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## *Geology and paleontology of the early Tertiary Chuckanut Formation*

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### ABSTRACT

Eocene nonmarine sedimentary rocks that occur in northwest and central Washington as a widespread series of outcrops are evidence of a meandering river system that existed prior to the mid-Tertiary uplift of the North Cascade Range. Arkosic strata appear to have initially been deposited in a basin that was later divided by strike-slip faulting, producing outcrops of the Swauk Formation on the eastern flank of the North Cascades, and the Chuckanut Formation to the west. Plant fossils are abundant in both formations, but the Swauk paleoflora has received little study. The Chuckanut Formation paleoflora records a marked shift in the region's paleoclimate. The Late Paleocene to Middle Eocene Bellingham Bay and Slide Stratigraphic Members, which comprise the lower 6000 m of the formation, contain diverse assemblages of subtropical plant fossils. In contrast, the overlying 3000-m-thick Padden Member contains taxa indicative of a warm temperate paleoclimate. An unconformity may separate the Padden Member from older Chuckanut strata, and the age of the Padden Member has not been determined. The climate shift may have been a Late Eocene fluctuation, but the possibility that the floral changes represent the transitional Eocene-Oligocene cooling event cannot be discounted. Animal fossils from the Chuckanut Formation include aquatic mollusks and a soft-shelled turtle, and track impressions from a variety of birds and mammals.

**Keywords:** Chuckanut Formation, Eocene, paleobotany, paleoclimate, paleontology.

### INTRODUCTION

The Eocene Epoch was a time of widespread nonmarine sedimentation in the Pacific Northwest. Fluvial and lacustrine deposits are preserved in a discontinuous series of structural basins that extend from southwestern Washington to central British Columbia (Fig. 1). The abundance of Eocene nonmarine strata is related to the region's tectonic evolution. The oblique

convergence of oceanic and continental crust plates (Atwater, 1970) created a series of fault-bounded basins where sediments accumulated. In addition, a broad floodplain extended from the Pacific coast to nearly to the Washington-Idaho border prior to the uplift of the Cascade Range, and meandering rivers left an extensive sedimentary record. One of North America's thickest sequences of nonmarine sediment, the Chuckanut Formation comprises ~8300 m of arkose, siltstone, conglomerate, and

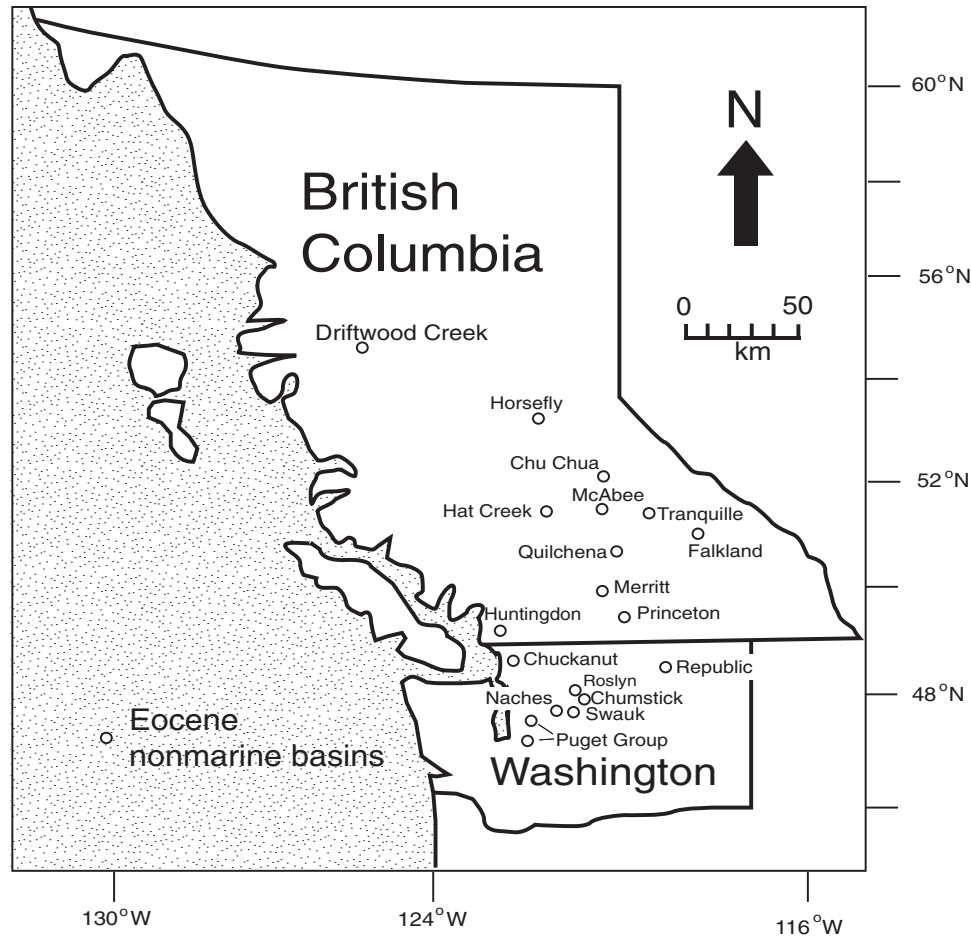


Figure 1. Eocene nonmarine basins in Washington and British Columbia.

coal. The best known outcrop zone is in western Whatcom and Skagit Counties, where the Early Tertiary sediments unconformably overlie Paleozoic and Mesozoic exotic terrane rocks (Dragovich et al., 2002). These exposures are only a small relict of a much larger depositional basin. Several formation names have been given to rocks that closely resemble the Chuckanut strata in terms of petrology, paleontology, and age. In southwest British Columbia, the Burrard and Kitsilano Members of the Huntingdon Formation (Mustard and Rouse, 1994) are considered to be Canadian extensions of strata that are described as the Chuckanut Formation on the American side of the international boundary. No sharp boundary separates Chuckanut outcrops from those of the Swauk Formation, though the type localities for the two formations lie on opposite flanks of the North Cascades. The geographic distribution of outcrops along the Straight Creek–Fraser and Darrington–Devil’s Mountain fault zones (Fig. 2) suggests that the sediments were initially deposited in a single large basin that was later broken up by strike-slip faulting. This faulting and the subsequent transport of the sedimentary materials was one of the important structural events in the geologic evolution of the North Cascades. Prior to

the development of modern methods for determining radiometric ages of crystalline rocks, the age of the Chuckanut Formation provided one of the only pieces of evidence for interpreting the onset of orogeny.

The Chuckanut Formation bears many petrologic and paleontologic resemblances to the Puget Group, an extensive series of coal-bearing sedimentary rocks of early Tertiary age that extend from the Seattle area south to Centralia (Wolfe, 1968; Burnham, 1994). Chuckanut and Puget Group rocks appear to have been deposited more or less contemporaneously, but in separate basins. Unlike the Chuckanut Formation, the Puget Group includes deltaic and marine sediments, and volcanic interbeds are commonly present. Wolfe (1968) concluded that the Puget Group strata are predominantly Eocene, with the youngest beds being Oligocene in age.

#### AGE OF THE CHUCKANUT FORMATION

Knowlton (1893, 1903) assigned an Eocene age to the Swauk Formation based on plant fossils, an interpretation that has been confirmed by many subsequent investigations (e.g.,

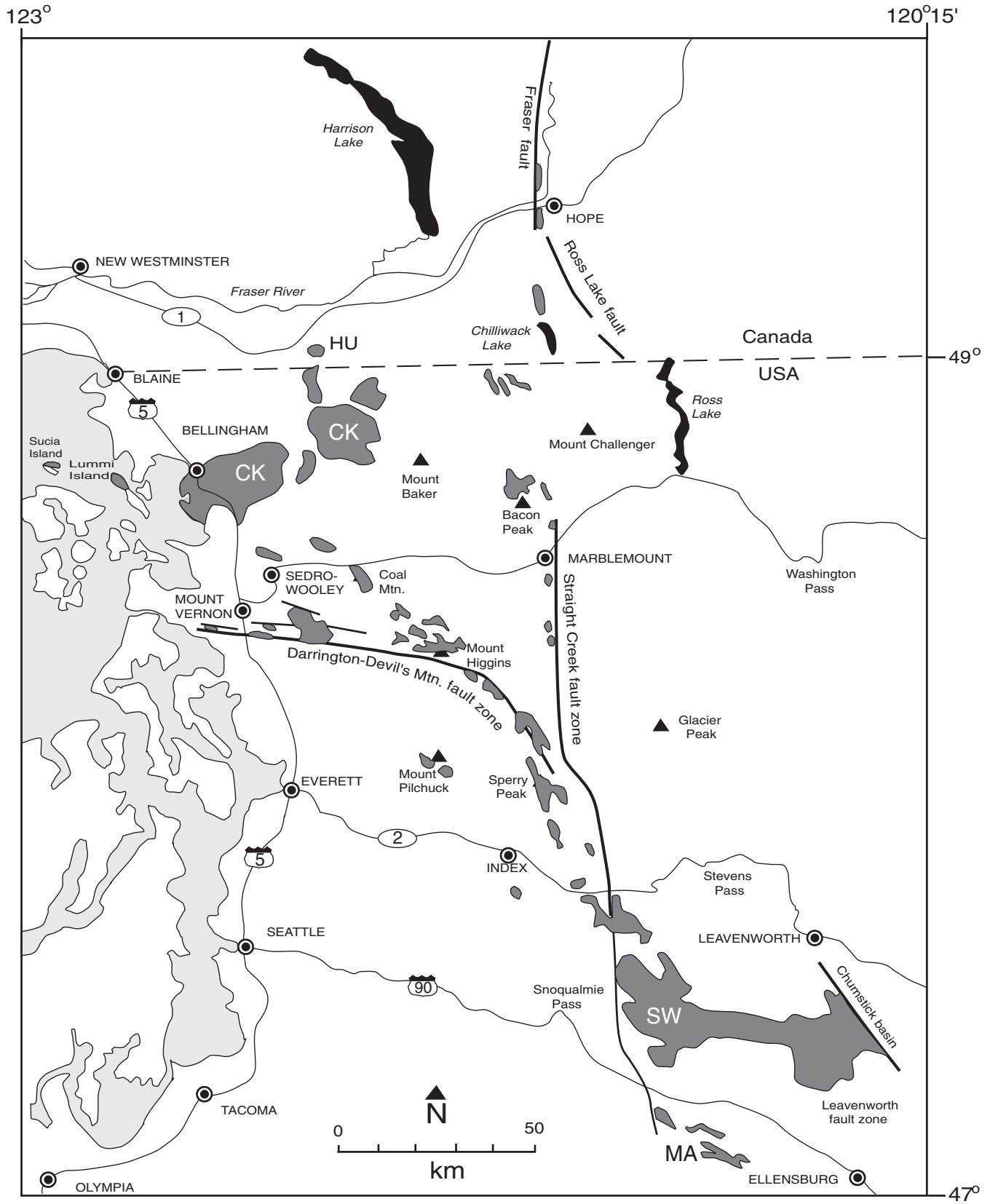


Figure 2. Outcrops of Eocene sedimentary rocks in central and northwest Washington are distributed along major strike-slip fault zones. CK—Chuckanut Formation, HU—Huntingdon Formation, MA—Manastash Formation, SW—Swauk Formation.

Gresens, 1982; Tabor et al., 1984; Taylor et al., 1988; Evans and Johnson, 1989). Prior to the early 1980s, the Chuckanut Formation was erroneously considered to be Late Cretaceous–Paleocene. This interpretation was largely based on the belief that Late Cretaceous Nanaimo Group marine strata on Sucia Island were a seaward extension of nonmarine Chuckanut Formation beds on the mainland (Pabst, 1968). This hypothesis dates from the time when the region's complex geologic history was not yet recognized; today we know that Nanaimo and Chuckanut strata owe their proximity to tectonic transport, not to coeval deposition.

Johnson (1982, 1984a) obtained the first radiometric age dates for the Chuckanut Formation main outcrop belt, and other workers have published radiometric ages for Chuckanut strata in other locations, and for the Swauk Formation in central Washington (Tabor et al., 1982, 1984; Evans and Ristow, 1994; Whetten and others 1988). In most instances, the relative stratigraphic positions of the dated samples were not determined, but ages of detrital zircons, volcanic interbeds, and overlying volcanic rocks, suggest that the Swauk and Chuckanut Formations are primarily composed of Eocene strata (Fig. 3). In the case of the Chuckanut Formation, Johnson (1982, 1984a) obtained a fission-track age of  $49.9 \pm 1.2$  Ma for a tuff bed located ~2600 m above the basal contact of the Bellingham Stratigraphic Member, the formation's oldest unit. Johnson's fission-track age determinations of numerous detrital zircons indicate that the oldest Chuckanut strata are no older than Late Paleocene. Other radiometric age determinations from Chuckanut Formation rocks (Fig. 3) have come from localities outside the main outcrop belt, where stratigraphic positions are uncertain.

The youngest Chuckanut beds were probably deposited in the Late Eocene, but no radiometric ages have been determined for these rocks. An Early Oligocene age cannot be excluded as a possibility, and occurrences of Oligocene arkosic sediments in western Skagit and Snohomish Counties (Marcus, 1991) are evidence that fluvial depositional environments were present in the region during this time period.

## SEDIMENTATION

Southwesterly paleocurrent directions indicate that the Chuckanut Formation sediments were probably largely derived from weathering of granitic bedrock of the Omineca Crystalline Complex near the present Washington-Idaho border. Paleocurrent directions in the younger beds provide evidence of the development of radial drainage patterns, probably a result of emergence of local highlands during the Late Eocene. These younger bedrock exposures contain increased abundances of chert and metamorphic rock fragments derived from local terranes.

Johnson (1984a, 1984b) provided detailed descriptions of sedimentary characteristics of the Chuckanut Formation. Cross-bedded arkose beds typically originated as point bar deposits, but some sandy sediments represent crevasse splay deposits that formed when riverbank levees were breached. Siltstone beds, commonly rich in plant fossils, represent overbank deposits that accumulated when episodic floods inundated the lowland forests adjacent to the ancient river. Conglomerate beds typically represent lag gravels in the main river channels. Lacustrine sediments are scarce in the Chuckanut Formation. Typical depositional environments are shown in Figure 4.

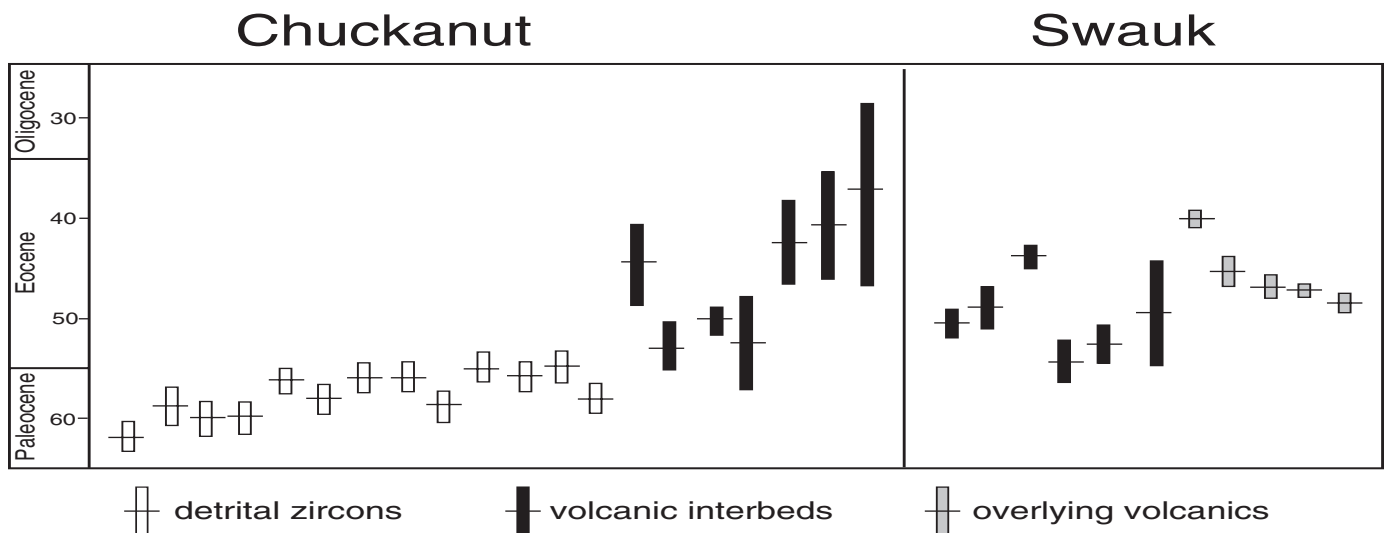


Figure 3. Compilation of radiometric age determinations that have been published for the Swauk and Chuckanut Formations. Data from Johnson (1982), Tabor et al. (1982, 1984), Whetten et al. (1988), Cheney (1994), and Evans and Ristow (1994). The relative stratigraphic positions of most dated samples are unknown, but the data plot provides important age constraints. Detrital zircon ages indicate that the oldest Chuckanut strata can be no older than late Paleocene, and volcanic interbeds have Eocene ages. For the Swauk Formation, the ages of overlying volcanics suggest that sediment deposition had ended by the Late Eocene.

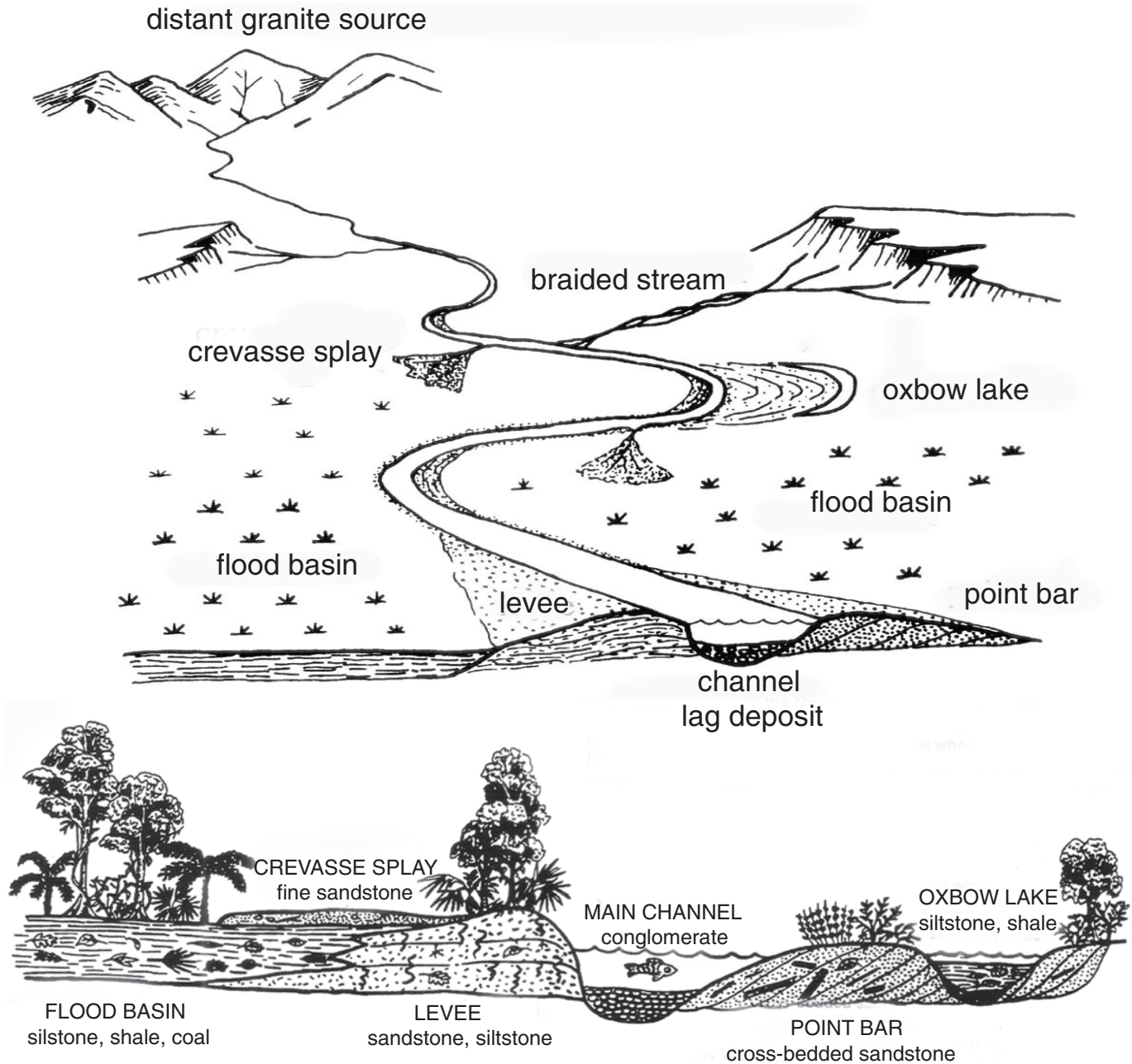


Figure 4. Depositional environments typical of meandering rivers.

## STRATIGRAPHY

Reconstructing the stratigraphy of the Chuckanut Formation is difficult, in part because of the great thickness and very large areal extent (>2000 km<sup>2</sup> in the northwestern outcrop belt). In addition, fluvial deposits consist mostly of interfingering lenses and ribbon-like beds rather than horizontal “layer cake” strata. The scarcity of distinctive marker beds further complicates stratigraphic analysis, along with a shortage of tephra layers or volcanic interbeds that might provide radiometric

dates. As a final challenge, the Chuckanut Formation has been folded and faulted (Fig. 5).

Despite these challenges, Johnson (1982, 1984a) divided the northwestern outcrop belt into 7 stratigraphic members based on petrologic characteristics (Fig. 6). As discussed later, Johnson’s stratigraphy was modified by Mustoe and Gannaway (1997) based on paleontologic evidence to produce the column shown in Figure 7. Johnson identified seven lithologically distinctive units within the Chuckanut Formation, but four of them are small and localized in comparison to three members that form



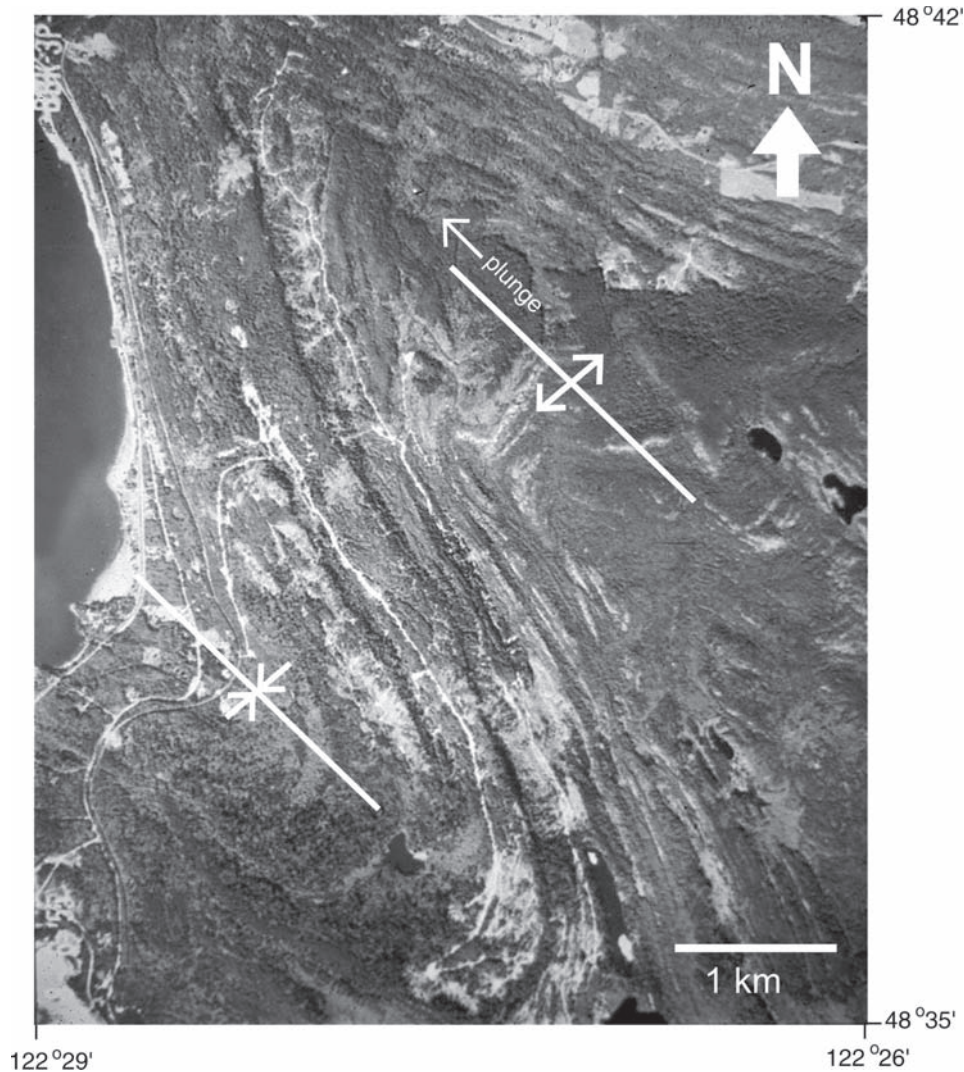


Figure 5. Air photo of Chuckanut Formation in the Chuckanut Mountain area south of Bellingham, Washington.

extensive outcrops. The Bellingham Bay and Slide Stratigraphic Members comprise the lower 5260 m of the Chuckanut Formation. Bellingham Bay Member beds are exposed as a 2600-m-thick stratigraphic section along Chuckanut Drive. In the Mount Baker foothills, the Bellingham Bay Member is overlain by the Slide Member, a unit that contains abundant beds of carbonaceous siltstone. No clear contact has been recognized between these two members, and they possibly represent a gradational facies transition. In the Bellingham area and in the foothills, these older Chuckanut beds are overlain by the 3000-m-thick Padden Member, a poorly understood unit first recognized as a separate stratigraphic entity by Johnson (1984a). Johnson considered the Padden beds to interfinger with those of the Slide Member, and he suggested that the two sets of strata represent different facies contemporaneously deposited within a single basin. This inter-

pretation was the basis for Johnson's estimate of ~6000 m for the total thickness of the Chuckanut Formation. Paleoclimate analyses support a different story (Mustoe and Gannaway, 1997). The Bellingham Bay and Slide Members preserve abundant fossil evidence of a subtropical environment. In contrast, the paleoflora of the Padden Member indicates the change to a warm temperate climate. This paleoclimate evidence (presented in more detail later in this paper) conflicts with Johnson's (1982, 1984a) hypothesis that the Slide and Padden Members represent contemporaneous deposition, and the total thickness is probably nearer to 8000 m than 6000 m. No contacts have been observed between the Padden Member and other Chuckanut strata have been found, and it is possible that an unconformity separates the Padden from the underlying beds. This shift from subtropical to warm temperate climate shift may be evidence of temperature fluctuations

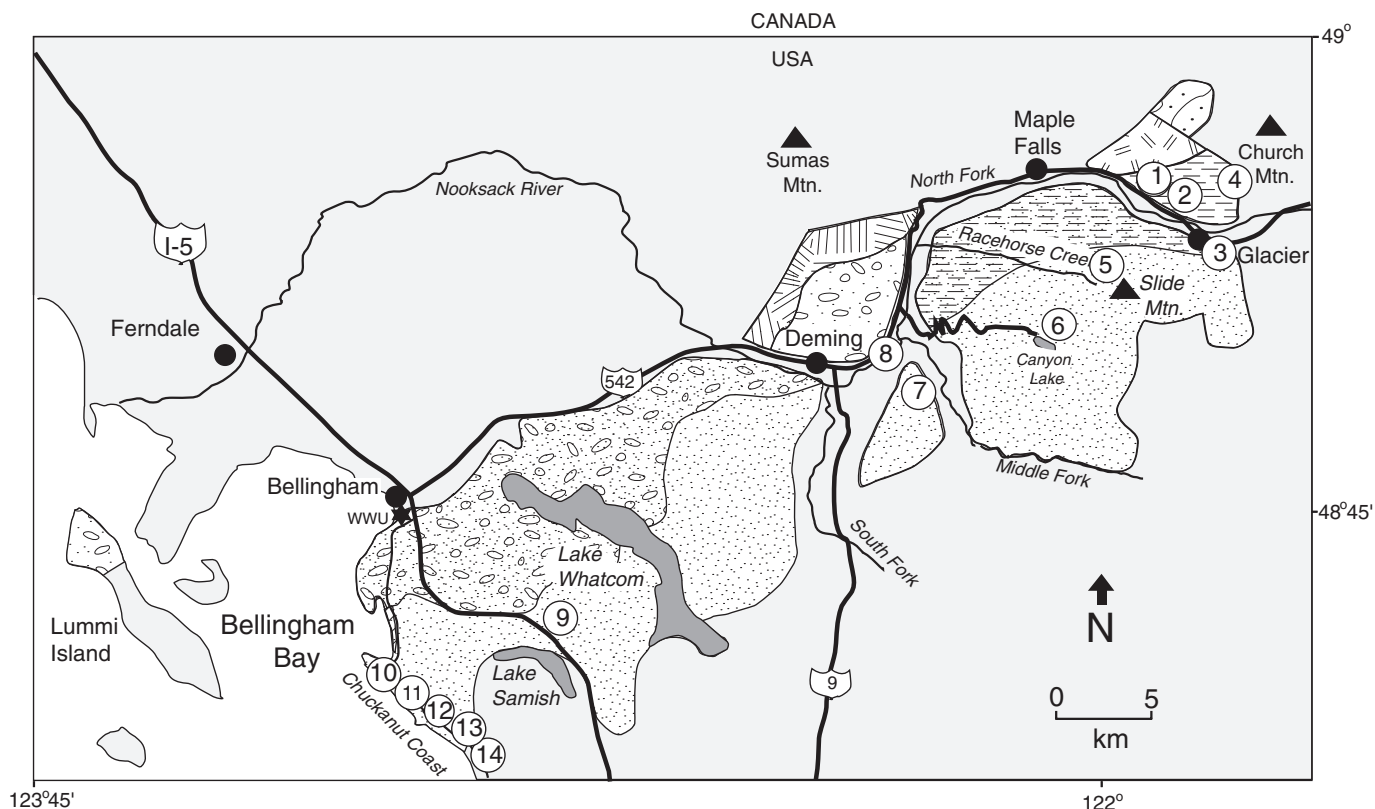


Figure 6. Map of the Chuckanut Formation northwest outcrop zone, adapted from Johnson (1984a). Numbered circles show field trip sites.

during the Eocene (Wolfe, 1978), but because an unconformity may separate the Padden Member from the underlying strata, the climate shift may possibly have been caused by the cooling event that occurred near the Eocene-Oligocene transition. Radiometric age evidence is needed to resolve this uncertainty.

#### WHERE ARE CORRELATIVE MARINE STRATA?

The great thickness of the Chuckanut Formation is a clue that the sediments were deposited in a basin that was undergoing subsidence. Otherwise, the rapid influx of sediment would have quickly filled the depression. Johnson (1985) interprets the tectonic setting to have been a basin created by right-lateral strike-slip faulting caused by the subduction of the Juan de Fuca plate below North America. The Eocene coastline was near to its present location during the early Tertiary, as evidenced by the occurrence of brackish and marine faunas preserved in interbeds within Eocene strata of the Centralia coal mine in Lewis and Thurston Counties, Washington (Brownfield et al., 1994), and in the Late Eocene-Oligocene Blakely Formation in King and Kitsap Counties (McLean, 1977). Fluvial deposition that produced the Chuckanut Formation must have also produced a large volume of deltaic and continental shelf sediments, but the present location of these marine correlatives remains a mystery. The most likely possibility is that a strike-slip fault transported

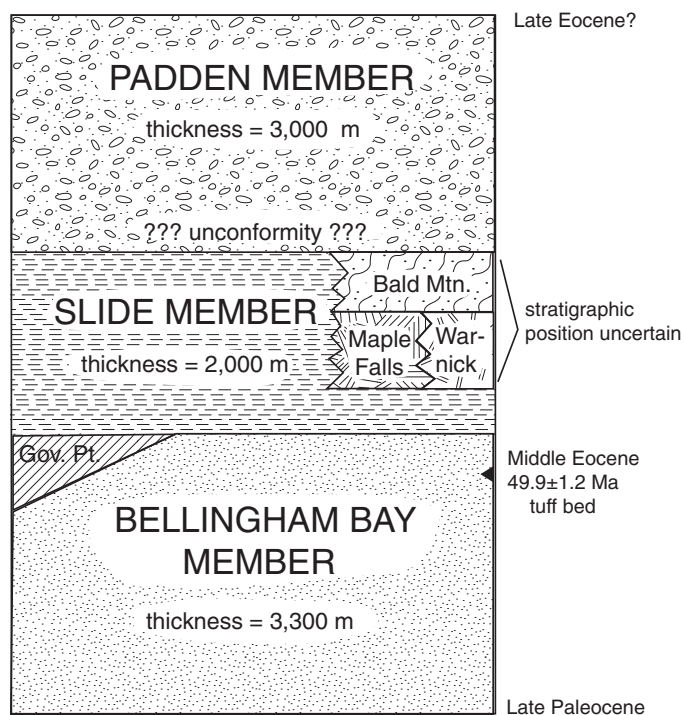


Figure 7. Stratigraphic column (Mustoe and Gannaway, 1997).



these facies northward, where they became an exotic terrane in the Gulf of Alaska. Johnson (1984c) postulated that transcurrent faulting that truncated the Chuckanut Formation corresponds to west- and northwest-trending faults on Vancouver Island.

## PALEONTOLOGY

Leaf impressions (Fig. 8) are abundant in fine-grained Chuckanut Formation strata. Floristic diversity is so great that almost every collecting site yields new taxa. Subtropical rain-forest paleoflora is typical of the Bellingham Bay and Slide Members. Lowland conifers such as *Taxodium* and *Glyptostrobus* are common, in association with the tree fern *Cyathea*, and a diverse assortment of flowering plants. Angiosperm remains include taxa whose modern descendants are found in Asia and Central America, as well ancient forms of plants that continue to flourish in North America (e.g., *Alnus*, *Hydrangea*, and *Platanus*). Chucka-

nut Formation plant fossils have not been studied in detail. Pabst (1968) described horsetail, conifer, and fern species, but relatively few of the flowering plants have been identified (Mustoe and Gannaway, 1997; Mustoe, 2002a). Permineralized wood is rare, but molds and casts of driftwood are abundant in sandy point bar deposits.

Paleoclimate estimates were made by Mustoe and Gannaway (1997), using the Climate Leaf Analysis Multivariate Program (CLAMP) devised by Wolfe (1993, 1995) to calculate climatic parameters based on morphologic characteristics of leaf fossils. The method is useful for the Chuckanut Formation because the calculations do not depend on taxonomy. Results for the Bellingham Bay and Slide Members indicate subtropical conditions. CLAMP data obtained from 66 leaf morphotypes from Bellingham Bay Member sites yielded a mean annual temperature (MAT) of 15 °C, a cold month mean temperature (CMMT) of 10 °C, and a mean annual range of temperature (MART) of

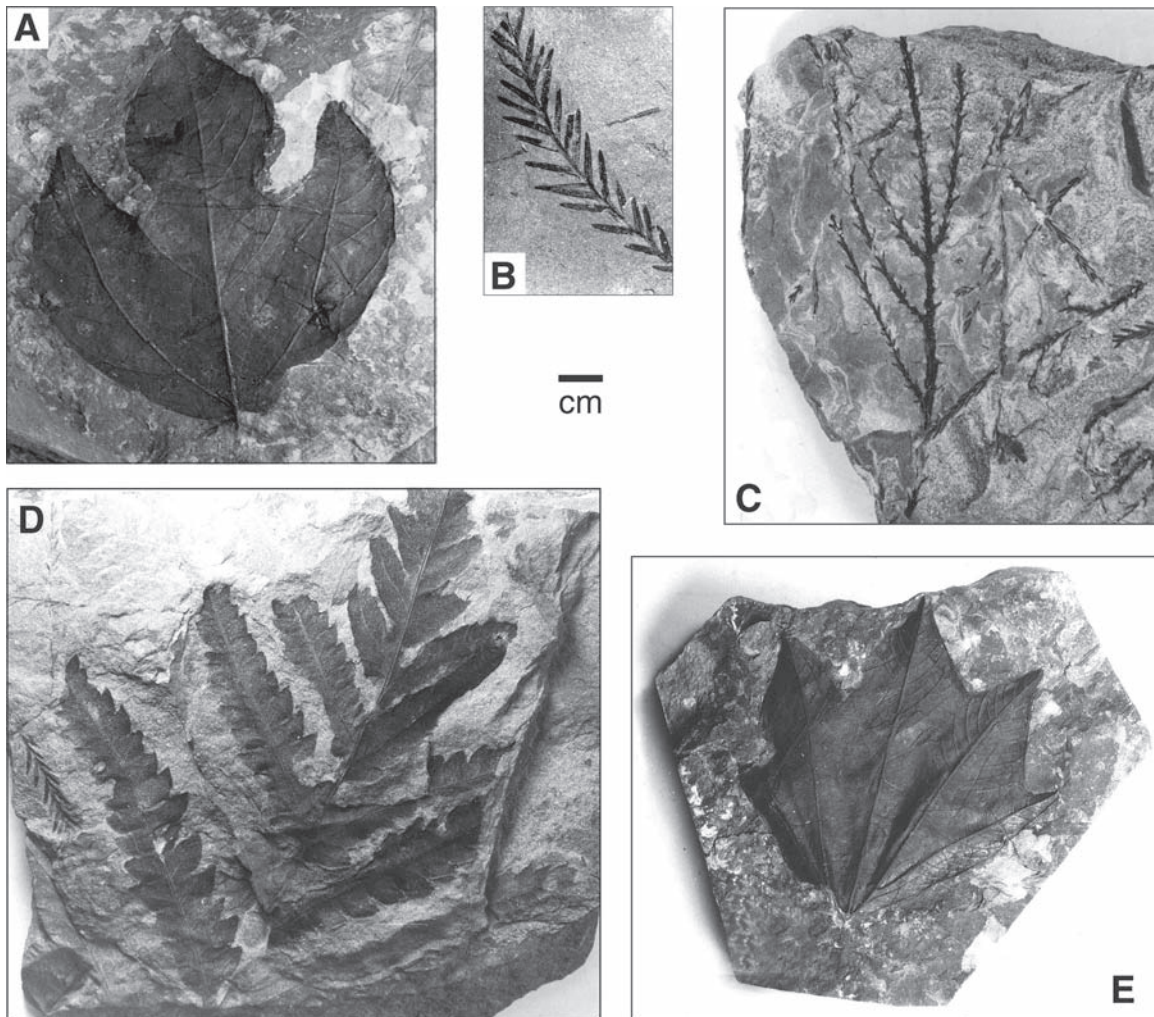


Figure 8. Chuckanut Formation leaf fossils: (A) *Sassafraz*; (B) *Taxodium* (swamp cypress); (C) *Glyptostrobus* ("water pine"); (D) *Cyathea* (tree fern); (E) *Macginitea* (sycamore).

10 °C. Results based on 30 leaf morphotypes from the Slide Member were MAT = 16 °C, CMMT = 13 °C, and MART = 6 °C. The abundance of fossil palm fronds in both stratigraphic members (Fig. 9; Mustoe and Gannaway, 1995) is consistent with the CLAMP data, because palms are restricted to habitats where the cold month temperatures are not less than 5 °C (Greenwood and Wing, 1995).

Plant fossils are uncommon in the Padden Member, which mostly consists of coarse sediments that offered unfavorable conditions for preserving plant remains. At localities where fos-

sils are present, the paleoflora is markedly different from that of the Bellingham Bay–Slide strata. Palm and tree fern fossils are absent, lowland conifers are rare, and flowering plant fossils have foliage characteristics indicative of a warm temperate rather than subtropical paleoclimate. CLAMP results from 64 angiosperm leaf morphotypes are MAT = 12 °C, CMMT = 3 °C, and MART = 18 °C (Mustoe and Gannaway, 1997). Until radiometric ages can be obtained from Padden Member strata, the cause of the transition from subtropical to warm temperate climate remains an enigma. However, this cooling trend can potentially be explained

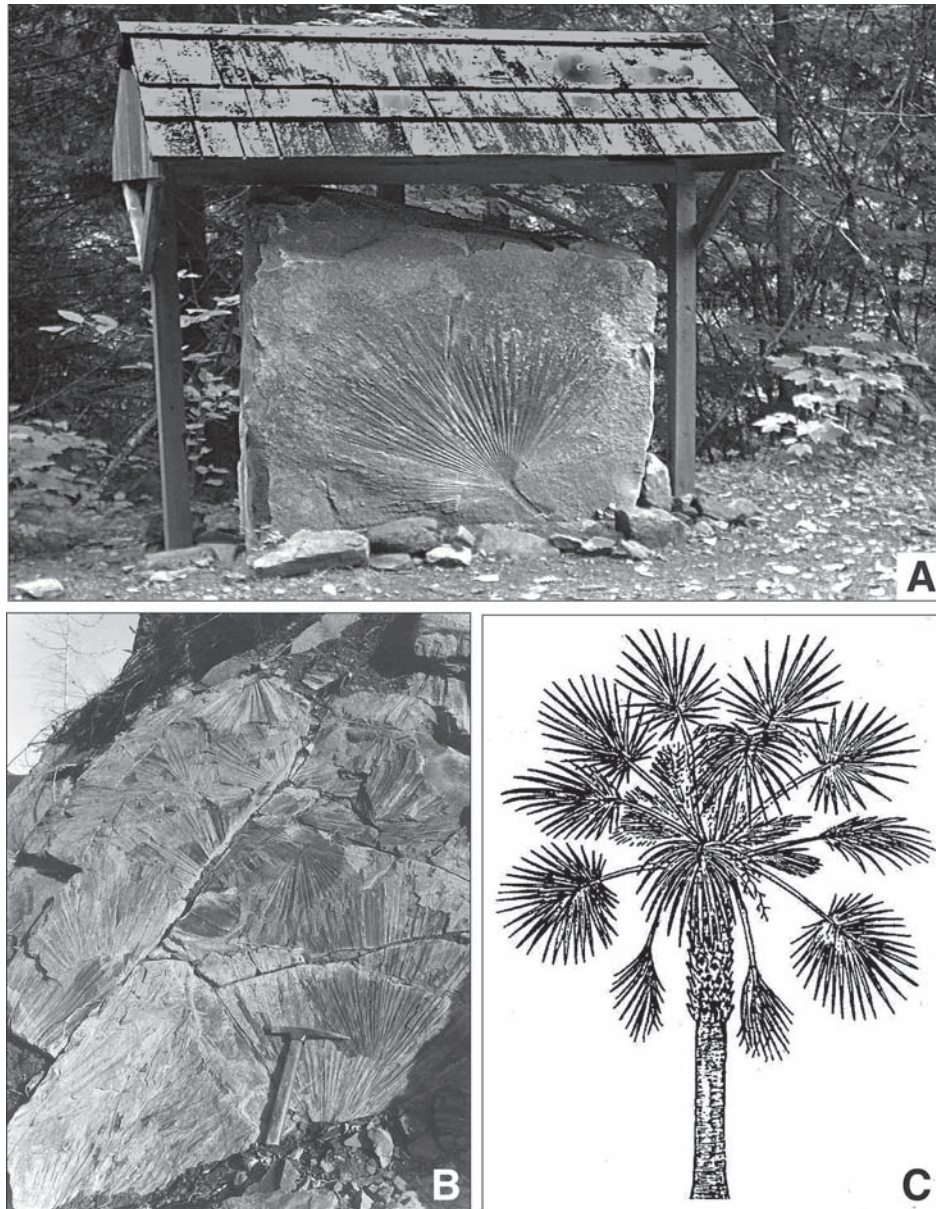


Figure 9. Palm frond fossils: (A) *Sabalites campbelli* Newberry specimen displayed at Canyon Lake Community Forest; (B) multiple *Sabalites* frond impressions preserved on Slide Member bedding plane in Mount Baker foothills; (C) artist's reconstruction of *Sabalites* (Berry, 1930).



in several possible ways. Perhaps the climate change reflects the global cooling that occurred near the Eocene-Oligocene boundary at ca. 34 Ma (Wolfe, 1995; Prothero, 1994). Alternately, the Chuckanut climate shift may have been caused by a transient cooling event during the Eocene. CLAMP data for the Puget Group in King County, Washington, indicate significant decreases in mean annual temperature at ca. 47 Ma and 40 Ma (Wolfe, 1995).

The only animal fossils that have so far been found in the Chuckanut Formation are freshwater mollusks from a few sites in the Slide Member (Mustoe and Gannaway, 1997) and the carapace of a soft-shelled turtle discovered in the Padden Member (Mustoe and Pevear, 1983; Mustoe and Girouard, 2001). Beginning in 1993, a variety of tracks have been found in Slide Member strata in the Mount Baker foothills. These ichnofossils include footprints left by a turtle, several types of birds, and at least two types of mammals (Mustoe, 1993, 2002b; Mustoe and Gannaway, 1997). One Slide Mountain outcrop (Fig. 10) preserves ~200 large circular impressions that appear to be tracks of a large hippopotamus-like mammal, perhaps a member of the Pantodonta or Dinocerata, two extinct orders that flourished in North America during the Early Tertiary. Tracks at a nearby site may have been left by a tapir or *Hyracotherium*, an early horse (Mustoe, 2002b). Invertebrate trace fossils, including trails left by mollusks and small arthropods, occur widely in the Chuckanut Formation, sometimes producing intense bioturbation.

## FIELD GUIDE TO THE CHUCKANUT FORMATION

### Part 1: Mount Baker Foothills

Chuckanut Formation rocks are exposed at numerous sites in the Mount Baker foothills in western Whatcom County. Many localities are accessed by unpaved roads, and road conditions are subject to changing weather. Snow may persist from October to May at elevations above 300 m. Logging road networks are continually being modified in accordance with timber harvesting, and this construction sometimes exposes important new outcrops. However, it is not uncommon to find roads gated to prevent public entry. All of these factors combine to hinder the development of a reliable field guide to the Chuckanut Formation in the Mount Baker foothills region. The following description lists several easily accessible sites along the Mount Baker Highway (State Route 542). Distances are measured from the intersection with Interstate 5 in north Bellingham, in accordance with milepost signs posted along the Mount Baker Highway. Additional localities are listed as “explorations”—sites that offer potential for persons who are willing to venture away from the beaten path without a precise destination.

#### *Locality 1. Mount Baker Scenic Overlook (Milepost 30)*

Park at the paved overlook, and backtrack west on foot along the highway for ~100m to reach steeply dipping Slide Member beds of arkose, siltstone, and shale exposed as a roadcut. Most layers are devoid of fossils, but near the center of

the roadcut an overhanging face preserves a multitude of palm frond fossils. On a clear day, the glacier-covered volcanic slopes of Mount Baker are visible to the southeast; otherwise, all of the neighboring hills consist of Chuckanut Formation bedrock. The site also offers a close-up view of the bed of the North Fork of the Nooksack River, where the modern braided river is producing point bars, levees, channel lag deposits, and other fluvial landforms shown in Figure 4.

#### *Locality 2. Canyon Creek (Milepost 31)*

This site offers only a limited look at in situ Chuckanut Formation strata, but a combination of interesting geologic and environmental characteristics make it worth a visit. Approximately 0.5 miles east of the entrance to Glacier Springs subdivision, the highway reaches a steel bridge over the Nooksack North Fork. Just before reaching the “narrow bridge” sign, a junction to the right (south) leads to a large parking area. Across the main highway, a line of boulders marks an abandoned road that provides a path northward into the forest bordering Canyon Creek. A five-minute walk leads to clearings that mark the former site of The Logs, a rustic lodge that was demolished a few years ago as part of the Whatcom County management plan for the Canyon Creek floodplain. At the north end of these clearings, ascend a gentle slope to reach the crest of the rocky levee.

The path on the crest of the levee can be followed upstream for approximately 0.5 mile (1 km), paralleling the rocky bed of Canyon Creek. Chuckanut Formation Slide Member strata are exposed near the southern end of the dike, where engineers cut through the bedrock to make a new route for the creek. Nearby blocks of siltstone contain leaf fossils, but the most abundant fossils are crinoid stems preserved in blocks of Pennsylvanian limestone used to construct the levee. This rock was quarried from Chilliwack Group strata near Maple Falls, and it is a good example of one of the classic exotic terranes of the Northwestern Cascades—a section of shallow ocean bottom that has been transported for more than 2000 km by plate tectonics to reach its present location high in the Mount Baker foothills.

The Canyon Creek levee was constructed at great public expense in the 1980s to provide protection against flood damage to a few summer homes. The changes to the channel, however, proved to be detrimental to wild salmon who utilize the stream for spawning ground. As a result, the effectiveness of the project has been reconsidered. The Logs resort was recently torn down and several adjacent homes were relocated away from the floodplain, to allow Canyon Creek to flow in a more natural path. Removal of at least part of the rocky levee is under consideration.

#### *Locality 3. Village of Glacier (Milepost 34)*

Glacier provides an oasis for visitors, offering several restaurants, general store, and public restrooms. At the east edge of town, the historic Glacier Ranger Station provides outdoor recreation information and interpretive exhibits about the area’s natural history. This U.S. Forest Service facility is open on weekends year-round, and daily from mid-June until mid-September.

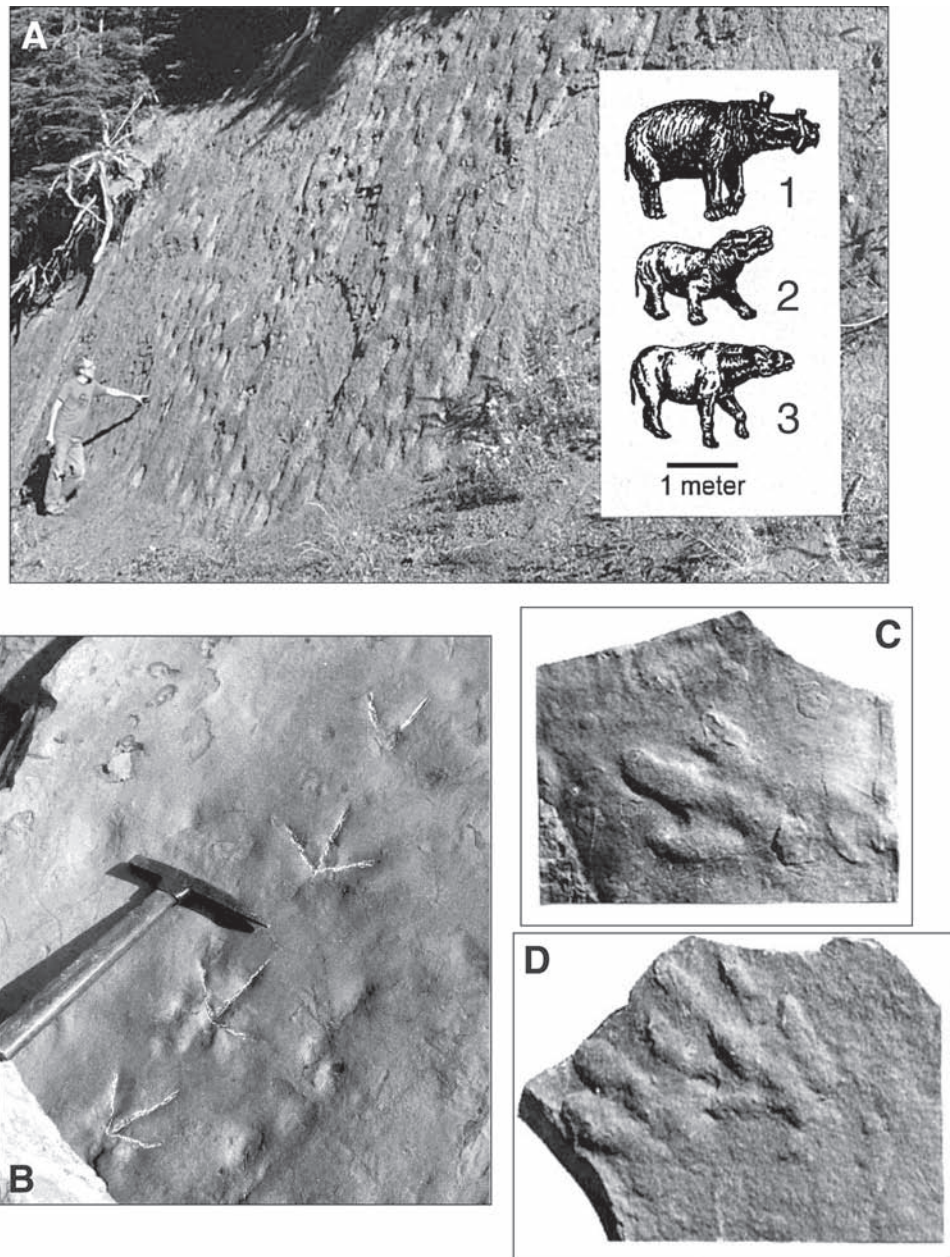


Figure 10. Vertebrate trace fossils from Slide Member outcrops in the Mount Baker foothills. (A) Numerous shallow footprints preserved at this Slide Mountain site were made by a group of large, short-legged mammals. Possible track-makers include members of the Pantodonta and Dinocerata. Examples: (1) *Eobasileus* (Dinocerata); (2) *Coryphodon* (Pantodonta); (3) *Paleosyops* (Dinocerata). Drawings from Rich et al. (1996, by permission). (B) Partial view of a trackway from a heron-like bird discovered in 1993 during construction of a logging road near Canyon Lake. (C, D) Unidentified mammal tracks from a Rutsatz Road outcrop show three toes on the hind feet and four toes on the front, an anatomical characteristic of the Eocene “dawn horse” (*Hyracotherium*) and members of the tapir family.

The hills south of Glacier contain beds of anthracite that formed when Chuckanut Formation bituminous coal heated during the North Cascades orogeny. The lack of local markets and the difficulty of mining the folded and faulted coal seam combined to hinder successful economic development of the resource. The most recent attempt in the 1980s led to the construction of a coal storage site that can easily be reached by visitors. From downtown Glacier, turn south on unpaved Gallup Creek road (marked “dead end, private road”) and drive a few minutes to reach the nearby coal dump.

## Explorations

### ***Locality 4. West Church Mountain (Milepost 36)***

Just past the entrance to Douglas Fir Campground, turn left (north) on Canyon Creek Road. A single-lane paved forest road climbs steeply. After several miles, a junction to the right (east) provides access to logging roads high on the west shoulder of Church Mountain, where Chuckanut strata have been faulted against Jurassic-Cretaceous shallow-water marine sedimentary rocks of Nooksack Group, one of the exotic terranes that comprise the bedrock of the northwestern part of the North Cascades.

### ***Locality 5. Racehorse Creek–Slide Mountain Logging Roads (Milepost 16)***

Turn south on Mosquito Lake road, and cross the Nooksack River. Turn left (east) on North Fork Road. Pavement ends after ~6 miles. From here, an extensive logging road network reaches high elevations on Slide Mountain and Racehorse Ridge, exposing Slide and Bellingham Bay Members strata. Good fossil collecting opportunities reward those who are willing to brave dusty roads and complex junctions.

### ***Locality 6. Canyon Lake (Milepost 16)***

From the Mount Baker highway junction, continue south on Mosquito Lake road two miles to reach a marked junction with Canyon Lake Road. This 6-mile-long gravel road climbs to reach the Canyon Lake trailhead parking area. The lake was created within the past few hundred years or less when a rockslide dammed the valley. Steeply dipping Chuckanut Formation beds are visible on the nearby mountainside, and blocks of sandstone comprise much of the slide material. The lake preserves a drowned forest, and the snags that rise above the surface are evidence of Canyon Lake’s young age. Thanks to efforts by the Whatcom County Land Trust, the lake and a large tract of old growth forest in the upper valley have been preserved as the Canyon Lake Community Forest. A new path circles the lakeshore, and the original logging road has been converted to a hiking trail that leads to the ancient forest and beyond to the ridge crest. Chuckanut Formation beds are exposed along the road leading to the lake, and at many sites in the upper valley. Fossil collecting is prohibited within the boundaries of the community forest,

but nearby logging roads provide access to many other outcrops. From the parking area, a short stroll leads to a display of a spectacular palm frond fossil (Fig. 9A).

### ***Locality 7. Rutsatz Road (Milepost 14)***

Turn south on Highway 9. After crossing the Nooksack River, turn west on Rutsatz Road. Continue 2.4 miles, where the road passes a prominent outcrop of sandstone exposed by construction improvements in 1997. One slab excavated from the large bedding plane preserved tracks left by a tapir or early horse (Fig. 10C, 10D) as well as footprints left by a small shorebird (Mustoe, 2002b). Strata near the top of the roadcut produced many excellent leaf fossils.

A half mile further along Rutsatz Road, turn right (west) on a gravel logging road. This road climbs 1.2 miles to reach a steeply dipping outcrop of Slide Member strata that contains abundant plant fossils. (At 1 mile, stay right on main road, ignoring a lesser junction to left.) The locality offers views to the east to Canyon Lake and Racehorse Ridge–Slide Mountain, and southeast to the Middle Fork of the Nooksack River and the Twin Sisters range.

### ***Locality 8. Deming Homestead Eagle Park (Milepost 15)***

Just east of the Highway 9 junction, turn right on Truck Road and continue a mile or two to reach the entrance to this small riverside park. Interpretive displays describe attempts to provide habitat for salmon. Ironically, soon after restoration efforts were completed, the meander pattern of the Nooksack River shifted, leaving the newly restored habitat area high and dry. No doubt the river will eventually resume its earlier route, but in the meantime the park offers an opportunity to stroll on the dry riverbed. The parking lot has been decorated with large boulders of dunite quarried from the Twin Sisters range, where a deep-seated fault transported mantle material to the surface. The site offers views of Racehorse Ridge, Slide Mountain and the Canyon Lake hanging valley, as well as Van Zandt Dike, the latter being not a dike but a high ridge of Chuckanut Formation bedrock.

## **Part 2: Bellingham Area**

### ***Locality 9. Lake Samish Freeway***

The northbound lanes of Interstate 5 provide an opportunity for seeing the type locality for the Padden Stratigraphic Member. These northward-dipping beds are predominantly composed of arkose, with siltstone and shale beds being scarce. The coarse-grained nature of the Padden strata is evidence of an increased flow velocity late in the depositional history of the Chuckanut Formation. Johnson (1982, 1984a, 1991) concluded this coarser sediment originated in a braided-stream environment produced when the region began to be uplifted.

The following sites are located along Chuckanut Drive, south of Bellingham. Distances are listed both as odometer readings from the intersection of Harris Avenue and 12th Street in central Fairhaven, 1.2 mi. from the Western Washington University



south campus, and relative to highway mileposts (the latter mileages measured northward from the junction of Chuckanut Drive with Interstate 5 in Skagit County).

**Locality 10. Larrabee State Park (5.4 mi; Milepost 14.5)**

Follow Chuckanut Drive south for 5.4 mi., then turn west on Cove Road, which leads to the state park public boat launch. Along the beach near the sign marking the park's northern boundary, the coastal bluff is penetrated by the portal to an abandoned coal prospect. Nearby, steeply dipping bedding planes preserve imprints of giant horsetails and other plant taxa. At the top of the bluff, the 50 Ma Bellingham Bay Member rocks are unconformably overlain by Holocene alluvium. Immediately south of the boat launch, a 120 ft (37 m) sandstone face provides a popular training site for local rock climbers. This cliff provides an example of the uniformly bedded Chuckanut arkose that once provided an important source of building stone. A century ago, the south edge of this outcrop was briefly used as a stone quarry, and sandstone blocks with squared edges can still be seen in the upper intertidal zone.

**Locality 11. Clayton Beach (5.9 mi.; Milepost 14)**

Just south of the Larrabee State Park main entrance, an intersection provides entry into a large trailhead parking area for Chuckanut Mountain and Clayton Beach. From here, cross Chuckanut Drive to reach the metal stairway that connects to the Clayton Beach path. The gentle but sometimes muddy grade follows the bed of the Interurban Railway, a one-car electric commuter line that once connected Bellingham to Mount Vernon, deactivated in 1930. After a ten-minute walk, the trail reaches the Burlington Northern railway tracks (a faint way trail through the woods can be used to avoid the final descent over a steep sandstone slab). After crossing the tracks, follow the path that leads to a cove just north of the main Clayton Beach sandy coast. The rocky back wall of this cove provides an excellent look at a variety of Bellingham Bay Member Strata. The rock ranges from arkose to shale and siltstone, including carbonaceous interbeds and possible paleosols. Keen-eyed visitors will discover that the sandstone preserves an abundance of leaf fossils, and nearby outcrops contain large driftwood impressions. (Please keep in mind that state park regulations prohibit fossil collecting.) During low tides, the beach walk between Clayton Beach and the main Larrabee State Park site is a spectacular hike.

Clayton Beach also provides excellent examples of honeycomb weathering. These natural rock sculptures result from salt weathering, caused when ocean water is splashed on the porous rock. Evaporation results in growth of halite crystals in the spaces between sand grains, causing disaggregation. As cavities develop, the growth of a carpet of lichens and algae provide a protective barrier for the side walls so that the cavities deepen inward rather much faster than they expand laterally (Mustoe, 1982). The result is a honeycomb-like network of erosion restricted to ~1 m above the high tide line (Fig. 11).

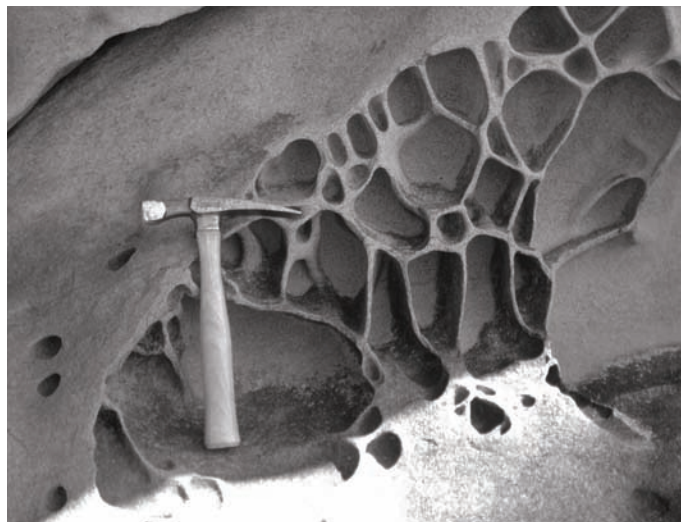


Figure 11. Honeycomb weathering in coastal cliff near Clayton Beach.

**Locality 12. Pigeon Point Picnic Area (7.8 mi.; Milepost 12)**

South of the Clayton Beach parking area, Chuckanut Drive follows a curving route offering spectacular scenic views (Fig. 12). Midway in this section of highway, a roadside picnic area at Pigeon Point provides an attractive vantage point. From the parking area, walk south 100 m along the roadside to reach an overhanging roadcut that contains a variety of fossil plant remains, including large palm fronds. This site is an excellent example of the subtropical paleoflora preserved in the Bellingham Bay Member. A mile-long series of roadcuts north of the picnic area offers good possibilities for fossil collecting, but traffic hazards make these outcrops unsafe for large groups or young children. At several points, impressions of large driftwood logs can be seen in cliffs along the road.

**Locality 13. Oyster Creek (9.4 mi.; Milepost 11)**

The very sharp curve where Chuckanut drive crosses the bridge over Oyster Creek marks the basal contact of the Chuckanut Formation. South of Oyster Creek, the bedrock consists of Mesozoic exotic terrane rocks of the Shuksan Metamorphic Suite. Crossing the bridge thus represents a geologic transition of ~100 m.y. The contact between the Bellingham Bay Member sedimentary rocks and the older metamorphosed oceanic rocks is not exposed, and it is possible that the Chuckanut strata were deposited as an unconformity on the surface of the eroded bedrock. However, the straight-line path of Oyster Creek suggests that the contact more likely represents a fault.

**Locality 14. Windy Point (10.5 mi; Milepost 9.5)**

Although this site does not contain Chuckanut strata, Windy Point provides an excellent opportunity for observing the underlying basement rocks of the Shuksan Metamorphic Suite. Situated at the final curve of Chuckanut Drive just before the road descends south to the lowlands bordering Samish Bay, Windy



Figure 12. Bellingham Bay Member strata are extensively exposed along Chuckanut Drive, shown in this 1927 photo by Clyde Banks (provided courtesy of Whatcom Museum of History and Art).

Point can be recognized by 120 ft (37 m) high, nearly vertical cliffs adjacent to the pavement. A small parking area is available, but visitors need to be keenly aware of hazards from passing traffic. The cliffs at Windy Point consist of seafloor basalt that has been metamorphosed to greenschist and serpentinite. At the north end of the outcrop, the face is cut by two steep faults to produce a prominent open corner. These surfaces bear glassy slickensides that can be used to judge the relative motion on the faults. The small island of bedrock near the parking spot on the west side of the highway contains a shear zone rich in talc, with chrysotile asbestos as an alteration product.

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