

LATE MIocene FISHES OF THE CACHE VALLEY MEMBER,
SALT LAKE FORMATION, UTAH AND IDAHO

by

PATRICK H. MCCLELLAN AND GERALD R. SMITH



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ABSTRACT

Fish fossils from the Neogene Salt Lake Formation in the vicinity of Cache Valley, Utah, were discovered in tuffaceous marl near Paradise, in southern Cache County, by Utah State University Professor J. Stewart Williams, and later in lacustrine carbonates in the Junction Hills, in adjacent eastern Box Elder County, by Williams' student, P. H. McClellan. In both cases, the fossils are from the Cache Valley Member of the formation, which is generally upper Miocene in this vicinity. The Junction Hills Local Fauna, and fish fossils collected from equivalent Salt Lake beds near Georgetown, Idaho, contain 11 fish species in four families and eight genera and are here called the Cache Valley paleofauna. In the aggregate, these 11 species comprise seven minnows (Cyprinidae) including *Ptychocheilus arciferus* (Pikeminnow), *Acrocheilus latus* or *A. "onkognathus"* (Chiselmouth Chub), *Mylopharodon* sp. (Hardhead Chub), *Mylocheilus* sp. (molariform chub), *Gila domininus* (Bear River Chub), *Rhinichthys* sp. (dace), and a new species, *Lavinia stuwilliamsi* (Hitch). Two suckers (Catostomidae) include *Chasmistes* sp. (lake sucker) and *Catostomus* sp. (river sucker). A catfish (Ictaluridae) is *Ameiurus vespertinus* (Bullhead). The sunfish is *Archoplites* sp. (western sunfish). Most of the Cache Valley fishes and molluscs are related to species from the late Miocene Chalk Hills Formation (8.4–4.5 Ma) and Pliocene Glenns Ferry Formation (4.3–1.8 Ma) on the Snake River Plain (SRP) of western Idaho and adjacent Oregon (WSRP). Four are also related to Bonneville basin and Upper Snake River species: *Chasmistes* sp., *Catostomus* sp., *Gila domininus*, and *Rhinichthys* cf. *R. osculus*. Vicariant populations of *Acrocheilus*, *Lavinia*, *Mylocheilus* sp. and *Archoplites* in the Cache Valley and Chalk Hills paleofaunas diverged morphologically, implying isolation from each other for an unknown time, possibly by super-eruptions at the intervening Twin Falls, Picabo, and Heise volcanic centers (11.3–4.5 Ma) on the Eastern SRP (ESRP). Relatives of Cache Valley species of *Mylocheilus*, *Lavinia*, and *Ptychocheilus* also occur in the middle Miocene Trapper Creek beds (13.5–11.0 Ma) near Oakley downstream in the Snake River drainage in south-central Idaho. Trapper Creek beds are in the Goose Creek drainage through which ancestral Cache Valley and Chalk Hills fishes could have dispersed both ways. The timing of these lowland fish connections is important because it bears on the development of hydrographic barriers and pathways associated with several volcanic centers along the time-progressive ESRP-Yellowstone track of rhyolitic volcanism. Cache Valley fishes and mollusks colonized the basin from four or five sources, separated in time: the middle Miocene Trapper Creek beds, the late Miocene Chalk Hills Lake, the Pliocene Glenns Ferry Lake, locally in the Cache Valley–pre-Bonneville basin, and Upper Snake and Bear Rivers. Also reported is the earliest record of *Acrocheilus*, in the middle Miocene Salt Lake Formation in Grouse Creek Valley, Utah; and the first records of fossil mammals from the Cache Valley Member, a lynx-size felid and a *Merychippus*-grade horse.

Keywords: vertebrate fossils, Hemphillian, Clarendonian, Blancan, Junction Hills, mollusks, *Podocarpus*, *Cathaya*, *Mahonia*, *Merychippus*, lynx, tephra, biogeography, J. Stewart Williams, Trapper Creek, Chalk Hills, Glenns Ferry.

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INTRODUCTION

The Junction Hills, located about 15 km south of the Utah-Idaho border, form a low divide that connects the Wellsville Mountains of the northern Wasatch Range with the southern Malad Range and separates Cache Valley on the east from the lower Bear River Valley (also known as Salt Lake Valley) on the west. Its ridgeline locally marks the boundary between Box Elder and Cache Counties (Fig. 1). Underlying the hills is a substantial nonmarine sedimentary record that spans as much as 6 m.y. of late Tertiary time, and is assigned to the Salt Lake Formation (Williams, 1962:133). In the Cache Valley area the Salt Lake Formation has been divided into several parts, including a basal conglomerate and an overlying unit called the Cache Valley Member, which comprises interbedded tuffaceous sandstone and siltstone and, in the Junction Hills, is capped by a distinctive oolitic limestone (e.g., Goessel et al., 1999; Biek et al., 2003). In the northern portion of Cache Valley (near the Utah-Idaho border), discontinuous conglomerate units are mapped higher in the section that overlie (Danzl, 1982, 1985; Sacks and Platt, 1985; Brummer and McCalpin, 1995:6) and intertongue with (Brummer, 1991:22; Janecke and Evans, 1999:81, fig. 8; Brummer and McCalpin, 1995:6 in subsurface data) the Cache Valley Member, and may be absent near the valley center (Brummer and McCalpin, 1995). Also in this vicinity, well logs in the Richmond Quadrangle show the conglomerate units are folded and faulted, and interbedded with shale and an oolitic limestone at least 60 m thick (Oaks, 2011). The Cache Valley Member is fluvial and lacustrine in origin and the conglomerate units are valley-margin facies (alluvial fans). Only the Cache Valley Member is present in the Junction Hills.

Our study focuses on fossil fishes from the Cache Valley Member collected in three areas: (1) in the Junction Hills, (2) at a locality near the town of Paradise in southern Cache County, and (3) from correlative beds near Georgetown, Idaho, in adjacent Bear Lake Valley. We refer to the combined

fish assemblage as the Cache Valley paleofauna, which represents the first diverse vertebrate fauna to be described from the Salt Lake Formation. The study area is situated near the intersection of the Middle Rocky Mountains and Basin and Range physiographic provinces, and the Great Basin and SRP hydrographic systems (Fig. 1). The Cache Valley Member and its Tertiary fossils may inform our understanding of the biostratigraphy and paleobiogeography of freshwater faunas (Table 1) that occupied the Neogene river and lake systems in these regions, as well as the tectonic evolution of the regions themselves.

The Cenozoic Salt Lake “Group” was first described and named by Hayden (1869) for light-colored tuffaceous strata in Weber Valley of northcentral Utah that he considered to be Pliocene. The strata in his type area were later identified as upper Eocene based on fossil mammals and radiometric dating (Gazin, 1959; Evernden et al., 1964; Bryant et al., 1989; K. Smith, 1997), and renamed the Norwood Tuff and designated as the basal unit of the Salt Lake Group (Eardley, 1944). In northern Utah and southern Idaho the Salt Lake “Formation” (as this unit is now typically ranked) was also studied by, among others, Mansfield (1920, 1927, 1952), Williams (1948, 1962, 1964), Mapel and Hail (1959), Adamson et al. (1955), Slentz (1955), Mullens and Izett (1964), McClellan (1977), Danzl (1982, 1985), Sacks and Platt (1985), Oviatt (1986), Brummer and McCalpin (1995), Goessel et al. (1999), Oaks et al. (1999), Janecke and Evans (1999), Oaks (2000, 2011), Biek et al. (2003), Carney and Janecke (2005), Steely et al. (2005), and more recently Miller et al. (2012) and Clark et al. (2014). Beyond Cache Valley, the Salt Lake Formation has been mapped as far west as Park Valley and Grouse Creek Valley in northwestern Utah (Oaks, 2004; Hurlow, 2004; Hurlow and Burk, 2008; Miller et al., 2012) and Elko County, Nevada (Mapel and Hail, 1959); northward to south-central Idaho at Trapper Creek (Mapel and Hail, 1959) and Raft River basin (Williams et al., 1982) in Cassia County; in the counties of southeastern Idaho (Mansfield, 1920, 1927, 1952);

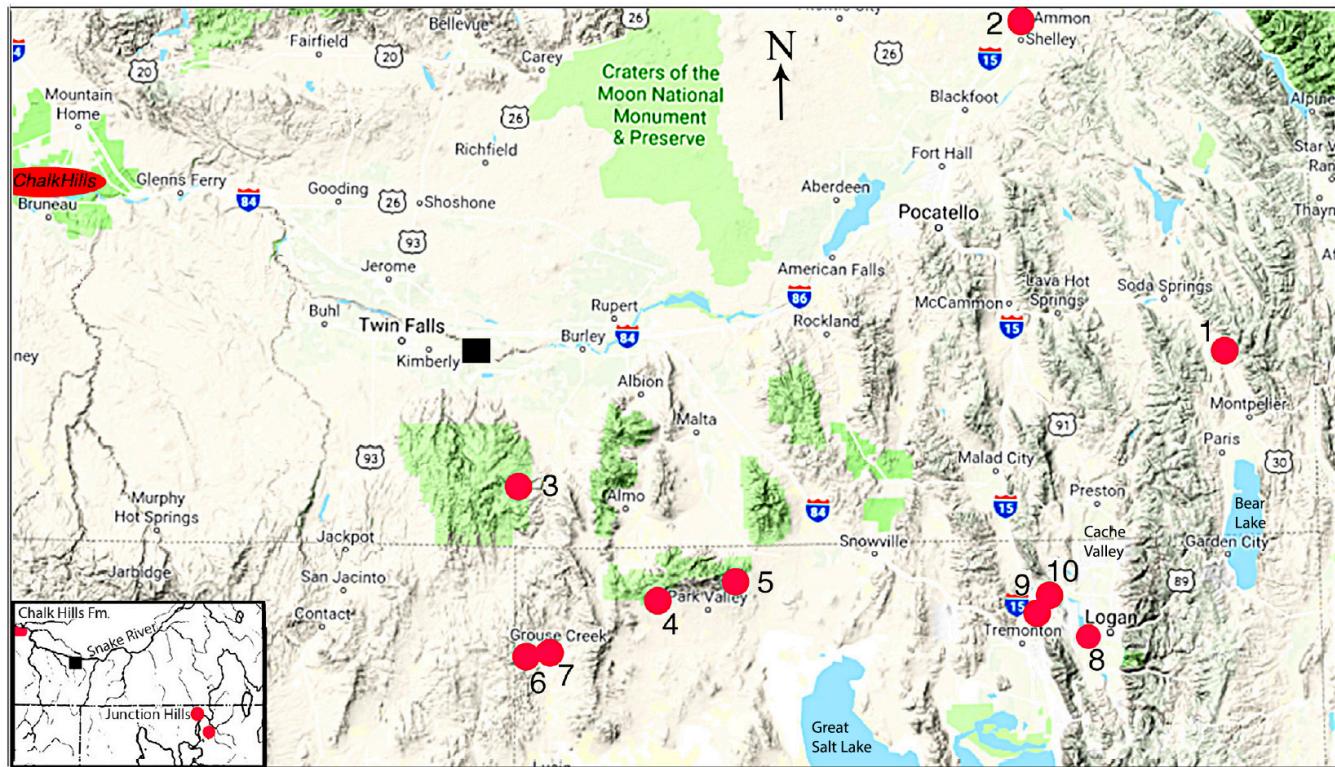


Figure 1: Fossil fish localities in the Salt Lake Formation and the Cache Valley Member from McClellan (1977) and this study: 1, Georgetown (N. Smith, 1953:76), Georgetown *Rhinichthys* (IMNH); 2, Ammon (Mansfield, 1952:46); 3, Trapper Creek, Goose Creek Valley (Mapel and Hail, 1956:6-8; 1959:226-227); 4, Park Valley sunfish locality (Felix, 1956:87); 5, Park Valley sculpin locality (Cavender, written communication, 1977); 6, Etna (UCMP V77142, this report) and 7, Dry Canyon (McClellan, 1977:20-21), mammal localities, Grouse Creek Valley; 8, Paradise *Lavinia stuwilliamsi* locality (Uyeno and Miller, 1963:26; UCMP V77193, this report); 9, Junction Hills fish locality (McClellan, 1977; UCMP V77020, V77021, this report); 10, Collinston Hill hyomandibula locality (UCMP V77022, McClellan, 1977:10-11). We have examined fish specimens from localities 3, 5, 6, 7, 8, 9, and 10. Fish localities 8–10 are in the lacustrine Cache Valley Member of the Salt Lake Formation (this report); the remainder are in lake beds assigned to the Miocene or Pliocene Salt Lake Formation (undifferentiated), except locality 3, which is in an adjacent basin of age-equivalent sediments. Exact localities of 4 and 5 not verified. Lake beds of the Chalk Hills and Glenns Ferry Formations extend from the southwestern part of the Western Snake River Plain near Bruneau, Idaho (red, upper left), to near Vale, Oregon, and from near Hagerman, Idaho, to Willow Creek, Oregon, respectively. The black square marks the vicinity of the Twin Falls Volcanic Field.

and east into Lincoln County of western Wyoming (Mansfield, 1916; Love and Christiansen, 1985). Across its mapped extent in northern Utah, tephras in the Salt Lake Formation appear to be younger eastward from the Promontory Range, with the base and top both older in the west than in Cache Valley (Smith, 1975; Smith and Nash, 1976; and Miller and Schneyer, 1994).

The Junction Hills sequence where we collected fish fossils is in eastern Box Elder County, north of the Bear River Narrows (Cutler Dam), in

the SE $\frac{1}{4}$ Sec. 16, T. 13 N., R. 2 W. The locality near Paradise, where J. S. Williams collected fish specimens (Williams, 1962), is in southern Cache County, in the S.E. $\frac{1}{4}$ Sec. 20, T. 10 N. R. 1 E., 35 km southeast of the Junction Hills site and 20 km south-southwest of Logan in southern Cache Valley (Fig. 1). A third locality, in correlative strata of the Salt Lake Formation near Georgetown, Bear Lake County, Idaho, in central Bear Lake Valley, produced a small collection of fish fossils that we also report here.

TABLE 1 -- Fish species occurrences in regional faunas

Localities	State	NALMA	max-min age																											
				<i>Ameiurus</i>	<i>Orthodon</i>	<i>Ptychocheilus</i>	<i>Mylopharodon</i>	<i>Siphateles</i>	<i>Lavinia</i>	<i>Gila</i>	<i>Klamathella</i>	<i>Acrocheilus</i>	<i>Richardsonius</i>	<i>M. copei</i>	<i>M. robustus s.l.</i>	<i>M. inflexus</i>	<i>Rhinichthys</i>	<i>Oregonichthys</i>	<i>Deltistes</i>	<i>Chasmistes</i>	<i>Catostomus</i>	<i>Pantosteus</i>	<i>Prosopium</i>	<i>Paleolox</i> <i>Salvelinus</i>	<i>Oncorhynchus</i>	<i>Esox</i>	<i>Archoplites</i>	<i>Cottus</i>	<i>Myoxocephalus</i>	<i>Kerocottus</i>
Lake Bonneville	UT	IR	15-11k						x	x									x	x	x	5	x	c		x				
Lahontan basin	NV	IR	15-11k																x	x		c		x						
Duck Point ESRP	ID	IRBL	8?-11k						x	x	x								x			c								
Bruneau Fm	ID	IR	1.8m		x	x				x	x								x	x										
Pre Lahontan loc	NV	HHBL	6-2.2m	x	x	x	x												x	x		c		x						
Glenns Ferry Fm	IDOR	BL	4.3-1.8m	2	x	x	x	x	x	x	x	x	x	x	x	x	2	2	x	2	2	m		2	x	2	5			
Cache Valley Mm	UT	HH	7.5-4.5m	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x					x						
Chalk Hills Fm	ID	HH	8.4-4.5m	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	m	3	x	x						
Teewinot loc	WY	HH	7.5-5.8m																x											
Drewsey Fm	OR	HH	8.8-8.5m	2	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x				
Poison Creek Fm	ID	CLHH	9.5-8.9m	2	x	x				x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x				
Ellensburg Fm	WA	CLHH	10.5-10m	x	x	x	x												x			x		x						
Picket Creek loc	ID	CLHH	10.5-8.5m																x					x						
				Catfish	Blackfish	Pikeminnow	Hardhead	Tui Chub	Hitch	Chub	Chub	Chiselmouth	Shiner	Babyjaw	Babyjaw	inflexus	Dace	Oregon Chub	Lost Suckers	Lake Suckers	River Suckers	Mtn. Suckers	Whitefish	Char	Trout	Salmon	Muskellunge	Small Sunfish	River Sculpin	Northern sculpin

Symbols for *Oncorhynchus* trout, c=clarkii; m=mykiss.

For this paper, PHM contributed the geological context, the paleobotanical and palynological research, mammalian paleontology, and a preliminary description of the Junction Hills fishes (McClellan, 1977, 1981); and GRS contributed new specimens and the updated and new taxonomic identifications and descriptions of the fish species

in the aggregate fauna, along with discussions of their paleobiogeography and evolution.

HISTORY OF INVESTIGATION

In Cache Valley and the surrounding region of Utah and Idaho, paleontological investigations

of the Salt Lake Formation have yielded fossils of plants (leaves and pollen), aquatic invertebrates (ostracods, mollusks, insects), and vertebrates both aquatic and terrestrial (fish, amphibian, reptile, bird, and mammal) that are mostly fragmentary and non-diagnostic as to age. In the Junction Hills they include Yen (1946, 1947) and Taylor (1966) on mollusks, Swain (1947) on ostracods, and McClellan (1977) on fishes. At the Paradise locality, investigators include Brown (1949) on leaves, J. S. Williams (1962) on fishes, and McClellan (1977) on pollen.

In adjacent Bear Lake Valley, from the Salt Lake Formation exposed in low hills and road cuts near Georgetown, Idaho, Neal Smith described (1953:76) fossiliferous sediments in which he identified plants, ostracods, mollusks, and fish; Yen (1947) reported a molluscan fauna of late Miocene age; and Sue Ann Bilbey collected fossil minnows and deposited them in the Idaho State Museum of Natural History (Smith et al., 2002:208). Mansfield (1952:46) reported fish remains from the Salt Lake Formation in Bonneville County southeast of Ammon, Idaho, judged by J. W. Gidley (at the U. S. National Museum) as "too fragmentary to determine further than...opercula of some freshwater fish about the size of the sucker or large minnow."

In Trapper Creek, tributary to Goose Creek, Cassia County, Idaho, Mapel and Hail (1959:226-227) reported disarticulated fish bones at several levels in fine-grained tuffaceous sediment assigned to the "Payette(?) Formation (now Tuff of Ibex Peak and Beaverdam Formation; Mytton et al., 1990), dated at 16 Ma (Axelrod, 1964), and Salt Lake Formation, 10 Ma (Armstrong, et al., 1975:248). Fossil *Mylocheilus*, *Lavinia*, and *Ptychocheilus* were collected from Trapper Creek sediments by Nathan Carpenter and Ralph Stearley from the College of Idaho in 2017. In neighboring Grouse Creek Valley, in western Box Elder County near Etna, Utah, PHM collected unidentifiable fish vertebrae, sunfish spines (*Archoplites*), and cyprinid (*Acrocheilus*) pharyngeal teeth in 1975

from tuffaceous fluviolacustrine sediments of the Salt Lake Formation near the northern end of the valley (NW ¼ T. 11. N., R. 18 W., elev. 1612 m [5290 feet]). The Etna fish remains were associated with a fragmentary middle Miocene vertebrate fauna containing species of frog, lizard, snake, bird, shrew, lagomorph, beaver, and camel, with a chalicotheres (Coombs, 1979) and rhinoceros that are Hemingfordian North American Land Mammal Age (NALMA) in aspect (McClellan, in prep.). Tephrae in this vicinity have been correlated with ashes dated at ~15 Ma (Perkins, 2014).

Also in Box Elder County, from the Salt Lake Formation east of the Grouse Creek Mountains in Park Valley, Tedrow and Robison (1999) reported teeth of a lagomorph and two rodent species of middle Miocene (Clarendonian) age; Felix (1956) cited a fossil centrarchid sunfish found by a Park Valley resident (probably near sections 5:8, T. 12 N., R. 12 W.); and a preopercle of a sculpin (Cottidae) was collected by Ted Cavender from near the sunfish locality.

The NALMA time scale used in this report is that of Janis et al. (2008). It is unclear which geochronological standard early investigators of the Salt Lake beds relied upon to define their concepts of Miocene and Pliocene time. Since the 1960s the Miocene-Pliocene boundary in North America has shifted later in time by roughly seven million years, from 13–11 Ma (e.g., Keroher et al., 1966:iv, Keroher 1970:iv) to 5.3 Ma (Berggren and Van Couvering, 1974). While there has been continued debate over the boundary's stratigraphic definition and chronological calibration (e.g., Hilgen and Langereis, 1988, 1993), a 5.33 Ma age is ratified in the current Miocene-Pliocene Global Boundary Stratotype Section and Point (International Commission on Stratigraphy, 2020). In many instances, this boundary shift has placed rocks formerly called lower and middle Pliocene in the Western United States into the middle and upper Miocene. We address this lack of clarity for the Cache Valley paleofauna below (see *Summary age of the Cache Valley paleofauna*).

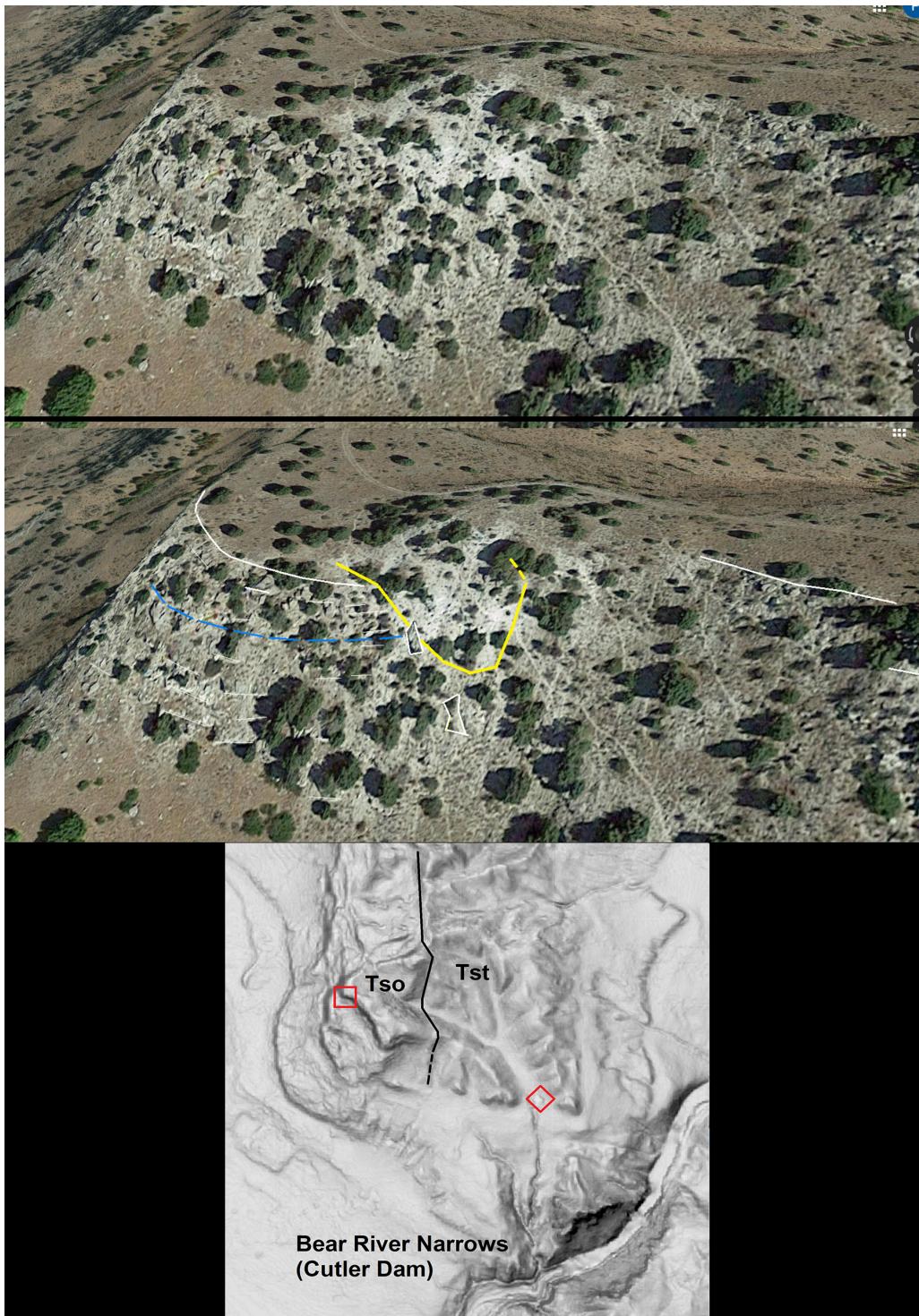


Figure 2: N end of the steep SW-facing landslide scarp in the Cache Valley Member (Plymouth oolite subunit) of the Salt Lake Formation, Junction Hills, Box Elder County, Utah. Original view (**top**), interpretation by PHM (**middle**). Lines are ledges of oolitic limestone or talus therefrom (**white**); the upper fish level of McClellan (1977) (**blue**); the base of the inferred channel fill that contains the Blancan molluscan fauna of Yen (1947) and Taylor (1966) (**yellow**). Source: Google Maps™ 2019 imagery, center at approximately 41.862, -112.073, view angle about 20 degrees downward on scarp crest. Relief map of Junction Hills (**bottom**) showing fossil localities of fish and mollusks (**square**) in oolite subunit (**Tso**), and horse (**diamond**) in tephra subunit (**Tst**), separated by Beaver Dam fault.

JUNCTION HILLS FISH LOCALITY

Geology of the Junction Hills. Over most of the Junction Hills, the exposed strata comprise the Salt Lake Formation, which unconformably overlies marine Paleozoic and Late Precambrian hard sedimentary bedrock. The earliest, and perhaps best, description of the Salt Lake beds here is that of Hague (in Hague and Emmons, 1877:406) from Clarence King's U. S. Geological Exploration of the Fortieth Parallel: "a deposit of Pliocene Tertiaries which have filled Cache Valley, and extended over the low pass at the 'Gates' of Bear River [the gorge presently occupied by Cutler Dam and Cutler Reservoir] into Salt Lake Valley. These Tertiaries consist here mostly of grayish-white limestones and sandstones, partly fine-grained and compact, and partly coarse and porous. Some of the beds are more or less oolitic, and some again are almost completely made up of aggregations of freshwater shells of Pliocene and recent species." (Hague referred this northern Utah deposit to the Humboldt beds, which the King survey had earlier observed in northern Nevada, on the basis of general similarity and stratigraphic position, presuming their age to be Pliocene and cautioning that "palaeontological evidence is yet too meager to throw any important light on the question" (Hague and Emmons, 1877:417-418).

The oolitic limestone is confined to a distinct vertical interval primarily at the western side of the Junction Hills in Box Elder County. Reconnaissance mapping in this vicinity initially placed the oolite at the base of the Cache Valley Member below a thick tuffaceous subunit (Adamson, 1955; Williams, 1964; and accepted by McClellan, 1977). However, detailed mapping by R. Q. Oaks, Jr. (in Goessel, 1999, plate 1, and p. 53) showed that the oolite occupies a much higher stratigraphic position. About 3 km NW of the fish locality, at the south end of the Malad Range, the oolite is in conformable stratigraphic contact above that tuffaceous subunit, with both units having similar dips around the axis of a small plunging syncline. Moreover, south of the Junction Hills, at

the north end of the Wellsville Mountains, Goessel (1999:34) recognized that up to 1 km of tuffaceous strata rest unconformably on older formations, with only thin lenses of the oolitic limestone occurring at the highest exposures of the Cache Valley Member; and that the oolite was nowhere found in stratigraphic contact with the Paleozoic basement while the tuffaceous subunit rests directly on basement in places. This, together with fault-mapping in the vicinity, indicated to Goessel (1999:33) that the oolite overlies a substantial thickness of the tuffaceous subunit and, in the Junction Hills, occupies an isolated, down-faulted block that juxtaposes the oolite against the older tuffaceous subunit exposed to the east, or against the underlying Pennsylvanian Oquirrh Formation (Goessel et al., 1999, fig. 11). We add that the conformable contact mapped to the northwest in the Malad Range opens the possibility that the nearshore lacustrine oolite and finer-grained fluviolacustrine tuffaceous subunit are, at least in part, time-equivalent sedimentary facies that intertongue across coeval alluvial fan, beach, delta and open-water environments of a common lake basin.

Later mapping ranked the oolite as a separate and mappable subunit overlying the Cache Valley Member. At the southern end of the Malad Range, Oaks (2000, 2004) and Biek et al. (2003) traced the Salt Lake Formation into the adjacent Junction Hills, where they named the fish-bearing limestone the Plymouth oolite subunit, and placed it near the middle of the local Tertiary succession above the tuffaceous interval of Goessel et al. (1999), which Biek et al. (2003) named the Junction Hills tephra subunit, and below a thick and poorly indurated clastic sequence, which they named the Washboard subunit (Biek et al., 2003, plate 3, stratigraphic column). We use the terms "Plymouth oolite" and "tephra subunit" hereafter in this report.

Structurally, the Junction Hills are a complexly faulted horst (e.g. Williams, 1948, 1958; Sprinkel, 1976; Oaks, 2000; Biek et al., 2003; Ellis and Janecke, 2018) separated from Cache Valley on the east by the east-dipping Junction Hills fault

and from the lower Bear River Valley on the west by a southwest-dipping low-to-moderate angle normal fault, the Beaver Dam fault (Sprinkle, 1976; Goessel et al., 1999). The Beaver Dam fault continues SSE based on gravity data and, thus, is not an extension of the Wasatch fault (Oaks, 2000, Fig. 1). The Plymouth oolite occupies the hanging wall of the Beaver Dam fault and is truncated against the older tephra subunit in the footwall to the east (Goessel, 1999, plate 1; Goessel et al., 1999, fig. 3; Oaks, 2000; this report, Fig. 2). The normal faults developed during the extension of the Basin and Range Province during the past 5 to 10 Ma (Goessel et al., 1999). Late Quaternary landslides along the western side of the Junction Hills have exposed in cross-section the subhorizontal Plymouth oolite subunit in a prominent southwest-facing head scarp. The scarp sequence contains at least 65 m of tuffaceous carbonate facies, including oolitic limestone interbedded with calcareous siltstone and sandstone, and tuffaceous siltstone, sandstone, and conglomerate (Figs. 2, 3). The upper 30 to 40 m of this scarp sequence, about 750 m W of the Beaver Dam fault, has produced all of the previously described fossil assemblages from the Junction Hills, including the mollusks, ostracods, and fishes, which collectively are here termed the Junction Hills local fauna.

Sedimentology of the fish-bearing sequence. We collected the Junction Hills fishes described here from two horizons 12 m apart near the middle of the vertical exposure in the landslide scarp, at the scarp's northern end (Figs. 2, 3), where R. Q. Oaks and his student, K. M. Goessel, measured their Section 2 (Goessel, 1999:44). Sedimentary rocks in the scarp sequence include calcilutite, calcarenite, calcareous tufa, cross-stratified pebble conglomerate, vitric tuff, and tuffaceous sandstone (McClellan, 1977). Distinctive syngenetic structures in the carbonates include skeletal beds composed predominantly of tests of ostracods and mollusks (Fig. 5), biostromes and possible bioherms of cabbage-shaped tufa heads and laterally linked hemispheres as tall as 50 cm (Fig. 6 e), convoluted bodies of contemporaneously

slumped sand up to 3 m thick (Fig. 6 c), and cross-stratified oolitic calcarenite in which ooids range from 0.1 to 4.0 mm in diameter in foreset packages that, along strike in the scarp exposure, range from a few cm to 17 m thick (Fig. 6 b) (McClellan, 1981). Geometry, attitudes, and orientation of foreset sediment packages were not specifically analyzed; however, pebble imbrication in the conglomerate at the NE end of the scarp (below the upper fish level) and inclination of oolite foresets generally suggest westward progradation of stream and shoreline deposits into the nearshore area of the paleolake. Elements of this suite are similar to the Hot Creek algal reef in the Chalk Hills Formation (Straccia et al., 1990; Bohacs et al., 2013), the oolites of the Glenns Ferry Formation in the nearby WSRP (Swirydczuk et al., 1979, 1980 a, b), and the "massive oolitic calcareous sandstone" in the Salt Lake Formation in the Georgetown area of Bear Lake Valley, Idaho (Yen, 1946; Cressman, 1964).

The lower fish level (UCMP locality V77020) is in a 15-m interval that is over 70% CaCO₃ and comprises an interbedded sequence of friable fine-grained oolitic calcarenite, calcilutite, and minor lenses of Paleozoic pebble conglomerate. The calcarenite contains allochthonous subangular grains of dark chert and white-to-colorless chert from 0.2 to 2.5 mm in maximum dimension along with sub-rounded to rounded gray carbonate clasts 1–5 mm in diameter. Both chert and carbonate clasts also occur in matrix-supported pebble lenses that are scattered throughout this level and become more common upward, along with ooids and structureless carbonate grains (pellets), ostracod tests, molds of mollusk shells, and fish bones that are in some instances articulated or closely associated. The ooids range in size from 0.1 to 0.7 mm in diameter, are usually pitted, and form a grain-supported, porous rock that variously is bound in sparry calcite or is poorly indurated. Other beds in the lower fish layer have ooids that range from 0.4 to 0.92 mm. Ooids vary in abundance from being the nearly exclusive component of the calcarenites, grading downward to rare, scattered features of the carbonate mud facies (McClellan, 1977). In this

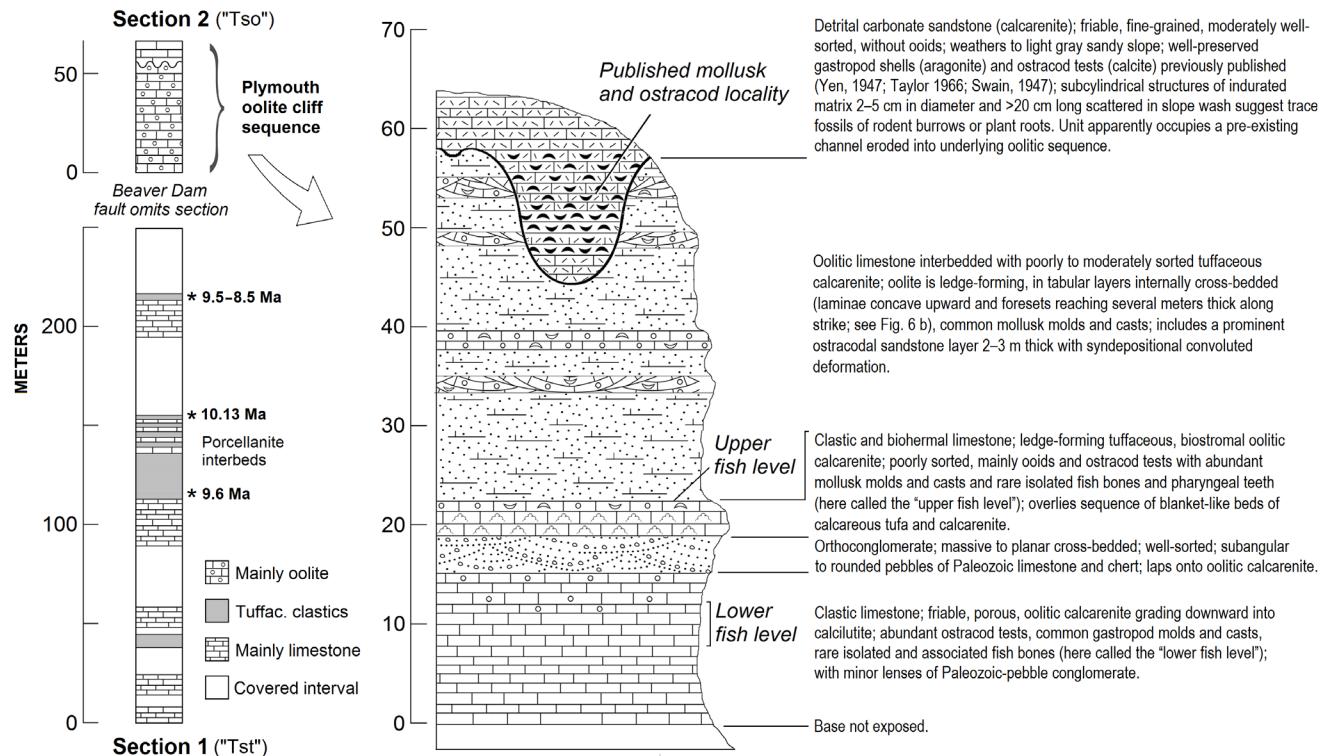


Figure 3: Schematic stratigraphic column of the Salt Lake Formation exposed in the prominent landslide scarp at the western margin of the Junction Hills (Fig. 2), 3.5 km NNW of the Bear River Narrows (Cutler Dam), Box Elder County, Utah. This distinctive oolitic limestone facies (**Tso**), assigned to the Cache Valley Member by Adamson (1955), Goessel (1999:31), Goessel et al. (1999, fig. 5) and others, was later named the Plymouth oolite subunit and ranked as a separate and mappable division of the formation by Oaks (2000, 2004) and Biek et al. (2003) overlying the tuffaceous beds of the Cache Valley Member (*sensu lato*), which they named tephra subunit (**Tst**). Detailed column shown here was measured (McClellan, 1977) in the subhorizontal carbonate sequence exposed in the headwall scarp near the northern end of the landslide. The section intersects the “lower” and “upper” fish levels (this report) and the overlying shelly deposit that produced previously described fossil mollusks (Yen, 1947; Taylor, 1966) and ostracods (Swain, 1947). New in this interpretation is the inferred unconformity (channel) between the fish-bearing oolitic limestone (Hemphillian age) and the overlying mollusk zone (Blancan, according to Taylor, 1966). Columns at left show wider stratigraphic context in the Junction Hills, generalized from Goessel et al. (1999, fig. 5, measured sections 2 [**Tso** in scarp sequence] and 1 [**Tst** about 1,500 m to E]); ages are their tephra correlations; porcellanite interval is the probable source of the Miocene horse tooth found as float (see below, Fig. 21b). (Compare Fig. 4).

interval, they are smaller, muddier, less well-sorted, and less agitated than ooids in the large Gilbert-style foreset beds (Fig. 6 b) elsewhere along the scarp sequence and in the Pliocene Glenns Ferry Formation on the WSRP (Swirydczuk et al., 1979, 1980 a, b). The ooid strata in the lower layer mark an upward transition from quiet to progressively higher-energy lacustrine conditions, as might be expected in a shoaling, open-water environment. The carbonate mud is interpreted as having been deposited in an open lake below wave base.

The upper fish level (UCMP locality V77021) is a ledge-forming oolitic and biostromal

calcarene (Fig. 6 e). Below its weathered surface is a 3-m sequence of interbedded calcareous tufa (considered here to be of algal origin) and oolitic limestone. The upper fish horizon grades downward into an unfossiliferous, fine-grained calcarenite that in turn lies above and in small troughs between underlying tufa heads. The tufa takes the form of irregular hemispherical heads of nodose, porous limestone which are often linked at their bases. The heads average 30–40 cm high and are tapered toward their tops. Shallow troughs formed between some adjacent heads. The structures are roughly similar to algal limestone in Pyramid Lake

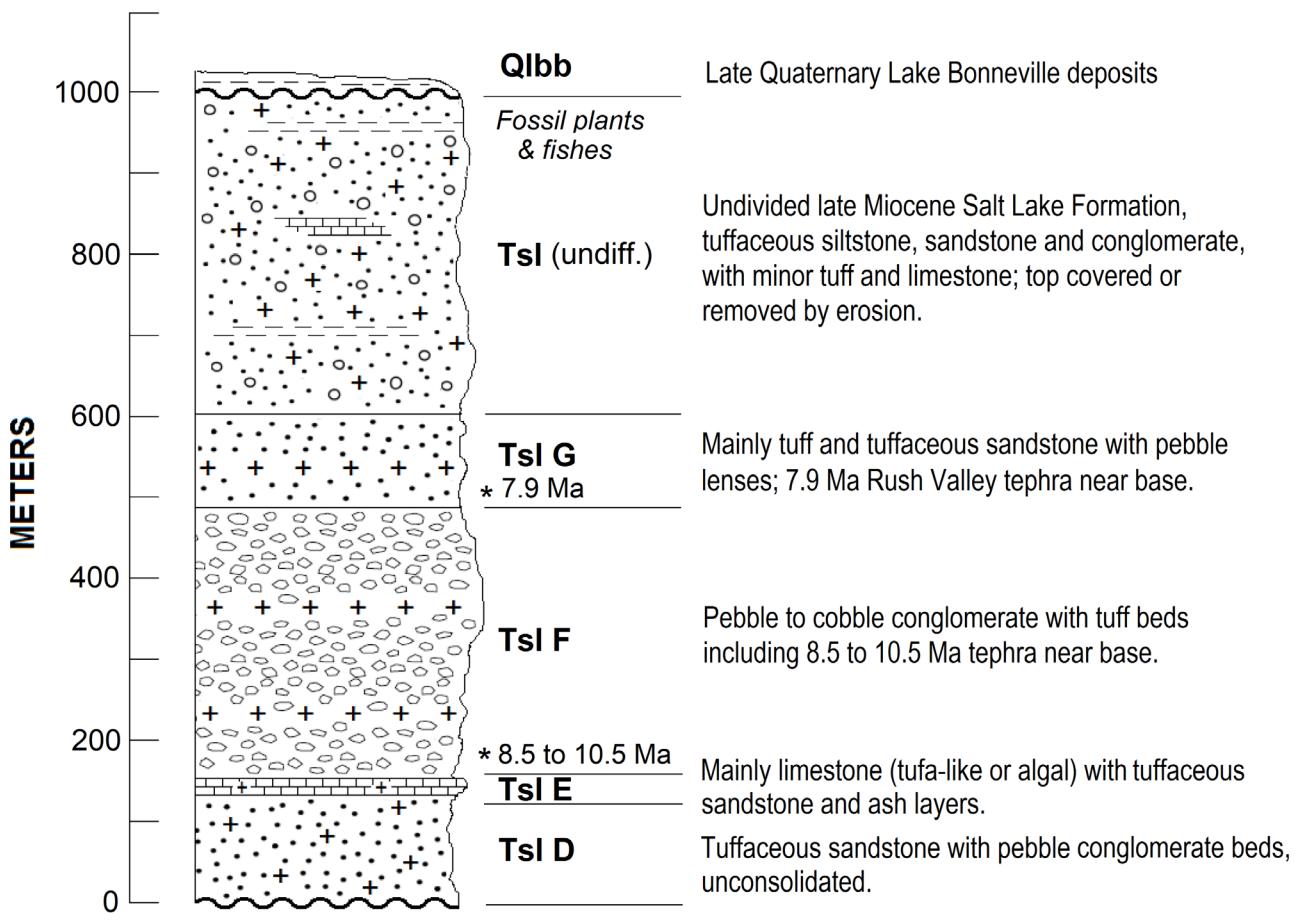


Figure 4: Schematic stratigraphic column of Salt Lake Formation (**Tsl**) northwest of Paradise in southern Cache Valley, Cache County, Utah. In this vicinity the formation is bounded below at a basal unconformity on eroded Paleogene Fowkes Formation and Norwood Tuff equivalents, and above at a post-late Miocene erosional surface beneath Late Quaternary lakebeds (**Qlbb**) deposited between the Bonneville and Provo shorelines of Pleistocene Lake Bonneville. The sequence is truncated on the east by a N-S normal fault inferred (Oaks, 2000) near the bluffs along the W bank of the Little Bear River. Thickness and lithology of subunits **Tsl-D through Tsl-G** are based on the measured section and descriptions by K. Smith (1997, section "B", fig. 5, table 6) and Oaks et al. (1999, same section labeled "2", fig. 6), and are extrapolated (this study) vertically to include the undifferentiated upper subunit of the formation (K. Smith, 1997, plate 1) and laterally to show the approximate position of two correlated tephra horizons identified (Oaks et al., 1999) in adjacent section "C" (= section "3") 1.6 km to the south. General position of the fossil plant and fish horizon (Brown, 1949; Williams, 1962; McClellan, 1977) is indicated near top of column; 3–4 km to the NW, limited exposures and water-well logging show an oolitic limestone (**Tsl** subunit "**M**" of Oaks et al., 1999, fig. 6 map, and fig. 7 section 1) several hundred meters above the level of the plant and fish locality that may be equivalent to the Plymouth oolite (Oaks, 2000, 2004).

(La Rivers, 1962), Utah Lake (Bissell, 1962), the Great Salt Lake (Eardley, 1938), Lake Bonneville shoreline gravels (McClellan, 1977), Cache Valley Formation (Williams, 1962), and the Chalk Hills Formation (Straccia et al., 1990; Bohac et al., 2013). Beneath that tufa layer is a similar sequence that rests with sharp contact on a pebble conglomerate.

Ooids and ostracod tests are the predominant clasts in the biostromal calcarenite, and mollusk molds and casts are the principal sedimentary structures. The disarticulated preservation of the fish bones in the upper level suggests water turbulence, and possible scavenging by snails. The heterogeneity of the calcarenite sequence suggests variable

deposition in a quiet-water setting, perhaps behind a barrier, with occasional storm-wave action.

The oolitic facies in this scarp sequence and the sedimentary structures associated with them, along with the invertebrate and fish fossils of the Junction Hills local fauna, reflect a shallow nearshore lacustrine paleoenvironment (McClellan, 1977) that demonstrates the Cache Valley Member here predates the extensional faulting that produced the Junction Hills horst.

Age of the Junction Hills Local Fauna. In the Junction Hills, the age of the Cache Valley Member was previously uncertain within the late Miocene and Pliocene despite its rich production of invertebrate fossils. Yen (1947) assigned a Pliocene age for the “well-preserved” mollusk fauna collected 20 m above the upper fish horizon, and Taylor (1966) later refined the mollusks to the Blancan NALMA. Swain (1947) described an ostracod fauna, apparently from the same horizon that produced the mollusks (Williams, 1964), but did not assign a specific age because 11 of the 12 species he described were new. Adjacent to Cache Valley, in Bear Lake Valley near Georgetown, Idaho, the lower tuffaceous member of the Salt Lake Formation contains a similar suite of interbedded tuff and sandstone with oolitic limestone that yielded lacustrine mollusks identified as upper Miocene by Yen (1946:487, 1947:268), Cressman (1964:58), and Taylor (1966:68).

Swain (1987) later resolved the Junction Hills ostracods to “late Miocene? to early or middle Pliocene age”, and finally decided on a Pliocene age (Swain, 1999). Throughout his sixty-year career, however, Swain rarely referred ostracod age determinations to provincial land mammal ages; so, it is unclear which “Miocene” and “Pliocene” he referred to. To clarify his Cache Valley age assignment we note that in the late 1940s, at the time Swain and Yen described the Junction Hills invertebrates, the base of the Pliocene epoch was understood to be approximately 12 Ma (e.g., Keroher 1970:iv), and the Clarendonian, Hemphillian, and Blancan NALMAs (succeeding oldest to youngest) were regarded to represent

generally the early, middle and late Pliocene, respectively, in North America (Wood et al., 1941).

During the 1960s, the consensus among European stratigraphers ultimately recognized the Miocene-Pliocene boundary to be the top of the evaporitic deposits in southern Italy (the Messinian stage) dated at 5.3 Ma (Berggren and Van Couvering, 1974). Subsequent analysis of the Messinian and overlying Zanclean Stages (Hilgen and Langereis, 1988, 1993) proposed a glacially tied eustatic sea-level rise—and the resulting restoration of open-marine circulation in the Mediterranean Basin—as the synchronous depositional event defining the base of the Zanclean. That refinement placed the Miocene-Pliocene boundary at 4.86 Ma using the geomagnetic polarity time scale (GPTS) of Berggren et al. (1985), 5.16 Ma using a later GPTS calibration (Cande and Kent, 1992), and 5.32 Ma using the astronomically calibrated time scale of Hilgen (1991). Today, a 5.33 Ma age is ratified as the current Miocene-Pliocene Global Boundary Stratotype Section and Point (International Commission on Stratigraphy, 2020).

The age of the Hemphillian-Blancan faunal boundary is not precisely defined. In Mexico it is identified at 4.7–4.8 Ma (Flynn et al., 2005) and farther north, in eastern Nevada, at 4.9–5.0 Ma (Lindsey et al., 2002). Using the first appearance of Blancan mammalian faunas the boundary is 4.6–5.2 Ma (Bell et al., 2004:252), and a date around 5.0 Ma is used for the boundary datum in North America generally (Woodburne, 2004; Janis et al., 2008). The Pliocene, thus shortened, includes all of the Blancan except for its latest part, which is now early Pleistocene, and just the latest Hemphillian, if any—depending on the GPTS calibration (4.86–5.33 Ma) and biochron boundary age (4.6–5.2 Ma) chosen.

In 1999 when Swain finally assigned the Junction Hills ostracods to the Pliocene (Swain, 1999), he cited as his chronostratigraphic standard the AAPG COSUNA Chart, which recognized the Messinian datum as the Miocene-Pliocene boundary (Salvador, 1985, fig. 3). Therefore, it appears Swain intended a Blancan or latest Hemphillian age for

TABLE 2 -- Tracking Sources of Cache Valley, Chalk Hills, and Glenns Ferry molluscs. Gray background indicates possible Chalk hills source for four of the species shared by Glenns Ferry and Cache Valley molluscs. The Glenns Ferry Formation inherited as many as 10 species from the Cache Valley Lake.

Chalk Hills Fm Mollusca. 8.4-4.5	Glenns Ferry Fm. Mollusca. 4.5-3	Cache Valley Mollusca. 7.9-6.4
<i>Margaritifera margaritifera</i>		
<i>Gonidea coalingensis</i>		
<i>Gonidea malheurensis</i>		
<i>Anodonta decurata</i>	<i>Anodonta</i> sp.	<i>Anodonta</i> sp.
<i>Sphaerium andersonianum</i>	<i>Sphaerium stratinum</i> ←	<i>Sphaerium stratinum</i>
<i>Sphaerium malhurensis</i>		
<i>Pisidium compressum</i> →	<i>Pisidium compressum</i>	<i>Pisidium compressum</i>
	<i>Pisidium punctatum</i> ←	<i>Pisidium punctatum</i>
<i>Flumenicola malheurensis</i>		
<i>Fluminicola columbiana</i>		
<i>Bulimnea</i>		
<i>Valvata</i> sp.	<i>Valvata humeralis</i> . ←	<i>Valvata humeralis</i>
<i>Fluminicola malheurensis</i>		
' <i>Melania</i> ' <i>taylori</i>		
<i>Gyraulus n sp</i> →	<i>Gyraulus</i> sp	<i>Gyraulus</i> sp.
<i>Gyraulus miller</i>	<i>Gyraulus parvus</i> ←	<i>Gyraulus parvus</i>
	<i>Omalodiscus pattersoni</i> ←	<i>Omalodiscus pattersoni</i>
<i>Carinifex n sp</i>		
<i>Vorticifex</i> →	<i>Vorticifex</i> sp.	<i>Vorticifex</i> sp.
<i>Vorticifex tryoni</i>		
<i>Payettidae</i> sp. →	<i>Payettidae</i> sp.	<i>Payettidae</i> sp.
<i>Payettia malheurensis</i>		
	<i>Limnaea occidentalis</i> ←	<i>Limnaea occidentalis</i>
	<i>Promenetus e. kansensus</i> ←	<i>Promenetus e. kansensus</i>
	<i>Promenetus umbilicatellus</i> ←	<i>Promenetus umbilicatellus</i>
	<i>Pliopholix</i> sp. ←	<i>Pliopholix</i> sp.
	<i>Lithoglyphus</i> sp. ←	<i>Lithoglyphus</i> sp.
Chalk Hills source, 4 species	Cache Valley or Glenns Ferry? source, 10 species	

the Junction Hills ostracods while not explicitly stating so. However, he allowed (F. M. Swain, written comm. to PHM, 1977) for an earlier age, noting that, "The occurrences of *Tuberocypris* in the Salt Lake Formation [holotype in the Junction Hills fauna of Swain, 1947] could be as young as early Pliocene [intending Clarendonian perhaps?], but in general, the occurrences of the genus seem to be Miocene or older."

Tephrochronology furnishes relatively

precise age control in the eastern portion of the Junction Hills, but west of the Beaver Dam fault its usefulness is limited. Multiple ash beds in the tephra subunit have been geochemically correlated with dated tephras in the western United States in the University of Utah ash-fall tuff database (R. Smith, 1975; Smith and Nash, 1976; Perkins et al., 1995; Nash and Perkins, 2012; and Perkins in Oaks et al., 1999, table 2, fig. 3; Goessel, 1999, table 3, fig. 16; Goessel et al., 1999, figs. 5 and 6; Oaks,

2000, table 2, appendix 1; and in Biek et al., 2003). The correlated ash horizons indicate the Cache Valley Member spans at least 6 m.y., from 10.9 to 4.75 Ma. Based on extrapolated sedimentation rates, its base may be as old as 11.6 and 13.0 Ma in the northern Wellsville Mountains and Junction Hills, respectively; and its top younger than 4.4 to 5.1 Ma at Clarkston Mountain on the south flank of the Malad Range (Goessel, 1999, fig. 20; Goessel et al., 1999, fig. 7; Oaks, 2000, table 2, appendix 1).

The oldest (10.94 ± 0.03 Ma) and the youngest (about 4.75 ± 0.35 Ma) known ashes in the Salt Lake Formation in the Junction Hills area (Perkins in Biek et al., 2003:1) were sampled 3 km NW (at the south end of the Malad Range on the adjacent Clarkston Mountain pediment) and 13 km NE (west of Bergeson Hill), respectively, from our fish site. At the top of the Cache Valley Member, above the Plymouth oolite subunit west of Bergeson Hill, is the undated Washboard subunit; it overlies the ~4.75 Ma datum (i.e., the Santee ash, Oaks et al., 1999, table 2), is as thick as 1,830 m (Oaks, 2000, Fig. 5; Steely and Janecke, 2005), and may range into the Quaternary (Biek et al., 2003:16).

In the Junction Hills, however, as noted above, the tephra subunit is in fault contact with the Plymouth oolite (Figs. 2, 3). The correlated ash beds, therefore, cannot be traced across the intervening Beaver Dam fault into the oolite; and, while a volcanic ash in the oolite scarp exposure was sampled and evaluated, it was not sufficiently pure to yield a chemical correlation (Goessel, 1999:53). In the tephra subunit, the sampled ash nearest the fish locality is about 1 km E of the fault and indicates an age of about 8 Ma ("likely"; Perkins in Goessel, 1999), and no other correlated ash horizon elsewhere in the Junction Hills indicates an age younger than about 6.4 Ma (R. Q. Oaks, Jr., written comm. to PHM, 1998). These dates limit the maximum age for the Plymouth oolite and the Junction Hills local fauna. Goessel et al. (1999) and Biek et al. (2003) suggested an age of about 5 Ma for the oolite based on their extrapolation of a sedimentation rate (assumed to be constant) from

the underlying tephra-calibrated horizons.

Biostratigraphic control for terrestrial Cenozoic rocks is optimally based on mammalian fossils; however, few are known across the geographic and geologic extent of the Salt Lake Formation. Age-diagnostic fossil mammals that have been collected from Salt Lake beds range dramatically in time, from the Duchesnian NALMA (regarded as late Eocene when cited in Oriel and Tracy, 1970:37, but now recognized as middle Eocene, e.g., Janis et al., 2008) at the type locality of the Salt Lake "Group" in Norwood Canyon, Utah (Hayden, 1869) 50 km S of Cache Valley—to post-Blancan Pleistocene 8 km N of Cache Valley, downstream from Red Rock Pass in Marsh Creek Valley, Idaho (PHM, unpubl.).

The only mammalian fossil collected from the Junction Hills scarp sequence is a fragmentary distal radius identifiable as a lynx-size adult felid (UCMP 299134, described below, Fig. 21 a) indeterminate to genus (R. H. Tedford, oral comm. to PHM, 1977); it was found as float (by PHM) on the ledge-forming limestone of the upper fish level. While it represents the only record of Carnivora known from the Salt Lake Formation, the fragment is of little biochronological value except to suggest a post-early Hemphillian age, which spans the temporal range of common small Felinae in North America (Martin, 1998).

Approximately 1 km SE of the Junction Hills fish locality, north of Long Divide Road in the NE $\frac{1}{4}$, Sec. 22, T. 13 N., R. 2 W. (UCMP locality V77191), a hypsodont lower molar of a small adult horse (UCMP 299135, described below, Fig. 21 b) was found, also as float (by PHM). The tooth was contained in a porcellanite cobble from the Salt Lake Formation that was excavated from a late Pleistocene terrace created during the high-stand of Lake Bonneville (along the Bonneville Shoreline at 5167 ± 5 ft [1566 m] elevation; datum in Oviatt, 1986, plate 1). The cobble was derived from the tephra subunit of the Cache Valley Member on which the wave-built terrace developed, likely from one of the porcellanite interbeds that today crop out upslope from the terrace (Goessel et al.

1999, measured section 1, 110–150 m above its base, fig. 10, pp. 42–43) and are exposed more extensively 1.8 km farther north (Goessel et al. 1999, measured section 3, 190–240 and 375–410 m above its base, fig. 12, pp. 47–50). The equid tooth is not identifiable beyond the subfamily Equinae; it shares characters of the equine tribes Equini and Hipparrisonini and is within the morphological range of the form genus “*Merychippus*” (see Description of Fossils, below). Hence, the tooth suggests a middle to late Miocene age (late Barstovian or Clarendonian) for the tephra subunit of the Cache Valley Member exposed here, which is consistent with tephra correlations of 10.3 (“feasible”) to <8.0 (“likely”) Ma associated with the porcellanite horizons mapped upslope (Goessel 1999; Oaks, 2000, fig. 4).

On the landslide scarp (Fig. 2, 3) 20 m above the upper fish level, PHM made a deliberate search for terrestrial vertebrate remains on the weathered slopes that produced the well-preserved mollusks and ostracods described by Yen (1947) and Swain (1947), respectively; however, no vertebrate fossils were found there besides traces within the shelly deposit that may represent filled animal burrows. About 500 m southward along the oolite scarp, impressions, and fragments of several associated mammalian ribs (of a goat-size animal) were observed on the surface of a limestone ledge (Fig. 6 d); however, they were not safely accessible and were left in place.

In summary, based on known fossil and tephrachronological data, the Plymouth oolite and the Junction Hills local fauna that it contains are younger than the nearest ash sampled in the underlying tephra subunit to the east of the Beaver Dam fault (8 Ma); probably younger than the youngest ash sampled in the tephra subunit elsewhere in the Junction Hills or Wellsville Mountains (6.4 Ma); and possibly as young as the tephra sampled west of Bergeson Hill (about 4.75 ± 0.35 Ma); although they may be closer to 5 Ma based on extrapolated sedimentation rate. These correlations place the fossils probably within the late Miocene (Hemphillian) or possibly within

the earliest Pliocene (latest Hemphillian). This bracketed age range is temporally equivalent to the upper Chalk Hills Formations in the WSRP (Nathan Carpenter, written communication, 11 April 2019).

Regional relationships of the Junction Hills Local Fauna. Taylor (1966) summarized the molluscan fauna of the Salt Lake Formation in the southern Cache Valley area as including about 25 species, several endemic but with close relatives in the Glenns Ferry Formation of southwestern Idaho. He interpreted the Cache Valley mollusks as being equivalent in age to the lacustrine facies (i.e., the lower portion) of the Glenns Ferry Formation, which is late Pliocene (Blancan) based on correlation of its mammalian faunal and radiometric and fission-track dates. We acknowledge there has been controversy about the absolute age of the lower section of the Glenns Ferry Formation, which has produced the diverse Blancan mammal fauna at Hagerman fossil beds. For example, the Deer Gulch lava flow within that section historically has been a key datum used to calibrate the age of the Hagerman fauna, and it has produced conflicting K-Ar dates of 3.5 Ma (Evernden et al., 1964:191) and about 6 Ma (Armstrong et al., 1975:237). The 3.5 Ma date has since become widely accepted as the age of this lava (e.g., Bell et al., 2004, fig. 7.1) and modern geochronological analyses of the flows and tephras in the Hagerman sequence indicate the age of this typical Blancan fauna ranges from 3.0 to at least 4.2 Ma (Hart and Brueseke, 1999; Walkup et al., 2016; Ruez, 2009). Taylor’s correlation of mollusks in the Salt Lake Formation with those in the Blancan Glenns Ferry Formation, therefore, implies an age of about 3 to 4 Ma for the Cache Valley mollusks.

However, Taylor’s Blancan correlation for the Junction Hills is complicated by two observations, one not widely appreciated, the other not previously recognized. First, Taylor noted (1966:82) that his southern Cache Valley fauna is a composite of species from several localities across a distance of “25 miles” (40 km). It mixes species previously described from the Junction Hills (Yen,

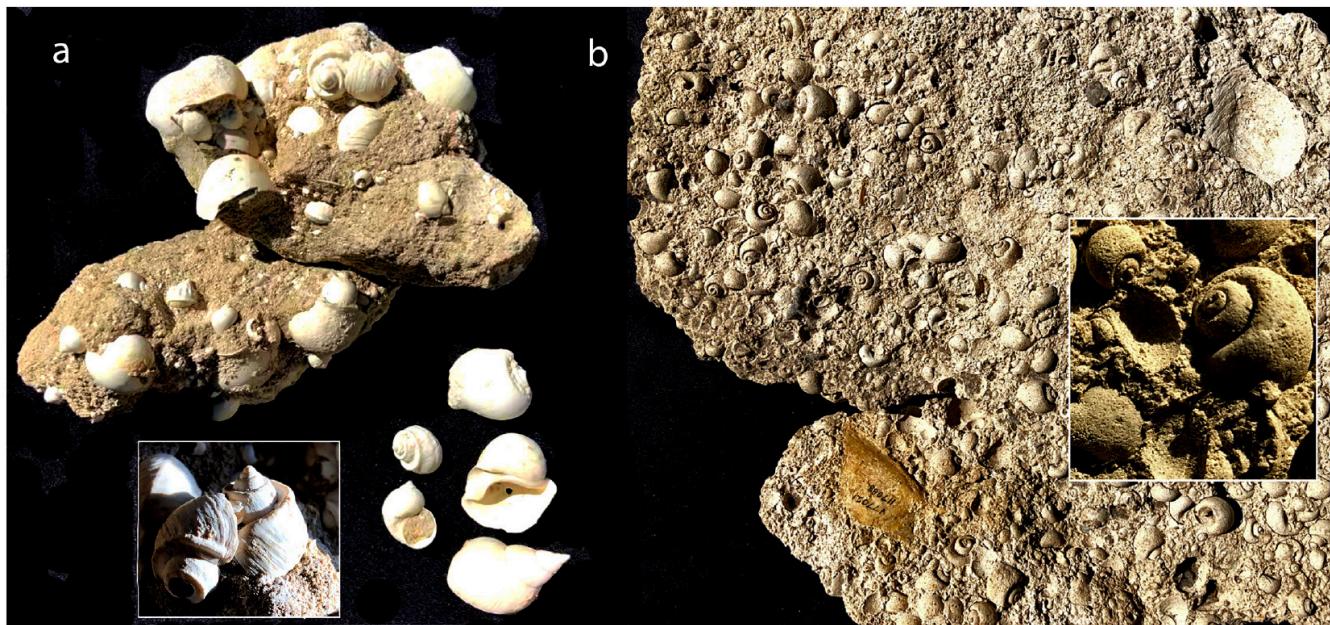


Figure 5: **a**, Perfectly preserved molluscan shells in friable detrital carbonate sand, from the site above the upper fish level that produced the mollusk fauna described by Yen (1947) and Taylor (1966); **b**, indurated oolitic limestone from the ledge-forming upper fish level, containing only molds and ooid-filled casts of mollusks and fish bones (catostomid operculum, UCMP 117088, in figure).

1947), from near Mendon (Meek, 1877), and from Collinston (Chamberlin and Berry, 1933) (see below); with species collected elsewhere by others whom he listed (e.g., Mullens and Izett, 1964); and with species he personally collected from some of those localities (e.g., the Junction Hills in 1954; Taylor, 1966:82). Some species are from oolitic facies, some are not, and all localities are of uncertain stratigraphic position within the Salt Lake Formation. Hence, it is unknown whether Taylor's Blancan mollusk correlation reflects a time-equivalence of the lower Glenns Ferry Formation with some or all Cache Valley localities, or is explained by a similarity of fluviolacustrine environments and molluscan communities adapted thereto that were time-transgressive across the region.

Second, it now appears that the source of the Junction Hills molluscan fauna, which was visited by Hague (Hague and Emmons, 1877), collected by Williams and described by Yen (1947), mapped by Adamson (1955), resampled and further studied by Taylor (1966), noted by McClellan (1977), and

remapped by Goessel (1999)—located 20 m above the upper fish level—is unconformable on the oolitic limestone that produced the Junction Hills ichthyofauna. Twenty-first-century refinements of high-resolution digital elevation models and draped aerial imagery (e.g., Google Maps™) enables examination of the precipitous fossil-bearing cliff exposure in low-altitude oblique 3D views from any perspective, zoomed, pitched or yawed. In these views of the scarp terrain, resistant limestone ledges and their general geometry are obvious (Fig. 2) and traceable over tens of meters along the scarp face (notwithstanding inevitable distortions of the superposed 2D aerial image in its orthographic projection on the steep landscape). The rendering is sufficiently clear to show that the friable light-gray sandstone, which produced the perfectly preserved molluscan shells that Yen (1947) and Taylor (1966) described (Fig. 5 a), fills a paleochannel eroded into and truncating the underlying resistant fish-bearing ledges (Fig. 2, bottom), which produced only shell molds and casts (Fig. 5 b). The two mollusk-rich lithotypes differ strikingly. The upper shell-rich

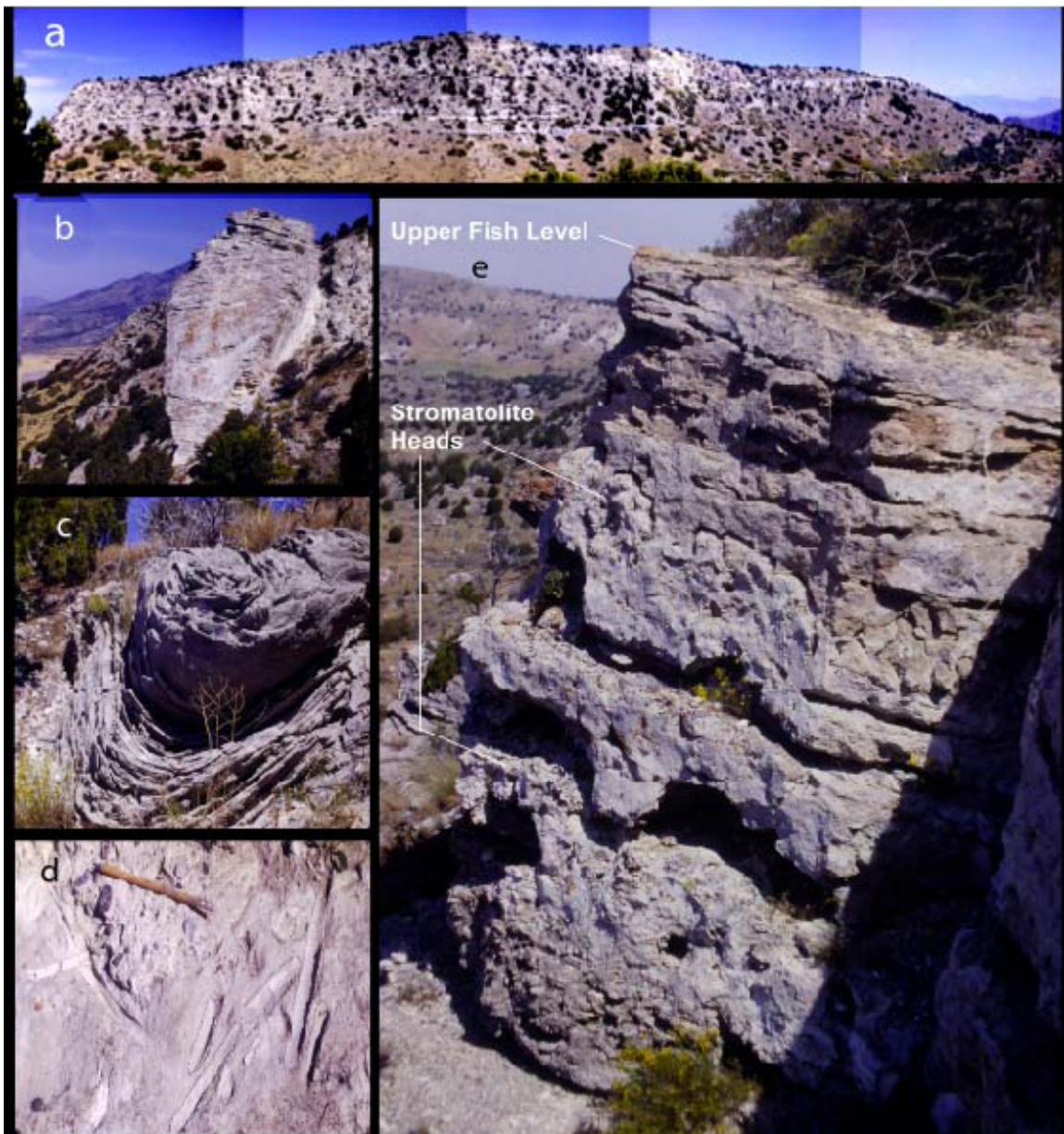


Figure 6: **a**, Panorama of the Junction Hills escarpment from apex of the landslide mass a few hundred meters W of the fish locality; **b**, giant Gilbert foresets in the oolitic limestone; **c**, syndepositional convoluted bedding in the oolitic limestone; **d**, unidentified bones (see text); **e**, multi-story biohermal structure (stromatolite blankets) underlying the upper fish level.

deposit is a detrital carbonate sand (silty clayey calcarenite) that is loosely cemented, fine-grained, and moderately well sorted, with mostly sub-angular to sub-rounded grains, without discernible ooids. (Mineralogy of detrital constituents was not specifically investigated.) The ledge-forming lower unit is a compact but porous and thoroughly indurated oolitic limestone in which no molluscan shell material (aragonite) remains. The cross-

cutting relationship of the upper sand against the lower strata indicates an unconformity separates them.

Goessel's Measured Section 2 (1999, fig. 9), ascending the southwest-facing cliff eastward (up-section), describes a "mostly covered" interval 10 to 15 m above the base of the cliff section (her fig. 11); covering that interval is colluvium that appears to be sourced in the friable shelly

channel deposit immediately upslope, which her traverse apparently does not directly intersect. Her description suggests a reason why a paleochannel was not recognized earlier: Previous workers (e.g., Adamson, 1955; Williams, 1962; Goessel, 1999; Biek et al., 2003) on these steep and slippery cliff slopes may have selected traverse lines for measurement based on optimal exposure of the continuous limestone ledges, which are not visible across the shelly colluvium—not because they are covered but because they are missing where a channel has removed them.

The fish-bearing sequence and the overlying shelly deposit are quite distinct geologically (Fig. 3). The fish-bearing sequence is an essentially pure, calcite-cemented oolitic calcarenite, with resistant and tabular ledge-forming limestone layers, and weathers to a light tan surface; while the overlying deposit is a clayey detrital carbonate sandstone, without ooids, that is friable and weathers light gray. Paleontologically, the upper fish level and the overlying shelly deposit both contain abundant fossil ostracods and mollusks, and their molluscan assemblages are similar (McClellan 1977:123, 135–136) with 10 of 17 genera in common; however, the shelly deposit contains more air-breathing snail taxa including three unique to this well-preserved assemblage, of which one genus is the only obligate terrestrial type in the collection (McClellan 1977:153, table 7). While the calcite ostracod tests are preserved in both zones, only the upper deposit retains the primary aragonite shells of the mollusks (Fig. 5 a). In the lower zone, the mollusk shells have been destroyed by alteration (dissolution) leaving behind only external molds and ooid-filled casts (Fig. 5 b). Unlike the oolitic limestone sequence, the upper shelly deposit produced no fish fossils after concerted searches (by PHM and GRS), weathers to a sandy slope wash containing scattered subcylindrical structures of indurated carbonate sand 2–5 cm in diameter (perhaps filled burrows or root casts), and appears to be a channel fill (Figs. 2, 3). Hence, the oolitic sequence is clearly lacustrine, while the overlying shelly deposit more likely represents a stream, pond

or marsh environment with emergent vegetation.

The proposed unconformity between these two lithotypes (Figs. 2, 3), along with their contrasting sediments, fossils, and diagenetic character, suggest a significant hiatus in the lacustrine record here, and indicate the fish-bearing sequence and overlying shelly deposit, rather than being coeval elements of the same lake, may differ substantially in age. The hiatus, if confirmed with future mapping (or perhaps drone photography) of the scarp sequence, must have been long enough for the lacustrine oolite to be exposed by uplift or lake regression (perhaps by a breach in the basin rim with outflow of the paleolake), followed by fluvial erosion of an unknown thickness of overlying strata to produce the channeled landscape on the resistant limestone, and subsequent deposition of the shelly channel fill.

The hiatus may help to explain perplexing regional correlations we observed between the Cache Valley paleofauna and fossil faunas elsewhere in the northeastern Great Basin. Taylor (1966) considered the shelly assemblage exposed in the scarp to be Pliocene based on faunal correlation with mollusks in the Glenns Ferry Formation, where similar taxa are associated with Blancan mammals. However, most of the fishes underlying the shelly zone may be ~4.75 Ma, significantly older than 4.2 Ma (near the maximum age of Glenns Ferry strata) and pre-Blancan based on fossil and tephra correlations. An unconformity between the fish-bearing oolite and the shelly zone 20 m higher in the section could account for the discordant Hemphillian versus Blancan correlations. Alternatively, the Junction Hills mollusks Taylor (1966) correlated with the Glenns Ferry fauna may not be Blancan after all. Taylor's (1966) comprehensive assessment of Blancan freshwater mollusks was a landmark study in its time. While it was based on extensive fieldwork and the best available data, after a half-century it now deserves a reanalysis. Much has changed in non-marine molluscan systematics, taxonomy, and ecology; in regional geology and chronostratigraphy; and in the boundary

definitions of the North American land mammal ages. It is likely that Taylor's conclusions about a Blancan age for some molluscan localities may reflect a time-transgressive ecological shift rather than lateral time equivalence. Many of the Cache Valley fish taxa are immigrants from a source recorded in the Chalk Hills lake beds of the WSRP, indicating these two regions shared a hydrographic connection before 6 Ma (pre-late Hemphillian age). We speculate that the Glenns Ferry mollusks were evolving in the Cache Valley Lake 6–4 Ma, at a time when only four of these species were in the Chalk Hills Lake or river system. The Cache Valley mollusks then could have colonized the Glenns Ferry Blancan fauna through an aquatic connection about 4 Ma (Table 2).

At least 25 species of mollusks and 11 species of fishes occupied the lake system recorded by the Cache Valley Member. The Junction Hills fishes are about equally similar to the fauna in the Glenns Ferry Formation on the WSRP and the fauna in the Chalk Hills Formation (Table 3) that underlies it (Smith et al., 1982), which is late Miocene (Hemphillian) in age. For that reason, we suggest an age of Hemphillian to earliest Blancan age on faunal correlation for the Junction Hills fishes, constrained to an interval from 6.4 to 4.75 Ma by tephrochronologic correlation. If future studies support this age, the apparent hydrographic connection between Cache Valley and the WSRP at that time may test hypotheses about the nature and timing of paleodrainage development during the time-progressive silicic volcanism along the ESRP. (See Discussion.)

PARADISE FISH LOCALITY

Geology and age of the Paradise fish locality. In southern Cache Valley, J. S. Williams collected plant fossils from eastward-dipping outcrops of grayish-white, thin-bedded, tuffaceous marl of the Salt Lake Formation (Figs. 1, 4), in the left bank of the Little Bear River SE ¼, sec. 20, T. 10 N., R. 1. E., between Hyrum and Paradise (Williams, 1962:134, Brown, 1949:224). Williams

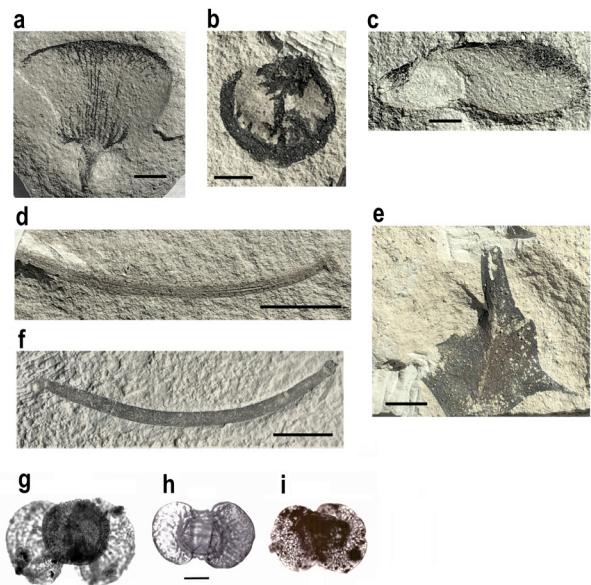


Figure 7: Additions to the flora of the Salt Lake Formation, Cache Valley Member, Cache County, Utah. Foliar fossils from Highway 30 road cut (UCMP plant locality PA1380), 15 km WNW of Logan: **a**, *Abies* cf. *A. sonomensis*, mature cone scale (UCMP 201252); **b**, *Abies*, apical cone scale (UCMP 201253); **c**, *Abies*, samara (UCMP 201254); **d**, *Pinus* cf. *P. ponderosa*, needle fragment (UCMP 201255); **e**, *Mahonia* n. sp. (?), long-spined terminal leaflet (UCMP 201256); **f**, ?*Cathaya*, needle (UCMP 201257), compare with ?*Cathaya* in the late middle Miocene Clarkia flora in northern Idaho (Rember, undated). Magnasaccate pollen: **g**, *Podocarpus*-like grain (UCMP 201259.01) from the palynoflora of the Paradise fish-bearing marl locality (UCMP PA1381, co-located with V77193), 20 km SSW of Logan, referred to cf. *Cathaya* (this report); compared with **h**, *Podocarpus nagei*, extant Japanese species (courtesy of Herbert Meyer); and **i**, *Podocarpus* sp. from late Miocene Beaverdam/Ibex Peak beds, Trapper Creek, Goose Creek Valley area (courtesy of Edie Campbell, U. of Utah). Scale bars: a, 5 mm; b, c, 2 mm; d and f, 10 mm; e, 4 mm; g, h, i, 20 microns.).

sent the collection to U. S. Geological Survey paleobotanist, R. W. Brown, who characterized the plants as scarce, fragmentary and biased in favor of tough seeds and leaves, indicating selective destruction of tender material during distant fluvial transport into a lake basin—but he added that the collection also included insect remains, ostracods, freshwater mollusks, fish bones, and bird feathers (Brown, 1949:224). Williams sent to the USNM and UMMP fossil fishes he referred to

this locality. In this report we describe those fishes (see Description of Fossils, below) and designate the vertebrate locality as UCMP V77193. In his description, Brown concluded the flora is probably middle to late Pliocene in age or, in modern chronostratigraphic usage, generally late Miocene (Hemphillian) to Pliocene (Blancan).

The plant fossils were deposited in the USNM (Accession No. 9090, specimen numbers 222734–222759) and remain the only described leaf flora from the Salt Lake Formation; however, subsequent references to this megaflora ignore the fact, made clear by Brown (1949:224), that it is a geographically mixed assemblage. Williams specified and Brown reported (1949:224), that the specimens were collected at two different sites: (1) from the Paradise marl locality (in southern Cache Valley), and (2) from platy, gray limestone in sec. 13, T. 12 N., R. 2 W. “about 10 miles [16 km] west of Logan” (at the west side of the valley). Section 13 is WNW of Logan and covered almost entirely by late Quaternary Lake Bonneville deposits that conceal the Salt Lake Formation (Goessel 1999, plate 1), and no fossils have been reported there by later workers. However, 300 m S of section 13, in section 24, platy and laminated light gray calcareous tuff is well exposed in a road cut along Utah State Highway 30, 9.5 miles (15 km) WNW of Logan. This road cut existed at the time Williams collected his fossils and, in the early 1970s, produced fossil plants similar to those from the Paradise locality (McClellan 1977). We tentatively assume this fossiliferous road cut is the second source to which Brown referred. The Paradise and Highway 30 localities are within the Cache Valley Member but separated by 24 km laterally and an unknown distance vertically. At the Highway 30 site, tephra is interlayered with the plant-bearing beds and is chemically correlated with ashes dated at 7.5 to 6.5 Ma (“likely”, Perkins in Goessel, 1999, table 3 and fig. 16, sample 13), or early Hemphillian.

Complicating interpretation of the leaf flora, Brown (1949), or Williams in his transmittal to him, did not distinguish which of the two localities in the Cache Valley Member produced any foliar

specimen that Brown described. In 1974 PHM re-collected both sites for megafossils—the Paradise plant locality, here designated UCMP PA1381 (co-located with V77193), and the Highway 30 plant locality, UCMP PA1380—and determined (McClellan, 1977, table 3) that both florules include aspen, gooseberry, willow, elm, and grass. Confirmed in the aggregate flora, as Brown suggested (1949:224) from a fragmentary conifer needle, are pine and fir by material from the western locality. Fir (*Abies*) is represented by a mature cone scale (Fig. 7 a) comparable to *A. sonomensis* in the Trapper Creek flora (Axelrod, 1964, plate 5), an apical cone scale (Fig. 7 b), and a winged seed (Fig. 7 c). A single fragmentary needle (Fig. 7 d) is referred to *Pinus* cf. *P. ponderosa* based on its conspicuous groove and length (restored) of at least 8 cm; its fascicle sheath, which is attached and apparently non-deciduous, is about twice as wide as the needle base, suggesting it originally enclosed 2 to 3 needles. An additional conifer specimen from the western florule is a solitary oblanceolate leaf (Fig. 7 f) without visible venation that we questionably refer to *?Cathaya*, a now-exotic Pinaceae genus, whose presence in the flora is supported by pollen evidence from the Paradise florule (Fig. 7 g, h, i; discussed below).

Added to the flora is *Mahonia*, based on a single dentate leaflet (Fig. 7 e) also from the western site. The specimen bears one or perhaps two spinose, obarcuate teeth per side, and a terminal tooth, which is the longest and very attenuate, suggesting the specimen is a terminal leaflet. Its looping secondary venation and craspedodrome tertaries distinguish it from *Ilex*, and its pinnate venation shows it to be within the *M. reticulata* (rather than palmate venation, as in *M. simplex*) group. It is distinct from other dentate, pinnately veined *Mahonia* species by its reduced tooth number (only one or possibly two long slender teeth, rather than 2–6 shorter, broader teeth, per side) and medial-blade area, and greater tooth length. On that basis, it may be a new *Mahonia* species (written communication, Howard E. Schorn, 1974; see also Schorn, 1966).

Notwithstanding the mixed provenance of the original specimens, Brown's original characterization of the flora remains apt for the two florules separately: "The presence of an aspen like poplar and a possible pine or fir [both now confirmed] points toward fairly high ground for at least part of the flora. The maple, sumac, gooseberry, serviceberry, indigo bush and juniper probably lived a little lower behind the streamside species of cottonwood, willow, and grass." At neither plant locality were additional fish or other animal fossils found in our study, except for rare and poorly preserved insect debris.

McClellan (1977, table 3) analyzed pollen in the leaf-bearing marl horizon that produced the Paradise fish fossils (following the method of Faegri and Iversen, 1975:101–114, in a 250-grain count using a Zeiss photomicroscope at approximately 200x). The palynoflora is dominated by pine (57%), fir (10%) and spruce (9%) with almost no grasses (1%). This is but a single sample and undoubtedly biased by differential production and dispersal of pollen of different species (e.g., pine pollen can disperse for several hundred km from its source, while fir and spruce generally fall out within a few tens of km; McAndrews and Wright, 1969). Nevertheless, it supports the interpretation that the pine/fir-dominated palynoflora at the Paradise locality and the pine and fir megafossils at the western locality indicate a similar proximity to the montane forest zone during deposition of the respective beds. The ecomorphic overlap of the two foliar assemblages (conifers, aspens, and herbaceous species) suggests the florules occupied similar mountain, stream and lakeside habitats, not unlike the elevated landscape and high relief of present-day Cache Valley. The taxonomic similarity between the two florules, combined with the tephra-calibrated age (7.5 to 6.5 Ma) at the site west of Logan, suggest a corresponding late Miocene (Hemphillian) age for the marl near Paradise and the fish fossils it produced—a conclusion supported in further discussion of the palynoflora in this report (see *Exotic evidence for age and biogeography*, below).

The USNM fish fossils were initially examined by UMMP ichthyologists Teruya Uyeno and Robert Rush Miller (to whom Williams sent specimen UMMP 42934), who identified it to family Cyprinidae (Uyeno and Miller, 1963:26). Ted Cavender and GRS re-examined the material and we describe it in this report (see Description of Fossils, below), assigning the Paradise specimens to a new cyprinid species of *Lavinia* (Hitch). Uyeno and Miller (*ibid.*) regarded the fossils to be middle Pliocene in age. As for what they intended by "middle Pliocene", the two relevant and contemporary authorities whom Uyeno and Miller referenced (1963:3–4) are Wilson et al. (1959) and Kulp (1961). The time scale of the former defined the base of the Pliocene as 10 Ma, and the latter as 13 Ma. Those absolute time scales, incorporated by reference in the "middle Pliocene" of Uyeno and Miller (1963), indicate that a Hemphillian age was intended for the Paradise fish specimens, or at the youngest, late Hemphillian-early Blancan.

To refine the age of the Paradise *Lavinia* specimens, we rely on Oaks et al. (1999) as the definitive modern study of the geology and geochronology of the Salt Lake Formation in the Paradise vicinity. That report combines extensive field mapping of stratigraphy and tectonic structure with tephrochronology, and provides a context for interpreting the age of the outcrop that produced the fish fossils. At Williams' discovery site, just northwest of Paradise, the Little Bear River flows north along the strike of the Little Bear River fault, which bounds the western edge of a narrow N-S graben where Paradise is situated (Oaks et al., 1999). The river's west bank here is a fault-line scarp, its eroded bluff 15–20 m high exposing thinly bedded, and in places platy, fissile and laminated, light tan tuffaceous marl of the Cache Valley Member (Fig. 4). The marl outcrop is within Salt Lake Formation subunit "H" of Oaks et al. (1999, fig. 11, cross-section A-A') at a stratigraphic level approximately 390–400 m above the base of subunit H (R. Q. Oaks, Jr., 2020, written comm.).

Across a distance of 9 km southward from Williams' fish locality, Oaks et al. (1999) sampled

several tephra horizons in the Cache Valley Member that are correlated to dated ashes elsewhere in the western U.S. Three are key to constraining the age of the *Lavinia* fossils. About 200 m stratigraphically below subunit H near the base of underlying subunit G, and about 4 km southward along strike from the *Lavinia* site (Oaks et al., 1999, fig. 6) is a sampled tephra layer chemically correlated with the Rush Valley ash dated at 7.9 Ma; and a further 3 km to the south, at the top of subunit G, is a tephra correlated to the Walcott ash dated at 6.4 Ma (Oaks et al., 1999, fig. 7, columnar sections 4 and 5 a, b; and table 2). Between those two dated tephra horizons, within subunit G, four other sampled ashes are correlated with calibrated tephras ranging from 7.5 to 7.0 Ma (Oaks et al., 1999, fig. 3). However, two of those four ash samples determined as 7.0 Ma are from mixed volcanic sources (i.e., Cascade and Yellowstone Hotspot) and, therefore, are reworked and likely younger than 7.0 Ma (Oaks et al., 1999:78). At the south end of Cache Valley, 9 km south-southeast of William's fish locality, in the upper part of subunit H (here about 500 m thick) is a tephra correlated to the Santee ash dated at 4.75 Ma (Oaks et al., 1999, fig. 3).

Because neither the Walcott nor Santee ashes are recognized near Paradise, their ages cannot be correlated with certainty or precision into the vertical sequence containing the fish fossils. Northwest of the Paradise fossil locality by 3–4 km, limited exposures and drillers' logs show that an oolitic limestone (Tsl subunit "M" of Oaks et al., 1999, fig. 6 map, and fig. 7 section 1) overlies the plant and fish level by several hundred meters and may be equivalent to the Plymouth oolite (Oaks, 2000, 2004). As a general statement, the Paradise marl exposure and the florule and *Lavinia* specimens it produced are probably younger than the bracketing dates of underlying subunit G (7.9 and 6.3 Ma), but likely older than the Plymouth oolite fish locality in the Junction Hills (~4.75 Ma). The leaf locality northwest of Logan, at 7.5 to 6.5 Ma, appears to be somewhat older, and better correlated with subunit G. Hence, the Paradise

Lavinia specimens are most likely late Miocene (Hemphillian) in age.

Exotic evidence for age and biogeography. Here we note new additional palynological evidence that informs our age and biogeographical interpretation of the Cache Valley paleofauna. In 1975, when studying the pollen of the Paradise fish locality, PHM encountered a surprising anomaly in the palynoflora: a single bisaccate conifer pollen grain in which the two sacci (bladders or wings) are significantly broader than the corpus (central cap or body) in polar view. This "magnasaccate" form is distinct from other saccate grains such as those of the common Pinaceae (Ting, 1968), including the *Pinus* (pine), *Abies* (fir) or *Picea* (spruce) that dominated the Paradise palynoflora (~75%), in which the two sacci and corpus are of subequal breadth ("equisaccate"). The distinctive grain (UCMP 201259.01, Fig. 7 g) was initially conjectured by PHM to be that of *Podocarpus* (compare Fig. 7 h), a conifer with characteristic magnasaccate pollen grains in the family Podocarpaceae, well-known for its "Gondwanan" distribution during the Mesozoic. Today, *Podocarpus* is distributed in warm temperate to tropical habitats mainly in the Southern Hemisphere and northward into southeast Asia, southern China, Japan, and Mexico. So unlikely was the occurrence of *Podocarpus* north of the Fortieth Parallel in the late Tertiary Cache Valley Member that the odd specimen was written off as an isolated aberrant Pinaceae pollen grain, written out of McClellan (1977, table 3, p. 114), and written up and figured in a manuscript that was ultimately abandoned.

Concurrently, Edie Campbell at the University of Utah was beginning graduate research on the palynology of the Salt Lake Formation. She wrote in 1977, "I am curious about the *Podocarpus* pollen that you found at Brown's plant locality because I have found what seems to be the same thing in quite a few of my samples" (E. Campbell, written communication to PHM, dated 6 Dec 1977). Her study focused on pollen in the late Tertiary lignites of the Goose Creek basin and the Trapper Creek drainage, Cassia County, Idaho—beds previously

assigned to the Salt Lake Formation in whole or part (e.g., Mapel and Hail, 1959) and dated at between about 14 and 8.5 Ma (Perkins et al., 1995). An older study of pollen in the Worthington lignite in that area, in the eastern half of sec. 3, T. 15 S., R. 20 E. (L. R. Wilson in 1950, in Youngquist and Haegle, 1956:13–14), reported:

I have not seen any finer preservation of spores and pollen. The flora consists of four, probably five, species of conifers of the following genera: spruce, fir, pine, and possibly *Podocarpus*. The last is essentially an Asiatic element which I hesitate to recognize until further study.

Campbell's research identified 47 genera or families of palynomorphs in these coal measures, including *Podocarpus* (Fig. 7 c) in nine horizons (Campbell, 1979, pollen profiles in fig. 4). Earl T. Peterson, a stratigraphic palynologist with Amoco, reviewed photomicrographs of the Paradise and Goose Creek material and agreed with the determinations (written communication to PHM, 16 Mar 1981). Moreover, he shared that in an exploration well drilled in the graben fill of Cache Valley, the same *Podocarpus* pollen phenotype (he called it simply *Podocarpus*, reasoning, "if it looks like a bow tie, it is *Podocarpus*") was found at multiple levels "several thousand feet down". Since that time, the existence of the Amoco #3 well (also called "1 Lynn Reese" well) has been declassified for academic research (e.g., Evans, et al., 1996:10; Oaks et al., 1999, figs. 1 and 2; Dover, 1995, table 1) and this may be the well to which Peterson alluded. Located about 5 km NW of Logan, it reached a total depth of 8,159 feet (2,472 m) and found the base of the Salt Lake Formation at 7,395 feet (2,241 m) (Brummer and McCalpin, 1995, table 1). Peterson's veiled description, therefore, implies the *Podocarpus* grains were found in the Salt Lake Formation and at multiple levels in the lower portion of the unit's thickness.

Elsewhere, rare *Podocarpus*-like pollen fossils

(typically referred to the form genera *Pityosporites* or *Podocarpidites*, or simply *Podocarpus* queried or not) have been reported in the Paleocene and Eocene of coastal western North America (e. g., Rouse, 1962; Martin and Rouse, 1966), the Ione gravels of the Sierra Nevada (Leopold in Penny, 1969:359), and northcentral Idaho, north-central Nevada, and in the late Eocene Florissant flora from the Green River beds in Colorado (Ting, 1968; Leopold et al., 2007; Leopold and Zaborac-Reed, 2019). More recently *Podocarpus* pollen in the late Tertiary has been reported beyond the Salt Lake Formation in the northern Great Basin-SRP-Columbia Plateau region, including the Vasa Park flora (11.4 Ma) at Bellevue, Washington (Dillhoff et al., 2015), the Palouse Falls flora (15.5 Ma) of the Yakima Basalt in southeastern Oregon (Barnett and Fisk, 1980; Beeson et al., 1985), and the flora of the Sucker Creek Formation (14.6–16 Ma) on the southern Oregon-Idaho border (Taggart, 1971, 1973; Graham, 1999, table 7.8; Dillhoff et al., 2015).

These late Tertiary occurrences are of late middle Miocene age (Barstovian) and roughly coincident with the middle Miocene climatic optimum (~17 to 14 Ma) in which the species richness of the North American terrestrial biota (floras and mammalian faunas in particular) spiked under an unusually warm climate linked to a singular peak in late Tertiary global CO₂ level (e.g., Kürschner et al., 2008). Thereafter in the Miocene, climate cooling in the northern hemisphere (cooling and drying associated with the initiation of permanent polar ice, e.g., Prothero, 1998:23) led to the contraction of the mixed conifer-deciduous hardwood forest of the Columbia Basin and corresponding westward expansion of the impoverished montane conifer forests of the Rocky Mountain cordillera (Leopold and Denton, 1987). That replacement included the extinction of many native plant species west of the continental divide that are now Asiatic or restricted elsewhere under warm-climate conditions. The magnasaccate *Podocarpus*-like pollen phenotype was part of that extinction, disappearing from North America in

the late Miocene (Liu and Basinger, 2000; Bouchal et al., 2016).

While rare fossil wood referred to Podocarpaceae has been reported in the Paleocene and Eocene of the U.S. (e.g., Torrey, 1923; R. A. Scott in Van Alstine, 1969; Dilcher, 1969), no corresponding woody or foliar evidence of the family is known from the late Tertiary, and this may signal the absence of *Podocarpus* in the U.S. since the Eocene. A closer examination of fossil *Podocarpus* palynomorphs explains this paradox. Recent re-analysis of North American fossil grains formerly identified through light microscopy as *Podocarpus* or *Podocarpidites* sp. (in the Florissant flora in particular) are unambiguously distinguished with scanning electron microscopy (SEM) as the Pinaceae genus *Cathaya* (Bouchal et al., 2016), a conifer that was widespread in North America until extirpated here in the late Miocene and which today survives as a single species only in southern China (Bouchal et al., 2016:60–61). The modern habitat of *Cathaya* is restricted to elevations of 900 to 1900 m in evergreen to evergreen/deciduous broad-leaved forests on mountain slopes and ridges (Bouchal et al., 2016:10). Dillhoff et al. (2015) identified this pollen phenotype in the late Miocene Vasa Park palynoflora as “*Incertae sedis* Podocarpaceae/*Cathaya* type” (compare Dillhoff et al., 2015, fig. 10-G, and Zetter et al., 2011, plate 3, fig. 11, with Fig. 6 a, this report). Cones, stems and leaves referred to *Cathaya* sp. are described in the exquisitely preserved middle Miocene (Barstovian) *Clarkia* flora in northern Idaho (Kvaček and Rember, 2000; Manchester and Rember, 2014) and may be represented in the Cache Valley megaflora by a broad curvilinear needle-like leaf collected by PHM (Fig. 7 f, compare with Rember [undated], fig. “*Cathaya?* 3”).

We note the preceding vignette to suggest that the fossil pollen grains identified in the 1970s under light microscopy as *Podocarpus* at the Paradise fish locality and in the subsurface of Cache Valley may, in fact, be referable to *Cathaya* upon SEM analysis. Extant species of both conifer genera are now absent in the U. S. and Canada, and occupy

warm, moist, and equable environments in the tropics and Southern Hemisphere (*Podocarpus*) and China (*Cathaya*) that no longer exist in the cool, xeric and temperate western interior. Whichever exotic genus is represented by the magnasaccate pollen in the Cache Valley and Trapper Creek paleofloras, its mutual occurrence in these two separate depositional basins suggests that a similar warm, moist, and equable environment existed in both basins of the Salt Lake Formation during the middle to late Miocene. This observation is consistent with our hypothesis of a biogeographic connection at that time between the WSRP and Cache Valley through the ancestral Trapper Creek drainage, through which the Cache Valley and Chalk Hills fish species might have exchanged (see *Discussion*). Moreover, the reported regional disappearance of this pollen type at the end of the Miocene further suggests the Paradise locality and its *Lavinia* fish fossils are not younger than late Miocene.

GEORGETOWN FISH LOCALITY

Geology and age of the Georgetown fish locality. In Bear Lake Valley, along the Bear River upstream of Soda Springs, Idaho, the Salt Lake Formation forms conspicuous white outcrops where U.S. Highway 30-N crosses the hills just north of Georgetown (Cressman 1964:57). Surrounding Georgetown, 20 km south of Soda Springs, the formation is eroded into low foothills along the Bear River Range (west) and Aspen Range (east). Here the unit is primarily tuffaceous with dense freshwater limestone, oolitic limestone, and calcareous and tuffaceous sandstone and conglomerate (*ibid.*). About 10 km southwest of Georgetown a molluscan fauna was collected from “a coarse light-gray massive oolitic calcareous sandstone” (Yen, 1946:485), assigned by Mansfield (1927:9) to the Salt Lake Formation. The tuffaceous beds in this vicinity are lacustrine as shown by the oolitic carbonates and their fossil freshwater molluscan fauna (Yen 1946:485).

Near Soda Springs, along the Bear River at the

north end of Bear Lake Valley, the tuffaceous unit is “Pliocene (?)” based on diatoms (K. E. Lohman written communication, 1951, in Cressman, 1964:58) or “Pliocene-Pleistocene” based on mollusks (T-C Yen written communication, 1951, in Cressman, 1964:58). Downstream in adjacent Gem Valley, 15 km to the southwest at Niter Cone, an *Acrocheilus* pharyngeal tooth was collected and dated as Pleistocene by Robert C. Bright (UMMP 44460). Upstream from Soda Springs, in Bear Lake Valley southwest of Georgetown, the oolitic limestone was determined from its fossil mollusks to be “upper Miocene” (Yen 1946:487). Based on lymnaeid snails in this fauna, Taylor (1966:68) concluded the fossils were pre-Blancan Pliocene (late Hemphillian). He further noted (p. 70) that the fauna was “strikingly different” from the assemblage in the Junction Hills, which he considered to be Blancan.

It is unknown where in the exposed Salt Lake Formation the fish fossils reported by N. Smith (1953:76) were collected beyond his description of the “low hills and road cuts near Georgetown”. The *Rhinichthys* specimens described in this report (see Description of Fossils, below), and possible catostomid and cyprinid bones, were collected from the foothills north of the town. Their discovery near Georgetown where Miocene strata are known, rather than near Soda Springs where the Salt Lake beds are shown to be Pliocene or younger, suggest a late Miocene age for the *Rhinichthys* material from Georgetown. Hence, we correlate the Salt Lake beds near Georgetown with the fish-bearing strata in the Junction Hills (across the intervening Bear River Range), based on their similar tuffaceous clastics and oolitic lacustrine carbonates, and infer a Hemphillian age for both. We speculate that the “strikingly different” faunal composition Taylor noted between the Georgetown and Junction Hills molluscan assemblages is due as much to a difference in habitat or hydrography (i.e., dispersal source) as in age (which could be as little as 1 Ma). We therefore group the Georgetown fish fossils with the Cache Valley paleofauna for this study and describe them below.

Summary age of the Cache Valley paleofauna. The foregoing tephra chemical correlations and paleontological evidence both faunal and floral, and inferences drawn therefrom, support the hypothesis that the Cache Valley paleofauna—including the Junction Hills local fauna from the Plymouth oolite subunit, the *Lavinia* specimens from the Paradise marl, and the *Rhinichthys* material from the Georgetown beds—is late Miocene in age, probably between 6.4 and 5 Ma (late Hemphillian). The *Lavinia* specimens are likely somewhat older than the Junction Hills fishes.

MENDON AND COLLINSTON FISH OCCURRENCES

Of potential significance pending further study are two additional fish localities in the Cache Valley Member, one at Collinston and the other near Mendon, Utah. The pair of sites is located at the north end of the Wellsville Mountains between the Junction Hills and Paradise localities. Both sites are W of the inferred location of the Beaver Dam fault (Goessel, 1999), and share the mollusk-bearing oolitic carbonate lithology of the Junction Hills fish locality. Fossil mollusks from both sites were described in early studies (Meek, 1877; Chamberlin and Berry, 1933). Each site has produced isolated fish bones that, while too sparse and fragmentary as yet to help refine correlations, demonstrate that fossil vertebrates can be found in most exposures of the Plymouth oolite facies of the Cache Valley Member.

Hills near Mendon (Cache County) (UCMP locality V77192). On the NE side of the Wellsville Mountains about 6.5 km NW of Mendon, 12 km SE of the Junction Hills and 24 km NW of the Paradise locality, are low foothills separated from the mountain front by a small valley containing a N-S county road (N 400 W). The hills are underlain by light tan to white oolitic sandstone containing molds and casts of mollusks. These may be the outcrops visited by F. B. Meek during Clarence King’s U. S. Geological Exploration of the Fortieth Parallel (1868–1871) and the “Mendon” source of

the type specimen of the fossil gastropod, *Lymnaea (Stagnicola) kingii* Meek (Meek, 1877:192-193), which is known living today only in Utah Lake in Utah County. Its type (USNM 8097) is “an external mold in a piece of oolitic tuffaceous coarse sandstone” (Taylor, 1966:83), a lithology matching that at this Mendon locality. A search of the resistant summit ridges and other bedrock exposures of these hills near Mendon for vertebrate fossils (by PHM in 2014) yielded occasional isolated fish bones in the oolite, mainly reddish-brown vertebrae among the white molds and casts of snails, in a road cut crossing a bedrock spur near the west base of the hills. These hills, primarily in sec. 25, T. 12. N., R. 2. W., are about 3 km N of the site Taylor proposed (1966:83) to be Meek’s *Lymnaea kingii* type locality.

Collinston Knoll (Box Elder County) (UCMP locality V77022). On the NW side of the Wellsville Mountains, about 6 km WNW of the Mendon fish locality, is a conspicuous knoll within the Wasatch fault zone at the northern edge of the village of Collinston. The low hill is underlain by pebbly oolitic limestone that contains abundant fossil snails and clams (mainly molds and casts) described by Chamberlin and Berry (1933). The site produced the first fish fossil discovered in the oolitic facies of the Cache Valley Member (collected PHM in 1973), a fragmentary hyomandibula of an unidentified catostomid (sucker) (UCMP 117089), preserved with a light tan color.

DESCRIPTION OF VERTEBRATE FOSSILS OF THE CACHE VALLEY PALEOFAUNA

The Junction Hills fish specimens described below were collected by PHM in 1974 and 2014, and deposited in the University of California Museum of Paleontology, Berkeley; and by GRS in March, 2000, and deposited in the Museum of Paleontology, University of Michigan, Ann Arbor. The Paradise fish specimens collected by J. S. Williams include articulated partial individuals of *Lavinia*, and are in his 1940s collection at the U. S. National Museum (Accession 1833391; Williams,

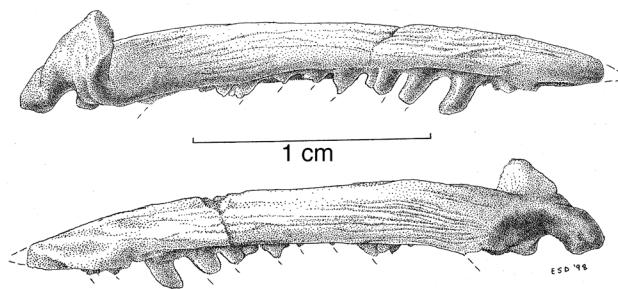


Figure 8: Right pectoral spine of *Ameiurus vespertinus* (UCMP 117086), dorsal (above) and ventral (below) showing single pointed denticles, proximal processes, and lower striations.

1962:134) and in the UMMP. Fish specimens were also collected by Sue Ann Bilbey and colleagues near Georgetown, Idaho, in 1994, and deposited in the Idaho State Museum, Pocatello (IMNH specimen numbers 15337–15387). The two mammal fossils were collected by PHM in 1974 and 2014 and are in UCMP. The Junction Hills fossils were collected with permission of the landowners at the time, the Scott Family of Fielding, Utah (1974); and the Rigby Hunting Club (Mr. Val Jay Rigby) and B&R Livestock (both in 2014).

Abbreviations: UCMP, University of California Museum of Paleontology; UMMP, University of Michigan Museum of Paleontology; USNM, U.S. National Museum (Smithsonian); IMNH, Idaho Museum of Natural History, Idaho State University, Pocatello. UMMZ; University of Michigan Museum of Zoology. “V” numbers (e.g., V77020) are catalogued UCMP localities.

TELEOSTEI FAMILY ICTALURIDAE *Ameiurus vespertinus* (Fig. 8)

Locality.—Upper fish level (UCMP V77021), Junction Hills, Box Elder County, Utah.

Referred specimens.—UCMP 117086, a complete right pectoral spine, 25.3 mm long.

The Junction Hills pectoral spine is dorsoventrally flattened, robust, and longitudinally striated, with 10 partial to complete, unbranched,

posterior denticles, as in many *A. vespertinus* of the Chalk Hills Formation (Kimmel, 1975:84, fig. 6C). The spacing of the denticles is 2.5–3 per spine width at the half-way part of the spine. The dorsal articulating surface and anterior process are nearly complete and characteristic of *A. vespertinus* of the Mio-Pliocene WSRP; the ventral process is broken off; the posterior fossa and central articulating surface are shallow, with abraded edges (terminology from Hubbs and Hibbard, 1951). The longitudinal ridges and grooves are more aligned with the orientation of the shaft of the spine and the denticles are more single-pointed than some *Ameiurus* in the WSRP.

Catfish spines are easily identified fish fossils because of their complex articulating processes and unique line of posterior (and sometimes anterior) denticles on the long, sharp, defensive spine. They are valuable indicators of low elevations, low gradients, warm temperatures, and chronostratigraphy in western U.S. *Ameiurus* was widespread in western North America in the late Miocene, first recorded at Rockville, Idaho (14.5–13.6 Ma) in the Drewsey-Juntura Graben. It also occurs in late Miocene and Pliocene sediments in the Columbia River drainage, Washington and Oregon, WSRP, and Great Basin, including the Truckee Formation of Nevada (Baumgartner, 1982). The last western U.S. catfish records are from the latest Blancan–earliest Irvingtonian Froman Ferry and Grandview faunas of southwest Idaho (Repenning et al., 1995). *Ameiurus* became extinct in western North America as climates cooled at the end of the Pliocene (Table 1).

FAMILY CYPRINIDAE

Ptychocheilus arciferus (Pikeminnow) (Fig. 9)

Localities.—Lower fish level (V77020) and upper fish level (V77021), Junction Hills, Box Elder County, Utah.

Referred specimens.—Lower level, UCMP 117064, fragment of a hyomandibula (Fig. 9 a); UCMP 294238, a 25 x 11 mm fragment of a large

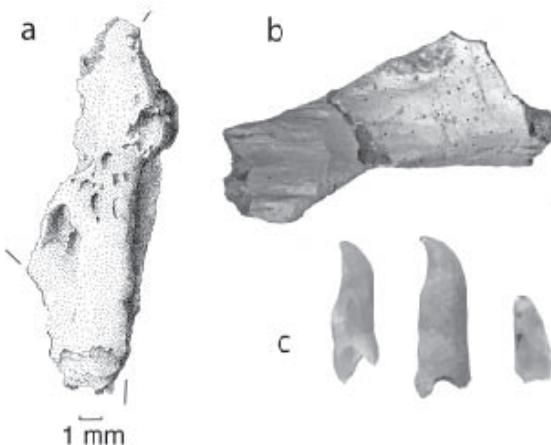


Figure 9: Fragments of *Ptychocheilus arciferus* from the Junction Hills paleofauna: **a**, left hyomandibula (UCMP 117064); **b**, posterior part of left maxilla, mesial view, 26 mm (UCMP 117078); **c**, pharyngeal teeth, 3 - 5.7 mm (left to right, UCMP 294246, 294247, 294248).

dentary. Upper level, UCMP 117078, posterior part of left maxilla (Fig. 9 b); UCMP 294246 (Fig. 9 c, left), 294247 (Fig. 9 c, center), 294248 (Fig. 9 c, right), long, slender, caniniform pharyngeal teeth characterized by reduced terminal hooks.

Junction Hills specimens are most similar to those from the WSRP. *Ptychocheilus* is diagnosed by its elongate, straight, and distally truncate dentaries, with a sharp biting edge, (evident in UCMP 294238, not figured); long slender maxillae, long head bones, and large caniniform teeth. It is also identified by the large body size; no other native minnow in North America grows as large as *Ptychocheilus* (0.6–1.5 m long). The genus *Ptychocheilus* includes four modern and several fossil species that inhabit the Columbia drainage (and former connectives) and the Umpqua, Sacramento, and Colorado River drainages. For 16 million years, it has been the most distinctive monophyletic group among western North American minnows on the basis of elongate skull and jaw bones, long pharyngeal arches and teeth, and other morphological synapomorphies, but some *Ptychocheilus* species' DNA sequences are paraphyletic on molecular cladistic trees (Schönhuth et al., 2012). This causes the history of

some genes to be confused with fish lineage history. Some DNA sequences have shorter histories than their fish lineage because past introgression erases some gene histories. The distribution of *Ptychocheilus* is restricted to drainages connected in the past to the Oregon-Idaho Graben (OIG), Drewsey-Juntura Graben (DJG), Poison Creek, Chalk Hills, and Glenns Ferry Formations of the WSRP, and the Duck Point paleofauna of the ESRP (Hearst and Smith, 2002). The oldest fossil *Ptychocheilus* is from 16 Ma Sucker Creek, in the OIG and the 15 Ma Priest Rapids site, Washington. Others have been identified from the Granger locality in the Ellensburg Formation (Smith et al., 2018) and Pliocene Ringold Formation (Smith et al., 2000), Washington; Bidahochi Formation, Arizona (Spencer et al., 2008); Mono Basin, California; Drewsey and Juntura formations, Always Welcome Inn, and Imbler paleofaunas, Oregon (Van Tassell and Smith, 2019); Rome beds, Oregon; Madelaine Plains, Alturus Basin, California (Wagner et al., 1997); Miocene and Pliocene sites in western Nevada (Kelly, 1994; Smith et al., 2002); and Miocene Trapper Creek, Idaho. In most of the ecological communities it inhabited, it was the top predator.

FAMILY CYPRINIDAE *Acrocheilus latus* and '*A. onkognathus*' (Fig. 10)

Localities.—Lower (V77020) and upper (V77021) fish levels, Junction Hills; and Etna mammal and fish locality (V77142, locality 6 in Fig. 1); Box Elder County, Utah.

Referred specimens.—Lower level, UCMP 117065, one *Acrocheilus latus* sigmoid pharyngeal arch, 9 mm, with two teeth, 5, 6 mm (Fig. 10 l); and UCMP 294239, nine teeth, 3.4–7.6 mm. Upper level, UCMP 117079, six teeth, 8.9–9.5 mm, with sharp grinding surfaces, one left articular fragment; UMMP 42395, one dentary with a diagnostic mesial inflection of the biting edge on the distal process (Fig. 10 d,e,f). Etna locality, UCMP 299136, 299137, 299138, 299139, 299140,

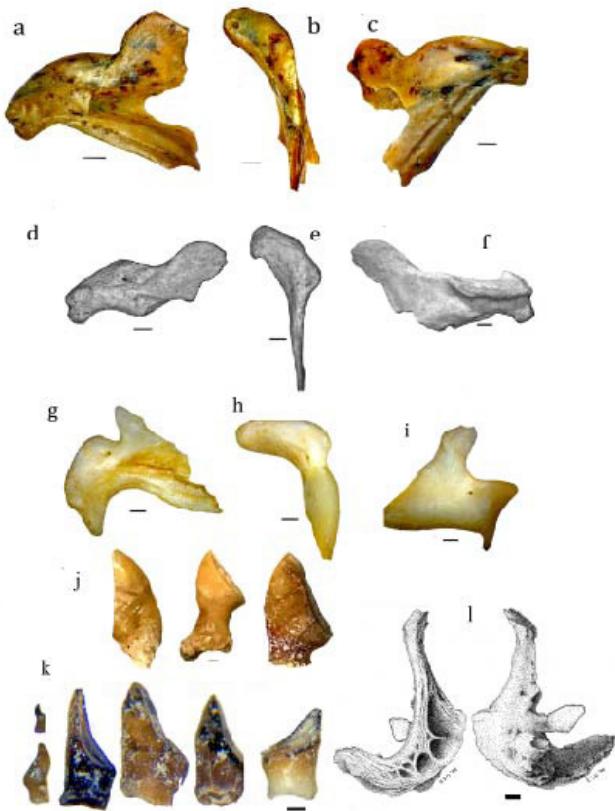


Figure 10: *Acrocheilus* dentaries, a, b, c, from Chalk Hills Formation, Idaho (UMMP 62588); d, e, f, Salt Lake Formation, Cache Valley Member, Junction Hills (UMMP 42395); and g, h, i, modern Snake River (left column, mesial views; center, dorsal views; and right, lateral views). j, Junction Hills, three teeth, UCMP 177079. k, Variation in a sample of six *Acrocheilus* teeth (upper left to right: UCMP 299136, 299137, 299138, 299139, 299140, 299141), about 1.6–8 mm long, collected (by PHM) near Etna, Box Elder County, Utah (locality 6, Fig. 1). l, Right pharyngeal arch from Junction Hills (UCMP 117065), 10.4 mm, lateral view (left) and mesial view (right). (Scale bars are 1 mm.)

and 299141 (left to right in figure), six pharyngeal teeth, 1.5–5.8 mm (Fig. 10 k).

The anterior symphyseal tips of the pharyngeal arches are offset by about a 40° angle and the dorsal limb normally has a short posterior process, giving the arch a sigmoid shape in lateral and mesial views for which Uyeno (1961) erected the generic name, *Sigmopharyngodon* (Fig. 10 l). Developing teeth may be slightly hooked terminally until worn to a sharp point. The grinding surfaces, when fully developed are ground down beyond

the enamel, leaving a softer, tear drop-shaped dentine lake about 1/4 to 1/3 as wide as long (Fig. 10 k). *Acrocheilus* dentaries are common in the Glenns Ferry Formation (Miller and Smith, 1967; Smith, 1975), but less common in the Chalk Hills Formation. Hybrid dentaries similar to the ones described here (Fig. 10 a, b, c, UMMP 62588) are in Chalk Hills collections, Malheur County, Oregon, where they were named *Orthodon onkognathus* (Kimmel, 1975: 82, fig. 6A). The Junction Hills dentary (UMMP 42395), is intermediate between *Acrocheilus latus* and *Lavinia*. The variability among samples of this form (Fig. 10 a-i), especially in the divergent parental traits, is evidence that some Miocene Cache Valley and Chalk Hills specimens are introgressed. The intermediate specimens are diagnosed by the inflection of the anterior (scraping) edge of the dentary at an abrupt 40° angle from straight (e.g., straight as in *Ptychocheilus*) (Smith, 1975). Most American minnows (e.g. *Klamathella*) have the edge of the dentary inflected about 20° toward the symphysis, with a rounded, not abrupt, angle. Modern *Acrocheilus alutaceus* and Glenns Ferry *A. latus* have the scraping edge of the dentary inflected abruptly at angles of 70°–90° respectively. The scraping edge has a broad, flat platform and a prominent anterior lip; the platform and labial process have a prominent anterolateral corner ahead of the mental foramen. The coronoid process is considerably larger (*Lavinia*-like) in hybrids rather than like *Acrocheilus* and is angled more posteriorly. A right dentary of this hybrid (UMMP 62560), 20.2 mm long, including the scraping part of the dentary and a large, complete coronoid process (Fig. 10 a, c) was collected from the Chalk Hills Formation at Tunnel Road, Malheur County Oregon, (P. G. Kimmel, 1975). The dentary resembles dentaries of '*Acrocheilus onkognathus*' from the Chalk Hills Formation; the teeth are like those of *Acrocheilus latus* of the Glenns Ferry Formation (Fig. 10 j). The labial anterior biting edge of the dentaries in Cache Valley and the Chalk Hills Formation are not as deep as in *A. alutaceus* (Fig. 10). '*Acrocheilus onkognathus*' dentaries are intermediate, possibly

hybrids, between *Acrocheilus* and *Lavinia*. The pharyngeal arch shares the sigmoid curve of the pharyngeal arches of all *Acrocheilus*.

Acrocheilus lived in the depositional environments of the Drewsey Formation (8.8–8.5 Ma), Poison Creek Formation (9.5–8.9 Ma), Chalk Hills Formation (8.4–4.5 Ma), Glenns Ferry Formation (4.2–1.8 Ma), the upper Ringold Formation (3.4–3.2 Ma), and, in the Pleistocene, the gravels of the Neely Formation at American Falls (Hearst and Smith, 2002) as well as at the Niter Cone near Soda Springs, Idaho (UMMP 44460). *Acrocheilus* in the Junction Hills local fauna differs from those at American Falls in the presence of a single row of pharyngeal teeth on each arch, as in *Acrocheilus latus* of the WSRP.

The significance of the Chiselmouth Chub at Etna (~17–15 Ma) is the extension of its distribution (1) geographically from the Fraser River, British Columbia, and WSRP region into the northern Basin and Range Province, and (2) chronostratigraphically into the middle Miocene, near the time of maximum Neogene temperature. The new record implies relatively high paleoelevation in the northwestern part of the Salt Lake Formation. This record, at the western edge of the formation in westernmost Box Elder County, Utah, is near the eastern boundary of the Humboldt Formation of Nevada, which is isolated from the Utah basins and has no *Acrocheilus*. The distribution of Chiselmouth Chub has been centered in the Columbia basin throughout its known history, implying a drainage connection between the Salt Lake Formation aquatic habitats and the Snake River drainage at least 500 m lower than the modern elevation at Grouse Creek. The easternmost records of *Acrocheilus* are in the Junction Hills local fauna (this report) and at Pleistocene Jaguar Cave in Eastern Idaho (Akersten and Smith, unpublished).

Modern *Acrocheilus alutaceus* live in the Columbia-Snake drainage below Shoshone Falls on the Snake River. The DNA of *Acrocheilus* is sister to DNA of Columbia basin *Klamathella* chubs, from which the *Acrocheilus* differ by mesially

inflected dentaries (Fig. 10, g, h, i), presence of a single row of pharyngeal teeth, usually five on the left arch and four or five on the right, with better-developed dorsal grinding surfaces than any other North American minnow except *Orthodon*. The identification of hybrids vs. plesiomorphic forms depends on sample sizes large enough to assess variation; both hybrids and plesiomorphic forms are expected to be intermediate, but introgressed samples differ in being hypervariable. The intermediacy of fish F_2 and backcrossed samples is usually a calculated average across divergent parental characteristics; many traits segregate among introgressed offspring, typical of one or both of the parents, as shown by lab-spawned and lab-reared hybrid fishes of many combinations (Hubbs, 1955; Neff and Smith, 1979).

FAMILY CYPRINIDAE

Mylocheilus cf. *M. whitei* (molariform chub) (Fig. 11)

Localities.—Lower (V77020) and upper (V77021) fish levels, Junction Hills, Box Elder County, Utah.

Referred specimens—Lower level, UCMP 117067, pharyngeal arch fragment, 5.3 mm. Upper level, UCMP 117082, one left pharyngeal arch, 22.8 mm, with three teeth and two tooth sockets (Fig. 11 a,b,e,f); UCMP 299142 (Fig. 11 c), 299143 (Fig. 11 d), and 299144, three pharyngeal teeth, 2.0–4.5 mm; UCMP 117081, five tooth fragments; UCMP 117085, anterior fragment of small arch, 11.9 mm.

The arch and the orientation of the teeth of this species (Fig. 11) are similar to *Mylocheilus whitei* Smith and Cossel (2002), from the Poison Creek Formation (9.5–8.9 Ma), WSRP, Idaho and Oregon, in that the pharyngeal arches are of dense bone, with reduced pores and nutrient foramina, but they differ in that the left and right pharyngeal teeth apparently occluded dorsally against the pharyngeal pad of the basioccipital rather than against their opposites. This is either a plesiomorphic or a hybrid trait. It is also somewhat similar to molariform chubs from the Juntura

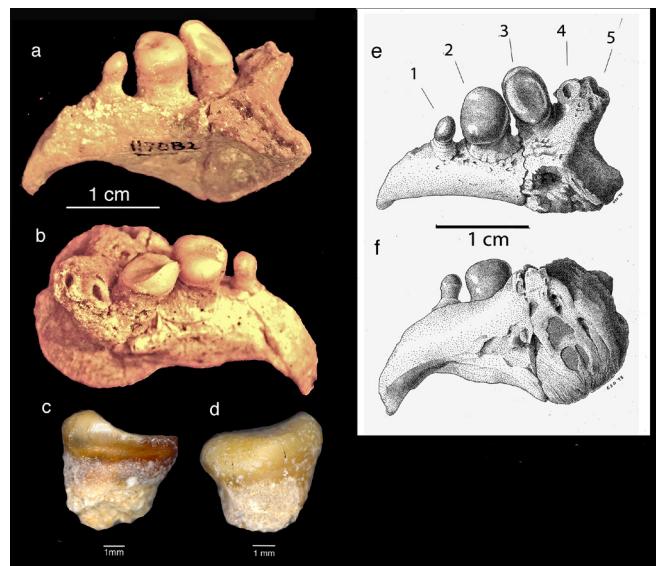


Figure 11: *Mylocheilus*, a, b, pharyngeal arch, dorsal and mesial views, respectively (UCMP 117082) showing flattened molar teeth, short anterior process, relatively shallow, solid, and rounded post-lateral flange; c (UCMP 299142), d (UCMP 299143), large, flattened molar teeth; e, f, dorsal and ventral views, respectively, of arches and teeth in a, b (UCMP 117082), showing apparent crushing surfaces of molar teeth 2 and 3 directed dorsally, not in left-right apposition as in *M. robustus*.

Formation, Oregon, and *Mylocheilus kingi* from the Chalk Hills Formation, Idaho and Oregon. It is less similar to the molariform chubs from the beds at Trapper Creek, Cassia County, Idaho, and the Ellensburg Formation, Washington. In addition to density of bone and orientation of arches and teeth the Cache Valley form is diagnosed by presence of five molariform teeth in the main row (Fig. 11). The usual two small teeth in the minor row are not present and apparently not developed, unlike *M. copei* and early *M. robustus* Smith, 1975; Smith et al., 1982). The pharyngeal arch (UCMP 117082) has a short, deflected anterior process (Fig. 11), and a short, rounded, robust main body under the tooth row. The lateral surface of the main body shows no large nutrient foramina (diagnostic), but is extremely solid, like the *Mylocheilus copei* and *M. robustus* series of the Chalk Hills and Glenns Ferry formations. The single specimen of the nearly complete left pharyngeal arch has teeth one, two, and three present, and numbers four and five

broken off. Tooth one is small and rounded, teeth four and five were small and elevated (Fig. 11).

FAMILY CYPRINIDAE
Genus *Lavinia* Girard
Lavinia stuwilliamsi new species
(Cache Valley Hitch)
(Fig. 12, 13, 14)

Localities.—Lower fish level (V77020), Junction Hills, Box Elder County, Utah; and J. S. Williams' Paradise locality (UCMP V77193), Cache County, Utah.

Referred specimens.—Junction Hills, lower level, UCMP 117068 (Fig. 12 b). J.S Williams Paradise locality, USNM 18394, head and body; USNM 18395, head and body; USNM 18396, part and counterpart; USNM 18397, head, body, fins; UMMP 42934, head, body, fins, pharyngeal teeth.

Holotype.—UMMP 42934, left side of a well-preserved specimen including an undisturbed head, teeth, body, and fins (Fig. 12, 13a; cover).

Paratypes.—Articulated fossils, USNM 18394, body and jaws (Fig. 13 b); USNM 18395, head and body with scales, proportionally larger head size and caudal fin, and narrower caudal peduncle (Fig. 13 c). The coronoid process visible in paratypes is narrower than in *Lavinia hibbardi*.

Description.—The Junction Hills specimens (UCMP 117068) include an 8 mm long tooth (Fig. 12 b), which has a rugose grinding surface, 2 x 0.4 mm. The anterior, biting, part of the dentary is short and robust (Fig. 12, distorted in 13 b) compared to *Gila* or *Mylopharodon*. The mental foramen is closer to the anterior end of the anterior labial process than in other local minnows. The *Lavinia* collected by J. S. Williams from southern Cache Valley are large specimens, with anteriorly flared dentaries, rugose scrolls on the grinding surfaces of the pharyngeal teeth (12 a, b), deep bodies, and large caudal, dorsal and anal fins (13 a); USNM 18396a and b, head, part and counterpart; USNM 18397, head, body, fins (Figs. 13 b, c, 14 a–e). The preserved quadrate and articular-angular are similar

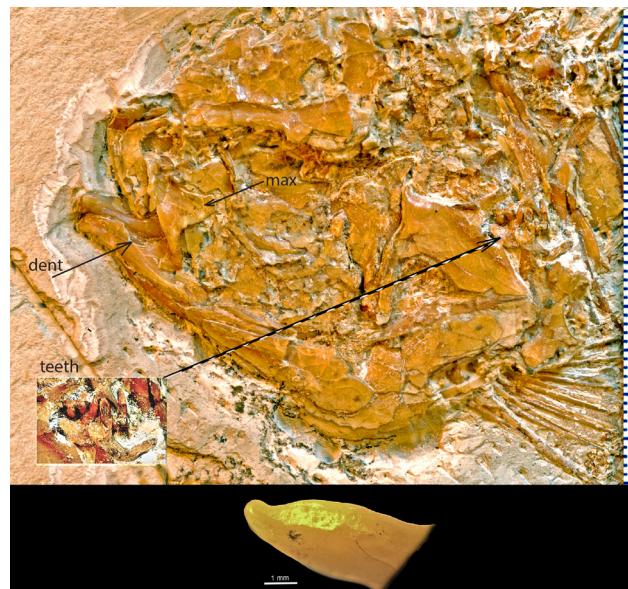


Figure 12: *Lavinia stuwilliamsi* n. sp., Miocene Cache Valley beds. **a**, Holotype, UMMP 42934, Paradise locality, Cache County, Utah, left side of head displaying jaws, opercular series, frontals, and textured grinding surfaces of dorsal side of teeth of left pharyngeal arch (inset). **b**, UCMP 117068, Junction Hills lower fish level, tooth showing textured grinding surface.

in their shapes to *L. exilicauda* of the Sacramento drainage, California. The deep preopercle matches that of *Lavinia exilicauda*, including seven sensory pores on the lower limb of the bone. Details of the dorsal, pectoral, and pelvic fins, as well as parts of the Weberian rib, vertebrae, opercle, cleithrum, and other fragments are not complete enough to help with the description of Cenozoic changes in the lineage. The anterior left side of a fish about 205 mm in standard length (USNM 18397), shows parts of the dorsal, pectoral, and pelvic fins as well as ribs and traces of scale rows. The dentaries show the flared biting edges and the high, narrow, angled coronoid process. The maxilla is shorter and more robust with a higher post-dorsal process. The well-preserved opercle has proportions and angles like *L. exilicauda*. The interopercle, subopercle, and cleithrum are similar to those bones in *L. exilicauda*, insofar as they are exposed. The first dorsal rays are more robust and longer before segmentation begins.

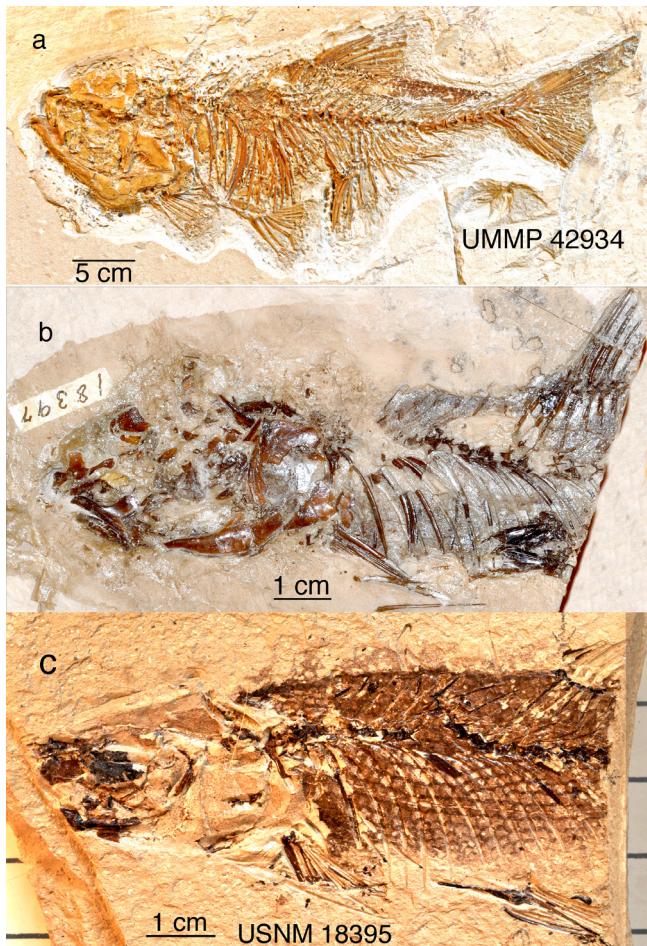


Figure 13: *Lavinia stuwilliamsi* n. sp. **a**, head and body of holotype, UMMP 42934, showing flared dentary, large, falcate anal fin, with 11 anal fin-rays, large, slender caudal peduncle, forked caudal fin, with thickened caudal rays in the centers of the upper and lower caudal lobes; **b**, paratype of *Lavinia stuwilliamsi*, USNM 18397, from Miocene Cache Valley beds, Paradise locality, Cache County, Utah, dentaries, maxilla, and premaxilla display unique apomorphies of *Lavinia* (see text); **c**, paratype of *Lavinia stuwilliamsi*, USNM 18395 part, also from Paradise locality, showing anterior vertebra and scale size.

Type Locality.—Collected by J. S. Williams about 1 km northwest of Paradise, 20 km south-southwest of Logan in the Salt Lake Formation, Cache Valley Member, Cache County, Utah, S.E. $\frac{1}{4}$ Sec. 20, T. 10 N. R. 1 E. (Fig. 1, locality 8), here designated UCMP V77193.

Diagnosis.—The sample is diagnosed from other genera by the unique elongate, narrow, rugose grinding surfaces formed on the upper

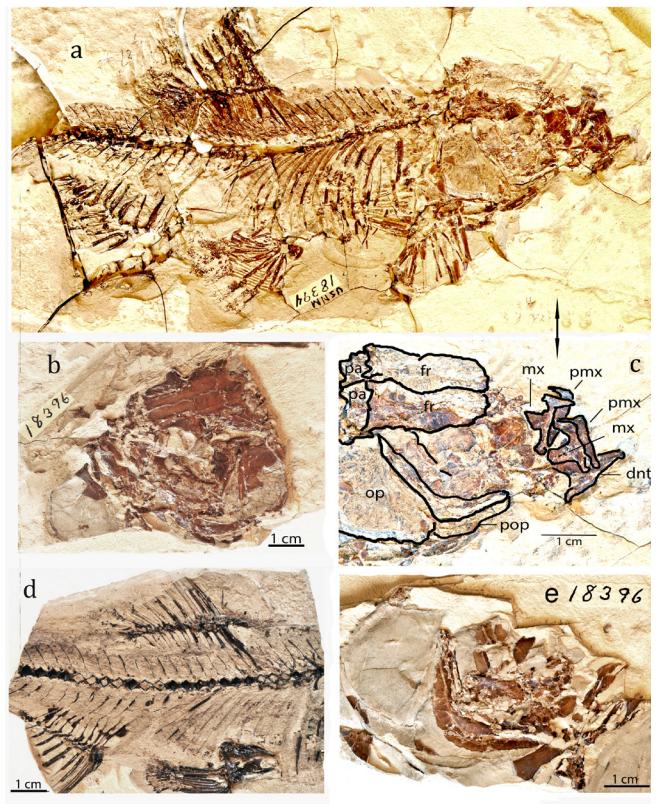


Figure 14: Paratypes of *Lavinia stuwilliamsi* n. sp. **a**, USNM 18394, head and body showing jaws and fin sizes and positions; **b**, USNM 18396a, showing diagnostic frontals and hyomandibula; **c**, USNM 18394, showing labelled jaws, skull roof, opercular series of a; **d**, USNM unnumbered, *Lavinia stuwilliamsi* midbody, showing 10 dorsal fin-rays, 10 anal fin-rays, and approximately 8 pelvic fin-rays; **e**, USNM 18396, showing jaws, preopercle, cast of opercle, subopercle and interopercle, and fragments of suspensorium and other head bones.

enamel surface of slender pharyngeal teeth (Figs. 12, 13 a, UMMP 42934) which occur in a single row of usually five teeth in the Cache Valley and modern forms. The scroll-like ridges on the grinding face (Fig. 12 a, b) are unlike *Acrocheilus*, *Gila*, *Mylopharodon*, *Mylocheilus*, *Siphateles*, *Rhinichthys*, plagopterines, *Klamathella* or any other North American minnow except *Algansea popoche* of Lake Chapala, Mexico. The labial process of the dentary is short and distinctly more anterolaterally flared with a slight concave-up curve, rather than the more vertical biting ridge of its similar relatives, *Siphateles* and *Mylopharodon*. There is a long gap between the posterior end of

the biting edge and the long coronoid process (Fig. 12, 13 b). *Lavinia stuwilliamsi* differs from modern *L. exilicauda* and WSRP *L. hibbardi* by its larger body size, proportionally larger head size and caudal fin, and narrower caudal peduncle. The coronoid process is narrower than in *Lavinia hibbardi*. The deep preopercle matches that of *Lavinia exilicauda*, including seven sensory pores on the lower limb of the bone. Details of the dorsal, pectoral, and pelvic fins, as well as parts of the Weberian rib, vertebrae, opercle, cleithrum, and other fragments are not complete enough to help with the description of Cenozoic changes in the lineage. The anterior left side of a fish about 205 mm in standard length (USNM 18397, Fig. 13 b), shows parts of the dorsal, pectoral, and pelvic fins as well as ribs and traces of scale rows. The dentaries show the flared biting edges and the high, narrow, angled coronoid process. The maxilla is shorter and more robust with a higher post-dorsal process. The well-preserved opercle has proportions and angles like *L. exilicauda*. The interopercle, subopercle, and cleithrum are similar to those bones in *L. exilicauda*, insofar as they are exposed. The first dorsal rays are more robust and longer before segmentation begins. The anal and dorsal fins are long, usually with 8–12 rays (Fig. 13 a).

Etymology.—Named for J. Stewart Williams, 1901–1984. Stu Williams received his undergraduate degree from Brigham Young University, MS from Columbia University, and PhD from George Washington University. He became Professor of Geology and Head of the Geology Department at Utah Agricultural College (UAC) in 1935. In 1950 he was named Graduate Dean at UAC (later renamed Utah State University), but continued to teach and head the Geology Department of USU until his retirement in 1967. He taught a variety of courses at USU, specializing in surficial geology, stratigraphy, paleontology, and groundwater geology in the Logan area, and continued teaching as Emeritus Professor into the early 1970s (when PHM was one of his students).

He mapped and published the Logan quadrangle.

Lavinia was formerly widespread in the Miocene and Pliocene of western U.S. (Smith et al. 1982), but now is restricted to the Sacramento River Drainage. It has been documented from the Aldrich Station Formation Nevada (12.5–12 Ma; Kelly, 2010), Sucker Creek (15.9–13.6 Ma), Carson Valley (5–3 Ma), the WSRP (7–3 Ma), and upper Ringold Formation (3–2.4 Ma; Smith et al., 2000; Smith et al., 2002). The Paradise locality marks the easternmost record for *Lavinia*. It was abundant in the Chalk Hills and Glenns Ferry lakes of the WSRP (Smith, 1975; Smith et al., 1982).

FAMILY CYPRINIDAE

Mylopharodon hagermanensis
(Fig. 15)

Localities.—Lower (V77020) and upper (V77021) fish levels, Junction Hills, Box Elder County, Utah.

Referred specimens.—Lower level, UCMP 294240, right dentary (Fig. 15 a,b); UCMP 117066, an isolated *Mylopharodon* tooth, 5.8 mm (Fig. 15 c), and a likely *Mylopharodon* tooth, 8.5 mm. Upper level, UCMP 299131, pharyngeal arch, posterior fragment, 9.2 mm (Fig. 15 d); UCMP 117080, one tooth, 5.2 mm; and UCMP 117084, a left parietal, 10.4 mm in its longest diagonal.

Mylopharodon is diagnosed by its rounded middle pharyngeal teeth, rarely flattened by wear (Fig. 15 c). The post-dorsal process of the pharyngeal arch is moderately long and pointed, with a distinct outward angle on the post-ventral margin (Fig. 15 d). The dentaries of fossil *Mylopharodon* are broader than those of the extant *Mylopharodon conocephalus* (Fig. 15 a, b).

Mylopharodon is distributed from the Miocene and Pliocene lakes of the WSRP, Summer Lake (Martin et al., 2019), Poison Creek Formation, Ellensburg Formation, Drewsey Formation, and the Modern Sacramento drainage. It also appears with *Gila domininus* in the fossils of the ESRP collected by Julia Sankey (ISMNH 659).

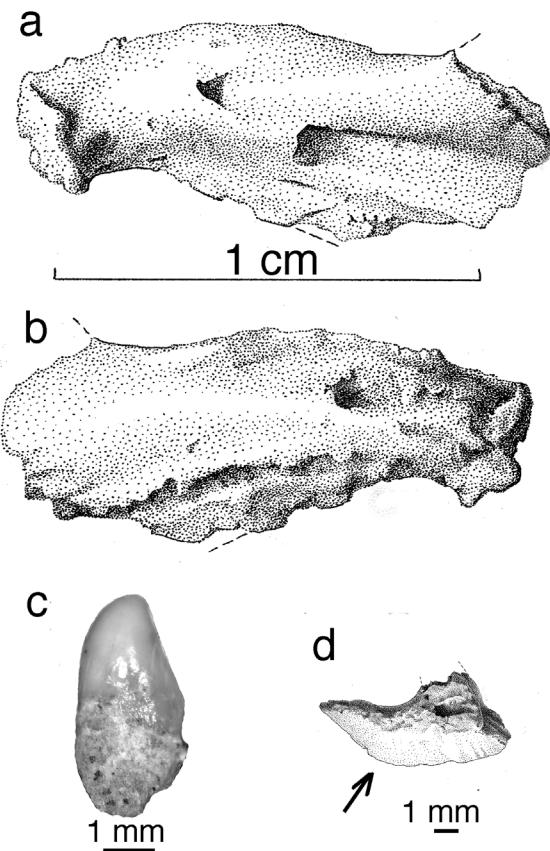


Figure 15: *Mylopharodon* cf. *M. hagermanensis*, **a** (mesial view), **b** (lateral view) of right dentary (UCMP 294240), showing short, wide position of mental foramen, and gap between the biting edge and base of coronoid process; **c**, conical pharyngeal tooth (UCMP 117066) with no grinding surface; **d**, pharyngeal arch fragment (UCMP 299131) with post-dorsal process showing moderately short dorsal point above sharp angle (arrow) on postero-ventral edge.

FAMILY CYPRINIDAE
Gila domininus (Cope) 1872
 (Bear River Chub)
 (Fig. 16)

Locality.—Lower fish level (V77020), Junction Hills, Box Elder County, Utah.

Referred specimens.—UCMP 117069, the fragmentary remains of a pharyngeal arch and teeth (Fig. 16 a).

Compared specimens.—*Gila domininus*, IMNH 659, part, (Fig. 16) 19 pharyngeal arches with

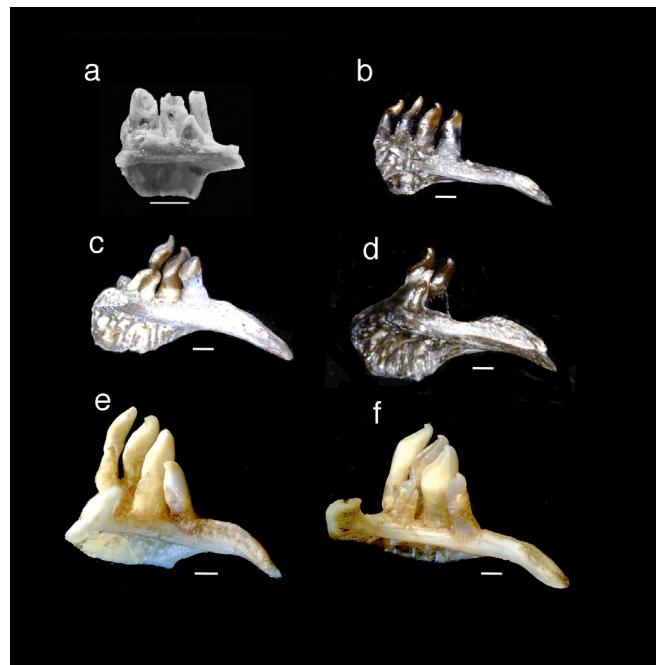


Figure 16: *Gila*, **a**, fragmentary left pharyngeal arch of juvenile *Gila domininus* (UCMP 117069), showing large post-lateral flange (ventral in photo), major teeth 2, 3, 4, one minor tooth; **b**, **c**, **d**, *Gila domininus* from the American Falls local fauna, Idaho (IMNH), showing enlarged post-lateral flanges and partial tooth rows; **e**, modern *Gila domininus* (UMMZ) showing enlarged post-lateral flange; and **f**, *Gila atraria*, Bonneville Basin (UMMZ), showing reduced post-lateral flange and well-developed grinding surfaces. Teeth b-f are from the right side; scale bars equal 1 mm.

teeth, collected from the Pliocene or Pleistocene American Falls beds, ESRP, by Julia Sankey and deposited at IMNH. UMMZ 92242, modern pharyngeal arches with teeth, UMMZ 144842, modern pharyngeal arches with teeth; *Gila atraria*, UMMZ 1174542, modern pharyngeal arches with teeth.

Description of Gila domininus.—Robust pharyngeal arches and teeth; lateral ala broad with an anteroventral point or hook. Tooth formula 2,5-4,2 first tooth in minor row sometimes missing; anterior limb short; first and sometimes second tooth robust, round in cross section, sometimes blunt or with terminal grinding surface; subsequent teeth 2,3, 4, (5) in major row increasingly compressed,

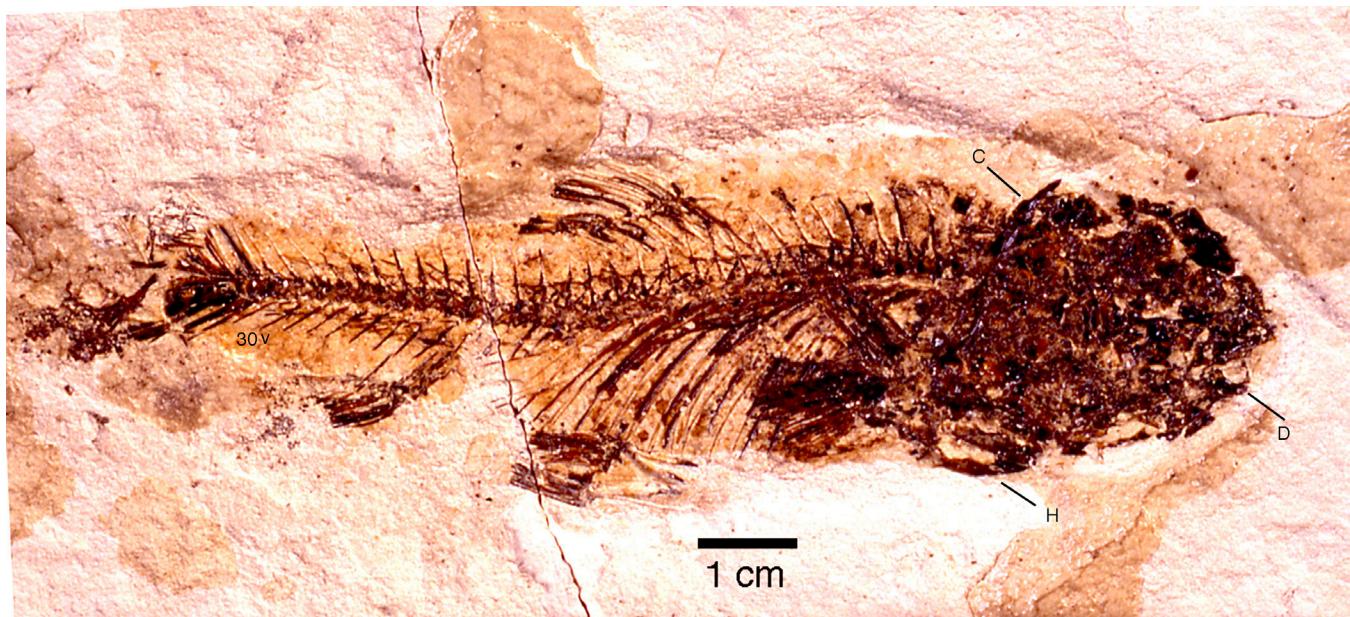


Figure 17: *Rhinichthys* cf. *R. osculus* from Salt Lake Formation near Georgetown, Idaho, demonstrating small head, small subterminal mouth, small fins, and ca. 30 post-Weberian vertebrae (IMNH).

with terminal hooks, with long, narrow, grinding surface on longer teeth; anterior teeth with wider grinding surface posterior teeth little elevated on right arch, base of tooth five elevated and extended from the left arch. Anterior limb of arch short, post-lateral skirt wide in one of the phenotypes present.

Range and diagnosis.—Upper Snake River and Bear River, formerly tributary to the Upper Snake River, now tributary to the Bonneville Basin (Bright, 1967), *Gila atraria* is the endemic species of the Bonneville Basin; the type locality is Utah Lake. Modern *Gila domininus* is found in the Bear River, Utah. *Gila domininus* differs from *G. atraria* in having larger lateral nutrient cavities on the wide part of the arch; a non-expanded anterior limb under the first tooth, and a more concave lateral ala under the first tooth; they have similar arch shapes anteriorly and post-dorsally, similar placement of the minor row of teeth, and compressed teeth, terminal hooks on teeth, and slender grinding surfaces, although the teeth of *G. domininus* are less compressed and more robust. In both, the tooth formula is usually 2,5-4,2, the teeth of the minor row are close together, the first tooth is adjacent

to the second tooth of the major row (third tooth on the left side) and the second tooth of the minor row is close to the fourth tooth (fifth tooth on the left side) of the major row. The first tooth in the minor row is sometimes missing. The fragmentary pharyngeal arch and teeth of *Gila* from the Cache Valley beds (UCMP 117069) is a left, 3 mm long, with broken proximal parts of teeth 3, 4, and 5 of the major row and 2 of the minor row. Tooth 1 of the minor row was adjacent to tooth 3 of the major row; tooth 2 of the minor row was adjacent to tooth 5 of the major row. The nutrient cavities under the teeth are large and the teeth have rounded, robust bases relative to their size, so are identified as *Gila domininus*. *Klamathella* differs in having a longer anterior process and in having the minor row of teeth more anterior by one position in relation to the major row of teeth.

Description of American Falls fossils.—The fossils from the American Falls paleofauna represent smaller fish (less than 130 mm standard length) than modern *G. domininus*, *G. atraria*, *Klamathella caerulea*, or fossil *K. milleri*, which may exceed 300 mm S.L. There are 19 pharyngeal

arches and teeth, one basioccipital 11 mm long, and one maxilla in IMNH 659. The complete left maxilla, 5.5 mm long, has the truncate dorsal process, strong points of attachment for the maxillaris muscles, and general proportions of *Gila*. (The *Mylopharodon* specimens present in the American Falls collection, have a rounded dorsal process of the maxilla, weak points of attachment for maxillaris muscles, and an elongated anterior section between the head of the bone and the dorsal process.) The basioccipital pad of *Gila domininus* is narrower than the ovoid pad of *Mylopharodon*.

Klamathella caerulea, the Blue Chub, was subdivided from the genus *Gila* by Miller (1945). Subsequent molecular studies (Smith et al., 2002) have found its DNA to be more plesiomorphic than *Gila*: the DNA is sister to *Acrocheilus*. *Klamathella* has *Gila*-like teeth, slender, with a terminal hook and weak grinding surfaces. The tooth formula is 2-5,4-2.

Johnson (2002), studied *Gila atraria* and found significant differences between *G. atraria* of the central and southern Bonneville Basin and the Bear River and Snake River populations that we identify as *Gila domininus* based on morphological, fossil, and molecular traits. The traits shared by *Gila atraria* and *Gila domininus* appear to be morphological synapomorphies that unite these as sister species.

Protoporus domininus Cope 1872 was described in Hayden's Geological Survey of Montana, 1871 (Hayden, 1872, p. 473), from the Snake River at Fort Hall, Idaho. It was said to be based on young of *Tigoma atraria* by Jordan et al. (1930, p 119). Böhlke (1984) in the Philadelphia Academy of Science Type Catalogue, found no types, but emended the name to *dominus*, contrary to original misspelling, *domninus*, by Cope and subsequent spelling, *domninus*, in Jordan et al. (1930). Eschmeyer (1990) spelled the name *domninus* in accordance with the International Rules of Zoological Nomenclature. Therefore, we regard *domninus* as the valid name for this species of *Gila*.

FAMILY CYPRINIDAE *Rhinichthys* cf. *R. osculus* (Fig. 17)

Locality.—Near Georgetown, Bear Lake County, Idaho.

Referred specimens.—A complete lateral body fossil of *Rhinichthys*, 114 mm in standard length, collected by Sue Ann Bilbey and deposited in the IMNH.

Rhinichthys is diagnosed by its small head, eyes, and fins, small slender body, and small subterminal mouth. The pharyngeal teeth have a dorsal blade (not seen in this fossil). *Rhinichthys osculus*, the Speckled Dace, is the most widespread and diverse species of fish in western United States, inhabiting all major Pacific drainages from southern Canada to the Mexican border (Smith et al., 2018). Fossil *Rhinichthys* occur in the Miocene Juntura Formation, Glenns Ferry Formation, and Pliocene Always Welcome Inn fauna of eastern Oregon (Van Tassell and Smith, 2019).

FAMILY CATOSTOMIDAE *Catostomus* cf. *C. ardens* (Fig. 18)

Localities.—Lower (V77020) and upper (V77021) fish levels, Junction Hills, Box Elder County, Utah.

Referred specimens.—Lower level, UCMP 117062, one dentary, 10.4 mm (Fig. 18 a); UCMP 117061, parietal, 13.6 mm; UCMP 117063, one cleithrum, 22.1 mm, eight pharyngeal teeth, 3.2–5.8 mm; UCMP 294230, two hyomandibulae, 17.2 mm, 12.3 mm; UCMP 294235, one quadrate, 14 mm; UCMP 294236, one vertebra 8 mm, 8 years old. Upper level, UCMP 117074, one right maxilla, 11.1 mm (Fig. 18 b); UCMP 117077, one palatine, 11.4 mm (Fig. 18 c), two ceratohyals, 5.7 mm, 8.5 mm; UCMP 117076, one dentary, 6.0 mm; UCMP 294242, one parasphenoid, 17.4 mm; UCMP 294243, one cleithrum, 20.5 mm.

Some of the bones resemble *Catostomus*

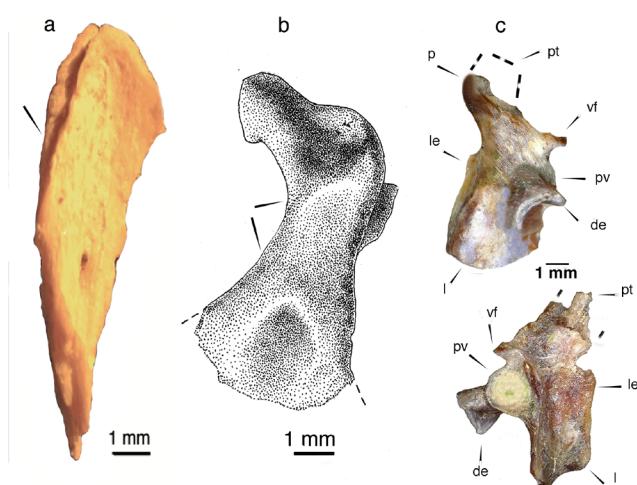


Figure 18: *Catostomus* sp. from the Junction Hills paleofauna, **a**, left dentary (UCMP 117062) with the anterior process of even width throughout its length and long, evenly-curved labial groove (arrow); **b**, anterior part of right maxilla (UCMP 117074) with a long slender neck anterior to a deep insertion of the maxillaris muscle (arrow); and **c**, right palatine (UCMP 117077) antero-dorsal view above and antero-mesial view below (**p**, posterior process; **pt**, pterygoid process; **vf**, prevomerine flange (broken); **pv**, prevomer socket; **de**, dermethmoid process; **l**, lacrimal process; **le**, lateral edge). The three Junction Hills specimens all differ from *Catostomus ardens* and *C. macrocheilus*, modern and fossil, by the dentary's labial margin, maxilla's long anterior neck, and the palatine.

ardens of the Bonneville drainage basin (Fig. 18) and upper Snake River rather than *Catostomus macrocheilus* of the lower Snake River and Columbia River drainages. The lineage's presence in the Cache Valley beds suggests that it has been present in the Cache Valley–Bonneville–Snake River basin through most of Pliocene to modern times, probably along with *Gila*, *Acrocheilus*, *Rhinichthys*, and *Chasmistes*. Differences between the dentaries, however, suggest extra limital variation is present. DNA of *C. ardens* from the Bonneville basin and the upper Snake River drainage are 4–5% different (Mock et al., 2006). *Catostomus* is one of the most widely distributed fish genera in North America, with exceptional Late Cenozoic and modern species diversity in the West (Smith et al., 1982; Smith, 1992).

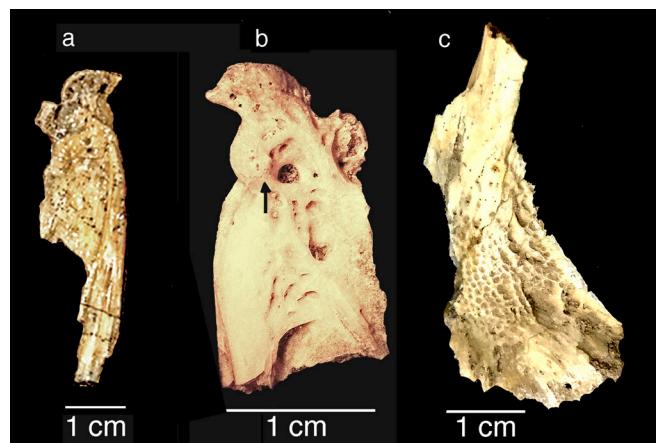


Figure 19: *Chasmistes batrachops* from the Junction Hills paleofauna, **a**, right hyomandibula (UCMP 294241); **b**, right hyomandibula fragment (UCMP 294231); **c**, right cleithrum showing abundant dorsal pore spaces (UCMP 117060).

FAMILY CATOSTOMIDAE *Chasmistes batrachops* (Fig. 19)

Locality.—Lower fish level (V77020), Junction Hills, Box Elder County, Utah.

Referred specimens.—UCMP 294241, one hyomandibula, 48 mm long (in matrix) (Fig. 19 a); UCMP 294231, right hyomandibula fragment (Fig. 19 b); UCMP 117060, one cleithrum, 64 mm (Fig. 19 c) and coracoid, 28 mm (attached in matrix); UCMP 117073, basioccipital, 20 mm; premaxilla, 24.5 mm.

Chasmistes, a lake sucker, is diagnosed by its large size, terminal mouth, long open-angled dentary, elongate anterior part of the maxillae, anterior orientation of the premaxillary process of the maxillae, obtuse angled premaxilla, porous cleithrum, wide neurocranium with porous roof bones, sharp keel on the basioccipital, and many features of the gill rakers and soft anatomy (Miller and Smith, 1981; Smith, 1992; Smith et al. 2018). The Junction Hills specimens are recognized by large size, porous cleithrum, boss for muscle attachment on the antero-lateral margin of the opercular condyle of the hyomandibula, and long life, 20+ years. The cleithrum has honeycomb-

like spaces in the dorsal surface of the concave part of the bone like the porous skull roof (Fig. 19), possibly for fat deposits that contributed to buoyancy in the mid-water lake sucker. *Chasmistes* has a possibly continuous record in the upper Snake drainage (from the Teewinot Formation to the Bonneville basin during the past ~6 million years. It is found as fossil in the lake deposits of Miocene Walker Lane between the Great Basin and Sierra Nevada, to Summer Lake (Martin et al., 2019), Ringold Formation, latest Chalk Hills Formation, and Glenns Ferry Formation, where it reaches its most apomorphic filter-feeding adaptations. It hybridizes with *Catostomus* at most localities (Smith et al. 2018).

FAMILY CENTRARCHIDAE
Archoplites taylori (western sunfish)
 (Fig. 20)

Localities.—Upper fish level (V77021), Junction Hills; and Etna locality (V77142); Box Elder County, Utah.

Referred specimens.—Junction Hills, UCMP 117072, 294244, two angulo-articulars, 6 mm, 7 mm (Fig. 20 a,b); UCMP 294245, one first-year vertebra, 3.7 mm. Etna, UCMP 299133, several fin spines.

Archoplites, a western representative of the Centrarchidae (sunfishes and basses) was widespread in northwestern drainages in the late Miocene and Pliocene. It is diagnosed by its 6 or 7 anal spines, 10 or more dorsal spines, one pair of pelvic spines, deep body, large mouth, large scales, large eyes, large supraoccipital crest, toothless maxilla, small teeth on the dentary and pharyngeal bones, and large sensory canals and pores on the frontal bones of the neurocranium.

Archoplites is represented in the Junction Hills by two angulo-articulars (UCMP 117072, 294244) (Fig. 20 a, b) with a boss on the dorsal edge anterior to the articular condyle, similar to *Archoplites* (Fig. 20 e, f) from the WSRP and unlike the smoothly curved edge in *Archoplites interruptus* (Fig. 20 c, d). *Archoplites* was present in many

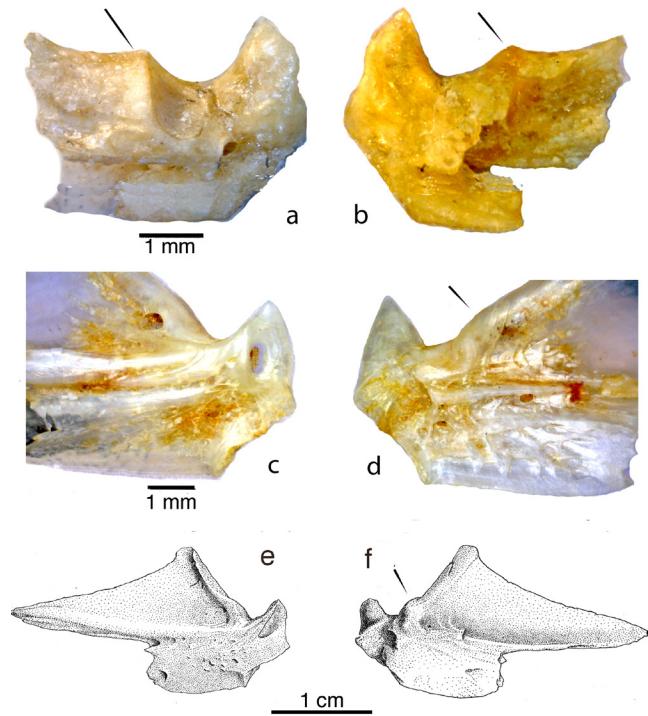


Figure 20: Comparison of posterior angulo-articulars of *Archoplites*. **a, b**, Mesial views of specimens from the Junction Hills paleofauna (UCMP 294244, 117072); **c, d**, lateral and mesial views of modern *Archoplites interruptus* from the Sacramento drainage; **e, f**, lateral and mesial views of (UMMP 59666) from the Glenns Ferry Formation. Arrows indicate different shapes of the ridge anterior to articular condyle.

Great Basin and Columbia–Snake drainages, but is now endemic to western California. It was uncommon in the Cache Valley beds, suggesting elevation similar to the northern Bonneville Basin (1370 m, 4500 ft) or higher. The vertebra indicates moderately rapid growth.

MAMMALIA
 CARNIVORA
 FAMILY FELIDAE
 Subfamily Felinae
 Genus et species indet.
 (Fig. 21 a)

Locality.—Upper fish level (V77021), Junction Hills, Box Elder County, Utah.

Referred specimen.—UCMP 299134, a

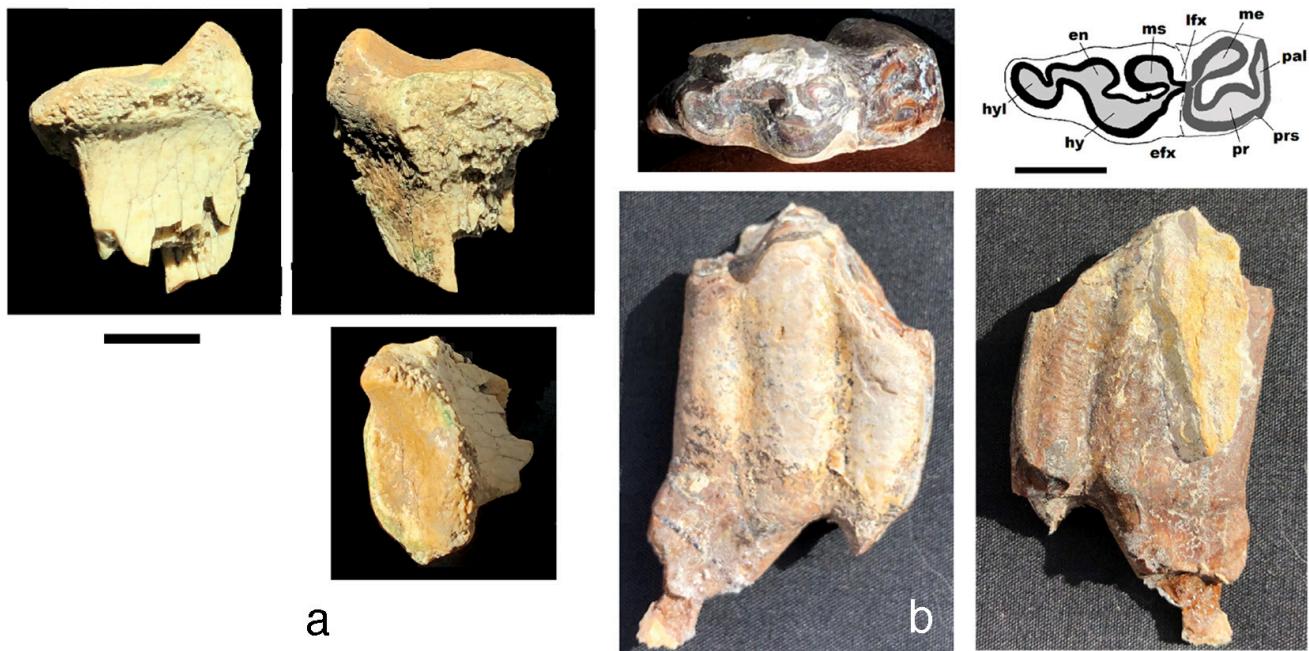


Figure 21: Fossil mammals from the Salt Lake Formation in the Junction Hills, Box Elder County, Utah. **a.**, Fragmentary distal right radius (UCMP 299134) of lynx-size felid found as surface float on upper fish level in scarp sequence of Plymouth oolite subunit; (clockwise from top left) posterior and anterior side, and distal articular surface, scale bar is 10 mm. **b.**, Right lower third molar (m_3) of middle to late Miocene horse (UCMP 299135), also float, from the Long Divide Road locality (UCMP V77191) on the tephra subunit of the Cache Valley Member; (top left) occlusal view, anterior to right; (top right) cusp diagram, grayed out where crown broken (**black**, enamel; **gray**, dentine; **white**, cementum; **efx**, ectoflexid; **en**, entoconid; **Ifx**, linguaflexid; **me**, metaconid; **ms**, metastyloid; **pal**, paralophid (protolophid); **pr**, protoconid; **prs**, protostyloid; **hy**, hypoconid; **hyl**, hypoconulid); (bottom left) labial and (bottom right) lingual views of crown (yellowish material is obstinate porcellanite), scale bar is 10 mm.

fragmentary distal right radius of a small adult cat (Fig. 21 a) (“lynx-size” per R. H. Tedford; oral communication to PHM 1975). Collected as float (by PHM) on the surface of the ledge-forming oolitic limestone of the upper fish level.

Specimen broken from shaft at 2 cm posteriad of distal end; epiphysis fused; scapholunar articulation surface intact and 17 mm transversely x 10 mm anteroposteriorly; styloid process extends 4 mm beyond rim of scapholunar facet; medial facet partially missing from breakage, but adjacent portion of ulnar facet is preserved.

PERISSODACTYLA
FAMILY EQUIDAE
Subfamily Equinae
Hypsodont genus et species indet.
(Fig. 21 b)

Locality.—Long Divide Road (V77191), Junction Hills north of Cutler Dam, in NE $\frac{1}{4}$, Sec. 22, T. 13 N., R. 2 W., easternmost Box Elder County, Utah, about 30 m north of Long Divide Road at mouth of N-S valley; found by PHM (2014) in a well-rounded cobble of tuffaceous porcellanite derived from an adjacent outcrop of Salt Lake Formation (Cache Valley Member) in a spoil pile excavated from underlying shoreline deposit of late Pleistocene Lake Bonneville.

Referred specimen.—UCMP 299135, a nearly complete right lower third molar (Fig. 21 b).

Moderately worn hypsodont m_3 with three roots (posterior two merged); occlusal surface of trigonid missing by breakage, exposing underlying tooth cross-section; crown 28.0 x 10.7 mm in maximum length and breadth (anteroposterior and transverse dimension of enamel, respectively) and 33–34 mm in maximum height (top of middle root

to highest point of metastylid). (Terminology after MacFadden, 1984:17.) On the worn but unbroken portion of crown, cement <1.0 mm thick on lingual and labial surface of columns, ectoflexid deep and cement-filled, entoflexid sediment-filled without visible cement; metastylid is subcircular, with pulp cavity filled by lighter-colored dentine; linguaflexid deep, subangular and unambiguously U-shaped; metastylid and metaconid are not only separated but mutually isolated by contact of the apposed linguaflexid and ectoflexid enamel at the posterior end of the metaconid (which on greater wear would become a dentine isthmus); metaconid (projected dorsad to approximate occlusal plane) is larger than and positioned somewhat more lingually than metastylid; hypoconid is the largest cusp and crescent-shaped, with a subtle rounded pli caballinid opposite a sharp bifurcated pli entoflexid; entoconid and hypoconulid (heel) connected by a smaller intervening dentine lake (an accessory cusp). As visible on broken trigonid surface, paralophid (protolophid) is well developed with a distinct protostylid and extends across nearly the entire width of anterior tooth column; metaconid and protoconid are flattened ovals and metaflexid is cement-filled.

Except identifying the specimen as of “*Merychippus*” grade, a definite taxonomic determination to genus is not possible from the fragmentary tooth without evidence from facial morphology, metapodials or other characters; and m3’s of this equid grade are not commonly described, figured and diagnosed in literature. Generally, the metaconid-metastylid separation and presence of pli entoflexid indicate the subfamily Equinae; and the crown dimensions are near the upper range of *Protohippus* and lower range of *Pliohippus* within tribe Equini (MacFadden, 1998), and in the range of the *Cormohipparion occidentale* group within Hipparionini (Woodburne, 2007, table 8). The subcircular metastylid, its isolation from the metaconid by intervening contact of linguaflexid and ectoflexid (at moderate wear), and presence of an accessory cusp on the heel appear apomorphic. The well developed protostylid, metastylid smaller

and positioned less lingually than metaconid, and the deep U-shaped linguaflexid favor certain Equini (Hulbert, 1989), possibly *Protohippus*; and those features together with the accessory cusp separating entoconid and hypoconulid are similar to the hipparionine *Hippotherium* (Macfadden, 1984, fig. 145). Based on this indefinite taxonomy, a general late Barstovian or Clarendonian age (ca. 15–9 Ma) seems to be indicated, perhaps in the latter part of that interval. This age range is consistent with the approximate 10–8 Ma dates on chemically correlated tephras sampled 300–500 m north of the locality in this N-S valley along the exposed gently E-dipping Salt Lake Formation, where similar porcellanite interbeds can be observed (see *Age of the Junction Hills Local Fauna* above).

DISCUSSION

Long considered “Pliocene” in age, the fossil biota of the Cache Valley depositional basin is now recognized to also include Miocene species represented by the first diverse fossil vertebrate fauna described (this report) from the Salt Lake Formation. This paleofauna, from the Cache Valley Member, comprises 11 species of late Miocene (Hemphillian) freshwater fishes in four families and eight genera, along with the first records of terrestrial mammals from the basin (a small felid contemporary with the ichthyofauna, and a middle Miocene equid). These Miocene records add a new dimension to the fluviacustrine ecosystem recorded by the Cache Valley Member, which for most of a century has been known only by its Pliocene mollusk and ostracod faunas. The study further shows that the “Pliocene” flora of the Salt Lake Formation in southern Cache Valley, associated with the ichthyofauna, is likewise late Miocene.

Also long recognized is the compelling taxonomic similarity between the Cache Valley paleofauna and more diverse fossil faunas in Idaho’s western Snake River Plain, in the Chalk Hills and Glenns Ferry Formations in particular (Taylor, 1966, for mollusks; McClellan, 1977, for

fishes). The paleontological affinity and associated lithologic correlations between these regions clearly favor a hydrographic connection during the late Miocene and Pliocene and justified the early proposal (McClellan, 1981) that "Lake Idaho" extended from the WSRP through the ESRP and into northern Utah.

However, in the following decades theoretical barriers along the ESRP emerged from plate tectonics that obstructed the proposed aquatic connection: the Yellowstone Hotspot theory. As summarized by Pierce and Morgan (1992), since the middle Miocene the North American plate has moved southwestward over a stationary thermal plume in the mantle, producing a "hotspot" in the lithosphere presently located beneath the Yellowstone caldera. Passage over the plume produced a linear trail of silicic volcanic fields that progressed through time, from NE Nevada in the middle Miocene to NW Wyoming where the hotspot is active today. In its wake the hotspot left the NE-trending eastern Snake River basin, which has been flooded by basaltic flows since the middle Pliocene to form the present ESRP.

A dynamic consequence of magma upwelling from a mantle plume is thermal uplift of the overlying crust, of which the elevated Yellowstone Plateau appears to be an example. Extrapolating backward in time and space along the hotspot track, a Yellowstone-like thermal uplift has been inferred at each major silicic volcanic center during its activity along the ESRP. As the Yellowstone Plateau also occupies the present continental divide, its coincidence with today's hotspot location implies that (a) antecedent silicic volcanic fields along the ESRP likewise mark past locations of the continental divide and (b) the divide migrated eastward with the hotspot, from central Idaho in the middle Miocene to the longitude of Cache Valley in the late Pliocene or Quaternary.

A migrating continental divide clearly challenges a proposed hydrographic connection between the Cache Valley paleofauna and the coeval fish faunas of the WSRP in western Idaho. Many species groups in common between the two

biogeographic regions are warmwater taxa and most are today restricted to elevations far lower than what would be expected along a continental divide. Figure 22 shows the elevations occupied by samples of recent counterparts of nine of the fish lineages that possibly dispersed between lakes of the WSRP and Cache Valley. Tables 2, 3, and 4 permit comparison of the presence and absence of lineages of fishes and snails that were physiologically adapted to low elevations of dispersal as opposed to the high elevations of the continental divide. The fossil records indicate low elevations between northern Utah and western Idaho during the relevant interval (6 to 5 Ma), when the region was high according to current Yellowstone Hotspot theory (Smith, 1999).

The first principle of fish biogeography is that fish colonize wherever they can swim, survive, and reproduce. Native fishes occur only in waters that they could have reached through surface water connections so that the dispersal of fishes is closely tied to regional aquatic systems history (Broughton and Smith, 2016:293). Applying this biological principle, we discuss below evidence from recent analyses of silicic volcanism along the ESRP that reinforces the hypothesis of hydrographic connections between Cache Valley and the WSRP.

Faunal origins. Ancestors of the aquatic Cache Valley paleobiota were derived from at least five sources: the Chalk Hills Lake, the Glenns Ferry Lake, the Miocene Trapper Creek area, the upper Snake and Bear Rivers, and the pre-Bonneville Basin. Pliocene mollusks of the Snake River Plain were identified by Taylor (1966:72), who assigned a Blancan age to the Cache Valley mollusks on the basis of their similarity to mollusks of the Glenns Ferry Formation. Those include 13 identical or very similar species and vicariant pairs, *Sphaerium striatinum*, *Pisidium compressum*, *P. punctatum*, *Valvata humeralis* / *incerta*, *Lymnaea occidentalis* / *kingi*, *Gyraulus parvus* / *annectans*, *Omalodiscus pattersoni*, [*Promenetus kansensis*?], *P. umbilicatellus*); *Anodontia* spp. (Unionidae), Payettiidae, *Pliopholyx campbelli* / *reedsidei* (Pliopholygidae), *Fluminicola superbus*

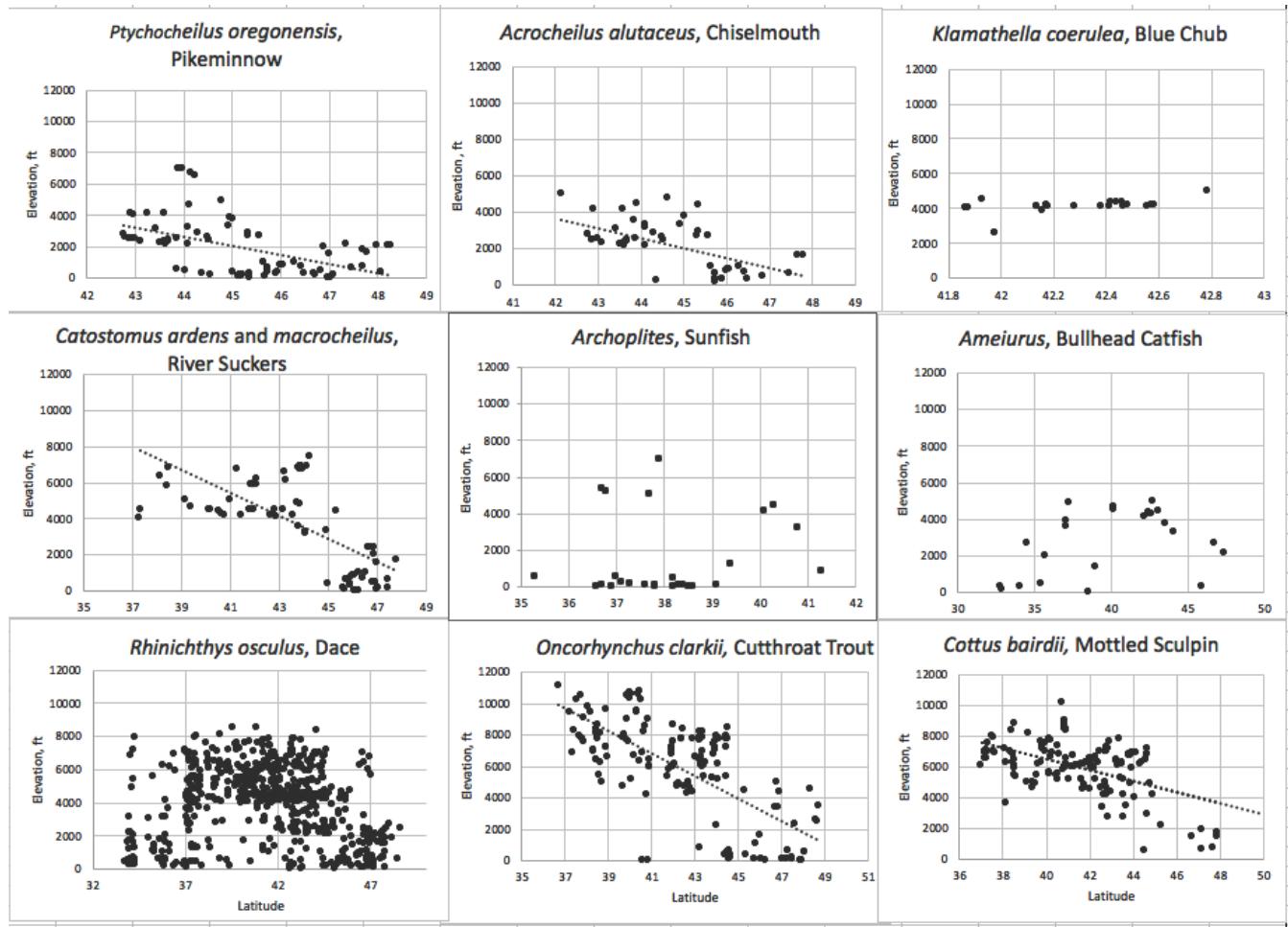


Figure 22: Comparison of altitudinal distributions of species related to the Chalk Hills and Junction Hills paleofaunas, plotted against latitude, with which altitude covaries. *Archoplites* (sunfish) and *Ameiurus* (catfish) are lowland indicators in the Chalk Hills Formation and the Cache Valley paleofaunas; *Oncorhynchus* (trout) and *Cottus* (sculpin) are Chalk Hills Formation and Snake River species not present in the Cache Valley paleofauna. The trout and sculpin appear later in the Bonneville paleofauna; the catfish and sunfish do not, suggesting the combined effects of elevation and Pleistocene temperatures.

(Hydrobiidae), *Vorticifex* spp. (Planorbidae), and *Gyraulus multicarinatus / monocarinatus*. While we have no basis at present to disagree with Taylor's Blancan age assignment, we suggest that after a half-century of advancement in taxonomic, biostratigraphic, and ecological knowledge, the Cache Valley molluscan fauna merits restudy.

Catfish (*Ameiurus*) and suckers (*Catostomus* and *Chasmistes*) in the Cache Valley paleofauna also fit that pattern. However, other Cache Valley fishes (*Acrocheilus* 'onkognathus') are either plesiomorphic or hybrids, like the late Miocene WSRP Chalk Hills *Acrocheilus*, and unlike the

more derived Pliocene Glens Ferry *Acrocheilus latus*. Sunfish were common in both the Chalk Hills and Glens Ferry lakes of the WSRP, but are inadequately known in Cache Valley sediments to differentiate their origins. Four lineages, *Gila*, *Rhinichthys*, and *Catostomus*, were probably native to the Cache Valley and pre-Bonneville drainages (Bear River and upper Snake River) as early as the Pliocene. *Chasmistes* has a long pre-Pliocene history (Teewinot Formation, ca. 6 Ma) in the upper Snake River and the WSRP and in the modern Bonneville basin.

Multiple origins require multiple connections.

Table 3. Cache Valley lake fishes are low elevation, warm-water or eurythermal lake and river species. *Ameiurus* (catfish) and *Archoplites* (sunfish) are warm-water fishes that probably dispersed between the Snake River Plain and Cache Valley at elevations lower than 5000 ft (1524 m) asl, their upper altitudinal limits (Fig. 22). *Ptychocheilus*, *Acrocheilus*, *Mylocheilus*, *Mylopharodon*, *Chasmistes*, *Deltistes*, and *Catostomus* are large fishes that inhabited large rivers or lakes. They are unlikely to have emigrated over headwater divides higher than 2 km. *Gila domininus*, *Rhinichthys osculus*, *Catostomus ardens*, and *Chasmistes* are in the modern Bonneville-Bear River fauna and were probably in the Plio-Pleistocene upper Snake River fauna.

Chalk Hills Formation	Cache Valley Member, Salt Lake Formation
* <i>Ameiurus vespertinus</i> , catfish (warm)	* <i>Ameiurus vespertinus</i> , catfish (warm)
* <i>Mylopharodon hagermanensis</i> , hardhead (warm)	* <i>Mylopharodon</i> cf. <i>M. hagermanensis</i> , hardhead (warm)
* <i>Ptychocheilus arciferus</i> , pikeminnow (eurytherm.)	* <i>Ptychocheilus arciferus</i> , pikeminnow (eurytherm.)
<i>Lavinia hibardi</i> , hitch (warm)	<i>Lavinia stuwilliamsi</i> , hitch (warm)
<i>Acrocheilus latus</i> , chub (eurytherm.)	<i>Acrocheilus latus</i> , chub (eurytherm.)
<i>Mylocheilus</i> sp., molariform chub (warm)	* <i>Mylocheilus</i> cf. <i>M. whitei</i> , molariform chub (warm)
<i>Mylocheilus inflexus</i> , molariform chub (warm)	
* <i>Klamathella milleri</i>	<i>Gila domininus</i>
	* <i>Rhinichthys</i> cf. <i>R. osculus</i> (eurythermal)
* <i>Deltistes</i> sp. 1, lakesucker (warm)	
* <i>Deltistes</i> sp. 2, lakesucker (warm)	
* <i>Chasmistes batrachops</i> , lakesucker (late, warm)	* <i>Chasmistes batrachops</i> , lakesucker (warm)
<i>Catostomus</i> sp. (warm)	* <i>Catostomus</i> sp (warm)
* <i>Oncorhynchus lacustris</i> , Redband Trout (cool)	
* <i>Oncorhynchus salax</i> , ancestral sockeye (cool)	
<i>Oncorhynchus ketopsis</i> , ancestral chum (cool)	
<i>Oncorhynchus rastrellus</i> , small tusktooth (cool)	
* <i>Archoplites</i> cf. <i>taylori</i> , sunfish (warm)	* <i>Archoplites</i> sp., sunfish (warm)
* <i>Cottus calcatus</i> , sculpin (cool)	

* lineages also in Glenns Ferry Formation

The Chalk Hills and Glenns Ferry lakes in the WSRP are far to the west of Cache Valley and separated from it by the ESRP. Moreover, according to Beranek et al. (2006), along the Yellowstone hotspot track in the late Miocene the volcanic tumescence of the Twin Falls volcanic center formed the continental divide separating the Western and Eastern SRP. A continental divide at this place and time implies the existence of a barrier to the dispersal of lowland fish species between western Idaho and northern Utah. As we explain below, recent investigations of the timing and extent of outflow ignimbrites from volcanic

centers along the ESRP provide ample evidence that lowland drainage systems streamed across the province during the late Miocene and Pliocene.

The locus of rhyolitic volcanism along the ESRP migrated northeastward since 10 Ma at a roughly uniform 3 cm/yr until 2 Ma, when it arrived at Yellowstone (Pierce and Morgan, 1992). Migrating with it, as inferred for a mantle hotspot, a regional thermal uplift, which the Yellowstone Plateau today apparently manifests. At the plateau's western edge in easternmost Idaho, the Heise volcanic field (active from 6.6-3.8 Ma) shows that a thermal uplift, if present there,

must have collapsed within only a few million years after hotspot passage, leaving a lowland of clustered rhyolitic calderas at the eastern end of the SRP. If the Heise field is representative of older volcanic centers to the SW along the SRP, including the Twin Falls volcanic field, then the thermal tumescence at those volcanic centers also was short-lived and their collapse after hotspot passage incrementally extended the low plain of the Snake River northeastward over the past 10 Ma.

A half-century after it was first proposed (Morgan, 1972), the existence of a deep-mantle plume beneath Yellowstone is still not a settled fact, and a time-progressive thermal uplift along its track in the ESRP remains controversial (Christiansen et al., 2002). Foulger et al. (2015) reviewed evidence from seismic tomography experiments across the western U.S. and concluded there is no throughgoing plume of low-velocity mantle below Yellowstone, as would be predicted by the Hotspot model. Across the studies reviewed, they observe that no coherent low-velocity anomaly is repeatably imaged that extends continuously from the surface down into the lower mantle or deflects subcrustal transition-zone discontinuities. Instead, they find a robust result that ultra-low seismic velocities underlie the ESRP-Yellowstone track along its entire length and only in the upper 200 km (2015:226-227). Neither do those authors find evidence for time-progressive regional uplifts along the sequence of rhyolitic calderas, as would be expected from passage over an upwelling mantle plume. Instead they and others (e.g., Knott et al., 2020) note that down-warping, not uplift, preceded caldera-filling eruptions.

Topographic relief along the ESRP in the late Miocene was sufficiently low that thin ignimbrite sheets (individual eruption units a few tens of meters thick) flowed from their source for up to 100 km over the contemporary landscape. For example, in the Cassia Hills south of Twin Falls a single eruption unit 60 m thick (10.6 Ma) flowed ~80 km along the southern central SRP (Knott et al., 2016:1127-1128). At the Picabo volcanic field,

rhyolites dated at 8.4 to 8.0 Ma are overlain by rhyolites of 6.12 and 6.38 Ma, which are in the age range of the Blacktail Tuff of the Heise volcanic field approximately 100 km to the NE and are not likely derived from Picabo magmatism based on isotopic and chemical typing (Drew et al., 2013:64). The ignimbrite of the Arbon Valley Tuff (ca. 10 Ma) also was widespread, extending from its source in the Picabo complex to the area of the later Heise volcanic field across a distance of at least 100 km. Most recently, Knott et al. (2020) extend and refine prior correlations of eruptive units to show that a single, unusually hot pyroclastic density current (the Grey's Landing ignimbrite at ca. 8.72 Ma) flowed unimpeded from its source near Twin Falls, crossing the entire width of the ESRP and into bordering valleys (e.g., the Rogerson graben), to cover >23,000 km² of southern Idaho and northern Nevada.

The distant spread of outflow rhyolites between adjacent eruption centers and across the ESRP implies low paleorelief on all sides of the migrating magma source. Moreover, in contrast to the present-day elevated Yellowstone Plateau, ignimbrites from the Twin Falls center were erupted into a regional northeast-trending "Snake River basin" that was actively subsiding at the time, as defined by basinward thickening and distal thinning of the flow units (Knott et al., 2016). Petrology of those ignimbrites further suggests the former presence of groundwater or surface water in the SRP, including sublacustrine and phreatomagmatic eruptions, at the time some units were emplaced (e.g., Knott et al., 2016:1131).

If fluid ignimbrite sheets traveled such distances, then surface water no doubt did likewise, in drainages across the cratered lowlands, around the flanks of migrating thermal uplifts (if any), and between intermittent lakes that likely occupied calderas and maars along the ESRP. Such streams and lakes provided lowland passage across southern Idaho for fish species found today in disjunct late Miocene and Pliocene lakebeds of northern Utah and the western Idaho.

Southern divide of the ESRP. The ENE-trending

divide along the southern edge of the subsiding Snake River basin presented a theoretical obstacle to lowland fish dispersal between the two regions during the late Tertiary. However, E-W extensional tectonics in the adjacent Basin and Range Province migrated northeastward at pace with the hotspot (Rodgers et al., 2002; Anders et al., 2009; Camillari et al., 2017, fig. 15) and can be called upon to bridge that biogeographic barrier. Graben, half-graben, detachment breakaways, and supradetachment-basin breakup events appear in the geologic record along the southern edge of the SRP, beginning about 16 Ma (middle Miocene) at the western end of the ESRP (athwart the Nevada-Idaho border) and culminating in the middle Pliocene at the longitude of the Heise volcanic field and Cache Valley to its south. The regional extension in the Basin and Range Province produced N-S faults and fault-bounded local basins that merged with the ESRP and created opportunities for differential fault-block subsidence, changes in local base levels, lake spillover events, and lowland drainage capture across the ENE-trending divide.

For example, in northeastern Nevada and southernmost Idaho, west of Salmon Falls Creek, Miocene faults define the ~30-km-long north-trending Rogerson graben (Camillari et al., 2017:1927). The graben formed during a time (ca. 10 and 8 Ma) of peak rhyolitic volcanism in the vicinity of the Twin Falls volcanic field and coincident subsidence of the Snake River basin. East of Rogerson graben by ~50 km, ignimbrite sheets (10.6 and 10.3 Ma) sourced in the SRP flowed southward into the depositional basins of Trapper Creek, Idaho, and Goose Creek, Nevada, maintaining a thickness of at least 10 m (Knott et al., 2016). About 50 km east of the Trapper Creek-Goose Creek basins in northern Utah and southernmost Idaho, detachment faults above the rising Albion-Raft River-Grouse Creek metamorphic core complex were active between 13.5 and 10.5 Ma. Motion on the N-S Albion fault created topographic depressions filled by the Salt Lake Formation, including ash-fall tuffs and rhyolite flows, and subsequent N-S faults

controlled late Miocene sedimentary basins there (Konstantinou et al. 2012). All of those local basins intersected the SRP.

Progressing northeastward, numerous N-S basin-range faults with Pliocene to Quaternary activity (e.g., Rockland, Arbon, and Portneuf Valleys; Blackfoot Mountains and Jackson Hole) likewise intersected the SRP, and their intervening fluviolacustrine basins record streams and lakes that likely communicated intermittently with late Tertiary drainages along the ESRP. Principal among them at the longitude of the Heise volcanic field are the Bannock detachment breakaway exposed along the east side of Cache Valley and N-S faults within the Bannock supradetachment basin, which the Salt Lake Formation filled commencing around 10 Ma (Janecke et al., 2003; Long et al., 2006). Carney and Janecke (2005) recognized a strong spatial association between the Salt Lake Formation and highly extended areas above regional detachment faults. As characterized by Steely et al. (2005:177), in the present Cache Valley area, the fluviolacustrine Salt Lake Formation filled a synextensional basin above the regional Bannock detachment fault to a thickness of several kilometers.

In the northern portion of Cache Valley, the lacustrine Cache Valley Member was deposited on top of the pre-detachment basal conglomerate (the Skyline Member) within the Salt Lake Formation. Tephra correlations within the Skyline Member dated at approximately 10-12 Ma indicate that E-W extension above the Bannock detachment commenced sometime thereafter in the late middle Miocene. Initial extension was a “translational phase” involving westward motion of the hanging wall (upper plate), which accommodated the regional lake system in which the Cache Valley Member accumulated (Steely et al., 2005:181). Later extension, a “breakup phase” beginning in the middle Pliocene, dismembered the hanging-wall basin and produced N-S Basin and Range-style faulting in the region.

The Bear River, which flows through Cutler Narrows in the Junction Hills today, joined the

TABLE 4 -- Species' elevation ranges indicate likely and possible elevation of dispersal pathways

Lineage	METERS ABOVE SEA LEVEL			ELEVATION (KM) OCCUPIED BY MODERN REPRESENTATIVES						N collections
	Minimum	Maximum	Drainage or Region	0--1.5	1.5--2	2--2.5	2.5--3	3--3.5	3.5--4	
<i>Ameiurus</i>	1	1524	Pacific NW	X						27
<i>Ptychocheilus</i>	1	2134	Western U.S.	X						90
<i>Acrocheilus</i>	30	1524	Pacific NW	X	x					55
<i>Klamathella</i>	823	1524	Pacific NW	X						22
<i>Lavinia</i>	1	427	Sacramento	X						30
<i>Mylopharodon</i>	24	1543	Sacramento	X	x					39
<i>Gila domininus</i>	1156	2591	Upper Snake		X	x	x			21
<i>Rhinichthys</i>	3	2590	Western U.S.	x	X	x	x			696
<i>Chasmistes</i>	1713	2195	Jackson Lake		x	X				7
<i>Catostomus</i>	1	2134	Columbia-Lower Snake	X	x					89
<i>Catostomus</i>	1280	2286	Bonneville; Upper Snake	x	x		X			52
<i>Archoplites</i>	1	405	Sacramento R	X						100
Two modern genera absent from the Cache Valley Lake fauna, but now in the region										
<i>Oncorhynchus</i>	1	3359	Western U.S.	x	x	X	x	x	x	187
<i>Cottus</i>	30	3054	Western U.S.	x	X	x	x	x	x	169
Relevant elevations										
Junction Hills	1800				X					
Grouse Creek at Oakley	1393			X						
Yellowstone Lake	2357					X				
Continental Divide	2518		Craig Pass				X			
Camp Davis Formation	2700						X			
N lots = N collections of a species population						Bold X indicates elevation of maximum abundance				

Snake River to the north in Plio-Pleistocene time and followed the present-day Portneuf or Blackfoot drainages at least into the middle Pleistocene. The Bear River was not diverted southward into Cache Valley and the Bonneville Basin until an episode of volcanism in the Blackfoot-Gem Valley volcanic field ~100–50 ka (Pederson et al., 2016).

Hence, there can be little doubt that, progressing west to east from the middle Miocene through early Pliocene, fault-controlled drainages in the pre-Bonneville basin intermittently penetrated the Snake River basin across the intervening ENE-trending divide at the southern margin of the ESRP. Those connections would have afforded dispersal pathways through which lowland fish species in the paleofaunas of western Idaho and northern Utah could have interchanged along the ESRP and do so earlier in the west than in the east.

Fish dispersal pathways through time. A late Miocene (7.9–6.3 Ma) connection between the Chalk Hills Lake downstream of Cache Valley through the Oakley Valley and Trapper Creek area

would provide access between the Chalk Hills and Cache Valley lakes, but not if the continental divide were at Twin Falls. The connections used by mollusks and some fish possibly occurred between 6 Ma and 4.5 Ma through lakes in craters left by Twin Falls, Picabo, and Heise volcanic eruptions in the Snake River Plain (Ellis et al., 2013; Knott et al., 2016, 2020).

Several million years later, Pliocene connections to the Bear River, including Bear Lake (Broughton and Smith, 2016) and the Snake River, would have allowed dispersal of mollusks and the fishes, *Gila domininus* and two species of catostomids, along the upper Snake River, perhaps Bear River, and Cache Valley. This hypothesis suggests that through these connections the Cache Valley mollusks (at ca. 4.5 Ma) were possibly the source of some species among the fauna of Pliocene Glenns Ferry mollusks (Malde and Powers, 1962) and some fishes (Table 2). Earlier, Chalk Hills and Trapper Creek fishes were probably a source (10–6 Ma) of Miocene cyprinid minnows in the Cache

Valley fauna.

The presence of six species of lowland, warmwater minnows and catfish, and absence of upland, coolwater trout, whitefish, and sculpins in the areas connecting the Chalk Hills Formation and Cache Valley is consistent with the discoveries by Knott et al. (2016, 2020) and Ellis (2013:745) of evidence for phreatic-Plinian explosive volcanoes in the Central Snake River Plain. These volcanoes left voluminous tuffs in the craters, in the subsiding centers, and up against the elevated margins of the plain. There were long periods (0.5–1 m.y.) of low elevations including lakes (and we infer fishes) between the higher plain margins, as opposed to a Yellowstone-like continental divide as proposed by Pierce and Morgan (1992) and Beranek et al. (2006).

The late Miocene Cache Valley Lake is represented by 40–60 m of beds in the Plymouth oolite subunit of the Junction Hills. Analysis of lake-sediment geography, geometry, and diversity of mollusks, ostracods, and fishes suggested a pre-Bonneville lake as large or larger than the Great Salt Lake and perhaps as large as the 47,000 km² (18,000 mi²) Lake Bonneville (McClellan, 1977). It lasted at least 6 m.y. before the advent of Lake Bonneville, and should have developed a fauna of at least 20 species of fishes in Utah and Idaho during that long time. Based on the presence of ooids and warmwater fishes and mollusks, mean water temperatures in this lakeshore habitat were fairly high in summer (~20° C; McClellan, 1977). The presence of warmwater catfish and sunfish in the fauna, as well as elevation and high relief and nearby sources of cold mountain streams suggest that the lake was sometimes dimictic. Articulated preservation of *Lavinia* and laminated marl at the Paradise locality suggests anoxic bottom waters with no scavengers, and hypoxic conditions are likewise suggested by associated fish skeletal elements in the lower level of the Junction Hills sediments. Thin kerogen layers present in the Cache Valley Member likewise support the interpretation of at least episodic hypoxia (Goessel, 1999; Oaks, 2000). Sedimentary evidence for lake-

level fluctuation is strong. The freshwater fishes and mollusks suggest salinities of less than 0.35%; comparison with salinities in Pyramid Lake support this estimate (Swirydczuk et al., 1980b). These data and inferred low salinity also suggest that, like coeval lakes in western Idaho, the Cache Valley lake was kept fresh by exterior drainage (D. W. Taylor in Malde and Powers, 1962), probably into the Snake River basin. Modal alkalinity for the mollusk species suggests moderately high alkalinity—between 60 and 180 ppm (McClellan, 1977).

Inquiry into this region's Cenozoic history is intensely interdisciplinary. Geophysical models of crustal evolution in the SRP and northeastern Basin and Range Province are diverse; while some models explain subregional geological relationships, all suffer shortcomings when applied across the region and tested independently by geochemistry, geochronometry, geophysics, detrital mineralogy, paleohydrography, or other disciplines. The biogeography of aquatic fossils provides an important test of those physical models—fish species in particular, as they cannot extend their geographic ranges except through drainage capture. A future investigation that might add clarity is integrating the distribution of fossil fishes and mollusks in time and space with the history of large-magnitude crustal extension across these provinces. E-W extension in southeastern Idaho since the middle Miocene, for example, may have exceeded 20% on detachment and later basin-range faults (e.g., Long et al., 2006), and farther south in the central Great Basin ranged as high as 46% (Long, 2018). Palinspastic restoration of this subregion and its fossil localities may better illuminate drainage correlations and more accurately test physical models of tectonic evolution.

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