# Accreted Terranes of the North Cascades Range, Washington

**Spokane to Seattle, Washington**
**July 21–29, 1989**

**Field Trip Guidebook T307**

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COVER Skagit orthogneiss exposed in Northern Picket Range. View SW from Luna Peak.

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**ACCRETED TERRANES OF THE NORTH CASCADES RANGE, WASHINGTON**

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TABLE OF CONTENTS



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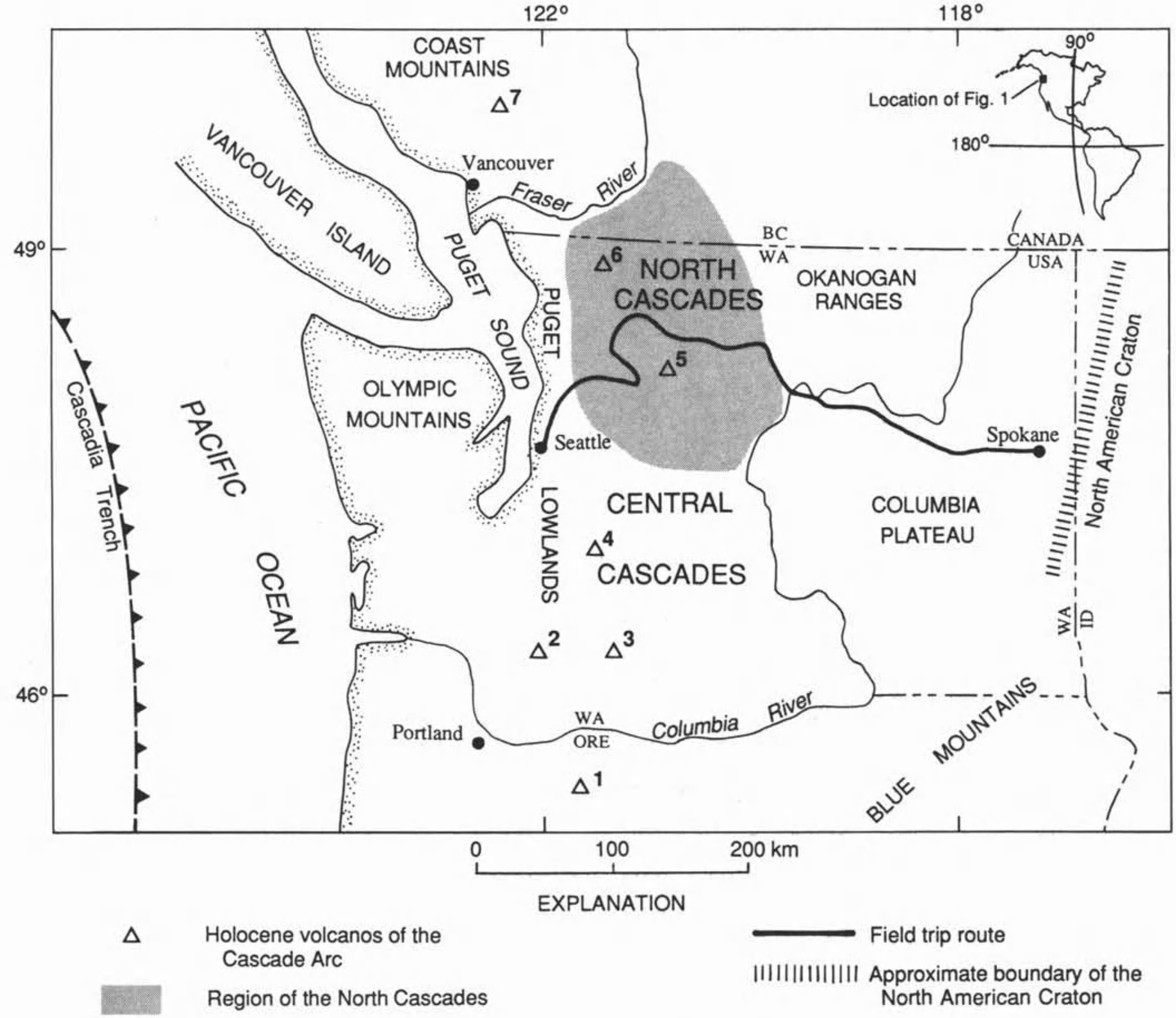


FIGURE 1. General location of the North Cascades Range and route of the field trip. Volcanoes of the Cascade Arc include: 1-Mt Hood, 2-Mt St Helens, 3-Mt Adams, 4-Mt Rainier, 5-Glacier Peak, 6-Mt Baker, and 7-Mt Garibaldi.

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## OVERVIEW OF THE GEOLOGY OF THE NORTH CASCADES

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### INTRODUCTION

The Cascade Range is an active north-trending volcanic arc at the western edge of North America (Figure 1). At the northern end of the range, between 47°N and 49°N, the average elevation increases, peaks become sharper, numerous small glaciers survive on the higher slopes, and volcanic rocks of the Cascade arc are scarce. This region is the North Cascades Range. The North Cascades are bounded on the west by the fore-arc basin of the Puget Lowland, on the south by the arc volcanic rocks of the Central Cascades, and on the southeast by the back-arc flood basalts of the Columbia Plateau. The geologic identity of the range is not so clearly defined to the north, but it is geographically bounded on the northeast by the Okanogan Ranges and on the northwest by the Fraser River, which separates the Cascades from the Coast Mountains.

The geology of the North Cascades strongly reflects processes of terrane accretion and dispersion at the western edge of the Cordilleran orogen. The range is remarkable for the number of apparently distinct tectonostratigraphic terranes exposed in a small region and the extent to which rocks of these terranes are involved in Cordilleran orogeny. This field trip traverses the range from E to W, viewing as many terranes as possible in the allotted time, and examining the evidence for terrane accretion and dispersion and the deformation, plutonism, and metamorphism that here constitute Cordilleran orogeny.

We intend this guide to be an introduction to the pre-Oligocene geology of the range, as well as a handbook to the stops of the field trip itself. Other works on the geology of the North Cascades and surroundings are cited below as appropriate. For brief geologic overviews of the range we especially recommend Misch [1988], Babcock and Misch [1988], Brown [1988], and the short synthesis of north-Cordilleran accretion by Monger and others [1982]. More detailed accounts of North Cascades geology by Misch [1966] and McTaggart [1970] predate the realization that parts of the range may be exotic; Davis and others [1978] and Hamilton [1978] briefly discuss the range from more mobilistic perspectives.

Our interpretations span much (though not all) of the range of opinion amongst workers in the range. In this guide we try to preserve some of this invigorating diversity. Many of the interpretations presented below stem from ongoing mapping projects and will undoubtedly be modified in the course of further work.

#### Acknowledgments

Many others have helped us in our studies, discussed Cascades geology with us, and kept us informed of their work. We are especially grateful to those geochronologists whose numbers grace the pages below: R. L. Armstrong, S. A. Bowring, J. S. Stacey, Peter van der Heyden, and J. A. Vance. Miller's work has been supported by NSF grant EAR-8707956. The text of this guide has been improved with the aid of careful reviews by F. K. Miller and R. E. Wells. Workers in North Cascades geology owe a special debt to the late Peter Misch, whose work forms the foundation of our present knowledge of the range. All of us were Peter's students.

### THE GEOLOGY OF THE NORTH CASCADES RANGE

The complex geology of the North Cascades results from superposition of at least four sets of phenomena. Bedrock largely consists of (I) several *pre-Late Cretaceous tectonostratigraphic terranes*. The time at which the terranes were accreted is not well defined, though most were involved in (II) *Late Cretaceous to Eocene(?) orogeny* that reflects significant crustal thickening within the North American continental margin. A poorly-understood (III) *Eocene event* has fragmented the Late Cretaceous orogen, and superimposed on all is (IV) the *Oligocene to Holocene Cascade magmatic arc*. The geology outlined below and described in the trip log is organized around these four headings.

The N-trending Straight Creek fault and several NW-trending fault zones divide the North Cascades Range into several tectonic blocks (Figure 2) within which strata, tectonic styles, and (or) facies of metamorphism are relatively coherent. Between most blocks there are substantial differences. We share the prejudice of most workers in the region that Late Cretaceous plutonism, metamorphism, and deformation tie the pre-Late Cretaceous terranes of the North Cascades together and that differences between the various blocks of Figure 2 reflect kilometer-scale to perhaps 100-kilometer-scale late-orogenic to post-orogenic displacement *within* this part of the Cordilleran orogen. However, we cannot satisfactorily restore most of the block-bounding faults. Displacements on the faults may be significantly greater and parts of the range could have been widely separated prior to the earliest Oligocene. Paleomagnetic studies of Late Cretaceous plutons in the North Cascades and the Coast Mountains to the north suggest that the western Cordilleran orogen as a whole is substantially allochthonous [Beck and others, 1981a, b; Irving and others, 1985].

Following the early work of Misch [1952, 1966], many workers have considered the North Cascades to be a complete two-sided orogen that could be understood in tectonic isolation. This tendency persists—indeed we are guilty of it in this guide—despite advances in our understanding of regional geology and orogenic dynamics. The reader should keep in mind that: (1) Many pre-Late Cretaceous terranes of the North Cascades may be parts of much larger units which can be recognized in northern California, in NE Oregon and W-central Idaho, and in western British Columbia and SE Alaska. (2) Similarities in timing of deformation, as well as the size of modern orogens, suggest that the North Cascades were but a small part of a much larger Cretaceous orogen that included most of the northern Cordillera, with its eastern limit in the Rocky Mountain foothills. (3) The Eocene event that modified the North Cascades was part of a regime of crustal extension in the core of the Cordilleran orogen, northward translation along the continental margin, and widespread magmatism and basin development that affected a region extending from the Pacific coast to the Rocky Mountains and from central Oregon to northern British Columbia.

**Present Topography and Glaciation**

Most summit elevations in the North Cascades range from 1800 to 2700 m, with intervening valleys not far above sea level. Most ridges and valleys trend NW-SE and reflect the structural grain of the underlying rock. Superimposed on this topography are Mt Baker and Glacier Peak, late Quaternary stratovolcanoes of the Cascade Arc (see Figure 8).

Uplift of the North Cascades is young. Near Wenatchee, Miocene flows of the Yakima Basalt Subgroup (of the Columbia River Basalt Group) are draped over the range (for example, Russell [1900]; Mackin and Cary [1965]; Tabor and others [1982a]). Westward thinning of Yakima flows along the east flank of the range, interbedded west-derived fluvial and lacustrine sediments, and deltas of Yakima basalt pillows produced by flow of lava into lakes ponded against the margin of the basalt field all point to some uplift prior to and during the middle Miocene. Uplift probably continues today, given the relief that characterizes much of the range.

Willis [1903] suggested that the concordant summits of the North Cascades outlined a dissected warped peneplain and that peneplanation postdated eruption of the Yakima Basalt Subgroup. The existence of a unique high surface has since been questioned [Waters, 1939]. A surface did develop during and after eruption of the Columbia River Basalt Group as streams responded to the temporary raising of local base level by the flood basalts [Waitt *in* Tabor and others, 1987a]. Remnants of this surface are readily identified adjacent to the lavas and in the Okanogan ranges to the east of the North Cascades, but in the high mountains subsequent glaciation has been so intense that relics of this surface have yet to be found.

Much of the mountainous scene traversed by the field trip owes its form to Pleistocene and, in the higher regions, Holocene glacial erosion. At the time of maximum growth of the Cordilleran ice sheet (about 15 ka) this region was all but covered with ice flowing south from Canada. In the mountains farther south, separate alpine glaciers had retreated prior to withdrawal of the Cordilleran ice in Puget Sound. West-side drainages were dammed by the Cordilleran ice, forming lake deposits, deltas, and moraine in valleys near the range front. For a summary and references, see Booth [1987].

The mountains strip moisture from the wet Pacific winds with remarkable efficiency. To the west, in the Puget Lowland, annual rainfall is a meter or less. As the winds rise over the western foothills, annual precipitation locally in excess of three meters waters one of the world's great forests. Old-growth douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) reached heights of 60 m, with trunks 2-4 m in diameter near the base. Logging, now waning because of overcutting and competition with cheaper lumber from lands of lower labor costs and less environmental protection, has long been the base of the regional economy. The forest hides much: natural outcrop is poor, cross-country travel is difficult, and most of the geologist's day is spent examining roadcuts along the net of logging roads that ensnares the western foothills.

Heavy winter snows in the heart of the range support the largest collection of glaciers in the United States outside of Alaska. Despite relatively warm average temperatures, snow-free ground can only be expected between July and October, and even during these months minor snowfall at higher elevations is likely. Outcrop varies from nonexistent to spectacular where recent deglaciation has exposed hectares of bedrock. Most of the center of the range is now dedicated wilderness managed by the National Park and National Forest Services: hikers and climbers are the major users. Within the past generation this region was summer home to the prospector, the sheepherder, and before them the aboriginal hunter. There has never been significant permanent settlement. Even now most access requires much walking (or a helicopter).

On the east slope annual precipitation drops to a half meter or less, ponderosa pine (*Pinus ponderosa*) becomes a dominant species in the forest, cross-country travel is easier, and outcrops are more abundant. The style of logging is different, reflecting smaller timber and a more open forest than on the west side. Run-off from the mountains has shaped more than the landscape: cheap hydroelectric power from the Columbia River (see figure 8) and river-irrigated apple, peach, and pear orchards are important to the local economy.

### (I) Pre-Late Cretaceous terranes

Going west across northern Washington, from the fringing miogeocline of stable North America, the traveler encounters a succession of tectonostratigraphic terranes (Figures 1, 2, 3).

The closest exposures of unremobilized **North American craton** lie far to the east, in the Laramide uplifts of the central Rockies. North of the 49th parallel, continental basement west of the Rocky Mountain trench has been recognized on seismic records. Overlying this basement are three sedimentary sequences: the thick (perhaps ~20 km) Middle Proterozoic Belt (Purcell in Canada) Supergroup, the Middle(?) and Late Proterozoic Windermere Group, thought to be rift-related, and the Cambrian to Jurassic Cordilleran miogeoclinal sequence. At the latitude of this trip the Phanerozoic miogeocline is not well preserved. Scattered pre-Tertiary outcrops near Spokane include metamorphosed Belt Supergroup, metamorphosed pre-Belt plutons, and abundant Mesozoic granitic rocks.

Westward from Spokane lies the Quesnel terrane, or **Quesnellia**, consisting largely of upper Paleozoic and Mesozoic arc and oceanic rocks which were accreted to North America in the Jurassic(?) [Monger and others, 1982]. Our route lies south of most exposures of these rocks. Though the western extent of Quesnellia is a matter for debate, we tentatively place its boundary at the Chewack-Pasayten fault (Figure 2). Plutons of the loosely-defined *Okanogan arc* intrude Upper Triassic arc strata at the western edge of Quesnellia. Correlative plutons north of 49°N are largely Late Jurassic and the complex seems to have cooled in the Early Cretaceous [Greig, 1988; Todd, 1987], unlike the Late Cretaceous and younger crystalline rocks of the North Cascades (cf. Davis and others [1978]).

**Pre-Late Cretaceous terranes east of the Straight Creek fault.** Mesozoic, mostly marine, sedimentary and minor volcanic strata constitute a coherent stratigraphic sequence which we include here in the **Methow terrane**. The rocks of this terrane form a NW-trending belt along the east edge of the North Cascades, between the Hozameen fault (including its probable southern extensions) and the Chewack-Pasayten fault. The margins of the depositional basin are not preserved: the Hozameen and Chewack-Pasayten faults appear to be younger and unrelated to Mesozoic sedimentation [Trexler and Bourgeois, 1985].

To the northwest, the belt is offset ~110 km to the north by the Straight Creek fault [Kleinspehn, 1985]. To the southeast, strata of the belt are in fault contact with the Leecher Metamorphics and Methow Gneiss of Barksdale [1948]. We include these metamorphic rocks in the Methow terrane, although their actual tectonic affinity is uncertain; they could be part of Quesnellia (but see **Stop 1-1**).

Aggregate thickness of the Mesozoic Methow section is on the order of 12 km or more [Barksdale, 1975; Coates, 1974] (Figures 3 and 4). The terrane is intruded by plutons of Late Jurassic, Cretaceous, and Eocene age [Tabor and others, 1968; Barksdale, 1975; Todd, 1987]. Many workers [e.g. Tennyson and Cole, 1978] have considered the marine sedimentary rocks to comprise a fore-arc or perhaps interarc sequence analogous to coeval parts of the Great Valley sequence of California; others [e.g. Kleinspehn, 1985] have characterized them as successor-basin deposits. Trexler and Bourgeois [1985] inferred an active strike-slip fault on the west margin of the basin during the mid-Cretaceous, based on facies patterns in sedimentary rocks of the Pasayten Group of Coates (1974) (see **Stops 2-1, 2-2**, and Figure 4).

A late Early Cretaceous change from a volcanic to a plutonic source for sandstone in the Jackass Mountain and Pasayten Groups (Figure 4) led Tennyson and Cole [1978] to infer that these strata record unroofing of the Okanogan arc (see Quesnellia, above) to the east. There is, at present, no other good evidence for a pre-Eocene link between the Methow terrane and Quesnellia. Volcanic rocks of the Upper Cretaceous Midnight Peak Formation of Barksdale [1948] (Kmm, map 1*) and coeval(?) plutons are similar in age to volcanic rocks which lie on Quesnellia to the northeast [Thorkelson, 1985]. This age similarity would suggest Late Cretaceous proximity, were it not that similar-age magmatic rocks are present throughout large parts of the Cordillera.

Poorly preserved Mesozoic radiolarians in chert pebbles from conglomerates of the Albian and Cenomanian Virginian Ridge Formation of Barksdale [1948] (Kms, map 1; equivalent to part of the Pasayten Group), as well as sparse greenstone pebbles [Trexler, 1985], suggest that the Hozameen Group (described below) or some other oceanic assemblage cropped out to the west during deposition of Virginian Ridge strata [Tennyson and Cole, 1978] (**Stop 2-1**).

The late Paleozoic to middle Mesozoic *Hozameen Group* of Cairnes [1944] constitutes the **Hozameen terrane** (MzPzh, map 4). It is composed of basaltic greenstone (metamorphosed pillow basalt, tuff, breccia, massive lava), chert, and argillite with minor amounts of limestone, gabbro, sandstone, and dacite(?) [McTaggart and Thompson, 1967; Haugerud, 1985; Ray, 1986].

On the northeast side, the Hozameen terrane is bounded by the Hozameen fault. On the southwest the Hozameen terrane is separated from the Skagit Gneiss of Misch (1966), in the Chelan Mountains terrane, by the Ross Lake fault zone and the intervening Little Jack terrane.

Permian radiolarians have been found in the Hozameen Group southeast of Jack Mountain (see Figure 9, map 4) [Tennyson and others, 1982], where the unit is mostly basalt with minor gabbro, chert, and limestone. In British

*Unit symbols and map numbers in parentheses refer to Figure 9.

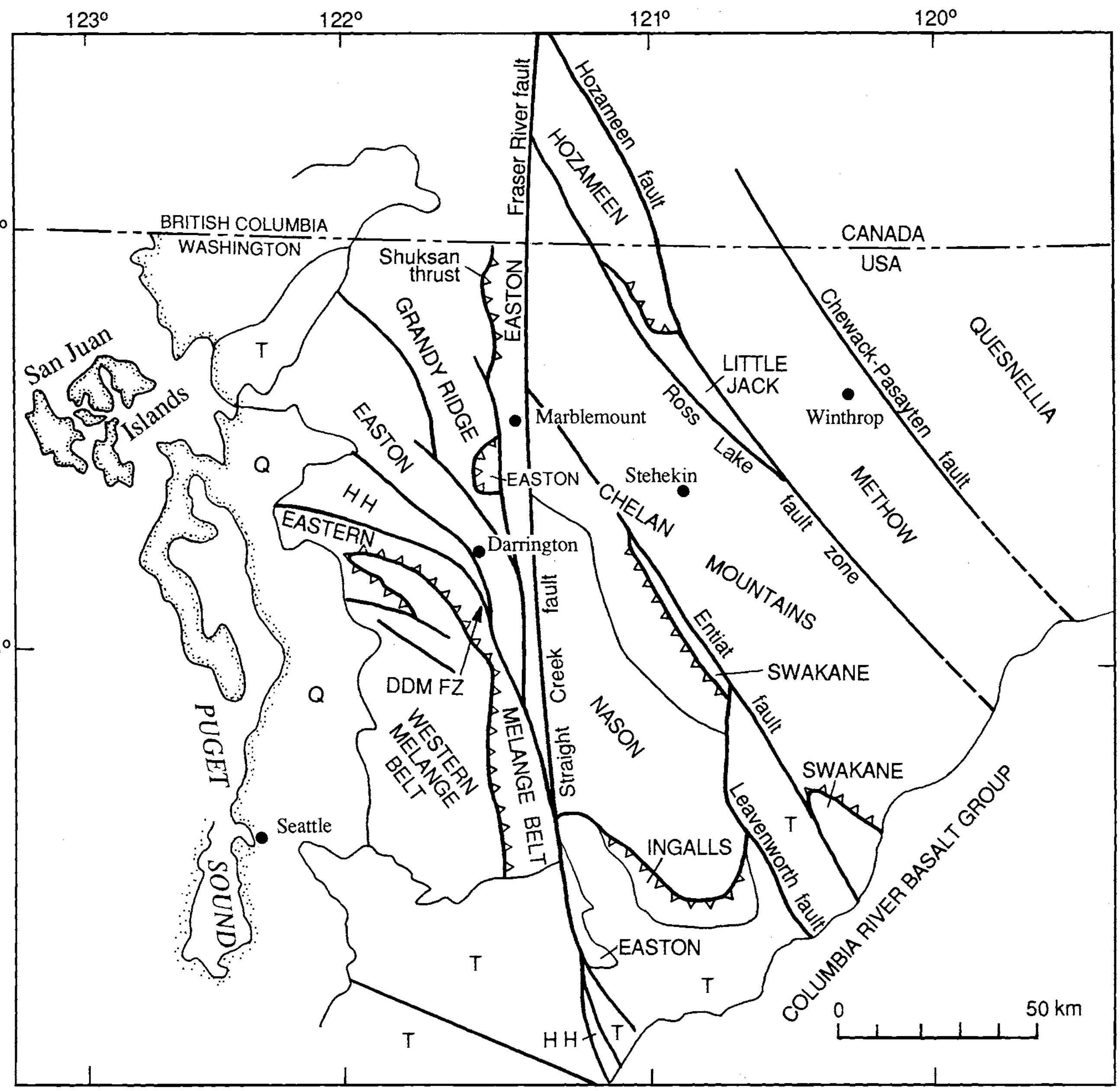


FIGURE 2. Sketch showing major terranes and faults. Q = unconsolidated deposits; T = Tertiary sedimentary and volcanic rocks; HH = Helena-Haystack melange.

Columbia, Middle and Late Triassic radiolarians have been identified in the Hozameen [Haugerud, 1985].

Ages, lithologies, and tectonic position demonstrate that the Hozameen Group is correlative with the Bridge River Complex of southern British Columbia. Correlation with other oceanic assemblages such as the Cache Creek Group of southern and central British Columbia, the Deadman Bay terrane of the San Juan Islands [Brandon and others, 1988] and parts of the Baker terrane of the Blue Mountains of northeast Oregon [Silberling and others, 1987] is attractive, though the Tethyan fusulinids distinctive of these terranes have not been found in the Hozameen.

The Twisp Valley Schist of Adams [1964] (TRct, map 1), here included in the Chelan Mountains terrane because of its similarity to other oceanic assemblages in that terrane, lies along strike to the SE of the Hozameen Group and may be its metamorphosed equivalent [Misch, 1966; Miller, 1987].

We lump together schists, phyllites, slates, and argillites and metavolcanic rocks of Misch's [1966] *Elija Ridge Schist, Jack Mountain Phyllite* and *North Creek Volcanics* as the **Little Jack terrane** (Mzlj, maps 1, 2, 4), named for exposures on Little Jack Mountain. All observed contacts of this provisional terrane with other strata are faults. To the southwest, the Ross Lake fault and intrusive rocks of the Ruby Creek area separate the Little Jack unit from the Skagit Gneiss and associated schist of the Chelan Mountains

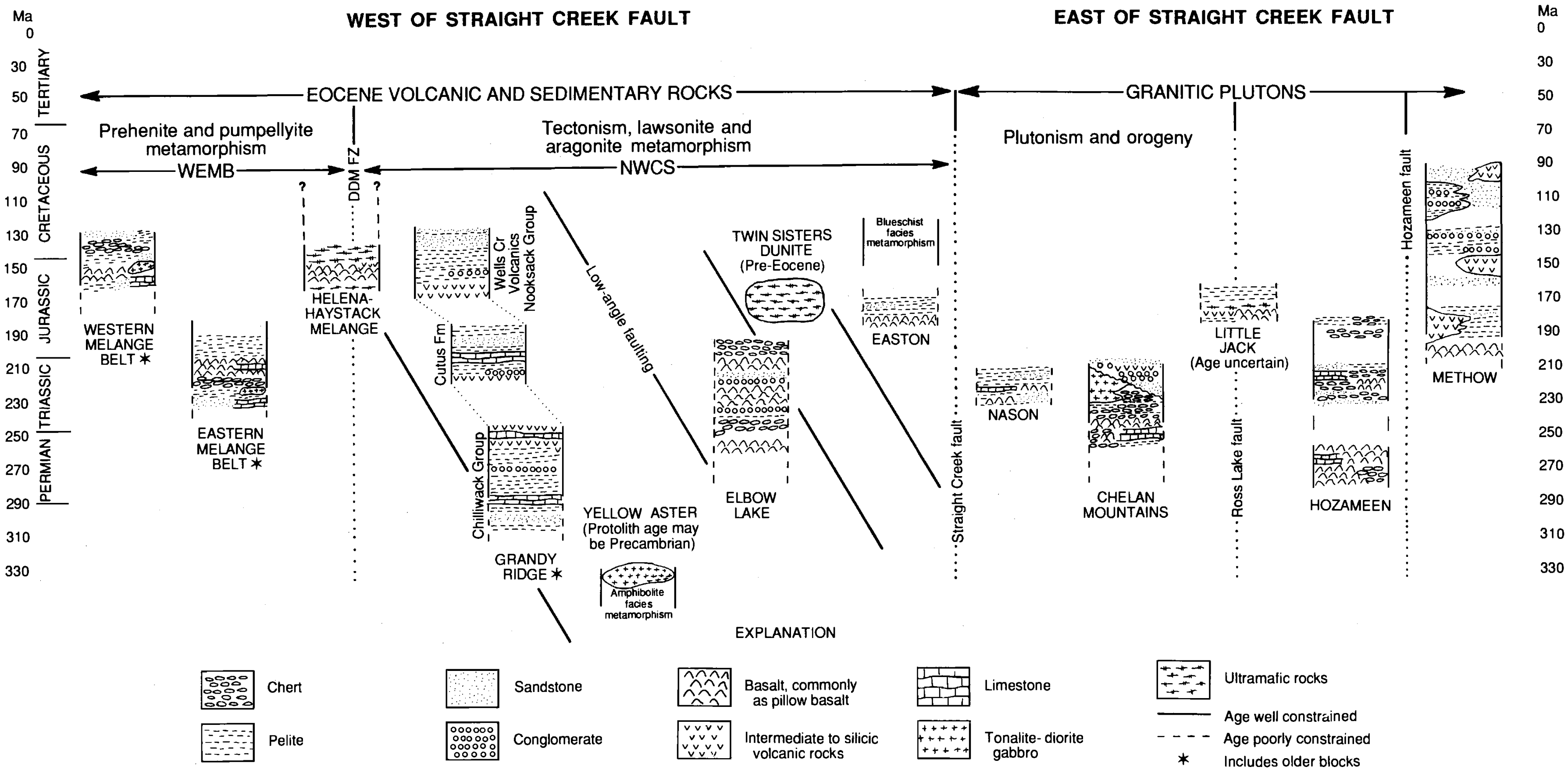


FIGURE 3. Summary of terrane protolith lithologies, approximate age ranges, and structural relationships. For sources of lithologic data see text. WEMB = western and eastern melange belts; DDMFZ = Darrington-Devils Mountain fault zone; NWCS = Northwest Cascades System.

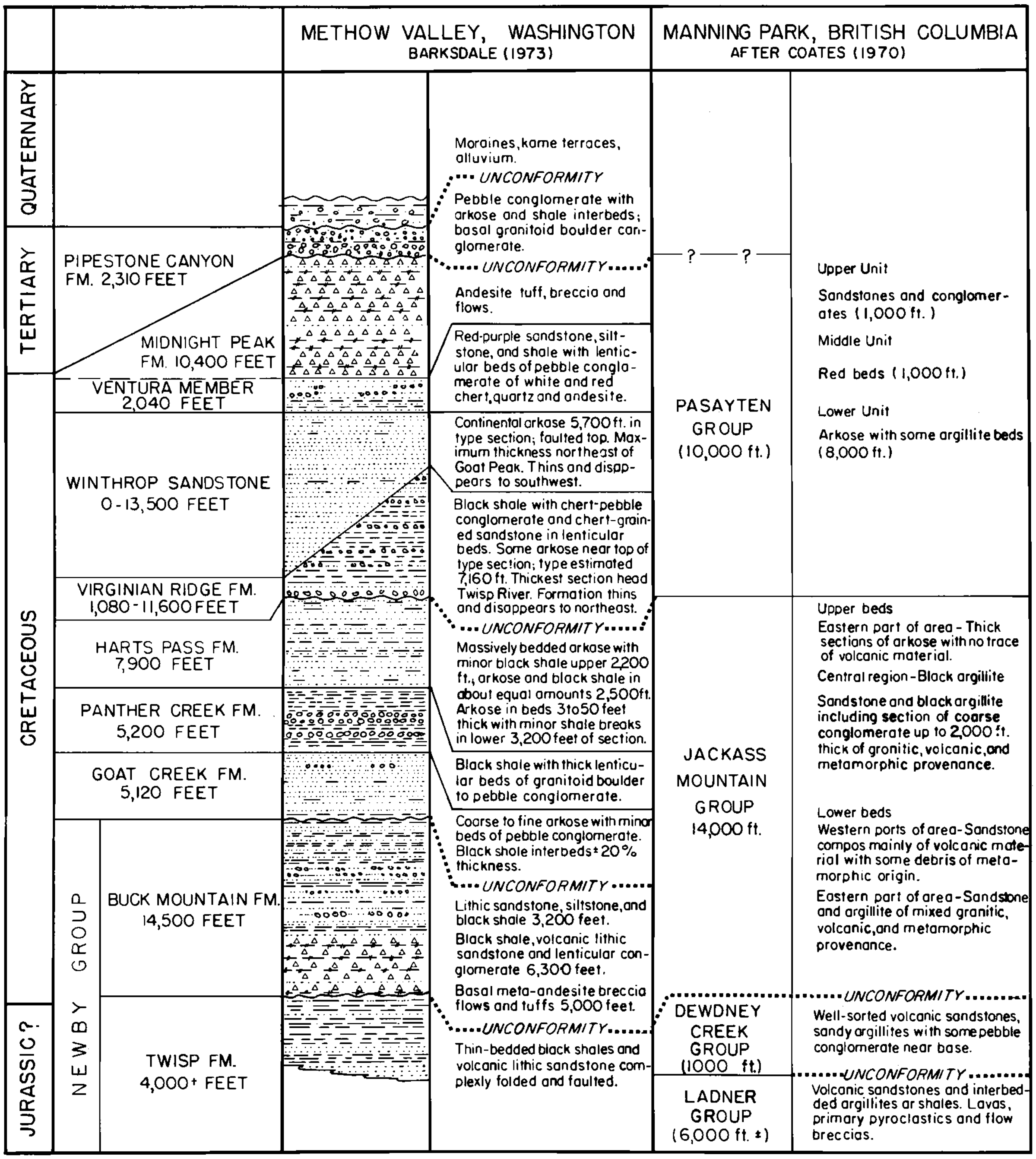


FIGURE 4. Correlation chart for units in the Methow terrane. After Barksdale [1975].