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MESOZOIC CONSTRUCTION OF THE CORDILLERAN "COLLAGE"
CENTRAL BRITISH COLUMBIA TO CENTRAL CALIFORNIA

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ABSTRACT

The western or "eugeosynclinal" portion of the Cordilleran orogen is a composite and accreted terrane--an orogenic "collage" to use a term coined by Helwig (1974). The Mesozoic "collage" was constructed across and against an Early to Middle Triassic continental margin of diverse type. This margin appears to have been essentially accretional in areas north of the Klamath Mountains. To the south, an accreted Paleozoic island arc and the continent itself had been subjected to faulting, possibly of left-lateral transform type, that produced a truncated, northwest-trending continental margin. In Middle Triassic to earliest Jurassic time this geologically diverse margin became the site of oblique(?) convergence and subduction of Pacific lithosphere along its entire length, as recorded by the development of a magmatic arc atop the western edge of the continent. Subsequently, areas north of 48° N. latitude and south of 44° had strikingly different Mesozoic histories. The northern region owes its greater breadth to the Mesozoic emplacement of two exotic, largely Paleozoic volcanic arcs--the Stikine block and "Wrangellia".

We do not regard the Northern Cascades of Washington as an exotic component of the Cordillera. Stratigraphic and geologic similarities between the Northern Cascades and the Okanogan terrane to the east suggest that the former is a continental margin assemblage of rocks shifted northwestward from an initial position south of, and in alignment with, the Okanogan region of north-central Washington. The dextral transcurrent faulting responsible for this shifting may have been related to the formation of a pull-apart oceanic re-entrant in the Mesozoic continental margin of what is now western Idaho. Pull-apart rifting can be tentatively dated as Late Jurassic and Early Cretaceous. Accretion of the exotic "Seven Devils" arc to this modified western Idaho segment of the continental margin must postdate the inferred rifting event.

We see no compelling evidence at the present time to postulate the existence in the southern Cordillera (Klamath Mountains, Sierra Nevada) of exotic Mesozoic arc terranes comparable to "Wrangellia" or the Stikine block. The Middle and Late Jurassic Klamath Mountains-Sierra Nevada can be interpreted as a single arc complex constructed across a previously sutured (Middle or Late Triassic to Early Jurassic) plate boundary between the North American continent and western oceanic rocks of "Calaveras"-type. Internal Jurassic disruption and imbrication of this arc by strike-slip and thrust faulting is believed to be an intraplate response to continued plate convergence to the west, and not a direct expression of the collision and accretion to the continent of multiple arc or remnant arc complexes foreign to North America.

INTRODUCTION

The pre-Laramide Cordillera of western North America consists of two principal stratigraphic elements--an eastern miogeoclinal sequence of sedimentary rocks deposited on a crust of sialic (continental) type, and a western "eugeosynclinal" accumulation in which rocks with oceanic and volcanic arc affinities are prominent. The miogeoclinal sequence can be traced for approximately 5000 km from the Arctic slope of Alaska to Sonora, Mexico, although physical continuity of the sequence is lost in west-central Idaho and southeastern California where cratonal basement and cover units abut the "eugeosynclinal" terrane directly (Fig. 1). Unlike the miogeocline, the "eugeosyncline" is noteworthy for its internal discontinuity and the extreme heterogeneity of its lithologic components. It is now widely accepted that the western Cordillera is a composite terrane consisting of both allochthonous and autochthonous elements--an orogenic "collage" to use a term coined by Helwig (1974). It is a terrane consisting of rock assemblages of different age and initial paleogeographic setting brought together by diverse tectonic processes along the evolving western edge of the North American continent.

This paper attempts to review the Mesozoic evolution of the Cordilleran accreted terrane, with the exception of the California Coast Ranges

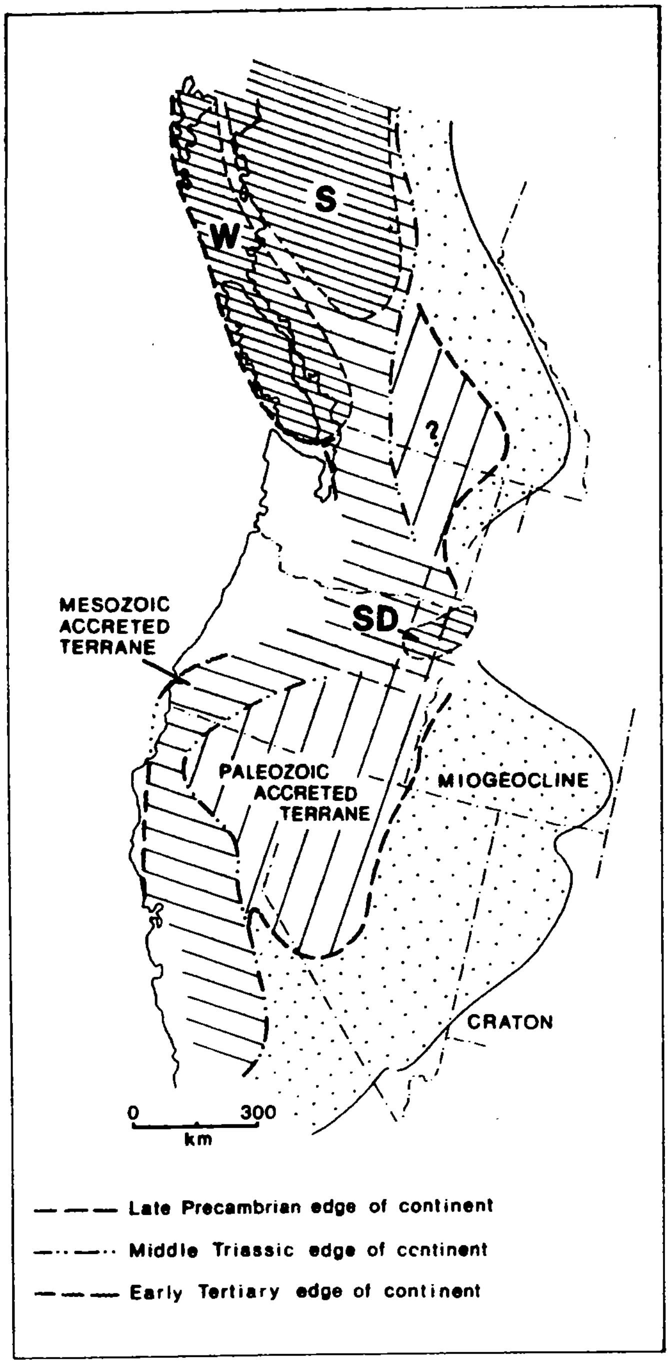

Figure 1. Major components of Cordilleran "collage". W = "Wrangellia"; S = Stikine arc; SD = "Seven Devils" arc.

with which the authors have no personal research familiarity. The paper builds, as all such papers must, on Warren Hamilton's perceptive analysis in 1969, of Cordilleran tectonics. Hamilton, whose companion paper appears in this volume, was perhaps the first to recognize the exotic nature of many of the components of the western Cordillera and to visualize the extreme mobility of tectonic processes responsible for their assembly. Although the emphasis in this volume is on the paleogeography of the western United States, our discussion treats portions of central and southern British Columbia in order that patterns of sedimentation, magmatism, and tectonics established there can be followed southward into the more complex areas of north-central Washington.

The Mesozoic is the time of much of the assembly of the Cordilleran "eugeosyncline" (Fig. 1), particularly in the Pacific Northwest (Oregon, Washington, and British Columbia). Evolutionary patterns south of latitude 44°N and north of latitude 48° appear to have been strikingly different, although the timing of some events along the entire length of the Cordillera is surprisingly similar. As can be seen in Figure 1, the Mesozoic accreted belt north of 48°N latitude is considerably wider than its continuation south of 44°. This difference in width largely represents the Mesozoic emplacement in British Columbia of two broad volcanic arc terranes that have no counterparts in southwestern Oregon and California. One, the "Stikine block" of northwestern British Columbia, was probably emplaced in the Late Triassic. The other, "Wrangellia" (Jones and others, 1977; Sicker-Skolai assemblage of Monger, 1977), lies near the present continental margin; it appears to have had a Cretaceous age of emplacement. These accreted arc terranes are now separated from each other and from rocks of the Mesozoic North American continent to the east by oceanic (ophiolitic) components of the Cordilleran "collage". Further south, e.g. California, broadly correlative ophiolitic assemblage were accreted to the continental margin, but without separation by major exotic arcs.

The migrating position of the evolving Mesozoic edge of western North America is most readily delineated by accreted belts of ophiolite and their associated supracrustal rocks, by the distribution of metamorphic rocks of blueschist facies, and by the position and duration of activity of continental margin magmatic arcs. Mesozoic ophiolitic assemblages incorporated into the Cordillera after the Permo-Triassic Sonoma orogeny are divisible into three broad "packages" or "belts" based on their times of emplacement. The oldest of the three was variably emplaced in the latter half of the Triassic. It consists mainly of Mississippian to Upper Triassic chert and argillite, carbonate containing a Permian Tethyan (verbeekinid) fusulinid fauna, greenstone and alpine-type ultramafic rock. Early Mesozoic sedimentary rocks have been recognized only recently as a constituent of this belt at a number of localities. The belt includes the Cache Creek Group of British Columbia, the Trafton Group of northwestern Washington, and, in Oregon, the Elkhorn Ridge Argillite, Burnt River Schist, Canyon Mountain Complex and related rocks. Paleozoic rocks of Cache Creek type may occur within the Klamath Mountains of northwestern California in the Ft. Jones-Yreka area (Fig. 2), and are present in the so-called "Calaveras Formation" of the western Sierra Nevada.

The second "package" was probably emplaced from Early(?) Jurassic through Late Jurassic time. It is lithologically similar to the older Cache Creek Group, but consists mainly of Upper Triassic to Middle Jurassic strata. Included blocks of older Cache Creek lithologies are enigmatically widespread. Representatives of this belt include the Bridge River and Hozameen Groups of British Columbia, possibly the Shuksan Greenschist of the Cascade Mountains and some rocks in the San Juan Islands, most rocks in the "western Triassic and Paleozoic" subprovince of the central Klamath Mountains, and presumably some components of the "Calaveras Formation" in the western

Sierra Nevada.

The third package, by far the best known, was emplaced in Cretaceous time and consists mainly of latest Jurassic and Cretaceous strata characterized by chert, argillite, and abundant graywacke. It includes the Franciscan complex of the California Coast Ranges, the Ingalls "ophiolite" and associated strata in central Washington, some units in the San Juan Islands, and the Pacific Rim Complex of western Vancouver Island.

The following discussion of western Cordilleran paleogeography is divided into four time intervals: (1) Late Paleozoic to Late Triassic; (2) Late Triassic and Early Jurassic (ca. 234-170 m.y.a., Armstrong, in press); (3) Middle Jurassic to mid-Cretaceous (ca. 170-96 m.y.a.); and (4) Late Cretaceous-Early Tertiary. Lithologic assemblages developed within or added to the accreting "eugeosyncline" within each time interval are briefly described and located on paleotectonic maps using the present geographic base.

LATE PALEOZOIC TO LATE TRIASSIC

The approximate position of the western margin of North America in pre-Late Triassic time is shown on Figure 1, although it should be emphasized that the deep, eastern embayment now seen between latitudes 42° and 48°N was either not present at the time or, more likely, was much less pronounced in form. Following the Permo-Triassic Sonoma orogeny, Late Paleozoic volcanic arcs lay inboard from the boundary in areas north and south of the embayment. The existence of a comparable arc in the area of what is now eastern Oregon and westernmost Idaho is uncertain. Hamilton (1976) has suggested that the presence of Precambrian cratonal basement rocks directly east of the outlined embayment is the consequence of local, Late Paleozoic rifting. Conversely, we believe it likely that a Paleozoic arc once lay west of the eastern end of the present embayment, but that it and younger adjacent and superjacent rock units were faulted away in mid-Mesozoic time. We agree with the observation of Hamilton and Myers (1966) that the Early Mesozoic continental margin in central and southern California cuts at a high angle across Late Paleozoic and earliest Mesozoic stratigraphic and tectonic trends with a northeast orientation. This relation is highly suggestive that the Permo-Triassic continental margin in this area was modified by northwest-trending, pre-Late Triassic faulting, proposed here to be of transform type.

British Columbia and Northern Washington

In south-central British Columbia and northern Washington a reasonable case can be made for locating the latest Paleozoic margin of western North America near the Okanagan Valley (119°30'W). From here to the east it is possible to establish some measure of Late Paleozoic stratigraphic continuity with "cratonic" North America (Fig. 3). Mississippian to Permian strata consisting of mafic to acidic volcanic, volcaniclastic, and sedimentary rocks probably grade eastwards into coeval sedimentary and volcanic rocks of the Milford and Kaslo Groups (Eastern assemblage of Monger, 1977).

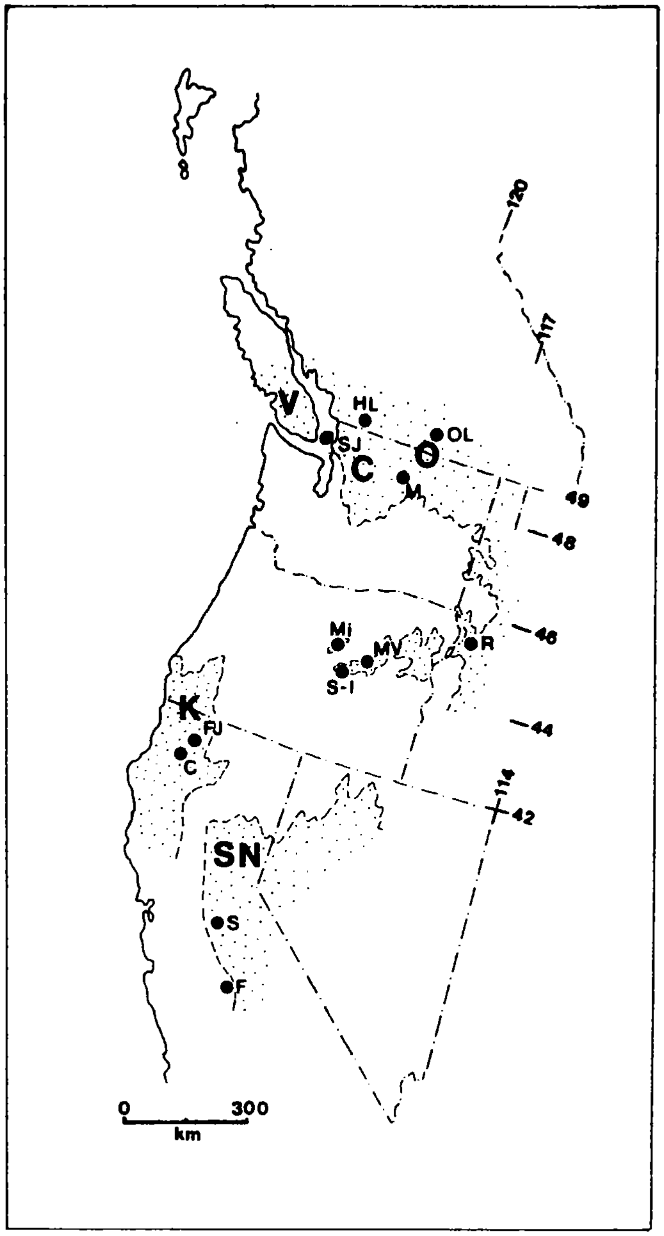

Figure 2. Location map of localities referred to in text. Stippled areas are areas of exposure of pre-Tertiary rocks. Areas (from north to south): V = Vancouver Island; C = Northern Cascade Mountains; O = Okanogan region (Okanagan in Canada); K = Klamath Mountains; SN = Sierra Nevada. Localities (from north to south): HL = Harrison Lake; SJ = San Juan Islands; OL = Okanagan Lake; M = Methow; Mi = Mitchell; R = Riggins; MV = Mount Vernon; S-I = Supplee-Izee area; FJ = Fort Jones; C = Callahan; S = Sonora; F = Fresno.

The western rocks, referred to informally as the Thompson assemblage (at the suggestion of A. V. Okulitch), comprise such units as the Mount Roberts Formation, Ararchist Group, Mission Argillite, Palmer Mountain Greenstone(?) and the (incorrectly named) "Cache Creek Group" near Kamloops and Vernon, British Columbia. There seems to be little doubt from the existence of fossiliferous tuffaceous rocks that the Thompson assemblage represents a volcanic arc that persisted at least from Early to mid-Permian time. Some Mesozoic plutons that intrude the assemblage have Sr^{87}/Sr^{86} initial ratios (>0.706) indicative of

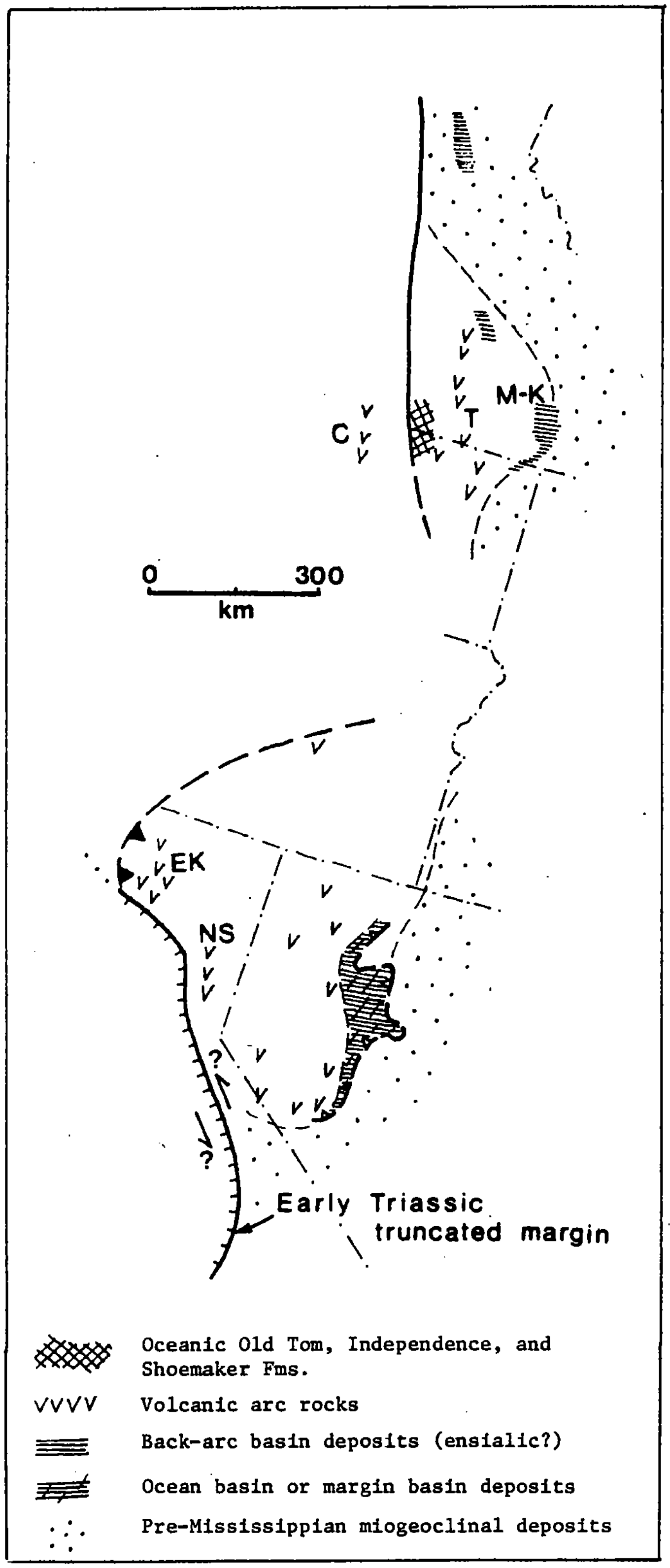

Figure 3. Distribution of Upper Paleozoic and lowest(?) Triassic rock assemblages. C = Chilliwack Group; T = Thompson assemblage; M-K = Milford and Kaslo Groups; EK = Eastern Klamath Mountains; NS = Northern Sierra Nevada.

a Precambrian continental basement for the arc (Armstrong and others, 1977; Petö and Armstrong, 1976). Precambrian crystalline rocks inferred to exist beneath the Okanogan terrane and known to underlie the Northern Cascades of Washington to the southwest lie west of the sedimentologically determined edge of the Precambrian North American plate and may have been tectonically accreted to that plate in early to middle Paleozoic time (Davis, 1977).

The Eastern assemblage comprises a lower, clastic-chert-carbonate sequence (Milford Group) and an upper, mafic volcanic-pyroclastic sequence intruded by basalt and serpentinite (Kaslo Group). It can be interpreted as an ensialic(?) basin marginal to the arc to the west. The Milford Group overlies unconformably a Paleozoic metamorphic terrane of uncertain affinities (Lardeau Group) near 49°N, but farther north in British Columbia it appears to lie in normal stratigraphic succession on the Proterozoic to Devonian miogeocline. These relations suggest that the Thompson and Eastern assemblages are tied to "cratonic" North America and extend the earliest Mesozoic margin of the continent to the Okanagan Valley.

Chert, argillite, basalt, and ultramafic rocks of the upper Paleozoic Old Tom, Independence and Shoemaker Formations exposed west of the Thompson assemblage near longitude 120°W are thought by Okulitch and Peatfield (1977) to represent Late Paleozoic oceanic crust. Thus the probable late Paleozoic ocean-continental arc boundary can be drawn near 119°30'W. Near latitude 49°N both eastern arc and western oceanic facies were deformed, subjected to low-grade regional metamorphism, and overlain by Upper and locally Middle Triassic strata on a regionally extensive angular unconformity. Read and Okulitch (1977) equate the Permo-Triassic deformation responsible for this well-documented unconformity to the Sonoma Orogeny.

Rocks of the Cache Creek Group in southern British Columbia (Fig. 4) extend northward from latitude 50°30', 1300 km into the Yukon Territory (Monger, 1977). Until recently, all dated fossils were from shallow water carbonates. On this basis the group was thought to range in age from Early Mississippian to Late Permian. Recent preliminary identifications by E. Pessagno and D. L. Jones of radiolaria and conodonts from chert collected by W. Travers (in press) and J. Monger, demonstrate Pennsylvanian, Permian, Middle and Late Triassic ages, thus extending Cache Creek deposition well into the Early Mesozoic. On the basis of their generic and specific diversity, in contrast with other fusulinaceans, and their association with calacreous algae and reefoidal buildups, the verbeekinid fusulinaceans so common in Permian strata of the Cache Creek Group have been regarded as tropical forms (Gobbett, 1967; Danner, 1976; Ross, 1976). On this basis in the Permian the Cache Creek Group was probably a part of the ancient Pacific Ocean floor lying well south of its future site of emplacement into Mesozoic North America.

Paleozoic strata on the west side of the Northern Cascades of Washington show some similarities to those in the Okanagan (spelled "Okanogan" in Washington) region of southern British Columbia farther to the northeast (Fig. 2). The Chilliwack

Group, on the west side of the Cascades, was an arc in the Early Permian (Monger, 1977). It has been correlated with rocks of the Thompson assemblage near Kamloops, British Columbia, on the basis of general lithological and paleontological likenesses (Sada and Danner, 1976). At latitude 50°30'N, the Cache Creek Group lies west of the Thompson assemblage. Similarly at 48°30'N, the Tethyan Trafton Group, in part lithologically and paleontologically similar to the Cache Creek Group (Danner, 1977), lies west of Chilliwack rocks. Structural relations between the similar and adjacent Cascade and Okanagan terranes are discussed in a later section of this paper.

Northeastern Oregon - Western Idaho

The western boundary of rocks that clearly were part of Paleozoic North America is more sharply defined in western Idaho than anywhere else. Proterozoic basement rocks and overlying Beltian(?) strata are in fault contact with "eugeosynclinal" strata to the west (Fig. 1). The boundary between Sr^{87}/Sr^{86} initial rations >0.706 (to the east) and <0.704 (to the west) is sharp and trends roughly north-south (Armstrong and others, 1977; Kistler, this volume). Three distinctive Late Paleozoic and Early Mesozoic sedimentary and volcanic assemblages lie west of this important tectonic boundary. Although analogs of each can be found in Washington and British Columbia, the lithic assemblages in eastern Oregon and westernmost Idaho trend roughly east-northeast. They appear to have been rotated clockwise as much as 120° with respect to their northern counterparts.

The southernmost of the three assemblages is recognized only in east-central Oregon. It includes unnamed Middle Devonian strata, the Coffee Creek (Mississippian), Spotted Ridge (Pennsylvanian), and Coyote Butte (Permian) formations of Merriam and Berthiaume (1943). Near Suplee (Figs. 2, 3) the Paleozoic section consists of felsite, limestone, chert, and volcaniclastic sedimentary rocks in apparent decreasing order of abundance (Dickinson and Vigrass, 1965). These formations appear to be similar lithologically and faunally to the Chilliwack Group to the north and, perhaps, to upper Paleozoic rocks in the eastern Klamath Mountains to the southwest. Dickinson (1976; written communication, 1978) now believes that the Paleozoic rocks are intermixed with early Mesozoic cherts and constitute large blocks in a melange. Nevertheless, it seems reasonable to us that they are indicative of the former existence very near the Suplee-Izee area of a Late Paleozoic volcanic arc.

North of this postulated arc terrane and extending from central Oregon into westernmost Idaho lies a group of marine rock units including widespread melange and/or olistostromal deposits. Sedimentary rocks of the marine assemblage (Elkhorn Ridge Argillite, Burnt River Schist, Fig. 4) are thought to have initially been deposited on an ophiolitic basement of Late Paleozoic age such as that seen in the allochthonous Canyon Mountain

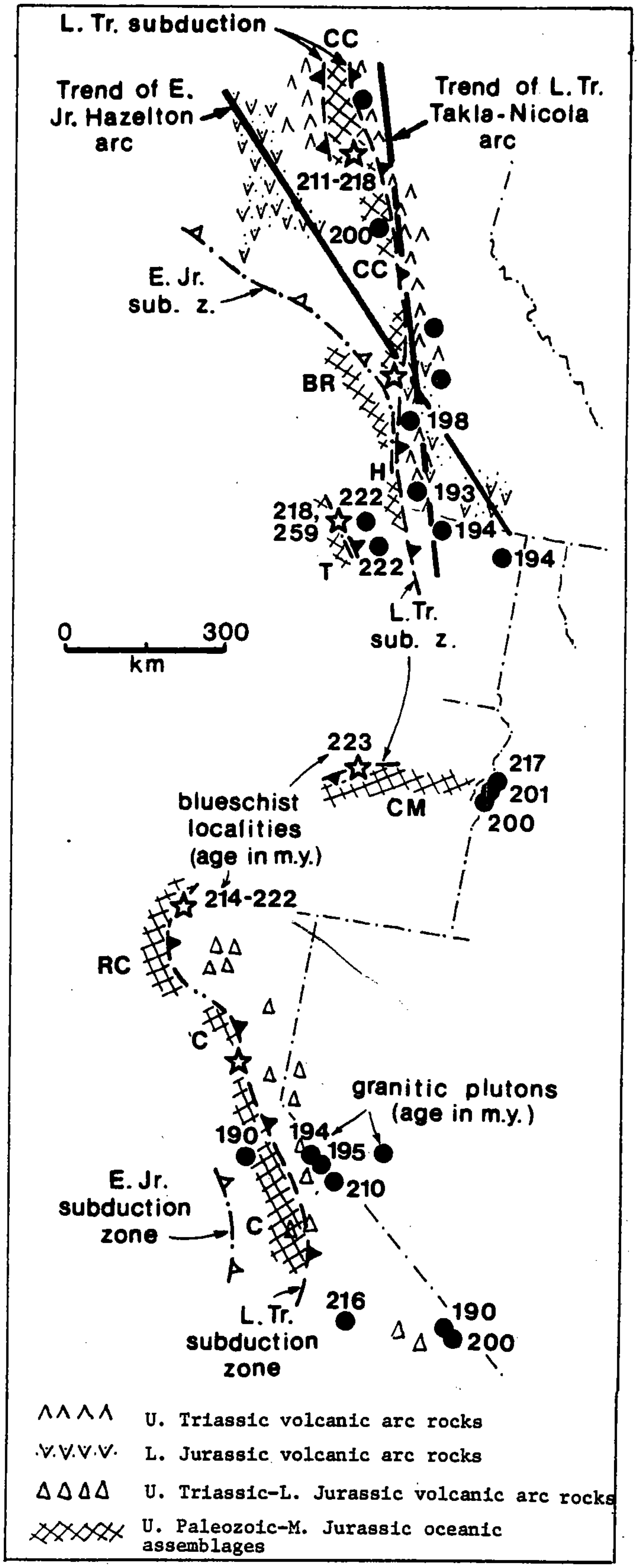

Figure 4 (to right). Distribution of Upper Triassic and Early Jurassic rock assemblages and major tectonic elements. CC = Cache Creek Group; BR = Bridge River Group; H = Hozameen Group; T = Trafton Group; CM = Canyon Mountain, Burnt River, and Elkhorn Ridge units; RC = Rattlesnake Creek and Hayfork-North Fork terranes; C = "Calaveras" Fm.

Complex (Vallier and others, 1977). Both lithologically (Monger, 1975) and paleontologically--in its Permian verbeekinid (Tethyan) fusulinid fauna (Bostwick and Nestell, 1967) and its Middle Triassic radiolarian fauna (Jones and Pessagno as referenced in Vallier and others, 1977)--this oceanic assemblage closely resembles parts of the Cache Creek Group of south-central British Columbia. Deformed rocks of both the arc and the oceanic assemblages in central Oregon are unconformably overlain by Late Triassic clastic strata, including the early(?) Karnian Begg Formation (Dickinson and Vigrass, 1965) and the late Karnian Vester Formation (Vallier and others, 1977). By Late Triassic time the edge of the North American continent in central Oregon must have been located outboard of the deformed oceanic assemblage (Figs. 1, 4).

In northeastern Oregon lies a third, largely volcanic assemblage believed to represent a second, more external volcanic arc than that described above for the central Oregon region. It includes (Vallier and others, 1977) the mafic volcanic and volcaniclastic Seven Devils Group (Upper Permian, Middle and Upper Triassic), the carbonate Martin Bridge Formation (Upper Triassic), and the argillite-carbonate Hurwal Formation (Upper Triassic-Lower Jurassic). According to Jones and others (1977) this stratigraphic sequence closely resembles coeval strata exposed on Vancouver Island, although the two sequences cannot now be physically contiguous. Although this arc assemblage may now be in direct tectonic contact with the Proterozoic rocks of west-central Idaho, it is not discussed further here because its incorporation into the Cordilleran "collage" is a younger, possibly Cretaceous event.

Southwestern Oregon and California

Upper Paleozoic-Early Mesozoic Klamath-Sierran arc

The configuration of the western continental margin south of central Oregon was drastically changed in latest Permian or earliest Triassic time with the accretion to the continent of an areally extensive Paleozoic island arc (Burchfiel and Davis, 1972; Silberling, 1973) or arcs. The arc, now apparently represented by exposures of Paleozoic volcanic and sedimentary rocks in central Oregon, northwestern Nevada, the eastern Klamath Mountains and the northern Sierra Nevada (Fig. 3), lay offshore an unknown distance from the continent prior to its collision and accretion during the Sonoma orogeny (see Dickinson, 1977, for a review of possible collisional geometries). Boucot and Potter (1977) comment that some Ordovician, Devonian, and Permian faunal assemblages of the eastern Klamath Mountains have North American affinities, a relation that suggests relative proximity of the arc to the continent during its development.

With the accretion of the Paleozoic Klamath-Sierran arc by early Early Triassic time, the continental margin shifted abruptly westward from central Nevada to the western or outer side of the former island arc terrane (Fig. 3). Metavolcanic and metasedimentary rocks of the Klamath central metamorphic subprovince (Salmon Hornblende Schist and Grouse Ridge Formation) had previously been thrust (subducted) eastward beneath the eastern Klamath arc and its Trinity ophiolitic(?) basement in Devonian time (Burchfiel and Davis, 1972). Thus following arc-continent collision at the time of the Sonoma orogeny the outer edge of the arc (the new continental margin) lay somewhere west of presently exposed rocks of the central metamorphic subprovince. That outer margin is apparently not preserved in the Klamath Mountains.

In the eastern Klamath Mountains of northern California, sedimentary and volcanic rocks of Late Triassic (Karnian) and Middle Triassic age are described as lying in a conformable section above Late Permian and Early Triassic volcanic rocks (Dekkas Andesite, Bully Hill Rhyolite); the latter units, in turn, sit with only probable disconformity on sedimentary and volcanic rocks of Middle Permian age (Nosoni Formation). One can, therefore, infer essentially continuous magmatic activity in an eastern Klamath volcanic archipelago before, during, and after the Permo-Triassic orogeny in areas to the east. The tectonic accretion of the Paleozoic arc to the continent in Nevada did not apparently influence the volcanic history of the eastern Klamath subprovince. If the colliding arc and the Klamath-northern Sierran arc were one and the same, the continuity of volcanic activity in the Klamaths argues for eastward subduction of oceanic lithosphere beneath the Klamath arc from late Paleozoic into Jurassic time. Conversely, it argues against Speed's conclusion (1977) that a northern California-western Nevada island arc was underlain in Permo-Triassic time by a west-dipping subduction zone that died at the time of Early Triassic collision.

Burchfiel and Davis (1972, 1975) concluded that Permo-Triassic volcanic rocks in the eastern Klamath Mountains (Dekkas Andesite, Bully Hill Rhyolite) were the products of eastward subduction of oceanic lithosphere beneath the arc—a geometry of ocean-arc convergence inherited at least from Siluro(?)-Devonian time. They concluded (erroneously) that the probable expression of this convergence is the east-dipping Siskiyou thrust fault, which separates upper plate rocks of the central metamorphic subprovince from lower plate "western Paleozoic and Triassic" units. The Siskiyou thrust fault is now known, however, to be of Jurassic age on the basis of recent field studies (Ando and others, 1977) and the occurrence of Jurassic radiolaria in lower plate rocks of the North Fork terrane (Irwin and others, 1977).

At the present time no candidate structures compatible with east-directed Permo-Triassic subduction beneath the Klamath segment of the arc are known, but the western edge of the arc where such structures might have been present has apparently not been preserved. Late Paleozoic-early Mesozoic rocks of Cache Creek affinity that once lay outboard of the Paleozoic arc are probably present in the Ft. Jones-Yreka area of the east-central Klamath Mountains, but such rocks do not appear to be widespread in the Klamath region. In the Ft. Jones area a presently fault-bounded assemblage of chert, argillite, and mafic volcanic rocks was metamorphosed in Late Triassic time (214-222 m.y.a., K-Ar, blueschist facies, Hotz and others, 1977). It may, therefore, be older than lithologically similar rocks exposed to the south in the central Klamath Mountains that Irwin and others describe as having been deposited on an ophiolitic basement of Late Triassic age (North Fork terrane; Irwin and others, 1977). In this latter area exotic blocks of late Paleozoic carbonates, some containing a Tethyan fauna, are disconcertingly abundant in the Triassic-Jurassic chert-argillite sequence of the North Fork (Hayfork) terrane, but the "Cache Creek" source terrane for these blocks is not known. It can be argued that the amount of Jurassic telescoping of Klamath rocks along the overlying Siskiyou thrust fault is extreme, and that the missing Late Paleozoic oceanic assemblage (and adjacent trench?) at this latitude lies hidden at depth below the Siskiyou thrust plate. Alternatively, the former outer margin of the Permo-Triassic Klamath arc and rocks of the Pacific ocean basin adjacent to it may have been removed by the rifting or transform faulting that modified the early Mesozoic continental margin to the south.

Continental truncation (post-Sonoma orogeny)

The northwest-trending Early Mesozoic margin south of the Klamath Mountains (Fig. 1) appears not to coincide with the Late Paleozoic outer edge of the accreted Klamath-Sierran arc. In central and southern California this margin truncates at a high angle the southwestward projections of all Paleozoic depositional ("eugeosynclinal", miogeoclinal, cratonal) and tectonic (Antler, Sonoma) trends (Figs. 4, 5). This geometric relationship argues strongly for Early Mesozoic continental truncation by rifting or transform faulting as originally proposed by Hamilton and Myers (1966) and schematically represented by Burchfiel and Davis (1972, Fig. 7). Schweickert (1976) has analyzed this post-Sonoma truncational event, but the complex plate geometries he proposes for it are incompatible with Klamath Mountains geology and must be regarded as imaginative, but unsupportable. Devonian metamorphic rocks of the central metamorphic subprovince in the Klamath Mountains, contrary to Schweickert's correlation, have no lithologic similarity whatsoever to rocks of the Antler orogenic belt. They cannot, therefore, be equivalents of that belt offset to their present Klamath Mountains location by right-lateral, Early Mesozoic transform faulting. Nor can the Triassic and Jurassic oceanic assemblage of the Klamath "western Paleozoic and Triassic" subprovince be offset representatives of Late Paleozoic oceanic rocks (Havallah sequence) that originally lay east of the Klamath-Sierran arc (Irwin and others, 1977).

Schweickert (1976) proposed that the truncated continental margin is defined by the Melones fault zone of the western Sierra Nevada. although as discussed below we consider the Melones to be a younger fault unrelated to the truncating fault zone. Nevertheless, in the northwestern Sierra, Late Paleozoic (Devonian) volcanic rocks of the Klamath-Sierran arc and an older, metasedimentary basement (Shoo Fly Formation) lie directly east of the Melones fault (Fig. 5). To the west of the fault and bodies of ultramafic rock which are present along it, lies the "Calaveras Formation", a structurally disarrayed terrane of metacherts, phyllites, metavolcanic rocks, and serpentinized ultramafic rocks that Davis (1969) has correlated with lithologically similar rocks in the Klamath Mountains ("western Paleozoic and Triassic" subprovince). Here then, the Melones fault does lie between rocks of the Paleozoic Klamath-Sierran arc and a western assemblage of oceanic rocks that are probably at least in part of younger age.

Within the central Sierra Nevada, however, the boundary between pre-truncational rocks to the east and accreted rocks to the west is less clear. It certainly lies west of pendants in the eastern Sierran batholith (Log Cabin, Ritter Range, Mt. Morrison, and Bishop Creek) that can be correlated with Paleozoic terranes of western Nevada (Speed and Kistler, 1977). The margin does not, however, appear to be coincident with the Melones fault, since here "Calaveras" rocks lie east of that fault, not west (Fig. 5). Chert-argillite units of the "Calaveras Formation" on both sides of the fault contains limestone lenses that have yielded scarce Permo-Carboniferous fossils, including Permian Tethyan fusulinids (Schweickert and others, 1977). We suggest that all "Calaveras" rocks must lie west of the truncated continental margin, and that in the central Sierra Nevada that margin lay east of the Melones fault zone (which must be a younger, unrelated structure) in a region now occupied largely by the Sierran batholith (Fig. 5). The "Calaveras Formation" is, in our opinion, a composite assemblage of remnants of one or more oceanic terranes. Older portions of the "formation" were carried into a subduction zone along the truncated margin and accreted to it in Middle or Late Triassic time. This exotic oceanic assemblage includes the dismembered Kings-Kaweah ophiolite east of Fresno (Saleeby and others, this volume). It has been dated from plagiogranites as Late Paleozoic (250 to 300 m.y., U/Pb, Saleeby, in press), and it may have as a northern counterpart the Canyon Mountain ophiolite of east-central Oregon (from which hornblende pegmatites cutting gabbro give 240-250 m.y. ages, K-Ar, Vallier and others, 1977). The position of the line of truncation farther south is geologically even less definite, again in large part due to extensive Mesozoic plutonism. The plutons, however, themselves provide a clue to its location. Following Kistler and Peterman (1973), the west to east change in Sr^{87}/Sr^{86} initial ratios in granitic rocks of the batholith from <0.704 to >0.706 appears to delineate the eastern edge of the accreted "eugeosynclinal" terrane and the westernmost extent of Precambrian crystalline basement. The position of this isotopic boundary, and, hence, the line of Early Triassic truncation is shown on Figure 5. Early Paleozoic "eugeosynclinal" rocks that occur in the El Paso Mountains east of the boundary (and north of the Garlock fault) pose a problem to this interpretation. But, very similar rocks lie east of the 0.706 line in central Nevada as well—in the Roberts Mountain thrust plate. We postulate that tectonic slicing along a truncated margin of transform type can explain these relations. The allochthonous(?) Lower Paleozoic rocks and the Upper Paleozoic clastic wedge sedimentary rocks deposited on them (Poole, 1974) may occur within a fault-bounded sliver east of the main transform boundary (Fig. 5). Offset of units in the hypothesized sliver from their initial position east of the zone of truncation is left-lateral. Perhaps the Late Precambrian-Early Paleozoic miogeoclinal section of the Caborca area, Sonora, Mexico, lies within another sliver, for it too is "out of place" in a left-lateral sense with respect to strikingly similar rocks in the Death Valley area. This suggestion is in accord with an earlier hypothesis of Silver and Anderson (1974), although the Early to Middle Mesozoic left-lateral fault that they proposed crosses the central Mojave Desert and is not coincident with that shown in Figure 5. Van der Voo and others (1977) present geologic arguments pertaining to the Gulf of Mexico region that are supportive of Permo-Triassic sinistral fault displacement between the southwestern United States and Mexico. Specifically, they suggest that the truncated Antler orogenic belt may have been offset from southern California into mainland Mexico.

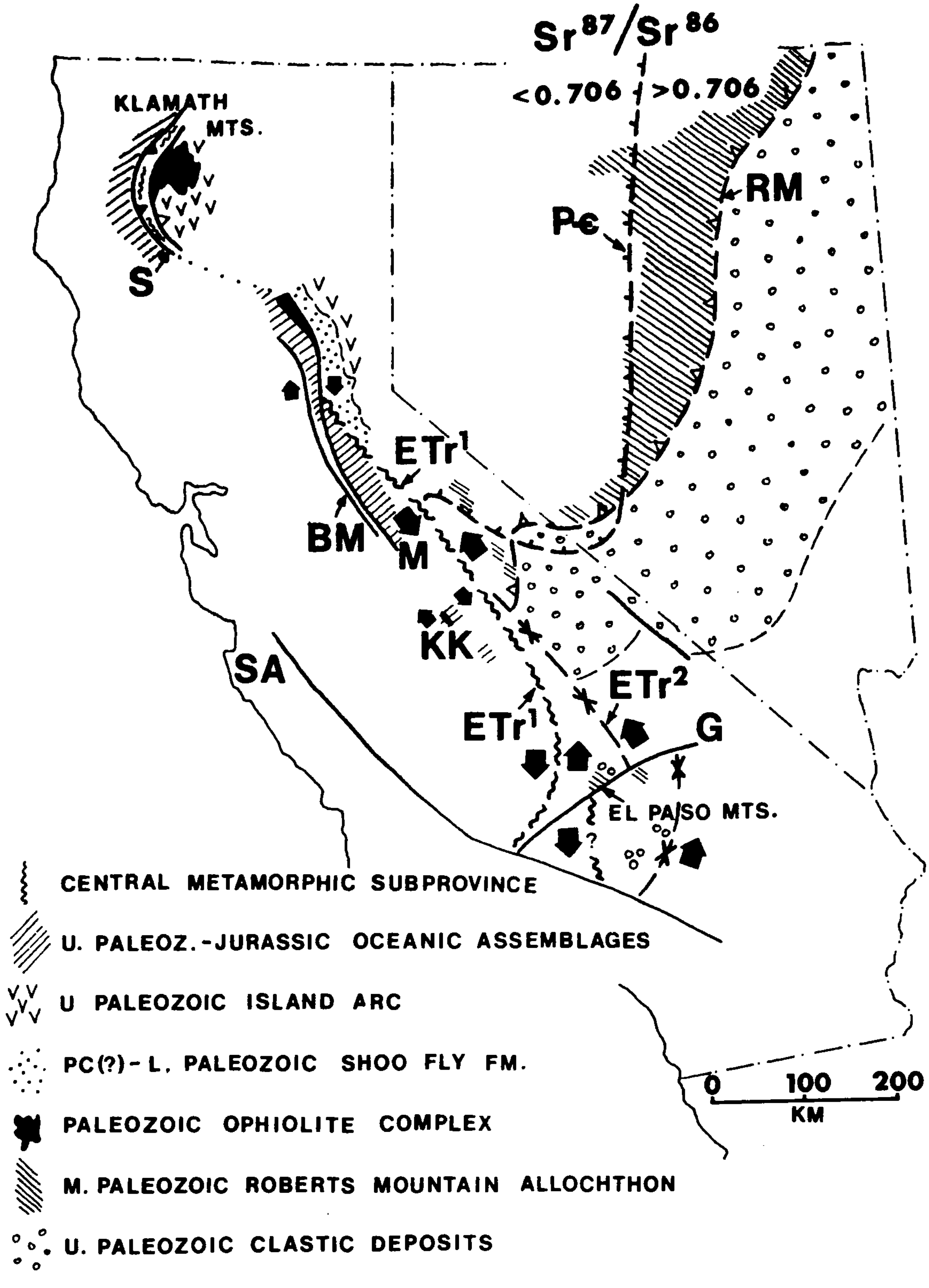

Figure 5. Geologic relations across line of Early Triassic continental truncation. ETr^1 = line of continental truncation and hypothesized transform fault with left-slip; ETr^2 = hypothesized inland fault related to ETr^1; Pє = western limit of Precambrian crystalline basement rocks; RM = Roberts Mountain thrust fault of Devono-Mississippian age; S = Siskiyou thrust fault; BM = Bear Mountains fault zone; M = Melones fault; KK = Kings-Kaweah area; SA = San Andreas fault; G = Garlock fault.

LATE TRIASSIC AND EARLY JURASSIC

As discussed above, different segments of the earliest Mesozoic continental margin of North America had different evolutionary histories. The margin appears to have been essentially accretional in areas north of the Klamath Mountains, but in southern areas an accreted Paleozoic arc and the continent itself had been subjected to faulting that produced a truncated continental margin, apparently of transform type. Beginning in Late Triassic time, however, this geologically diverse margin became the site of similar magmatic, sedimentary, and metamorphic phenomena along its entire length—the consequence of oblique(?) convergence and subduction of Pacific Ocean lithosphere beneath the continent (Hamilton, 1969; Monger and others, 1972; Burchfiel and Davis, 1972). Convergence is recorded by widespread arc magmatism with initial ages of ca. 220 to 195 m.y. (Late Triassic to Early Jurassic if the Triassic/Jurassic boundary is taken at 212 m.y.a., R. Armstrong, in press), and by equally widespread and coeval ages for rocks of blueschist facies that lie west of the arc in oceanic rock assemblages (Fig. 4). The western margin of the continent was largely submerged and the volcanic arc appeared as islands that supplied clastic detritus to adjacent basins. Marine basins that lay within or behind the arc were of epicontinental type. To the west of the volcanic archipelago lay a consuming trench, beyond which lay an ocean basin floored by upper Paleozoic and lower Mesozoic rocks of Cache Creek lithology. During the Late Triassic and Early Jurassic east-directed back-arc thrust faults formed in the southern Cordillera across miogeoclinal and cratonal terranes. These intraplate thrust faults were antithetic to contemporaneous eastward subduction of oceanic lithosphere beneath the western margin of the arc. With their development, the southern Cordillera, at least, acquired a "two-sided" geometry with respect to tectonic vergence (Burchfiel and Davis, 1968).

British Columbia and Washington

Upper Triassic and Jurassic strata are relatively rare in Washington east of the Northern Cascades. In Canada strata of this age are exposed in: (1) the Front Ranges and Foothills of the southern Canadian Rockies; (2) 150 km to the west (long. 117°30') near the southern end of the Shuswap Metamorphic Complex; and (3) 100 km farther west (long. 119°30') in the Okanagan area of southern British Columbia. In spite of the lack of physical continuity between the three areas of exposure a reasonably coherent paleogeographic picture emerges of, from east to west, (1) a shallow marine basin in the Rocky Mountains with cratonally-derived clastics, (2) a deep, backarc basin containing argillite, siltstone, and tuffaceous and volcanic rocks, (3) a composite arc terrane (U. Triassic Nicola and Takla Groups; Lower and Middle Jurassic Nicola, Hazelton, and Rossland Groups) dominated by mafic to intermediate volcanic rocks, and (4) an ocean basin floored by Late Paleozoic and Early Mesozoic ophiolitic rocks and their sedimentary cover (Cache Creek, Bridge River, and Hozameen Groups).

In the Okanagan region of south-central British Columbia most rocks of the continental margin arc belong to the Nicola Group (Fig. 4) which lies with angular unconformity (at least locally) on the earlier Thompson arc assemblage (Read and Okulitch, 1977). The Nicola Group is perhaps 5000 m thick. Fossils from it, although mainly of Late Triassic age, range in age from late Karnian to Early and possible Middle Jurassic (Schau, 1968; Preto, 1977; Read and Okulitch, 1977). The group consists of a stratigraphically complex assemblage of alkaline and subalkaline basaltic and andesitic flows, breccias, tuffs and lahars, with local conglomerate, shale, and reefoidal carbonate. Deposition was principally marine, but locally subaerial. Numerous small comagmatic dioritic and monzonitic bodies intrude Nicola units, as do several larger plutons of ultramafic (intrusive) to syenitic and granodioritic composition. Included among the latter are the Guichon batholith (198 m.y.a., K-Ar) and the Copper Mountain stock (193 m.y.a., K-Ar) in southern British Columbia (Gabrielse and Reesor, 1974). To the south along the axis of the arc in the Okanogan region of northern Washington, the Loomis pluton (194 m.y.a., K-Ar) intrudes Permian(?) strata of the Anarchist Group (Thompson assemblage) that had been strongly folded along north-northwest axes prior to intrusion (Fox and others, 1977). North of the Okanagan region in central British Columbia Late Triassic rocks of Nicola lithology are assigned to the Takla Group.

Tectonic and stratigraphic relations between rocks of the Takla-Nicola arc and "oceanic rocks of Cache Creek lithology to the west (including the Mesozoic Bridge River and Hozameen groups) are complex and not well understood, in part because of the disruptive effects of younger, major transcurrent faulting. The two assemblages are now separated in central British Columbia by the younger, transcurrent(?) Pinchi fault zone which contains fault-bounded blocks of blueschist that yield ages of 211-218 m.y.a. (Fig. 4; K-Ar, Paterson and Harakal, 1974). A latest Triassic subduction relationship between the two assemblages is supported by the occurrence of the blueschists, but not documented by their present field relations.

At the present time the lithologically similar and partly coeval Cache Creek, Bridge River, and Hozameen groups must be treated collectively in southern British Columbia. To the north, however, these oceanic rocks appear to bifurcate into two distinguishable belts (Cache Creek on the east and Bridge River on the west) that border the Stikine block (Figs. 1, 4), an extensive terrane in northern British Columbia of Upper Paleozoic calc-alkaline flows and pyroclastic rocks and carbonates. Monger and others (1972) and Monger (1977) interpret the Stikine assemblage as an offshore island arc emplaced into the Cordilleran "collage" in the latest Triassic. Cache Creek oceanic rocks inboard (east) of the Stikine arc were trapped between it and the Takla-Nicola arc at the time of collision. Closure of the Cache Creek ocean basin may have occurred by both eastward subduction beneath the Takla-Nicola arc and westward subduction beneath the eastern edge of the Stikine block, the latter giving rise to the Late Triassic Stuhini volcanic arc assemblage (Fig. 4).

Following accretion of the Stikine block to North America eastward subduction continued beneath the Nicola arc in southern British Columbia, but appears to have shifted in areas to the north to the outer (western) margin of the accreted Stikine terrane. Volcanic rocks of the Lower and Middle

Jurassic Hazelton Group record this westward shifting of subduction-related volcanism. Figure 4 illustrates that the northerly trend of the Late Triassic Takla-Nicola arc is crossed in southern British Columbia by the younger northwest-trending Hazelton arc. The cessation of Takla arc activity and the Early Jurassic construction of the Hazelton arc across the sutured boundary between the Stikine block and continental North America dates the incorporation of the Stikine block into the Cordilleran "collage" as a latest Triassic event. Deformed Cache Creek rocks in the suture zone of central British Columbia are cut by a 200 m.y. old pluton that supplied detritus to nearby Pliensbachian conglomerates (Tipper, 1978). Oceanic rocks of the Lower Mesozoic Bridge River Group presumably lay outboard of the Hazelton-Nicola (Jurassic) arc in a manner comparable to the spatial relations between older Cache Creek rocks and the Takla-Nicola arc (Fig. 4). A general transition from alkaline magmatism in the Late Triassic arc to calc-alkaline magmatism in the Early Jurassic arc may reflect a change from oblique subduction along the Takla-Nicola continental arc margin to more orthogonal subduction along the Hazelton margin. As pointed out by Monger (1977), it is difficult to find a clear-cut stratigraphic relationship in western Canada between Upper Triassic rocks of the Takla-Nicola arc assemblage and the Cache Creek Group, although probable Cache Creek detritus has been reported at several localities in closely adjacent Upper Triassic strata. Some ophiolitic rocks of Hozameen Group affinity may have been accreted onto the leading edge of the arc prior to Early Jurassic deposition of the Ladner Group. Sedimentary rocks of the Ladner Group and the Ashcroft Formation lie west of the Nicola arc (Fig. 4) and comprise the oldest depositional units in the Tyaughton-Methow trough (see Tennyson and Cole, this volume). The Sinemurian to lower Bajocian Ladner Group consists of an eastern section, over 2000 m thick, of subaerial volcanics and shallow water volcanogenic sediments, and a western, thinner section of pelagic sediments and deep water turbidites (Coates, 1974). Anderson (1976) claims that basal pelitic and volcaniclastic Ladner rocks of western facies lie depositionally on basalts of the Coquihalla belt northeast of Hope. This belt includes diabase, gabbro, and serpentinized peridotite. It is interpreted by Anderson as an ophiolitic assemblage and the oceanic basement for distal Ladner rocks in the Tyaughton-Methow trough.

To the east the Ladner and Nicola groups are separated by a belt of granitic rocks, but the two clearly overlap in time. The Ashcroft Formation, exposed farther to the northeast, consists of shale, graded sandstone, conglomerate, and local olistrostromes. It locally lies on the Nicola Group, but elsewhere is separated from it by a zone of chaotic deposits (W. Travers, in press).

It thus appears that distal sedimentary rocks of the Tyaughton-Methow trough (Ladner Group) lie on oceanic crust, whereas proximal sediments (of the Ashcroft Formation) lie on a Nicola basement. Anderson (1976) and Travers (in press) regard the Ladner Group and Ashcroft Formations, respectively, as constituting deposits of an Early Jurassic fore-arc basin. To the west across an intervening subduction zone complex lay oceanic rocks of the undifferentiated Cache Creek, Hozameen, and Bridge River groups.

Northern Cascade Mountains

Similarities between Late Paleozoic assemblages in the Northern Cascades of Washington (Trafton and Chilliwack) and the Okanagan area (Cache Creek and Thompson) have previously been mentioned. Lithologic similarities extend into the Late Triassic to Middle Jurassic time period discussed here. The core of the Northern Cascade Range experienced widespread Late Triassic plutonism (Marblemount belt, 220 m.y., Pb^{206}/U^{238}; Mattinson, 1972) that perhaps corresponds to Nicola magmatism (Fig. 4). Blueschists occur west of the Cascade crystalline core in the Shuksan thrust plate. Although R. L. Armstrong (personal communication, 1976) has obtained Cretaceous ages (K-Ar, ca. 130 m.y.) from phengitic micas from phyllite in the Shuksan blueschist metamorphic suite, Misch (1966) reported K-Ar ages of 259 ± 8 m.y. on crossite schist and 218 ± 40 m.y. on crossite. The similarity of the latter age to Pinchi blueschists in central British Columbia is intriguing. Finally, the Cultus Formation of the western Northern Cascades (Upper Karnian to Sinemurian), is a shale-sandstone sequence similar to the Ladner in bedding characteristics and, like it, largely derived from a volcanogenic source.

Northeastern Oregon and Western Idaho

The Late Triassic to Middle Jurassic history of the western Cordilleran between latitudes 44° and 48°N is poorly understood, in part because so much of this critical terrane is covered by Cenozoic volcanic rocks. Nevertheless, in general terms the history of this region bears important similarities to that of the southern British Columbia area just described.

The lithology of the Upper Triassic (Karnian) Vester Formation, the Upper Triassic to Lower Jurassic Aldrich Mountains Group, and Middle Jurassic rocks in east-central Oregon is indicative of extensive post-Sonoma volcanic activity, perhaps in a southern equivalent of the Nicola arc. These units unconformably overlie deformed rocks of both the oceanic and arc terranes described previously (Fig. 4). A 3000 m-thick composite Vester section northeast of Izee includes pebbly conglomerate, black shale, water-laid andesitic tuff, and ophitic basalt; sedimentary units predominate (Beaulieu, 1972). The Vester is overlain unconformably by a thick (15,000 to 20,000 m) Norian to Callovian sequence of unconformity-bounded units that are largely marine and volcaniclastic in nature (Dickinson, 1976; Thayer and Brown, 1976). Andesitic and dacitic rocks, mostly fragmental, are important components of some sections, and their distribution suggests to Brown and Thayer (1966) that major volcanic centers lay to the north.

Continuing deformation in the depositional environment represented by Vester and higher units is much in evidence. For example, near Mt. Vernon Triassic (Norian?) basalt and graywacke lie unconformably above a Middle Triassic "melange", but were folded and in-faulted into the underlying rocks during later Triassic deformation (Brown and Thayer, 1966). Vallier and others (1977) consider that the Mesozoic rocks under discussion here were deposited in an arc-trench gap, with volcanic activity north and west of the axis of sedimentation. This view is difficult to reconcile with the absence of a coeval trench to the south and east. An intra-arc environment of deposition seems more probable. In areas to the east (Fig. 4), granitic plutons ranging in age from 217 to 200 m.y. (K-Ar, Armstrong and others, 1977) crosscut Upper Triassic strata in westernmost Idaho and substantiate the existence of a Late Triassic-Early Jurassic magmatic arc in this general region.

As in British Columbia, blueschists of Late Triassic age occur outboard (north and west) of the badly preserved arc. Unfortunately, also as in British Columbia, the blueschists occur in an enigmatic tectonic setting that implies the existence of a Late Triassic subduction zone, but does not unequivocally prove it. Lawsonite-bearing blueschists exposed north of Mitchell (Fig. 4; 223 m.y.a., K-Ar, Hotz and others, 1977) occur in fault-bounded exposures admixed with highly sheared sedimentary, metasedimentary, and metavolcanic rocks of probable Late Paleozoic (Permian?) age.

The location of a convergent Late Triassic-Early Jurassic plate boundary in central Oregon is highly speculative. It seems most likely that it once extended northeastward from the area near Mitchell, toward the Oregon-Idaho boundary and along the northern edge of the deformed pre-Upper Triassic oceanic terrane described previously. The geometric and temporal relationships of this inferred subduction zone to the 7 km-thick Seven Devils-Martin Bridge-Hurwal volcanic arc section of northeasternmost Oregon are uncertain, but for reasons discussed below we consider incorporation of the "Seven Devils arc" into the Cordilleran "collage" to be a probable Cretaceous event.

Klamath Mountains, Oregon and California

Eastern Klamath arc

Late Triassic through mid-Jurassic (Bajocian) volcanic arc activity is well preserved in the stratigraphic section of the eastern Klamath Mountains of northwestern California (Fig 4). Broadly correlative volcanic and sedimentary strata occur to the south in the "eastern" belt of the Sierra Nevada (Schweickert and Cowan, 1975) where, voluminous plutonic intrusion has obscured many initial stratigraphic relations. As mentioned previously, volcanic and sedimentary rocks of Late (Karnian) and Middle Triassic age in the eastern Klamath section sit with apparent conformity on Permo-Triassic rocks (Irwin, 1966). McMath (1966), however, reports that shelf-type carbonates of Late Triassic age (Norian; Hosselkus Limestone, Swearingen Fm.) lie with angular unconformity on Permian and probable Permian pyroclastic and volcaniclastic strata in the Taylorsville area of the northern Sierra Nevada.

Rocks in the Klamath-Klamath-Sierran arc are lithologically diverse and include andesitic lava, tuff, and breccia, siliceous pyroclastic rocks and ignimbrite, argillite, shallow water limestone, and tuffaceous sandstone. No Late Triassic to mid-Jurassic granitic plutons occur in the Klamath portion of the arc, but a northwest-trending belt of 190-210 m.y. old plutons lies along the eastern margin of the Sierran batholith and extends into the eastern Mojave Desert (Fig. 4). The discontinuous belt parallels the truncated Early Mesozoic margin of the continent and crosscuts older, northeast-trending stratigraphic and structural elements (Burchfiel and Davis, 1972).

Western oceanic assemblages

An open ocean basin lay somewhere west of the eastern Klamath arc in Late Triassic and Early Jurassic time. Eastward subduction of oceanic lithosphere beneath the arc is implied by the magmatic activity of the arc and by the occurrence along its present northwestern margin of an allochthonous blueschist terrane of appropriate age (222-214 m.y., Hotz and others, 1977). The present structural setting of the blueschists near Ft. Jones may or may not, however, date from the time of Late Triassic convergence. Field relations in areas to the south subsequently treated suggest that major thrust faulting in the Ft. Jones area may be of Jurassic age.

Triassic oceanic crust west of the eastern Klamath and central metamorphic subprovinces is represented by at least two ophiolitic sequences in the "western Paleozoic and Triassic" subprovince (Fig. 6). Identified by Irwin (1972) as the North Fork and Rattlesnake Creek terranes they lie along the eastern and western margins of the subprovince respectively in areas south of 41°15'N latitude. Irwin has also defined a centrally located lithologic assemblage, the Hayfork terrane, which Ando and others (1977) consider to be largely correlative with sedimentary and volcanic rocks of the North Fork terrane. The Preston Peak ophiolite (Snoke, 1977) lies along the western edge of the subprovince just south of the Oregon border. It may be a northern equivalent of either the ophiolitic Rattlesnake Creek or North Fork terranes, although its age and geologic relations with these terranes is not known.

The North Fork ophiolite is tectonically dismembered and lacks the sheeted dike complex characteristic of many other ophiolites. Gabbro exposed in the core of a regional north-plunging antiform (between the Salmon and Trinity Rivers) grades abruptly upward into fine-grained diabase of hypabyssal character (Ando in Ando and others, 1977). Sheetlike units of serpentinized peridotite (North Fork and Twin Sisters bodies) are tectonically interleaved between core gabbro and diabase and structurally higher pillow basalt, chert, and volcaniclastic rocks. Irwin and others (1977) report that radiolarians from red chert "associated with the ultramafic-mafic rocks of the ophiolite" in an area south of the Trinity River are probably Late Triassic. Structurally higher siliceous tuff and chert assigned to the North Fork terrane have yielded radiolarians of Early or Middle Triassic age.

Previously, rocks of the North Fork-Hayfork, and Rattlesnake Creek terranes were considered to be at least in part of Paleozoic age on the basis of (?)Siluro-Devonian, Pennsylvanian and Permian fossils collected from carbonate bodies--now interpreted as exotic blocks in intermixed cherts and argillites that are at least in part of olistostromal origin (Cox and Pratt, 1973; P. Cashman, work in progress). In this respect, the rocks of the North Fork-Hayfork terrane resemble those of the Bridge River Group of British Columbia in that both of these Early Mesozoic assemblages contain pods of older carbonate rocks (some, in the Klamath Mountains, bearing a Tethyan fusulinid fauna). Exotic blueschist blocks with a

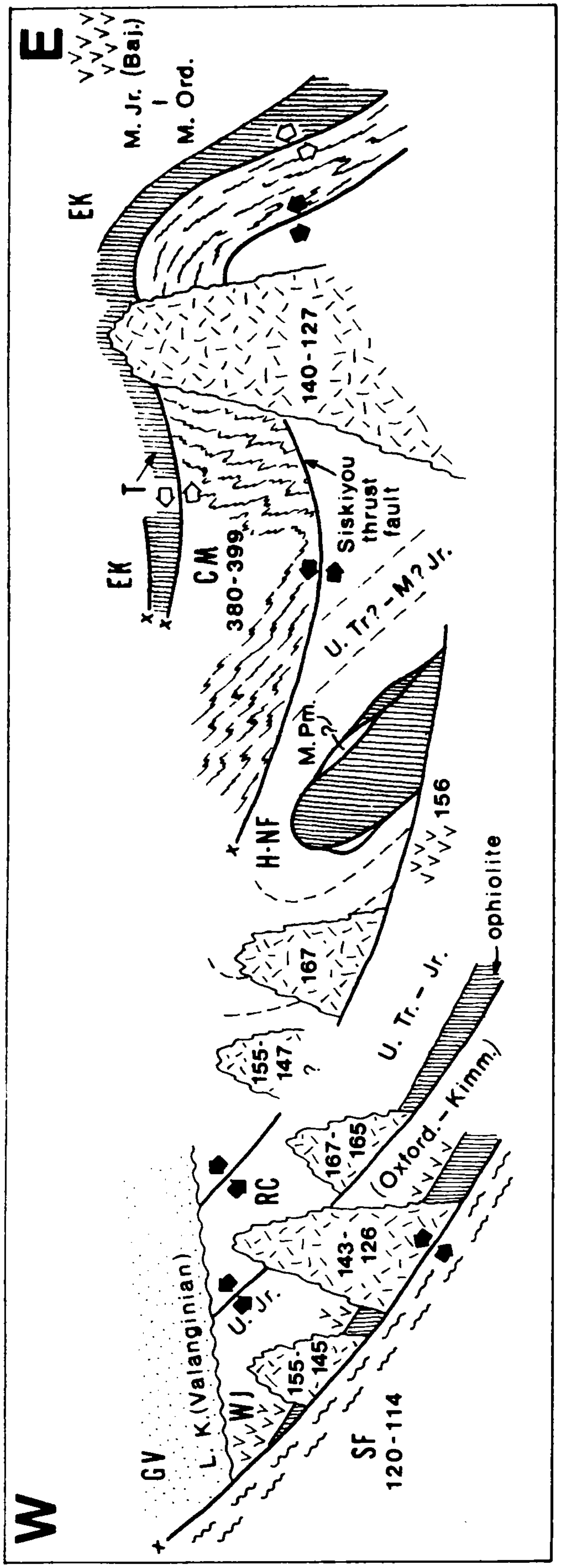

Figure 6 (to left). **Diagrammatic representation of stratigraphic and radiometric age controls on thrust faulting in the Klamath Mountains, California and Oregon. Length of section is approximately 200 km. SF = South Fork Mountain** Schist; GV = Great Valley sequence; WJ = Western Jurassic subprovince; RC = Rattlesnake Creek terrane; H-NF = Hayfork-North Fork terrane; CM central metamorphic subprovince; T = Trinity ophiolite; EK = eastern Klamath subprovince. Thrust faults with black relative motion arrows are post-Paleozoic in age. Radiometric age data from Hotz (1971), Dick (1973), Young (1974), Lanphere and others (1975), Snoke (1977), and Irwin (1977).

lawsonite-glaucophane-(jadeite) mineralogy (E. Ghent, written communication, 1977) occur in a poorly exposed chaotic (olistostromal?) zone within cherts of the North Fork terrane (Davis, 1968). The blocks are undated, but some resemble mineralogically the Ft. Jones area blueschists and a 220 m.y. initial age for them seems likely. They are present on both flanks of the North Fork antiform (Fig. 6), in the North Fork section to the east and the Hayfork section to the west, a relation that supports the equivalency of the "two" terranes (Ando and others, 1977).

The relation of the North Fork-Hayfork and Rattlesnake Creek ophiolitic terranes to each other is not clear, although both appear to be essentially coeval (cherts in the latter have also yielded Late Triassic and Jurassic radiolaria). Irwin (1972) has previously indicated that the fauna from carbonate pods in the two terranes (now interpreted as exotic blocks) is markedly different and almost mutually exclusive--the Rattlesnake Creek terrane is characterized by a coral-like chaetetid fauna, the North Fork-Hayfork by a fusulinid fauna. However, D. Charlton (1978, personal communication) believes that detritus from a Jurassic volcanic-plutonic assemblage spatially related to the Rattlesnake Creek terrane (see below) can also be found in Hayfork strata to the east.

The two terranes appear to be separated by a major east-dipping thrust fault and possibly by a volcanic-plutonic belt (island arc?) of Triassic(?) to Middle Jurassic age. The Hayfork Bally Meta-andesite of this belt (156 m.y., M. Lanphere as referenced in Irwin, 1977) is interpreted by Irwin (1972, 1977) as the lower stratigraphic unit of the Hayfork terrane. Alternatively, Ando and others (1977) have expanded upon Cox's contention (1967) that the meta-andesite lies structurally below folded rocks of the North Fork (=Hayfork) terrane and is separated from them by a major low-angle thrust fault (Fig. 6). They suggested among other possibilities that the meta-andesites, some of which are strongly mylonitized, might represent rocks of the Rattlesnake Creek terrane thrust beneath a North Fork allochthon. This view is supported by Charlton (1978; personal communication, 1978) who reports that hemipelagic sediments and volcaniclastic rocks correlative with the Hayfork Bally Meta-andesite lie depositionally on pillow basalts that he tentatively assigns to the Rattlesnake Creek ophiolite. Nearby meta-andesites are intruded and deformed by the Ironside Mountain batholith (165-167 m.y., Lanphere and others, 1968).

Possible paleogeographic relations between the eastern Klamath arc, the North Fork and Rattlesnake Creek oceanic terranes, and the volcanic rocks of the Hayfork Bally Meta-andesite are discussed in a later section since faults that presently separate these lithologic assemblages are probably all of Late Jurassic age.

Sierra Nevada

The "Calaveras Formation" of the western Sierra Nevada appears to be in part a southern counterpart of the North Fork-Hayfork and Rattlesnake Creek Mesozoic ophiolitic terranes (Davis, 1969). However, the presence of the ate Paleozoic Kings-Kaweah ophiolite in the southwestern Sierra Nevada (Fig. 5) upon which Calaveras-type olistostromes were "deposited" (Saleeby and others, this volume) indicates that pre-Mesozoic oceanic rocks of Cache Creek affinity are also a component of the "formation". Saleeby (1977) and Saleeby and others (this volume) believe that the ophiolite and its sedimentary cover, a chert-argillite olistostromal complex, were accreted to the western edge of the continent along a dextral transform fault zone that had been responsible for the Permo-Triassic truncation discussed above. A Late Permian Tethyan fusulinid fauna has been collected from the "Calaveras" rocks, specifically from a limestone block in a chert-argillite olistostromal unit (Schweickert and others, 1977). This unit is overlain by continent-derived quartzitic strata of Late Triassic and Early Jurassic age, that are in turn overlain by felsic volcanic rocks. Metamorphic tectonites derived from mafic members of the ophiolite yield K-Ar ages of 190 m.y., an Early Jurassic age considered by Saleeby to be the likely age for emplacement of the ophiolite against the continent. Geologic relations described by Saleeby lead to the following conclusions: (1) the original truncated margin lies east of all "Calaveras" rocks in the Kings-Kaweah area (Fig. 5); (2) late Paleozoic "Calaveras" rocks and their ophiolitic basement were brought against that continental margin following the initiation of Middle to Late Triassic plate convergence along it; (3) subsequent shifting of the zone of convergence to the west of the accreted oceanic terrane was followed, in Early Jurassic time, by its internal disruption along a major strike-slip fault zone (the Kings-Kaweah "suture"); (4) this zone was parallel to an active trench to the west and its existence implies oblique convergent motion along that plate boundary (Saleeby and others, this volume); and (5) Late Triassic and Early Jurassic sedimentary volcanic rocks that depositionally overlie western "Calaveras" units (and were also offset by transcurrent faulting) may conceal in areas to the east the older truncational and younger collisional boundary.

Schweickert (1976) and Schweickert and others (1977) have concluded that Calaveras-type rocks in the western Sierra Nevada were probably originally deposited in a marginal ocean basin that lay between the Klamath-Sierran Paleozoic arc and the North American continent prior to their collision. This conclusion seems erroneous for several reasons, not the least of which is the remarkable, although admittedly discontinuous occurrence of Calaveras-type rocks from the southwestern Sierra Nevada to northern British Columbia--and always in a tectonic position outboard from the early Mesozoic continental margin (Figs. 4, 5). As mentioned above, Irwin and others (1977) have pointed out that Calaveras-type rocks in the southern Klamath Mountains are of Late Triassic and Jurassic age and could not have been deposited in a Paleozoic marginal basin before being displaced into the Klamaths. Finally, Speed (1977) has challenged on lithologic grounds the correlation of "Calaveras" rocks in the western Sierra Nevada with Late Paleozoic rocks in Nevada from the inferred marginal basin (Havallah sequence).

Despite convergent accretion of some or all of the "Calaveras" terrane in the Triassic period, Late Triassic and earliest Jurassic strata in the Sierra Nevada appear to record a time of relative arc inactivity, in contrast to the eastern Klamath Mountains. A number of Sierran stratigraphic sequences of this age are non-volcanic or, at best, contain only minor contributions from volcanic sources (Schweickert and Cowan, 1975). This relationship is surprising, since scattered eastern Sierran plutons have ages which fall in a Late Triassic-Early Jurassic time period (220 to 190 m.y.) and do attest to at least sporadic magmatic activity within the newborn arc (Fig. 4). During later Early Jurassic time Andean-type magmatism in the Sierran region was evidently more widespread. Thick sequences of volcanic rocks dating from this time are present in the northeastern and east-central Sierra Nevada (Stanley and others, 1971; Fig. 4). Saleeby (1977) has suggested that in the southern Sierra Nevada, arc volcanism spread far enough westward that Lower Jurassic volcanic rocks and sediments derived from the older "Calaveras" terrane were deposited on top of the ophiolitic complex of the Kings-Kaweah area. Thus by Early Jurassic time subduction at this latitude had stepped westward from its Middle to Late Triassic position.

The volcanic rocks that lie west of the Melones fault zone in the Sierran foothills have generally been regarded as Middle and Late Jurassic in age (Schweickert and Cowan, 1975), but the studies of Saleeby cited above and Morgan and Stern (1977) suggest that older volcanic (and plutonic) rocks are also present in the western Sierra Nevada. Morgan and Stern (1977) report that a small pluton near Sonora yields a U-Pb age of 190 m.y. (Early Jurassic). It intrudes alpine-type ultramafic rocks and unconformably overlying Peñon Blanco volcanic rocks (Fig. 4) that occur west of the Melones fault zone and east of the Bear Mountains fault zone. Although the mafic Peñon Blanco volcanic rocks (lava, breccia, tuff) may be oceanic in affinity rather than an expression of arc activity, the pluton that intrudes them is indicative of surprisingly early plutonism in this area.

The ages of metavolcanic and metatuffaceous rocks (Franklin Canyon and Duffey Dome formations) that occur between the Melones and Bear Mountain fault zones in the northernmost Sierra Nevada and lie unconformably above deformed "Calaveras" cherts, phyllites, and discontinuous limestone bodies are not known (Fig. 5). Hietanen (1973) tentatively correlates them with Late Paleozoic units of the Klamath-Sierran arc to the east of the Melones fault. We believe that a Mesozoic age assignment is more likely since these metavolcanic rocks unconformably overlie an accreted "Calaveras" terrane in a manner comparable to relations described by Saleeby far to the south, and because we consider it unlikely that any rocks of the Paleozoic Klamath-

Sierran volcanic arc are preserved west of the Melones fault. Hietanen (1977) does report that lower grade metavolcanic rocks of variable composition (mafic augite basalt, andesite, dacite, soda-rhyolite) and probable Late Jurassic age (Bloomer Hill Fm.) overlie phyllites of unknown age north of Lake Oroville. The phyllites are extensions of an undifferentiated "Calaveras" unit mapped by Creely (1965) in the Oroville quadrangle to the south where a Late Triassic(?) ammonite was collected from overlying strata that includes metavolcanic rocks.

MIDDLE JURASSIC TO MID-CRETACEOUS

During the Middle Jurassic to mid-Cretaceous time interval the Cordillera evolved from a largely marine terrane with islands and peninsulas built up mainly by volcanic activity, to a broad, predominantly subaerial mountain chain of Andean character with marine deposition restricted to its margins. Although the lower age limit of this period is somewhat arbitrarily selected for the Cordillera as a whole, the mid-Cretaceous upper limit was chosen as the youngest possible time for the incorporation into the Cordilleran "collage" of major allochthonous terranes in northeastern Oregon ("Seven Devils arc") and westernmost British Columbia ("Wrangellia"). Eastward subduction of oceanic lithosphere, probably with a pronounced northward component, occurred along most of the continental margin during this time interval. The possibility must be considered that west-dipping subduction zones lay beneath some offshore island arcs ("Wrangellia", "Seven Devils") prior to their accretion into the Cordilleran "collage". East of the arc, sediments were shed into a foredeep that was continuous from Canada to southern Nevada, and spatially and genetically related to west-dipping, backarc thrust faults.

By comparison with the previous Late Triassic-Early Jurassic interval, the quantity of arc-related volcanism in British Columbia and northern Washington appears to be far less voluminous. This difference may be exaggerated by subsequent erosion since plutonic rocks emplaced during this interval are extensively exposed. In contrast, late Early, Middle, and Late Jurassic arc volcanism in California was considerably more voluminous than that of the Late Triassic.

Omineca Crystalline Belt, British Columbia and Washington

In western Canada during this time interval the dominant paleogeographic feature was an uplifted linear terrane, the Omineca crystalline belt (Fig. 7), which shed clastic detritus eastward into a foreland basin on the craton and westward across older arc terranes (Eisbacher, 1974; Eisbacher and others, 1974). The belt was cored by high-grade metamorphic rocks and local anatectic(?) granitic intrusions and flanked on both sides by folds and thrust faults that fanned outward from its axis. It is difficult to envision the uplifted terrane as a conventional magmatic arc in most of British Columbia as done by Dickinson (1976) since it apparently lacked volcanic activity and developed 500 km or more east of any coeval subduction zone involving oceanic crust. It has been described (Eisbacher and others, 1974) as a zone of tectonic thickening and subsequent uplift, perhaps developed by regional compression of thermally weakened crust in a backarc setting to the Early Mesozoic arcs. Metamorphosed strata as young as Late Triassic and possibly Early Jurassic age are cross-cut by plutons as old as 163 m.y. (Wheeler and Gabrielse, 1972;

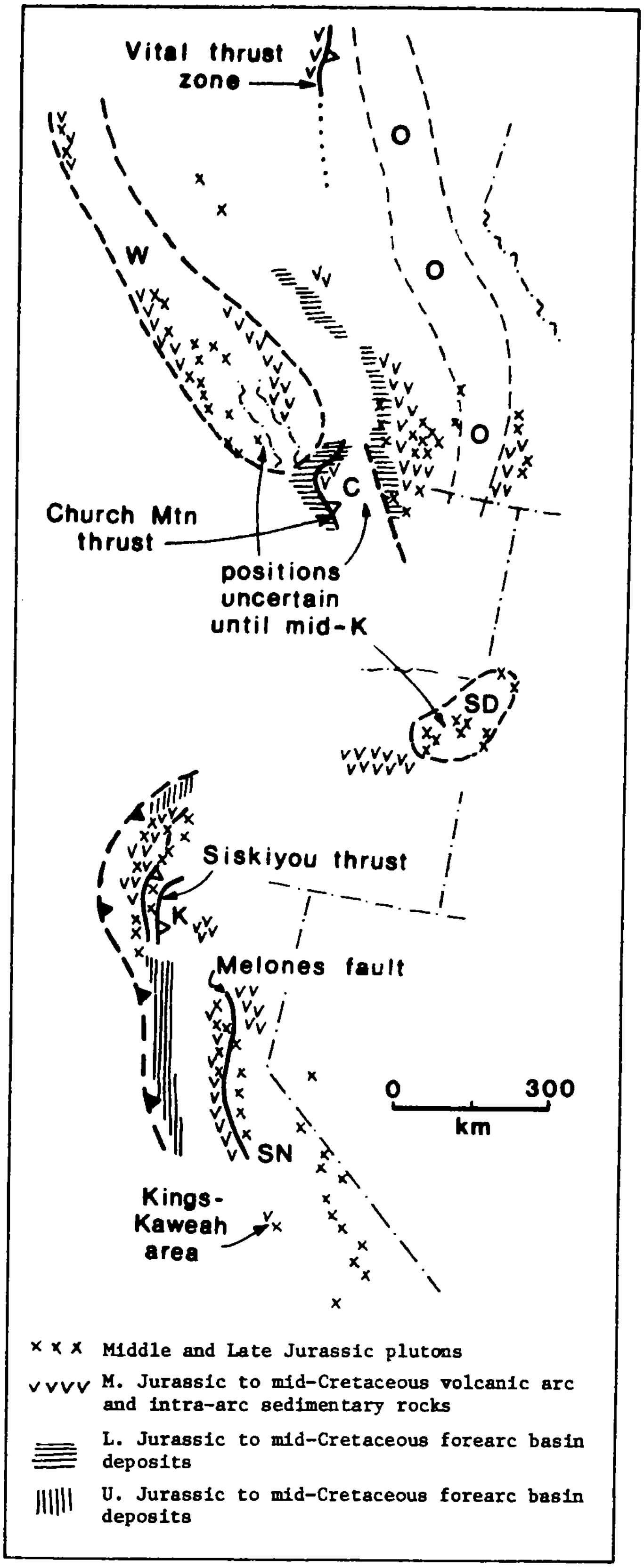

Figure 7. Distribution of Middle Jurassic to mid-Cretaceous rock assemblages and major tectonic elements. W = "Wrangellia"; C = "Cascadia"; O = Omineca crystalline belt; SD = "Seven Devils arc"; K = Klamath Mtns.; SN = Sierra Nevada.

Pigage, 1977).

The Omineca belt is flanked on both sides by thrust faults, along which underthrusting of rigid, sialic to intermediate crust took place--presumably contributing to uplift (Eisbacher and others, 1974). On the west, intraplate thrusting occurred along the east-rooting King Salmon-Nahlin-Vital fault zone of northern and central British Columbia (Fig. 7) in Late Jurassic-Early Cretaceous time (Monger and others, in press), although uplift began here in the Callovian. Early Mesozoic and Late Paleozoic arc rocks were foreshortened by possibly as much as 200 km along the former zone of Early Mesozoic subduction complexes delineated by the Cache Creek Group. Thrust faults on the east flank, those of the Rocky Mountain belt, will not be treated here. Estimates for the amount of crustal shortening that they produced range downward from a maximum of 200 km, depending on the extent of basement involvement in the deformation.

The southward continuation of the Omineca belt includes the Okanogan plutonic-metamorphic complex of north-central Washington. The crystalline terrane here was apparently of more "normal" arc type. Open ocean bordered the arc on the west, since the earlier accreted Stikine block of northern and central British Columbia did not extend this far south. Abundant volcanic detritus shed westward from the northern Washington crystalline complex during Jurassic and earliest Cretaceous time confirm the existence of an extensive arc-related volcanic cover (unlike the Omineca belt farther north), and indicate the presence of an offshore, east-dipping subduction zone. It may be that the King Salmon-Nahlin-Vital intraplate thrust zone of northern and central British Columbia continued southward to link up with the offshore subduction zone, although the effects of younger deformations and transcurrent faulting obscure physical evidence for this linkage.

Northern Cascade Mountains
Washington and British Columbia

The Northern Cascade Mountains represent a second pre-Tertiary crystalline terrane in northern Washington and southwestern British Columbia, one largely separated from the Okanogan terrane to the east by a fault-bounded "trough" of Late Mesozoic sediments (the Methow trough). The Cascades have been the subject of much speculation regarding their local versus far-traveled derivation and the manner of incorporation into the Cordilleran "collage". Hamilton (this volume), for example, believes that they are an exotic component of the Cordillera. Misch (1966) regards the Northern Cascades as having evolved in situ. In contrast, we present the interpretation that they are a southern extension of an Okanogan continental margin terrane that has been shifted northwestward into an offshore position by dextral transcurrent faulting of Late Jurassic-Early Cretaceous age.

It will be clear from our discussion of Cascade orogenesis that many problems remain in the complex geometry and timing of the plate motions of "Cascadia" (the Northern Cascade block), "Wrangellia", and mainland North America. We have not been able to combine into a unified plate tectonics interpretation, the disparate kinematic and geometric models proposed herein for the transcurrent movement of "Cascadia" and the apparently coeval convergent motion between it and "Wrangellia". We are optimistic, however, that ongoing studies in the San Juan Islands (Whetten and Cowan, this volume; Danner, this volume), which physically link "Wrangellia" (Vancouver Island) and the western Cascades, will clarify these problems.

Methow trough

The sedimentary rocks of the Methow trough record critical information regarding the erosional and tectonic history of the continental margin during Jurassic and Cretaceous time. This history has been summarized by Tennyson (1974), from which much of the following information has been taken.

Clastic sediments derived from the Jurassic-Early Cretaceous Okanogan metamorphic and magmatic complex were deposited along the continental margin to the west (Fig. 7). They are now preserved in the Methow trough of north-central Washington and southernmost British Columbia, a depositional site recently interpreted as a forearc basin that lay between open ocean and the arc to the east (Tennyson, 1974; Dickinson, 1976). The Methow trough was once continuous with the Tyaughton trough in south-central British Columbia, although the two have since been almost completely separated by strike-slip faulting. Because the paleogeographic setting of the Tyaughton trough after Late Jurassic time is in dispute, only the Methow trough is discussed at this time.

All Methow sediments of Jurassic through Early Cretaceous (Aptian-Albian) age, including those of the Ladner Group described earlier, were derived from the magmatic arc to the east. Until Neocomian time (lowermost Cretaceous), clastic material is almost exclusively from a volcanic provenance. Neocomian arkosic sediments and granite-bearing conglomerate, also derived from eastern source areas, attest to erosion of the arc to deeper plutonic levels. Volcanic detritus is increasingly subordinate in younger Aptian and Albian sediments.

An extremely significant change in sedimentational patterns occurred in mid-Cretaceous time with the first arrival of abundant clastic material from the west. The Albian(?)-Cenomanian Virginian Ridge Formation of the western Methow trough, Washington, consists of black mudstone and siltstone, chert-grain sandstone, and chert-pebble conglomerate. Detrital constituents, other than chert, include poly-crystalline quartz and quartzite, and lithic fragments of phyllite and mafic to intermediate volcanic rocks (Barksdale, 1975). The Virginian Ridge Formation interfingers eastward with the coeval Winthrop Sandstone, a marine-fluviatile arkosic unit with an eastern plutonic provenance. In the Manning Park section of southernmost British Columbia, the first sediments transported from the west are of Late Albian age (Coates, 1974).

The sedimentary record clearly heralds the mid-Cretaceous appearance of a chert-volcanic, low-grade metamorphic terrane to the west of the Methow forearc basin where no land mass is in evidence before. Deposition of the Virginian Ridge Formation was immediately preceded by deformation of older sediments. The formation rests with marked angular discordance on folded pre-Aptian sediments (Newby Group) south of latitude 48°30'N. To the north it rests on Aptian-Albian units (Harts Pass Group) with only mild discordance (Barksdale, 1975). Coates (1974) reports that major deformation of the Manning

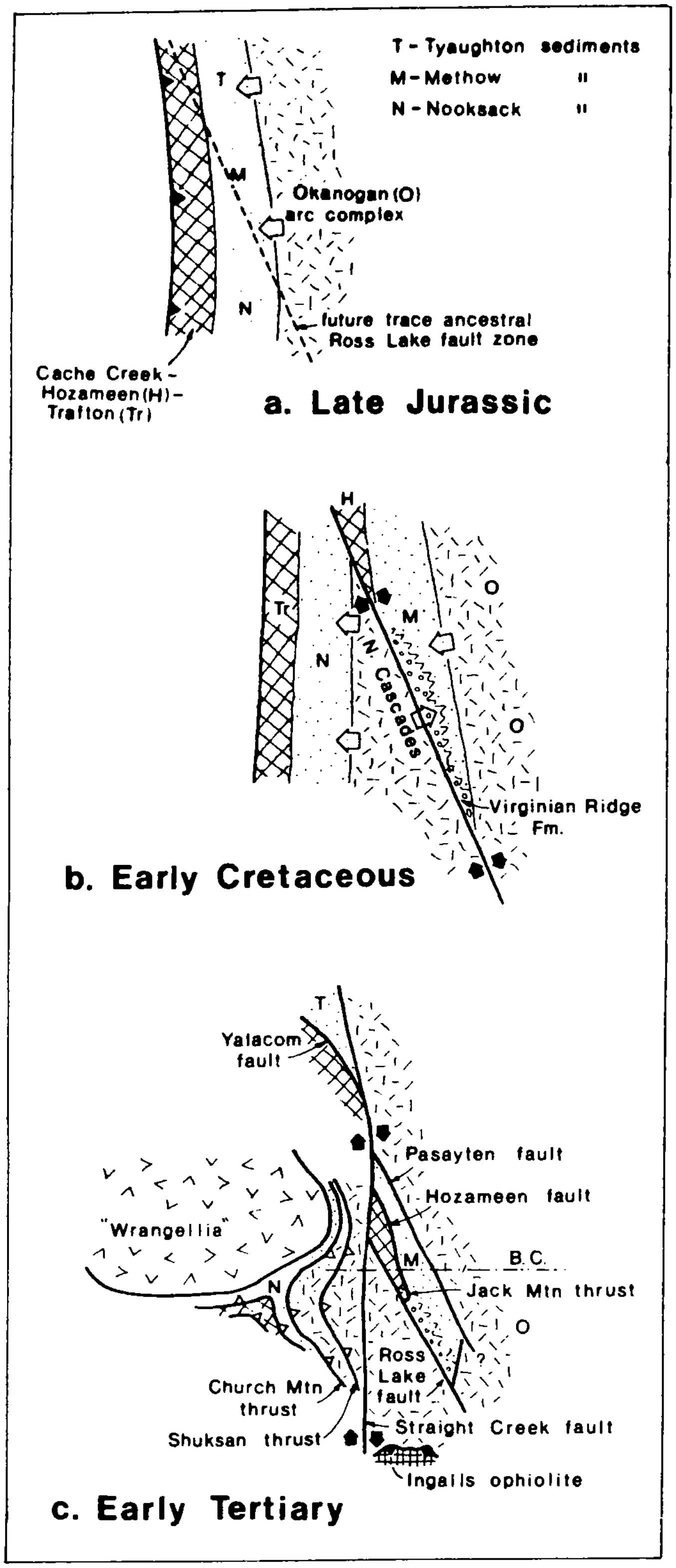

Figure 8. Hypothesized stages in the emplacement and deformation of "Cascadia", Late Jurassic to Early Tertiary time.

Park section did not occur until earliest Late Cretaceous time. Deformation began in western parts of the basin and was accompanied by folding and thrust-faulting with eastward vergence.

<u>Origin and Emplacement of "Cascadia"</u>

We propose that the western land mass that appeared west of the Methow forearc basin was "Cascadia", the ancestral Northern Cascades, now largely represented by the metamorphic core complex of the Cascade Range. Its emplacement is considered to be the consequence of major right-lateral strike-slip faulting at a low angle to the continental margin. Structural and stratigraphic relations outlined briefly above consistently date the tectonic juxtaposition of the Northern Cascade terrane against distal (western) portions of the Methow basin as a late Albian (latest Cretaceous) to early Cenomanian (earliest Late Cretaceous) event.

"Cascadia" is interpreted as a continental margin assemblage of rocks shifted northwestward from an initial position south of and in alignment with the Okanogan terrane of north-central Washington (Fig. 8a). This faulting thus resulted in a "doubling up" in northern Washington of the Early Cretaceous ocean-arc plate margin. Following transcurrent displacement, a north-projecting peninsular configuration for the Cascade block is envisioned (Fig. 8b). Ocean crust (Hozameen, Bridge River, Cache Creek) may have separated the northern end of the Cascade "peninsula" from its counterpart Okanogan "mainland".

Minimum right-slip of 160 km (100 miles) is represented by the length of unbroken Cascade crystalline terrane west of Jura-Cretaceous sediments in the Methow trough. This distance is measured from the southern end of the trough, near Methow, where Cascade and Okanogan crystalline rocks are in fault contact, to the Hope area of British Columbia where Cascade core rocks are faulted out against the Hope-Straight Creek fault system. The northernmost extent of Cascade rocks west of the Straight Creek fault is not known because of the obliterative effects of the Coast Range batholithic complex.

The fault(s) along which transcurrent movement of "Cascadia" is postulated has not survived intense mid- to Late Cretaceous deformation, metamorphism, and migmatization in the Northern Cascades. It can, perhaps, be considered as an ancestral Ross Lake fault zone since the "late Middle to Late Cretaceous" Ross Lake fault (Misch, 1966) now defines the eastern margin of the Cascade complex and the western edge of the Methow trough (Fig. 8c). This fault juxtaposes and mylonitizes Cascade core gneisses (Skagit, Gabriel Peak) and schists (Elijah Ridge) that lie below metamorphosed Lower Cretaceous strata of the Methow trough. It is extensively intruded by the late syntectonic Black Peak pluton (88 m.y., K-Ar, Tennyson, 1974).

Before documenting the essential equivalency of Cascade and Okanogan units, a brief summary of the complex Northern Cascade Range seems warranted. Misch (1966) has published the most complete study of that portion of the range in the State of Washington, and his account is the classic contribution to the literature on this topic. Reduced to its briefest essentials, the Northern Cascades consist of a crystalline core complex bounded on the east by the steep Ross Lake fault zone, on the west by a stacked succession of east-dipping thrust plates involving oceanic, forearc, and arc units, and on the south by a structurally higher thrust plate of Jurassic ophiolitic rocks and associated marine sediments (Fig. 8c).

Diverse rock units comprise the crystalline core of the Northern Cascades which was subjected to pervasive metamorphism and migmatization 90 to 60 million years ago (Mattinson, 1972). Precambrian gneisses and Late Triassic plutons, both identified by Mattinson (1972), have previously been mentioned. Other core components include ophiolitic(?) metaplutonic rocks of probable Ordovician age (ca. 460 m.y., Pb^{206}/U^{238}; Mattinson, 1972), and the Cascade River Schist, a metamorphosed assemblage of clastic rocks (graywackes, sandstones, and shales), andesite, subordinate limestone and chert, and plutonic rocks of intermediate to mafic composition. A metatuff from possible correlative strata in the Holden area is of Late Paleozoic age (265 m.y.a., Pb^{206}/U^{238}; Mattinson, 1972), but minor conglomerates in areas mapped by Misch (1966) to the north contain clasts of the Triassic Marblemount Quartz Diorite. Misch has stated that from overall composition, the Cascade River Schist could be derived from the Chilliwack Group of sedimentary and volcanic rocks (described below), but that positive correlation is not justified.

The Shuksan thrust plate lies west of the crystalline core and may root eastward within it. This major west-directed allochthon contains metaclastic rocks (phyllites to meta-graywackes) and structurally higher metabasaltic rocks, both of blueschist metamorphic grade. The age and idenity of the protolith of these Shuksan suite rocks are not known. Allochthonous rocks below the Shuksan thrust fault are assigned by Misch (1966) to the Church Mountain thrust plate. They include the Chilliwack Group, a thick (>3 km) and varied assemblage of Devonian to Permian clastic rocks (commonly volcaniclastic), limestone, chert, and volcanic rocks (dacite to basalt), and the Upper Triassic to Upper(?) Jurassic Cultus Formation. A disconformity separates the two units. Most Cultus rocks are pelites and fine-grained sandstone.

The Church Mountain thrust plate in turn overlies Jura-Cretaceous volcaniclastic rocks of the Nooksack Group, a unit equivalent to the upper part of the Cultus (Monger, 1970). Various units lie below the Nooksack, but perhaps the most significant are those of the Trafton Group described by Danner (1977) as underlying Nooksack strata with pronounced unconformity. This entire assemblage of western Cascade rocks is itself allochthonous with respect to underlying units in the San Juan Islands to the west (J. Whetten, personal communication, 1977).

All major pre-mid-Cretaceous rock units present in the Okanogan terrane of north-central Washington and southernmost British Columbia (or tied to it by tectonic or depositional relationships) appear to be present in the Northern Cascade Mountains. Suggested correlations include: the Thompson and Chilliwack assemblages (Late Paleozoic); the Cache Creek and Trafton groups (Late Paleozoic-Early Mesozoic); the Pinchi and Shuksan blueschists (Triassic); the Nicola and Marblemount plutons (Late Triassic-Early Jurassic); and Ladner-Cultus sedimentary rocks. The key element to the correlation of the two terranes, however, seems to be the Nooksack Group sediments of the western Northern Cascades. They are, most likely, forearc deposits of the Methow trough offset by strike-slip faulting and displaced to the northwest relative to their original position (Figs. 8a, 8b). Misch (1966) and Jeletzky and Tipper (1967, p. 75) are among those who have previously commented on the similarity of Nooksack rocks with those of the Methow trough. Misch, for example (op. cit., p. 119) in referring to sediments in the western part of the Methow trough states that

> "The lower Early Cretaceous strata in this sequence resembles the Nooksack Group and likewise are rich in volcanic detritus. . . Within the Lower Cretaceous I mapped a thick but lenticular conglomerate unit which recalls the Late Jurassic conglomerate of the Nooksack Group and likewise contains granitic pebbles that locally are accompanied by pebbles of gneiss."

The different "basements" for Nooksack and conformably older sediments in the western Northern Cascades have interesting paleogeographic implications. Cultus Formation pelites and sandstones in the Church Mountain thrust plate (the Upper Jurassic units of which are Nooksack equivalent; Monger, 1970) lie unconformably on older Chilliwack arc rocks. If these sediments were originally deposited in a southern portion of the Tyaughton-Methow trough, then "basement" Chilliwack units would represent a southern extension of the Late Paleozoic Thompson arc. In contrast, Nooksack sediments of a more westerly facies below the Church Mountain thrust plate overlie Late Paleozoic Trafton rocks (radiolarian cherts, pillow basalts, etc.) unconformably. This relation implies that Nooksack strata were originally deposited across an inactive (sutured) tectonic boundary between two older lithologic assemblages--oceanic (Trafton-Cache Creek) to the west, and arc (Chilliwack-Thompson) to the east.

The Cascade River Schist is presumably, at least in part and as Misch (1966) originally suggested, the metamorphosed equivalent of the Late Paleozoic arc assemblage. Precambrian basement (Yellow Aster Complex, 1452-2000 m.y.; Swakane Gneiss, >1650 m.y., Pb/U, Mattinson, 1972) beneath the Cascade River Schist should presumably be present beneath the Thompson arc of the Okanogan terrane if the tectonic and stratigraphic correlations proposed here are valid. Isotopic evidence for its presence (Sr^{87}/Sr^{86} initial ratios) has previously been reported by Petö and Armstrong (1976) for southern British Columbia and by Armstrong and others (1977) for northern Washington. A Precambrian zircon age has been obtained from orthogneiss in the Shushwap complex of southeastern British Columbia (1960 m.y., Wanless and Reesor, 1975).

A possible corollary of the Cascade-Okanogan "doubling" of the western continental margin by transcurrent faulting is that a pull-apart gap may have formed in the Mesozoic continental margin somewhere south of present exposures of the Okanogan-Methow terrane. The presence of Late Paleozoic through Jurassic units in east-central Oregon that are broadly correlative with those of the Okanogan continental margin (as developed in preceding sections), and the absence of such units is westernmost Idaho (Riggins area) support our conclusion that the pull-apart formed there.

Figure 9 explores this hypothesis geometrically.

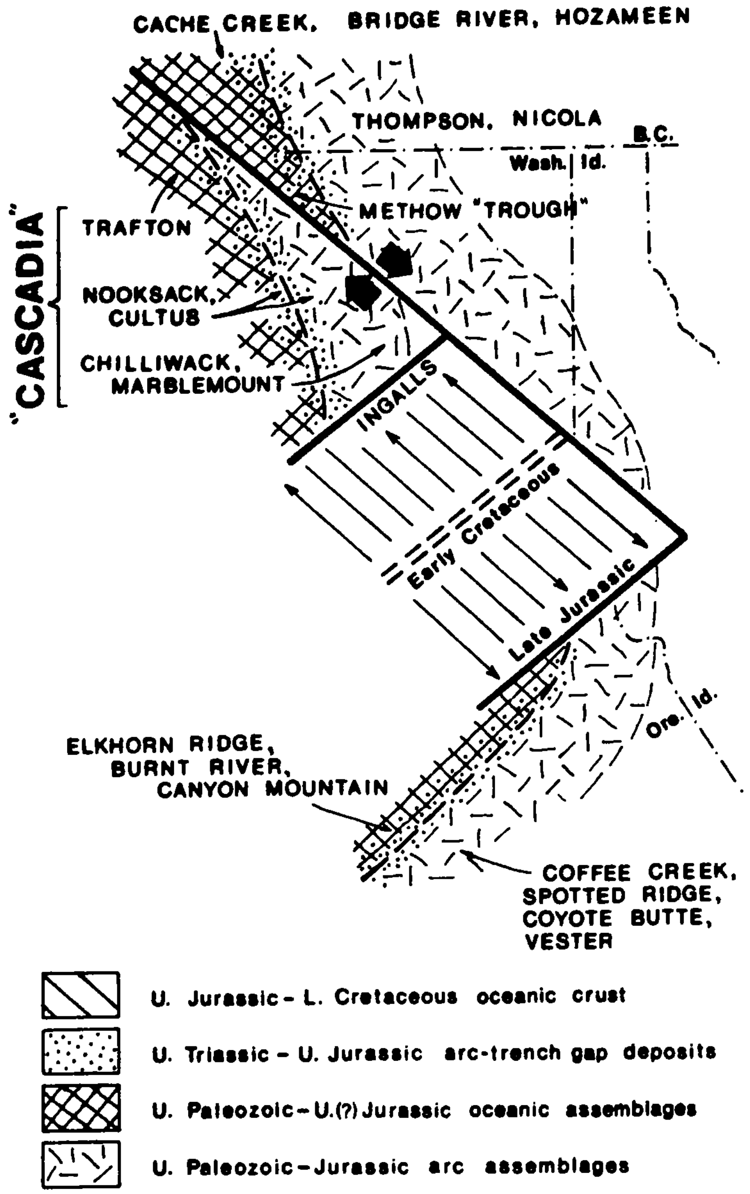

Figure 9. Hypothesized derivation of "Cascadia" from original continental margin location in southeastern Washington, western Idaho, and northeastern Oregon.

Note that pre-Cretaceous terranes in east-central Oregon have been rotated counterclockwise from their present position in order to undue effects of Cenozoic clockwise rotation related to Basin-Range extension. Transcurrent emplacement of "Cascadia" is attributed to continental rifting in an area now represented by northeastern Oregon, southeastern Washington, and west-central Idaho. The "ancestral Ross Lake fault" is shown as a transform fault related to sea-floor spreading parallel to the rifted margin. Geometrically, the plate configuration pictured resembles that responsible for the present translation of Baja California away from mainland Mexico, although lacking the combined transform-spreading geometry responsible for the Gulf of California. The admittedly simplistic plate geometry of Figure 9 is grossly compatible with the known and inferred distribution of Precambrian crystalline basement in this region based on (1) Sr^{87}/Sr^{86} initial isotopic ratios (Armstrong and others, 1977), and on (2) recent geophysical studies that indicate that southeastern Washington (the Columbia Plateau) is underlain by thin crust (<25 km) with an abnormally high P-wave velocity (ca. 7.0 km/sec; Hill, 1972; Smith, in press).

An interval of Late Jurassic through Early Cretaceous sea floor spreading can be assumed on the basis of the presence of the Late Jurassic Ingalls ophiolite along the southern margin of the Northern Cascade block (Fig. 8c; the ophiolite and associated cherts and slates were obducted northward across Cascade core rocks during the Cretaceous; Southwick, 1974; Miller, 1977), and by the arrival of "Cascadia" opposite the Methow trough in mid-Cretaceous time. The present distance between the inferred southern end of the Northern Cascades (Mt. Stuart area southeast of Stevens Pass) and Baker, Oregon (in the area of preserved Late Paleozoic-Early Mesozoic oceanic complex) is approximately 320 km. Neglecting the minimizing effects of Cenozoic clockwise rotation of east-central Oregon, this distance is a reasonable estimate of the width of ocean crust generated during Jura-Cretaceous rifting and the amount of northwestward displacement of "Cascadia". The inferred rifting event offers not only an explanation for the origin and emplacement of "Cascadia", but may serve as a model to explain the subsequent large-scale strike-slip faulting that occurred within the western Cordillera along a zone extending from northern Washington (Straight Creek fault) to eastern Alaska (Tintina fault) in Late Cretaceous to Eocene time.

Cascade orogenesis

Middle to Late Cretaceous orogeny in the Northern Cascades is not accounted for by the simple transcurrent drift of the block away from its southern Okanogan source area. Although open ocean presumably lay west of the Tyaughton-Methow-"Nooksack" trough through Early Cretaceous time, the somewhat younger thrust belt of the western Cascades lies at least in its northern portion between two continental blocks: that of the Northern Cascades and that of the southern Coast Ranges and Vancouver Island. These latter areas comprise the southern portion of a geologic terrane that appears to be exotic or allochthonous with respect to the North American continent. This terrane has recently been called "Wrangellia" by Jones and others (1977) and the Sicker-Skolai assemblage by Monger (1977). It includes on Vancouver Island, among other units, granodioritic to dioritic gneisses and granitoid intrusions that have yielded single zircon ages between 295 and 384 m.y. (Muller, 1977), Sicker Group sedimentary and volcanic rocks of pre-Devonian(?) to Permian age, and thick (up to 6 km) tholeiitic basalts of the Upper Triassic Karmutsen Formation. The Triassic part of the section is described by Jones and others (1977) as being remarkably similar, both lithologically and faunally, to coeval rocks in the "Seven Devils arc" of northeastern Oregon. They and Hillhouse (1977) also claim that recent paleomagnetic studies on basalts of Karmutsen age and lithology in the Alaskan portion of "Wrangellia" were formed at latitudes far south of Triassic rocks contiguous with North America in Late Triassic time, although mid-Jurassic intrusions on Vancouver Island do not appear to show any great latitudinal displacement with respect to North America (Symons, 1971). From a geological standpoint, the occurrence of pre-Devonian plutonic gneisses and Paleozoic rocks judged to be of arc type (Sicker Group) outboard of an oceanic assemblage or assemblages of younger age (Cache Creek-Hozameen-Bridge River Groups) argues strongly that "Wrangellia" is indeed an exotic component of the North American Cordillera.

What is not clear is when "Wrangellia" was incorporated into the Cordilleran "collage" and what its relationship is to Cascade orogenesis. The problem can be discussed in terms of the Tyaughton trough, the northern extension of the Methow (and, presumably, Nooksack) trough. Although there is wide agreement among workers that the Tyaughton trough occupied an arc-trench gap setting in the Early Jurassic (with open ocean to the west and "Wrangellia" still farther west), its Middle and Late Jurassic setting is less clear.

Jeletsky and Tipper (1968) propose that the Tyaughton trough in the Taseko Lakes map-area began

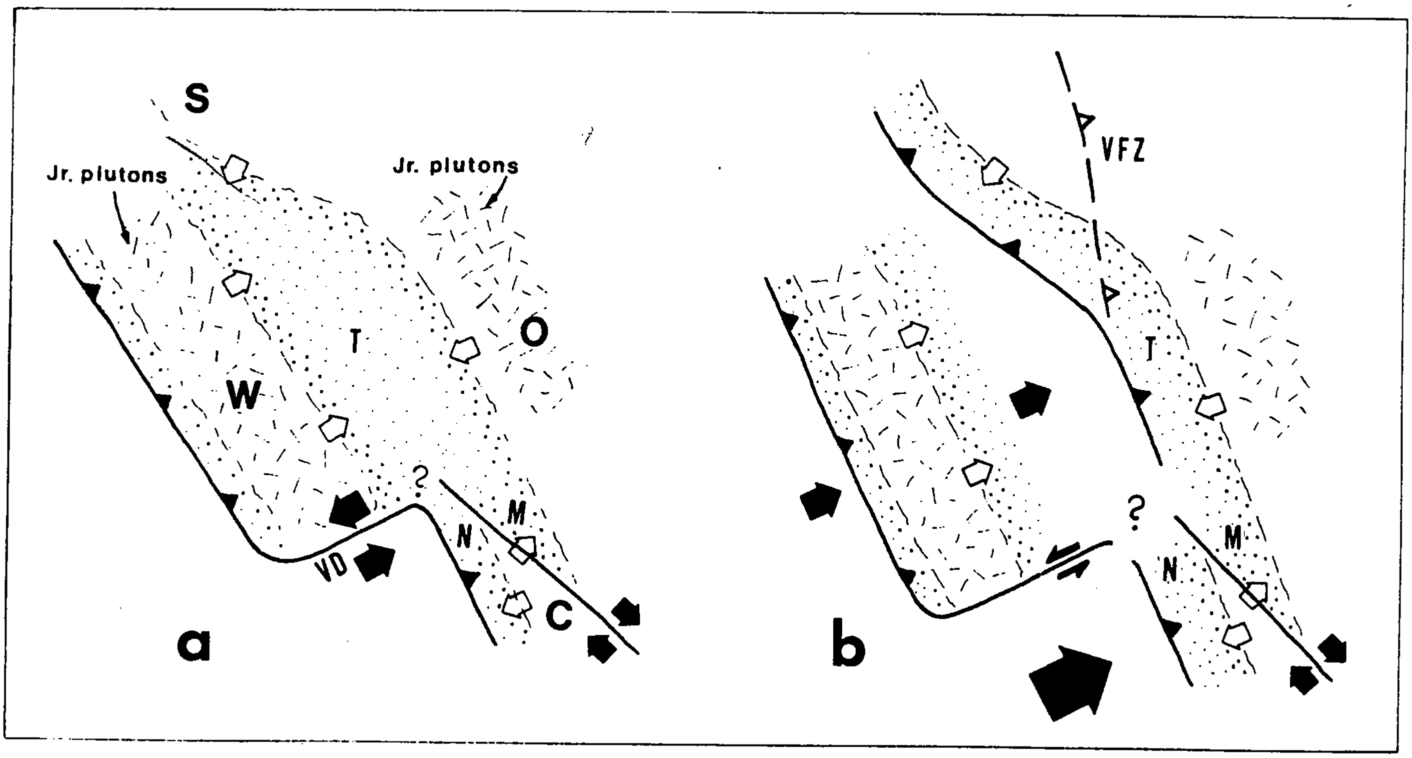

Figure 10. Alternative geometries for Late Jurassic-Early Cretaceous plate interactions in the Pacific Northwest. Black arrows indicate relative fault or plate displacement. Open arrows indicate directions of sediment transport. W = "Wrangellia"; S = Stikine arc; O = Okanogan terrane; C = "Cascadia"; VD = Vedder Discontinuity; VFZ = Vital fault zone; T = Tyaughton basin; M = Methow basin; N = Nooksack basin.

to receive terrigenous detritus (including granitic pebbles) from a source area to the southwest in Late Jurassic (late Oxfordian) time, as did Tyaughton sediments near Chiko Lake and west of Harrison Lake in the Valanginian (Fig. 10a). Other lines of stratigraphic evidence indicate to Tipper and Richards (1976) that all of Vancouver Island and the adjacent mainland constituted a single depositional basin of Early and Middle Jurassic age (their "Hazelton Trough" which encompasses at least northern portions of the Methow-Tyaughton trough). They correlate Lower Jurassic volcanic rocks on the west side of Vancouver Island (Bonanza) with coeval calc-alkaline volcanic rocks in west-central British Columbia (Hazelton).

It is thus conceivable that "Wrangellia" had moved into a position outboard of the former forearc Tyaughton trough in pre-Late Jurassic time, and that the trough, with the cessation within it of subduction along a consuming trench between "Wrangellia" and the continent, had evolved into an intra-arc or successor basin (Fig. 10a). At this time only a single zone of east-dipping subduction along the western side of "Wrangellia" would have been present, perhaps represented by Upper Jurassic-Early Cretaceous Pacific Rim strata on Vancouver Island (Muller, 1977). "Wrangellia" may have terminated to the south along a possible transform structure termed the "Vedder Discontinuity" by Danner (1977a) and the "Orcas Fault Zone" by Muller (1977). South of the hypothesized transform, which could have linked Late Jurassic-Early Cretaceous trenches along the western edges of "Wrangellia" and the Okanogan-Cascade continental margin, lay only open ocean. Early Cretaceous subduction along the western Cascade margin is indicated by the 130 m.y. blueschist ages from rocks of the Shuksan suite and the presence of lawsonite in Jurassic rocks of the Cultus Formation.

The paleogeographic interpretation presented above and illustrated in Figure 10a poses several major problems, not the least of which is the tentative mid-Jurassic age for some Bridge River (=Hozameen) cherts (D. L. Jones in Monger, 1977) and, therefore, for the ocean basin that separated "Wrangellia" and North America. Another problem is that Valanginian clastic rocks west of Harrison Lake, assigned by Jeletsky and Tipper (1968) to the Tyaughton trough and interpreted by them as having a western source area, lie in the plate below the Church Mountain thrust fault. They are thus tied structurally to the Northern Cascades and, by the hypothesis offered above for emplacement of "Cascadia", to the Methow trough and an eastern source area. Jeletsky and Tipper (1968) did comment on the similarity of the Jura-Cretaceous Harrison Lake section to Nooksack strata in northwestern Washington, although W. R. Danner (written communication, 1977) is not convinced that these two assemblages are stratigraphically or lithologically equivalent.

Another problem posed by an Early to mid-Jurassic accretion of "Wrangellia" to the North American plate comes from the present distribution of Middle Jurassic to mid-Cretaceous plutonism in southern British Columbia. There is an apparent east-west separation by 200 km of areas of Middle and Late Jurassic plutonism (175-140 m.y.a.; Jackson, 1976) on Vancouver Island and in the Okanogan region of south-central British Columbia and northern Washington (Figs. 7, 10). If the two centers of coeval plutonic activity are related, then magmatism for this time frame extended across a belt 700 km wide. Early to mid-Cretaceous plutons (140-80 m.y.) in the Coast Ranges of southwestern British Columbia and the Okanogan area show a similar, but less striking separation. If the western and eastern plutonic belts are related to a single, east-dipping subduction zone along the west side of accreted "Wrangellia" (cf. Monger and others, 1972) then the great width of the adjacent igneous arc and its "split" pattern of plutonism are difficult to explain.

As a solution to these problems two Jurassic-Early Cretaceous subduction zones can be postulated—one beneath "Wrangellia" (east or west-dipping) and a second, east-dipping zone west of the Tyaughton-Methow trough (Fig. 10b). The second, eastern zone may have been joined to the north by the east-dipping intraplate Vital fault zone that was active in Late Jurassic or Early Cretaceous time. Following mid-Cretaceous collision of "Wrangellia" with North America, only one subduction zone remained. It lay along the west side of Vancouver Island, the new continental margin, is represented by the Pacific Rim Complex (Muller, 1977), and continued southward to the west of the Cascades. A somewhat similar interpretation of the evolving geometry of late Mesozoic subduction in this region has been presented by Dickinson (1976).

Thrust-faulting along the western side of the Northern Cascades (Shuksan, Church Mountain, and lower plates in the San Juan Islands) may simply be a "normal" expression of tectonic processes along a consuming ocean-arc plate boundary, although one profoundly modified north of 49°N latitude by the mid-Cretaceous collision of "Wrangellia" with the continent. The northeasterly trend of thrust faults that cross the U.S.-Canadian border can be postulated as the direct consequence of collision between "Wrangellia" and the Cascade continental margin, an idea that dates back to Crickmay (1930, p. 491) who described structural relations between the Cascades and "Wrangellia" (his "Coast Range batholith") as follows:

> "The structural trends are roughly parallel with the boundaries of the Jurasside Coast Range batholith and its probable southern continuation" (beneath the lower Fraser River valley). "This makes it seem as though the Cascade Mountains, were formed as a result of the compression of the geosynclinal cumulus of sediments against the resistant mass of the Coast Range batholith . . . they are thrust toward it as against a vertex."

The suture between the two plates has apparently been obliterated in the southern Coast Mountains of British Columbia by voluminous younger plutonism. Granitic plutons west of Harrison Lake, for example, intrude Jurassic rocks (Nooksack equivalent and older) below the Church Mountain allochthon.

It is likely that before compressive interaction of the "Cascadian" and "Wrangellian" blocks, whatever its nature, that Hozameen-floored ocean basin lay east of the northern end of the Cascade block (peninsula?) and west of the axis of the present Tyaughton-Methow trough. Eastward thrusting of Hozameen rocks across Lower Cretaceous sedimentary rocks in the trough along the relatively minor Jack

Mountain thrust (Fig. 8c) can be explained as backthrusting related to convergence of "Cascadia" and "Wrangellia". Late movement along the Ross Lake fault has separated the thrust plate from its roots (Misch, 1966).

Northeastern Oregon and Western Idaho

Dickinson and Vigrass (1965) consider the Late Jurassic (post-Callovian) and/or Early Cretaceous to be a time in east-central Oregon of compressional deformation, generally along northeasterly trends. The stratigraphic record for this time interval in eastern Oregon is essentially nonexistent, being represented only by the locally preserved units described below. One, the Callovian to Oxfordian Coon Hollow Formation is exposed in the Snake River Canyon 25 km NNW of Riggins, Idaho (Fig. 2). Euxinic sedimentary rocks (flyschlike mudstone and sandstone) dated by ammonites lie unconformably on Upper Triassic rocks of the Seven Devils Group (Vallier and Hooper, 1976). In east-central Oregon, early Albian and Cenomanian fluvial and shallow marine sediments of the Hudspeth/Gable Creek and Bernard formations lie with angular unconformity on deformed Permian(?) rocks (and structurally associated blueschists of Late Triassic age), Upper Triassic, and Middle Jurassic strata.

We propose that at some time in the Early Cretaceous the exotic and possibly far-traveled "Seven Devils arc" of northeastern Oregon and westernmost Idaho was emplaced against the rifted continental margin of western Idaho. (Fig. 7). Others have previously suggested arc-continent collision in the area, but at earlier times—Late Permian or Triassic (Hamilton, 1976), Jurassic (Brooks, 1976), and Late Jurassic(?) (Jones and others, 1977). Descriptions of the stratigraphic section of the "Seven Devils arc" (Vallier and Hooper, 1976; Vallier and others, 1977; Jones and others, 1977) indicate that despite a Late Permian-Early Triassic hiatus in the section no significant deformation occurred during its Early Permian to Early Jurassic history of accumulation. This strongly implies that suturing between the arc and continent could not have occurred until at least after final deposition of Hurwal marine strata in the Early Jurassic. Our very tentative timing for this event is based largely on the presence of post-Hurwal, Late Jurassic marine strata (Coon Hollow Formation) along the eastern edge of the Seven Devils terrane, and on the Late Jurassic-Early Cretaceous rifting event hypothesized above to account for the origin and northwestward displacement of "Cascadia". At the present time geologic relations in western Idaho, as we understand them, seem not inconsistent with this timing, although additional field, geochronologic, and paleomagnetic studies in the area are badly needed.

Geologic relations in the Riggins area along the requisite suture zone between arc and craton have been complicated by regional metamorphism, thrust faulting, Late Cretaceous plutonism (Idaho batholith), and the obscuring effects of a patchy cover of Miocene basalts. It is thus not surprising that recent interpretations of the geology of this area are markedly different (cf. Hamilton, 1969a, 1976; Onasch, 1976; Brooks, 1976). A few kilometers north of Riggins in the Harpster quadrangle east-dipping faults (35°-85°), some with demonstrable thrust displacement, and broad zones of cataclasis bound a narrow, central assemblage of granitic and metamorphosed peridotitic, sedimentary and volcanic rocks. These lie between lower grade, possibly equivalent rocks of the "Seven Devils arc" to the west and Precambrian (Belt) metasedimentary rocks to the east. The arc and cratonal assemblages now lie within 2 km of each other, but dislocational movements in the "suture zone" between them occurred before, during, and after Late Cretaceous emplacement of the Idaho batholith (Myers, 1976). Hamilton (1969a) demonstrated that east-dipping thrust faults in the Riggins area, which appear to be a continuation of the thrust faults mapped by Myers, postdate granitic intrusion and regional metamorphism of amphibolite grade in upper plate rocks of "eugeosynclinal" facies. He was only able to define the age of thrust faulting, however, as either Jurassic or Cretaceous in age.

Late Jurassic plutonism in the area of the "Seven Devils arc" (Fig. 7) is reasonably well documented (Armstrong and others, 1977), but its plate tectonics context is unknown. With that admission, westward consumption of oceanic lithosphere beneath the arc could account for Jurassic plutonism there and lead to later arc-continent collision. Post-collisional eastward subduction beneath the new continental margin, the western edge of the accreted arc, is seen as a less speculative explanation for Cretaceous intrusion of the Idaho batholith (100 to 70 or 80 m.y.a.; Armstrong and others, 1977).

Klamath Mountains, California and Oregon

The Klamath Mountains of northwestern California and southwestern Oregon are a geologic continuation to the northwest of the Sierra Nevada (Davis, 1969; Hamilton, 1969). This point has been discussed previously in terms of correlative Early Mesozoic and Late Paleozoic arc and oceanic rock assemblages in the two geographic areas (Figs. 3, 4, 7). Most of the Klamath Mountains province west of the Siskiyou thrust fault and much of the Sierra Nevada province west of the Melones fault consists of Jurassic sedimentary and igneous rocks with both arc and oceanic affinities. With the advent of plate tectonics an increasing number of authors have interpreted the Jurassic rocks of the western Klamath Mountains and Sierra Nevada as exotic elements of the Cordillera, i.e. units alien to the North American plate but carried to it atop Pacific Ocean lithosphere that was subducted in Jurassic time along the western edge of the continent (e.g. Hamilton, 1969, this volume; Moores, 1972; Schweickert and Cowan, 1975; Dickinson, 1976; Irwin, this volume).

It is our opinion that such hypotheses are conceptually pleasing, but increasingly difficult to defend as mapping studies in the western Klamath and Sierran regions progress. We attempt to develop in the following sections on the two areas an alternative concept. Specifically, that at least the Middle and Late Jurassic rocks of the two regions constitute portions of a single complex arc that was constructed across a previously sutured (Middle Triassic to Early(?) Jurassic) plate boundary between western oceanic rocks of "Calaveras" type and the continent. We present evidence that major Jurassic faults within this Klamath-Sierra arc are not former sutures along which multiple exotic arcs collided, but are instead intraplate faults that developed within the evolving arc. The test of our alternative hypothesis, as well as that of contrasting interpretations, will come from additional field, paleontologic, and paleomagnetic studies in these important terranes.

Rogue and Galice Formations

Late Jurassic rocks (Oxfordian and Kimmeridgian) in the Klamath Mountains are well represented by the Galice Formation, a unit of phyllite, slate, and semischist (Fig. 6), of the western Jurassic subprovince. At most localities the metasedimentary rocks are intercalated with and overlie metavolcanic and metapyroclastic rocks of intermediate to silicic composition--the Rogue Formation in northernmost California and southwestern Oregon. Near O'Brien, Oregon, Vail and Dasch (1977) report that Galice slate and graywacke depositionally overlie pillowed spilite of the Jurassic Josephine ophiolite. Late Jurassic plutons ranging in age from 155 to 140 m.y. intrude the Rogue and Galice formations and mafic and ultramafic rocks assigned to the Josephine ophiolite in both Oregon (Hotz, 1971; Dick, 1973) and California (Young, 1974). At the present time, all these Jurassic units (sedimentary, volcanic, plutonic) lie in the upper plate of a regional thrust fault above Tithonian and younger Franciscan rocks (in Oregon, Dothan) of the Coast Ranges.

The paleogeographic setting of the Rogue-Galice assemblage is uncertain. Vail and Dasch (1977) believe that the Josephine ophiolite probably formed "near the continental margin". . ."in a marginal basin behind an island arc represented by volcanic rocks of the Galice and Rogue Formations" (1977, p. 520). Farther north, in an area west of Grants Pass, pyroclastic, volcanic, and volcaniclastic rocks correlated with the Rogue and Galice formations are also interpreted by Garcia (1976) as comprising a volcanic arc originally constructed on oceanic lithosphere. Snoke (1977) postulates that Galice sediments were initially deposited (Callovian-Oxfordian time) in a basin that lay east of an east-dipping subduction zone and a Jurassic arc (of Rogue-equivalent volcanics), then were deposited (Oxfordian-Middle Kimmeridgian time) in a forearc basin as the locus of arc magmatism jumped to the east of the Galice basin. Whatever the specific paleogeographic setting for Galice sedimentation, the presence of heavy detrital minerals in Galice graywackes (including glaucophane, hornblende, garnet, tourmaline, epidote and zircon; Harper, 1978) indicates that Galice sediments were derived from older Klamath crystalline rocks, were deposited near the North American continental margin, and may not have been separated from the continent by an intervening oceanic trench. It is, therefore, difficult to visualize the Rogue-Galice assemblage as being a far-traveled and exotic component of the Cordilleran "collage". As discussed in a later section, a similar conclusion can be drawn for the Logtown-Ridge-Mariposa sequence of the western Sierra Nevada with which the Rogue-Galice sequence has often been correlated.

Nature of the Middle and Late Jurassic Klamath arc(s)

As recently stated by Irwin and others (1977, p. 562) for the Klamath and Coast Range provinces, the "multiplicity of volcanogenic elements indicates that the Jurassic Period was a time of great tectonic complexity and that the region may have been a broad archipelago". It is appropriate here to review the apparent components of this terrane.

In the eastern Klamath Mountains an Early Mesozoic volcanic arc rose locally above sea level until at least the Bajocian (Middle Jurassic); younger strata, if once present, may now lie hidden beneath an eastern cover of Cenozoic volcanic rocks. This arc, although constructed upon an ensimatic arc of Paleozoic age, was firmly tied to continental North America after the Permo-Triassic Sonoma orogeny. To the west, the North Fork-Hayfork ophiolitic terrane appears to represent ocean crust, but the presence within it of older blueschist, metachert, and carbonate olistoliths(?) suggests the existence of a nearby source area (or areas) of uncertain location. In the North Fork terrane southwest of Cecilville, low-grade mafic volcanic and pyroclastic rocks that appear to lie depositionally above rhythmically bedded cherts are overlain unconformably by shallow water limestones. Rounded cobbles of metabasalt are present in basal layers of the limestone, which is itself overlain by more rhythmically bedded chert (Davis, 1968). Samples apparently collected from this upper chert unit yield radiolarians of Late Triassic age (Irwin, Jones, and Kaplan, this volume, localities 8, 9, 10).[1] This stratigraphic sequence is indicative of the growth on the ocean floor of a seamount, its emergence and erosion as an oceanic island, and its subsequent subsidence all before the deposition of Late Triassic cherts.

Farther west, volcaniclastic, pyroclastic, and volcanic(?) strata intruded by Middle Jurassic plutons (Ironside Mountain batholith, 167-165 m.y.) are considered by Charlton (1978; personal communication, 1978) to represent an ensimatic arc constructed on the Rattlesnake Creek ophiolite. To the north the Preston Peak ophiolite and overlying metabasaltic and metasedimentary rocks (some of the latter include grit and conglomerate) are interpreted by Snoke (1977) as a remnant of a primitive, ensimatic island arc. Similar island arc interpretations for the pluton-intruded Rogue-Galice assemblage of rocks have already been cited.

It is simply not possible at this time, in our opinion, to fit these diverse and inadequately dated volcanogenic rock assemblages into a coherent plate tectonics setting. Attempts to do so (e.g. Schweickert and Cowan, 1975; Snoke, 1977) appear to us as premature. At present the western Jurassic, Rattlesnake Creek, North Fork-Hayfork, and eastern Klamath volcanic and sedimentary assemblages are all separated from each other by major east-dipping thrust faults (as diagrammatically represented in Fig. 6). Geologic and geochronologic data bracket each of the three separating faults rather closely. The lower two (between western Jurassic, Rattlesnake Creek, and North Fork-Hayfork terranes) are almost certainly Late Jurassic in age. The higher Siskiyou thrust fault could conceivably be somewhat older (Middle or Late Jurassic) because of the uncertainties concerning the age of the youngest rocks to be found in the underlying North Fork terrane. None of these three faults can be identified with certainty as a convergent plate boundary at the time of its formation, and at least one--the Siskiyou

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[1] Mid-Permian (Wardian) radiolarians and conodonts were taken from a red chert collected in the same vicinity (locality 11). This anomalously old chert appears to lie within a major dislocational zone that separates disrupted ophiolitic rocks of the core of the North Fork antiform from the higher chert-mafic-volcanic-limestone-chert stratigraphic sequence on its eastern flank (Fig. 6). The age of the North Fork ophiolite in the area southwest of Cecilville is, therefore, in question.

thrust--is an intraplate fault that crosscuts older structures in both upper and lower plates (Fig. 6; Ando and others, 1977).

Geologic relations are suggestive that all Middle and Late Jurassic volcanic rocks and coeval plutons in the Klamath Mountains could be components of a single, evolving magmatic arc that was constructed across a previously sutured ocean-continent boundary and was related to eastward subduction along a western trench that has not been preserved. Although an east-dipping Late Triassic or Early Jurassic subduction zone may once have separated the North Fork oceanic terrane from the continental plate to the east, the presently intervening Siskiyou thrust fault does not appear to be a direct expression of such an inferred plate boundary. As mentioned above, the Siskiyou thrust is younger than episodes of low-angle faulting, major antiformal folding, greenschist facies regional metamorphism, and, possibly, Middle Jurassic granitic intrusion into rocks of the North Fork-Hayfork lower plate.

It is possible that a consuming plate boundary is represented by the thrust fault that separates the North Fork-Hayfork and Rattlesnake Creek terranes, the latter with its Ironside Mountain batholith/Hayfork Bally Meta-andesite arc components (as interpreted by D. Charlton). However, geologic relations favor the interpretation that this fault, too, is the consequence of intraplate shortening. The North Fork-Hayfork terrane is intruded by a Middle Jurassic pluton (Forks of Salmon) that is identical in age (167 m.y., K-Ar) and similar in composition (syenodioritic) to the Ironside Mountain pluton (Hotz, 1971; Figs. 7, 11). Thus coeval plutonism appears to have affected both of the ophiolitic terranes prior to the period of thrust faulting that now juxtaposes them. The possibility that detritus from the Rattlesnake Creek-Hayfork Bally Meta-andesite "arc" is present in Hayfork strata (D. Charlton, personal communication, 1978) may be supplemental evidence that the two terranes were in proximity during Early to Middle Jurassic time.

It might be argued that the east-dipping regional thrust fault that separates footwall rocks (Josephine ophiolite-Rogue-Galice) from higher lithological assemblages (Rattlesnake Creek and Preston Peak) represents a fundamental Late Jurassic plate boundary, particularly since the Josephine and Rattlesnake Creek ophiolites appear to be of considerably different ages (Jurassic and Triassic respectively). However, in the context of Klamath plutonism it is difficult to view this thrust fault as other than an intra-arc (intra plate) structure. The thrust postdates strata in the Galice Formation as young as early Kimmeridgian, but it is intruded by plutons of latest Jurassic-earliest Cretaceous ages (ca. 143-126 m.y., K-Ar, Snoke, 1977). Plutons of somewhat older age intrude both footwall Rogue-Galice rocks (155-145 m.y., K-Ar, Hotz, 1971; Dick, 1973; Young, 1974) and hanging wall rocks of the "western Paleozoic and Triassic" subprovince (155-147 m.y., Hotz, 1971). Unfortunately, their age relation to thrust faulting is not known. Since some of the plutons have ages that fall within the Kimmeridgian stage (ca. 157-150 m.y., R. Armstrong, in press) they may be essentially contemporaneous with Rogue-Galice volcanism and, therefore, older than thrusting. More stratigraphic and radiometric age data is obviously needed, but the data reviewed here raise the distinct possibility that Late Jurassic and Early Cretaceous plutons were emplaced before *and* after thrust-faulting into rocks of both the western Jurassic and "western Paleozoic and Triassic" subprovinces.

The most reasonable interpretation of the relationships is that thrusting between the two lithologic assemblages occurred *within* a Late Jurassic-Early Cretaceous magmatic arc, not along a plate boundary. If the widespread Late Jurassic-Early Cretaceous plutonism is related to subduction of oceanic lithosphere beneath the arc, then the convergent plate boundary (trench) lay considerably west of present exposures of Rogue-Galice rocks. Since Late Jurassic and Middle Jurassic plutons are spatially superimposed in the western Klamath Mountains, the possibility exists that both are related to the same east-dipping subduction system.

Collectively, the spatial and temporal relationships between Klamath plutonism and thrust faulting described above indicate that an evolving Middle and Late Jurassic arc complex was internally disrupted and telescoped by Late Jurassic faulting. This deformation can be tied to the effects of plate convergence between ocean basin and arc, as can of course, the widespread Jurassic volcanism and plutonism. This idea, which is amplified in the succeeding section on the Sierra Nevada, is admittedly conservative and raises a number of unresolved questions. Why, for example, is oceanic crust beneath the proposed arc complex younger to the west (Josephine ophiolite) than in areas farther east (Rattlesnake Creek, North Fork ophiolites)?[2] Nevertheless, we suggest that our conservative approach is philosophically at least as satisfying as concepts currently in vogue that three (or more) separate and independently evolving Jurassic volcanic arcs are now preserved in the narrow, 200 km-wide Klamath terrane.

Sierra Nevada

Middle Jurassic through Early Cretaceous volcanism and plutonism is well documented in the geologic record of the eastern Sierras and western Nevada. This magmatic activity is representative of an Andean-type arc formed along the leading edge of the North American plate. However, as in the Klamath Mountains, broadly coeval volcanism and plutonism occurred in areas west of what many consider to be the main, continental margin arc. In the case of the Sierra Nevada, these igneous rocks lie west of the Melones fault zone (Fig. 7), and correlate, in part, with the Rogue/Galice assemblage of the western Jurassic Klamath subprovince. Their plate tectonic setting is uncertain. They have recently been interpreted (Schweickert and Cowan, 1975) as exotic components of the Cordilleran "collage" that include from east to west, an ensimatic east-facing island arc, an interarc basin floored by oceanic crust, and a remnant arc split from the main arc to the east. Collision of the east-facing island arc with the west-facing Sierran continental arc is purported to have occurred along the Melones fault, an arc-continent suture of Late Jurassic age. The Bear Mountains fault zone to the west represents a

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[2] J. Saleeby (personal communication, 1978) suggests that Jurassic ophiolitic assemblages in the western Sierra (Smartsville) and western Klamath (Josephine) regions may have formed in intra-arc pull-apart basins, rather than having been "swept" into the continental margin from places unknown.

zone of partial collision of the remnant arc with its eastern "parent" arc.

This interpretation is troubling to us for a number of reasons--some of them reminiscent of Klamath Mountain problems discussed above, but largely independent of them. In the western Sierra Nevada the Smartsville ophiolite is bordered on the east and west by Schweickert and Cowan's Jurassic island arc and remnant arc respectively. They tentatively interpret the Jurassic ophiolite as the oceanic floor of an interarc basin, formed during rifting of the remnant arc from its parent. The ophiolite, however, has an antiformal structure, and studies by E. Moores and his associates (Bond and others, 1977; Buer, 1977) point to the distinct possibility that flanking Middle and Upper Jurassic volcanic and sedimentary rocks were deposited upon the ophiolite. In other words, the interarc basin may not exist. Another problem with the interarc basin paleogeography of Schweickert and Cowan is that their western (remnant) and eastern (island) arcs are separated near the Consumnes River by a melange belt (Duffield and Sharp, 1975) that contains rocks of "Calaveras" lithology, including limestone blocks bearing a Tethyan Permian fusulinid fauna (Douglass, 1967). This relation is difficult to explain if the hypothesized interarc basin formed by the Jurassic rifting of a Jurassic ensimatic island arc.

The relationships between Mesozoic volcanic and sedimentary rocks in the Sierran Foothills and older oceanic rocks of Calaveras-type are interesting. Saleeby's studies (1977, in press) between the Kings and Kaweah rivers in the southwestern Sierra Nevada indicate that "Calaveras" rocks accreted to the continent were overlain by continent-derived sedimentary rocks of Triassic age and by Jurassic volcanic rocks that can be related to a more westerly, east-dipping subduction zone (Fig. 7). The location of the Kings-Kaweah area with respect to the Melones fault zone to the north is not definite, but Saleeby believes that it is a southern extension of eastern portions of the Sierran Foothills terrane. If so, Jurassic volcanic rocks and somewhat younger plutons that lie west of the Melones fault were part of the continent in Jurassic time and cannot be exotic with respect to North America.

At the opposite, northern end of the Sierra Nevada, studies by Hietanen (1973) and Creely (1965) document that here, too, "Calaveras" rocks west of the Melones fault zone form the basement for Mesozoic volcanic rocks. For example, volcanic rocks of Logtown Ridge (=Rogue Formation?) lithology and age overlie "Calaveras" phyllites in the vicinity of Oroville. Such rocks lie east of the younger oceanic basement represented by the Smartsville ophiolite. Elsewhere in the Sierran Foothills some lithic clasts in Mariposa (=Galice Formation?) graywackes were derrived from a "Calaveras" source terrane (Behrman and Parkinson, 1977). Others were derived from older Paleozoic units (including the Shoo Fly Formation) that lie east of the Melones fault and were part of continental North America at the time of Mariposa sedimentation (R. Schweickert, personal communication, 1978).

In central parts of the Foothills belt, the relationship described by Duffield and Sharpe (1975) that a Calaveras-type "melange" along the Bear Mountains fault zone separates similar Jurassic volcanic terranes, could also be explained by the initial deposition of volcanic rocks atop a previously disrupted "Calaveras" basement. As Schweickert and Cowan (1975) point out, it is extremely significant that no fragments of the adjacent (overlying?) volcanic rocks (Logtown Ridge Formation) occur within the melange.

These geologic relations collectively suggest a paleogeographic and tectonic alternative to the hypotheses of Schweickert and Cowan (1975). We propose a markedly different explanation for the relations between Jurassic volcanic and plutonic rocks now in areas east and west of the Melones fault. The explanation is compatible with that presented above for the Klamath Mountains which are, of course, a northern extension of the Sierran terrane. We postulate that Early(?), Middle, and Late Jurassic volcanic and plutonic rocks in the Sierra Nevada belong to a magmatic arc complex that was built across a previously sutured (Middle to Late Triassic) convergent plate boundary. East of the boundary, the Jurassic arc was constructed on an older basement terrane that included the Late Triassic Sierran arc and older litho-tectonic elements (from northwest to southeast, the Paleozoic Klamath-Sierran arc, Antler and Sonoma allocthonous units, the miogeoclinal prism, and cratonal basement and cover). Directly west of the boundary the arc was built on accreted Late Paleozoic and Early Mesozoic oceanic rocks of the "Calaveras" terrane (equivalent to Cache Creek, North Fork, Rattlesnake Creek assemblages farther north). Still farther west, its basement was at least locally relatively undisturbed ocean crust—the Smartsville ophiolite (probably older than, but comparable to the Josephine ophiolite of the western Klamath Mountains).

The arc did not develop statically across these diverse basement terranes. Marine sedimentation, volcanic activity, and plutonic intrusion were accompanied, as in the Klamath Mountains, by profound internal disruption and imbrication of the evolving arc by strike-slip and thrust faulting. Saleeby's Kings-Kaweah "suture" is certainly the best documented example of the former. Displacement along this zone of transcurrent faulting began roughly 190 m.y. ago and continued until at least the Late Jurassic as indicated by a 157 m.y. concordant U/Pb zircon age for a synkinematic intrusion pluton emplaced across it (Saleeby, 1977; in press). To the north, the Melones fault zone, which may be a component of the Kings-Kaweah "suture", disrupts a 162 m.y. old diorite stock; movement along it appears to have ceased by 140 m.y. ago (Morgan and Stern, 1977).

Relationships between the steep, east-dipping faults of the western Sierra and the low-angle, east-rooting thrust faults of the Klamath Mountains have been explored by Davis (1969). He proposed that these broadly coeval fault systems are linked structurally and that the thrust faults of the Klamaths must steepen southward into apparently deeper structural levels now exposed in the western Sierra Nevada. Saleeby's analysis of right-slip along the Kings-Kaeweah suture and the probable right-lateral offset of the "Calaveras Formation" across the Melones fault (Fig. 5) indicate that intraplate thrust-faulting in the Sierran-Klamath Jurassic arc had a major strike-slip component.

In conclusion, we find no compelling reason to believe that more than one Early(?) to Late Jurassic magmatic arc is represented in the geologic terrane east of the Great Valley of California. The extreme narrowness of separate exotic island and remnant arcs presumed by others to occur in the western Sierra Nevada (and western Klamath Mountains) can be explained as the consequence of internal imbrication of a single Jurassic arc in response to Pacific-North American plate convergence. The trench and east-dipping subduction zone responsible for arc magmatism lay to the west (Fig. 7), but is doubtful that either has been preserved in the geologic record.

LATE CRETACEOUS AND EARLY TERTIARY

By Late Cretaceous time the paleogeography of the western Cordillera had become much simpler than that of the preceding Middle Jurassic to mid-Cretaceous time interval. In the north, the continental margin lay along the west side of accreted "Wrangellia", although shallow marine seas (Nainamo Basin) lay between southern Vancouver Island and the mainland to the east (Fig. 11). In California, the continental margin lay west of the present Great Valley and the Klamath Mountains. The Jurassic archipelago of the Klamath-Sierran region now constituted a largely emergent continental border that contributed detritus into the "Great Valley" forearc basin to the west. Much of the better documented history of subduction zone tectonics in the Cordillera for Late Cretaceous-Early Tertiary time comes from studies of the Franciscan complex and Great Valley Sequence in the California Coast Ranges. Unfortunately, the location of the continental margin between northern California and the Puget Sound area, the region of the so-called Columbia Embayment, is obscured by a Cenozoic volcanic cover and is open to considerable speculation (see below).

As Hamilton proposed in 1969, eastward subduction of Pacific lithosphere along the continental margin in Late Cretaceous time is supported by the record of widespread magmatism to the east. But, the hundreds of age dates that have become available since Hamilton's paper indicate that this magmatic history is pronouncedly diachronous. There are obvious complexities in the geometry and history of Late Cretaceous-Early Tertiary subduction along the continental margin.

In most of California, western Nevada, north-central Washington, and southcentral British Columbia, a major plutonic pulse, dated as occurring between 110 and 80 m.y. ago (Armstrong and Suppe, 1973; Armstrong and others, 1977) was followed by a magmatic hiatus that persisted into the Early Tertiary. Plutons of 110-80 m.y. age are also present in Idaho, southeastern California and southern Arizona, but in these areas (and western Montana) the major magmatic pulse occurred between 80 m.y. and latest Cretaceous to Eocene time. The diachroneity of Cordilleran magmatic phenomena is reflected in temporal and spatial variability of back-arc Cordilleran tectonics, as discussed elsewhere (e.g. Burchfiel and Davis, 1975; Dickinson, 1976).

We limit our discussion of the Late Cretaceous-Early Tertiary evolution of the western Cordillera to a single, but extremely important (and puzzling) topic--the existence of major right-lateral strike slip faulting within the Cordillera north of Oregon. This topic supplements other evidence for dextral plate interactions along the evolving Mesozoic continental margin, among them: the likelihood of

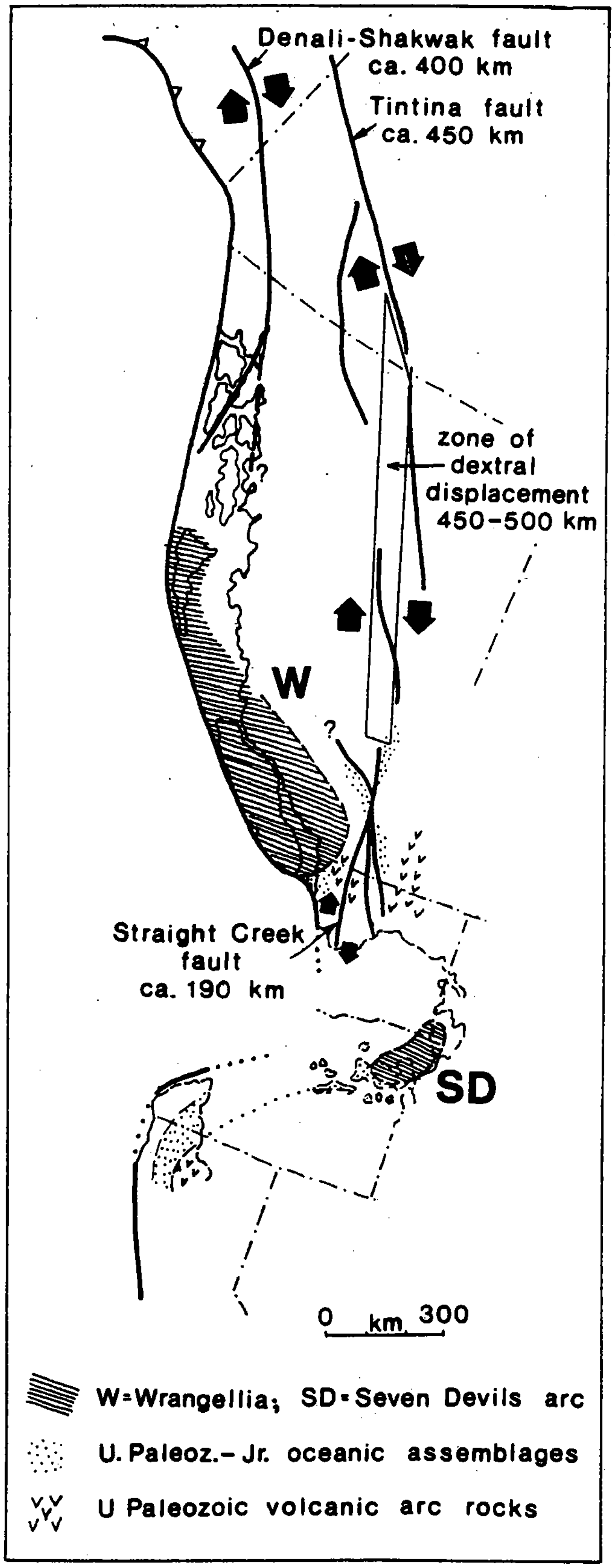

Figure 11. Location of Late Cretaceous-Early Tertiary continental margin with respect to major intracontinental transcurrent faults in the northern Cordillera.

the northward migration (relative to North America) of exotic rock assemblages now present in the Cordilleran "collage" (e.g. Cache Creek assemblage, "Wrangellia"); the Jurassic disruption of the western Sierra Nevada along faults with right-slip components; the inferred Late Jurassic to Early Cretaceous transcurrent displacement of "Cascadia" from a southern source terrane; and, finally, the Late Mesozoic or Early Tertiary dextral oroclinal bending of stratigraphic and structural elements in the southern Sierra Nevada, a topic to be discussed elsewhere (Burchfiel and Davis, in preparation).

Dextral Transcurrent Faulting in the Northern Cordillera

The Northern Cascades of Washington were affected by a profound deformational and metamorphic event of mid- to Late Cretaceous age. Northwest-trending elements in the metamorphic core of the Cascades have been offset by the north-striking Straight Creek fault and juxtaposed against the higher level Shuksan thrust plate of the western Cascades. Misch (1977) considers that total right-slip of approximately 190 km along the Straight Creek fault is required by the displacement of metamorphic rocks across it. Specifically, he correlates the distinctive Chiwaukum Schist east of the fault near Stevens Pass, Washington, with the Settler Schist near Harrison Lake, B. C. Lesser dextral displacements of 160 km and 120 km have been proposed, respectively, by Anderson (1977) and Okulitch and others (1977).

The Straight Creek fault is the most prominent of a number of post-orogenic faults that disrupt the largely crystalline terrane of north-central Washington. Other faults include the Ross Lake fault along the eastern side of the Cascade crystalline core and the Chewack-Pasayten fault at the eastern edge of the Methow trough. The amounts of transcurrent displacement, if any, along these two faults is unknown. To some (Okulitch and others, 1977), the Chewack-Pasayten fault is probably the most significant transcurrent fault in southern British Columbia. Coates (1974), however, interpreted the Chewack-Pasayten fault as a normal fault with major downthrow to the west in mid-Cretaceous time. The lack of correspondence between clasts in Cretaceous conglomerates and crystalline source rocks due east of the fault suggested to him a transcurrent component of movement along it, with perhaps "right-lateral separation of several tens of miles" (Coates, 1974, p. 63). Barksdale (1975, p. 58) concludes that "there is great vertical displacement along the Chewack-Pasayten Fault", but "Evidence that some of the movement was strike-slip in nature could not be documented."

Collectively, the post-orogenic faults of north-central Washington and their northern extensions in the Fraser fault system of southern British Columbia appear to represent the southernmost members of a major intraplate zone of dextral transcurrent faulting that extends at least as far north as eastern Alaska (Fig. 11; Gabrielse and others, 1977). Gabrielse and Dodds (1977) propose that cumulative right-lateral displacements of 450-500 km are necessary to explain offset geologic terranes in north-central British Columbia. This estimate agrees well with a 450 km offset well documented for the Tintina fault zone (Yukon Territory) still farther north and on strike with the zone of faults reported by Gabrielse and Dodds (Tempelman-Kluit and others, 1976). Dextral faulting in these northern areas is variably described as "mainly late Cretaceous to Eocene age" (Gabrielse and Dodds, 1977) and occurring "shortly after" mid-Cretaceous granitic intrusion (Tempelman-Kluit and others, 1976).

The time of strike-slip displacement along the Straight Creek fault has not been conclusively established. It truncates the Ross Lake fault which is intruded in Washington by the syntectonic 88 m.y. old Black Peak pluton (Tennyson, 1974). According to Okulitch and others (1977) major transcurrent displacement along the Hope (Canadian) segment of the Straight Creek fault ceased before intrusion of the Spuzzum pluton across it (84 m.y. ago). Nevertheless, Tertiary dip(?)-slip reactivation seems required, for the Hope fault cuts Eocene conglomerates in the Fraser River valley. Mattinson's radiometrically-based conclusion (1972) that metamorphic rocks in the core of the Northern Cascades formed between 90 and 60 m.y. ago, necessitates a post-Cretaceous age for their lateral offset by the Straight Creek fault. Transcurrent movement had clearly ended by Oligocene time since the composite Chilliwack batholith intrudes the fault and has not been laterally offset along it.

Despite uncertainties regarding the age and displacement histories of major north and northwest-striking faults in the Cascade-Okanogan region, we consider it highly probable that they belong to the zone of intra-Cordilleran transcurrent faulting described briefly above and illustrated in Figure 11. These faults disappear to the south beneath a Cenozoic volcanic cover. It should be emphasized that the cumulative lateral displacements for Canadian portions of this fault zone are apparently several times that of the Straight Creek fault alone. Perhaps some of the Canadian offset dates from earlier, pre-mid-Cretaceous transcurrent faulting related to the northward emplacement of "Cascadia".

The origin of this intra-Cordilleran transcurrent zone is problematical, but the geometric problems posed by its existence are clear. Consider the Straight Creek fault only. When right-slip along the Straight Creek fault is reversed by 190 km to bring the once adjacent Stevens Pass and Harrison Lake areas into juxtaposition (Fig. 12), it becomes apparent that pre-latest Cretaceous rocks on the east side of the fault must extend as far south of Stevens Pass as they do on the other side south of Harrison Lake, i.e., 225 to 320 km. In other words, pre-Tertiary rocks must underlie the western Columbia Plateau at least as far south as the present Columbia River and apparently into northern Oregon. Thus, although the Straight Creek fault must extend into northern Oregon, a good case can be made that it does not offset pre-Tertiary terranes in central Oregon. The probable continuity of pre-Cretaceous paleographic elements and rocks assemblages between the Klamath Mountains and east-central Oregon has been presented at length in this paper. In addition, regional gravity anomalies in central and northeastern Oregon parallel these geologic trends and are unbroken along a southward projection of the Straight Creek fault (Thirnvathukal, 1970).

In short, the Straight Creek fault appears to terminate abruptly beneath the lava-covered Columbia Embayment. To make matters worse, there is no apparent "room" to accomodate additional reversals of slip that might be assumed to have occurred along

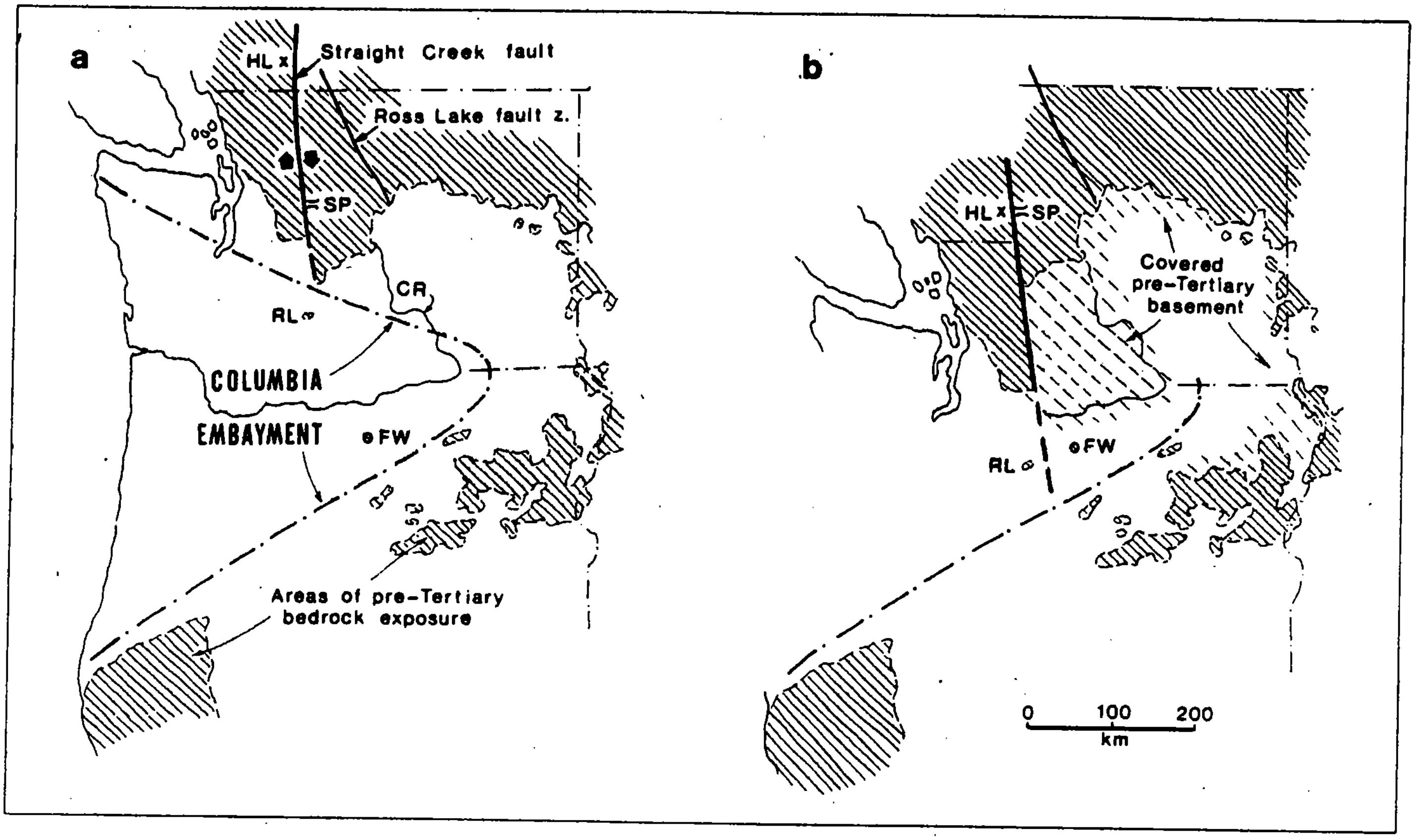

Figure 12. (a) Location map of the Columbia Embayment and areas of pre-Tertiary bedrock exposures. HL = Harrison Lake; SP = Stevens Pass; RL = Rimrock Lake inlier of Upper Jurassic ophiolitic assemblage; FW = Fitzpatrick well (Chevron) with basement of Jurassic argellite (S. Reber, personal communication, 1977); CR= Columbia River. (b) Reconstruction of pre-Tertiary bedrock terranes prior to Straight Creek faulting (190 km right-slip). The effects of Cenozoic clockwise rotation of pre-Tertiary rocks in Oregon have not been reversed in this reconstruction.

other, more easterly faults in northern Washington (such as the Chewack-Pasayten). These geometric problems can be relieved as discussed below, but a complete solution for them is not now at hand. First, it can be assumed that the trends of Mesozoic bedrock terranes in Oregon were originally much more northerly than they are today. Their present northeasterly orientation would be the result of Cenozoic clockwise rotation of an initially more linear continental margin. Hamilton (1969) among many others has proposed this, and Simpson and Cox (1977) have recently presented some paleomagnetic evidence for it.

If such rotation has occurred, the Straight Creek fault might have originally intersected the continental margin in central Oregon at a small angle (Fig. 13a). Alternatively, displacement along the Straight Creek and parallel faults could be related to transverse rifting of the continental margin (Fig. 13b), with a geometry comparable to that proposed for the earlier northward drifting of "Cascadia" and, perhaps, in some way related to it. This latter geometric alternative cannot yet be tested, since the age of basement rocks in the Columbia Embayment west of the postulated trace of the Straight Creek fault is not known.

Both geometric alternatives require that the Straight Creek fault (and related transcurrent structures) join in some manner a Late Cretaceous-Early Tertiary ocean(Kula?)-continent plate boundary in central Oregon. This boundary was either a dextral transform fault or a subduction zone characterized by northeastward convergence. The cessation of arc magmatism in northern Washington and British Columbia between 80 and 55 million years ago is most compatible with a boundary of transform type.

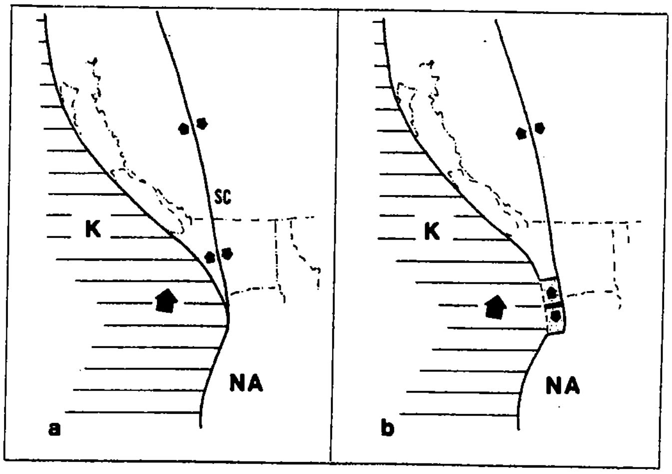

Figure 13. Possible Pacific (K = Kula?)-North American plate interactions as an explanation for latest Cretaceous-Early Tertiary transcurrent faulting within the northern Cordillera.

FINAL COMMENTS

The summary we have presented here of the Mesozoic evolution of the Cordilleran "eugeosyncline" is obviously only one "state-of-the-science" version as of January, 1978. It is evident to us from the great number of 1977-dated references we have cited herein, that a January, 1979 version may differ in significant respects from this. Indeed, the detailed studies by others in this volume may require modification of parts of our synthesis at the time of its publication. We believe, however, that several general observations can be made about the Cordillera that should stand the test of time reasonably well.

One is that the post-Early Triassic tectonic history of the western Cordillera has been fundamentally governed by the right-lateral motion of Pacific plates along and obliquely beneath the continental margin. This conclusion has been previously widely accepted for Late Cenozoic tectonics. The evidence for Mesozoic-Early Cenozoic dextral plate interaction is most easily seen in northern portions of the Cordillera where exotic terranes of initially more southerly derivation are now components of the orogen, and where major transcurrent faults dominate the structural grain of northern Washington, British Columbia, the Yukon Territory, and Alaska. But, a similar story is beginning to emerge from studies in the western part of the southern Cordillera and will clarify with time.

Another observation is that major east-dipping thrust faults within the accreted "eugeosyncline" of the western Cordillera will probably be increasingly recognized as intraplate structures, not former convergent plate boundaries or sutures. It is our opinion that late crustal shortening within the accreted terrane occurs in response to continued plate convergence offshore, and is likely to produce the most conspicuous and sharply defined thrusts within that terrane. These intraplate thrust faults characteristically obscure or cover earlier, inactive convergent plate boundaries. that can be inferred from the geologic record. This relation suggests that their locations are often controlled by inherited crustal anisotropies. Examples of such intracontinental thrusts in the northern Cordillera include the King Salmon-Nahlin-Vital thrust system of British Columbia which is spatially coincident with an older Cache Creek-Nicola/Takla plate boundary, the Church Mountain thrust of the western Cascades which separates Nooksack strata deposited on both older oceanic rocks (lower plate) and arc-continent rocks (upper plate), and thrust faults in the Riggins area, Idaho. Southern Cordilleran examples include the Siskiyou thrust fault in the Klamath Mountains, the Coast Range thrust of the northern California Coast Ranges (Suppe, 1977), and possibly the Melones fault zone of the western Sierra Nevada. The telescoping of the western Cordillera along late Mesozoic thrust faults has been so extreme that few, if any, original plate boundaries between its accreted components have survived. When combined with the obliterative effects of plutonism, metamorphism, and transcurrent faulting, and the extensive cover of younger volcanic rocks in the Cordillera, the search for Mesozoic and Paleozoic "sutures" is not promising.

Finally, an observation is in order about the apparent complexity of plate interactions in parts of the Mesozoic Cordillera. We have presented, for example, several hypotheses concerning the geometry and kinematics of plate interactions in the Cascade region of northern Washington and southwestern British Columbia. But, as admitted in the text, we are not yet able to resolve all aspects of plate motion in the area into one coherent, internally consistent model or synthesis. In part, this is due to the inadequacies of the geologic record for this complex area. It may, in part, be due to our own conceptual limitations. But surely some portion of the problem can be attributed to the likely initial complexities of plate interactions in the region. Studies of contemporary tectonics in ocean-arc-continent domains such as the Caribbean, the southwestern Pacific, and Indonesia reveal the bewildering array of convergent, transform, and divergent plate motions that occur synchronously between plate elements in geographically restricted areas. If any of these modern domains become collapsed against and accreted to a neighboring continent, it is most unlikely that incontrovertible evidence for their transient, pre-accretional geometries and kinematics will survive. We face precisely such problems in the Mesozoic Northern Cascades and, perhaps, other areas of the Cordilleran "collage". It is unlikely that all will be solved, but the attempts must be made.

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