mountain terrane in late Devonian–early Mississippian time in Nevada–Idaho and a similarly dated widespread detrital disturbance on the miogeocline in much of the northern Cordillera, and late Triassic to middle Jurassic arc and/or transform-rift derived, southwestern source areas in the southern Cordillera of the American Southwest and adjacent Mexico.

The evidence seems to be that once the first major accretions had taken place by late Jurassic time, possibly related to a rapid northwesterly motion of North America at this time (O'Hare *et al.* 1982, Coney 1987), deformation in the North American Cordillera was nearly continuous from then down to the present time. Most of the large-scale regional telescoping and associated intraplate strike-slip faulting actually took place from late Jurassic to early Cenozoic time, but local convergence, transform faulting and widespread extensional tectonics have dominated middle and late Cenozoic time. It was during the 100 Ma long period between late Jurassic and the Eocene that the Cordilleran-long foreland thrust belts evolved, apparently essentially continuously, and that the massive roof thrusts and deeper crustal duplexing seen along the overlap between the accreted terranes and the cratonic margin took place. As the process progressed and the Cordillera consolidated, back thrusts and large-scale intraplate strike-slip faulting became important. A very significant percentage of Cordilleran deformation took place between late Cretaceous and early Cenozoic time, extending from the foreland across the entire width of the accreted terranes. This took place during and after the accretion of Greater Wrangellia, later phases of Franciscan accretion, and the accretion or emergence of Guerrero terrane. This, of course, is the classic Laramide orogeny.

The rates and directions of plate convergence along the evolving Pacific margin are sufficiently well known, particularly from late Cretaceous down to the present, that we can be quite certain that the accreted terranes must have detached from subducting 'Pacific' plates almost immediately upon accretion. Otherwise they would have indented deep into North America's interior up to several thousand kilometers (Coney 1987). This suggests the North American Cordillera is not collisional, it is accretionary, and that most of the deformational strain we see is intraplate in origin, driven by transpressive convergence in a high stress regimen between a generally northwestward to westward-moving North America with an evolving array of variable moving 'Pacific' plates.

Strike-slip faulting has been a very significant aspect of the structural geology of the North American Cordillera. This is particularly true of the Cordillera in Canada and Alaska where the total distributed displacements could attain up to 2000 km or more, based on geologic evidence alone. This total, however, is considerably less than that suggested by certain paleomagnetic results (Monger & Irving 1980, Irving *et al.* 1985). In fact, the paleomagnetic data have been interpreted to suggest large percentages of the Canadian Cordillera, including most of the suspect terranes, stood off California as recently as late Cretaceous time. Similarly, much of southern California and western Mexico has yielded paleomagnetic results suggesting this ground was at latitudes of southern Mexico in Cretaceous time (Champion *et al.* 1984). For the most part, the geologic evidence for such extreme movements is lacking or even considered contradictory (Price & Carmichael 1986). Regional structural geologists, however, should remain attentive. The arguments are very similar to those of the 1950s, in that then those shocked by the tectonic implications of paleomagnetic data supporting continental drift grasped for alternative explanations for divergent polar wandering paths. Plate tectonics quieted that discussion. Presumably more data will resolve this one.

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