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The First Discovery of a Fish Fossil (*Phareodus* sp.) from Paleogene Fluvial Deposits in Western Washington State, USA

George E. Mustoe

Geology Department, Western Washington University, Bellingham, WA 98225, USA; mustoeg@wwu.edu

Abstract: The 2023 discovery of a fish fossil from lower Eocene strata of the Chuckanut Formation provides new insights into the paleoenvironment and paleoecology of one of the region's most prolific fossil deposits. The detrital clastic fluvial and floodplain deposits of the Chuckanut Formation are not favorable for the preservation of fish, but the high quality of preservation of this specimen is evidence that some Chuckanut Formation sediments provide suitable depositional conditions for the preservation of skeletal remains. This information improves our understanding of the range of depositional environments within the Chuckanut Formation, and provides clues for searching for additional specimens. The discovery of this fossil has larger significance; the skeletal remains of fish are scarce in fluvial and floodplain deposits. Despite its incompleteness, dorsal fin and caudal fin ray anatomy suggest that the specimens represent the extinct genus *Phareodus*, an open-water carnivore that has previously only been reported in North America from the Green River and Bridger Formations in Wyoming and Utah, USA.

Keywords: Chuckanut Formation; Eocene; fish fossil; *Phareodus*

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1. Introduction

On 7 January 2023, hikers exploring the banks of Racehorse Creek in the Mt. Baker foothills region of northwest Washington, USA (GPS: 48.879N, 122.126W), discovered a fractured block of sandy siltstone that contained partial fish fossil remains. The hikers left the specimen at the discovery site and contacted the Geology Department at Western Washington University. The next day, the hikers led paleontologists to the site. The specimen consists of incomplete skeletal remains of a teleost fish, consisting of a positive mold and a matching counterpart (Figure 1). The anatomical features include dorsal and caudal fins and most of the anal fin. This report describes the fossil in detail, and discusses this occurrence in relation to the paleoecology and paleoenvironment of the Chuckanut Formation.

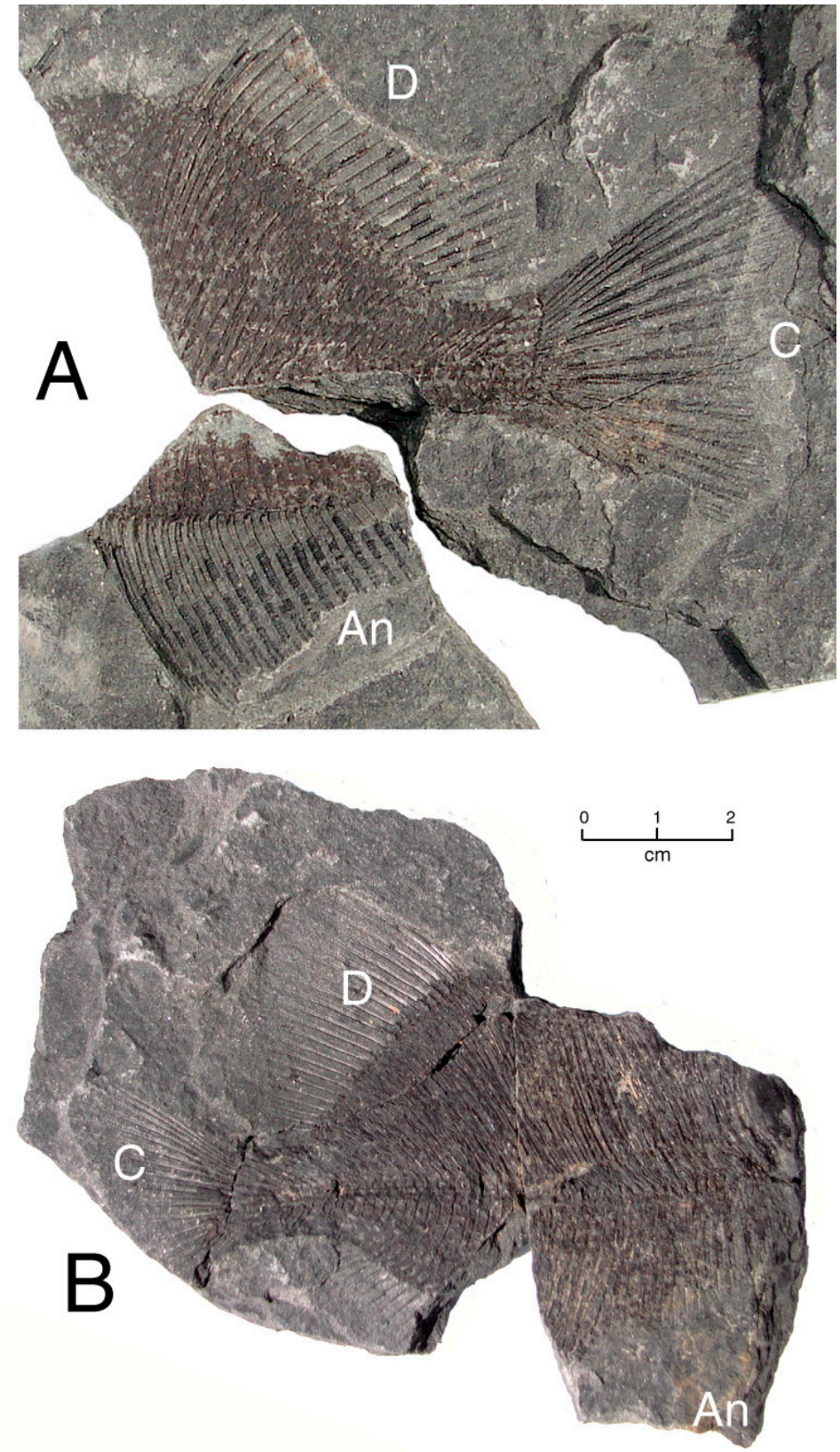


Figure 1. Chuckanut Formation fish fossil. (**A**) Anatomical features include anal fin (An), caudal din (C), and dorsal fin (D). (**B**). Partial counterpart shows the more complete preservation of dorsal fin rays (D), the partial preservation of the upper caudal fin rays (C), and a larger area of the main body.

2. Geologic Setting

The Chuckanut Formation consists of beds of Paleogene conglomerate, arkosic sandstone, siltstone, and coal that unconformably overlie Paleozoic and Mesozoic metamorphic basement rocks. These fluvial sediments were deposited on a broad floodplain that existed prior to the late-Tertiary uplift of the North Cascade Range [1,2]. The main outcrop belt occurs in Whatcom and Skagit Counties, USA (Figure 2). Isolated exposures extend along fault zones to connect the main outcrop belt on the west side of the Cascade Range with the Swauk Formation in central Washington. Correlative strata also extend north into British Columbia where they are called the Huntingdon Formation [3]. Mustoe and Gannaway [4] suggested that this far-flung outcrop distribution is evidence of a large depositional basin that was dissected via strike-slip faulting (Figure 3).

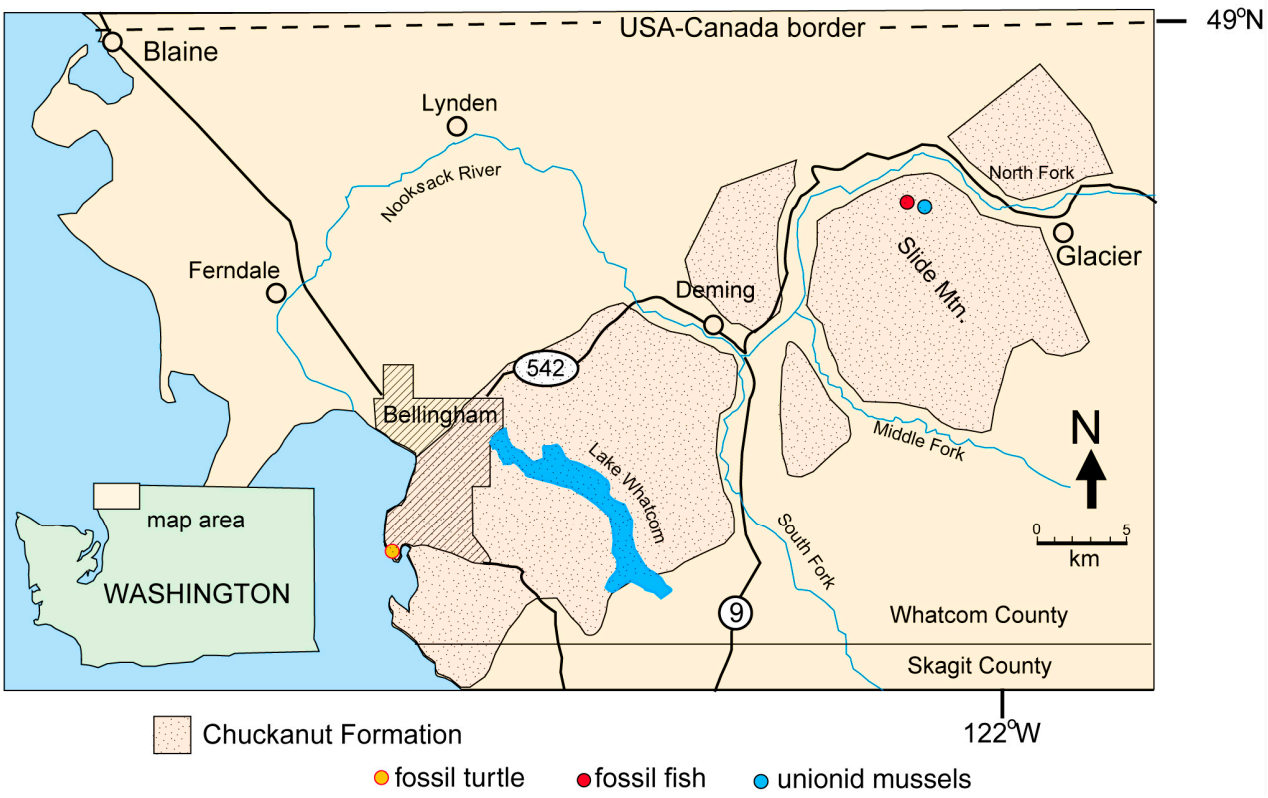


Figure 2. Chuckanut Formation main outcrop belt showing locations for fossils described in this report.

The Chuckanut Formation is one of the thickest non-marine sedimentary formations in North America, but extensive forest cover restricts measurement of continuous stratigraphic sections. Estimates of the total thickness of the formation in the main outcrop belt in northwest Washington range from 3000 m [5] to 8300 m [6]. Mapping by Breedlovestrout [7] suggests a minimum thickness of 4000–5000 m.

Several schemes have been proposed for dividing the Chuckanut Formation main outcrop into stratigraphic members [1,4,7]. The basic architecture is a three-component system composed of the basal late-Paleocene–early Eocene Bellingham Bay Member, overlain in the Mount Baker foothills by the early Eocene Slide Member (Figure 4). The third component is the middle-Eocene–late-Eocene Padden Member, which is perhaps separated from underlying strata by an unconformity. The stratigraphic positions of several minor members remain uncertain [7].

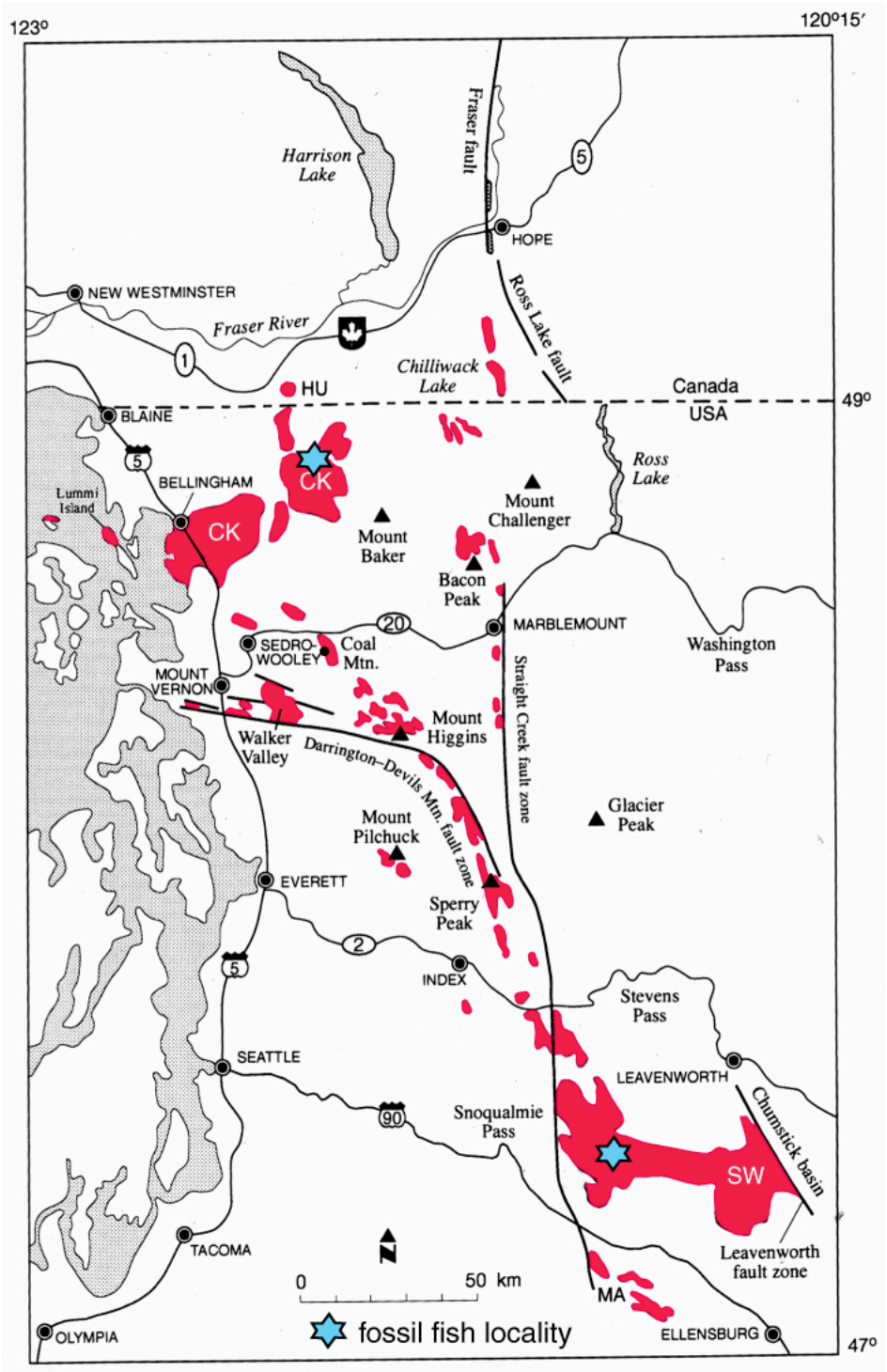


Figure 3. Outcrops of Eocene sedimentary rock in central and northwest Washington are distributed along major strike-slip fault ones. CK—Chuckanut Formation, HU—Huntingdon Formation, SW—Swauk Formation, MA—Manastash Formation. Fault-dispersed segments of the original basin are shown in red. Locations of the Chuckanut Formation and Swauk Formation fish fossil sites are shown in blue.

The meandering river origin of the Chuckanut Formation included a variety of sedimentary environments where fish fossils might be preserved. These include sandbar and levee deposits, oxbow lakes, crevasse splays, and overbank deposits (Figure 5).

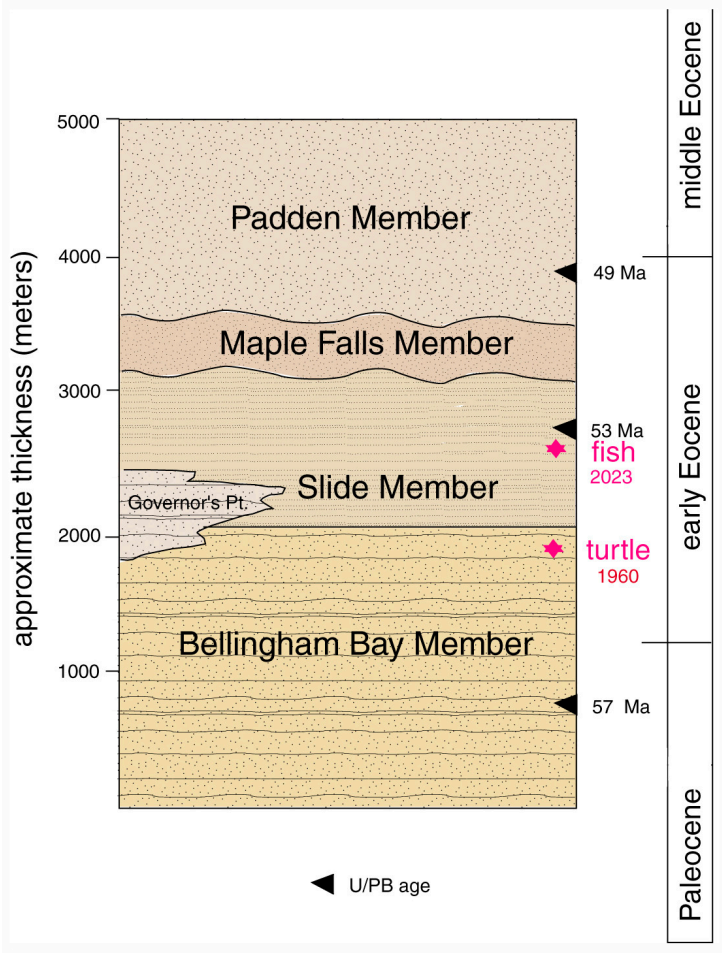


Figure 4. Generalized stratigraphic sequence for the Chuckanut Formation main outcrop belt.

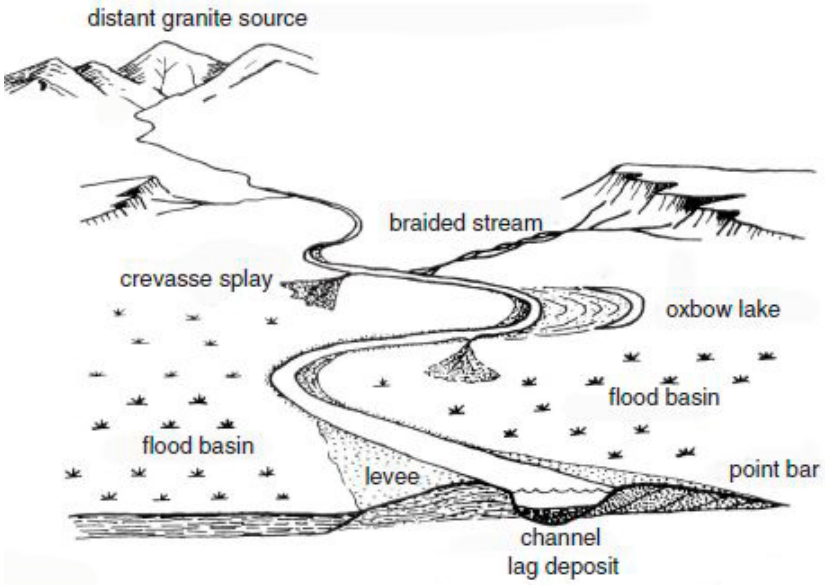


Figure 5. Depositional environments in the Chuckanut Formation [4].

3. Paleontology

The formation has been subject to paleontological study for more than a century beginning with fossils collected in 1841 by James Dwight Dana of the Wilkes Exploring Expedition [4]. The Chuckanut Formation has produced a multitude of plant fossils dating

from an era when the region was inhabited by low-elevation subtropical rainforests [7,8]. A recent study was devoted to invertebrate trace fossils [9]. Vertebrate footprints represent a diverse array of birds, mammals, and reptiles [4,6,10–13].

This discovery is only the second time that vertebrate skeletal remains have been found in the early Tertiary Chuckanut Formation, despite more than a century of fossil collecting. The only previous vertebrate discovery was a cast of a pond turtle (Figure 6) that was found near Bellingham in 1960 [14].



Figure 6. Internal **c**ast of a pond turtle shell (*Trionix* sp.) from Bellingham Bay Stratigraphic Member.

The indirect evidence of fish in the ancient fluvial environment comes from the discovery in the 1970′s of fossilized freshwater mussels (Family Unionidae) in a siltstone bed near Racehorse Falls, in the same region where the skeletal remains were found. These "river mussels" produce planktonic larvae (glochidia) that become encysted in fish gills, where they exist as parasites for weeks or months until they detach and settle to the river bed and transform into adult mollusks (Figure 7) [15].

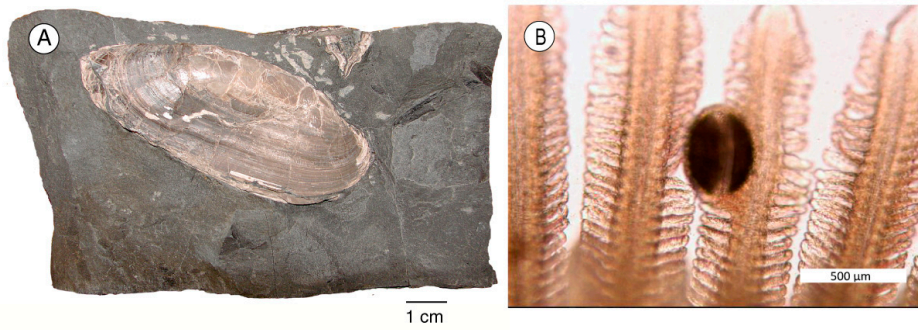


Figure 7. Freshwater mussel fossil and modern larval stage. (**A**) Unionid mussel shell fossil from Racehorse Creek. (**B**) Formerly planktonic larva of modern river mussel now attached to the gills of a sunfish (Centrarchidae). Photo courtesy of Craig Banner [16].

4. Results

Taxonomy

The incompleteness of the specimen is a hindrance for taxonomic analysis, but the specimen has several distinctive characteristics. The dorsal fin is positioned in proximity to an emarginate caudal fin (Figures 1 and 8). This anatomy is a feature of members of the osteoglossomorph genus *Phareodus* Leidy 1873 (Teleostei: Osteoglossidae) [17], an extinct genus known in North America from the Eocene Green River and Bridger Formations in Wyoming and Utah [18]. The fin ray statistics are consistent with data from *Phareodus* specimens from these localities (Table 1). The dimensions of the incomplete remains suggest the total length was approximately 22 cm (Figure 8), comparable to the size range for *P. testis*, which was about half the size of the larger *P. encaustus.* The latter species reached lengths as long as 76 cm [19].



Figure 8. Chuckanut Formation fish fossil shown in relation to *Phareodus testis* Cope 1877 from the Green River Formation, Wyoming, USA. Chuckanut fossil image is combined from part and counterpart components, projected on an image of a *P. testis* specimen to show the anatomical correspondence.

Table 1. Fin ray anatomy. *Phareodus* data from [18,19].

	Dorsal Fin Ray Count	Anal Fin Ray Count	Caudal Fin Ray Count **
Chuckanut fish	21	>18 *	i-8-7-i
Phareodus genus	16–21	22–28	i-8-7-i
Phareodus testis	7–20 mostly 19	25–28 mostly 26	i-8-7-i
Phareodus encaustus	17–22 mainly 18–21	22–25	i-8-7-i

* Anal fin not fully preserved. ** Caudal ray count based on the method of Fricke [20].

Details of dorsal and caudal fin anatomy are shown in Figures 9 and 10.

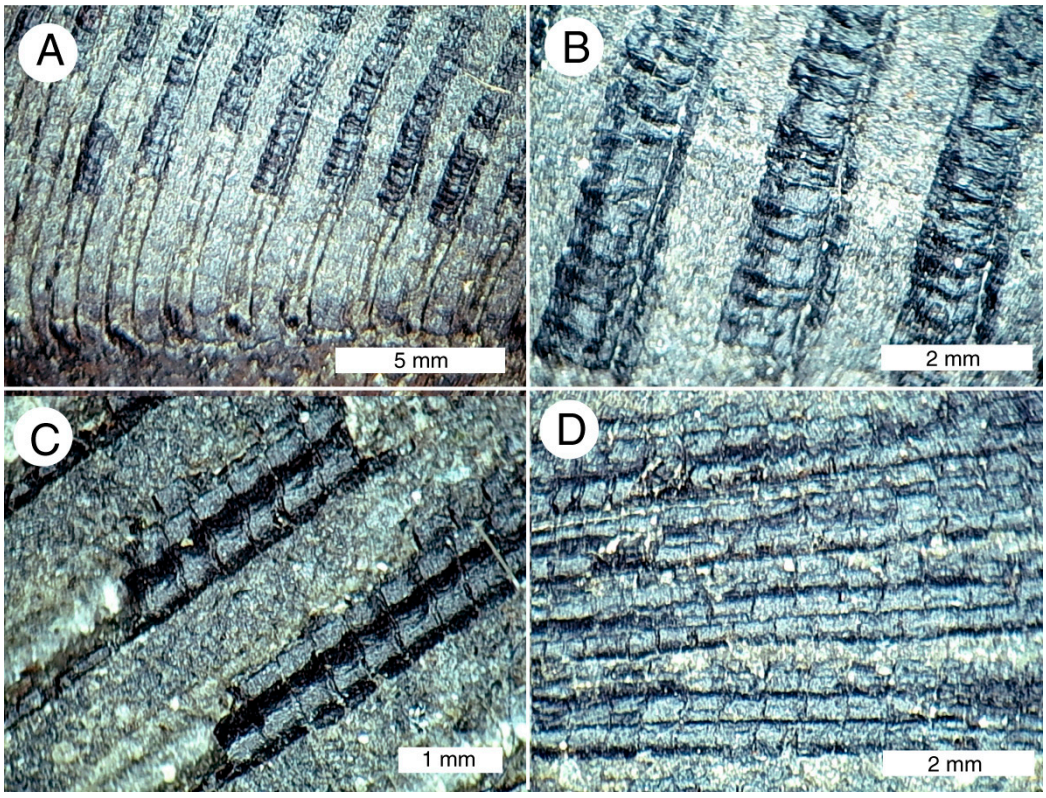


Figure 9. Segmented soft rays in Chuckanut Formation fish fossil. (**A**–**C**) Dorsal fin rays. (**D**) Caudal fin rays.

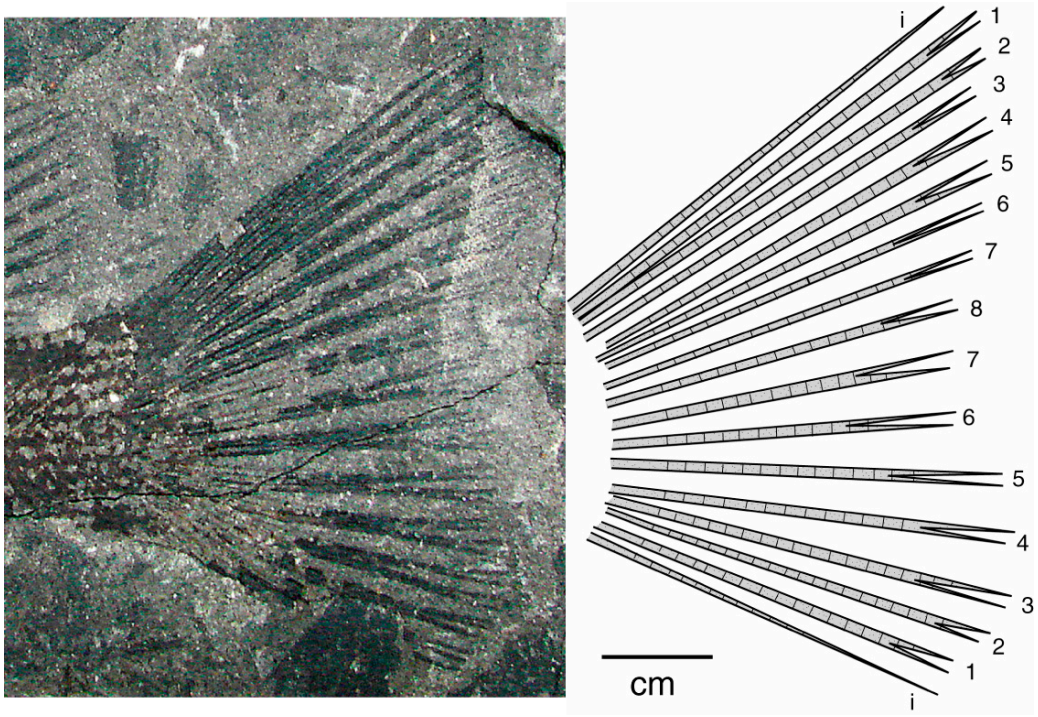


Figure 10. Caudal fin of Chuckanut Formation fish fossil. Caudal ray count is based on the method of Fricke [20].

Areas of the fossils show a mottled pattern that was initially presumed to be traces of scales. However, magnified images show that the patterns are caused by local defects in the carbon film (Figure 11).

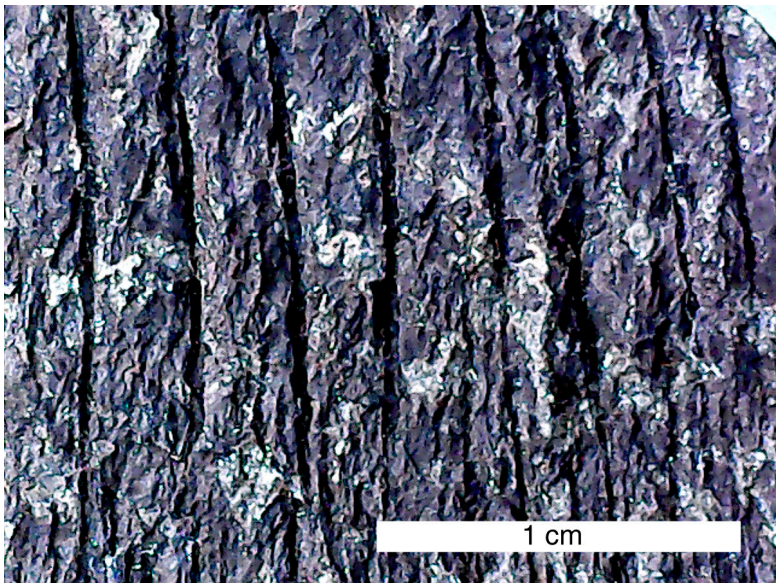


Figure 11. Detailed view of mottled patterns on main body area.

The anatomical characteristics of vertebrae can be used for the taxonomic analysis of fish, with much of this research conducted using disarticulated skeletal remains [21–23]. Examples include several osteoglossimorph taxa. The Chuckanut Formation fish fossil does not preserve the anatomical details of vertebra (Figure 12).

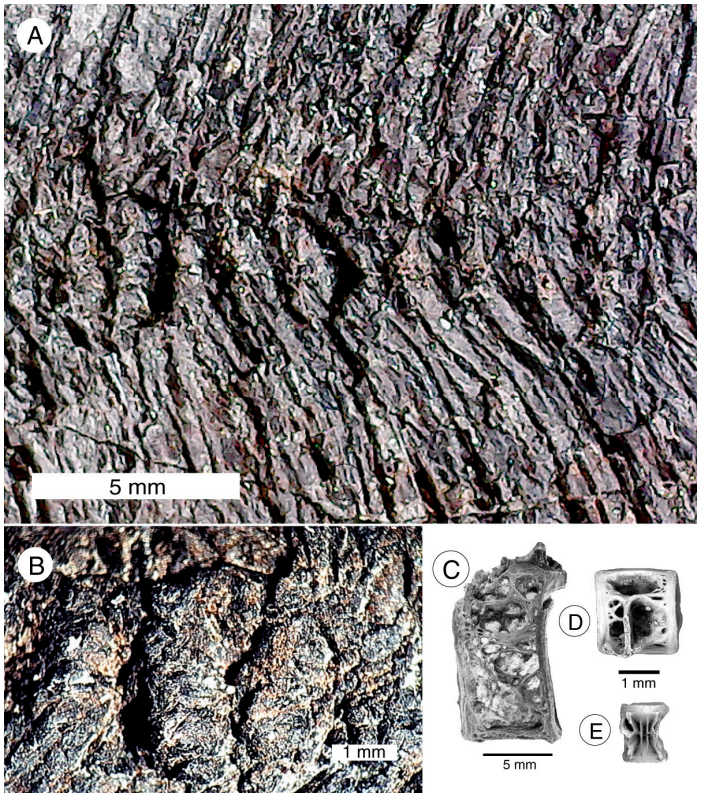


Figure 12. Anterior vertebral column of Chuckant Formation fish and isolated centra from other osteoglossids. (**A**,**B**) Chuckanut fish fossil showing poor preservation of vertebral column. (**C**)*Phareodus*, Eocene [22]. (**D**) *Coriops* sp., Late Cretaceous [23] (**E**) *Wilsonicthys*, Late Cretaceous [23]. Vertebra dimensions reflect the size of the individual fish, and are not fundamental taxonomic characteristics.

The identification of the Chuckanut Formation fish as *Phareodus* has several caveats. Fin ray counts are somewhat variable within a given fish species [24]. Identification of *Phareodus* species is dependent on the aspects of skull anatomy that are not available for the Chuckanut Formation fossil. Five species were once included in this genus, revised to three [25], and later reduced to two, *P. encaustus* and *P. testis* [19]. An Australian species, *Phareodus queenslandicus* proposed by Hills [26], was renamed as *Phareoides queenslandicus* [27]. A European fish fossil named as *Phareodus(=Brachaetus) muelleria* and the Australian *Phareoides queenslandicus* have been suggested to by sister species to *Phareodus encaustus* [28].

5. Discussion

Eocene fish fossils have been found at a number of localities in the western United States, the majority of these being preserved in lacustrine deposits. Fish are typically poorly preserved in sediments in floodplain environments, a topic that has been discussed in detail by Smith et al. [29]. The main reason for this paucity of fossilization is the abrasiveness of clastic fluvial sediments that quickly abrade skeletal remains. The recovery of disarticulated bones may be achievable by washing and screening sediments, a technique that only works when the matrix is unconsolidated or only weakly lithified.

The principal requirements for fossilization are fine-grained sediments that can provide the preservation of delicate anatomical features, an absence of predation, and conditions that inhibit microbial decay or chemical decomposition. Spectacular examples locally occur in the Eocene Fossil Lake deposits of the Green River Formation in Wyoming, USA, where a single bedding plan may contain a multitude of fossilized fish. The cause of these death assemblages has been debated, with the most commonly accepted hypotheses being H_2S released from sediment via a seismic event, or a toxic algal bloom [19]. For the Chuckanut Formation, fish preservation was likely caused by rapid deposition, where plant and animal remains were quickly buried in wet sediment that excluded oxygen and prevented predation and decay. The laminated texture of the matrix of the Chuckanut fish fossil is evidence of episodic deposition (Figure 13).

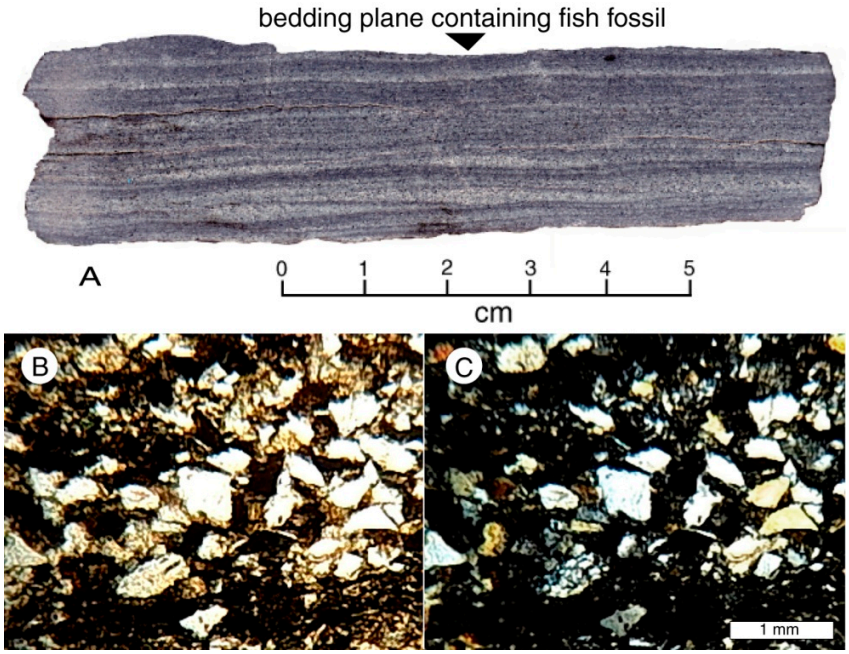


Figure 13. Sedimentary matrix for the Chuckanut fish fossil. (**A**) Sawn cross-section showing the lamination of the sandy siltstone. (**B**,**C**) Thin section photomicrographs showing the sharply angular shape of sand grains. Photo B shows ordinary transmitted light view; C is the same field of view under transmitted polarized light.

The geologic environment that preserved the Chuckanut fish is difficult to determine because the specimen was collected from a rock on the stream bank that had been transported from its original strata. Racehorse Creek is a fast-flowing mountain stream with rocky shorelines that contains a diverse variety of rocks that have been eroded from the adjacent Chuckanut strata (Figure 14). In this environment, rocks from different depositional conditions are juxtaposed. One bedding plane preserves the tracks of a giant gastornithid ground bird, evidence of subaerial deposition. Coarse sediment blocks containing casts of driftwood logs represent sand bars. Sandy siltstones containing leaf fossils are evidence of overbank deposits. As noted earlier, strata containing unionid mussel fossils represent channel sedimentation.



Figure 14. Racehorse Creek. (**A**)View upstream from the fossil site. The fish specimen was presumably transported from the outcrops on the right (west) bank. (**B**) Field team member at the site where the fish fossil was collected from a sandy siltstone block. (**C**) Giant ground bird tracks (*Rivavipes giganteus*) [12] in a nearby silty sandstone outcrop. (**D**) Tree fern frond, *Cyathea pinnata*, in a transported block of fine sandstone found on the stream bank a few meters from the fish-bearing block. (**E**) Driftwood log cast in a point-bar sandstone block ~10 m upstream from the fish fossil site.

Semitropical rainforests flourished in the lowland bordering the ancient river, and overbank deposits are typically rich in carbonized plant remains. The absence of carbonaceous matter in the matrix suggests that the fish fossil may have been preserved in an oxbow lake. The absence of bioturbation is an indication that the sedimentary environment was relatively sterile, which is consistent with the undecayed character of the fossil.

Because the specimen was transported from the adjacent strata, the exact original stratigraphic position cannot be determined. However, the thickness of these streamside beds are ~10 m, positioned within the ~1000 m thickness of the Slide Stratigraphic Member. The local region has been geologically and stratigraphically mapped [7], so the general stratigraphic position can be determined, as shown in Figure 4.

The Swauk and Chuckanut Formations were deposited by meandering rivers that flowed westward during an era that predates the rise of the Cascade Range, producing sediments that have a ribbon-like distribution. The regional stratigraphic relationships are uncertain. The lowest Chuckanut unit, the Bellingham Bay Member, may have been originally deposited in the same basin as the Swauk Formation, as evidenced by similarities in lithology and paleobotany. The overlying Slide Member strata probably originated after the original basin had been partitioned by faulting (Figures 2 and 3). In central Washington, the Roslyn Formation overlies the Swauk Formation, having been deposited in a younger structural basin. The Roslyn *Priscacara* and the Chuckanut *Phareodus* were therefore not contemporaries. In contrast, *Priscacara* and *Phareodus* co-existed in ancient Lake Gosiute in the Green River Basin, Wyoming, USA [19,30].

The best-known fish fossil localities in western USA occur in the Green River Formation in south-central Wyoming, and adjacent areas of Utah and Colorado. The extinct genus *Phareodus* has previously been found in abundance in the Fossil Butte and Laney Members of the Green River Formation in southwest Wyoming, and in the Green River and Bridger Formations in Wyoming and Utah [18,19,30].

Fish fossils have also been found in abundance in the Eocene lakebeds of northeast Washington and southern British Columbia. These localities comprise fault-bounded basins created via tectonic extension (Figure 15). Occurrences range from Driftwood Creek and Horsefly, where fish fossils occur in abundance, to McAbee, Princeton, and Republic, where fish fossils are less common. At these localities, fish fossils are preserved in fine-grained lacustrine sediments. For the fluvial Eocene deposits in Washington, the Chuckanut specimen marks only the third time that a fish fossil has been reported. A specimen collected in 1928 from a coal mine in middle-to-late-Eocene Roslyn Formation was described as a new species of *Priscacara* [31]. A small percomorph fish collected from the Swauk Formation near Swauk Pass in the 1990s remains unidentified.

Limnology is important for the distribution of fish species. Lacustrine environments can be divided into two categories, littoral (nearshore) and limnetic (open-water). In both environments, fish fossilization occurs when carcasses are deposited on the sedimentary substrate. For the Green River basin, the abundance of fish fossils is related to the sedimentology; lake-bottom sediments consist of fine-grained laminated carbonates and an absence of detrital clastic sediments such as sandstone, siltstone, and mudstone. In contrast, littoral sediments are dominated by these coarse-grained clastic sediments, preserving relatively few vertebrate remains [32]. Fluvial depositional environments like those of the Chuckanut Formation are lithologically akin to the lacustrine littoral environment, a key difference being that fluvial deposits are likely to show evidence of downstream current flow. Table 2 shows the distribution of Eocene fish fossils in the region's fluvial and lacustrine deposits.

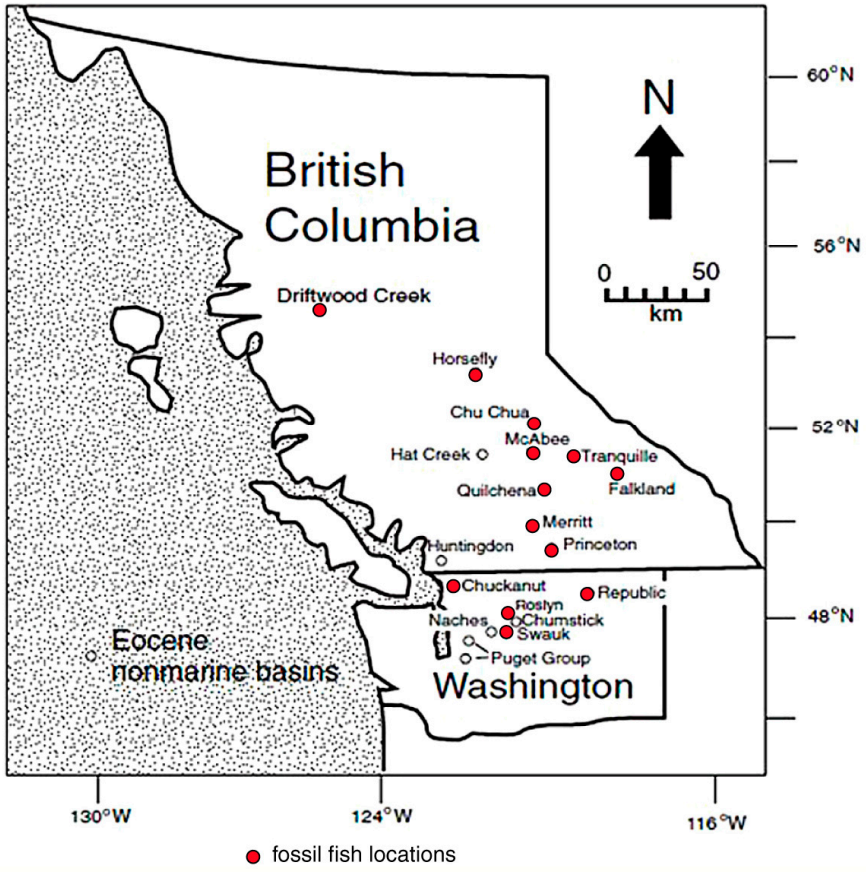


Figure 15. Eocene basins in Washington and British Columbia, showing formations where fish fossils have been found.

Table 2. Known Eocene fish fossil taxa from western Canada and Washington, USA. Data from [33,34].

Fish Genus	British Columbia, Canada			Washington USA		
	Princeton *	Driftwood Canyon *	Horsefly *	Republic *	Roslyn **	Chuckanut **
Amia	X	X	X	X		
Eohiodon	X	X	X			
Amyzon	X	X	X	X		
Eosalmo	X	X	X	X		
Priscacara			X		X	
Phareodus						X

* lacustrine, ** fluvial/floodplain.

Phareodus was one of four major predators in the ancient lakes of the Green River Formation. The others were *Lepisosteus*, *Amia*, and *Mioplosus*. *Phareodus* is an uncommon species at Green River Formation fossil quarries, but extensive excavations spanning many years have yielded hundreds of specimens. For example, during the summers of 1976 and 1977, the J.E. Tynsky Quarry produced 285 *Phareodus* specimens, 5.45% of the sample population. *Phareodus* was less abundant at two other fossil quarries, representing 0.5 and 1.2% of the total sample populations [19]. These low population ratios are not unexpected for a large carnivore that requires an abundance of smaller fish to sustain its dietary needs.

Phareodus has been found in North America in the Green River basin deposits, and its presence in the Chuckanut Formation marks an extension of the known geographic range. As a piscine carnivore, the existence of *Phareodus* implies the presence of other smaller fish taxa that served as prey.

6. Conclusions

The early Tertiary Chuckanut Formation has long been known for abundant plant fossils that date from the semi-tropical forests that flourished in northwest Washington, USA, and adjacent British Columbia, Canada. The traditional presumption that vertebrate fossils were largely not represented has been revised after the discovery of diverse mammal, reptile, and avian trackways [4,6,12,13]. The recent discovery of a partial fish fossil (*Phareodus* sp.) provides an indication of the possible presence of other skeletal remains. Relatively coarse detrital clastic sediments (Figure 13) provide an unfavorable depositional environment for fossilization compared to the fine-grained lakebed sediments characteristic of major fish fossil localities in the Pacific Northwest. Indeed, fish fossils are scarce in the Cenozoic floodplain and backwater lake deposits in all regions, with most specimens having been reported from Pliocene and Pleistocene deposits [29]. Despite its incompleteness, the high preservation quality of the Chuckanut *Phareodus* specimen is encouraging for the search for more vertebrate fossils. The cooperation of amateur fossil enthusiasts and paleontologists offers an inspiring model for future research.

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Data Availability Statement: The specimens described in this report are on display at the Geology Department Museum, Western Washington University, Bellingham, WA 98225 USA, cataloged as WWU-CK-23/1/7.

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Conflicts of Interest: The author declares no conflict of interest.

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