Geoscience Canada

DNAG #4. The Cordilleran Orogen in Canada

H. Gabrielse and C. J. Yorath

Volume 16, Number 2, June 1989

URI: https://id.erudit.org/iderudit/geocan16_2art03

See table of contents

Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

Explore this journal

Cite this article

Gabrielse, H. & Yorath, C. J. (1989). DNAG #4. The Cordilleran Orogen in Canada. *Geoscience Canada*, *16*(2), 67–83.

DNAG #4. The Cordilleran Orogen in Canada [1]

H. Gabrielse
Geological Survey of Canada
Cordilleran Division
100 West Pender Street
Vancouver, British Columbia V6B 1R8

C.J. Yorath
Geological Survey of Canada
Pacific Geoscience Centre
P.O. Box 6000
Sidney, British Columbia V8L 4B2

INTRODUCTION

The Cordilleran Orogen: Canada is the title of Volume G-2 of the Decade of North American Geology (DNAG) series on the geology of the North American continent and adjacent ocean basins. The Canadian Cordilleran volume is the product of the efforts of sixty-seven contributors from the federal and provincial governments, universities, mineral and petroleum exploration companies and private consultants. The volume will be published by the Geological Survey of Canada as Number 4 of its new Geology of Canada Series and as a contribution to the centennial celebrations of the Geological Society of America.

The volume includes a completely revised edition of the Tectonic Assemblage Map compiled by J.O. Wheeler. This map, like its predecessor (Tipper *et al.*, 1981) portrays assemblages of rocks which accumulated in response to specific tectonic environments. The new map and its legend encapsulate the geology of the region in much greater detail; moreover, each of its 119 tectonic assemblages are numbered in order to provide assemblage identity to each of the rock units in the 90-column correlation charts.

Additional pocket figures include a terrane map, a new physiographic map by W.H. Mathews using landsat imagery as background to physiographic divisions and a new metamorphic map by P.B. Read, H. Greenwood, E. Ghent and G.J. Woodsworth which, for the first time, utilizes vitrinite reflectance and conodont coloration indices to characterize metamorphic facies of the Foreland Belt as well as employing conventional criteria to illustrate the diverse metamorphic character of the remainder of the Cordillera. Fourteen structural cross-sections at scales of 1:750,000 and 1:500,000 show the general structural style of the orogen throughout its length. The distributions of terrane-specific mineral deposits are illustrated on a pocket map compiled by K.M. Dawson as are the distributions of plutonic rocks which have been grouped into "plutonic suites" by G.J. Woodsworth, R.G. Anderson and R.L. Armstrong, each suite defined in terms of its age, petrology/chemistry and tectonic setting.

STRUCTURE OF THE VOLUME

The following is a brief description of the chapter content together with a listing of authorship.

Chapter 1. Introduction

(H. Gabrielse and C.J. Yorath)

Scope of the volume, editorial policy and discussion of the history of ideas on the development and architecture of the Cordillera.

Chapter 2. Tectonic Framework

This chapter is divided into three sections.

A. *Morphogeological Belts, Tectonic Assemblages and Terranes*

(H. Gabrielse, J.W.H. Monger, J.O. Wheeler and C.J. Yorath)

This sub-chapter defines the terms by which the Cordillera is characterized in all subsequent chapters. The five morphogeological belts (Figure 1), the boundaries of which are largely, but not entirely coincident with major terrane boundaries, are the principal tectonic elements by which the current structure and morphology of the orogen is recognized.

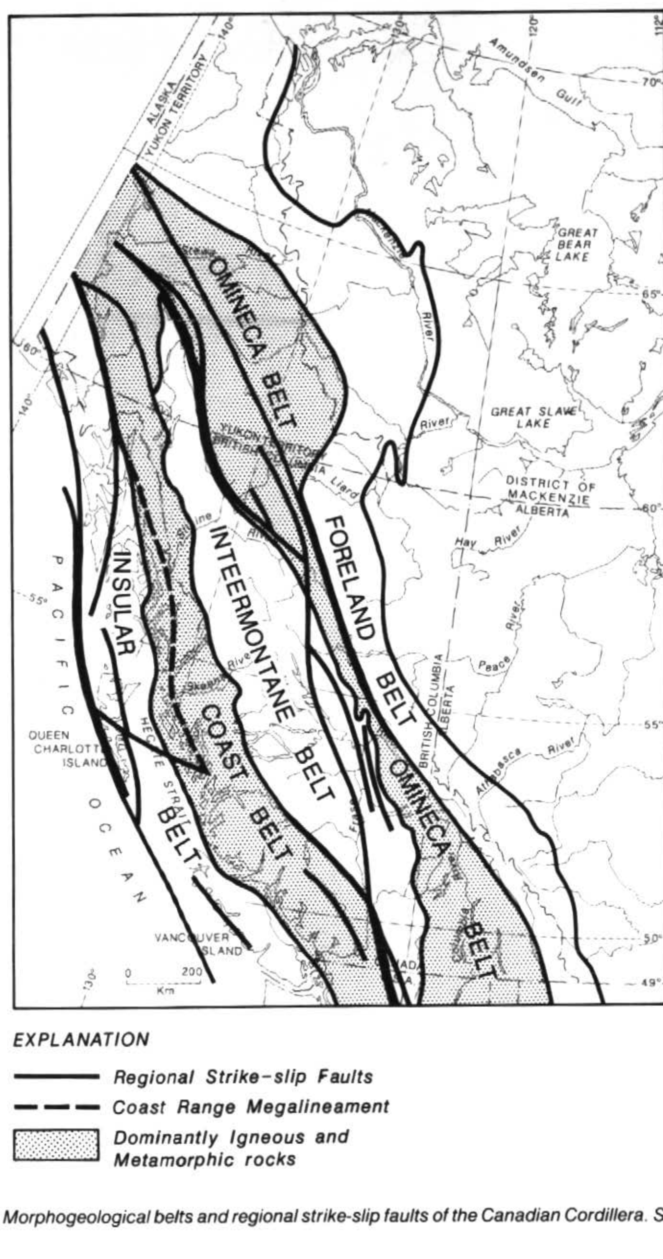


Figure 1 *Morphogeological belts and regional strike-slip faults of the Canadian Cordillera. See also Figure 6.*

[1] Geological Survey of Canada Contribution No. 49388

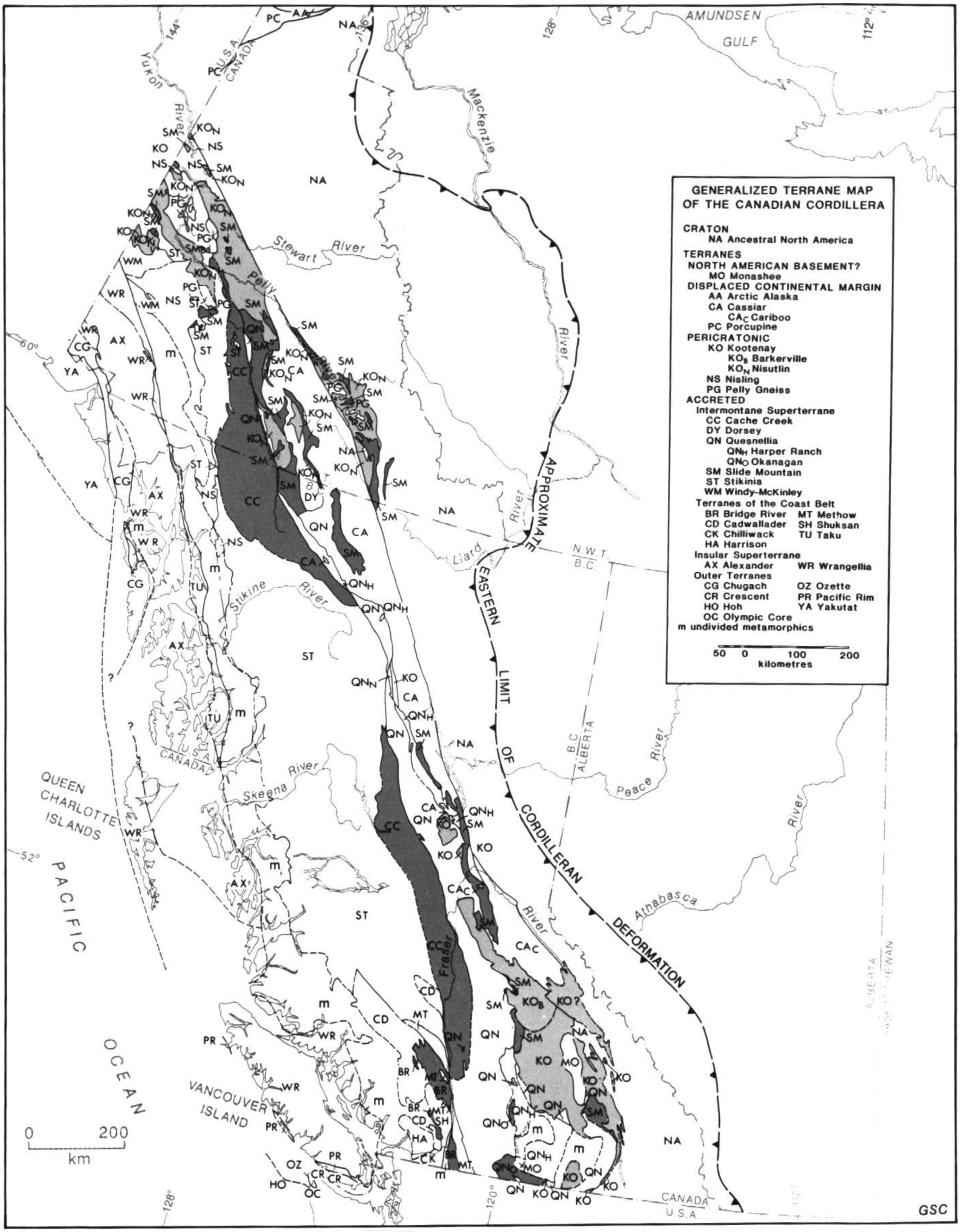


Figure 2 *Simplified terrane map of the Canadian Cordillera.* ***PR & CR****, Pacific Rim and Crescent terranes;* ***CG & YA****, Chugach and Yakutat terranes;* ***WR****, Wrangellia;* ***AX****, Alexander Terrane;* ***GN****, Gravina-Nutzotin Terrane;* ***CP & MRX****, Coast Plutonic and Metamorphic Rocks;* ***BR-CD-SH-HA-CK-MT****, Bridge River, Cadwallader, Shuksan, Harrison, Chilliwack and Methow terranes;* ***ST****, Stikinia;* ***CC****, Cache Creek Terrane;* ***QN****, Quesnellia;* ***SM & DY****, Slide Mountain and Dorsey terranes;* ***KO****, Kootenay Terrane;* ***NA****, North American Terrane (ancestral North America);* ***MO****, Monashee Terrane (North American Basement);* ***PG & NS****, Pelly Gneiss and Nisling Terrane.*

Tectonic assemblages, most of which are bounded by unconformities, reflect specific depositional or volcanic settings and/or responses to one or more tectonic events. Most assemblages are named for an important constituent stratigraphic unit although a few are named after the region where they are best developed. Each assemblage is identified according to the age range of its components and characterized in terms of its tectonic or depositional setting. The assemblages can be related readily to the morphogeological belts and terranes within which they occur.

The degrees of confidence in the identifications of associated tectonic and depositional settings vary considerably and, in some cases, are controversial. Most assemblages are characterized in terms of settings currently observable on modern continental margins, island arcs and in ocean basins. Others are defined with reference to their orogenic position (foredeep, clastic wedge, *etc.*) or to their cratonal position (passive continental margin sediments). Regardless of their morphogeological belt or terrane associations, the assemblages are the fundamental components of Cordilleran geology and provide an effective means of describing the tectonic and depositional history of the many parts of the orogen.

Recognition and establishment of tectonic assemblages developed concurrently with the idea that many parts of the western Cordillera are "suspect" as to their paleogeographic relationships with one another and with ancestral North America (Coney *et al.*, 1980). Each of these so-called "terranes" possess a unique tectonic assemblage that differs from those of adjacent terranes (Figure 2).

B. *Paleontological Signatures of Terranes*
(E.S. Carter, M.J. Orchard, C.A. Ross, J.R.P. Ross, P.L. Smith and H.W. Tipper)
In this sub-chapter, discussion is limited to those aspects of paleontology that are applicable to the identification of the age span of terrane assemblages and their paleogeographic origin. In these regards, the sub-chapter discusses the biostratigraphic and paleogeographic significance of fusulinids, radiolaria, conodonts and ammonites.

C. *Crustal Geophysics*
(J.F. Sweeney, R.A. Stephenson, R.G. Currie and J.M. DeLaurier)
This sub-chapter describes the geophysical signature of the Cordillera as revealed by seismic reflection and refraction, seismicity, gravity, magnetic, heat flow and magnetotelluric studies. Application of these methods is new to the Cordillera except in the offshore where geophysical investigations of the continental margin and adjacent oceanic plates have been intensive since the late 1960s.

Chapter 3. Paleomagnetism: Review and Tectonic Implications
(E. Irving and P.J. Wynne)
The current (1987) status of paleomagnetic investigations is discussed together with implications of results with respect to the paleolatitude of origin and timing of accretion of the several component terranes of the Cordillera. Data discussed here remain to be fully integrated with inferences based purely on geological constraints.

Chapter 4. Precambrian Basement Rocks
(R.R. Parrish)
Precambrian crystalline basement rocks are intermittently exposed in the Foreland and Omineca belts where they comprise granitic gneiss, minor amphibolite and metasedimentary rocks. This chapter discusses their associations with the tectonic provinces of the Canadian Shield and their relationships to superincumbent Proterozoic sedimentary rocks deposited upon the passive margin of ancestral western North America.

Chapter 5. Middle Proterozoic Assemblages
(J.D. Aitken and M.E. McMechan)
The first of the stratigraphic assemblage chapters, this contribution describes the lithostratigraphy and correlations among the classical Purcell (Belt) and Wernecke supergroups as well as the Cap Mountain, Hornby Bay and Muskwa Ranges successions (1.7 to 1.2 Ga) and similar characteristics among the components of the Mackenzie Mountains Supergroup (1.2 to 0.78 Ga).

Chapter 6. Upper Proterozoic Assemblages
(H. Gabrielse and R.B. Campbell)
This chapter describes the lithostratigraphy of the Windermere Supergroup, a classical passive margin rift assemblage.

Chapter 7. Cambrian to Middle Devonian Assemblages
(W.H. Fritz, M.P. Cecile, B.S. Norford, D. Morrow and H.H.J. Geldsetzer)
This chapter is primarily concerned with Cambrian to Middle Devonian assemblages on the miogeocline of ancestral North America and neighbouring pericratonic and displaced terranes. In considerable detail and for the first time, the Cambrian System of western Canada is synthesized in terms of its biostratigraphic zonation and widespread cyclical character. In contrast, the Ordovician to Middle Devonian successions are described in terms of their paleogeographic settings and with reference to sequences which are broadly identifiable with all or parts of the Sauk, Tippecanoe and Kaskaskia sequences established on the craton.

Chapter 8. Upper Devonian to Middle Jurassic Assemblages
This chapter is divided into two sub-chapters.

A. *Ancestral North America*
(S.P. Gordey, H.H.J. Geldsetzer, D.W. Morrow, E.W. Bamber, C.M. Henderson, B.C. Richards, A. McGugan, D.W. Gibson and T.P. Poulton)
Upper Devonian to Permian carbonate and shale-siltstone assemblages and Upper Devonian to Mississippian clastic assemblages reflect fundamentally different tectonic settings. The former accumulated as dominantly platform and reef to basinal clastic successions during continued stability near the western margin of the miogeocline, whereas the latter developed in response to uplift of northern and western sources. Throughout the Triassic to Middle Jurassic, miogeoclinal sedimentation became increasingly clastic, sources for which remained entirely cratonal.

B. *Cordilleran Terranes*
(J.W.H. Monger, J.O. Wheeler, H.W. Tipper, H. Gabrielse, T. Harms, L.C. Struik, R.B. Campbell, C.J. Dodds, G.E. Gehrels and J. O'Brien)
Most rocks described in this sub-chapter are Upper Devonian through Jurassic marine volcanic and sedimentary strata. During their accumulation these rocks occupied unknown or uncertain paleogeographic positions with respect to each other and with the ancient western margin of cratonal North America. Consequently, discussion of these successions is terrane specific.

Chapter 9. Upper Jurassic to Paleogene Assemblages
(C.J. Yorath, H. Gabrielse, D.F. Stott, J. Dixon, R.G. Anderson, J.G. Souther, G.J. Woodsworth, H.W. Tipper, J.W.H. Monger, A. Sutherland Brown, R.B. Campbell and C.J. Dodds)
The Upper Jurassic to Paleogene assemblages of the Cordillera record the effects of successive accretion of the Intermontane and Insular superterranes with the western margin of ancestral North America (Figure 3). Moreover, it was during this interval when the five morphogeological belts and the modern plate tectonic regime were established. In this chapter, the assemblages are treated with reference to the five belts rather than with the various terranes.

Chapter 10. Neogene Assemblages
(J.G. Souther and C.J. Yorath)
Neogene volcanic and sedimentary assemblages are described relative to inferred plate tectonic settings throughout the past 24 million years.

Chapter 11. Physiographic Evolution of the Canadian Cordillera
(W.H. Mathews)
The paleogeomorphology of the Cordillera is considered from the time of terrane accretion to ancestral North America. As a consequence of terrane accretion the Cordillera adopted its present form, which the author compares to the modern island of New Guinea.

Chapter 12. Quaternary Glaciation and Sedimentation
(J.J. Clague)
The Quaternary stratigraphic record in the Cordillera is mainly a product of brief sedimentation events separated by long periods of nondeposition and glacial erosion. Thick stratified sediments lie mainly in valleys and coastal lowlands and were deposited in proglacial and ice-contact environments during periods of growth and decay of the Cordilleran Ice Sheet.

Chapter 13. The Modern Plate Tectonic Regime of the Western Canada Continental Margin
(R.P. Riddihough and R.D. Hyndman)
This chapter begins with a review of estimates of contemporary plate motions along the continental margin. This is followed by a discussion of the tectonic interactions and structure of the five parts of the plate system: the Juan de Fuca Ridge system, the Pacific-America transform margin, the Pacific-America-Juan de Fuca plate triple junction, the Pacific-America subduction boundary and the deformation within the America Plate.

Chapter 14. Volcanic Regimes
(J.G. Souther)
Volcanic rocks occur in most of the major assemblages throughout the western Cordillera. Traditional models of their origins have been superseded by tectonic models involving the concept of terrane accretion. This model allows for a three-fold subdivision of Cordilleran volcanic regimes: volcanic rocks of the miogeocline, volcanism in accreted terranes and post-accretionary volcanism.

Chapter 15. Plutonic Regimes
(G.J. Woodsworth, R.G. Anderson, R.L. Armstrong with contributions by L.C. Struik and P. van der Heyden)
This chapter emphasizes the chemical and petrographic characteristics of plutonic suites throughout the Cordillera, their ages and tectonic settings. As with other rocks, plutonic rocks may be pre-, syn- or post-accretionary. The exception to a chronological approach is the discussion of the Coast Plutonic Complex which is treated as an entity embracing rocks of many different ages.

Chapter 16. Metamorphism
(H.J. Greenwood, G.J. Woodsworth, P.B. Read, E.D. Ghent and C.A. Evenchick)
In this review, the facies and zone classification together with the petrogenetic grid on

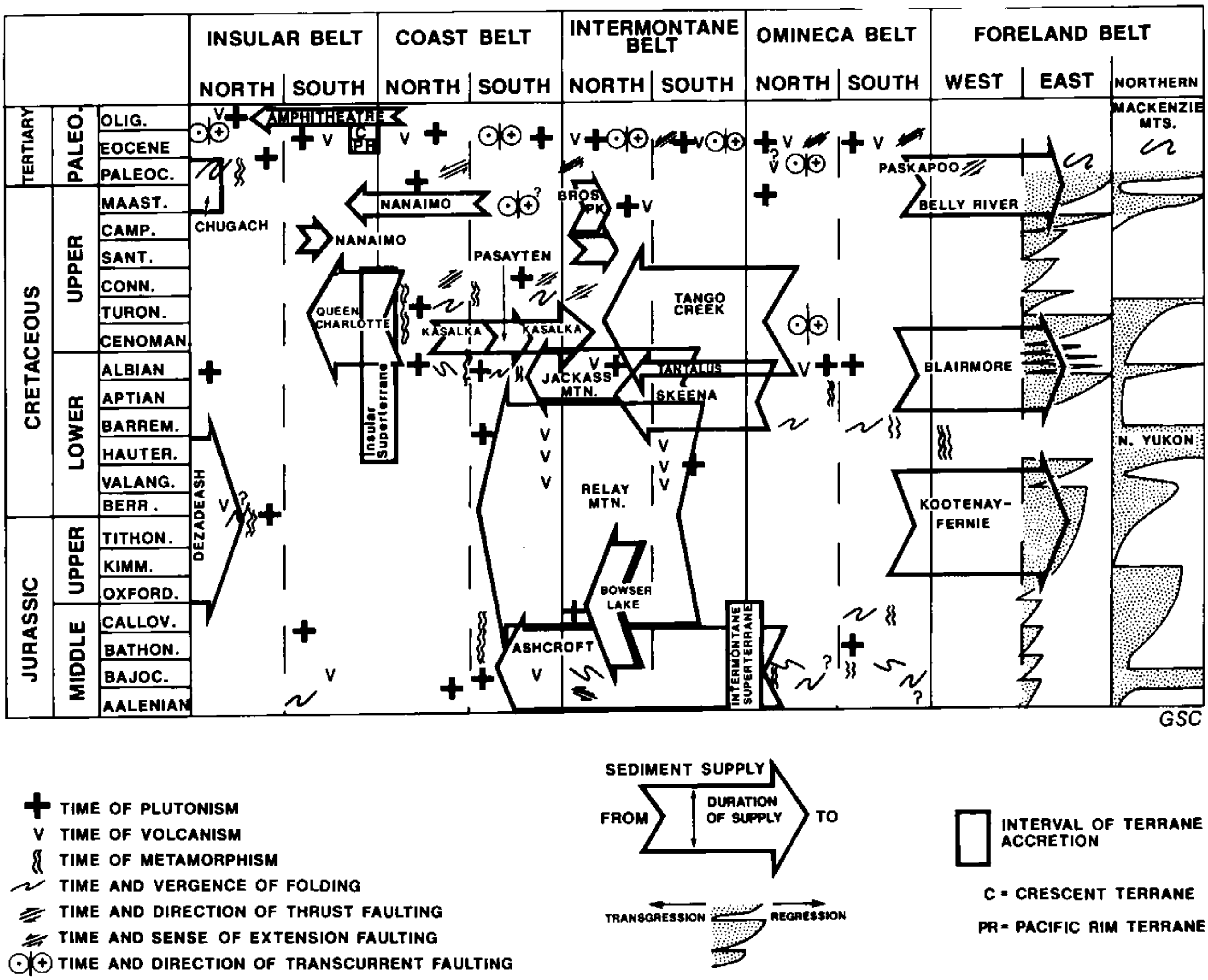


Figure 3 *Summary diagram of principal Middle Jurassic to Paleogene tectonic events in the Canadian Cordillera*

which they are based are described. Metamorphism in the Cordillera is discussed sequentially from east to west, using the five morphogeologic belts as a broad framework insofar as contrasting metamorphic style is one of the criteria for distinguishing among the belts. Emphasis is on the southern Cordillera, particularly the Omineca Belt.

Chapter 17. Structural Styles
(H. Gabrielse, R.B. Campbell, C.J. Dodds, C.J. Yorath, A. Sutherland Brown, G.J. Woodsworth, J.W.H. Monger, D.J. Tempelman Kluit, C.A. Evenchick, J.L. Mansey, R.L. Brown, J.M. Journeay, L.S. Lane, L.C. Struik, D.C. Murphy, C.J. Rees, P.S. Simony, J.T. Fyles, T. Hoy, S.P. Gordey, R.I. Thompson, M.E. McMechan, T.A. Harms, D.G. Cook, R.R. Parrish, R.M. Friedman and R.L. Armstrong)
This chapter describes the structural styles of the five morphogeological belts of which the Coast and Omineca belts represent greatly uplifted granitic and metamorphic orogenic core zones. Structures commonly verge outward from the core zones so that, in broadly regional cross-section, the Cordilleran Orogen contains two symmetrical sub-orogens, each arising all or in part from terrane accretion.

Chapter 18. Tectonic Synthesis
(H. Gabrielse and C.J. Yorath)
In this chapter, an attempt is made to summarize the temporal and spatial evolution of the Cordillera in terms of modern tectonic processes and to compare it to other orogens. This chapter forms the basis of much of the following discussion.

Chapter 19. Metallogeny
(K.M. Dawson, A. Panteleyev and A. Sutherland Brown)
This chapter describes the metallogenesis of the Cordillera in terms of terrane-specific, accretionary and post accretionary mineral deposits and presents several models of their origin and controls on emplacement.

Chapter 20. Energy and Groundwater Resources of the Canadian Cordillera
(C.J. Yorath, P.L. Gordy, G.K. Williams, R.M. Bustin, R.T. Bell, J.G. Souther and E.C. Halstead)
The character, distribution and size of energy resources including petroleum, coal, uranium-thorium and geothermal resources are described. Also discussed are Cordilleran groundwater resources, their recharge and discharge potential and distribution relative to bedrock type and physiography.

Chapter 21. Natural Hazards
(J.J. Clague)
This chapter summarizes naturally occurring processes that are potentially dangerous to life and property in the Cordillera, namely earthquakes, landslides, volcanism, snow avalanches, floods, tsunamis and erosion.

Chapter 22. Outstanding Problems
(H. Gabrielse and C.J. Yorath)
The synthesis of Cordilleran geology presented in the volume provides the reader with a summary of the current geoscience data base and leading hypotheses derived therefrom. This chapter focusses upon some of the numerous problems that arise from insufficient data to resolve conflicting models of Cordilleran evolution.

TECTONIC EVOLUTION OF THE CANADIAN CORDILLERA

Introduction

The tectonic evolution of the Canadian Cordillera encompassed a wide variety of processes including: (1) development of a miogeoclinal succession along the rifted passive margin of western ancestral North America beginning in Middle Proterozoic time, (2) an orogenic event which resulted in rifting, volcanism and plutonism in the outer part of the miogeocline in Late Devonian time, (3) the amalgamation and accretion of volcanic, island arc and oceanic terranes with deformation, metamorphism, volcanism and plutonism during Mesozoic and Cenozoic time, and (4) major displacements along dextral transcurrent faults during Cretaceous and Cenozoic time. In the following account, an attempt is made to summarize the principal events in the temporal and spatial evolution of the Cordillera as described by the many authors of the volume. Insofar as each chapter is supported by extensive references, only those considered essential to the following discussion are listed.

First, some general comments and definitions.

1. Throughout the volume considerable reference is made to "ancestral North America" and the "miogeocline". The former applies to the craton, which, throughout the Phanerozoic, remained relatively stable. The western edge of ancestral North America, from mid-Proterozoic to early Mesozoic time, is thought to have coincided approximately with the western part of the Omineca Belt and southern British Mountains in northern Yukon Territory (Figure 1). Since the early Mesozoic, successive episodes of terrane accretion have led to the modern outline of the western part of the continent. The "miogeocline" refers to the westward expanding, then tapering wedge of supracrustal rocks, that accumulated upon the westerly sloping Precambrian crystalline basement of ancestral North America from mid-Proterozoic to Middle Jurassic time. Although many digressions from geometrical uniformity exist, the overall regional concept employed is that of a broad, flat to gently west-sloping depositional surface upon which mainly shallow water carbonates and associated terrigenous clastics were deposited.

2. Throughout the text, the common Precambrian era terms "Aphebian", "Helikian" and "Hadrynian" are replaced by "Early", "Middle" and "Late" Proterozoic with lower age limits of 2500 Ma, 1600 Ma and 800 Ma respectively. This three-fold subdivision is based on recent stratigraphic, geochronological and paleomagnetic data and is more suitable to Cordilleran Proterozoic assemblages than the former terms established for time-stratigraphic subdivisions in the Canadian Shield.

3. A second departure from established practice is the discarding of formal names for Cordilleran orogenies. During the past few decades numerous terms have been applied to local or regional Cordilleran orogenies on the basis of different and often not widely accepted criteria. The two most commonly used terms have been "Columbian" and "Laramide" for deformational and/or metamorphic events of roughly mid-Jurassic to mid-Cretaceous and Late Cretaceous to Eocene ages, respectively. In many parts of the western Foreland Belt, the assignment of deformation to either of these is arbitrary and it is probable that the two events are part of an orogenic continuum. Terms used for local deformational events such as the Middle Triassic Tahltanian, Early Jurassic Inklinian and Middle Jurassic Nassian orogenies have not been used extensively in Cordilleran literature. Definition of the mid-Paleozoic Cariboo orogeny remains confused and the term is seldom used. The Precambrian Racklan, Hayhook, East Kootenay and Goat River orogenies represent local deformations of arguable significance and which are difficult to correlate regionally. As consequence of these and other criticisms, the many tectonic events evident in the Cordillera are described in terms of their age and the nature of the phenomena involved.

4. Definitions.

(1) *Terranes* are parts of the Earth's crust which preserve a geological record different from those of neighbouring terranes. The term has no genetic significance nor does it imply an origin far removed from neighbouring terranes or its present position. The boundaries between terranes are faults, although in some cases these are obscured by younger cover. There are several different types of terranes:

(2) *Accreted terranes* are those which became incorporated with ancestral North America at a late stage in their tectonic histories. Each has a distinctive stratigraphy and characteristic paleontological and/or paleomagnetic signature which indicate that they originated at varying distances from

and along the continental margin of ancestral North America. All contain assemblages indicative of ensimatic volcanic arc and/or oceanic to marginal basin settings. Examples include Stikinia, Quesnellia, Wrangellia and the Slide Mountain, Cache Creek and Alexander terranes (Figure 2).
(3) *Superterranes* are composed of two or more component terranes that were amalgamated prior to their accretion to North America. Examples are the Intermontane Superterrane including Stikinia, Quesnellia, the Cache Creek and Slide Mountain terranes; and the Insular Superterrane which includes the Alexander Terrane and Wrangellia together with some smaller terranes in the southern Coast Belt.
(4) *Pericratonic terranes* occur between the accreted terranes and ancestral North America and form components of the Omineca Belt. Parts have stratigraphic affinities with the ancient continental margin and thus may not have been greatly displaced from their locale of origin. Other parts, however, have stratigraphic and structural characteristics that are not observed in the rocks of the ancient margin. An example is the Kootenay Terrane (Figure 2).
(5) *Displaced terranes* are parts of the ancient continental margin that have been displaced by Late Cretaceous and Tertiary dextral motions along transcurrent faults. They also include superimposed terranes which had previously accreted to the edge of the continent. An example is the Cassiar Terrane, containing miogeoclinal assemblages, and which was displaced northward hundreds of kilometers from its original position (Figure 2).

Precambrian Basement

Gneissic Precambrian basement rocks occur rarely and intermittently throughout the length of the Omineca Belt and, locally, in the southern part of the Foreland Belt where they fall into three age groups: 2.1 – 1.85 Ga, 1.2 – 1.1 Ga and 0.8 – 0.7 Ga. Although the oldest of this group has an age span similar to that of the Wopmay Orogen and Thelon tectonic zones of the Canadian Shield, there is no unequivocal evidence that these rocks belong to ancestral North America. The middle group is related to an extensional event that produced the Coppermine Lavas and the youngest is thought to reflect rifting along the western margin of ancestral North America.

Middle Proterozoic Passive Margin

Middle Proterozoic clastic and carbonate sequences are included in at least two thick assemblages of miogeoclinal character. The older (Sequence A) comprises the Purcell (Belt) Supergroup in the southern Cordillera where it overlies crystalline basement rocks greater in age than 1.7 Ga, the Wernecke Supergroup in the Ogilvie and Wernecke mountains, possibly the Muskwa Ranges succession in the northern Rocky Mountains and a sequence exposed at Cap Mountain in the southern Franklin Mountains. The younger assemblage, the Mackenzie Mountains Supergroup (Sequence B), occurs only north of latitude 60° and may include the Pinguicula Group in the Wernecke and Ogilvie mountains. A wide range of data suggest that the older succession represents an interval between 1.7 and 1.2 Ga. The Mackenzie Mountains Supergroup and possibly the Pinguicula Group, based upon correlations with the Rae Group of the Coppermine Homocline, is younger than 1.2 Ga and older than 770 Ma, the age of diabase dykes which intrude the sequence in Mackenzie Mountains.

Thicknesses of more than 10 km, as well as the character of stratigraphic units point to a passive margin setting for Middle Proterozoic rocks. In the southern part of the orogen, and perhaps in the northern Rocky Mountains, although facies and thickness trends are approximately orthogonal to the regional structural grain of basement rocks as interpreted from potential field data, it is suggested that the older sequence of Middle Proterozoic rocks may have been deposited in one of several southwestward opening aulacogenes indenting a northwest-trending rifted continental margin.

The upper sequence of Middle Proterozoic rocks, the Mackenzie Mountains Supergroup, appears to have accumulated upon a deeply subsiding epicratonic platform. Assuming that the Muskwa Ranges succession belongs to the older Purcell (Belt) Assemblage, much of the Cordillera throughout British Columbia and the United States contains no record of the interval between 1.2 Ga and 0.8 Ga, the age of the basal part of the overlying Windermere Supergroup. Given a rifted craton origin of the latter, it is possible that initial uplift of the craton edge associated with rifting resulted in extensive erosion of Mackenzie Mountains Supergroup equivalent strata.

Fragmentary evidence for deformation, metamorphism and granitic intrusion in the Purcell rocks suggests one or two episodes of tectonism prior to Windermere deposition. The lack of an associated clastic wedge renders an unknown significance to these events.

Late Proterozoic Rifted Margin

In contrast to the areally restricted Middle Proterozoic assemblages, thick, dominantly clastic strata of the Upper Proterozoic Windermere Supergroup occur throughout the full length of the Cordillera and bear close spatial relationships with lower Paleozoic migeoclinal rocks. Windermere strata lie variously upon crystalline basement ranging in age from about 0.73 Ga to more than 2.0 Ga and deformed and weakly metamorphosed Middle Proterozoic strata.

The great variety of sediment types, abrupt facies changes, the widespread occurrence of mafic dykes and flows, the local presence of evaporites and the abrupt thinning to disappearance toward the craton suggest a rift origin for these rocks, not unlike that of the modern Atlantic margin. Significant local relief is indicated by abundant feldspathic sandstone and pebble conglomerate derived from crystalline basement. The upper part of the succession has characteristics typical of passive margin deposition. Cherty iron formation in the Mackenzie Mountains, of probable volcanic-exhalative origin, and diamictite at numerous localities, some of which of confirmed glacial origin, are distinctive lithologies. Although the North American craton was undoubtedly the primary source for these sediments, U-Pb zircon ages from Windermere metasediments at several localities suggest additional sources older and other than Cordilleran basement rocks and the adjacent craton (Aleinikoff *et al.*, 1984; Gabrielse *et al.*, 1982; P. Erdmer and H. Baadsgard, pers. comm., 1986; L.C. Struik, pers. comm., 1986).

The eastern limit of Windermere rifting throughout the length of the North American Cordillera is indicated by the extensive lateral distribution of like facies. For example, diamictites of probable glacial origin, are common from Yukon Territory to southeastern California. Based mainly on data from the Canadian Cordillera, rifting and glaciation began less than 0.8 Ga ago, when, as suggested by Eisbacher (1985) a supercontinent including the Adelaide and Sinean basins, respectively, of Australia and China may have been juxtaposed with the Windermere margin during mature stages of rifting and glaciation.

Approximately 700 to 900 Ma separated the Middle and Late Proterozoic rifting events, time enough to create at least five ocean basins the size of the modern Pacific even at moderate spreading rates. This suggests that the two events were unrelated, and moreover, that within that interval one or more continental configurations completely different from Pangaea could have developed. If, as is probable, a complete Wilson cycle occurred between the two events, the lack of evidence for an intervening, widespread Proterozoic collision orogen is puzzling. Deformation and metamorphism of the Wernecke and Purcell (Belt) supergroups are at least local evidence for a Proterozoic orogenic event(s).

Cambrian to Middle Devonian

The early Paleozoic evolution of the Canadian Cordillera is illustrated most completely by the stratigraphy of the miogeocline of ancestral North America and the Alexander Terrane in northwestern British Columbia and southwesternmost Yukon Territory (Figure 2). In the Kootenay Terrane, a fairly complete stratigraphic succession occurs, but lack of age control inhibits reliable correlation and analysis.

Ancestral North America

The miogeocline, including the displaced Cassiar Terrane and possibly parts of the Kootenay Terrane, consisted of a subsiding shelf that passed abruptly into a deeper, off-shelf region to the west. The shelf contains platform carbonate and mature clastic sediments, olistostromal deposits near the shelf margin, local volcanic rocks and narrow, shale-bounded carbonate reef tracts. In northern Yukon Territory the early Paleozoic miogeocline was the site of platform carbonate and intra-platform trough and basin clastic accumulation, the components of which were derived from cratonic sources to the east and northeast and possibly from terranes in the area of modern Canada Basin.

The lower Paleozoic rocks of the miogeocline are generally attributed to a passive margin setting superimposed upon the rifted margin of ancestral North America. Bond *et al.* (1985) constructed tectonic subsidence curves for Cambrian to Lower Ordovician rocks and concluded that the transition from rift to post-rift cooling and subsidence occurred in latest Proterozoic or Early Cambrian time. The character of Lower Cambrian sediments almost everywhere implies nearly synchronous environments of deposition along the length of the margin, beginning with thick, relatively mature sandstone units near the eastern limit of deposition which define a pronounced flexure near the edge of the cratonic margin. These pass westward into finer grained clastic rocks of probable continental slope affinity. Mafic volcanic rocks are known locally in Lower Cambrian strata in the Yukon and in the uppermost Proterozoic units of the Hamill Group of the southeastern Cordillera.

Although the early Paleozoic was a time of dominantly passive margin development, several criteria suggest episodic, but local, rift environments. Richardson Trough in northern Yukon (Figure 4) may have developed as a Middle Cambrian aulacogene and, moreover, may have connected with the Hazen Trough in the Arctic Archipelago. In the Muskwa Ranges of the northern Rocky Mountains and in the eastern Ogilvie and Wernecke mountains olistostromal debris flows are restricted to grabens or half grabens on either side of which sedimentary strata are of markedly different facies. Farther west in Kechika Basin (Figure 4) reefoid narrow tracts of Middle Cambrian and Middle Devonian carbonates are bounded by deep water sediments. Between Early Ordovician and Middle Devonian time more than 4000 m of dominantly carbonate strata were deposited in the northerly trending Meilleur River Embayment of Selwyn Basin (Figure 4) and Root Basin (Liard Depression). Broad crustal attenuation between the Cordilleran and Franklinian miogeoclines may have caused local rift basins to form.

Middle Ordovician volcanic rocks, perhaps associated with rifting, occur at many localities in miogeoclinal strata north of the Peace River Arch. Not widespread, but locally important, was Late Cambrian-Early Ordovician volcanism on the Cassiar Platform and in Selwyn Basin. Volcanic rocks occur in Ordovician, Silurian and Devonian strata in the Misty Creek Embayment of Selwyn Basin and Silurian alkalic volcanism occurred at about latitude 54° near the Southern Rocky Mountain Trench.

The Mesozoic and Cenozoic Atlantic passive margin of North America provides a useful model for comparison with the Cordillera (Figure 5). The former evolved over a span of about 190 Ma, about the same as the interval between the Early Cambrian and Middle Devonian epochs. A comparison between like margin facies suggests that the break between thick shelf carbonate and condensed off-shelf strata to the west, must have been associated with a change in the character of the underlying crust. Decoupling of the supracrustal rocks from their original basement during Mesozoic and Cenozoic deformation, however, precludes an assessment of where the crustal change occurred.

The presence of continental crust beneath Selwyn Basin is indicated by mid-Cretaceous, S-type granitic rocks. Two different models can be applied. The first assumes easterly dipping, mid-Cretaceous Benioff subduction of oceanic lithosphere generating granitic magma in, or greatly contaminated by, thinned sialic crust that formed the basement of Selwyn Basin. The second assumes westerly dipping Ampferer subduction of cratonic basement during the mid-Cretaceous with the consequent insertion of sialic material beneath Selwyn Basin which, until the Mesozoic, was underlain by transitional crust.

Accreted Terranes

The oldest rocks recognized in the Alexander Terrane (Figure 2) of the Saint Elias Mountains are Cambrian and possibly Upper Proterozoic strata grouped with an Upper Cambrian to Lower Ordovician sequence of volcaniclastics. An overlying succession comprises Lower Ordovician to Devonian limestone, clastic and minor volcanic and volcaniclastic rocks. In southeastern Alaska, where the terrane is more widely and completely exposed, episodes of pre-late Early Ordovician and Late Silurian to Early Devonian tectonism are recorded.

The pericratonic Kootenay Terrane, situated between ancestral North America and the accreted terranes (Figure 2) comprises assemblages of volcanic, clastic and carbonate rocks of Late Proterozoic to Triassic ages enclosing Ordovician, Devonian and Mississippian plutons. Sedimentary units may represent off-shelf margin facies of the miogeocline of ancestral North America. Tholeiitic basaltic rocks in the early Paleozoic Lardeau Group of the southeastern Cordillera suggest an extensional setting whereas felsic tuffaceous rocks of the Eagle Bay sequence to the northwest indicate an island arc environment distant from North America. An unconformity at the base of the Mississippian Milford Group truncates previously folded and metamorphosed Lardeau strata, but the age of deformation is otherwise unconstrained. No evidence of early Paleozoic deformation is recognized in rocks of the miogeocline farther to the east, although, in the southern Rocky Mountains, a widespread unconformity separating Upper Devonian from Ordovician and Silurian strata attests to broad epeirogenic movements.

Late Devonian to Triassic

During late Paleozoic and early Mesozoic times the contrast in stratigraphy and inferred tectonism between those terranes linked to ancestral North America and the accreted terranes is most evident. In particular, Wrangellia, the Alexander Terrane, Stikinia, the Cache Creek and Slide Mountain terranes together with several of the smaller terranes have fairly complete stratigraphic records allowing comparison among them and with ancestral North America.

Ancestral North America and the Displaced Terranes

In ancestral North America and on the displaced miogeoclinal terranes (Cassiar and North Slope, Figure 2), marine shelf conditions persisted throughout Late Devonian to Triassic time. However, in the northern Cordillera, widespread deposition of Upper Devonian to Lower Mississippian coarse to fine-grained clastics and local accumulation of alkalic volcanics occurred perhaps in part as a consequence of rifting along the edge of the miogeocline and partly as the result of contractional Ellesmerian deformation. Alkalic intrusive rocks and carbonatites occur at several localities near the shelf to off-shelf facies change. In the United States, similar rocks are attributed to the Antler Orogeny.

In latest Carboniferous to earliest Permian time, uplift and erosion occurred along the ancestral Aklavik Arch (Figure 4). Elsewhere throughout the eastern Cordillera pronounced unconformities appear at the base of the Permian and Triassic systems. Conceivably, the sub-Permian unconformity could have formed as a consequence of eustatic lowering of sealevel resulting from Carboniferous to Permian continental glaciation in the southern hemisphere.

Accreted Terranes

The stratigraphic succession defining Wrangellia (Vancouver Island, Queen Charlotte Islands and Saint Elias Mountains, Figure 2) includes mid-Paleozoic and Lower Jurassic calc-alkaline arc volcanic and volcaniclastic rocks and minor plutons, upper Paleozoic platform carbonate and clastic

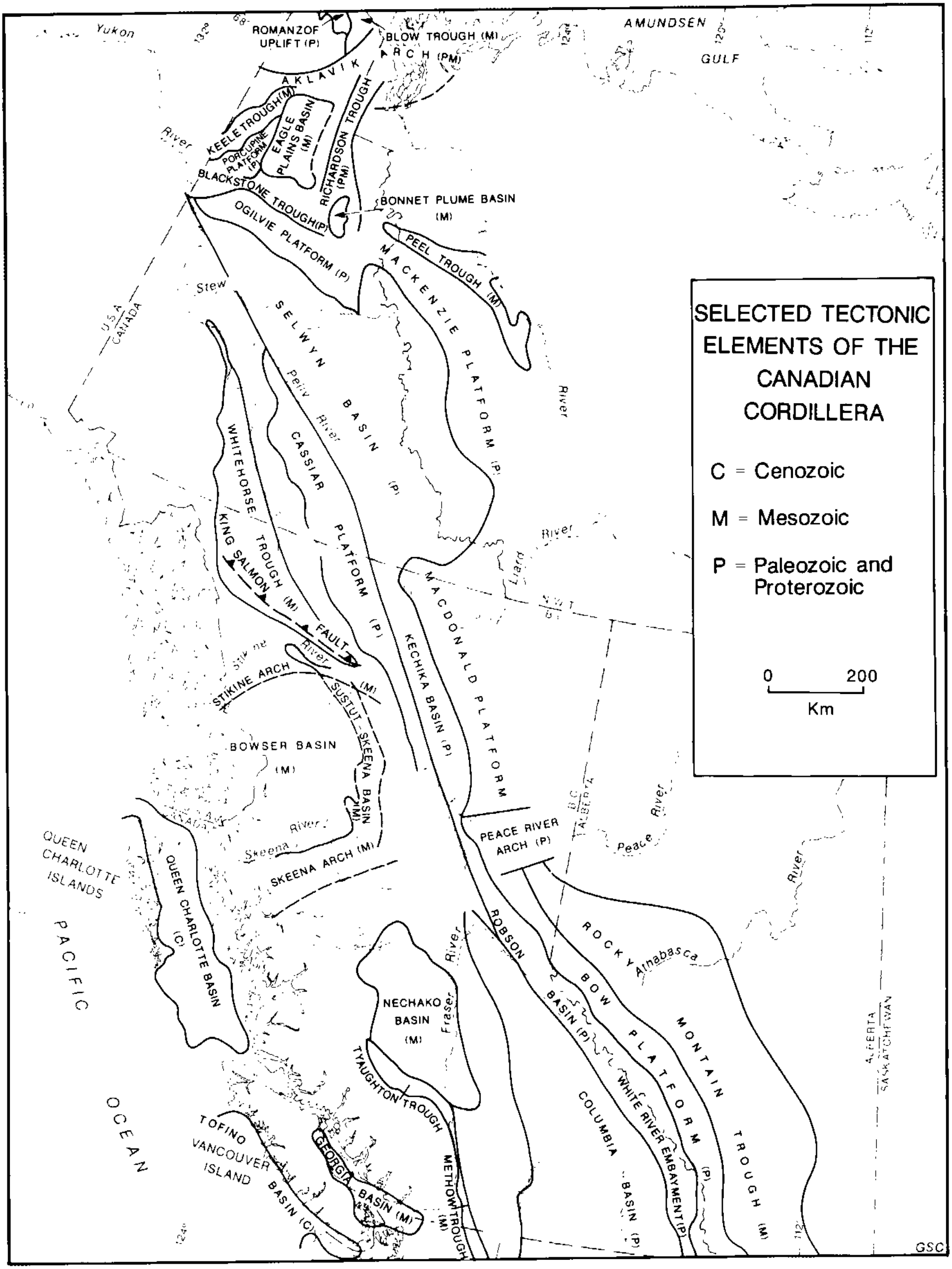


Figure 4 *Distribution of principal basins and platforms in the Canadian Cordillera.* ***P****, Paleozoic;* ***M****, Mesozoic,* ***C****, Cenozoic.*

strata and a thick, widespread unit of Upper Triassic tholeiitic, ocean-rift basalt.

In the Alexander Terrane, a variety of volcanic, clastic and carbonate rocks, ranging in age from Middle Devonian to Late Triassic is interpreted to have accumulated in island arc and, ultimately, rift environments. As in Wrangellia, a regional unconformity separates upper Paleozoic from Upper Triassic rocks.

Island arc settings also are interpreted for most of the upper Paleozoic and Triassic rocks of Stikinia (Figure 2). A belt of Mississippian and Permian limestone, about 400 km in length along the northwest side of the terrane, suggests intervals of quiescence and stability. In the northern part of the terrane, structural and metamorphic differences distinguish Paleozoic from Mesozoic rocks, but the nature of the causative tectonic event is not understood. During the Triassic Period, a volcanic and plutonic arc extended from the southwestern Yukon along the Stikine Arch (Figure 4) and thence along the east boundary of the terrane.

The Cache Creek and Slide Mountain terranes are characterized by typical oceanic rocks ranging from mid-Paleozoic to Triassic in age. The identification of a Tethyan fusulinid fauna in the Cache Creek Group provided the first evidence for exotic terranes in the Canadian Cordillera. The Slide Mountain Terrane, on the other hand, has a North American fauna, although possibly greatly displaced northward relative to the craton, and includes minor sedimentary units of probable cratonal source.

The record of Quesnellia, which separates the oceanic Cache Creek and Slide Mountain terranes, is mainly one of Late Triassic to Middle Jurassic arc volcanism, plutonism and sedimentation; local rift settings are suggested by the presence of alkalic volcanic rocks. Upper Devonian to Upper Permian rocks are included in the Harper Ranch Subterrane. Zoned, Alaskan-type ultramafic rocks are characteristic of Quesnellia.

The most distinguishing feature of the Kootenay Terrane is the presence of Late Devonian to Early Mississippian granitic rocks, locally associated with calc-alkalic volcanics. In the south, evidence exists for a significant pre-Lower Mississippian unconformity.

Among the smaller terranes the most complete stratigraphic record is preserved in island arc rocks of the Chilliwack Terrane. Carboniferous and Permian rocks there have affinities with those of Quesnellia.

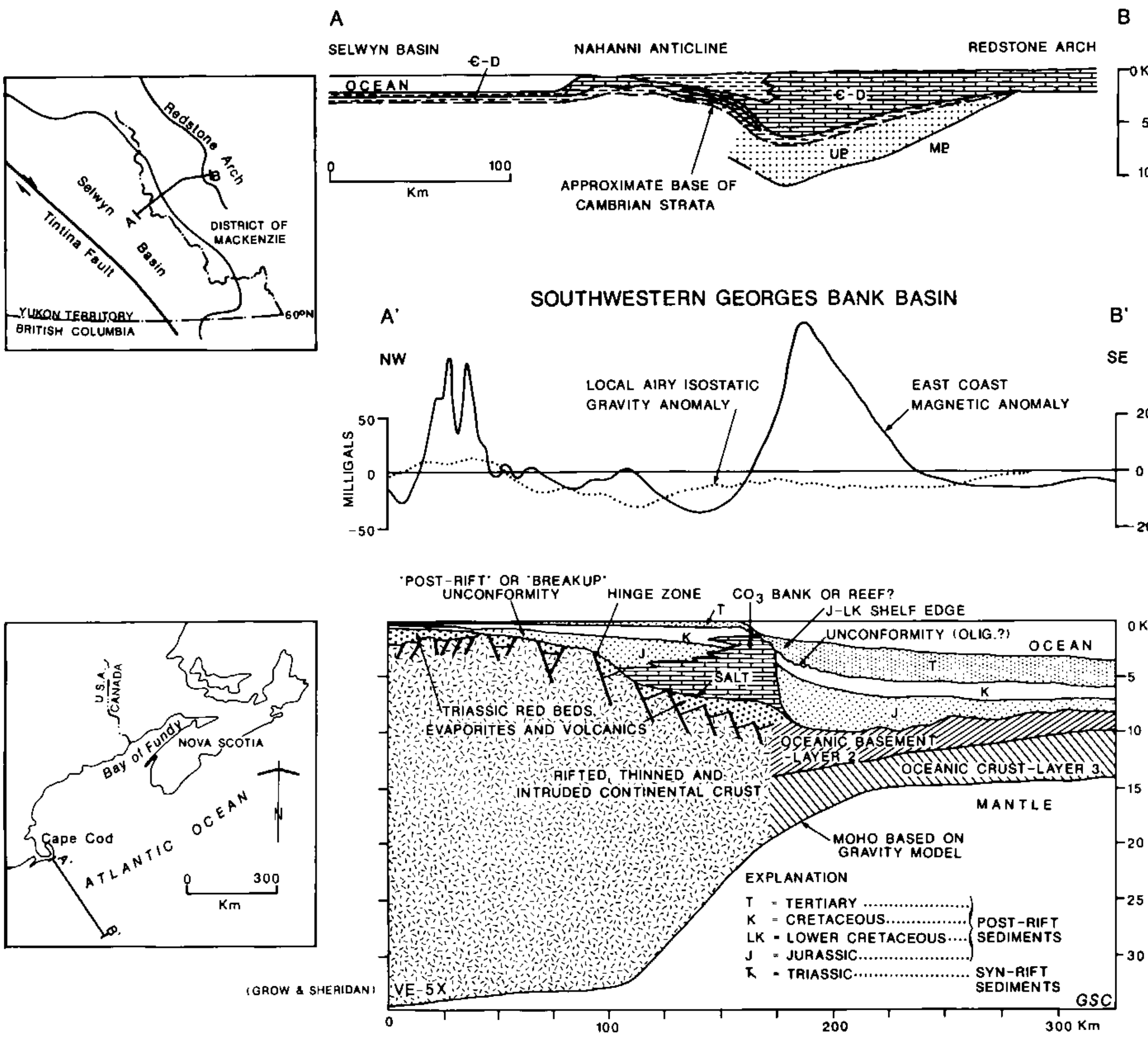


Figure 5 *Interpretive crustal cross-section through the North American passive margin (A'–B'; Grow, 1981) compared with a restored stratigraphic cross-section for upper Proterozoic and Lower to mid-Paleozoic rocks from Mackenzie Platform into Selwyn Basin (A–B; S.P. Gordey, pers. comm., 1987).*

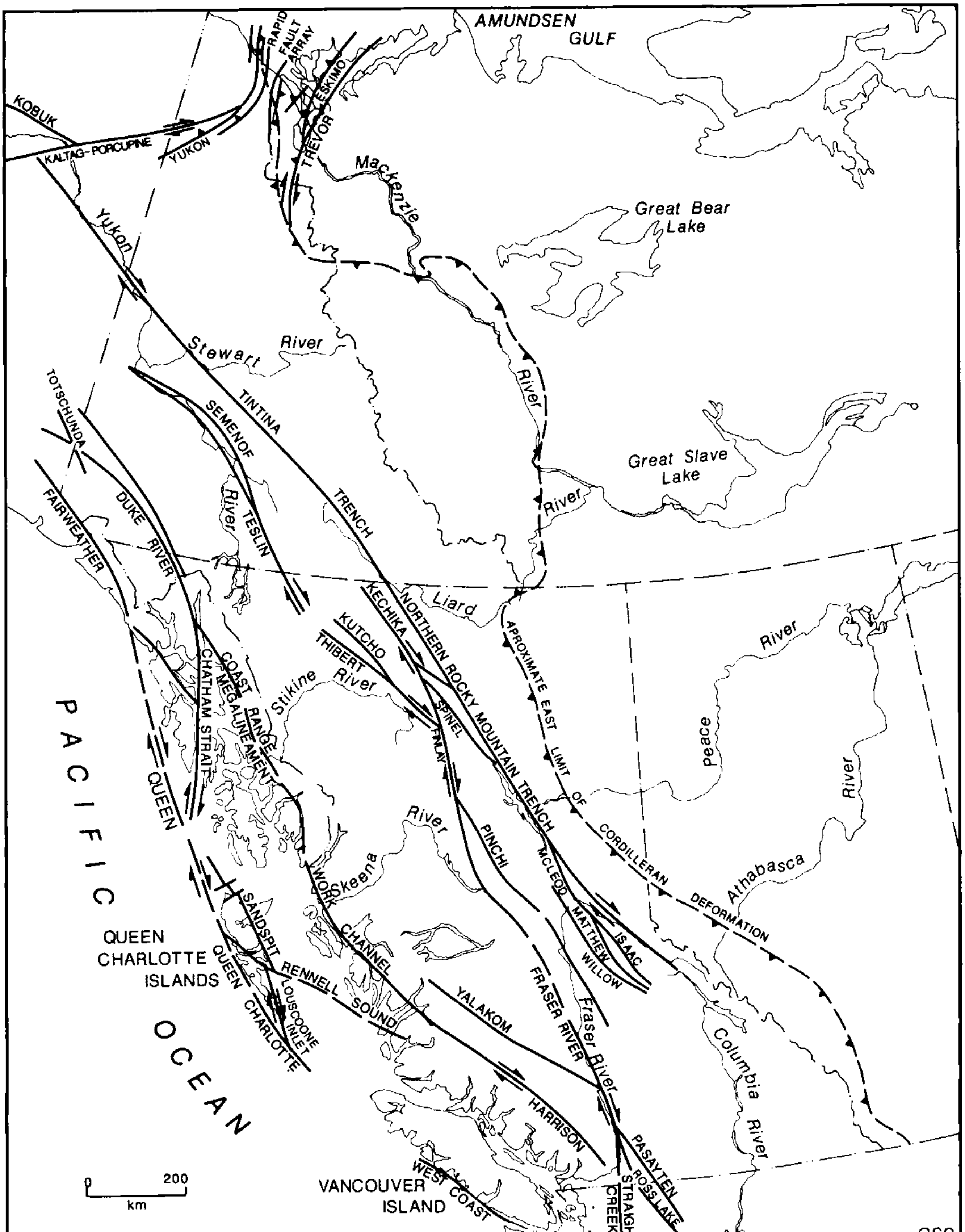


Figure 6 *Distribution of the main transcurrent faults in the Canadian Cordillera and adjacent Alaska.*

Correlations and Terrane Linkages
Within the Canadian Cordillera, there is little evidence to suggest linkages during late Paleozoic to Late Triassic time among the accreted terranes and between them and the pericratonic terranes to the east. An exception is that between Wrangellia and the Alexander Terrane where a recently discovered Middle Pennsylvanian plutonic complex intrudes basement rocks of both terranes (Gardner *et al.*, 1988). The Permo-Triassic unconformity is common to all terranes of island-arc affinity and thus appears to have resulted from a global phenomenon; it is not recognized in terranes of oceanic origin. In the northern part of the Cache Creek Terrane, radiolarian chert accumulated until Late Triassic (Norian) time whereas in the south, chert locally contains radiolaria as young as Middle Jurassic. During latest Triassic time, hints of linkages appear among Stikinia, the Cache Creek Terrane and Quesnellia. In the south, the Cache Creek Terrane perhaps became an accretionary prism beneath Quesnellia from where clasts derived from the Nicola Group volcanic arc contributed to the wedge. In the north, a similar relationship occurs where Upper Triassic to Lower Jurassic greywacke, conceivably from Quesnellia, flooded the northern part of the Cache Creek Terrane upon which a volcanic arc was constructed in Late Triassic time.

A link between the pericratonic Kootenay Terrane and the miogeocline of ancestral North America is suggested by the timing of plutonism, volcanism, rifting and clastic sedimentation. During Late Devonian to Early Mississippian time, coarse clastic sediments, probably derived from uplifted rift margins in the northern Cordillera spread eastward onto the craton. In the southern Kootenay Terrane folding preceeded deposition of Mississippian sediments and throughout the terrane granitic rocks were emplaced coincident with local eruptions of calc-alkaline volcanics.

In the North Slope Terrane, an unconformity separates Carboniferous carbonate and basal clastic strata from underlying rocks. Because of stratigraphic continuity of these late Paleozoic rocks with those in the Ogilvie Mountains of ancestral North America, the subdivision into terranes is debatable. An unresolved problem is whether these terranes are separated by a fundamental suture or are simply offset by the transcurrent Kaltag-Porcupine fault (Figure 6).

Components of the Slide Mountain Terrane occur almost everywhere as internally imbricated, sheet-like klippen emplaced onto miogeoclinal strata. In the northern Canadian Cordillera, Slide Mountain allochthons overlie Upper Triassic rocks along their eastern margins, which in the Yukon, include Upper Triassic mylonite, similar in lithology to the rocks of the allochthons. Thus, emplacement of the allochthons probably began earlier than Late Triassic time and may have led to subsidence of the Liard Basin throughout the Triassic Period.

In all well-studied examples, the Slide Mountain and correlative terranes comprise successions of thrust-bounded sheets (Harms, 1986; Struik and Orchard, 1985). In some cases, the degree of imbrication and variation in lithology between thrust sheets suggest contraction of a wide ocean basin (Harms, 1986). A setting proximal to the Kootenay Terrane has been demonstrated in the Kootenay Arc region of southern British Columbia (Klepacki and Wheeler, 1985). In the northern Cordillera, Early Permian tonalite is contained within the Sylvester Allochthon and cuts some, but not all, of the thrust faults (Harms, 1986). In the Kootenay Arc, some imbrication of Upper Permian strata took place in pre-Late Triassic time (Klepacki and Wheeler, 1985). Muscovite, associated with blueschist minerals and eclogites in the allochthons of southern Yukon Territory, has yielded mainly Late Permian ages (P. Erdmer, pers. comm., 1986). One explanation for these relationships is that contraction of an ocean basin began in the late Paleozoic and culminated with the emplacement of its contents onto the miogeocline of ancestral North America in the early Mesozoic. Perhaps related to this process was the evolution of the early Mesozoic volcanic and plutonic island arc of Quesnellia (Nicola Group).

Early Jurassic to Paleogene
The evolution of the Canadian Cordillera from the Early Jurassic to the Paleogene embraces the development of most of the region's main structural elements and marks a change from the dominance of disparate terranes to that of morphogeological belts resulting from amalgamation and accretion of terranes to the pre-Middle Jurassic continental margin. Within this broad concept, however, there are many problems which preclude unequivocal synthesis. These include the precise nature and timing of terrane amalgamation, the spatial relationship of tectonic phenomena in the accreted terranes with respect to those in ancestral North America, the temporal continuity of migrating tectonism *versus* tectonic pulses, the effects of oblique *versus* orthogonal collisions, the roles of Benioff as opposed to Ampferer subduction in tectonic processes and the clear identification of the tectonic processes that reorganized the northernmost Cordillera in the Late Jurassic and Cretaceous.

Early Jurassic
In the Canadian Cordillera, the Early Jurassic was a time of transition from terrane-specific volcanism, plutonism and sedimentation to one of development of overlap or post-accretionary assemblages during the Middle Jurassic. In Wrangellia, Late Triassic rifting of a Paleozoic arc was followed by re-establishment of a largely subaerial arc in Early Jurassic time on Vancouver Island and by Late Jurassic time in the Queen Charlotte Islands. Stikinia and Quesnellia, respectively, were the sites of marine and non-marine (Hazelton/Nicola) arcs which continued until Bajocian time. In the Cache Creek Terrane of the Yukon Territory and northern British Columbia, Lower Jurassic greywacke appears to have been derived from Quesnellia on the east and Stikinia to the west indicating closure of the northern Cache Creek ocean. In the south, however, oceanic environments persisted locally until Middle Jurassic time. On the central and southern miogeocline, condensed, incomplete successions of shale and some limestone accumulated in a stable tectonic setting.

Middle Jurassic to Early Cretaceous
Although Lower Triassic rocks provide hints of the amalgamation of Stikinia, Quesnellia and the Cache Creek and Slide Mountain terranes to form the Intermontane Superterrane, it was the Middle Jurassic that witnessed the onset of orogeny resulting in the formation of the Omineca Belt and the development of the clastic wedge of the Foreland Belt (Figure 3).

Island arc environments continued during the Middle Jurassic in northern Wrangellia. The time of collision of the Insular Superterrane with the Intermontane Superterrane is contentious, but probably occurred by mid-Cretaceous time. The similarity of stratigraphy across several small terranes of the southern Coast Belt, however, suggests that amalgamation may have occurred as early as Late Jurassic time.

Evidence for the collision of the Intermontane Superterrane with Ancestral North America is contained in the record of sedimentation, deformation, plutonism and metamorphism. The best sedimentary and structural evidence for the timing of accretion comes from the region in and near the northern Bowser Basin (Figure 4) where Bajocian marine and non-marine conglomeratic strata are known to have been derived from uplifted Cache Creek Terrane strata to the northeast. Farther south the main influx of Cache Creek detritus into Bowser Basin occurred during the Bathonian Stage. The King Salmon Thrust Fault, carrying Cache Creek rocks in its hanging wall, and associated southwesterly directed structures, were cut by granitic plutons ranging in age from about 175 to 147 Ma. Continuing uplift of the Cache Creek Terrane and perhaps the northern fringe of Stikinia facilitated the progradation of a deltaic wedge over older, deep marine turbidites of the Bowser Basin during Late Jurassic time. The sedimentary history is similar along the eastern margin of the basin but there, knowledge of the structural development is obscured by younger strike-slip faults.

The paleolatitude of the Bowser Basin, relative to ancestral North America during

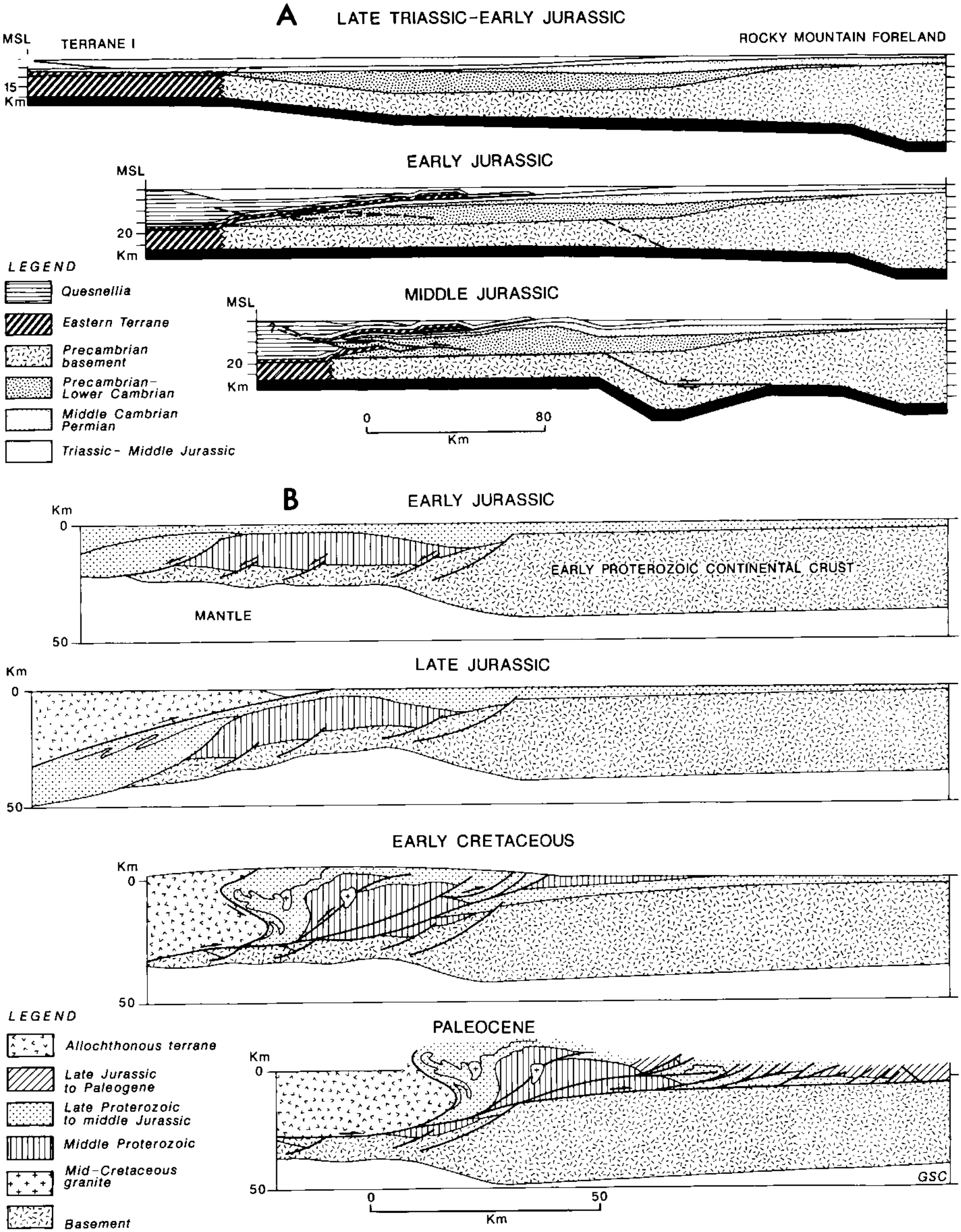


Figure 7 A *Model for Jurassic terrane collision involving obduction and eastward underthrusting of sialic crust. (After Brown* et al., *1986).*
B *Model for Jurassic to Paleocene deformation involving obduction, wedging and delamination. (After Price, 1986).*

Middle and Late Jurassic time is in doubt, insofar as the aforementioned deformational and sedimentary events may reflect collision with the craton farther south. Indeed, current interpretations of paleomagnetic data suggest that the combined Intermontane and Insular superterranes (Baja, BC) were at more southerly paleolatitudes during mid-Cretaceous time than at present. Even though accretion with North America may have occurred at such latitudes, it was not until early in the Tertiary Period that they reached their present position by coastwise translation. This interpretation suggests that either a northern extension of the Intermontane Superterrane, or an entirely different terrane, had collided with the craton during the Middle Jurassic and was subsequently displaced or replaced. Paleontological data support a northern hemisphere position for Stikinia as early as Pliensbachian time. Both interpretations, however, show that an important accretion event occurred during Middle Jurassic time; the resolution of this problem awaits further research.

Significant uplifts in the western part of southern Quesnellia are recorded by thick, easterly derived clastic rocks and by the evidence for termination of marine sedimentation throughout Quesnellia in Bajocian time. Collision of the Intermontane Superterrane with ancestral North America also resulted in the eastward emplacement of Quesnellia and probably the Slide Mountain Terrane onto the outer part of the miogeocline.

Dating of metamorphism, deformation and plutonism in the Omineca Belt is well constrained in the Columbia Mountains where highly deformed and regionally metamorphosed rocks (Quesnellia and Kootenay Terrane and the miogeocline) are cut by Middle Jurassic granitic plutons that have yielded radiometric ages ranging from about 180 to 160 Ma. These are the oldest plutons that clearly occur in all of these terranes.

In the Foreland Belt, the first direct evidence for clastic sediments derived from the west is the presence of clasts of radiolarian chert, from either or both of the Slide Mountain and Cache Creek terranes, in the Upper Jurassic to Lower Cretaceous Monteith Formation (M.E. McMechan, pers. comm., 1985). It is probable, however, that some Oxfordian clastics also were westerly derived. Uplift of the western miogeocline is clearly shown by the first (Kootenay Assemblage) of three thick clastic successions that accumulated in the foredeep of the rising orogen (Figure 3).

In the northern Yukon, long established northern source areas for clastic sediments were replaced in Albian time by sources within the Cordillera to the south. Debate continues on the nature and timing of tectonic reorganization, however recent paleomagnetic results obtained by Halgedahl and Jarrard (*in press*) support the model of counter-clockwise rotation of the Brooks Range away from the Arctic Archipelago and the consequent opening of Canada Basin sometime between Early to mid-Cretaceous time (Lawver and Scotese, *in press*). The Albian age of thrusting in the Brooks Range possibly constrains the time of cessation of opening. It is suggested that the centre of rotation is expressed by the "Porcupine Virgation", a region of structural trend bifurcation and change in structural style west of Mackenzie Delta (D.K. Norris, pers. comm., 1987).

The eastern limit of Middle Jurassic tectonism is unknown, but no data show that it extended farther east than the Omineca Belt. Data obtained from equilibrium assemblages of metamorphic minerals show that a considerable increase in crustal thickness occurred there at that time. Burial of Upper Proterozoic rocks to depths greater than 25 km and heating at temperatures between about 550 and 650°C indicate the important role of contractional deformation in more than doubling the probable stratigraphic thickness (Archibald *et al.*, 1983; Brown *et al.*, 1986; Pigage, 1978; Simony *et al.*, 1980; Evenchick, 1986; Mansy, 1986). A less significant part of the thickening resulted from the emplacement of the Slide Mountain Terrane, and to a lesser extent, Quesnellia onto the miogeocline of ancestral North America.

Two hypotheses have been proposed to explain the early phase of Mesozoic structural development in the western part of the miogeoclinal wedge, and in particular, the westward verging structures in the western part of the Omineca Belt. One proposes eastward obduction of the Slide Mountain Terrane and Quesnellia followed by the development of west-verging back folds and back thrusts in supracrustal rocks balanced by eastward decoupling and underthrusting of basement rocks (Brown *et al.*, 1986; Figure 7A). The alternative hypothesis proposes obduction of the accreted terranes followed by tectonic wedging. In this case, a wedge of accreted rocks was driven eastward between westward-verging, parautochthonous, supracrustal rocks delaminated from an autochthonous basement complex (Price, 1986; Figure 7B). Vergence was determined by structural position above or below the wedge.

Two axes of structural divergence formed, perhaps sequentially, during the early phase of Middle Jurassic to Early Cretaceous deformation. One occurs in the Intermontane Belt and separates the westward-verging structures of the Cache Creek oceanic rocks caused by collision with Stikinia from the eastward-verging structures related to the emplacement of Quesnellia and the Slide Mountain Terrane. The other occurs in the Omineca Belt within the thickened prism of parautochthonous rocks.

From a broader perspective, the collision of terranes arising from closure of the Cache Creek and Slide Mountain oceans, and subsequent intraplate deformation necessitated the delamination and obduction of oceanic crust. Studies by Harms (1986) and Struik and Orchard (1985) indicate that the width of the Slide Mountain ocean was substantial and that subsequent contraction of obducted material began in late Paleozoic time. The polarity of inferred subduction zones and, indeed, their positions during this interval, however, are not obvious. Early and Middle Jurassic plutons in Quesnellia and the pericratonic Kootenay Terrane could be explained by eastward-directed subduction and development of melange in the Cache Creek accretionary wedge. Deformation and uplift of Cache Creek rocks in Middle Jurassic time north and east of Bowser Basin was probably accomplished by intraplate deformation.

Pre-Hauterivian to Barremian

Clastic sedimentation, containing the record of Middle Jurassic to Early Cretaceous uplifts was succeeded by apparent Cordillera-wide erosion and pedimentation east of the Coast Belt. This event is demonstrated by an unconformity at the base of the middle clastic wedge in the southern Foreland Belt, beneath Hauterivian strata in the northern Yukon and central British Columbia, under mid-Albian strata in northern British Columbia, and beneath Barremian strata in the Tyaughton-Methow Trough (Figure 4) in the southeastern Coast Belt. Widespread uplift coincided with a lull in granitic plutonism and volcanism throughout the western Cordillera between 135 and 125 Ma (Armstrong, 1988) and a period of relatively slow motion of the North American Plate (Engebretson, 1982).

Barremian to Paleocene

A second clastic wedge (Blairmore Assemblage) was shed eastward into the foredeep of the emerging orogen between Barremian and Cenomanian time in response to another pulse of uplift in the Cordillera to the west (Figure 3). In the northernmost Cordillera, orogenic activity, arising from the opening of Canada Basin, spread eastward into the British and Barn Mountains. The resulting Brooks orocline thus confined clastic sedimentation to the Blow Trough west of Mackenzie Delta wherein thick accumulations of flysch and molasse were deposited in response to continuing uplift associated with dextral strike-slip and normal faulting. Whereas most large-scale bends in structural grain in the North American Cordillera were controlled by the initial shape and thickness of the supracrustal rocks, the Brooks Orocline may be one of the few that formed as a result of rotation about a vertical or semi-vertical axis. During the same time, considerable quantities of clastic marine to non-marine sediments were shed westward from the Omineca Belt into Sustut and Skeena basins and Tyaughton-Methow Trough (Figure 4). Equally thick successions of clastics, locally with volcanics, were deposited in the regions of the Coast and

Insular belts. The first sediments in the latter region derived from uplift of the Coast Belt to the east are of Albian to Cenomanian age. Clastic wedge sedimentation was coupled with uplift of the Omineca Belt which was the locus of deformation, widespread felsic S-type granitic plutonism characterized by rocks having $^{87}Sr/^{86}Sr$ ratios of 0.710 to 0.740, minor volcanism and regional metamorphism. The eastern limit of mid-Cretaceous plutonism is parallel with but much to the west of the eastern limit of Foreland Belt deformation. Mid-Cretaceous plutonism, characterized by I-type granitic rocks with strontium isotope ratios generally less than 0.7045 and associated with volcanism was extensive in the southern Coast Belt, where Cenomanian uplift provided a source of coarse clastic sediment for the Tyaughton-Methow Trough to the east and the Insular Belt to the west. In the western part of the central Coast belt, west-verging structures developed synchronously with plutonism and regional metamorphism.

In the Foreland Belt, the eastern limit of mid-Cretaceous deformation and the western limit of deposition are difficult to determine. Directly east of the Northern Rocky Mountain Trench, deformation was accompanied by regional metamorphism dated at a minimum of 120 to 125 Ma. There, and in the Selwyn Mountains, pre-mid-Cretaceous contraction of at least 50% is expressed by intense imbrication of lower Paleozoic strata indicating crustal shortening of possibly 200 km or more (S.P. Gordey and R.I. Thompson, pers. comm., 1987). In the Omineca Belt, all regional contractional structures are cut by mid-Cretaceous plutons. No mid-Cretaceous structures are evident in the middle Albian part of the Sustut Group.

In the Cassiar and Omineca mountains, mid-Cretaceous deformation formed broad anticlinoria and synclinoria in previously deformed and regionally metamorphosed rocks. Structurally lowest rocks in the cores of the anticlinoria yield presumably reset mid-Cretaceous K-Ar ages, whereas the flanks, with structurally highest rocks, yield earliest Cretaceous K-Ar ages. Rb-Sr dating of the former give ages as old as Middle Jurassic (Parrish, 1979). In the southeastern part of the Omineca Belt, rocks that had been buried to depths of more than 20 km during Middle Jurassic tectonism were uplifted more than 13-14 km and intruded by mid-Cretaceous granite (Archibald *et al.*, 1983). By about middle Albian time, dextral strike-slip faulting began in the northern Cordillera (Gabrielse, 1985).

West-verging structures were generated in mid-Cretaceous time along the west side of the Coast Belt in southeastern Alaska and east of the Queen Charlotte Islands and on the west side of the Cascade segment of the Coast Belt including the San Juan Islands, whereas east-verging thrusts developed on the east side of the Cascade Mountains.

By the beginning of Late Cretaceous time, the Coast and Omineca belts were well established as uplifted metamorphic and plutonic welts. The latter, for the most part, had undergone renewed uplift whereas the Coast Belt had just evolved from an island arc into a fully developed plutonic-metamorphic welt. The evolution of the Coast Belt has been related partly to collision between the Insular Superterrane and North America, which, by mid-Cretaceous time, included the Intermontane Superterrane. Coeval, extensive plutonism, although of markedly different lithology and chemistry in the Coast and Omineca belts, raises questions concerning the collision mechanism. The suturing of the Insular and Intermontane superterranes along the axis of the Coast Belt could have been accommodated by eastward-dipping subduction between the two superterranes although the temporally closest arc volcanism (Gambier Assemblage) is Early Cretaceous in age. The magmatic arc with its ductile structures contrasts with much less penetrative westward-verging contraction structures that disrupt Wrangellia on eastern Vancouver Island and which may have formed during collision of the two superterranes. Another possibility is that much of the crustal thickening in the Coast Belt resulted from intraplate contraction and that the suture zone between the Coast and Insular belts may have been farther west. The parallelism of the eastern limit of granitic rocks in the Omineca Belt with the eastern margin of Cordilleran deformation suggests a coupled relationship in which the generation of plutons resulted from westward subduction of continental crust. The S-type nature of Omineca plutons points to a source within sialic material.

Late Cretaceous to Paleocene time witnessed the deposition of the third and youngest of the clastic wedges (Brazeau Assemblage; Figure 3) in the foredeep of the Foreland Belt. During Campanian time, uplift and deformation of the Coast Belt resulted in a reversal of sediment transport from westward to eastward in the Sustut Basin and from eastward to westward in the Insular Belt where a thick clastic wedge accumulated in Georgia Basin (Figure 3). This was a time of great crustal shortening in the southern Omineca and Foreland belts (up to 200 km), but considerably less than that in the northern Cordillera. Upward and eastward movement in the Coast Belt resulted in marked contraction of the supracrustal rocks in the Bowser Basin and Tyaughton-Methow Trough and was possibly related to westward thrusting in the Insular Belt. The magmatic front lay mainly west of the Coast Range Megalineament in mid-Cretaceous time but moved to generally east of the megalineament in Late Cretaceous time. Throughout the Intermontane Belt, block faulting was associated with local plutonism and volcanism. Explosive felsic volcanism was particularly important during Campanian and Maastrichtian times, as shown by widespread tuff in Sustut Basin and in the Foreland Belt. Abundant volcanics, in part alkaline in eastern exposures, attest to widespread volcanism in southwestern Yukon Territory. Dextral transcurrent faulting probably occurred on many of the northwesterly trending faults although precise dating of the movements is not established. Accretionary wedges formed along the boundary between the Pacific and North American plates in the Gulf of Alaska. Structures in the central Coast Belt indicate a significant component of dextral shear between the Kula and North American plates.

Eocene

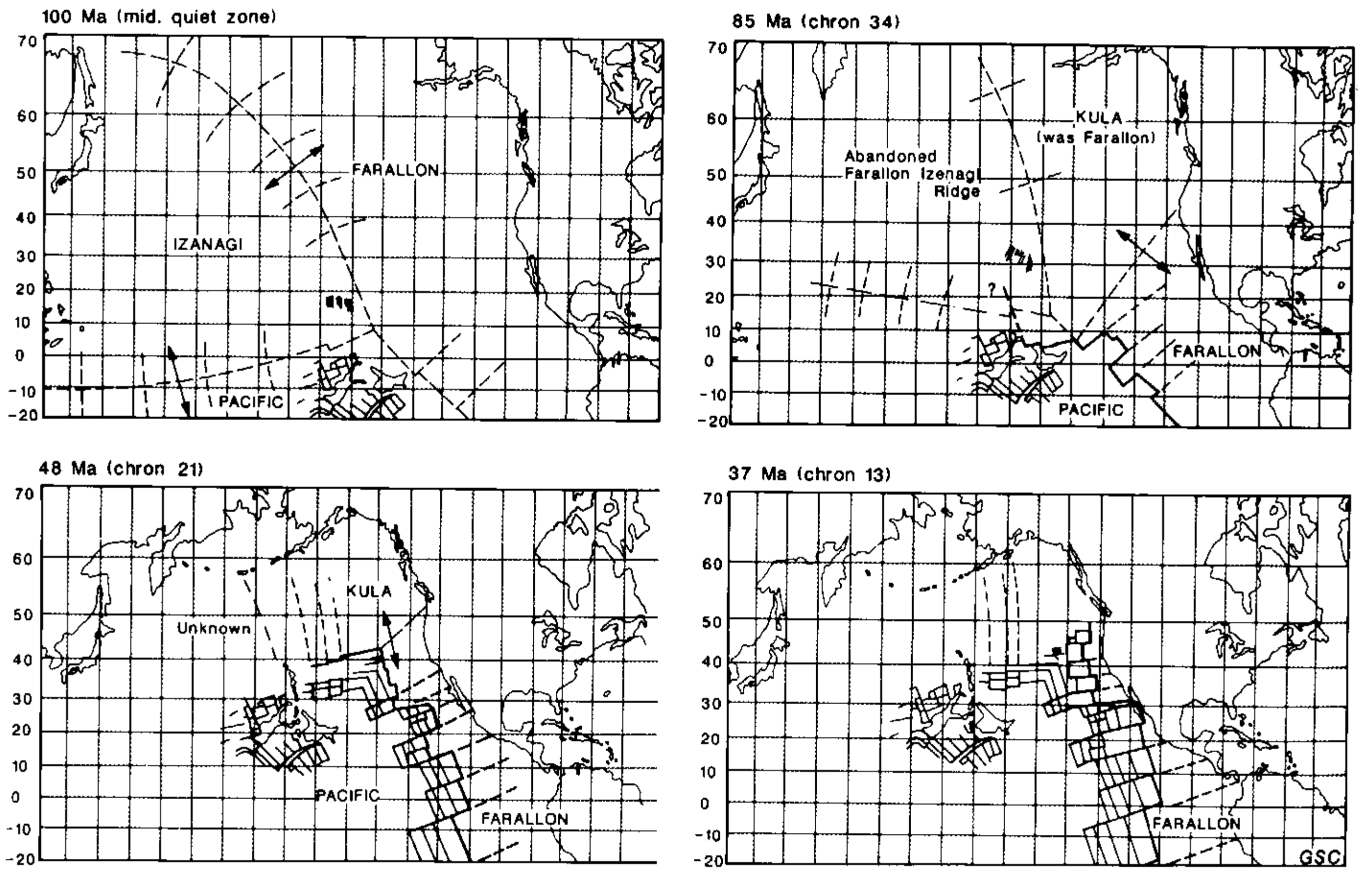
A short-lived (55 to 45 Ma), intense and widespread phase of granitic magmatism and uplift in the Coast and Omineca belts postdated the last main episode of contractional deformation and sedimentation east of the Insular Belt. Non-marine sedimentation was restricted to linear basins along dextral transcurrent fault zones or occurred in extensional basins related to a dextral strain regime. Thick non-marine to marine successions were deposited in the Georgia Basin and on the west flank of the Insular Belt and continued to form an accretionary wedge along a subduction zone in the Gulf of Alaska.

In the Omineca Belt of south-central British Columbia, Eocene uplift was synchronous with volcanism and extension faulting. Locally, the amount of extension may have approached 100 km (Tempelman Kluit and Parkinson, 1986). High heat flow is indicated by the widespread resetting of K-Ar ages in biotite and hornblende in structural culminations. Dextral transcurrent faulting continued along the Northern Rocky Mountain and Tintina trench systems and was important along the Fraser River system (Figure 6). In the Cassiar Mountains next to the Northern Rocky Mountain Trench, thrust faults of Late Cretaceous to Eocene age formed in response to compression along a left-stepping transcurrent fault (Evenchick, 1986).

The largest areas of Eocene granitic rocks are along the eastern margin of the Coast Belt where they were emplaced between 62 and 48 Ma near the close of a period of rapid uplift. A remarkable feature of the Coast Belt is a foliated, steeply dipping tonalitic body, about 10 to 15 km wide, that lies immediately east of the Coast Range Megalineament and extends from near the British Columbia-Yukon border to south of Prince Rupert, a distance of more than 800 km (Brew and Ford, 1978; Woodsworth *et al.*, 1983). Ages of the body range from Maastrichtian to Late Paleocene. Ductile structures along the western margin have been related to emplacement during deformation, perhaps involving strike-slip faulting (Woodsworth *et al.*, 1983). Alternatively, the tonalite may represent an upturned slab originating at a deep crustal level in the Coast Plutonic Complex, and, as such, may be similar to tabular bodies of gneissic tonalite that occur at the base of an uptilted block of Archaean crust along the Kapuskasing Uplift in the Canadian Shield (Percival and Card, 1983).

The change from a contractional regime, presumably caused by orthogonal to oblique convergence of the Farallon Plate in the late Mesozoic and Paleocene, to one of uplift and extension east of the Insular Belt in the Eocene, has been attributed to changes in the relative motions among the Farallon, Kula, Pacific and North American plates (Engebretson, 1982; Figures 8A and 8B). Prior to mid-Cretaceous time, relative movements of the Farallon and North American plates indicate oblique convergence with a component of sinistral shear, following which, in mid-Cretaceous time, relative motions between the two plates became essentially orthogonal. At about 85 Ma, initiation of the Kula Plate with its dominantly northward motion relative to North America provided potential for dextral shear north of the ridge separating it from the Farallon Plate. With the demise of the Kula Plate at about 43 Ma, the same result was obtained north of the triple junction between the Pacific, Farallon (Juan de Fuca) and North American plates.

In the Canadian Cordillera, there is considerable evidence for dextral shear since mid-Cretaceous time, probably as a result of oblique convergence. The Paleocene and Eocene epochs, with rapid west-to-southwest relative motion of the North American Plate (Figure 8B), was an interval when



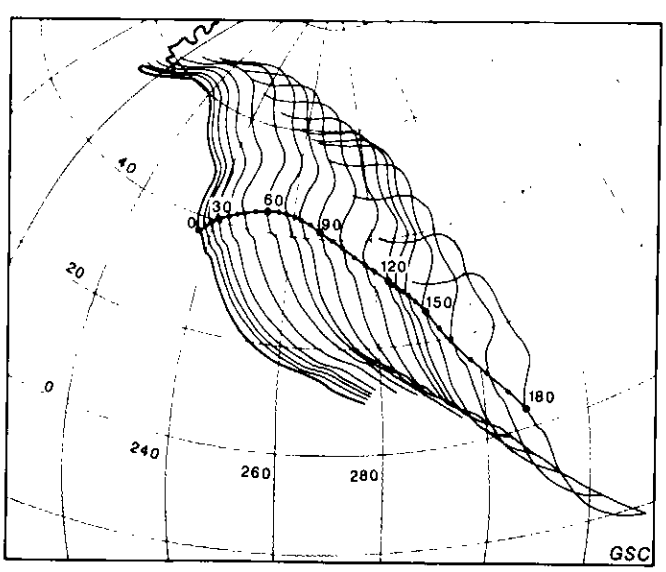


Figure 8 A *Plate reconstructions in fixed hotspot reference frame.*
B *Motion of North America with respect to hotspot reference for past 180 m.y. at 10 m.y. intervals. (After Engebretson, 1982).*

the component of dextral shear was paramount. Structural data and magnetic history suggest a dextral shear regime coupled with eastward subduction. Throughout the Jurassic to Eocene history of the Canadian Cordillera, there is good correlation among episodes of deformation, plutonism, volcanism and changes in velocity and/or direction of North American Plate motion.

Neogene

The Neogene history of the Canadian Cordillera was determined largely by the interaction of the Pacific, Juan de Fuca (Farallon) and North American plates. As a consequence of the northward motion of the Pacific Plate, sediment derived from the uplifted Coast and Insular belts has contributed to accretionary prisms adjacent to the Queen Charlotte Islands and in the Gulf of Alaska. Calc-alkaline volcanism occurred above the subducting plate in the Saint Elias Mountains. In the Insular Belt, Queen Charlotte Basin (Figure 4) may have formed as a consequence of rifting associated with a regional dextral stress regime and through flexural subsidence due to the initiation of oblique convergence and subduction of the Pacific Plate beneath the Queen Charlotte Islands. Recent work however, has cast some doubt on the role of transcurrent faulting in the Queen Charlotte Islands (R.I. Thompson, pers. comm., 1988). North of the triple junction, which moved southerly along the continental margin from north of the Queen Charlotte Islands in early Neogene time to its present position between the Queen Charlotte Islands and Vancouver Island (Figure 9), northerly trending rifts related to the same regional stress system localized alkaline volcanism in the Stikine region. South of the triple junction, two distinct volcanic-plutonic arcs formed above the subducting Juan de Fuca Plate; the Early to Late Miocene, northwest-trending Pemberton Belt, and the Late Miocene to Recent, more northerly trending Garibaldi Volcanic Belt (Cascade). In the interior of southern British Columbia, flood basalts of about the same age as the Pemberton Belt volcanics reflect a back-arc setting. The conspicuous, easterly-trending Anahim Volcanic Belt may reflect the trace of a hotspot across central British Columbia, where, from west to east, peralkaline volcanic centres become progressively younger. Rapid Pliocene to Recent uplift of the southern Coast Belt above the passively overridden Explorer Plate and the subducting Juan de Fuca Plate is attributed to thermal expansion and magma emplacement (Parrish, 1982).

Seismic reflection profiles across southern Vancouver Island reveal imbricate thrust faults related to Benioff subduction, similar to those of Ampferer type in the Foreland Belt. In the Insular Belt, Neogene contraction and uplift of Wrangellia were due to emplacement of the Pacific Rim and Crescent terranes beneath Wrangellia at about 42 Ma, probably as a consequence of a change on the Pacific Plate motion regime (Figure 2).

For the most part, the modern geophysical signature of the Cordillera reflects its post-accretionary character and clearly defines the tectonophysical nature of the active convergent and transform components of the continental margin. There are two zones in the Cordillera across which regional geophysical properties change. The eastern zone is nearly coincident with the Southern Rocky Mountain Trench and, from east to west, is characterized by a 10 to 15 km shoaling of the Moho, an apparent 40 $mW \cdot m^{-2}$ increase in surface heat flow, a 50 to 100 mGal increase in Bouguer anomaly values, a smoothing of long wavelength magnetic anomalies and a pronounced increase in electrical conductivity. The western zone occurs in the Coast Belt, close to the Garibaldi (Cascade) volcanic arc. From east to west, the crust thickens by about 20 km, surface heat flow declines by as much as 40 $mW \cdot m^{-2}$, low level seismicity rises sharply within a horizontal distance of 20 km and the Bouguer anomaly increases by up to 150 mGal over a distance of about 80 km. A linear magnetic anomaly high of about 1000 nT is associated with the western zone. The region between these zones, the Omineca and Intermontane belts and the eastern part of the Coast Belt, has a relatively thin, less dense crust, high heat flow, attenuated long wavelength magnetic anomalies and high conductivity.

CONCLUSIONS

The present architecture of the Canadian Cordillera is the product of an evolution that spans an interval of about 1.7 Ga. The dominant elements of structure, metamorphism, plutonism and volcanism, however, are mainly the result of Mesozoic to Recent tectonism. Much of the orogen's complexity can be attributed to the widely disparate origins

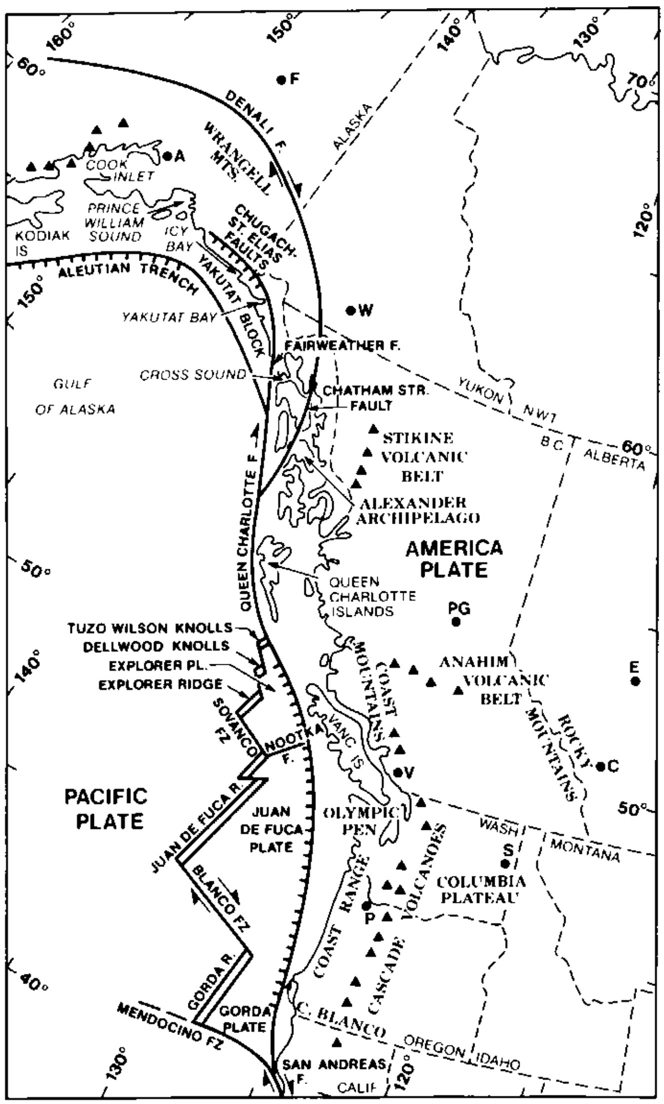


Figure 9 *Modern plate tectonic regime of the northeast Pacific.*

of the distinct component terranes and the timing and dynamics of their accretion to the continent. Although the general characteristics of the volcanic-arc and oceanic terranes are known, the internal tectonic history of many are poorly understood. For example, the age and spatial relationships of volcanic island arcs that dominated the evolution of Stikinia throughout the late Paleozoic and early Mesozoic eras require much study. Almost nothing is known about the basement of Stikinia although initial strontium ratios suggest a crust less evolved than that of ancestral North America. The extent of depositional basins within the small terranes in the southern Coast Belt and their interrelations, if any, have only recently become topics for detailed study. Similarly, the problems of movements between the displaced terranes and ancestral North America are now being addressed with the realization that paleogeographic restorations of the Cordilleran region must account not only for contractional deformation, but for important and very large transcurrent displacements.

In conclusion, despite its complexity, the Canadian Cordilleran Orogen contains remarkably well-exposed and preserved examples of many tectonic elements that contribute to the development of the Earth's crust. These include assemblages representative of passive margins, volcanic and plutonic island arcs, ocean basins and foredeeps all involved variously in contractional, extensional and strike-slip deformation. The oceanic spreading centres and a host of related phenomena including the Cascadia subduction zone are among the world's most accessible and have great potential for studies of plate-tectonic processes and metallogenesis. The scope for detailed investigations of these subjects is exciting and unlimited.

Acknowledgements
The writers express their gratitude to P.J. Coney, S.J. Jenness and B.D. Bornhold for their critical assessment of this and earlier versions of the manuscript. In particular they thank the many contributors to the Cordilleran volume, without whose support it would not have been written.

References

Aleinikoff, J.N., Foster, H.L., Nokelberg, W.J. and Dusel-Bacon, C., 1984, Isotopic evidence from detrital zircons for Early Proterozoic crustal material, east-central Alaska, *in* Coonrad, W.L. and Elliott, R.L., eds., The United States Geological Survey in Alaska: Accomplishments during 1981: United States Geological Survey, Circular 868, p. 43-45.

Archibald, D.A., Glover, J.K., Price, R.A., Farrar, E. and Carmichael, D.M., 1983, Geochronology and tectonic implications of magmatism and metamorphism, southern Kootenay Arc and neighbouring regions, southeastern British Columbia. Part I: Jurassic to mid-Cretaceous: Canadian Journal of Earth Sciences, v. 20, p. 1891-1913.

Armstrong, R.L., 1988, Mesozoic and Early Cenozoic magmatic evolution of the Canadian Cordillera: Rogers Symposium Volume.

Bond, G.C., Christie-Blick, N., Kominz, M.A. and Devlin, W.J., 1985, An early Cambrian rift to post-rift transition in the Cordillera of western North America: Nature, v. 315, p. 742-745.

Brew, D.A. and Ford A.B., 1978, Megalineament in southeastern Alaska marks southwest edge of Coast Range batholithic complex: Canadian Journal of Earth Sciences, v. 15, p. 1763-1772.

Brown, R.L., Journeay, J.M., Lane, L.S., Murphy, D.C. and Rees, C.J., 1986, Obduction, backfolding and piggy back thrusting in the metamorphic hinterland of the southeastern Canadian Cordillera: Journal of Structural Geology, v. 8, p. 255-268.

Coney, P.J., Jones, D.L. and Monger, J.W.H., 1980, Cordilleran suspect terranes: Nature, v. 288, p. 329-333.

Eisbacher, G.H., 1985, Late Proterozoic rifting, glacial sedimentation and sedimentary cycles in the light of Windermere deposition, western Canada: Palaeogeography, Palaeoclimatology and Palaeoecology, v. 51, p. 231-254.

Engebretson, D.C., 1982, Relative motions between oceanic and continental plates in the Pacific Basin, unpublished PhD thesis, Stanford University, 211 p.

Evenchick, C.A., 1986, Stratigraphy, metamorphism, structure and their tectonic implications in the Sifton and Deserters ranges, Cassiar and northern Rocky Mountains, northern British Columbia, unpublished PhD thesis, Queen's University, Kingston, Ontario, 197 p.

Gabrielse, H., 1985, Major dextral transcurrent displacements along the northern Rocky Mountain Trench and related lineaments in north central British Columbia: Geological Society of America, Bulletin, v. 96, p. 1-14.

Gabrielse, H., Loveridge, W.D., Sullivan, R.W. and Stevens, R.D., 1982, U-Pb measurements on zircon indicate middle Paleozoic plutonism in the Omineca Crystalline Belt, north-central British Columbia: Geological Survey of Canada, Paper 82-1C, p. 139-146.

Gardner, M.C., Bergman, S.C., Cushing, G.W., MacKevett, E.M. Jr., Plafker, G., Campbell, R.B., Dodds, C.J., McClelland, W.C. and Mueller, P.A., 1988, Pennsylvanian pluton stitching of Wrangellia and the Alexander Terrane, Wrangell Mountains, Alaska: Geology, v. 16, p. 967-971.

Grow, G.A., 1981, Structure of the Atlantic margin of the United States, *in* Geology of Passive Continental Margins: American Association of Petroleum Geologists, Education Course Note Series No. 19, p. 3-1–3-41.

Halgedahl, S. and Jarrard, R., in press, Paleomagnetism of the Kuparuk River Formation from oriented drill core: Evidence for rotation of the North Slope block, *in* Tailleur, I.L. and Weimer, P., eds., Alaskan North Slope Geology: Society of Economic Paleontologists and Mineralogists, Pacific Section.

Harms, T.A., 1986, Structural and tectonic analysis of the Sylvester Allochthon, northeastern British Columbia: Implications for paleogeography and accretion, unpublished PhD thesis, University of Arizona, 80 p.

Klepacki, D.W. and Wheeler, J.O., 1985, Stratigraphic and structural relations of the Milford, Kaslo and Slocan groups, Goat Range, Lardeau and Nelson map-areas, British Columbia: Geological Survey of Canada, Paper 85-1A, p. 277-286.

Lawver, L.A. and Scotese, C.R., in press, A review of tectonic models for the evolution of the Canada Basin, *in* Grantz, A., Johnson, G.L. and Sweeney, J.F., eds., The Arctic Region: Geological Society of America, The Geology of North America, v. E.

Mansy, J.L., 1986, Géologie de la Chaine d'Omineca des Rocheuses aux Plateaux Interieurs (Cordillere Canadienne), son evolution depuis le Precambrien, unpublished Doctorat d'Etat des Sciences Naturelle, University of Lille, France, 718 p.

Parrish, R.R., 1979, Geochronology and tectonics of the northern Wolverine Complex, British Columbia: Canadian Journal of Earth Sciences, v. 16, p. 1428-1438.

Parrish, R.R., 1982, Cenozoic thermal and tectonic history of the Coast Mountains of British Columbia as revealed by fission track and geological data and quantitative thermal models, unpublished PhD thesis, University of British Columbia, Vancouver, 166 p.

Percival, J.A. and Card, K.D., 1983, Archean crust as revealed in the Kapuskasing uplift, Superior province, Canada: Geology, v. 11, p. 323-326.

Pigage, L.C., 1978, Metamorphism and deformation on the northeast margin of the Shuswap Metamorphic Complex, Azure Lake, British Columbia, unpublished PhD thesis, University of British Columbia, Vancouver, 289 p.

Price, R.A., 1986, The southeastern Canadian Cordillera: thrust faulting, tectonic wedging and delamination of the lithosphere: Journal of Structural Geology, v. 8, p. 239-254.

Simony, P.S., Ghent, E.D., Craw, D., Mitchell, W., and Robbins, D.B., 1980, Structural and metamorphic evolution of northeast flank of Shuswap complex, southern Canoe River area, British Columbia, *in* Crittenden, M.D., Jr., Coney, P.J. and Davis, G.H., eds., Cordilleran Metamorphic Core Complexes: Geological Society of America, Memoir 153, p. 445-461.

Struik, L.C and Orchard, M.J., 1985, Later Paleozoic conodonts from ribbon chert delineate imbricate thrusts within the Antler Formation of the Slide Mountain Terrane, central British Columbia: Geology, v. 13, p. 794-798.

Tempelman Kluit, D.J and Parkinson, D., 1986, Evolution of late Proterozoic to early Paleozoic Adelaide foldbelt, Australia: Comparisons with post-Permian rifts and passive margins: Tectonophysics, v. 70, p. 115-134.

Tipper, H.W., Woodsworth, G.J. and Gabrielse, H., 1981, Tectonic Assemblage Map of the Canadian Cordillera: Geological Survey of Canada, Map 1505A.

Woodsworth, G.J., Crawford, M.L. and Hollister, L.S., 1983, Metamorphism and structure of the Coast Plutonic Complex and adjacent belts, Prince Rupert and Terrace areas, British Columbia: Geological Association of Canada, Mineralogical Association of Canada and Canadian Geophysical Union, 1983 Annual Meeting, Victoria, B.C., Field Trip No. 14, 41 p.

Accepted 11 April 1989.