Chapter 2 – Cordilleran Tectonics and the Evolution of the Western Canada Sedimentary Basin

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Introduction

The Cordilleran Connection

The connection between the Western Canada Sedimentary Basin and global plate tectonics lies in the Cordillera, because the origin and evolution of the Western Canada Sedimentary Basin was linked inextricably to the origin and evolution of the Cordillera, and thereby to the global plate tectonic processes that produced the Cordillera. Episodes of epeirogenic subsidence and sediment accumulation in the Western Canada Sedimentary Basin generally can be ascribed directly to the effects of concurrent episodes of orogenic deformation in the Cordillera (Porter et al., 1982), and, thereby, indirectly to the displacements between the North American craton and the adjacent lithospheric plates to the west of it that produced the Cordillera (Monger and Price, 1979). The main purpose of this chapter is the elucidation of the Cordilleran connection.

The Supracrustal Wedge

The Western Canada Sedimentary Basin, as viewed from the perspective of a cross section of the continental lithosphere, is a very thin, northeastward-tapering wedge of supracrustal rocks overlapping the Precambrian crystalline rocks that form the core of the North American craton. The thickness of this supracrustal wedge increases gradually southwestward, over a distance of between 600 and 1200 km, from a zero edge along the exposed margin of the Canadian Shield, to between 3 and 5 km at the northeastern margin of the foreland thrust and fold belt (Wright et al., *this volume*, Chapter 3), and even there it comprises only 10 to 15 percent of total thickness of about 40 km of continental crust (Richards, 1958).

The thickest and stratigraphically most complete part of the supracrustal wedge occurs farther west, within the eastern part of the Cordillera (Fig. 2.1), in the Rocky Mountain Foreland Thrust and Fold Belt and the eastern part of the Omineca Belt (Bally et al., 1966; Price, 1981; Price and Mountjoy, 1970; Thompson, 1979). Stratigraphic relations in this part of the supracrustal wedge are partly obscured by deformation, regional metamorphism and granitic plutons because this part of the wedge has been incorporated into the accretionary prism that separates the North American craton and its cover of autochthonous supracrustal rocks from the tectonic collage of allochthonous terranes that make up the main mass of the Cordillera. The supracrustal rocks within the accretionary prism have been detached from their basement and displaced northeastward. They were scraped off the North American craton and accreted to the overriding tectonic collage of allochthonous terranes. Although this part of the supracrustal wedge has been horizontally compressed and tectonically thickened by folding and imbricate thrust faulting, palinspastic reconstructions of the deformed rocks in the accretionary prism show that prior to the formation of the accretionary prism, the thickness of the supracrustal wedge increased southwestward relatively abruptly, over a distance of 200 km or less, from between 3 and 5 km at the present position of the northeastern margin of the foreland thrust and fold belt to between 10 and 15 km along the former position of the Paleozoic and early Mesozoic continental margin of North America (Bally et al., 1966; Price and Mountjoy, 1970; Thompson, 1979; Price, 1981; Price and Fermor, 1985). The birth, growth and deformation of this part of the supracrustal wedge is the main focus of this chapter because it holds the key to the understanding of the origin and evolution of the remaining undeformed part of the Western Canada Sedimentary Basin that lies east of the Rocky Mountain Foreland Thrust and Fold Belt, beneath the western plains.

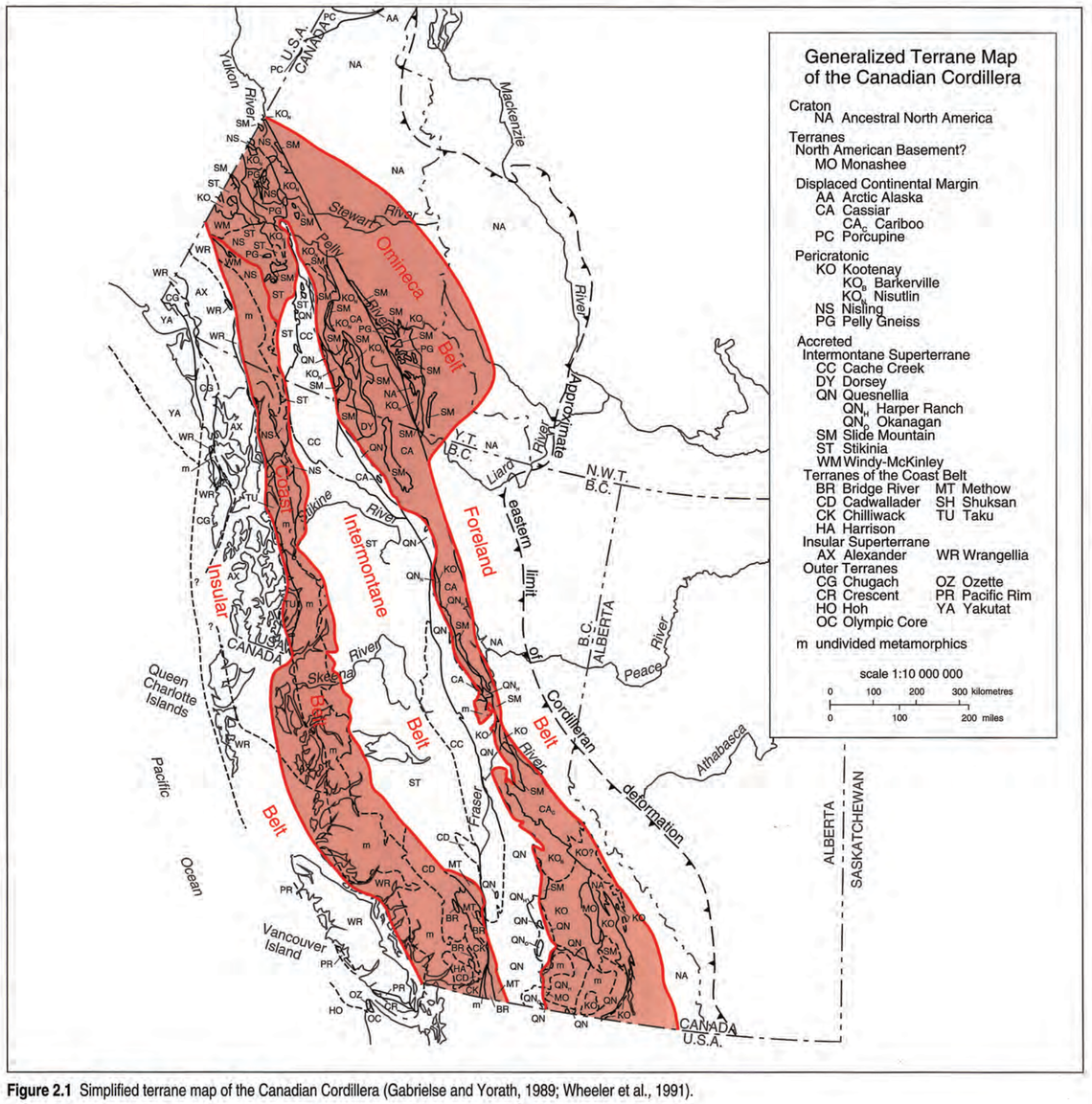


Figure 2.1 Simplified terrane map of the Canadian Cordillera (Gabrielse and Yorath, 1989; Wheeler et al., 1991).

Stages of Tectonic Evolution

Two main stages in the development of the Western Canada Sedimentary Basin are distinguished by a profound change in provenance of the clastic sediment preserved within the supracrustal wedge (Bally et al., 1966; Price and Mountjoy, 1970). A Late Proterozoic to Late Jurassic miogeocline-platform stage, during which the main external source of the sediment was to the northeast on (and beyond?) the present North American craton, has been correlated with the continental rifting and drifting that created the initial Cordilleran continental margin of the North American craton and its adjacent ocean basin, and subsequently, the continental terrace wedge (miogeocline) that was prograded outboard from this "passive margin" (Stewart, 1972; Monger and Price, 1979). A Late Jurassic to Early Eocene foreland basin stage, during which the main source of sediment was to the southwest in the emerging Cordilleran mountain belt, has been correlated with the accretion of a tectonic collage of allochthonous oceanic terranes that occurred following the subduction of intervening oceanic lithosphere, and consequent closure of intervening ocean basins (Davis et al., 1978; Monger and Price, 1979). During the foreland basin stage, as a result of oblique collision between the accreted terranes and the North American craton, the outboard part of the miogeocline-platform component of the supracrustal wedge was detached from its basement, displaced northeastward, compressed and thickened. The weight of the displaced and tectonically thickened supracrustal rocks induced subsidence of the foreland basin (Price, 1973; Beaumont, 1981), and the associated uplift and erosion provided much of the sediment that accumulated in the foreland basin. This cannibalization of the supracrustal wedge continued as some of the older deposits of the foreland basin component were themselves detached from their North American basement, attached to the colliding accreted terranes, and uplifted and eroded to provide the sediment that formed some of the younger foreland basin deposits. The pattern of growth of the foreland thrust and fold belt, and of the foreland basin component of the supracrustal wedge, were effectively terminated by an episode of Early and Middle Eocene crustal extension in the central part of the Cordillera that marked the transition to the present-day plate tectonic regime (Ewing, 1980; Price, 1979; Price, 1986).

Plate Tectonics and Cordilleran Tectonic Evolution

Contemporary Cordilleran Plate Tectonics

The present-day plate tectonic regime provides an actualistic model for outlining the role of plate tectonics in the orogenic evolution of the Cordillera. At the present time the tectonically active western boundary of the North American Plate consists of three contrasting segments (see Fig. 2.2). The southern segment is a subduction zone, along which slabs of oceanic lithosphere of the Juan de Fuca Plate, and its recent offshoot the Explorer Plate, are slipping northeastward under the overriding continental lithosphere of southern British Columbia and adjacent Washington and Oregon at 20 to 46 km/Ma. They are sinking into the asthenosphere under the magmatic arc that is marked by the Cascade volcanoes extending from Mount Shasta in northern California to Mount Garibaldi in southwestern British Columbia. The central segment, which extends northward into the Gulf of Alaska from just south of the Queen Charlotte Islands, consists of the Queen Charlotte and Fairweather (?and Denali) right-hand transform faults, along which the Pacific Plate and the Yakutat "block" (?and the Wrangell Mountains "block") are slipping northwestward or northward relative to the North American Plate at about 55 km/Ma. The northern segment comprises the Aleutian Trench and the Chugach-St. Elias faults, along which the Pacific plate and the Yakutat "block", respectively, are sliding under the Aleutian Islands and the Wrangell Mountains, respectively, and sinking into the lithosphere under the magmatic arc that follows the Aleutian volcanoes westward from Cook Inlet. The Yakutat "block" is an allochthonous terrane. It consists of Cenozoic and Mesozoic clastic sediments that have been carried northward into the Gulf of Alaska on the Pacific Plate, and are now in the process of colliding with and becoming accreted to the North American Plate. This general pattern of oblique convergence, involving a combination of right hand strike-slip, the subduction of oceanic lithosphere of the Pacific Ocean floor beneath western North America, and the accretion of buoyant bodies of rock that are embedded in the oceanic lithosphere has dominated the evolution of the Canadian Cordillera since mid-Cretaceous time.

Reconstructions of Late Mesozoic-Tertiary Plate Motions

Reconstructions of Late Mesozoic-Tertiary plate motions that are based on the analysis of sea-floor magnetic anomaly patterns and the tracks of mantle hot spots (Engebretson et al., 1985), involve a protracted history of more than 160 Ma of convergence between North America and the oceanic lithosphere of the Pacific Ocean basin, and they show that there has been a change from a pattern of near orthogonal and left-lateral oblique convergence prior to mid-Cretaceous time to a pattern of right-lateral oblique convergence in Late Cretaceous and Tertiary time. It has been estimated that a strip of oceanic lithosphere some 11,500 km wide has been subducted beneath the western edge of the North American Plate between latitudes 20 and 60° north since the Jurassic (Engebretson et al., 1988). Accordingly, large horizontal displacements involving the transport of relatively buoyant masses such as oceanic volcanic arcs, oceanic plateaus and seamount chains that are embedded in the oceanic lithosphere (Debiche et al., 1987), and the tectonic accretion of such far-travelled allochthonous terranes are the expected norm along the long-lived convergent plate boundaries that separate North America and the eastern Pacific Ocean basin (Ben-Avraham et al., 1981).

Cordilleran Terranes

Most of the Canadian Cordillera consists of a tectonic "collage" of allochthonous terranes (Fig. 2.1), each of which is characterized by a geological history that sets it apart from the others and from autochthonous or parautochthonous North American rocks (Davis et al., 1978; Monger et al., 1982). The larger terranes (Quesnellia, Stikinia, Wrangellia and Alexander) are coherent bodies comprising laterally persistent tectonostratigraphic assemblages that are dominated by oceanic volcanic arc rocks. They are bordered by disrupted terranes (Slide Mountain, Cache Creek, Bridge River, Hozameen, Pacific Rim and Chugach) that are dominated by deep-ocean-basin sedimentary rocks, basaltic volcanic rocks and bodies of ultramafic rock (Monger and Price, 1979). The disrupted terranes appear to be mainly oceanic accretionary prisms marking the sites of former ocean basins, marginal seas or back-arc basins. Kootenay Terrane consists of lower Paleozoic pelite, feldspathic quartz wacke and grit, and basic and acidic volcanic rocks that commonly are deformed and intruded by Devonian granites, and unconformably overlapped by upper Paleozoic pelite, conglomerate, sandstone, limestone and basic volcanic rocks. The stratigraphic succession bears some resemblance to the coeval North American stratigraphic succession that lies farther east, but the latter contains no feldspathic quartz wacke and grit nor basic and acidic volcanic rocks, nor any record of early Paleozoic orogenic deformation and Devonian intrusions (Monger, 1989). Kootenay Terrane probably represents the contents of an early Paleozoic back-arc or marginal basin. Cassiar Terrane is a sliver of the North American miogeocline that has been displaced northwestward by the Tintina Trench-Northern Rocky Mountain Trench right-lateral strike-slip fault system (Tempelman-Kluit, 1979; Price and Carmichael, 1986).

Most of the terranes fit Oxburgh's (Oxburgh, 1972) definition of "tectonic flakes". They consist of upper crustal rocks that have been detached from their lower crustal and upper mantle lithosphere counterparts, and have been juxtaposed over the western margin of the North American craton (Tempelman-Kluit, 1979; Struik, 1986) and over each other (Monger, et al., 1985) along a system of major interleaved, northeast-verging and southwest-verging thrust faults. The tectonic flakes apparently were produced by tectonic wedging during collisions with the North American continental margin, and by delamination of oceanic lithosphere that separated the tectonic flakes from the dense lower crustal and mantle rocks that have been subducted (Price, 1986).

Displacements of Terranes

In the mobilist world of plate tectonics disparate terranes must be suspected of being far-travelled with respect to North America and to each other until proven otherwise (Coney et al., 1980) by, for example, overlapping stratigraphic units, crosscutting plutons that stitch them together, or evidence of sedimentary provenance of coarse clastic detritus that links them to each other (Monger et al., 1982). Evidence of large horizontal displacements of terranes may be provided by paleobiogeographic data, paleomagnetic data and structural geology.

Monger and Ross (1971) and Ross and Ross (1983) have argued that juxtaposition of different Permian fusulinid faunas provides evidence that Wrangellia, Quesnellia, Stikinia, Cache Creek and Alexander terranes are far-travelled with respect to western North America. Tozer (1982) and Smith and Tipper (1986, 1991) have advanced similar interpretations on the basis of ammonite faunas from Middle Triassic and Lower Jurassic rocks, respectively (see Fig. 2.4).

Paleomagnetic measurements can be used to estimate latitudinal displacements between a suspect terrane and North America (or another suspect terrane) provided that the magnetization can be dated and referred to the appropriate paleohorizontal datum, and that accurate, well dated North American (or other) reference paleopoles are available (Irving and Wynne, 1991). Estimates of the displacements of suspect terranes made in this way have played a critical role in the development of current concepts on the relations between the accretion of allochthonous terranes and orogeny in the Canadian Cordillera (Monger et al., 1982). Monger and Irving (1980) and Irving et al. (1980) used paleomagnetic measurements from Upper Triassic and Lower Jurassic bedded volcanic and sedimentary rocks and a mid-Cretaceous layered anorthositic gabbro to argue that, until mid-Cretaceous time, Stikinia and adjacent rocks of the Cache Creek Terrane were about 1300 km south of their present position relative to North America. Subsequently Irving et al. (1985) used paleomagnetic measurements from mid-Cretaceous plutons at the south end of the Coast Plutonic Complex to further develop this interpretation as the "Baja British Columbia" hypothesis, according to which Wrangellia and Stikinia were welded together by mid-Cretaceous time while still 2000 km south of their present position relative to the North American craton and formed a superterrane that had moved into its present position relative to North America by Eocene time.

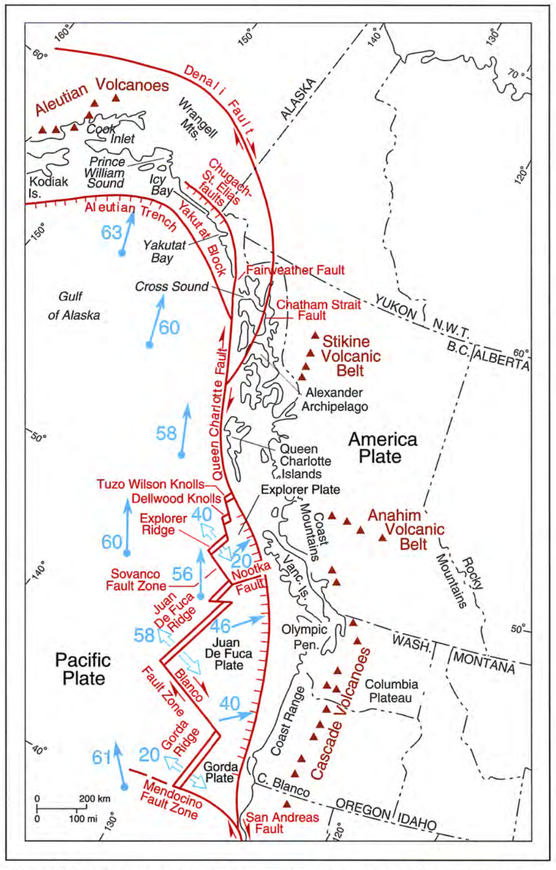


Figure 2.2 Contemporary plate tectonic regime of the Canadian Cordillera and adjacent Pacific Ocean basin (Riddihough and Hyndman, 1991, Figs. 13.1 and 13.2A) showing in blue the direction (arrows) and rate (in mm/a = km/Ma) of displacement of offshore plates relative to North America.

This interpretation of the paleomagnetic data has been challenged by May and Butler (1986) who have argued, on the basis of a reappraisal of the Jurassic apparent polar wander curve for North America, that Stikinia was at essentially the same latitude relative to North America in the Jurassic as it is now. It has also been challenged by Butler et al. (1989), who have argued, on the basis of stratigraphic, structural and metamorphic evidence, that the discordant paleomagnetic inclinations reported by Irving et al. (1985) are due to Cenozoic tilting of the mid-Cretaceous plutons and not to large post mid-Cretaceous displacements of "Baja British Columbia".

Hypotheses about the places of origin of the accreted terranes are controversial. Wernicke and Klepacki (1988) have argued that Stikinia originated immediately south of Quesnellia, that together with Quesnellia it formed a single late Paleozoic and early Mesozoic volcanic belt along the western margin of North America, and that as a result of an oblique collision with Wrangellia, Stikinia was dislodged and "escaped" northward to become accreted to the west side of Quesnellia. This interpretation provides an appealing explanation for the absence of both Quesnellia and Stikinia between Wrangellia and parautochthonous North American rocks in the United States west of the Idaho batholith; however van der Heyden (van der Heyden, 1992) has argued, on the basis of a critical review of relations across the northern Coast Belt, and some new geochronological data, that Stikinia was attached to Alexander Terrane and Wrangellia by Middle Jurassic time. Moreover, both of these interpretations conflict with an elegant tectonic model by Nelson and Mihalynuk (1992), according to which Stikinia originated outboard of Nisling Terrane as the northern continuation of the same oceanic volcanic arc as Quesnellia, and subsequently Stikinia, along with Nisling Terrane, was rotated clockwise relative to Quesnellia, trapping the ocean-basin rocks of Cache Creek Terrane in the tight oroclinal bend between them (Fig. 2.1). Clearly, large uncertainties about the places of origin of the allochthonous terranes, and about the magnitudes and directions of the displacements of the allochthonous terranes prior to collision and accretion is still a vexing problem for the elucidation of Cordilleran tectonic evolution.

The history of the kinematics of terrane accretion for the period after the inception of the terrane collisions is a much less formidable problem. The detailed records of the places of origin of the allochthonous terranes, and of their motions before they made contact with North America or with each other have in general been obliterated by the subduction that destroyed any ocean basins, marginal seas or back-arc basins that lay between them. In contrast, the history of accretion of the terranes after they made contact and began colliding with North America and with each other is generally well preserved in the rock record as geological structures, sedimentary deposits, stratigraphic relations, crosscutting plutons, and metamorphism.

Orogeny and Terrane Accretion/Collision

The North American continent has grown laterally in the Canadian Cordillera by about 500 km since the Early Jurassic, mainly as a result of collisions with and accretion of suspect terranes (Monger et al., 1985). Stratigraphic and structural evidence bearing on the times and order in which the terranes were amalgamated with one another and accreted to North America is summarized in Figure 2.3. Monger et al. (1982) argued that amalgamation of smaller terranes prior to accretion with North America produced two composite superterranes, Intermontane Superterrane and Insular Superterrane (Price et al., 1985), and that collisions involving these superterranes produced two broad suture belts, each of which is

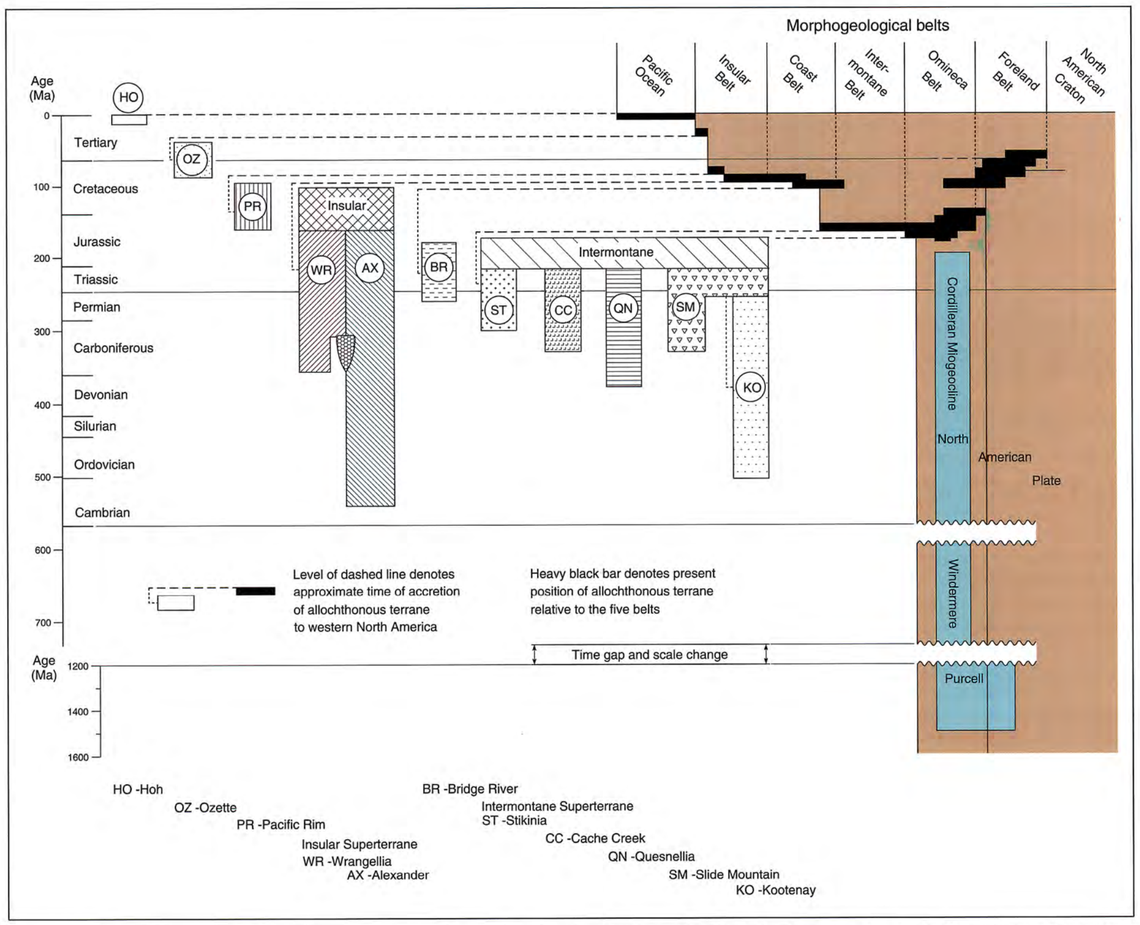


Figure 2.3 Space and time relations between the suspect terranes of the southern Canadian Cordillera and the North American craton (see Fig. 2.1 for present distribution of terranes). Figure shows: 1) depositional time interval spanned by each terrane, 2) gaps between columns indicating unknown spatial relations among terranes, 3) ages of intrusive bodies that stitch terranes together, 4) depositional time intervals of overlap assemblages that define Insular and Intermontane superterranes, 5) light brown area showing westward growth of the western margin of North America by terrane accretion, and 6) spatial relations of Canadian Cordilleran morphogeological belts to terrane accretion. The coincidence of the Omineca Belt and Coast Belt with suture zones between Intermontane Superterrane and North American rocks, and Insular Superterrane and Intermontane Superterrane, respectively, indicate that these tectonic welts are at least partly collisional in origin (modified after Monger, Price and Tempelman-Kluit, 1982; Price, Monger and Roddick, 1985).

characterized by widespread granitic magmatism, crustal thickening and uplift that has exposed extensive regional metamorphism and plutonism as well as outward-verging thrust and fold belts on both flanks. The Omineca Belt occupies the suture zone between Intermontane Superterrane and the North American Cordilleran miogeocline. The Coast Belt occupies the suture zone between Insular Superterrane and Intermontane Superterrane.

Intermontane Superterrane formed prior to the end of the Triassic by the amalgamation of Stikinia, Cache Creek Terrane, Quesnellia and Slide Mountain Terrane (Fig. 2.3), the latter having already been thrust over Kootenay Terrane and stitched to it by crosscutting Permian intrusive rocks (Klepacki and Wheeler, 1985). Poulton and Aitken (1989) have argued that a widespread basal Jurassic (Sinemurian) phosphorite unit up to 10 m thick in the Cordilleran miogeocline of southern Canada implies that there were upwelling ocean currents immediately outboard of the Cordilleran miogeocline of southern Canada in Early Jurassic time and, therefore, that Intermontane Superterrane must have been elsewhere when the phosphorites were deposited (Fig. 2.5a). However by late Middle Jurassic time (Fig. 2.5b), Intermontane Superterrane had been detached from its basement and overridden the western margin of the Cordilleran miogeocline of southern Canada (Archibald et al., 1983). Subsequently, but prior to mid-Cretaceous time, the direction of overthrusting reversed (Fig. 2.5c), presumably because of the relative buoyancy of the Cordilleran miogeoclinal rocks, and the miogeoclinal rocks were thrust southwestward over Intermontane Superterrane, and were re-deformed by southwest-verging folds. During Cretaceous and Paleocene time, as Intermontane Superterrane converged with North America, the outboard part of the miogeocline was detached from its basement, horizontally compressed, and displaced northeastward (Fig. 2.5d). This resulted in profound subsidence of the foreland basin.

Two contrasting tectonic models have been proposed to explain the episode of westward-verging thrusting and folding. Price (1986, 1983), *in* Porter et al.(1982) and *in* Archibald et al. (1983) has ascribed the west-verging deformation to tectonic wedging of Intermontane Superterrane between the outboard part of the Cordilleran miogeocline and its crystalline basement (Fig. 2.5). According to this hypothesis, the west-verging structures are thin-skinned and only occur along the top of the tectonic wedge, but the east-verging structures that characterize the bottom of the wedge extend eastward beyond its tip (Fig. 2.5c). A distinctly different model proposed by Brown et al. (1986) is based on the premise that the west-verging structures are the shallower manifestations of thick-skinned, east-dipping thrust fault(s) that offset and tectonically thicken the crystalline basement (and the mantle lithosphere?) beneath the Cordilleran miogeocline. The basic premise of this model is that there has been about 50 km of Middle Jurassic horizontal shortening of the crystalline basement beneath the Cordilleran miogeocline (Brown et al., 1986, Fig. 7), and this is inconsistent with the tectonostratigraphic record of the Jurassic Fernie Group. This record shows that during the Early and Middle Jurassic (Sinemurian to Callovian inclusively) the Cordilleran miogeocline, which lay immediately behind the west-verging structures, was a tectonically stable, shallow continental shelf. It was not uplifted and deeply eroded as a result of the crustal (and whole-lithosphere?) thickening that should have resulted from thick-skinned, deeply rooted, east-dipping thrust faulting, and moreover, this shallow continental shelf did not subside significantly until the onset of rapid foreland basin sedimentation in the Late Jurassic (earliest Kimmeridgian or latest Oxfordian) (Poulton, 1984).

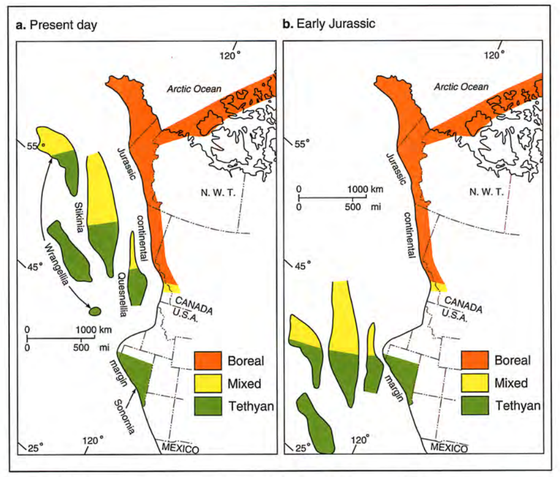


Figure 2.4 Biogeographic reconstruction of accreted terranes based on Pliensbachian (Lower Jurassic) faunal assemblages (after Smith and Tipper, 1991): **a.** present latitudinal distribution of terranes relative to North America; **b.** latitudinal distribution of terranes relative to North America in the Pliensbachian as deduced from variations in faunal assemblages.

During the Late Jurassic and Early Cretaceous, after Intermontane Superterrane had become wedged beneath its outboard margin, the Cordilleran miogeocline was scraped off its basement and accreted to the advancing front of Intermontane Superterrane, where it formed the oldest part of the Rocky Mountain Foreland Thrust and Fold Belt and contributed sediment to the oldest component (Late Jurassic-Early Cretaceous) of the foreland basin (Fig. 2.5c). Crosscutting mid-Cretaceous epizonal and mesozonal granitic plutons (Fig. 2.5c and W in Fig. 2.6) define the minimum age of the final movements on the suture zone between Intermontane Superterrane and the detached miogeoclinal rocks (Archibald et al., 1983) and also the minimum age of the final movements on thrust faults that lie in the interior of the foreland thrust and fold belt in the western Rocky Mountains and west of the Rocky Mountain Trench (Price, 1981).

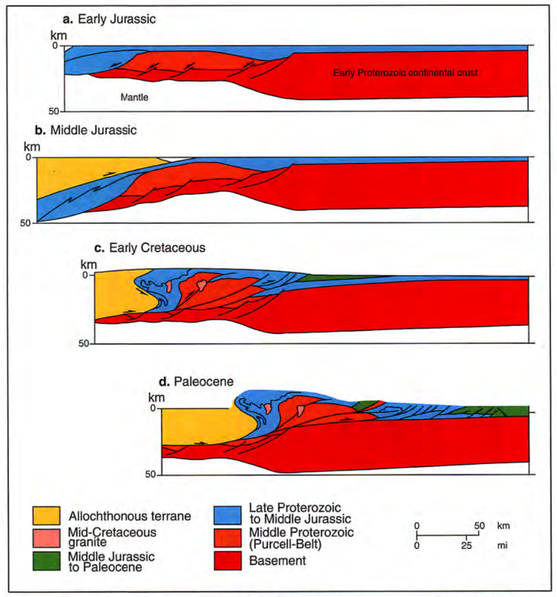


Figure 2.5 Stages in the evolution of the Rocky Mountain Foreland Thrust and Fold Belt along 49° 45' N latitude (the line of section W-E of Fig. 2.6), balanced section with no vertical exaggeration (after Price, 1986). **a.** Crustal-scale palinspastic section derived from section W-E of Figures 2.6 and 2.7; extension faults of Middle Proterozoic, Late Proterozoic and early Paleozoic age are shown schematically, as is the abrupt change in thickness between the cratonic platform and the miogeocline. **b.** Paleozoic rocks and underlying Proterozoic rocks of the outboard part of the miogeocline are deformed, synkinematically metamorphosed and intruded by granite at depths of more than 20 km beneath the allochthonous Intermontane Superterrane in the Middle Jurassic at 171 Ma (Archibald et al., 1983). **c.** A reversal of tectonic vergence in the Jurassic resulted in tectonic wedging of Intermontane Superterrane between the Cordilleran miogeocline and its basement, and delamination and tectonic thickening of the miogeocline while it was still outboard of the edge of the cratonic platform. The crosscutting, high-level mid-Cretaceous granitic plutons establish a minimum age for thrust and fold structures in the Purcell Anticlinorium and in the suture zone between Intermontane Terrane and the North American rocks. **d.** The final stage in the evolution of the foreland thrust and fold belt terminated at the end of the Paleocene after the miogeocline had been displaced over the edge of the craton, producing about 10 to 15 km of crustal thickening and about 10 km of isostatic subsidence of the underlying Lower Proterozoic continental crust and lithospheric mantle.

Insular Superterrane, which formed prior to the end of the Jurassic by the amalgamation of Wrangellia and Alexander terrane, collided with the outboard part of Intermontane Superterrane from mid-Cretaceous to Middle Eocene time (Fig. 2.3). The Gravina-Nutzotin tectonostratigraphic assemblage that overlaps both Wrangellia and Alexander terranes was used by Monger et al. (1982) to date the minimum time of accretion of these terranes (see Fig. 2.3), but recently Gardner et al. (1988) reported that plutons that stitch the boundary between Wrangellia and Alexander terranes have yielded a U-Pb zircon date of 309 ± 5 Ma (mid-Pennsylvanian) as well as $^{40}K/^{40}Ar$ dates indicating cooling between mid-Pennsylvanian and Early Permian. During the collision with Insular Superterrane, Intermontane Superterrane was shoved northeastward over the margin of the North American continent, scraping off more of the supracrustal rocks of the Western Canada Sedimentary Basin to produce the rest of the Rocky Mountain Foreland Thrust and Fold Belt and of the foreland basin (Fig. 2.5d). It was also dragged northwestward, producing the set of major right-lateral strike-slip fault systems (Tintina Trench-Northern Rocky Mountain Trench, Shakwak-Denali, Yalakom-Ross Lake, and Fraser River-Straight Creek) that dominate the structural fabric of the Canadian Cordillera (see Figs. 2.11, 2.12).

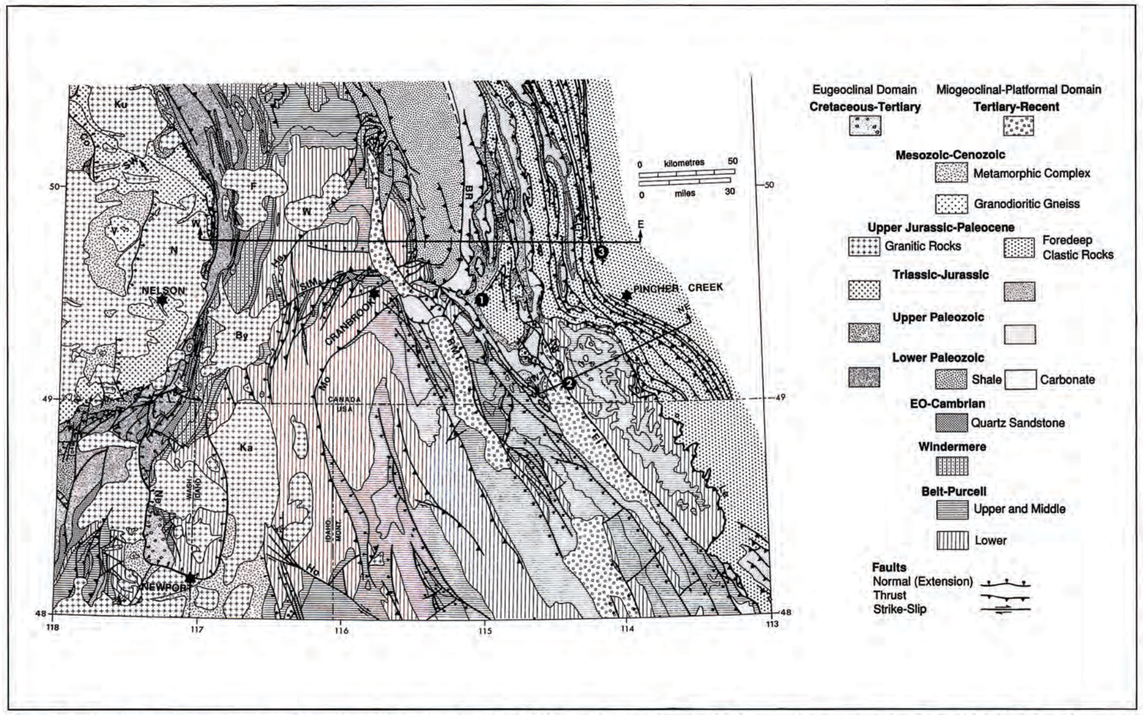


Figure 2.6 Simplified geological map of the Rocky Mountain Foreland Thrust and Fold Belt along the Canada-U.S.A. boundary (modified after Price, 1981). W-E, line of section of Figure 2.7; SW-NE, line of section of Figure 2.8d; white numbers in black circles, locations for time-thickness curves of Figure 2.8. Symbols identifying the more important faults are as follows: Bo, Bourgeau; BR, Bull River; Co, Columbia River; Fl, Flathead; Ha, Hall Lake; Ho, Hope; Le, Lewis; Li, Livingstone, Mo, Moyie; Ne, Newport; Pu, Purcell; RMT, Rocky Mountain Trench; StM, St Mary. Symbols identifying batholiths are as follows: By, Bayonne; F, Fry Creek; Ka, Kaniksu; Ku, Kuskanax; N, Nelson; W, White Creek. The Valhalla metamorphic complex is identified by the symbol, V.

Thus the Rocky Mountain Foreland Thrust and Fold Belt is a transpressional accretionary prism. It consists of supracrustal rocks that were scraped off the North American plate and accreted to an overriding tectonic collage of allochthonous terranes that collided obliquely with North America from Middle Jurassic to Middle Eocene time. Palinspastic reconstructions of the accretionary prism provide the framework for outlining the pre-collisional tectonic history of the Cordilleran miogeocline and the evolution of the foreland basin, which developed as the collisions were underway and the accretionary prism was forming.

Rocky Mountain Foreland Thrust and Fold Belt

Palinspastic Reconstruction of the Foreland Thrust and Fold Belt

Figures 2.6 and 2.7 illustrate a palinspastic reconstruction of the Rocky Mountain Foreland Thrust and Fold Belt at 49° 45′ N latitude. Details concerning the data and interpretations upon which the structure section and palinspastic section are based have been published (Price, 1981) and are not repeated here, but several salient features of the sections do require comment. The Triassic to Paleocene rocks in Figure 2.7 include the foreland basin component of the supracrustal wedge that filled the Western Canada Sedimentary Basin. The Cambrian to Permian rocks, and probably the Upper Proterozoic (Windermere Supergroup) rocks as well, comprise most of the miogeocline-platform component of the supracrustal wedge. Along the line of structure section W-E the 'hinge zone' between the platform (which is characterized by a thin upper Paleozoic sequence, a very thin Cambrian to Middle Devonian sequence and no Upper Proterozoic strata) and the miogeocline (which is dominated by a very thick Cambrian to Middle Devonian sequence underlain by variable thicknesses of Upper Proterozoic rocks) coincides approximately with the Bourgeau Thrust Fault (Figs. 2.6, 2.7). In the palinspastic reconstruction (Fig. 2.7) the 'hinge zone' coincides with the present position of the west flank of the Purcell Anticlinorium (the Kootenay Arc). Price (1981) noted that the west flank of the Purcell Anticlinorium is basically a crustal-scale monoclinal flexure marking a change in level of exposure involving an aggregate thickness of about 20 km of stratigraphic section from the lower part of the Middle Proterozoic Purcell (Belt) Supergroup on the east side to the Triassic-Jurassic volcanogenic rocks of Quesnellia on the west side, and that it coincides with a strong gradient in the Bouguer gravity anomaly field and a westward decrease in the depth to the base of the crust, as well as the palinspastically restored position of the 'hinge zone' between the platform and the miogeocline. On the basis of these relations Price (1981) suggested that the west flank of the Purcell Anticlinorium is a crustal-scale fault-bend fold along the ramp marking the early Paleozoic rifted margin of the North American craton, that the thick section of lower Paleozoic miogeoclinal strata accumulated outboard of this ramp on a basement of tectonically attenuated continental crust or oceanic crust, and that the thin section of lower Paleozoic platformal strata accumulated inboard of the ramp on a normal thickness of unfaulted continental crust (Figs. 2.5, 2.7).

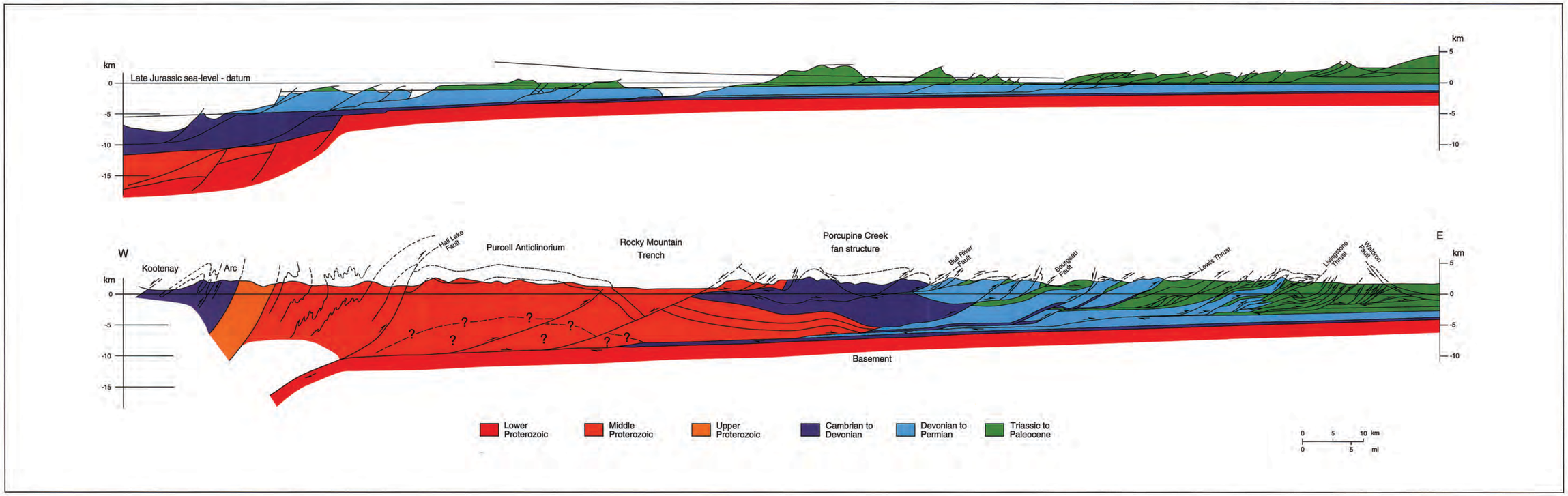


Figure 2.7 Structure section (lower) and palinspastic section (upper) along line W-E of Figure 2.6 (modified after Price, 1981). The thickness of the supracrustal rocks below the Late Jurassic horizontal sea-level datum in the palinspastic section defines the depth to the Early Proterozoic crystalline basement immediately prior to tectonic subsidence that resulted from the load imposed on the lithosphere by tectonic thickening of the supracrustal rocks during thrusting and folding. In the palinspastic section, the thick Cambrian to Devonian shaly facies of the miogeocline, and the underlying thick sequence of Proterozoic rocks occupy nested rift basins west of the present locus of the Purcell anticlinorium and the Kootenay Arc.

Cordilleran Miogeocline

There is a close correlation between the location of the miogeocline-platform 'hinge zone' and the eastern limit of Upper Proterozoic Windermere Supergroup rocks. This indicates that the locus of the early Paleozoic margin of the North American continent was defined by the Late Proterozoic rifting that was responsible for the accumulation of the Windermere Supergroup. Northward from section W-E (Fig. 2.6) to the Mackenzie Mountains, the locus of both the miogeocline-platform 'hinge zone' and the eastern limit of Windermere strata (within the displaced supracrustal rocks of the accretionary prism) follows the western Front Ranges of the Rocky Mountains, but south of section W-E both the miogeocline-platform hinge zone and the eastern limit of Windermere strata swing abruptly southwestward across the Rocky Mountain Trench and the Purcell Mountains to the west flank of the Purcell Anticlinorium at 118° W longitude, west of Newport, Washington (Fig. 2.6). This southwestward deflection in the locus of the hinge zone separating the early Paleozoic miogeocline and platform coincides with a southwestward deflection in the Kootenay Arc, which follows the west flank of the Purcell Anticlinorium (Fig. 2.6). It marks the northwest margin of Montania (Benvenuto and Price, 1979), which encompassed most of the area of the Middle Proterozoic Belt (Purcell) basin and was a tectonically positive element that behaved like part of the North American craton during Paleozoic time. Thus, although elsewhere the locus of the Rocky Mountain Foreland Thrust and Fold Belt generally follows the 'hinge zone' between the miogeocline and the platform, south of Crowsnest Pass (which extends from Pincher Creek to Cranbrook in Fig. 2.6) the location of the thrust and fold belt is controlled instead by the eastern edge of the much older Middle Proterozoic Purcell (Belt) basin.

Bond and Kominz (1984) used tectonic subsidence curves from the Cordilleran miogeocline to argue convincingly that the rifting that created a new continental margin and initiated the Cordilleran miogeocline occurred in latest Proterozoic or earliest Cambrian time (at about 575 Ma), and not with the beginning of Windermere sedimentation at about 750 Ma as suggested by Stewart (1972). The tectonic subsidence curves were based upon the variation as a function of geological age of the cumulative thickness of fully lithified lower Paleozoic sediments. They were prepared by estimating and compensating for the effects of sediment compaction, of eustatic sea-level variation and isostatic subsidence of the lithosphere in response to the weight of overlying sediments and water.

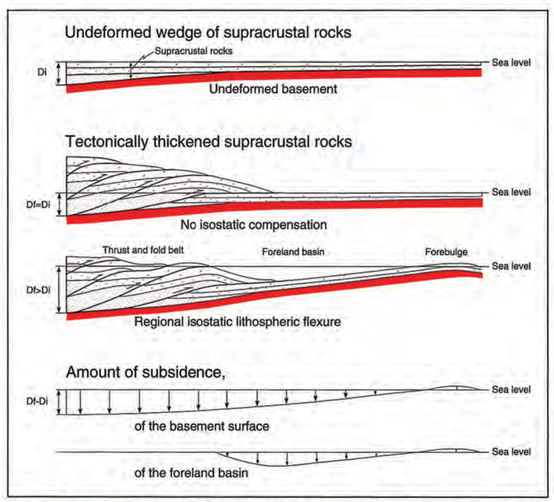


Figure 2.8 Conceptual model for formation of the foreland basin by regional isostatic flexure of the continental lithosphere in response to loading imposed by tectonically thickened supracrustal rocks of the thrust and fold belt (after Price, 1973). Di, initial depth to basement; Df, final depth to basement; Df - Di, amount of subsidence.

New global paleogeographic reconstructions of Gondwana (Dalziel, 1991; Moores, 1991), which indicate that southeastern Australia was adjacent to western North America in latest Proterozoic time, provide support for the correlation by Bell and Jefferson (1987), Jefferson (1978, 1983) and Eisbacher (1985) of the Belt-Purcell and Windermere rocks of the North American Cordillera with coeval rocks in south-central Australia, and for the conclusion (Bond and Kominz, 1984) that the rift-drift transition that marked the initiation of sea-floor spreading and the development of an early Paleozoic ocean basin adjacent to western North America occurred at the end of the Proterozoic. Ross (1991) argued that the Windermere Supergroup may record one or more earlier cycles of crustal extension and thermal subsidence of attenuated lithosphere prior to the episode that marked the beginning of the Paleozoic transgression over the stable craton (the Sauk Sequence); however, similarities in Upper Proterozoic stratigraphy between the Cordilleran miogeocline and south-central Australia presumably indicate that the rift-drift transition that separated the two Precambrian cratons occurred after deposition of the Windermere Supergroup.

The Windermere Supergroup appears to record a unusually long interval of (intermittent?) intracontinental rifting (750-575 Ma) preceding actual continental separation and drift of North America and Australia in earliest Cambrian time. In this respect the evolution of the pre-Cordilleran margin of North America may resemble the evolution of the continental margins of the North Atlantic, where a protracted interval of rifting dating back to the mid-Paleozoic and early Mesozoic preceded the final continental separation and drift that occurred in the Late Cretaceous and Early Tertiary (Ziegler, 1988).

The transgressive overlap of the North American craton by the Sauk Sequence, which marked the birth of the Western Canada Sedimentary Basin, can be attributed to regional isostatic response of the lithosphere to loads imposed on it at the newly formed continental margin (Bond and Kominz, 1984). These 'loads' include both the effects of cooling and thermal contraction of hot lithosphere that had been emplaced beneath and adjacent to the newly formed margin during rifting and sea-floor spreading, and of the weight of the sediments that were deposited along the continental margin during and after the rifting.

Significant but enigmatic episodes of block faulting and volcanism occurred along the Cordilleran miogeocline after the rift-drift transition, particularly during the Middle Cambrian in the northern Rocky Mountains and Mackenzie Mountains (Fritz et al., 1991). These episodes of block faulting and volcanism point to significant differences in tectonic setting between the Cordilleran miogeocline and passive margins such as those bordering the modern Atlantic ocean basin. It was on this basis that Monger and Price (1979) argued that an oceanic volcanic arc and marginal basin probably lay outboard from the continental margin during early Paleozoic time.

Block faulting and volcanism along the miogeocline occurred intermittently throughout early Paleozoic time. However they were most important during Middle and(?) Early Devonian time, just prior to a second major episode of tectonic subsidence and transgressive overlap along the Cordilleran miogeocline in Late Devonian and Carboniferous time (Kaskaskia Sequence), which also dominated the stratigraphy of the cratonic interior. Extensional block faulting occurred during the formation of the Liard Basin of northern British Columbia and adjacent Northwest Territories (Wright et al., *this volume*, Chapter 3, Fig. 3.3), the emergence of the Peace River Arch of northeastern British Columbia (Cant, 1988; O'Connell et al., 1990) and also, probably, the uplift of the northwestern edge of the positive area Montania (Benvenuto and Price, 1979). In the case of the latter there is about 7 km of stratigraphic relief on the sub-Fairholme Group (sub-Upper Devonian) unconformity from the south side to the north side of the northeast-trending Moyie-Dibble Creek Fault, which extends into the Rocky Mountains from the Purcell Mountains just south of Cranbrook, British Columbia (Fig. 2.6). Much of this sub-Fairholme stratigraphic relief is due to differential vertical movements across the northern margin of Montania during Cambrian and(?) Ordovician time. South of the Moyie-Dibble Creek Fault, both the thin, platformal Cambrian sequence that is characteristic of Montania, and the upper part of the underlying Middle Proterozoic Purcell (Belt) Supergroup are unconformably overlapped northward by the Fairholme Group, whereas north of the Moyie-Dibble Creek Fault, the Fairholme Group is underlain by about 6 km of lower Paleozoic strata comprising the Western Main Ranges shaly facies of the Cordilleran miogeocline.

This crustal-scale, pre-Late Devonian deformation appears to have been mainly extensional in the Cordilleran miogeocline in Canada (Gordey et al., 1987; Struik, 1981). The early Paleozoic basic and acid volcanism, Late Devonian granitic intrusions, and Devonian or Early Mississippian folding and penetrative deformation that is characteristic of Kootenay Terrane suggest that the extension may have occurred behind an east-dipping subduction zone and overlying volcanic arc that lay outboard from the miogeocline in a tectonic setting similar to that postulated by Gabrielse (Gabrielse, 1991) for the Late Devonian/Early Mississippian of the northern Canadian Cordillera. Whatever the cause of the pre-Late Devonian deformation in the miogeocline, it was essentially contemporaneous with the compressional deformation and the obduction of continental slope and rise deposits over the cratonic margin in the southwestern U. S. Cordillera during the Antler Orogeny (Turner et al., 1989), and also with the subsidence of the basins and the uplift of the arches in the stable interior of the North American cratonic platform (Porter et al., 1982).

The apparent synchroneity between the epeirogenic deformation that defined the basins and arches on the stable craton, and the orogenic deformation that is expressed as faulting and volcanism along a "passive" margin that wasn't really tectonically passive is a long-standing enigma (Porter et al., 1982). Recently, Kominz and Bond used basin modelling to argue for a nearly synchronous episode of rapid subsidence between Middle Devonian and earliest Mississippian time in almost all pre-existing margins and interior basins of North America and an accompanying large sea-level rise relative to the stable cratonic platform. They suggested that the timing and magnitude of basin subsidence and sea-level change are explicable in terms of the predictions of mantle-convection models for the assembly of supercontinents (Gurnis, 1988), in this instance the onset of the accretion of Pangea above a major zone of mantle downwelling (Kominz and Bond, 1991).

Foreland Basin

Isostatic Flexure

Subsidence of the Western Canada Sedimentary Basin during the foreland basin stage can be ascribed to isostatic flexure of the North American lithosphere under the weight of the tectonically thickened supracrustal rocks of the foreland thrust and fold belt (Price, 1973). As in the case of the Pleistocene ice sheets with their proglacial lakes, the isostatic flexure of the lithosphere induced by the weight of the tectonically prograding foreland accretionary prism produced a migrating moat that trapped the detrital outwash eroded from the emerging foreland thrust and fold belt (Fig. 2.8). Beaumont (1981) used a mathematical model of the process to demonstrate, on the basis of the record of sedimentation and erosion preserved in the foreland basin, that large volumes of rock have been eroded from the thrust and fold belt since thrusting began and that up to 10 km of rock has been eroded since the thrusting stopped.

Migrating Depo-axis

The pattern of growth and evolution of the foreland basin can be illustrated by comparing the records of subsidence that are preserved in a series of stratigraphic sections of the foreland basin sequence across the Rockies in the Crowsnest Pass area. The cumulative subsidence curves in Figure 2.9 show the approximate depth of burial of the Devono-Mississippian Exshaw Formation as a function of time. They do not take into account the effects of post-depositional compaction of the sediments, which has reduced the thickness of the sediment and therefore the apparent amount of subsidence, or the isostatic effect of the weight of the sediment itself, which has amplified the 'tectonic' subsidence; nevertheless, the curves do illustrate the basic pattern of time and space variations of subsidence across the deformed part of the foreland basin.

The initial phase of subsidence in the westernmost preserved part of the foreland basin, which was marked by the deposition of the upper part of the Fernie Formation and the overlying Kootenay Group (Fig. 2.9a), did not begin until the Kimmeridgian (Late Jurassic), about 160 Ma ago, although Intermontane Superterrane had begun overriding the outboard part of the Cordilleran miogeocline prior to the emplacement of granodiorite plutons in the southern Kootenay Arc that have been dated at 170-165 Ma (Archibald et al., 1983), about 10 Ma earlier. The initiation of subsidence in the foreland basin probably can be correlated with the change in style of deformation at the suture zone, from westward subduction (under Intermontane Superterrane) of oceanic lithosphere that lay outboard of the North American continental margin to "collision" between Intermontane Superterrane and the outboard part of the miogeocline. The "collision" initiated the development of the accretionary prism that eventually expanded to become the Rocky Mountain Foreland Thrust and Fold Belt (Fig. 2.5). After a brief hiatus, marked by the sub-Blairmore unconformity, a second major episode of subsidence of the foreland basin occurred with the deposition of the Blairmore Group in late Early Cretaceous time. The areas of greatest subsidence associated with both of these earlier episodes of foreland basin subsidence were restricted to relatively narrow belts immediately adjacent to the advancing thrust front, which was still situated outboard from the rifted margin of the North American continent (Fig. 2.5c), on lithosphere that was presumably less stiff, and which therefore produced a shorter wavelength flexure.

The amount of tectonic thickening by folding and thrusting of the supracrustal wedge during the development of the accretionary prism is, in general, uncertain because a large but indeterminate part of the accretionary prism has been removed by later erosion. The preservation of Lower Oligocene fanglomerates along the down-dropped hanging wall of the Flathead Normal Fault in southeastern British Columbia (Fig. 2.9d) provides a unique opportunity to establish a much more accurate minimum value for the amount of tectonic thickening. Lower Cretaceous strata of the Blairmore Group that are preserved beneath the Lower Oligocene fanglomerates in the hanging wall of the Flathead Fault imply that in Early Oligocene time, when the initial displacement on the normal fault was underway, the Lewis Thrust Sheet in the uplifted footwall block of the normal faults still contained a stratigraphic section extending from the Middle Proterozoic Purcell (Belt) Supergroup through the Paleozoic and lower Mesozoic to the Lower

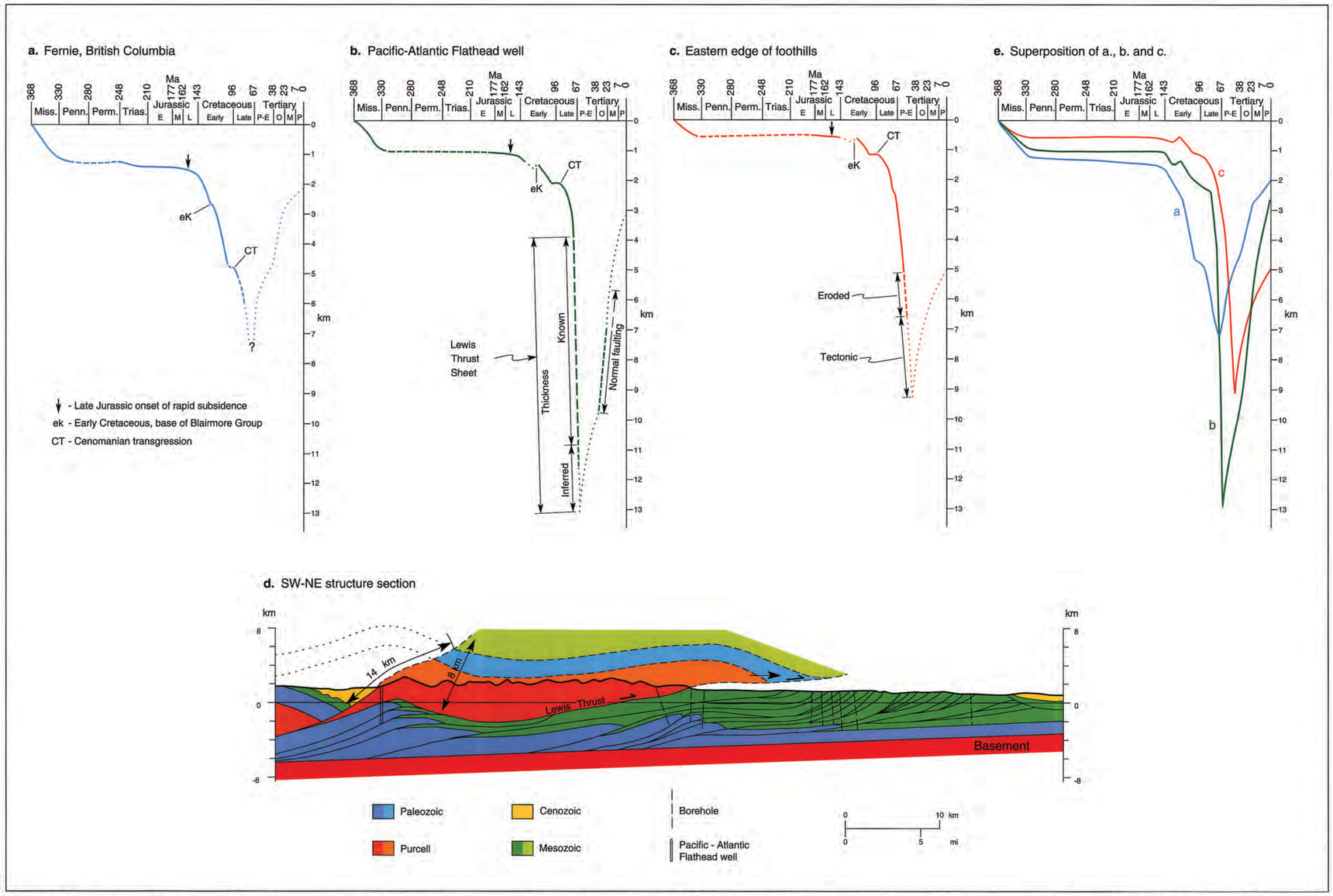


Figure 2.9 Times and rates of subsidence in the southern Canadian Rocky Mountains in the Crowsnest Pass area. **a**, **b**, and **c** are time-depth (= cumulative stratigraphic thickness) curves for the Devono-Mississippian Exshaw Formation at: **a**. Fernie, B.C. (location 1 in Fig. 2.6); **b**. the Pacific-Atlantic Flathead well at Sage Creek, B.C. (location 2 in Fig. 2.6), dashed lines show subsidence under Lewis thrust sheet and uplift due to unroofing by normal faulting; and **c**. eastern edge of the foothills north of Pincher Creek, Alberta (location 3 in Fig. 2.6), dashed line shows thickness of foreland basin sequence that was eroded, as deduced from moisture content of coals (Nurkowski, 1984). **d**. A SW-NE structure section through the Pacific-Atlantic Flathead well (modified after P.L. Gordy *in* Gordy et al., 1977), see SW-NE in Figure 2.6 for location of section. Preservation of the Lower Cretaceous Blairmore Group below Upper Eocene-Lower Oligocene fanglomerates in Flathead valley graben implies that the Lewis thrust sheet was still more than 8 km thick at the end of the Eocene (37 Ma), more than 20 Ma after the termination of thrusting and folding at 58 Ma. **e**. The superimposition of curves a, b, and c illustrates the eastward migration of depo-axis of the foreland basin.

Cretaceous Blairmore Group, and, therefore, that the Lewis Thrust Sheet was still at least 8 km thick. Some additional, but indeterminate thickness of Mesozoic strata had already been eroded from this part of the thrust and fold belt in the interval of more than 20 Ma since earliest Eocene time, when the accretionary prism had stopped growing because of the onset of regional extension in the interior of the Cordillera (Parrish et al., 1988). Accordingly, the time-depth curve of Figure 2.9b, which takes into account the sediment eroded from the Lewis thrust sheet since the beginning of the Oligocene, may provide a more realistic portrayal of the subsidence history of this part of the foreland basin.

The third cumulative subsidence curve (Fig. 2.9c) is for a location near the margin of the foreland fold and thrust belt along the line of section W-E (Fig. 2.6). The autochthonous Exshaw strata at this locality are overlain by tectonically thickened Mesozoic strata beneath the west-verging Waldron Fault (Fig. 2.7). On the basis of variations in the moisture content of near-surface coal seams, Nurkowski (1984) estimated that between 1 and 2 km more sediment has been eroded from this area than from areas farther east in the Interior Plains. The cumulative subsidence curve of Figure 2.9c is an attempt to accommodate the effects of both known tectonic thickening and the estimated minimum post-thrusting erosional removal.

Superimposition of the three cumulative subsidence curves (Fig. 2.9e) illustrates the variations in amount of subsidence and of uplift and erosion from locality to locality across the foreland basin during various stages in its evolution. It shows how the locus of maximum subsidence migrated northeastward with time as the accretionary prism was tectonically prograded over the flank of the continental craton.

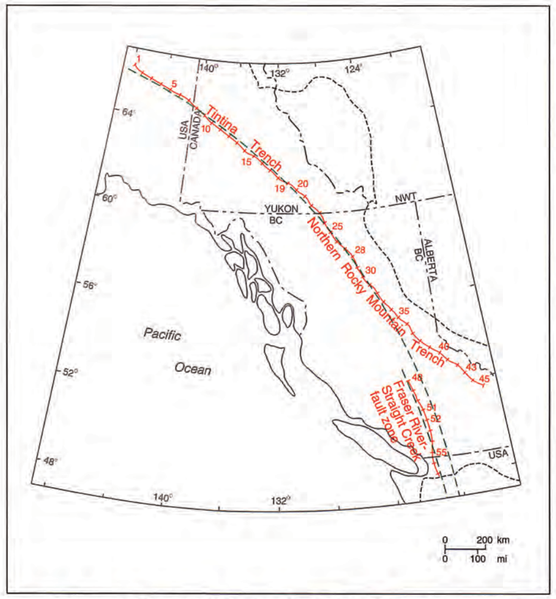


Figure 2.10 Tintina Trench (TT) - Northern Rocky Mountain Trench (NRMT) fault zone and Fraser River (FR)-Straight Creek (SC) fault zone in stereographic projection centred on axis of best fitting small-circle (green) for TT-NRMT fault zone. Numbered ticks along the red fault traces are points along TT-NRMT and FR-SC fault zones that were used to calculate the best fitting small-circles. Long green dashed line is best fitting small-circle curve for points 1-34; its axis is at lat. 35.4° N, long. 158.7° W, and its radius is 3430 km (apical half-angle = 31.2°). Short green dashed curve is drawn about the same axis, but with a radius of 3350 km (apical half-angle = 30.5°), which corresponds to the mean distance between points 48 to 57 on FR-SC fault zone and best fitting small-circle through points 1 to 34 on TT-NRMT fault zone (after Price and Carmichael, 1986).

Oblique Collision, Transpression and Transtension

Mid-Cretaceous to Early Eocene Transpression

The collisions between North America and the accreted superterranes were driven by oblique convergence with adjacent oceanic lithosphere (Engebretson et al., 1985). They involved transpressional and transtensional deformation, including the development of large strike-slip faults within the Cordillera, and lateral transformations between strike-slip faulting and either thrust faulting and folding or extension faulting (Monger and Price, 1979; Price, 1979; Price and Carmichael, 1986; Price et al., 1985). Lateral transformations between strike-slip faulting and thrust faulting and folding during mid-Cretaceous to Late Eocene right-lateral transpression had a profound influence on lateral variations in the size of the Rocky Mountain Foreland Thrust and Fold Belt and in the amount of subsidence in the foreland basin.

The Tintina Trench-Northern Rocky Mountain Trench (TT-NRMT) fault, along which there has been 450 km of right-lateral strike-slip in the Yukon since mid-Cretaceous time (Roddick, 1967; Tempelman-Kluit, 1979), dies out along the southern Rocky Mountain Trench south of 56° N latitude (Fig. 2.10). From east-central Alaska to about 56° N latitude the TT-NRMT fault follows an almost perfect small-circle trajectory (as it must if it is a strike-slip fault, on which the slip must, by definition, be parallel with the spherical surface of the Earth), but south of 56° N latitude, a conspicuous

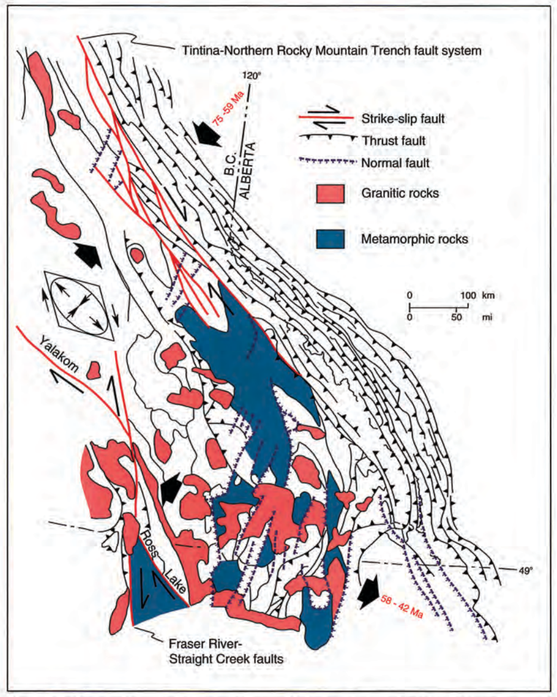


Figure 2.11 Transforms, thrusts and normal faults in the southeastern Canadian Cordillera (after Price, *in* Price et al., 1985). Large, solid black arrows indicate direction of compression during interval from 75 to 59 Ma, and direction of extension during interval from 58 to 42 Ma.

easterly deviation from the small-circle curve marks a restraining bend across which there must have been a combination of convergence and right-lateral strike-slip. This deflection in the surface trace of the TT-NRMT fault zone coincides with a conspicuous change in 1) the amount of Late Cretaceous and Paleocene horizontal shortening across the foreland thrust and fold belt, 2) the width and height of the Rockies, and 3) the amount of subsidence in the foreland basin. Price (Price et al., 1985; Price and Carmichael, 1986) argued, on the basis of these relations, that part of the right-lateral strike-slip on the TT- NRMT fault must have been transformed southward during Late Cretaceous and Paleocene time into the thrusting and folding that produced the southern Canadian Rockies, and also, on the basis of the en echelon relation between the TT-NRMT fault zone and the Fraser River-Straight Creek (FR-SC) fault zone and the widespread occurrence of Early and Middle Eocene crustal stretching in the area of overlap between them, that part of the right-lateral strike-slip on the TT-NRMT fault zone was transformed southwestward via ductile stretching during Early and Middle Eocene time to right-lateral strike-slip on the FR-SC fault zone (Price, 1979; Price and Carmichael, 1986; Price et al., 1985). Early and Middle Eocene right-lateral slip on the Yalakom-Ross Lake fault system has recently been documented by Coleman and Parrish (1991). It occurred before the Yalakom-Ross Lake fault was offset by the FR-SC fault, and it also apparently was integrated with the crustal extension, and with the slip on the TT-NRMT fault zone. These relations are illustrated in Figure 2.11.

The southward transformation of right-lateral strike-slip on the TT-NRMT fault zone into compressional deformation in the southern Canadian Rockies was the dominant influence on the evolution of the Cordilleran foreland basin during Late Cretaceous and Paleocene time because it controlled the amount of horizontal compression and vertical thickening of the supracrustal rocks in the foreland thrust and fold belt and thereby the amount of isostatic subsidence imposed on the North American lithosphere by the weight of the tectonically thickened supracrustal rocks.

The net subsidence of the basement beneath the Rocky Mountain Foreland Thrust and Fold Belt since the Late Jurassic, and the net uplift of the surface can be estimated by comparing a palinspastic section of the thrust and fold belt, in which the horizontal datum is the boundary between the marine strata of the Fernie Formation and the non-marine strata of the Kootenay Group, with the corresponding structure section (Price, 1973). The palinspastic section gives the depth to the basement, as it was in the Late Jurassic, just prior to the beginning of isostatic subsidence in response to the weight of tectonically thickened supracrustal rocks and of the weight of the sediment in the foreland basin, whereas the structure section gives the present depth to the basement and the present elevation of the surface along the same line of section after about 60 Ma of erosion and isostatic uplift that followed the termination of thrusting and folding in the foreland belt at the beginning of the Eocene. The net subsidence of the basement and the net uplift of the surface are clearly illustrated by superimposing the palinspastic section on the structure section, using sea level as the common datum. Five structure sections that have been analyzed in this way illustrate the contrast in amount of subsidence between the southern Canadian Rockies and the part of the Canadian Rockies that lies north of 56° N latitude (see Fig. 2.13). They show that beneath the Alberta segment of the Canadian Rockies, south of 56° N latitude, the net subsidence of the basement ranges from 2 to 3 km in the northeast to 5 to 6 km in the southwest, whereas in the northeastern British Columbia segment, north of 56° N latitude, it is about one fifth that amount.

The southward transformation of right-lateral strike-slip on the TT-NRMT fault zone into compressional deformation, and the consequent deeper basement subsidence in the southern Canadian Rockies, is matched by a commensurate southward increase in the amount of Late Cretaceous and Paleocene subsidence of the foreland basin (see Figs. 2.14 - 2.16). The conspicuous change in the pattern of subsidence in the foreland basin that occurred between the Cenomanian and the Campanian (see Leckie et al., *this volume*, Chapter 20; Bhattacharya, *this volume*, Chapter 22; Krause et al., *this volume*, Chapter 23; and Dawson et al., *this volume*, Chapter 24) can be ascribed directly to the initiation of displacement on the TT-NRMT fault system and the transformation of that displacement south of 56° N latitude into the oblique convergence and the thrusting and folding that formed the southern Canadian Rockies.

The palinspastic map of Figure 2.14 shows the distribution of the displaced terranes in the Canadian Cordillera at 58 Ma, prior to Early and Middle Eocene strike-slip faulting and crustal extension. The map was prepared by compensating for the effects of: 1) about 125 km of east-west crustal stretching in south-central British Columbia (Price, 1979; Tempelman-Kluit and Parkinson 1986; Parrish et al., 1988), 2) about 100 km of right-lateral strike-slip on the TT-NRMT, Yalakom-Ross Lake, and Fraser River-Straight Creek fault systems, and 3) about 300 km of right-lateral strike-slip on the Shakwak-Denali Fault system (Eisbacher, 1976; Lanphere 1978), part of which was linked to the Chatham Straight Fault, and part of which may have extended along the Coast Plutonic Complex into the Yalakom-Ross Lake fault system. The arrows on the palinspastic map of Figure 2.14 illustrate the relations between the right-lateral strike-slip faulting that was accompanied by minor

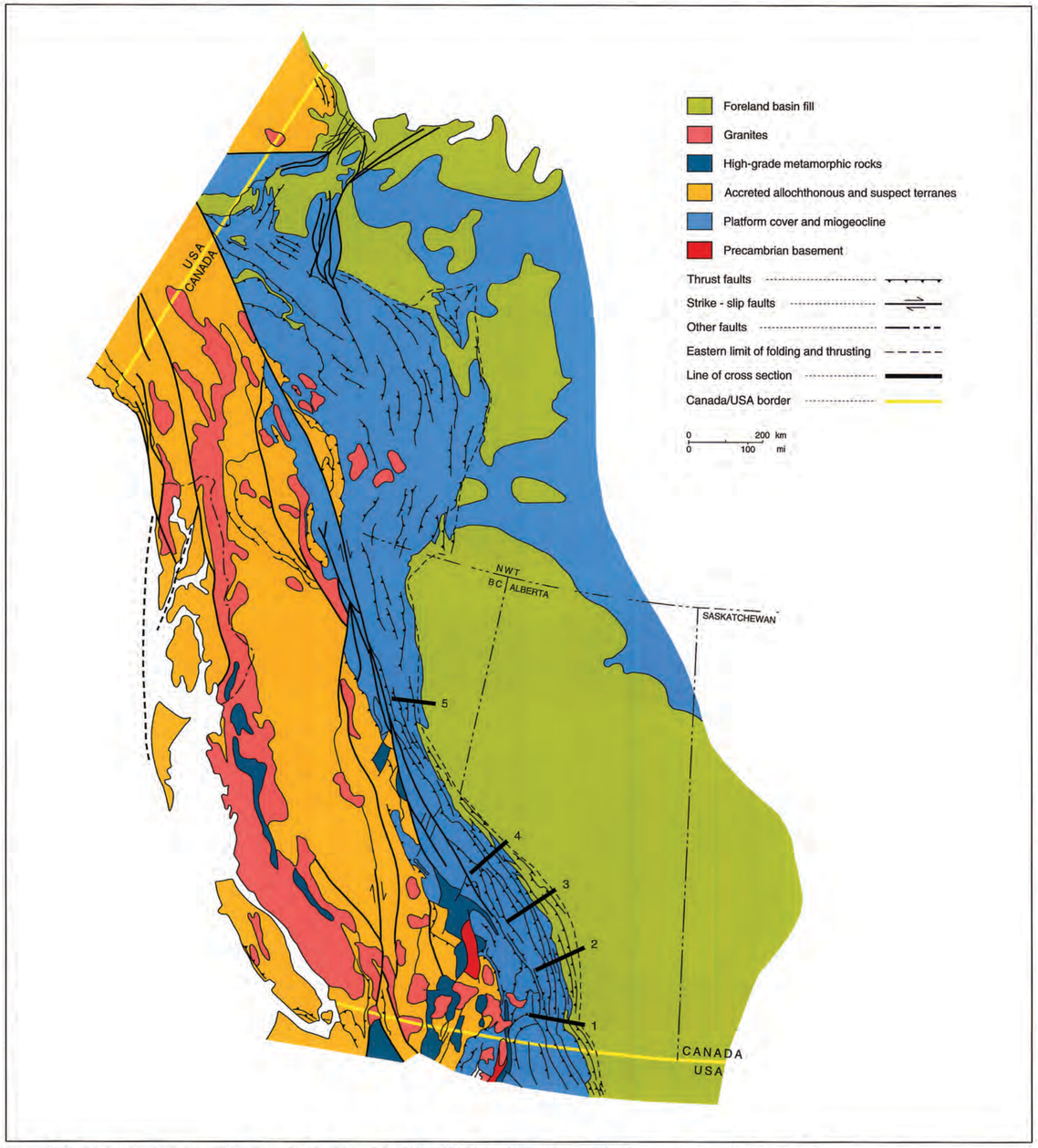


Figure 2.12 Regional tectonic map of the Canadian Cordillera (after Price, 1986) showing locations of structure sections 1 to 5 of Figure 2.13.

horizontal convergence and thrusting and folding in the northeastern Canadian Cordillera and the oblique terrane convergence, large-scale thrusting and folding, and the pronounced foreland basin subsidence that occurred only along the southeastern Canadian Cordillera (south of 56° N latitude). These relations characterize a distinct tectonic regime of right-lateral transpression that dominated the evolution of the Canadian Cordillera and the Western Canada Sedimentary Basin in Late Cretaceous and Paleocene time.

The palinspastic map of Figure 2.15 shows the relation between thickness variations in the Early Cretaceous part of the foreland basin and the distribution of the displaced terranes in the Canadian Cordillera at 90 Ma, prior to the Late Cretaceous and Paleocene right-lateral transpressional regime. The map was prepared by compensating for the effects of 1) an additional 350 km of right-lateral strike-slip on the TT-NRMT fault system, part of which was transformed southeastward into oblique compression, but part of which apparently was linked via the Finlay and Ingenika faults into the suture zone between Quesnellia and Stikinia (Gabrielse,

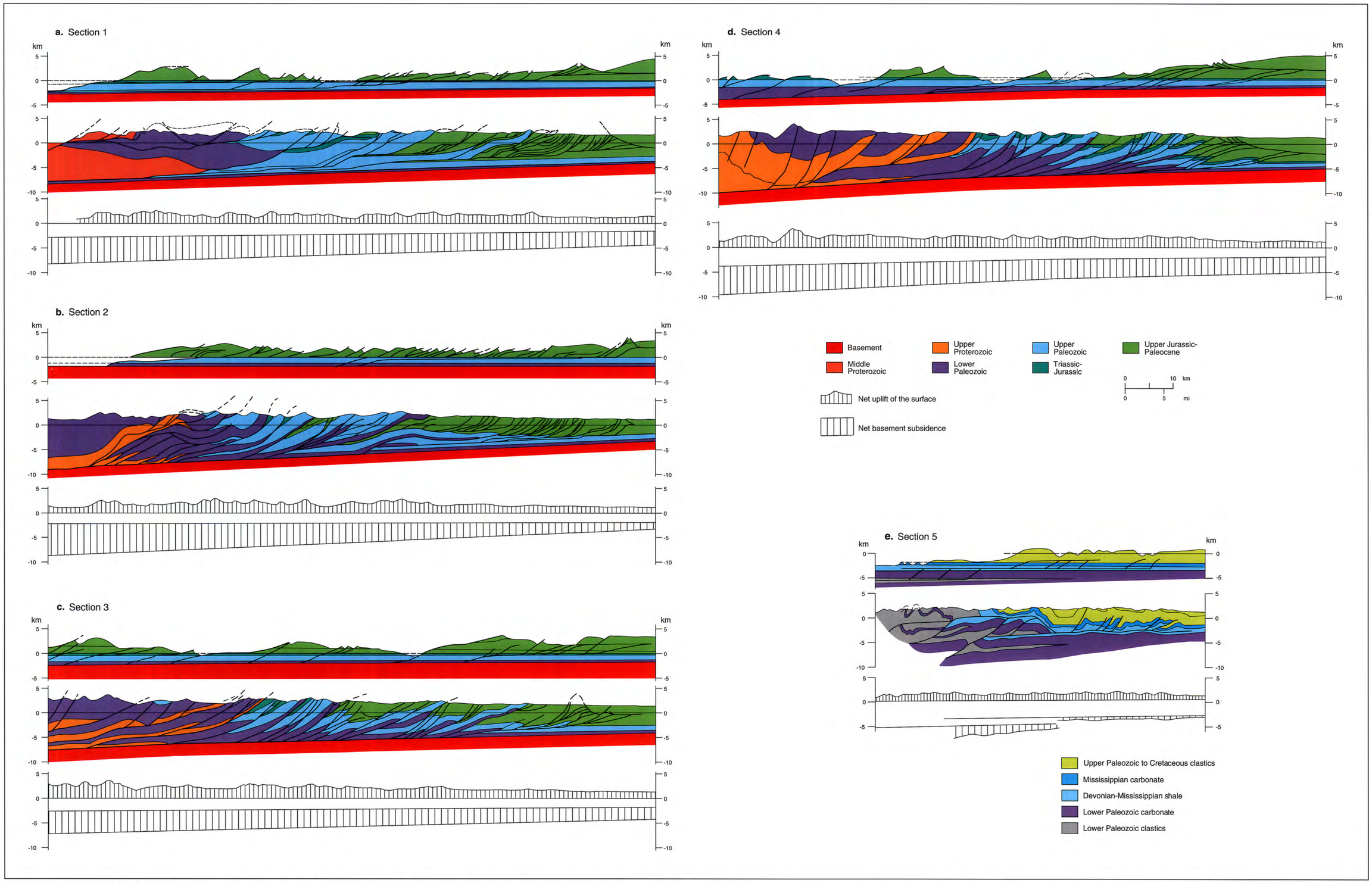


Figure 2.13 Net subsidence of the basement (widely spaced vertical ruling) and net uplift of the surface (closely spaced vertical ruling) due to formation of the Rocky Mountain thrust and fold belt in southwestern Alberta, as estimated by superimposing the palinspastic sections (upper panels) on the structure sections (middle panels) using the present-day sea level of the structure section and the Late Jurassic horizontal sea-level datum of the palinspastic section as a common datum. The difference in depth to the basement at the present time and in Late Jurassic time is the net subsidence (i.e., the total subsidence less the amount of erosion and isostatic uplift that has occurred since the thrusting and folding). The net uplift of the surface is the difference between the present topographic profile and the Late Jurassic sea-level datum. **a**. Section 1 of Figure 2.12 (after Price, 1981). **b**. Section 2 of Figure 2.12 (after Price, 1981). **c**. Section 3 of Figure 2.12 (after Price and Mountjoy, 1970). **d**. Section 4 of Figure 2.12 (after Mountjoy, 1980). **e**. Section 5 of Figure 2.12 (after Thompson, 1981).

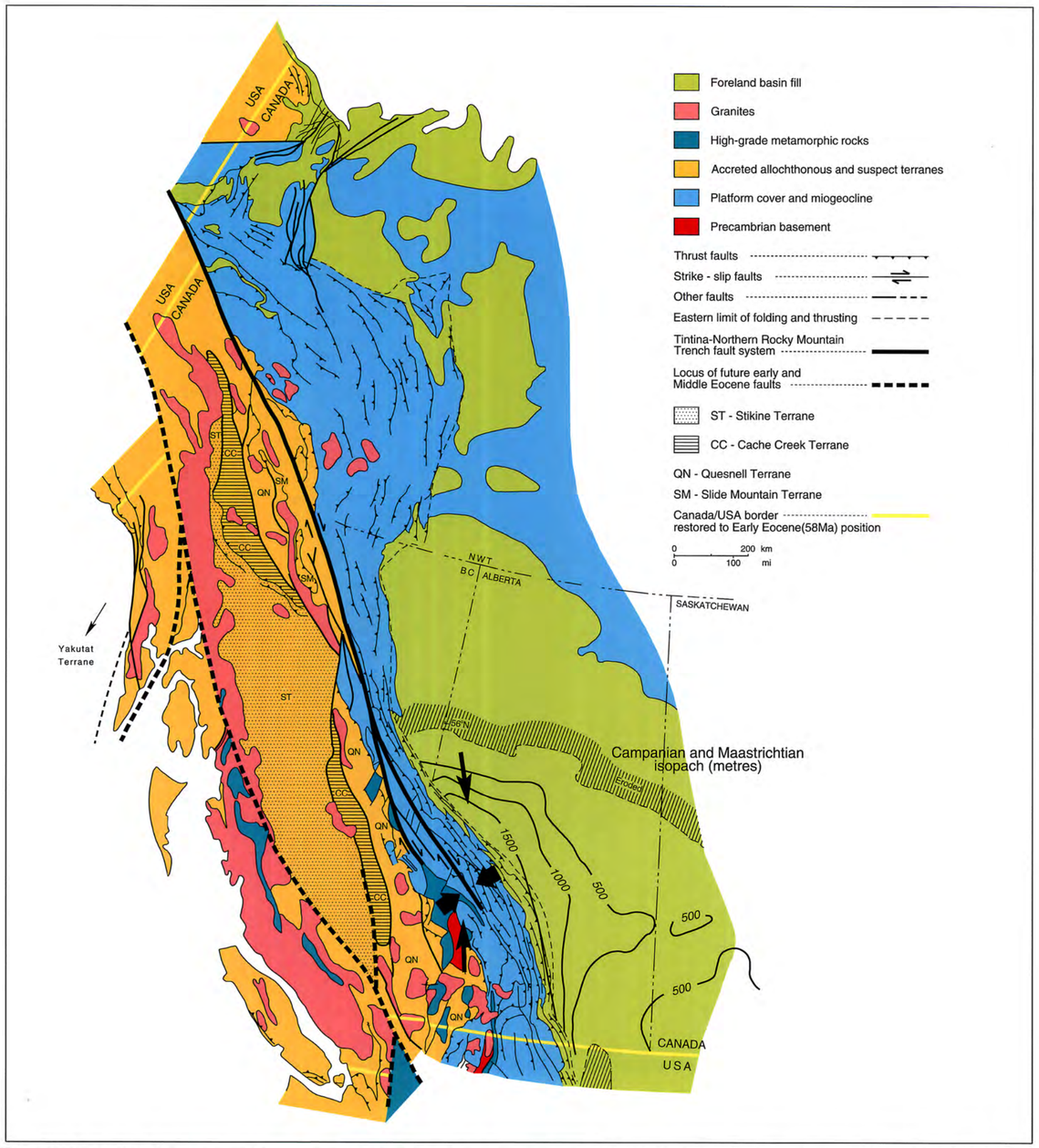


Figure 2.14 End of Late Cretaceous and Paleocene tectonic regime of right-lateral transpression: major faults are restored to 58 Ma; heavy broken lines mark locus of future Early and Middle Eocene faults; heavy solid lines mark Tintina-Northern Rocky Mountain Trench fault system with 100 km of Early and Middle Eocene right-lateral strike-slip displacement eliminated; isopachs in the plains show the main locus of Late Cretaceous and Paleocene foreland basin subsidence adjacent to restraining bend in Tintina-Northern Rocky Mountain Trench right-lateral fault system.

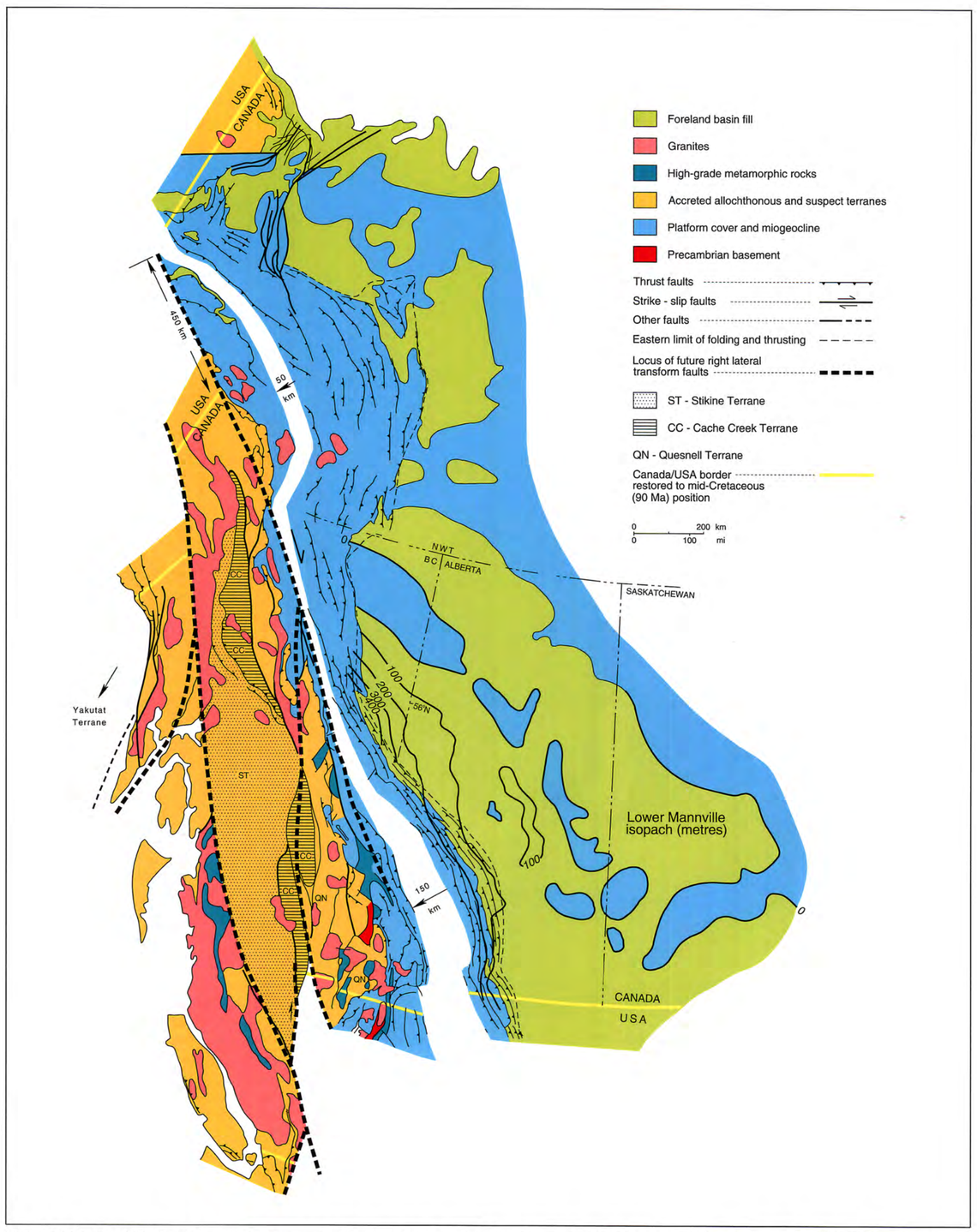


Figure 2.15 End of Middle Jurassic to mid-Cretaceous tectonic regime of terrane collision and accretion: major right-lateral transform faults and the horizontal convergence across the foreland thrust and fold belt are restored to 90 Ma; heavy broken lines mark locus of future right-lateral transform faults; isopachs show main locus of foreland basin subsidence during deposition of the Lower Cretaceous (Aptian) Bullhead Group and equivalents.

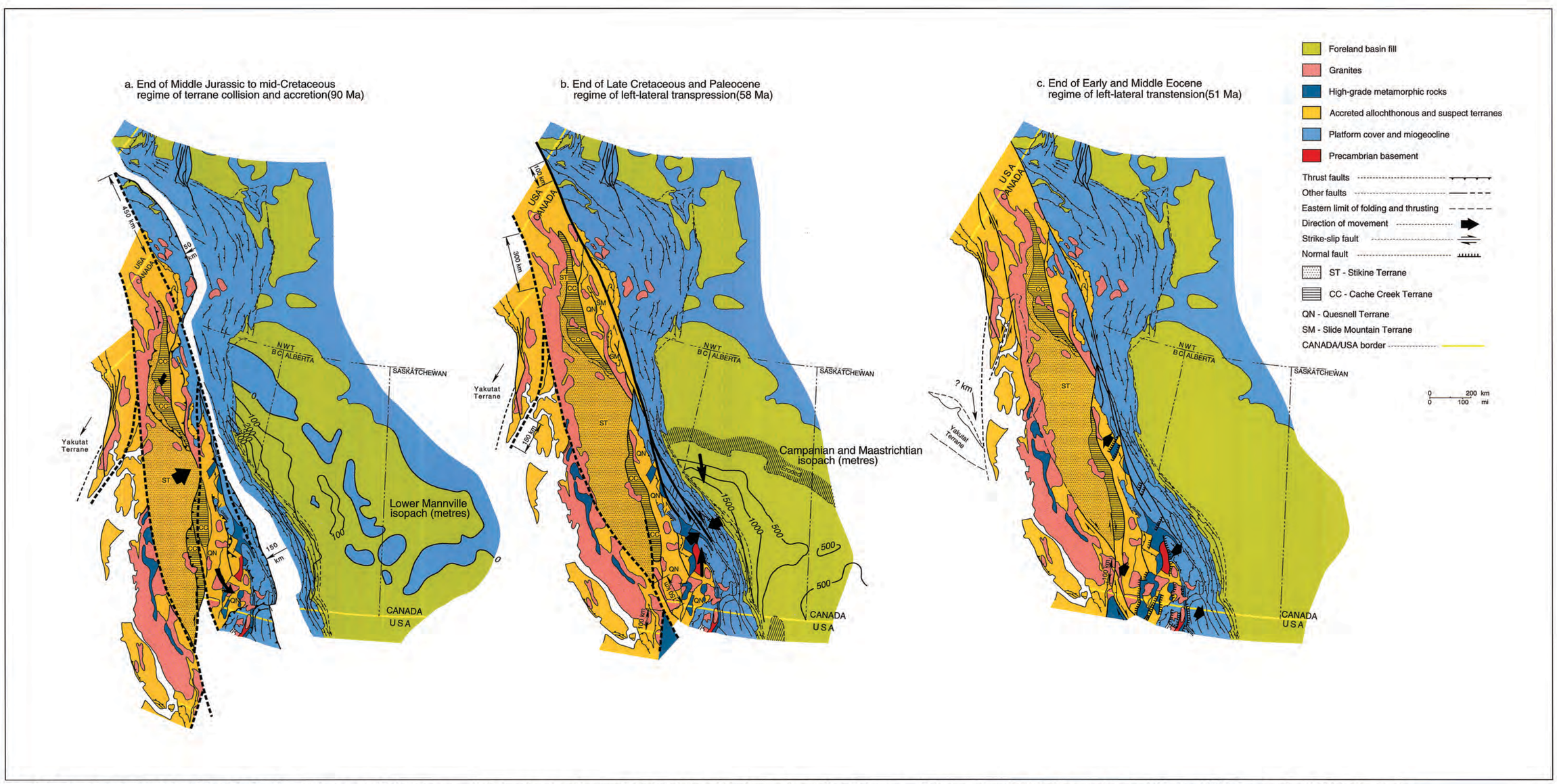


Figure 2.16 Three stages in the tectonic evolution of the Canadian Cordillera: **a**. end of Early Cretaceous and Late Jurassic regime of terrane collision, indentation and lateral escape; **b**. end of Late Cretaceous and Paleocene regime of left-lateral transpression; **c**. end of Early and Middle Eocene regime of left-lateral transtension.

1985), and 2) about 150 km of Late Cretaceous and Paleocene convergence between the displaced terranes and North America in the southern Canadian Rockies (Bally et al., 1966; Price, 1981; Price and Fermor, 1985; Price and Mountjoy, 1970), but only about 50 km in the northern Canadian Rockies (Gabrielse and Taylor, 1982; Thompson, 1979), and the Mackenzie Mountains and Ogilvie Mountains (Gordey, 1982). The palinspastic map of Figure 2.15 illustrates the relations between the accreted terranes and North America at the end of a Late Jurassic-Early Cretaceous tectonic regime, during which Intermontane Superterrane was wedged under the outboard part of the miogeocline, deforming it, and producing a foreland basin that extended northward from Montana into northeastern British Columbia beyond 56° N latitude. The thickest accumulation of Late Jurassic and Early Cretaceous deposits during this stage in the evolution of the foreland basin occurred in and adjacent to the northern Canadian Rockies in northeastern British Columbia (Stott, 1984), adjacent to the zone in which Stikinia appears to have been driven into Quesnellia as an indenter (Fig. 2.15), forcing the southern part of Quesnellia and Slide Mountain Terrane, and the North American miogeoclinal rocks to which they were partly attached, southward (Fig. 2.16a). Large tectonic overlaps across several Early Cretaceous and/or late Jurassic northeast-trending faults in southeastern British Columbia, including the suture zone between Quesnellia and the North American rocks, and faults that follow the former northwest flank of Montania (see Fig. 2.6), imply left-lateral transpression in this part of the Cordillera during Late Jurassic and/or Early Cretaceous time.

Three stages in the tectonic co-evolution of the southern Canadian Cordillera and the foreland basin component of the Western Canada Sedimentary Basin are illustrated schematically in Figure 2.16: a) an Early Cretaceous and(?) Late Jurassic stage of terrane collision, indentation, and lateral escape (Fig. 2.16a); b) a Late Cretaceous and Paleocene stage of right-lateral transpression dominated by strike-slip in the north and by compression in the south (Fig. 2.16b); and c) an Early and Middle Eocene stage of right-lateral transtension dominated by strike-slip in the north and extension in the south (Fig. 2.16c). The major shift in the locus of foreland basin subsidence that occurred between the first and the second stages was due to a change in patterns of relative movement of the accreted terranes and the resulting major shift in the locus compression, tectonic thickening and northeasterly displacement of the miogeoclinal rocks. At the beginning of the Eocene, subsidence of the foreland basin was replaced by isostatic uplift and erosion because the change from transpressional deformation to transtensional deformation between North America and the accreted terranes shut off the convergence between the accreted terranes and North America that was driving the growth of the foreland thrust and fold belt and, therefore, of the foreland basin. Displacement between North America and the main mass of the Cordilleran accreted terranes ended in the Middle Eocene at about 42 Ma, presumably because of global rearrangement in the pattern of relative movement of lithospheric plates that is clearly marked by the pronounced bend in the Hawaii-Emperor seamount chain.

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