Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera

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ABSTRACT

The Omineca Crystalline Belt and Coast Plutonic Complex are the two major regional tectonic welts in the Canadian Cordillera in which were concentrated intense deformation, regional metamorphism, granitic magmatism, uplift, and erosion. The welts, which formerly were thought to result from subduction of Pacific Ocean lithosphere beneath the western edge of North America, can now be viewed partly as the result of tectonic overlap and/or compressional thickening of crustal rocks during collisions between North America and two large, composite, allochthonous terranes that were accreted to its ancient western margin. The inner composite terrane, Terrane I, includes four smaller terranes that apparently were together by the end of Triassic time. The outer composite terrane, Terrane II, comprises two terranes, amalgamated by Late Jurassic time. The Omineca Crystalline Belt formed mainly from mid-Jurassic time onward, during and following the collision of Terrane I with North America. This belt straddles the zone of overlap of autochthonous and allochthonous terranes, and its characteristic metamorphism and structure are superimposed on both. The Coast Plutonic Complex formed mainly in Cretaceous to early Tertiary time during and following the attachment of Terrane II to the new, Jurassic, continental margin. It lies along the boundary of Terrane I and Terrane II and involves elements of both terranes. The collisions took place within the overall setting of the North American plate moving relatively westward into various Pacific plates from Jurassic time onward and in conjunction with subduction of Pacific Ocean lithosphere.

INTRODUCTION

The three major, throughgoing, late Mesozoic–early Tertiary elements of the North American Cordillera—(1) the western subduction complexes or accretionary prisms, (2) the central granitic and metamorphic complexes, and (3) the eastern fold and thrust belt—are reasonably interpreted in terms of an Andean model. Although apparently valid on a continental scale, such a model does not explain the different characteristics of the various segments of the Cordillera.

The Canadian segment of the Cordillera is divisible into five physiographically distinct belts (Fig. 1, inset; Table 1). The Rocky Mountain, Intermontane, and Insular Belts are suprastructure, composed of unmetamorphosed and low-grade metamorphic rock, in which is preserved much of the stratigraphic record of the Cordillera. By contrast, the Omineca Crystalline Belt and Coast Plutonic Complex are major regional tectonic welts, in which the metamorphic and plutonic infrastructure of the Cordillera is exposed and which became differentiated between Jurassic and mid-Tertiary time when deformation, metamorphism, granitic magmatism, and uplift were concentrated in them. These welts have been imposed on and separate rocks in the other three belts and are the most conspicuous manifestation of Mesozoic orogeny in the Canadian Cordillera, but their significance in terms of plate-tectonics processes remains equivocal. Previous suggestions that the Omineca Crystalline Belt and Coast Plutonic Complex are magmatic arcs produced by subduction of oceanic crust (Monger and others, 1972; Dickinson, 1976) warrant careful reappraisal in view of the observation that these two welts straddle boundaries of allochthonous terranes that collided with one another and with the ancient western margin of North America.

STRATIGRAPHIC ANALYSIS

The notion that the Canadian Cordillera is in part a collisional orogen emerges from regional stratigraphic analysis of the supracrustal rocks. This shows that the Cordillera is a collage of discrete crustal fragments, or terranes (Monger, 1977; Jones and others, 1977; Davis and others, 1978; Coney and others, 1980). Each terrane is characterized by a distinctive, laterally persistent stratigraphic record that differs from the coeval records in neighboring terranes, from which it is separated by major faults and/or structurally complex zones, intrusions, or a cover of younger rocks. Terranes are defined solely on the basis of the integrity of their internal stratigraphic record, and not on the basis of any genetic or tectonic model. Each terrane consists of one or more tectonostratigraphic assemblages, each of which can be interpreted by analogy with modern examples as having formed in a particular tectonic setting (Monger and Price, 1979; Tipper and Woodsworth, 1981).

As an example, the mainly upper Paleozoic rocks identified as "old eugeosynclinal deposits" by King (1969) are distributed over four-fifths of the width of the Canadian segment of the Cordillera and include

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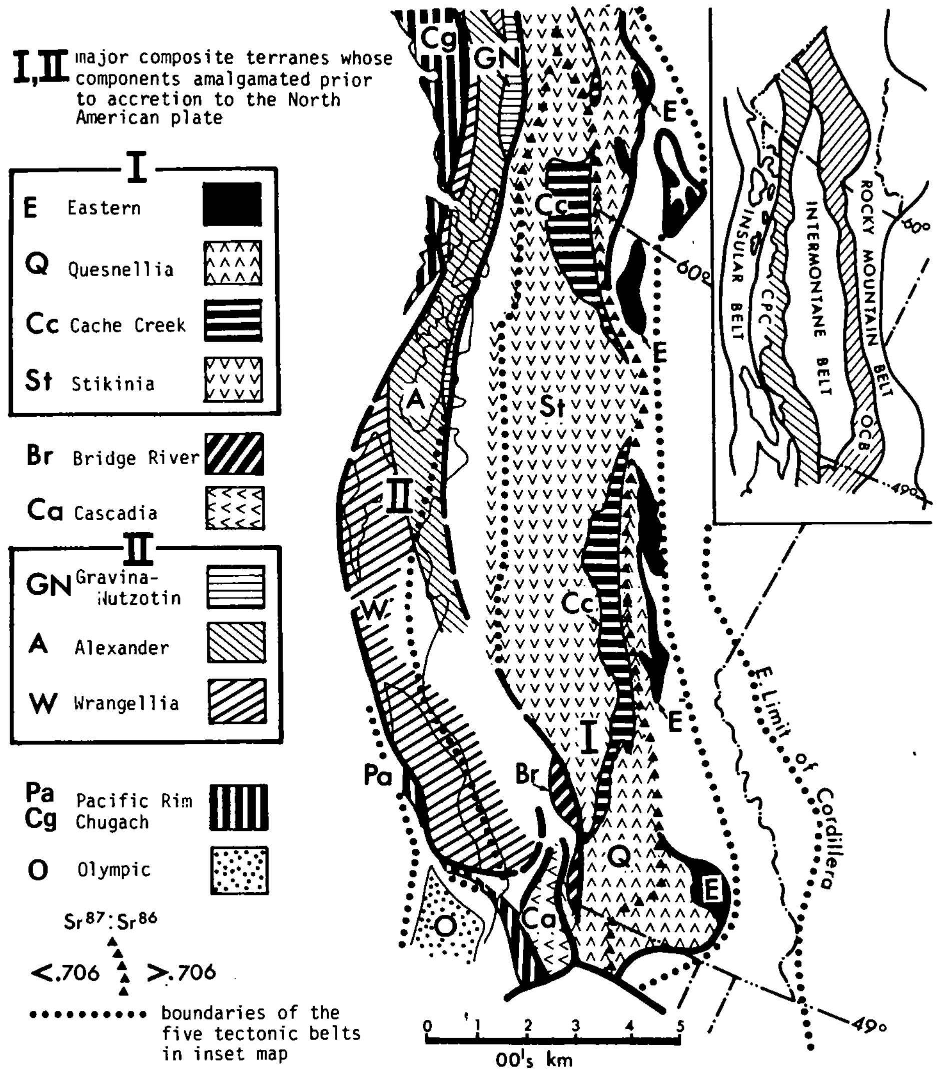

Figure 1. Distribution of allochthonous (or suspect) terranes in Canadian Cordillera, and their relationship to the five geologic and physiographic belts in inset map. Heavy lines enclose terranes (I, II) composed of small, originally independent terranes that amalgamated prior to accretion to western margin of the North American craton. Note coincidence between former boundaries of North America and I, and of I and II with, respectively, Omineca Crystalline Belt (OCB) and Coast Plutonic Complex (CPC). ^{87}Sr:^{86}Sr line (Armstrong and others, 1977; Armstrong, 1979; personal commun.) marks probable western limit of Precambrian continental crust at ancient continental margin or in blocks that may have been displaced outboard from it.

at least six laterally persistent, discrete tectonostratigraphic assemblages in Canada (Monger, 1977) and probably three more in southeastern Alaska (Berg and others, 1978). The westernmost assemblage (Sicker-Skolai) is stratigraphically overlain on Vancouver Island and in southern Alaska by at least two depositionally stacked, lower Mesozoic tectonostratigraphic assemblages. The sequence of three assemblages forms the terrane called Wrangellia by Jones and others (1977; W in Fig. 1 here; Table 2), which apparently persisted as a discrete entity until Late Jurassic time, when it coalesced with a second terrane (A in Fig. 1; Table 2) to form a composite terrane (II in Fig. 1). On the basis of the nature of each of its constituent assemblages, Wrangellia appears to have been a volcanic arc in Late Pennsylvanian–Permian time, a submarine to subaerial plateau of tholeiitic flood basalt in Late Triassic time, and a marine basin and a volcanic arc in Early Jurassic time (Monger and Price, 1979). It is important to recognize that the tectonic setting during deposition of an assemblage in an allochthonous terrane may have no direct significance in terms of the coeval tectonic history along the margin of the North American craton, where that terrane was subsequently lodged.

EVIDENCE FOR LARGE HORIZONTAL DISPLACEMENTS

Documentation of large horizontal displacements between accreted terranes and between them and the ancient western margin of North America involves structural, paleomagnetic, and paleontological evidence.

1. Palinspastic reconstructions based on matching offset counterparts of geologic markers across major fold and thrust belts, large strike-slip fault zones, and systems of listric normal faults have shown, for example, horizontal components of displacements of at least 200 km across the fold-thrust system of the southern Canadian Rockies (Price, 1981) and about 450 km along the Tintina right-lateral strike-slip zone in the Yukon (Tempelman-Kluit, 1979). Lack of geologic markers across many of the other major fault systems precludes any reliable estimates of displacements across them, but because many juxtapose terranes of different stratigraphy and different faunal provinces, the displacements are likely to be large.

2. Paleomagnetic data from different terranes in the western Cordillera document northward paleolatitudinal shifts relative to North America of as much as several thousands of kilometres (for example, Irving and Yole, 1972; Hillhouse, 1977; Van der Voo and others, 1980; Irving and others, 1980). As an example, Triassic, Jurassic, and Lower Cretaceous rocks on Stikinia (Fig. 1) appear to have been displaced northward relative to cratonic North America by about 13°, and Triassic strata of Wrangellia may have been displaced by as much as 30°.

3. Faunas in Permian, Triassic, and Jurassic rocks in the different terranes may be disjunctive with one another and with those in rocks deposited on or near the North American craton (Tozer, 1970; Monger and Ross, 1971; Yancey, 1975; Nichols and Silberling, 1979; Tipper, 1982). Only the Permian faunas of the Cache Creek Group, which closely resemble Permian faunas in areas surrounding the western Pacific and ancient Tethys, obviously are exotic with respect to North American faunas. Other faunas differ from coeval ones now at the same latitude on the craton, but most appear to have counterparts in the southwestern United States and Mexico. Even so, their present distribution suggests northward displacements for considerable distances.

The only Mesozoic and older stratigraphic sequences of the Canadian Cordillera that definitely can be identified as always having been in physical continuity with adjacent parts of the North American craton are those that form the northeasterly tapering wedge of mainly shallow-water sedimentary rocks that comprises the Cordilleran miogeocline, the platformal cover of the North American craton, and the synorogenic fill of the foreland basin overlying both of them. Even this wedge, which includes all of the Rocky Mountain Belt and adjacent parts of the Omineca Crystalline Belt, exhibits a significant degree of allochthoneity. It is cut by an interfingering and overlapping array of northeasterly verging, imbricate listric thrust faults and related folds that formed in later Mesozoic and early Tertiary time, when the Cordilleran miogeocline was de-

TABLE 1. NATURE OF MAJOR GEOLOGIC AND PHYSIOGRAPHIC SUBDIVISIONS OF THE CANADIAN CORDILLERA

Belt	Description
Rocky Mountain Belt	Northeasterly tapering wedge of mid-Proterozoic to Upper Jurassic (1500-150 M.y.) miogeoclinal and platformal carbonates and craton-derived clastics, and overlying Upper Jurassic to Paleogene exogeoclinal, cordillera-derived clastics; horizontally compressed and displaced up to 200 km northeastward onto craton in Late Jurassic to Paleogene time
Omineca Crystalline Belt	Mid-Proterozoic to mid-Paleozoic miogeoclinal rock, Paleozoic and lower Mesozoic volcanogenic and pelitic rock, local Precambrian crystalline basement, highly deformed and variably metamorphosed up to high-grades in mid-Mesozoic to early Tertiary time, and intruded by Jurassic and Cretaceous plutons
Intermontane Belt	Upper Paleozoic to mid-Mesozoic marine volcanic and sedimentary rock, mid-Mesozoic to upper Tertiary marine and nonmarine sedimentary and volcanic rock; granitic intrusions comagmatic with the volcanics; deformed at various times from early Mesozoic to Neogene
Coast Plutonic Complex	Sedimentary and volcanic strata of known late Paleozoic to Tertiary age and probable early Paleozoic and Precambrian age, variably metamorphosed up to high grades, and dominant, mainly Cretaceous and Tertiary granitic rock
Insular Belt	Upper Cambrian to Neogene volcanic and sedimentary strata, granitic rocks in part comagmatic with the volcanics; deformed at various times from Paleozoic to Neogene

Note: See Figure 1 for distribution of these subdivisions.

TABLE 2. NATURE OF ALLOCHTHONOUS (OR SUSPECT) TERRANES

Terrane	Description
A: Alexander (composite)	Precambrian(?) Paleozoic and Mesozoic volcanic, clastic and carbonate rocks
Br: Bridge River	Permian to Middle Jurassic melange and tectonically disrupted chert, argillite, basalt, alpine-type ultramafics, and minor carbonate
Ca: Cascadia (composite)	Crystalline and pelitic gneiss, in part of Precambrian age; Paleozoic and Mesozoic volcanics and associated sedimentary rocks, disrupted Mesozoic greenschist, blueschist, and phyllite
Cg: Chugach (composite)	Deformed upper Mesozoic flysch and melange; lower Cenozoic flysch and volcanics
Cc: Cache Creek	Mississippian to Upper Triassic melange and tectonically disrupted chert, argillite, basalt, alpine-type ultramafics, extensive carbonate, and local blueschist
E: Eastern	Upper Paleozoic and(?) lower Mesozoic basalt, alpine-type ultramafics, chert, argillite
GN*: Gravina-Nutzotin	Upper Jurassic and Lower Cretaceous flysch and volcanics; lies stratigraphically on A and W
O: Olympic	Lower Cenozoic volcanics and associated deep- and shallow-water sedimentary rocks. Basement presumed to be oceanic
Pa: Pacific Rim	Upper Jurassic and Lower Cretaceous flysch and melange
Q: Quesnellia	Upper Paleozoic and Lower Triassic volcanics, volcaniclastics, and carbonates; Upper (locally Middle) Triassic to Lower Jurassic volcanics, clastics, and argillite; Upper Triassic and Lower Jurassic strata lie stratigraphically on E, and probably on Cc. In Yukon, includes possible upper Precambrian to lower Paleozoic metamorphic rocks of continental crustal affinities
St: Stikinia	Possible upper Precambrian basement, with Mississippian and Permian volcaniclastic rocks, basic to acidic volcanic rocks and carbonate rocks, locally deformed and intruded in Middle to Late Triassic time, overlain by Upper Triassic to Middle Jurassic andesitic volcanic strata. Uppermost Triassic to Middle Jurassic rocks probably linked to Cc
W: Wrangellia	Paleozoic volcanic complexes composed of flows, breccias, and volcaniclastic rocks overlain by limestone, clastic rocks, and chert, and Upper Triassic pillowed and subaerial basalt flows succeeded by Triassic and Jurassic limestone, cherty limestone, and clastic and volcanic rocks

Note: Descriptions, in part, from Coney and others (1980)
*Strictly, GN is an overlap assemblage on both A and W.

tached from its basement, horizontally compressed, and displaced more than 200 km northeastward over the margin of the North American craton (Price, 1981).

HISTORY OF AMALGAMATION AND ACCRETION

The times and order in which the allochthonous terranes amalgamated with one another and accreted to the ancient western margin of North America bear directly on the problem of the origins of the Omineca Crystalline Belt and Coast Plutonic Complex. Stratigraphic evidence suggests that the small terranes that lie mainly in the Intermontane Belt, but which extend into the Omineca Crystalline Belt and Coast Plutonic Complex (E, Q, Cc, St in Fig. 1), were together by latest Triassic–earliest Jurassic time, and they formed the large composite terrane, Terrane I, prior to accretion to the ancient margin of North America in Jurassic time. Terranes mainly in the Insular Belt, but extending into the Coast Plutonic Complex (A, W in Fig. 1) were amalgamated by Late Jurassic time into the composite Terrane II, but probably were not attached to terranes to the east (I, Ca, and North America) until Cretaceous time. The general coincidence of the Omineca Crystalline Belt with the boundary between I and the ancient margin of North America and the Coast Plutonic Complex with the boundary between I and II, together with the ages of structural and metamorphic features that characterize these belts, and the times at which they appear in the stratigraphic record as sedimentary source terranes supplying detritus to flanking supracrustal regions suggest to us that the two tectonic welts are due, at least in part, to collisions between Terrane I and the North American craton and between Terranes I and II (Figs. 1, 2). Estimated pressures of more than 7 kb during prograde metamorphism in high-grade metasedimentary rocks in both the Coast Plutonic Complex (Pigage, 1976; Hollister, 1979) and the southern Omineca Crystalline Belt (Ghent and others, 1979) imply depths of burial greater than 25 km. These can be explained by tectonic burial during overriding of one terrane by another and/or compressional thickening of the crust during collisions, but otherwise are enigmatic.

In the Intermontane Belt four distinct assemblages of mainly upper Paleozoic rocks (in terranes E, Q, Cc, and St) seem to have amalgamated to form Terrane I by the end of the Triassic. Two of them (E and Q) are stratigraphically overlapped by Middle or Upper Triassic strata in south-central British Columbia (Read and Okulitch, 1977). Earlier suspicions that a third, the Cache Creek terrane (Cc), is a subduction complex related to Late Triassic arc activity on Quesnellia and Stikinia (Monger, 1977; Travers, 1978), are supported by recent discoveries. Cache Creek melange in southern British Columbia, which comprises fossiliferous Upper Pennsylvanian to Upper Triassic strata, includes foreign volcanic blocks identical to lithologies in the Upper Triassic Nicola Group of Quesnellia to the east. Also, radiolarian chert clasts, presumably eroded from nearby Cache Creek strata, are in Nicola clastic rocks (Monger, 1981; Shannon, 1981). However, the youngest rocks known in the Cache Creek melange are radiolarian cherts of latest Triassic age (D. L. Jones, 1981, personal commun.), indicating that pelagic sedimentation continued at least locally until the end of the Triassic. In central British Columbia, Upper Triassic conglomerate, in an extensive volcano-sedimentary sequence flanking the Cache Creek, contains distinctive clasts of Cache Creek rock types (Paterson, 1977). In northwestern British Columbia and the southern Yukon, Triassic radiolarian chert of the Cache Creek terrane (M. L. Orchard, 1981, personal commun.) is intercalated with graywacke identical to that of Upper Triassic volcaniclastic rocks of Sti-

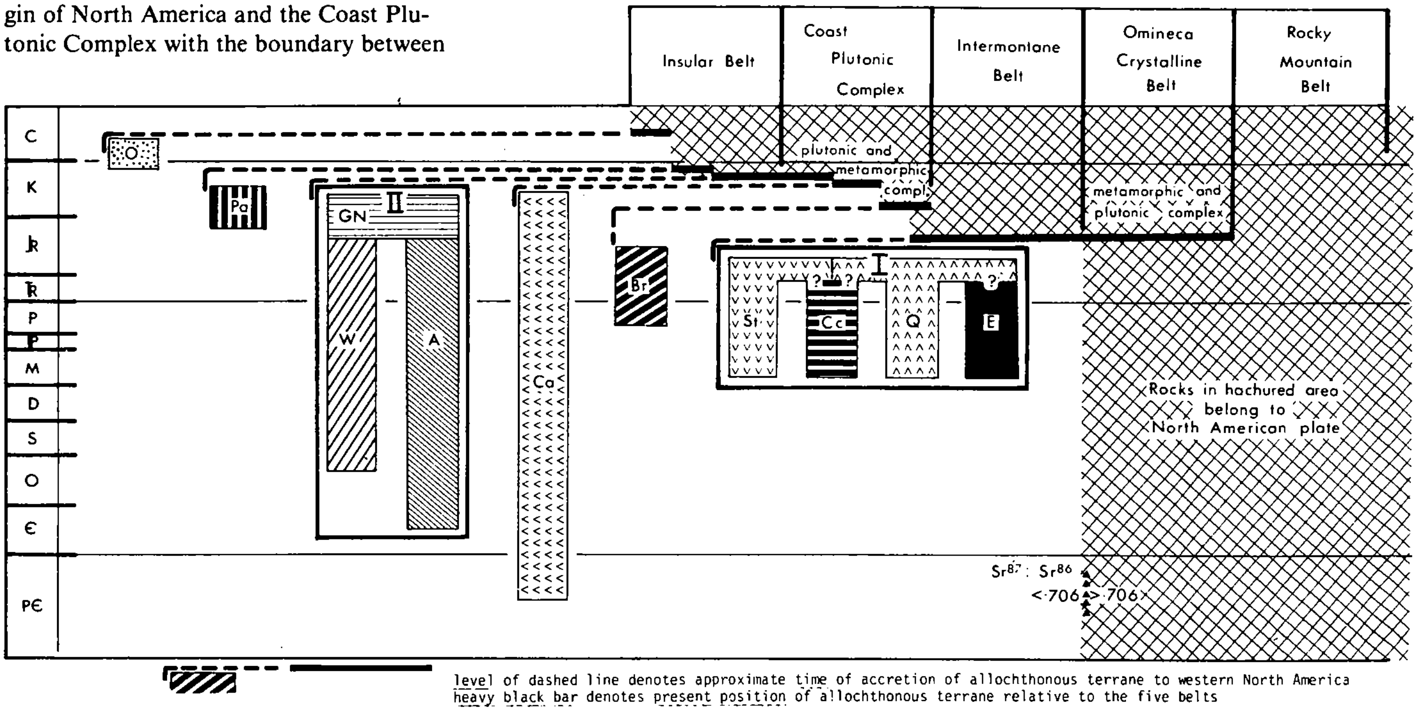

Figure 2. Space and time relationship of allochthonous (or suspect) terranes in Canadian Cordillera. Shown are depositional interval represented by each terrane; overlap assemblages in terranes I and II, indicating coalescence prior to accretion to western North America; unknown spatial relationships during deposition of allochthonous terranes, indicated by vertical spaces separating them; times of accretion to western margin of North America and present location with respect to the five belts; coincidence of metamorphic and plutonic Omineca Crystalline Belt and Coast Plutonic Complex with boundaries between, respectively, I and North America and II and (mainly) I; and accretionary, westward-built, nature of western margin of North American plate. Figure does *not* show structural relationships between terranes. These may be thrust faults (for example, Ca on II, I on North America) or strike-slip faults (for example, Ca with Br and I).

kinia to the southwest, supporting the idea that Stikinia and the Cache Creek terrane were conterminous by Late Triassic time. Since the Cache Creek Group extends more-or-less continuously for the length of the Canadian Cordillera, it seems probable that all four terranes (E, Q, Cc, St), which were independent of one another in the Permian (Monger, 1977), had been assembled by the end of the Triassic, forming Terrane I. However, the final amalgamation of the four small terranes in Terrane I did not come until at least mid-Jurassic time, when Stikinia was thrust under rocks to the north and east as Terrane I collided with North America. Stikinia is overlapped on the north and east sides by thrust faults, some of which emplace Cache Creek strata on Stikinia. Clasts derived from the Cache Creek Group form the upper Middle and Upper Jurassic conglomerates of the Bowser Basin, which lies entirely on Stikinia, and detritus eroded from metamorphic rocks of the Omineca Crystalline Belt is in Lower Cretaceous deposits overlying Bowser rocks (Eisbacher, 1974; Monger and others, 1978; Monger and Price, 1979).

In the Yukon, the Teslin suture, which marks the boundary between Terrane I and the early Mesozoic margin of North America, is the root zone from which thrust nappes, comprising cataclastically deformed ophiolite, metasedimentary rock, and arc-related granitic rock, can be followed more than 100 km northeastward over Upper Triassic and older rocks of the Cordilleran miogeocline (Tempelman-Kluit, 1979). Crosscutting, post-tectonic, mid-Cretaceous granites show that the thrust nappes were emplaced prior to the mid-Cretaceous. Congruence of the nappe structures with dated thrust faults to the northeast involving miogeoclinal strata suggests that the nappes are as young as Late Jurassic or Early Cretaceous. In central British Columbia, Struik (1982) has shown that Permian-Pennsylvanian rocks of the Eastern terrane (E of Fig. 1; Table 2) are thrust eastward onto Permian and older miogeoclinal strata. Thrusting predates major regional deformation and metamorphism, which is post-Triassic and pre–Late Jurassic (Pigage, 1977). In southeastern British Columbia, Lower Jurassic strata of Quesnellia were involved in the regional metamorphism that forms the core of the Omineca Crystalline Belt (Hyndman, 1968). Similar strata were thrust under the outer, western part of the Cordilleran miogeocline prior to emplacement of crosscutting mid-Cretaceous plutons, and the western part of the Cordilleran miogeocline was compressed, thickened, and displaced toward the craton during Late Jurassic and Early Cretaceous time (Little, 1960; Price, 1981). These relationships, and those in the Stikinia region discussed above, lead to the conclusion that initiation and early development of the Omineca Crystalline Belt are almost coincident with impingement of Terrane I against the ancient western margin of North America in Middle Jurassic time.

To the west, amalgamation of the Alexander Terrane and Wrangellia to form Terrane II is recorded in southern and southeastern Alaska by the Late Jurassic–Early Cretaceous Gravina-Nutzotin assemblage, which overlaps them both (Fig. 1; Berg and others, 1972; Coney and others, 1980). Terrane I is linked to Terrane II by the mainly Cretaceous and lower Tertiary granitic rocks of the Coast Plutonic Complex, which intrude Terrane I in northwestern British Columbia and Terrane II in southwestern British Columbia.

The Coast Plutonic Complex consists mainly of Cretaceous and lower Tertiary granitic rocks with septa of variably metamorphosed strata and intrusions whose protoliths range in age from probable late Precambrian to early Tertiary. Because its axis lies about 200 km east of Upper Jurassic and Cretaceous accretionary prisms represented by the Pacific Rim Complex and the Chugach terrane of southeastern Alaska (Pa, Cg, in Fig. 1), the complex is reasonably interpreted as a magmatic arc related to east-dipping subduction of Pacific Ocean lithosphere (Monger and Price, 1979). However, among the subduction-generated magmatic rocks are high-grade metamorphic rocks and migmatite complexes containing supracrustal rocks that were metamorphosed under pressures of more than 7 kb (Hollister, 1979). We suggest that these may have originated during collision between Terranes I and II as one terrane overlapped or compressed the other. A collision or obduction model for the Coast Plutonic Complex was suggested by Godwin (1975) to account for the ages (95 to 45 m.y.) of porphyry-type mineral deposits in the central Coast Plutonic Complex and Intermontane Belt. He proposed that two east-dipping subduction zones, one located east and one west of the Insular Belt (here equivalent to Terrane II) were responsible for both magmatism and doubling up of the crust at the site of the Coast Plutonic Complex, where Terrane II was driven beneath the North American plate. Subsequent uplift of 5 to 25 km and erosion in the early Tertiary locally exposed the granulite-facies metamorphic rocks reported by Hollister (1975, 1979). Additional evidence of collision in the evolutio of the Coast Plutonic Complex comes fro the profound contrast between the Coast Plutonic Complex and the Northern Cascade system in the vicinity of Vancouver, British Columbia, which is difficult to explain if both systems are parts of a single magmatic arc. The various models that have been offered to explain this contrast (for example, Davis and others, 1978) involve the southern termination of both Coast Plutonic Complex and Terrane II at about the same latitude, and the late Early to early Late Cretaceous ages of reversals of clastic sedimentary transport directions, with roughly synchronous thrust faulting, regional metamorphism, and granitic intrusion. It is difficult for us to avoid the conclusion that several terranes came together in this region by mid-Cretaceous time.

CONCLUSIONS

We submit that the two high-grade metamorphic and granitic welts that characterize the Canadian segment of the Cordillera developed subsequent to collision of large composite allochthonous terranes, and that features of those welts, such as some structures and some high-grade metamorphism, can be interpreted as the result of collisions. The Omineca Crystalline Belt straddles the boundary between the ancient continental terrace wedge (miogeocline) of North America and a large composite terrane, I, that collided with and was accreted to North America in about mid-Jurassic time. The Coast Plutonic Complex straddles the boundary between Terrane I (the new North American plate margin) and another large displaced terrane, II, that collided with and was accreted to western North America in about mid-Cretaceous time. These collisions took place within the overall setting of the North American plate moving relatively westward into various Pacific plates and was accompanied by subduction of Pacific Ocean crust. It should be noted, however, that in the California-Colorado segment of the Cordillera there is no obvious correspondence between many of the terrane boundaries, times of amalgamation and development of metamorphic and granitic welts.

The importance of northward, transcurrent movements in the emplacement of these terranes (Irving and others, 1980) has been ignored herein, in order to emphasize the collisional origins of the Coast Plutonic Complex and Omineca Crystalline Belts. Such movements, whose youngest manifestations are probably the great right-lateral strike-slip faults such as the Tintina in the Yukon, active in Late Cretaceous–early Tertiary time, the Denali in Alaska, active in mid-Tertiary time, or the present offshore Queen Charlotte–Fairweather system, appear from paleomagnetic and paleontological evidence to have been extremely large. Available paleomagnetic data suggest that much of the latitudinal displacement of the allochthonous terranes is due to postcollisional strike-slip faulting along the continental margin; just how much is due to precollisional oblique subduction remains to be determined.

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