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REPUBLIC CENTENNIAL ISSUE

Featuring articles about the geology of the Republic area, the Republic Mining District, and Eocene fossil deposits

WASHINGTON STATE DEPARTMENT OF
Natural Resources
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Cover Photos: The top photo shows a horse race up Clark Avenue, the main street of Republic; the race was part of the Fourth of July festivities in 1908, a dozen years after the founding of the town whose centennial we celebrate in this issue. The lower photo is taken from slightly higher up the hill and shows Clark Avenue in 1996.

The 1908 photo and all other photos of historic Republic used in the articles herein were kindly provided by the Ferry County Historical Society. 1996 photo by Lisa Barksdale.

IN CELEBRATION OF THE REPUBLIC CENTENNIAL

Raymond Lasmanis
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On April 18, 1896, a group of 64 men gathered where the Okanogan mail trail crossed Eureka Creek to organize the Eureka mining district. The gold rush town of Eureka sprang up overnight and was soon renamed 'Republic', after the Republic Gold Mining & Milling Company. In 1899, Ferry County was established out of the western portion of Stevens County. Republic became the county seat.

The mines of the area have long been the economic focus of the town. The gold has come from ores deposited in Eocene hot-springs systems, and production from two large operations from the last six years alone has exceeded 813,000 oz of gold. The rich history of the mining activities is documented in the geologic literature as well as by local historical associations. (See, for example, Western Historical Publishing Company, 1904.)

More recently, the world-class Eocene fossil deposits have attracted the interest of the scientific community. The deposits contain the best North American record of upland warm temperate to subtropical habitats. The geologic forces associated with the development of the ores played a major role in the diversification and later distribution of the flora.

From the paleontological interest has come a unique cooperative venture, the Stonerose Interpretive Center, which encourages the public to visit the deposit and collect and learn, with the paleontologists, about this remarkable flora and fauna.

In celebration of Republic's centennial, this issue of *Washington Geology* brings together renowned earth scientists to discuss the aspects of the geologic history of the area that have had such a major impact on the development of geologic knowledge worldwide. We are indebted to Wesley Wehr, Thomas Burke Memorial Washington State Museum, for proposing this project and interesting so many geologists, paleobotanists, and other specialists in contributing their expertise to this broad overview.

Reference

Western Historical Publishing Company, 1904, An illustrated history of Stevens, Ferry, Okanogan, and Chelan Counties, State of Washington: Western Historical Publishing Company, Spokane, p. 403-447. ■

Stonerose Interpretive Center Sponsors Field Seminar

Wes Wehr will be leading another of his weekend field seminars Sept. 13–15 at the Stonerose Interpretive Center in Republic. The cost is $75. For more information or to sign up for the seminar, contact Wes at the Burke Museum, University of Washington, Seattle, WA 98195; *phone:* (206) 543-0495 or *fax:* (206) 685-3039.

Regional Geology of the Republic Area

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Introduction

This article describes the regional geology of the Republic area and considers more than the Eocene stratigraphic units that have made Republic famous both as a gold producer and a paleontological treasure. However, for those who are primarily interested in these topics, the main points are that (1) the Eocene formations are portions of regional, not local, unconformity-bounded sequences within the larger Challis sequence, and (2) rather than having been deposited in a local fault-bounded basin or graben, the formations are preserved in the upper plates of one or more low-angle normal faults as a regional synform between two antiformal metamorphic complexes. These and other concepts are discussed more fully in Cheney and others (1994) and Cheney (1994). However, the information in those articles is not explicitly referenced here.

Figure 1 shows the regional geology of northeastern Washington. East of the Huckleberry Ridge, Columbia, and Waneta thrust faults, pre-Challis rocks are the Proterozoic to Paleozoic stratigraphic units native to North America. West of these faults, especially in the Republic area, the pre-Challis rocks are predominantly those of Quesnellia, a terrane that accreted to North America in the mid-Jurassic (about 175 million years ago). Eocene sedimentary and volcanic rocks of the Challis unconformity-bounded sequence (55 to 36 million years old) overlie the pre-Challis rocks. The metamorphic core complexes (MCCs) are Eocene antiformal uplifts of crystalline basement separated from the pre-Challis and Challis rocks by low-angle normal (detachment) faults. The MCCs underlie most of the major mountain ranges in the area of Figure 1. The Walpapi sequence (18 to 2 million years old), unconformably overlies all other rocks. The most voluminous lithostratigraphic unit of the Walpapi sequence is the Columbia River Basalt Group.

The dominant rocks in the Republic area (Fig. 2) are greenschist-facies Quesnellian rocks, four unconformity-bounded formations of the Challis sequence, and the amphibolite-facies metamorphic rocks and granitic plutons of the MCCs.

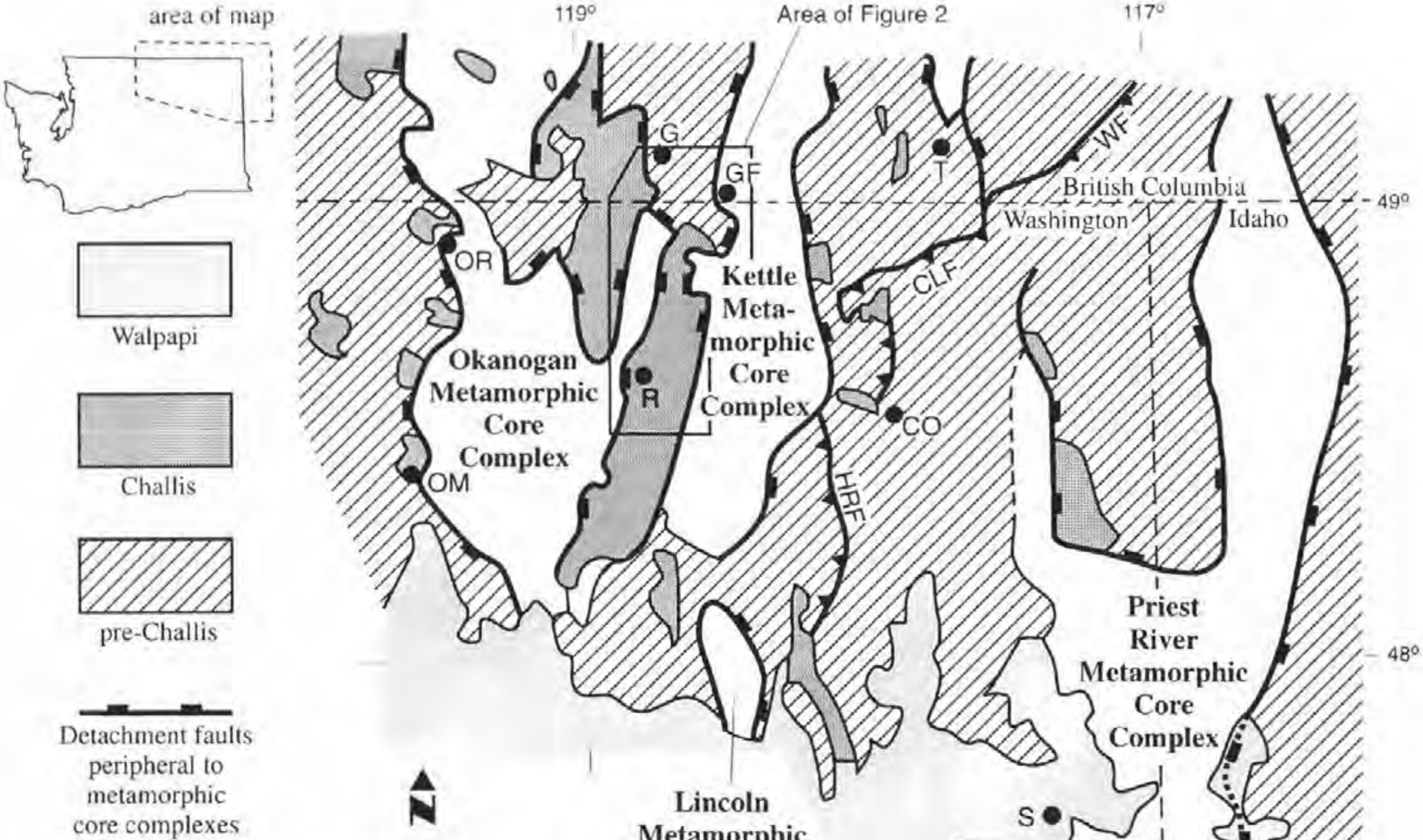


Figure 1. Tectonic map of northeastern Washington and adjacent areas. (See text and Table 1 for explanation.)

Table 1. Explanation for geologic and geographic features of Figures 1 and 2

MAP UNITS

Challis sequences

- Tk — Klondike Mountain Formation volcaniclastics and felsic flows
- Ts — Sanpoil Volcanics rhyodacitic flows
- Tm — Marron Formation alkalic flows
- To — O'Brien Creek Formation arkosic and tuffaceous rocks

Quesnellia

- Mi — Granitic to alkalic plutons
- PMu — Quesnellian rocks, undivided
- Jr — Jurassic Rossland Group argillite, mafic and felsic volcanic rocks
- Ћb — Triassic Brooklyn Formation argillite, chert, conglomerate, limestone
- Pa — Carboniferous to Permian Attwood Group pelitic phyllite, argillite, felsic volcanic rocks, limestone
- Pk — Carboniferous to Permian Knob Hill Group greenstone, mafic volcanic rocks, chert
- um — Ultramafic rocks

Metamorphic Core Complexes

- Eh — Eocene Herron Creek quartz monzonite
- Ei — Eocene felsic plutons
- pTm — Amphibolite facies Cretaceous orthogneiss and Proterozoic and Paleozoic paragneiss

FAULT TYPES

- High-angle fault—dashed where approximate
- Detachment fault—blocks on upper plate
- Thrust fault—sawteeth on upper plate

FOLD TYPES

- Upright antiform
- Overturned antiform
- Upright syncline

NAME ABBREVIATIONS

Towns (●○)

CO, Colville	C, Curlew
G, Greenwood	GF, Grand Forks
M, Midway	OM, Omak
OR, Oroville	R, Republic
S, Spokane	T, Trail

Mines (■□)

KH, Knob Hill	L, Lamefoot
OL, Overlook	P, Phoenix

Faults

BCF	Bacon Creek fault
BMF	Bodie Mountain fault
CLF	Columbia fault
CF	Chesaw fault
EMF	Eagle Mountain fault
GDF	Gold Drop fault
GRF	Granby River fault
GWF	Greenwood fault
HRF	Huckleberry Ridge fault
LCF	Lind Creek fault
LMF	Lambert Creek fault
MAF	Mount Attwood fault
MWF	Mount Wright fault
No. 7F	No. 7 fault
SF	Sherman fault
SPF	Saint Peter fault
SKF	Scatter Creek fault
SNF	Snowshoe fault
TMF	Thimble Mountains fault
WF	Waneta fault
WMF	White Mountain fault

Quesnellia

The best description of the Quesnellian rocks is given in Fyles (1990). The formation names that Fyles and his Canadian predecessors defined are now used in the U.S. Quesnellia includes a Carboniferous to Permian ophiolitic suite of ultramafic and mafic igneous rocks, mafic volcanic rocks, and chert (the Knob Hill Group) and a seemingly coeval succession of dark argillites with minor felsic volcanic to volcaniclastic rocks, and limestone (the Attwood Group). Both of these suites are unconformably overlain by the Triassic Brooklyn Formation (chert meta-conglomerate, clastic limestone, and argillite). A younger unconformable succession of oceanic volcanic to volcaniclastic rocks and sedimentary rocks may be part of the Brooklyn Group (Fyles, 1990), part of the Jurassic Rossland Group (Cheney and others, 1994) as shown in Figure 2, or both.

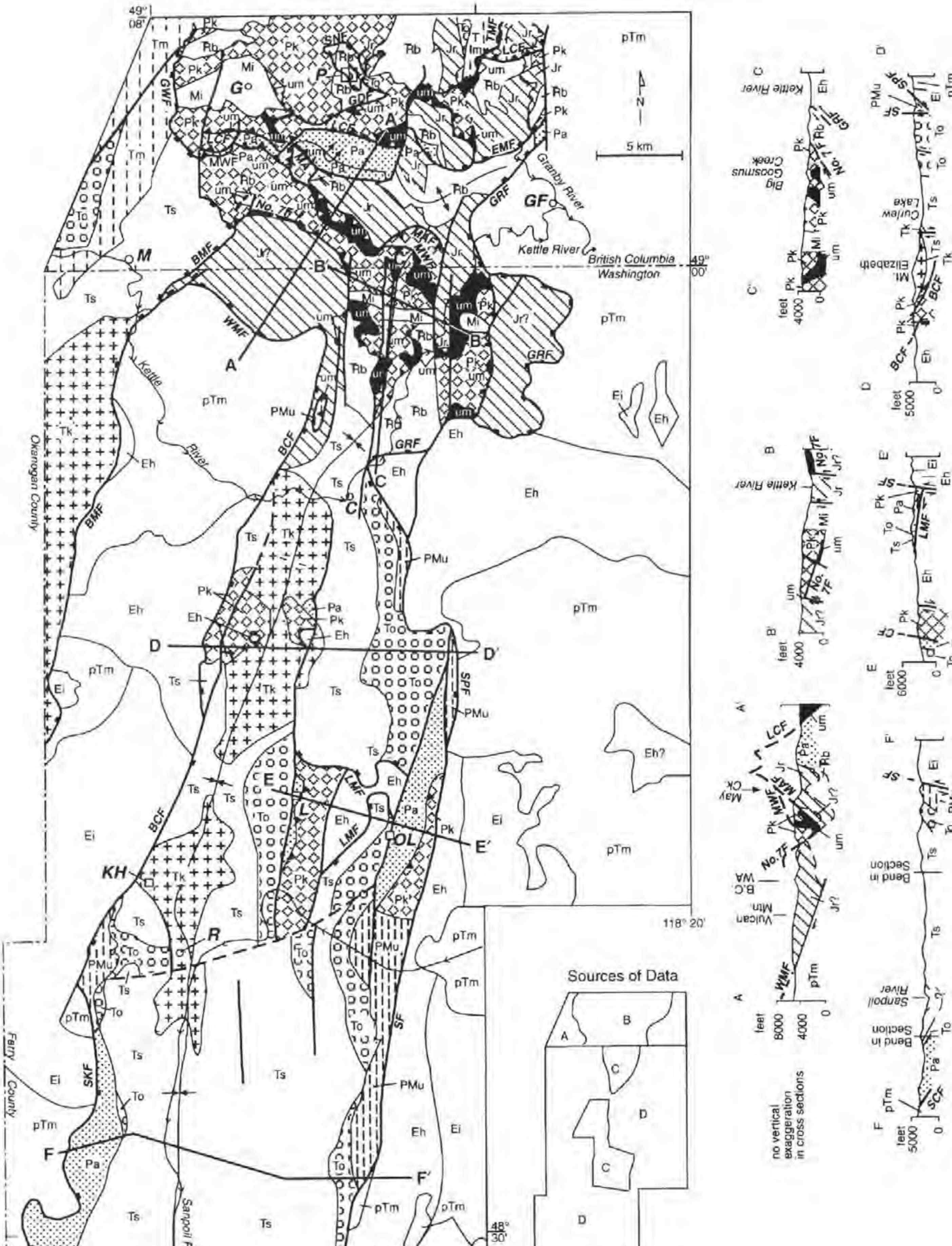
Although few large-scale, recumbent folds have been mapped in the area of Figure 2, the Quesnellian rocks are significantly folded or rotated. For example, the Attwood Group at the Overlook gold mine northeast of Republic is subhorizontal but overturned (Rasmussen, 1993), and the Brooklyn Formation north of Curlew dips 30° northwestward but is overturned.

The regional, mid-Jurassic Chesaw thrust fault placed the ophiolitic Knob Hill Group over the Attwood Group. The trace of the thrust and its splays are marked by discontinuous bodies of serpentinite (hydrated ultramafic rock), listwanite (carbonated ultramafic rock), metagabbro, and amphibolite-facies rocks. Portions of the thrust are extensive along the international border (Fig. 2), but have not yet been mapped in many areas south of Curlew. Thus, some Quesnellian rocks are shown as a single unit, PMu, in Figure 2.

Although Fyles (1990) believed that the thrusts north of the international border are individual faults, Cheney and others (1994) suggested that upright folds repeat splays of a single fault (cross section C–C′, Fig. 2), the Chesaw thrust. Our mapping of a klippe north of Curlew (Fig. 2) implies that at least some of the thrusts are folded.

Two important mining districts occur in Quesnellian rocks. The Greenwood district in southern British Columbia is mostly between Greenwood, the Phoenix mine, and the international border, but mineralization extends a few kilometers south of the border. The deposits are primarily (but not exclusively) skarns (Church, 1986); mining in the district has been largely inactive since the 1970s. The Belcher district about 10 km northeast of Republic has a number of gold deposits associated with a magnetite/sulfide horizon in the Attwood

Figure 2. *(right)* Geology of the Republic area. Sources of data are **A**, Monger (1968); **B**, the modification of Fyles (1990) shown in Cheney and others (1994); **C**, our mapping since 1993; and **D**, Parker and Calkins (1960), Muessig (1967), and Stoffel and others (1991).


49°
08'
49°
00'
British Columbia
Washington
5 km
N
Kettle River
Granby River
Okanogan County
Ferry County
Sanpoil River
118° 20'
118° 30'
118°50'
48°
30'
Sources of Data
A
B
C
D
no vertical exaggeration in cross sections

Group; major deposits that have been mined since 1990 are at the Overlook and Lamefoot mines (Rasmussen, 1993).

Challis Sequence

The Eocene formations of the Republic area are smaller unconformity-bounded sequences within the Challis sequence. The oldest unit of predominantly tuffaceous and feldspathic sandstone and siltstone is called the O'Brien Creek Formation south of the international border and the Kettle River Formation north of it. The Marron Formation of alkalic volcanic rocks lies unconformably upon the Kettle River Formation and barely extends south of the border. The Sanpoil Volcanics (biotitic rhyodacite and seemingly minor volcaniclastic rocks) are the most extensive Challis rocks within 15 km of Republic. However, the paucity of bedding within the Sanpoil makes its stratigraphy and structure difficult to assess.

The youngest Challis unconformity-bounded unit is the Klondike Mountain Formation (mostly volcaniclastic rocks and felsic flows). The three members of the formation defined by Muessig (1967) near Republic also are bounded by unconformities, but all are shown as a single unit in Figure 2. The fossiliferous basal Tom Thumb Tuff Member is the topic of other papers in this issue, especially Gaylord and others.

In the area of Figure 2, the maximum preserved thickness of each of the four formations is at least a kilometer. Because the three unconformity-bounded sequences at Republic extend well beyond the Sanpoil/Curlew valley (Fig. 3), they were not deposited in a local basin or graben now occupied by the valley. Paleontological correlation of the various successions of Figure 3 would be most welcome and may emerge from the studies described in this issue. These unconformity-bounded formations also are poorly dated radiometrically.

Metamorphic Core Complexes

In the area of Figure 2, Proterozoic and possibly Paleozoic amphibolite-facies metasedimentary gneisses and three suites of Paleocene to Eocene granitic plutons are restricted to the MCCs. Only the youngest of the three suites (the Herron Creek suite of Holder and Holder, 1988) is shown separately in Figure 2. MCCs are bounded by low-angle normal (detachment) faults marked by 10 m to 100 m of chloritic breccia in the crystalline rocks. Herron Creek rocks are capped by detachment faults in the middle of the Sanpoil/Curlew valley (cross sections D–D′ and E–E′ of Fig. 2). Because the chloritic breccia is so thin, it rarely crops out. Mylonites are rare or weak below the chloritic breccias, but in the MCCs beyond Figure 2, the chloritic breccias are underlain by as much as 4 km of mylonitic gneiss.

Considerable rotation may have occurred along some detachment faults, either because the faults are listric (decrease in dip downward) and (or) because of extension over ductile Eocene granitic plutons in a manner similar to that described by Brun and others (1994). Possible evidence for such rotation is that near the Lamefoot and Overlook gold mines the O'Brien Creek Formation is nearly vertical.

The unconformity that truncates the top of the Tom Thumb Tuff Member of the Klondike Mountain Formation may mark the rise of the MCCs. The gold- and silver-selenide mineralization at Republic is in veins adjacent to the Bacon Creek detachment fault and is in Sanpoil and Tom Thumb rocks below this unconformity. Furthermore, large bodies of brecciated Herron Creek quartz monzonite in the middle member of the Klondike Mountain Formation west of the Bodie Mountain detachment fault are rock-avalanche deposits (Malte, 1995). Similar deposits occur along State Route 20 four miles west of the Okanogan/Ferry County border. Rock-avalanche deposits in southeastern California mark the uplift of MCCs in that area (Topping, 1993).

The metamorphic core complexes, or the detachment faults that bound parts of them, may have distinctly different ages. The unconformity at the top of the Tom Thumb Tuff Member may be contemporaneous with the Scatter Creek/Bacon Creek/White Mountain detachment fault, but the Bodie Mountain fault cuts the younger members of the Klondike Mountain Formation and the White Mountain fault. Furthermore, the rock-avalanche deposits in the Klondike Mountain Formation may not be related to the Bodie Mountain fault that cuts the formation: plots of SiO_2 vs. K_2O and of Cr, Ba, and Th against TiO_2 from Malte's data (1995) show that the rock avalanche deposits are less like the Herron Creek Empire Lakes pluton between the Bodie Mountain and Bacon Creek faults than the Herron Creek Long Alec Creek batholith east of Curlew and the Granby River fault in the Kettle MCC. If the rock avalanche deposits are derived from the Long Alec Creek batholith of the Kettle MCC, the intervening structural high (northeast arm of the Okanogan MCC) caused by the Bodie Mountain fault could not have formed yet.

Post-Quesnellian Structure

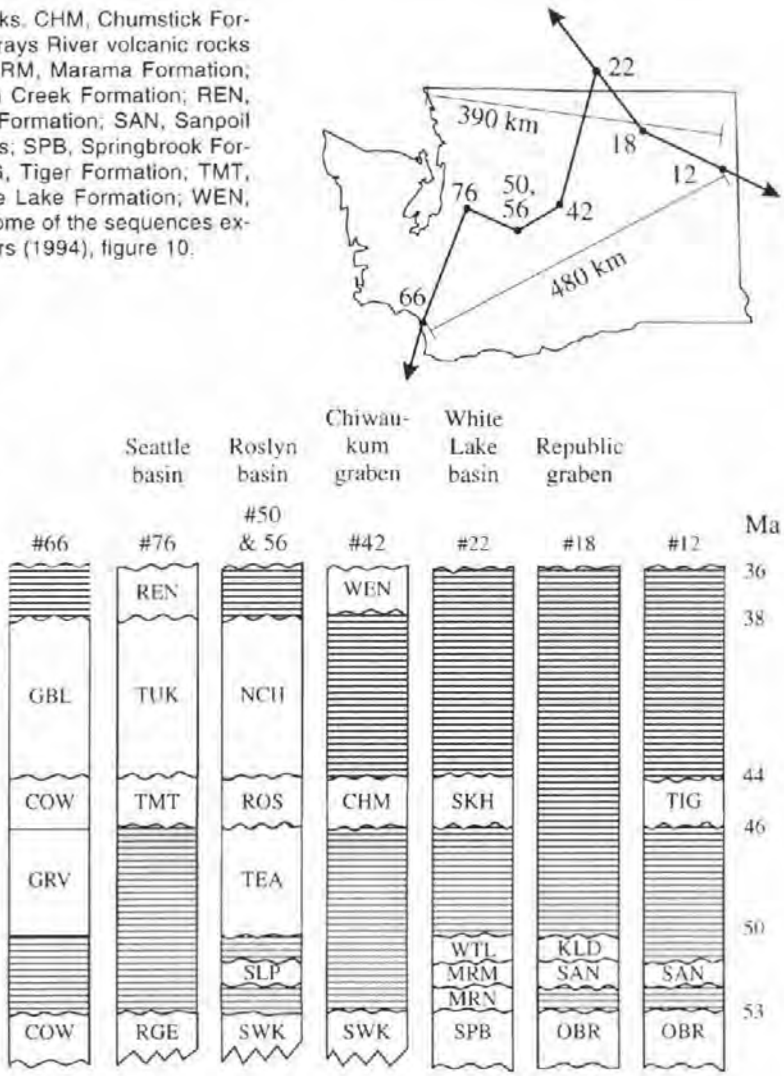
The Quesnellian and Challis rocks in Figure 1, and especially in the Sanpoil/Curlew valley (the so-called Republic 'graben'), are mostly bounded by detachment faults. Younger high-angle NNE-trending faults, the largest of which is the Sherman fault, appear to cut some of the detachment faults, but the 'graben' is primarily the upper plate of one or more detachment faults.

Low-angle faults do occur in the upper plates of the detachment faults. Fyles (1990) mapped several in the Quesnellian and Challis rocks north of the international border (Fig. 2). Similar features have been mapped in small open-pit mines in the Belcher Mining District. The paucity of low-angle faults south of the international border may be due to less detailed mapping (fostered largely by the inability to recognize mappable units in the Sanpoil Volcanics). Alternatively, if the faults are listric, the higher structural level south of the international border (abundant Challis instead of abundant Quesnellian rocks) would result in fewer low-angle faults.

Much of the geology is obscured by abundant Scatter Creek rhyodacite. This rhyodacite is a shallow intrusive suite similar in composition to the Sanpoil Volcanics and the Tom Thumb Tuff Member (Muessig, 1967; Tschauder, 1989). Not only is the Scatter Creek unit difficult to distinguish texturally from the Sanpoil Volcanics, it is also more resistant than the intruded rocks so that the intruded rocks are under-represented in outcrops. North of Curlew, bodies of Scatter Creek rocks are fine-grained quartz monzonite (Parker and Calkins, 1964) and are particularly abundant along the trace of the No. 7 fault (Chesaw thrust). Thus, here the Scatter Creek may be a tabular body or swarm of tabular bodies. North of Curlew, the Scatter Creek is intricately jointed and locally even brecciated along the No. 7 fault and along the NNE high-angle faults that cut the thrust. Descriptions by Muessig (1967) suggest that the Scatter Creek also is well-jointed along other faults. Perhaps, this minor rejuvenation of faults happened during the waning stages of uplift of the MCCs.

The maps of Parker and Calkins (1964) and of Muessig (1967) show that the Scatter Creek also preferentially intrudes Quesnellian rocks and the O'Brien Creek Formation in the

Figure 3. Inter-regional sequence stratigraphy of the Eocene rocks. CHM, Chumstick Formation; COW, Cowlitz Formation; GBL, Goble Volcanics; GRV, Grays River volcanic rocks of the Cowlitz Formation; KLD, Klondike Mountain Formation; MRM, Marama Formation; MRN, Marron Formation; NCH, Naches Formation; OBR, O'Brien Creek Formation; REN, Renton Formation; RGE, Raging River Formation; ROS, Roslyn Formation; SAN, Sanpoil Volcanics; SKH, Skaha Formation; SLP, Silver Pass volcanic rocks; SPB, Springbrook Formation; SWK, Swauk Formation; TEA, Teanaway Formation; TIG, Tiger Formation; TMT, Tiger Mountain Formation; TUK, Tukwila Formation; WTL, White Lake Formation; WEN, Wenatchee Formation (lower member). The arrows indicate that some of the sequences extend beyond Washington. Sources of data are in Cheney and others (1994), figure 10.



hanging walls of the detachment faults that bound the MCCs. Although the intruded rocks appear scarce in these areas (see the maps of Parker and Calkins, 1964, and Muessig, 1967), their consistent strikes and dips imply that their structural pattern is not disrupted and that the Scatter Creek is therefore discontinuous.

Because the Scatter Creek obscures the map pattern, it is omitted from Figure 2 and the intruded rocks are shown in its place. The widespread Quaternary deposits are also omitted from Figure 2. These omissions enhance the pattern of the Sanpoil syncline in the Sanpoil/Curlew valley, shown by Parker and Calkins (1964) and Muessig (1967). The syncline is outlined by the three Challis sequences and by considering all of the Quesnellian rocks to be a fourth basal unit (Fig. 2). North of Curlew, the synformal structure is marked by the Knob Hill Group in the Curlew klippe of the No. 7 fault of the Chesaw thrust. Thus, much of the structural relief of the Republic 'graben' is synclinal.

Because the Sanpoil syncline has a length, northerly strike, and structural relief similar to those of the adjacent antiformal MCCs and is largely bounded by the same detachment faults, it is the synformal counterpart of the antiformal MCCs. Thus, the Challis regional sequences were not deposited in a local 'graben' but, rather, are structurally preserved in the upper plates of detachment faults.

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A Historical Perspective on Ore Formation Concepts, Republic Mining District, Ferry County, Washington

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The Early Days

The mining history of the Republic District is a tribute to its prospectors, miners, engineers, metallurgists, geologists, and financiers. By February 21, 1896, when the north half of the Colville Indian Reservation was opened to claim staking, most of the gold-bearing lodes were already known to local trappers, pack train drivers, and former employees of the Hudson Bay Company. Between February 20 and 29, thirty claims were staked, covering all the major gold-bearing quartz veins in and around Eureka Gulch (M. S. Warring, Ferry County Historical Society, written commun., 1996). On March 5 of that year, two prospectors, Philip Creaser and Thomas Ryan, who were grubstaked by L. H. Long, C. P. Robbins, and James Clark of Spokane, located the Republic and Jim Blaine claims. With financing provided by Patrick F. (Patsy) Clark, the district was rapidly developed.

A gold rush ensued, and thousands of claims were staked, encouraged by published accounts during 1897 in the *Seattle Post-Intelligencer* by L. K. Hodges, who wrote, "One of the greatest showings of free-milling ore has been made in Eureka Camp...." By 1898, three mills were operating to treat low-grade ores. The high-grade ore was shipped by wagon to smelters in Washington and British Columbia.

The Republic claim had some of the more extensive veins known at the time and became the site of the large Republic mill owned by the Republic Reduction Company (Landes and others, 1902). In 1899, the Republic mine and mill were sold to Canadian investors for the unheard-of sum of $3,500,000 (Walter and Fleury, 1985).

During 1898, the gold-rush town of Eureka was renamed 'Republic' after the claim, mill, or company. (The name 'Eureka' had been pre-empted by a post office in business at the time.) On February 18, 1899, Governor Rogers signed a bill creating Ferry County. A reflection of the population growth and business activity was the Republic post office, which in its opening year (1899) processed more registered letters than Los Angeles, Seattle, Spokane, or Portland.

In the summer of 1902, two railroads reached Republic to serve the mills and mines—the Kettle Valley Railroad and the Great Northern Railroad (Walter and Fleury, 1985).

In those early years, the discovery and development of the veins in the Republic District did not require any geological knowledge. The veins, resistant to weathering, stood out as bold outcrops that could be sampled for gold. If sufficient values were returned by assay, a mine was started at the surface and worked down-dip from adits and by shafts.

Metallurgy, however, was a problem because the very finely crystalline ore minerals and silica encapsulation of electrum (a mixture of gold and silver) made it difficult to extract metals by the technology of the day. In fact, all the early mills had failed by 1904 due to poor metal recoveries. However, the district continued to ship gold/silver crude ore to smelters in British Columbia and Washington. By 1919, there were no mills operating in the Republic District, and the town still did not have an adequate and cheap source of electricity (Patty, 1921).

Development and mining activity in Republic soon attracted the attention of the state's geological survey. In his annual report for 1901 (Landes, 1902), State Geologist Henry Landes described the development work and listed the widths of veins and their gold and silver assays or values; he included a section on general geology and a description of metallurgical tests. One whole chapter is devoted to the Republic Reduction Company plant.

The significance of the Republic District was demonstrated when the Washington Geological Survey published its first bulletin *Geology and Ore Deposits of Republic Mining District* (Umpleby, 1910). This report described in detail the history, development, wall rocks, vein configuration, and gold/silver ore at the various mines, but it included no discussion of ore controls and genesis. Without coming to any conclusions about ore deposition, Umpleby (1910) pointed out that there are some similarities between Republic ores and those of Tonopah and Goldfield, Nevada.

A New Way of Thinking

While the discovery and development of mines in the Republic District was taking place, on the east coast a budding young Swedish mining engineer and metallurgist joined the U.S. Geological Survey (USGS) and began studying mineral deposits in the western U.S. under the guidance of George F. Becker. In 1900, the USGS published Waldemar Lindgren's exhaustive report on the Silver City and De Lamar, Idaho, gold/silver deposits. In 1905, Lindgren was appointed to head the USGS section for precious and semiprecious metals (Graton, 1933).

It was Lindgren who developed an ore genesis model applicable to Republic ores and similar deposits such as Tonopah, Goldfield, and De Lamar. He called the deposits "epithermal" and noted that they have features in common with hot springs (Lindgren and Bancroft, 1914). Also of significance, Lindgren and Bancroft observed in 1914 that between the Tom Thumb mine and Knob Hill mine "the quartz spreads widely through the lake beds and forms no well-defined lodes."

From 1908 to 1912, Lindgren presented a series of lectures about ore deposits at Massachusetts Institute of Technology. His notes led to the classic text book *Mineral Deposits*. In the revised fourth edition (Lindgren, 1933), there was an extensive description of gold/silver-bearing hot spring systems and their relation to epithermal deposits, including those at Republic, De Lamar, and other locations. Lindgren also noted the significance of active hot springs at Rotorua, New Zealand, where sinter is enriched in gold, silver, and mercury.

Lindgren was a visionary in modeling the process of ore deposition. It is amazing that his epithermal hot spring model, as it applies to the Republic and other western deposits, was

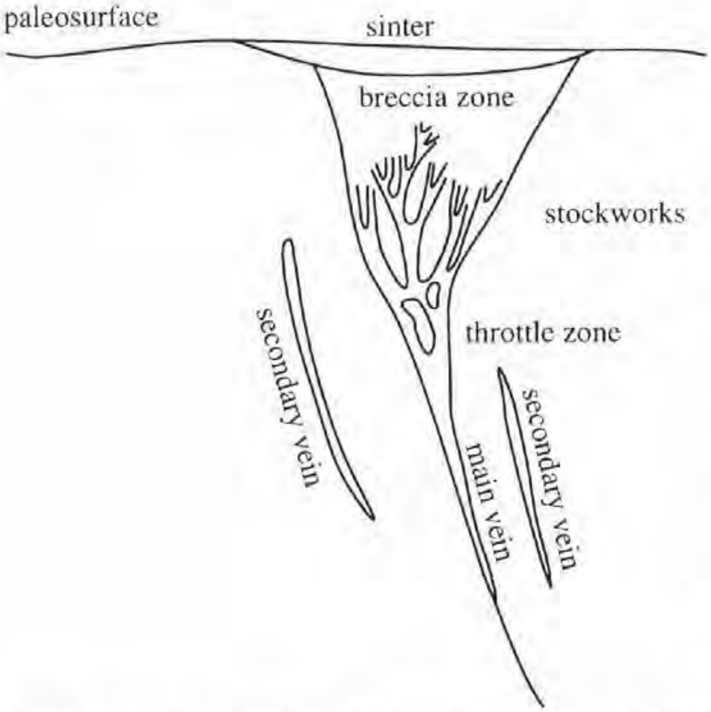

Figure 1. Components of an epithermal precious metal hot spring system modeled after the deposits in the Republic Mining District. No scale is implied. (From Tschauder, 1989)

forgotten for more than 40 years, probably because the bonanza ores of epithermal districts were depleted in the western U.S. and explorationists concentrated their search efforts on porphyry copper deposits and Carlin-type gold ores.

At Republic, the Knob Hill mine had been producing crude ore for smelters since 1910—until a 400-ton-per-day cyanide mill went into operation on May 10, 1937 (Lasmanis, 1989). Recovery problems were overcome by grinding the ore to -200 mesh, as had been suggested in 1914 (Lindgren and Bancroft, 1914). Flotation cells were added to the mill in 1940, and the mill's design capacity increased to 500 tons of ore per day.

In the mid-1960s, the USGS conducted a study of the district. The resulting publication (Muessig, 1967) thoroughly describes the regional geology, with an emphasis on the structural setting of the Republic District. The veins are described in this structural context, but without reference to the epithermal model. Republic ore deposits are further documented by Knob Hill Mines, Inc., geologists in the standard reference work at that time, *Ore Deposits of the United States, 1933–1967* (Full and Grantham, 1968). In Volume Two, the various veins are keyed to structural adjustments related to the Republic graben. A three-dimensional description of the Knob Hill mineralized system was presented: deep narrow veins branching upward into a stockwork and overlain by mineralized "rubble" in the lakebeds of the Tom Thumb Tuff Member of the Klondike Mountain Formation (Full and Grantham, 1968). (See Fig. 1.)

The first indications of a revival of the epithermal model and its implications were in a report by mining geologist Harrison Schmitt (father of geologist/astronaut Jack Schmitt). In 1950, he wrote a paper titled "The fumarolic-hot spring and mineral deposit environment" (Schmitt, 1950). He applied knowledge gained from detailed studies at Yellowstone to Lindgren's epithermal model. He also postulated how gold and silver are transported and deposited in modern systems such as Steamboat Hot Springs, Nevada, and hot springs in New Zealand.

During the 1950s, extensive research conducted by Donald E. White of the USGS at Steamboat Hot Springs led to a series of publications on gold deposition (White, 1955), but at the time, the significance of his studies was not fully appreciated by the mining community.

The Knob Hill mine continued to produce into the 1970s but did not attract much attention because the daily underground production was modest compared to modern open pit operations. Day Mines, with producing mines at Republic from 1916 to 1975, had a property interest at De Lamar, Idaho, that was acquired by the author on behalf of Canadian Superior. After a four-year exploration and development program by Canadian Superior, Earth Resources Company, and their consultants Al Perry, Jim Knox, and Moe Kaufman, a decision was made in October 1974 to mine the De Lamar deposits by large-tonnage open pit methods. This was the first substantial open pit gold/silver mine of the epithermal type associated with Tertiary volcanic activity.

A Unified Model

Suddenly, epithermal gold/silver deposits came into vogue throughout the industry. Both industry and academic research on epithermal deposits and the role of thermal springs were accelerated. Tertiary volcanism and caldera development played a role in the model. In Japan, a three-dimensional view of a Miocene hot spring precious metal deposit was published for the Iwato mine (Saito and Sato, 1978). A more sophisticated vertical section was proposed for the Las Torres mine in Mexico (Buchanan, 1979). In 1979, Paul Eimon gave a paper on the evolving epithermal model for bulk silver deposits in volcanic rocks (Eimon, 1979), and then, in 1981, he presented an exploration concept for hot spring epithermal deposits, including a genetic model by Byron Berger of the USGS.

It all came together during a three-day conference in October 1981 titled "Zoning in Volcanic and Sub-Volcanic Mineral Deposits". The conference was organized by H. F. Bonham, D. C. Noble, F. J. Sawkins, and R. Sillitoe of the Mackay School of Mines in Nevada. Berger published his fully developed model in 1985. The search for epithermal deposits turned into a gold rush when the McLaughlin mine in California started producing gold during March 1985 from a hot spring sinter deposit that was discovered by Homestake in 1978 (Lehrman, 1986).

On October 21, 1981, Hecla Mining Company acquired the operating properties at Republic from Day Mines. By 1983, reserves in the Knob Hill mine were down to six months of production. However, mining continued after the discovery of the Golden Promise ore bodies, initially accessed from the Knob Hill mine. On June 24, 1989, Hecla celebrated the production of 2 million ounces of gold from a single shaft—the Knob Hill No. 2. Only six other gold mine shafts in the U.S. have that distinction.

It was the application of the ore models developed during the 1970s and 1980s that led to the discovery of the Golden Promise vein system in 1984 (Lasmanis, 1989). A model of an epithermal precious metal hot spring system for the Republic District was finally published in 1989 (Tschauder, 1989). It resembles very closely the models of Buchanan (1979) and Berger (1985) and has features that were documented by Lindgren back in 1914.

The Republic Unit of Hecla Mining Company ceased operations in 1995 when the Golden Promise mine ran out of ore on January 2. The mill shut down in mid-February after 37 years of continuous operation. Production, since the 2 million ounce mark was reached, for the Republic Unit, is given in Table 1.

The Future

Although underground mining has ceased at Republic, there is potential for a large tonnage open pit mine on the Golden Eagle deposit. Santa Fe Pacific Gold Corp. has leased the property from Hecla, drilled in 1995, and is evaluating the feasibility of producing from the 11.3-million-ton deposit that has an average grade of 0.1 oz gold per ton. Santa Fe has a proprietary metallurgical process for gold extraction from refractory ores that they hope to apply to the Golden Eagle deposit (Hecla Mining Company news release, August 8, 1995).

The formally designated Republic Mining District extends over 440 mi^2 and includes a mineralized area east of Curlew Lake known as the Belcher District; that district was created on December 15, 1906. There, Kettle River Operations unit, which consists of underground and surface gold mines and a central mill, are operated by Echo Bay Minerals. Echo Bay is a relative newcomer in the district. They started a gold exploration program in 1986 after forming a joint venture with Crown Resources, Inc., and Texas Gold, Inc. The first bar of dore bullion was produced at the mill in January 1990. For production statistics, see Table 2. Kettle River Operations is now a major contributor to the economy of Ferry County and the city of Republic.

Echo Bay and staff of Crown Resources used a very imaginative and creative exploration approach that was not based on an epithermal hot springs model. Instead, they began to search for gold deposits associated with skarns (deposits formed by contact metamorphism of carbonate rocks) and other iron-rich deposits. Lindgren and Bancroft (1914) had given some tantalizing descriptions of the Oversight, Copper Key, and Belcher contact-metamorphic deposits, mentioning that they are gold bearing. Additional descriptions of Belcher District mines and prospects were given by Huntting (1956). Gold there is associated with magnetite, pyrrhotite, and pyrite. Once it was established that the deposits have a magnetic signature, Echo Bay turned to state Division of Mines and Geology Report of Investigations 20 (Hunting Geophysical Services, Inc., 1960) and noted the large magnetic anomaly under Cooke Mountain near the Key prospects (Fig. 2). Walt H. Hunt of Echo Bay (oral commun., 1991) attributes the discovery of the large Overlook deposit by drilling in 1987 at Cooke Mountain to that Division publication.

Table 1. Hecla Republic Unit production, Golden Promise mine. Data from annual mineral industry reports by R. E. Derkey in *Washington Geology*. * from clean-up of the mill

Year	Tons	Au (oz)	Ag (oz)
1988	79,210	80,301	354,077
1989	80,000	72,000	318,000
1990	90,000	81,400	326,000
1991	96,562	77,736	311,445
1992	102,631	58,343	299,957
1993	110,846	49,601	276,688
1994	120,165	39,085	283,326
1995	nil	3,098	15,320*

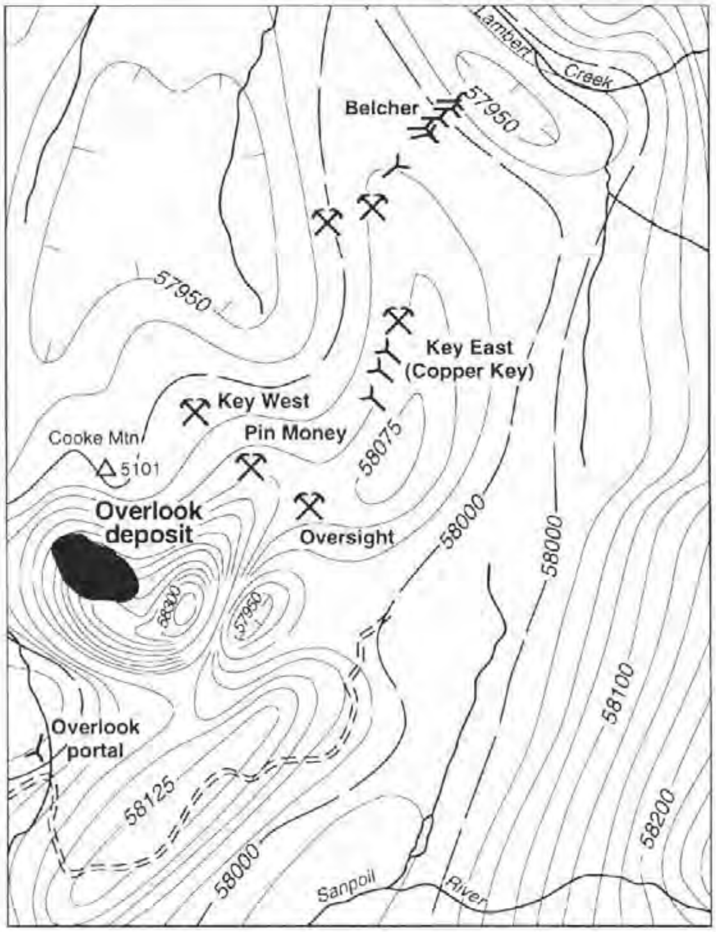

Figure 2. Belcher District mines and aeromagnetic anomalies. Contours in gammas. (Modified from Hunting Geophysical Services, Inc., 1960.)

Mines that have produced for the Echo Bay mill are the Overlook, Kettle, Key East, Key West, and currently the Lamefoot. Only the Kettle is of the epithermal type; the remaining mines are in deposits that were thought to be skarns.

Recent studies by M. G. Rasmussen and others have demonstrated that the Overlook deposit is not a skarn deposit or of a replacement type. Echo Bay geologists did consider a syngenetic model, but because the footwall was limestone, the idea was ultimately rejected. During 1990, E. S. Cheney and Rasmussen noted that the deposit is overturned, thus making it possible to apply a volcanogenic massive sulfide model to the deposit (Rasmussen, 1993).

The application of that model in Permian rocks outside the Tertiary Republic graben speaks well for the future of gold mining in Ferry County. As a result of Echo Bay's success, a new wave of exploration commenced in Washington State and adjacent British Columbia. This has resulted in the discovery

Table 2. Echo Bay Kettle River Operations production. Data from annual mineral industry reports by R. E. Derkey in *Washington Geology*

Year	Tons	Au (oz)	Ag (oz)	Mines
1990	N.A.	83,310	nil	Overlook, Kettle
1991	644,950	90,272	nil	Overlook, Kettle
1992	657,099	89,848	nil	Overlook, Kettle
1993	575,460	73,431	nil	Overlook, Key
1994	523,400	66,782	10,500	Overlook, Key, Lamefoot
1995	547,597	100,419	22,800	Overlook, Lamefoot

and outlining of the Crown Jewel deposit by Battle Mountain Gold Company and Crown Resources Corporation on the eastern flank of Buckhorn Mountain in adjacent Okanogan County. This world-class skarn gold deposit, when in production, will further stimulate the economy of Ferry County.

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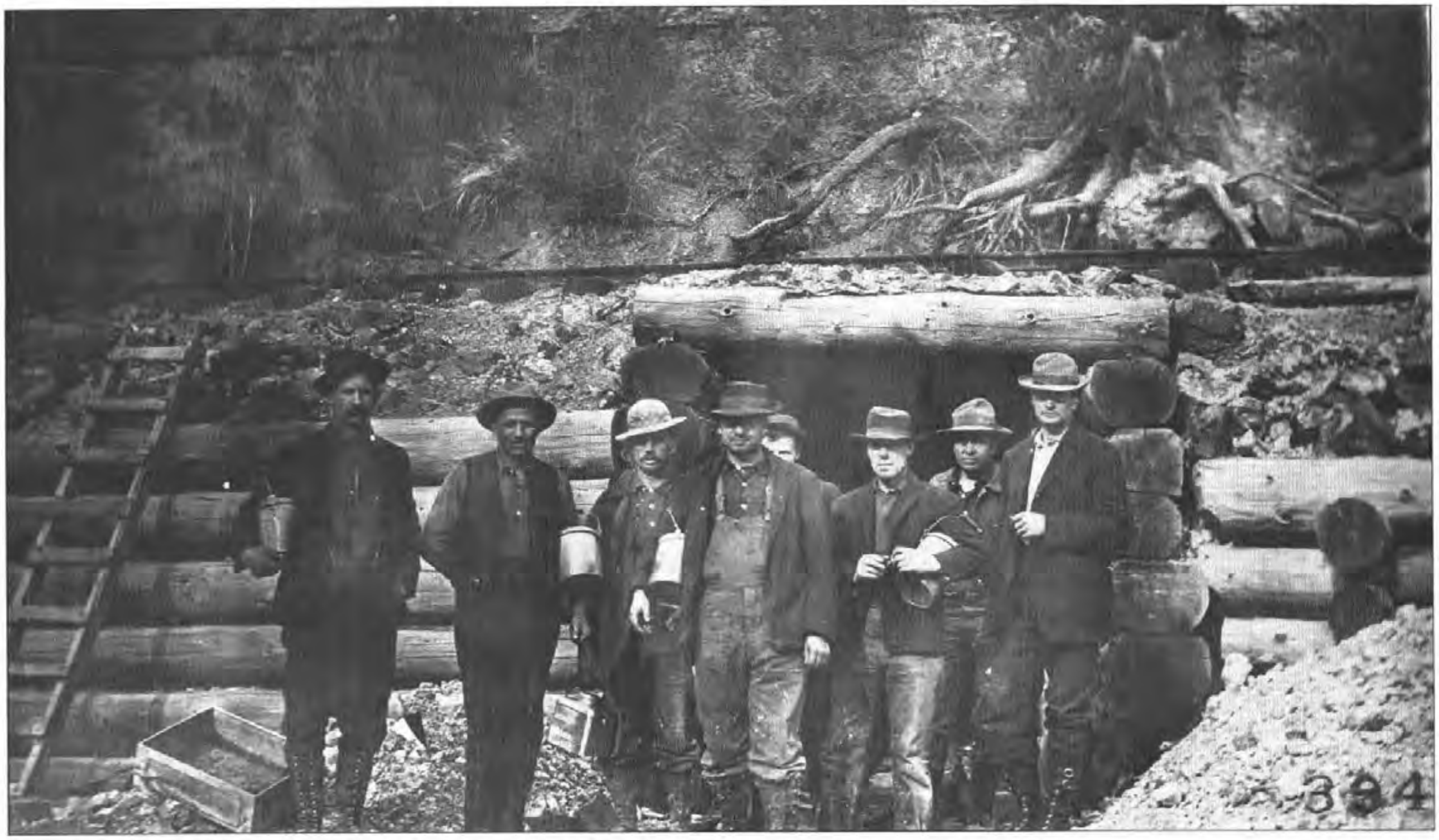
Tunnel of the Surprise and Jim Clark mines, Eureka Gulch, ca. 1904.



Miners pose in front of the Great Northern tracks over the Pearl mine entrance, ca. 1904.

Early Republic district prospector, May 3, 1900.

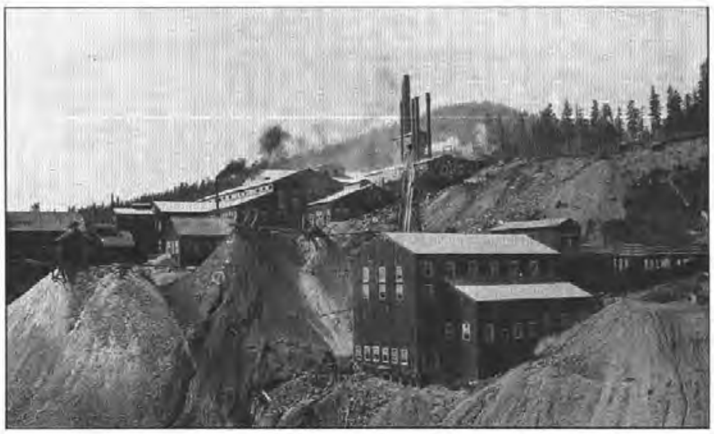
Hank Levine (left) and 'Old Man' Simons (right) bagging ore, ca. 1900. John Yenter, Dick Cook, and unidentified man in background.

Patsy Clark mill at the Republic mine, 1898.

The Surprise mine and Great Northern tracks, ca. 1900.

Mountain Lion mill and mine, ca. 1900.

Last Chance mine, ca. 1910.



Republic Consolidated Gold Mining Company, ca. 1900.

Knob Hill mine, ca. 1949.

Knob Hill mine, ca. 1904.

Mid Eureka Gulch, 1904. A Kettle Valley Railroad locomotive sits on the tracks to the right. The Great Northern tracks are on the left.

Quilp mine and Great Northern bridge at the lower end of Eureka Gulch, ca. 1904.

Depositional History of the Uppermost Sanpoil Volcanics and Klondike Mountain Formation in the Republic Basin

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Fossiliferous, leaf- and insect-bearing sedimentary strata of the middle Eocene Klondike Mountain Formation in the Okanogan Highlands of northern Washington and southern British Columbia (Fig. 1) accumulated in a series of north-northeast-trending, en echelon grabens and half-grabens that formed during regional extension, plutonism, volcanism, and metamorphic core complex emplacement (Muessig, 1962, 1967; Parker and Calkins, 1964; Staatz, 1964; Pearson, 1967; Fox and others, 1976; Pearson and Obradovich, 1977; Cheney, 1980; Orr and Cheney, 1987; Fox and Rinehart, 1988; Hansen and Goodge, 1988; Holder and Holder, 1989; Parrish and others, 1988; Holder and others, 1990; Price, 1991; Suydam, 1993). Examination and analysis of Klondike Mountain Formation strata in the Republic and Curlew basins of the Republic graben suggest much of this unit accumulated in relatively limited (<200 km^2) sedimentary basins occupying topographic and volcano-tectonic lowlands (Gaylord and others, 1990, 1994; Price, 1991; Suydam and Gaylord, 1991; Suydam, 1993; Suydam and Gaylord, 1993). Klondike Mountain strata in these basins preserve the most fossil-rich sedimentary deposits in the Okanogan Highlands (see, for example, articles by Schorn and Wehr, Wehr and Barksdale, and Wilson in this volume). This paper focuses on the depositional history of the Klondike Mountain Formation in the Republic basin.

Klondike Mountain strata were first formally described by Muessig (1962, 1967). Muessig named the unit for Klondike Mountain, a prominent hill immediately north of Republic, and subdivided the unit into one formal and two informal members (stratigraphic subdivisions of formations) (Fig. 2). The lower, fine-grained sedimentary rocks of the Klondike Mountain Formation were grouped into and formally named the Tom Thumb Tuff Member (essentially the "lake beds" of Umpleby (1910) and Lindgren and Bancroft (1914). The rest of the formation was subdivided into the informally named middle and upper members (Muessig, 1962, 1967).

Subsequent workers (Gaylord and others, 1990, 1994; Price, 1991; Suydam, 1993) have adopted an informal two-tiered system for the Klondike Mountain Formation, dividing the unit into a lower (sedimentary-dominated) member and an upper (volcanic-dominated) member (Fig. 2). These subunits of the Klondike Mountain Formation are adopted here. The lower member deposits include the fine-grained lake deposits of the Tom Thumb Tuff Member as well as coarse-grained alluvial sandstone and conglomerate of Muessig's (1962, 1967) middle member. Upper member volcanic-dominated deposits correspond to Muessig's informal upper member. These strata are characterized by variously altered flow rocks that range in composition from basaltic andesites to rhyolites (Wagoner, 1992); they unconformably overlie the sedimentary rocks of the lower member.

The Klondike Mountain Formation in the Republic basin consists of at least 900 m of mixed epiclastic (reworked volcanogenic sedimentary detritus) and volcanic flow rocks (Gaylord and others, 1988; Gaylord, 1989; Price, 1991) (Fig. 2). Curlew basin deposits are generally similar stratigraphically and lithologically to the Republic basin deposits—with one exception: they include sedimentary clasts derived from crystalline plutonic and metasedimentary sources. By contrast, Republic basin deposits are composed almost exclusively of reworked andesite derived from the underlying Sanpoil Volcanics.

Overall, Klondike Mountain Formation strata in the Republic basin consist of a generally coarsening-upward succession of mudstone-, sandstone-, and conglomerate-dominated deposits unconformably overlain by lithoidal to glassy lava flow rocks. The basal part of the Klondike Mountain Formation consists of a 0–50-m-thick sequence of breccia, conglomerate, and minor lava flows that unconformably overlie dacite and andesite flows of the Sanpoil Volcanics. Muessig (1967) believed the basal contact of the Klondike Mountain Formation was an angular unconformity. However, detailed examinations of strata across the Republic basin reveal essentially concordant bedding attitudes between these two units (Gay-

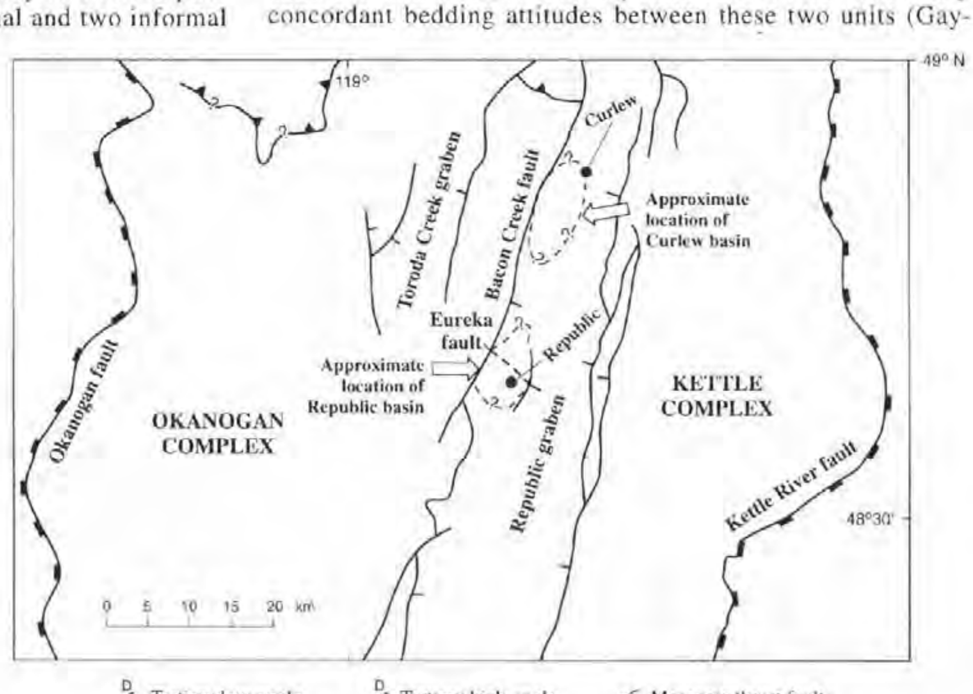

Figure 1. Index map showing approximate limits of the Republic and Curlew basins. (Geology after Price, 1991, and Suydam, 1993.)

lord and others, 1988; Price and Gaylord, 1989). Above the basal breccia and conglomerate, the Klondike Mountain Formation grades upward from: (1) 100–150 m of thick mudstone-dominated strata, to (2) 150–200 m of sandstone-dominated deposits, to (3) 30–500+ m of conglomerate, to (4) 0–80 m of volcanic flow rocks. The black, vitrophyric dacite and andesite flow rocks that overlie the upper conglomerate were deposited on an irregular topographic surface exhibiting from 25 to 75 m of relief. Fossiliferous leaf-, insect-, and fish-bearing strata for which the Klondike Mountain Formation is famous are concentrated in the mudstone- and sandstone-dominated deposits in the lower half of the unit.

The major geologic events that characterized the development and infilling of the Republic basin through Klondike Mountain Formation time are outlined below:

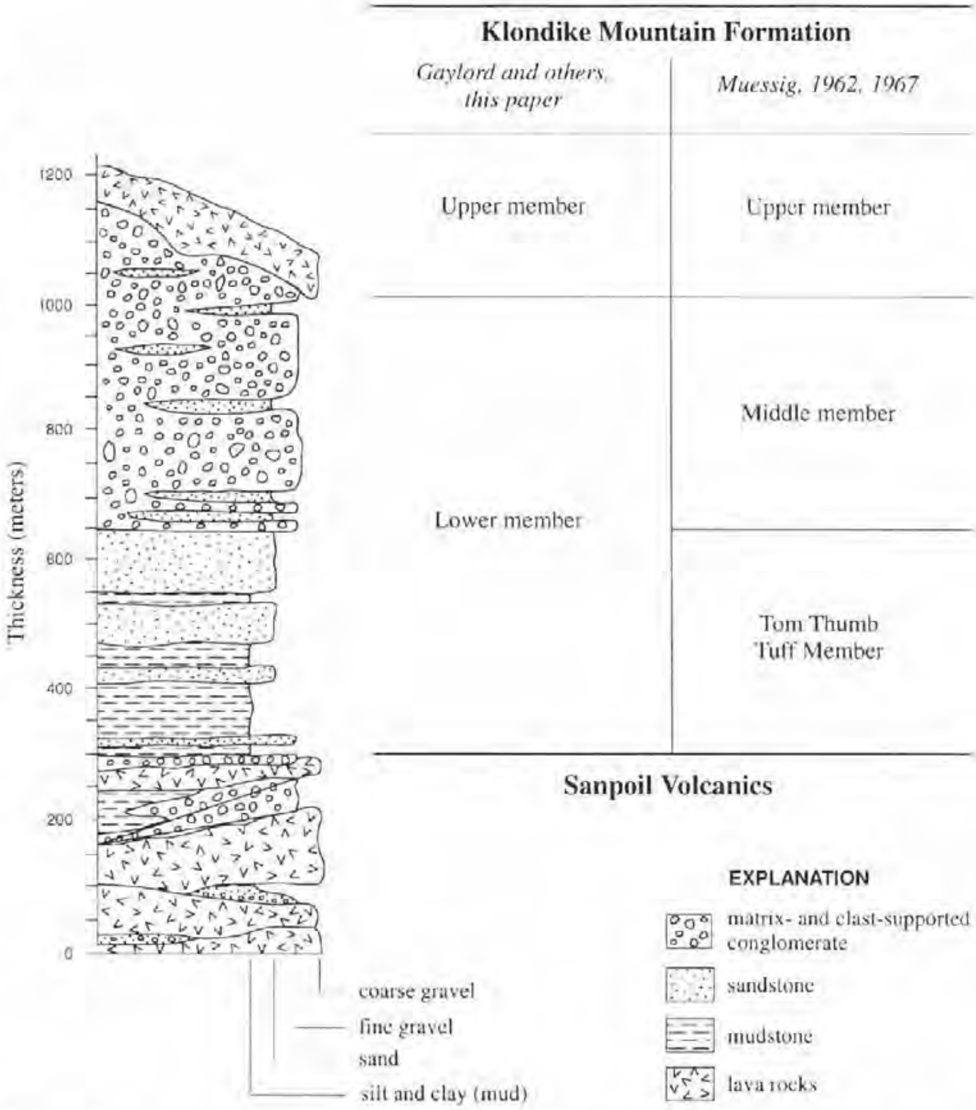

Figure 2. Generalized composite stratigraphic section of the Klondike Mountain Formation and uppermost Sanpoil Volcanics in the Republic basin. The graphic profile of the section reflects the relative resistance to weathering (tied to sediment grain sizes and rock types). Fossils are best preserved in strata from the lower member of the Klondike Mountain Formation. Limits of informal members used in this paper and formal and informal members described by Muessig (1962, 1967) are also indicated.

(1) *Upper Sanpoil Volcanics–1.* An elongate volcano-tectonic basin developed in the Republic area via half-graben subsidence that paralleled the trends of the Bacon Creek and Eureka faults. Lava flows emanating from feeder systems along the flanks of the Republic graben flowed into and achieved their greatest thicknesses within the subsiding graben (Holder, 1990).

(2) *Upper Sanpoil Volcanics–2.* Hydrothermal activity promoted precious-metal epithermal mineralization and extensively altered older Sanpoil strata (Tschauder, 1989). Topographic and volcano-tectonic depressions became the sites of hot springs and localized lakes. Lake sediments that accumulated in these basins were cemented with silica and interstratified with porcelaneous silica sinter (Tschauder, 1989).

(3) *Uppermost Sanpoil Volcanics.* Explosive hydrothermal eruptions centered within the Republic basin ejected brecciated and silicified, laminated lake deposits, porcelaneous silica sinter, and quartz-vein fragments from deeper in the hot springs feeder system (Price and Gaylord, 1989). Poorly sorted, loosely consolidated hydrothermal eruptive detritus was readily reworked by epiclastic processes. Coincidentally, rising lake waters prompted either by volcano-tectonic subsidence or by lava damming of outlet streams (or both) drowned these early, coarse-grained lake deposits beneath subsequent mud- and locally sand-rich lake sediments.

(4) *Lowermost Klondike Mountain Formation.* As lake waters in the Republic basin continued to rise, hydrothermally altered detritus remaining from the earlier hydrothermal eruptions as well as recently eroded Sanpoil Volcanics detritus were transported to the lake from surrounding highland areas primarily via sedimentary mass movement (debris flows) and alluvial (stream) reworking. Debris-flow deposits are recognizable as poorly sorted, clay- and mud-rich, matrix-supported breccia and conglomerate. Clasts of siliceous quartz sinter and quartz veins are mixed with clasts of brecciated, silicified, and laminated lake sediments in these conglomerates. Alluvial deposits are poorly preserved in the Klondike Mountain Formation because of the ease with which they were removed by subsequent erosion. Where preserved, though, these deposits generally are moderately to well sorted and relatively sand rich and exhibit stratification and cross-stratification.

(5) *Lower to middle Klondike Mountain Formation–1.* As the drainage basins of streams feeding the lake enlarged with time, the lake continued to grow, probably reaching a minimum size of 25 km^2 based on lateral extent of preserved lake deposits. Filling of the lake proceeded via stream systems whose deposits, as noted earlier, generally have not been preserved as part of the Klondike Mountain Formation stratigraphic succession. Lake sediments consist largely of subangular to rounded andesite and dacite grains, which suggests that the lake was fed by streams that eroded only the Sanpoil Volcanics. In contrast, sediments in the Curlew basin were carried to the lake by streams that transported a wider variety of rock types, including weathered Sanpoil Volcanics and older metamorphic and plutonic rock particles.

Streams feeding the Republic basin provided mud to gravel-size material to the lake. The thick sequence of mudstone, sandstone, and conglomerate in the Republic basin accumulated by suspension settling, low- and high-density turbidity currents, and debris flows (Gaylord and others, 1990; Price, 1991; Suydam, 1993). Gray to brown mudstone deposits likely represent seasonal suspension settling and deposition by the distal portions of low-density turbidity currents. Laminated organic-rich mudstone represents suspension deposition in a thermally stratified lake where at least the deepest part of the water column was unaffected by seasonal overturn. Normally graded to massive and horizontally stratified sandstone deposits are consistent with suspension and traction sedimentation from sand-rich, high- and low-density turbidity currents (Lowe, 1982). Occasionally, coarse, gravel-rich sediments were delivered into the lakes via debris flows to produce beds of matrix- and clast-supported conglomerate.

It was during this time that some of the richest concentrations of now-fossilized leaves, insects, and fish were buried and preserved within the lake. Much of the wood and leaf material transported to the lake was macerated by the abrasive action of more resistant sediment particles either in feeder streams or by wave action along the beach. It is striking that there has been such widespread preservation of intact leaves and fossils in such a dynamic depositional setting. Apparently, leaves and pollen often were transported to the lake by streams and wind and later settled into deeper parts of the lake where burial was swift and reworking by waves was minimal. The common coincidence of fossils with thinly to thickly laminated, normally graded couplets of fine sand to mud indicates that in many cases the fish, insects, and leaves were able to remain intact in spite of the frequent turbidity currents that flowed across the lake bottom. Curiously, these fossiliferous strata show only local evidence of bioturbation, suggesting that either oxygen levels were too low to support burrowing organisms or that deposition rates often were exceptionally high.

(6) *Lower to middle Klondike Mountain Formation–2.* As the drainage basin feeding the lake continued to enlarge, coarser grained, sand-rich detritus was shed farther out into the lake. Sand thickness maps (isolith maps) suggest that sand-rich fan-deltas (spatially connected to alluvial fans on land) prograded across the lake (Gaylord and others, 1990; Price, 1991; Suydam, 1993). Fossils preserved in the Klondike Mountain Formation during this episode of sedimentation largely consist of macerated debris. Deposition at this time signaled an increase in sediment input and a possible decrease in relative basin subsidence or increased highland uplift, or both.

(7) *Middle to upper Klondike Mountain Formation.* Sedimentation in the lake at this time was dominated by gravel-rich deposition. Gravel-rich sediments accumulated in the lake via subaqueous debris flow and density current depositional processes as fan-delta progradation continued. Sediment input increased as the drainage basin of the streams filling the lake continued to enlarge; however, basin subsidence and (or) highland uplift either slowed or ceased at this time. Price (1991) concluded, on the basis of the geometry and thickness of Gilbert-type delta foreset beds, that the lake waters may have been at least 300 m deep at this time. Ultimately, the lake basin was filled, thus creating the coarsening-up stratigraphic sequence seen in the composite stratigraphic section (Fig. 2).

(8) *Upper Klondike Mountain Formation–1.* Regional upwarping, possibly associated with the thermal expansion that probably accompanied extrusion of the overlying lava flows (Wagoner, 1992), promoted alluvial incision of the uppermost coarse-grained, gravel-rich deposits of the Klondike Mountain Formation. Streams that drained this surface produced local topographic relief of 25 to 75 m.

(9) *Upper Klondike Mountain Formation–2.* Glassy to lithoidal basaltic andesites and rhyolites (Wagoner, 1992) were extruded across the irregularly dissected erosional surface of the upper Klondike Mountain Formation. Volcanism in the Republic graben at this time was characterized by dome-like eruptive centers situated along extensional faults. Minor sedimentary deposits derived largely from erosion of the lava flows occurred during interflow episodes. This interstratified sequence of volcanic and minor sedimentary rocks caps the Klondike Mountain Formation strata in both the Republic and Curlew basins.

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ERRATUM

On page 31 in our previous issue, there are two geologic units mislabeled. The Tl unit in the center of the right side of the map should be Kqm (Mount Spokane granite), and the small unit in that area labeled Kqm is TKa (alaskite, pegmatite, aplite).

New Home Page for the Office of Mines and Minerals

The Office of Mines and Minerals home page can be accessed via:

http://dnr.state.il.us/ildnr/offices/mines/omm.html

The list of links to mines and mining sites can be reached by:

http://dnr.state.il.us/ildnr/offices/mines/minelynx.html

The list of links includes about 2,250 items and is constantly growing. Watch for it to be subdivided in the future. Please notify terpstra@etana.osmre.gov if there are problems with the page and contents.

Republic Leaf Deposits and Eocene Ecology

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The leaf floras of the Republic graben are a spectacular lot. Each slab one splits has the potential to display a complete reddish-brown leaf that is highlighted by dark brown veins and isolated on the creamy white matrix. (See Fig. 1.) The beauty of the fossils in deposits like these deserves to be studied in detail. Similar lakebed preservational conditions are rare, but well known: Florissant and Green River in Colorado, Wind River in Wyoming, and Clarkia in Idaho.

In the excitement of finding a species new to science or of uncovering a complete specimen of one of the known species, it might be tempting to set aside until later the idea that the flora and the deposit are a snapshot of an ancient ecosystem. Once we put the Republic flora in an evolutionary, biogeographic, or ecological context, we can see the importance of a whole suite of details, from rock texture to floral diversity. The conditions under which the deposit formed (the taphonomy) give us information about the local Eocene ecosystem. It is this information that allows us to travel in our minds through the ancient forest.

The floras at Republic were deposited in quietly accumulating muds rich in fine volcanic debris. Periodic eruptions of volcanoes choked the air and the rivers with volcanic dust, but these were *not* times of deposition of the plants we know best from Republic. Instead, these piles of volcanic dust and debris were incorporated slowly into the soil profile and into the sediments of rivers leading away from the volcanic slopes. Debris dams were formed occasionally, ponding rivers into short-lived lakes. These lakes filled rapidly with fine sediments, but they still probably preserved very little plant material that has the quality of the plants described above.

Slowly the landscape recovered from the inundation of volcanic sediment. The unstable slopes were leveled and the gullies were filled during the erosion-fill process. Depressions became permanent lakes. Some of the depressions owed their presence to local faults. Movement along these faults maintained the geologic structure in the area and slowly deepened the lakes, allowing them to continue accumulating sediments. The landscape took on a more stable appearance and started to support forests between the river courses and along the lake edges. Sediment influx to the lakes continued, but only the finest sediment reached the lake, the coarser material dropping out in the rivers as they made their way to lake basins.

Fine sediments are essential if the fine details of leaf veins and margins or sculpturing of fruits and seeds are to be preserved. Clearly, large quantities of fine sediment reached the lake because the ratio of sediment to organic matter is low. Leaves were both carried to the lake in the rivers and probably fell directly into the lake from surrounding trees. The leaves would have floated some distance, but once waterlogged, they settled to the lake bottom and were quickly covered by the arriving volcanic-rich mud. Leaves arriving in the rivers may have been torn during transport, but a waterlogged leaf is more plastic than a dried leaf from the forest floor, so the river-transported leaves may be represented by both torn and fairly fresh-looking leaves.

The presence of hot mineral springs in the area may have aided plant preservation in some cases. In modern volcanic environments, mineral deposits have been noted coating leaves with a fine precipitate. This precipitate may prevent bacterial degradation and impart durability to the otherwise fragile leaf, thus helping to preserve, rather than degrade, the leaves.

We know that the landscape was relatively stable during the time of deposition of the leaves at Republic for a couple of reasons. First, the predominant grain size in the plant deposits is fine: silt to clay particles entomb the leaves. Rivers carrying larger grain sizes would have left some larger grains on the fossils, but this is rare in the deposits from which we have collected the best leaf specimens at Republic. Second, the high species richness of the plants and animal traces in the deposits at Republic indicates that the ecosystem was relatively stable, at least in the short terms of hundreds of years. A limited range of plants and animals can withstand constant perturbation. A modern parallel might be the weeds along the roadside. They are a limited subset of the total flora—those that can stand crushing and partial uprooting throughout their lives. So the volcanic activity, which in modern volcanoes has enormous energy for moving sediment, represents a pause in deposition of the highly productive plant layers at Republic. In some cases the periods of quiet plant deposition ended abruptly when a large plug of coarse sediment covered the plant-rich deposit.

Taken together, then, the leaves and their enclosing sediments give us a picture of the Eocene landscape that we cannot see as clearly from fossils or rock in isolation. ■

Figure 1. A typical, beautifully preserved leaf of an extinct relative of the sumac (*Rhus malloryi* Wolfe and Wehr); SR88-43-1, x1.65. The fine grain size of the sediment enhanced the preservation of the details. (Photo by Lisa Barksdale.)

The Presence of Fagaceae (Oak Family) in Sediments of the Klondike Mountain Formation (Middle Eocene), Republic, Washington

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Near Republic, Washington, outcrops of the Klondike Mountain Formation offer an exceptional opportunity for studying megafossils because of their abundance and excellent preservation. The Republic flora, for which the age has been radiometrically calculated as early middle Eocene, suggests a mixed coniferous forest with principal components such as *Pinus* (pine), *Picea* (spruce), *Tsuga* (hemlock), *Abies* (fir), and *Thuja* (cedar). As part of the understory, although not as well represented, are dicotyledonous shrubs and trees such as *Hydrangea*, *Ribes* (wild currant), *Prunus* (cherry), *Corylopsis* (winter hazel), *Phoebe* (laurel), *Populus* (poplar), and *Salix* (willow). In spite of the fact that most elements of this type of forest are amenophilous (wind-pollinated), some of its elements, such as the understory trees and shrubs, are entomophilous (pollinated by insects). This type of forest indicates a microthermal climate in which the mean annual temperature is slightly less than 13°C (about 55°F).

At least 50 families of flowering plants have been identified as elements of the Republic flora. Among the most interesting of these, the family Fagaceae (beeches and oaks) is represented by remains that are assignable to both extinct and modern genera. The modern Fagaceae is a large family of both trees and shrubs that has a northern hemisphere distribution. There are nine extant genera. Of these, *Quercus* (oaks) and *Fagus* (beeches) are placed in the subfamily Fagoideae, *Castanea* (chestnuts) in the subfamily Castanoideae. (Some authors place *Quercus* in a third subfamily, Quercoideae.) *Quercus* and *Fagus* are pollinated by wind, whereas all members of the Castanoideae are insect-pollinated.

Our knowledge of the history of the Fagaceae has been greatly enriched by descriptions of fossil wood, leaves, staminate catkins, pollen grains, pistillate infructescences, and fruits. The first microfossil record identifiable as belonging to the Fagaceae consists of pollen grains resembling those of the modern Castanoideae that were found in Late Cretaceous rocks of the San Joaquin Valley in California. The first indisputable megafossil evidence for both subfamilies consists of wood, leaves, and fruits from the middle Eocene. By the late Eocene, the family was already widespread in North America; fossils (mostly leaves) assigned to Fagaceae are known from several formations in different states and provinces.

The fagaceous fossils found at Republic vary from specimens that appear almost identical to modern members of the family to extinct forms that appear to have no modern analogs. Perhaps the most interesting of the novel forms is *Fagopsis undulata* (Knowlton) Wolfe and Wehr (Plate 1, figs. 1 and 2), known from specimens of both isolated leaves and fruits. The leaves are characterized by the combination of elliptical shape, straight unbranched secondary veins, and simple prominent teeth separated by shallow sinuses. The type of serration along the leaf margin allows *Fagopsis* to be identified as belonging in the Fagaceae because this character is of wide occurrence in extant genera of the family. Some dispersed circular aggregations of fruit-wedges, also collected in the Klondike Mountain Formation, fit the description of *Fagopsis* fruits. Each wedge has a cone-like shape and is toothed at the distal end. Fossil leaves that resemble modern *Castanea*, *Fagus*, and perhaps *Quercus* have also been reported from the lakebed strata.

The genus *Castaneophyllum* (Plate 1, figs. 3 and 4), erected for isolated *Castanea*-like fossil leaves, is almost identical in leaf features to the extant genus *Castanea*. The shape, margin, high-order venation, and areolation relate the fossil genus *Castaneophyllum* to modern *Castanea*, and for this reason some researchers believe that *Castaneophyllum* should be considered a member of the subfamily Castanoideae.

The leaves of *Fagus* (Plate 1, figs. 5 and 6) are characterized by a serrate margin, simple teeth regularly spaced, rounded sinuses, and distinctive secondary venation. These features allow them to be easily distinguished from those of other families as well as other genera of Fagacaeae and to be considered as belonging to the subfamily Fagoideae.

Various fragmented specimens show leaf characters similar to those of the genus *Quercus* (Plate 1, fig. 7), but any assignment to *Quercus* at this time is doubtful. The presence of *Quercus* in the Republic flora still needs to be confirmed.

Although Fagaceae is poorly represented in the Republic flora, because of its position early in the development of modern genera of the family, further collecting and work on the fossils at this site have potential to shed light on major events in the evolution of the family.

Acknowledgments

The figured specimens were generously donated by Bonnie Blackstock, Marion Dammann, Keith Nannery, Mark Reeves, and Michael Spitz. ■

Plate 1. Fossil leaves and fruit of the oak family from the Okanogan Highlands of Washington and British Columbia. UWBM, University of Washington, Burke Museum. **1.** *Fagopsis undulata*, leaf, UWBM 57491a, loc. B3389, One Mile Creek [OMC], near Princeton, BC. **2.** *Fagopsis undulata*, fruit, UWBM 74317, loc. B5097, Midway, BC. **3.** *Castaneophyllum* sp., leaf, UWBM 76557, loc. B3389, OMC. **4.** *Castaneophyllum* sp., leaf, UWBM 56705, loc. B3389, OMC. **5.** *Fagus* sp. leaf, UWBM 71065, loc. A0307, Republic, WA. **6.** *Fagus* sp. leaf, UWBM 56314, loc. B3389, OMC. **7.** *?Quercus* sp., UWBM 31245, loc. A0307, Republic. The bar beside each figure represents 1 cm.

The Conifer Flora from the Eocene Uplands at Republic, Washington

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As you collect fossil plants in Republic, and the bright sun of a warm August afternoon begins to bear down on you, you probably reach a point where you look around for some shade. The largest trees in the immediate area are the ponderosa pines and Douglas firs. Lean back against a ponderosa, close your eyes and conjure up the forest scene that existed here some 49–50 million years ago. What kind of a tree would you be leaning against in the Eocene forest? What conifers were here then? Just how do the Republic fossils help us understand the geologic history of the conifers?

If you could travel back to the Republic area during the middle Eocene about 50 million years ago, you easily would recognize the conifers growing in the forest. It was an association of species that no longer lives together in any one small area on the face of Earth. But even though the association of species was different from any known today, you still would recognize the distinct forms that made up the forest, especially if you were reasonably familiar with the modern forest of eastern Asia (Wang, 1961). Nearly one-half of the conifer genera found at Republic live today only in China and (or) Japan.

The fossils that are the remains of the various parts of the ancient plants look very similar to their modern counterparts. There are impressions of branches with attached leaves, winged seeds, cone scales and cones (see photos, p. 36), individual leaves or needles, and groups of fascicled needles. We do not know with certainty whether the Eocene plants were large forest-dwelling trees, but we assume from their modern relatives, modern associations, and from other areas where petrified 'forests' of large stumps are found, that the Republic forest had canopy levels or strata of large trees just as in modern warm temperate forests (that is, warm microthermal climate of Fig. 1).

As you 'rest' in your Eocene landscape you might well be leaning back against a pine tree. There were at least three types of pines in the forest. In fact, the Republic flora probably has the richest concentration of conifer genera of any known Tertiary flora. Even adjusting for the possible errors that can be made in identifying some of the leaves that look very similar, there were probably 16 genera, and at least 18 species, of conifers living in the Republic forest (Table 1).

The large number of coniferous taxa found at Republic as mega-impressions among the very large number of fossils retrieved at these localities is not simply an expression of the great amount of collecting that has been done. Other fossil floras, as thoroughly collected and from similar depositional environments, do not yield such a diversity of mega-impressions. The entire Republic flora is rich in fossil specimens and is very diverse in numbers of different species (Gooch, 1992; Schorn and Wehr, 1986; Wehr and Schorn, 1992; Wehr and Hopkins, 1994; Wolfe and Wehr, 1991). This diversity reflects the moderate, or more equable, temperate climate that existed at Republic some 50 million years ago.

The distinctly greater generic diversity among the fossil conifers at Republic is clearly expressed when it is compared with the lower diversity from other essentially contemporaneous floras that grew at lower and at higher elevations (Fig. 2) in the Eocene Pacific Northwest.

During the Eocene, just as in present forests, the most diverse assemblages of coniferous genera grew under warm temperate conditions (that is, in warm microthermal to cool mesothermal climates), where the temperature was neither too warm nor too cold, and where sufficient precipitation was distributed throughout the growing season. When the three floras from Figure 2 are plotted according to their inferred temperature requirements (Fig. 1) it is easy to visualize the relationship between temperature conditions, elevation, forest type, and conifer diversity.

The Republic and contemporaneous Princeton, British Columbia, localities offer us a substantial view of what the forest cover was like in this region during the early middle Eocene. Just how important is this information as it relates to increasing our understanding of the history of the conifers? One way to appreciate the crucial importance of the Republic flora is to simply ask, "What would our picture be like without the Republic collections?" We would have quite a different understanding, for sure. First of all, the Republic flora provides us with the earliest unequivocal record of three conifer genera: fir (*Abies*), hemlock (*Tsuga*), and spruce (*Picea*) (Wehr and

Table 1. Conifer taxa in the Republic flora (from Wehr and Schorn, 1992)

Ginkgoaceae	
Ginkgo (maiden hair tree)	1 species
Taxaceae	
Amentotaxus-type (Chinese yew)	1 species
Taxus-type (yew)	1 species
Torreya (California nutmeg)	1 species
Cephalotaxaceae	
Cephalotaxus-type (plum-yew)	1 species
Cupressaceae	1 species
Chamaecyparis (Port Orford cedar)	1 species
Thuja (arbor-vitae)	1 species
Taxodiaceae	
Cryptomeria-type branches (Japanese cedar)	1 species
Glyptostrobus-type branches (Chinese water pine)	1 species
Sequoia (coast redwood)	1 species
Metasequoia (dawn redwood)	1 species
Pinaceae	
Abies (fir)	1 species
Pseudolarix (golden larch)	1 species
Tsuga (hemlock)	1 species
Picea (spruce)	1 species
Pinus (pine)	
Pinus (*Strobus*) (soft pine)	2 (3?) species
Pinus (*Pinus*) (hard pine)	1 (2?) species

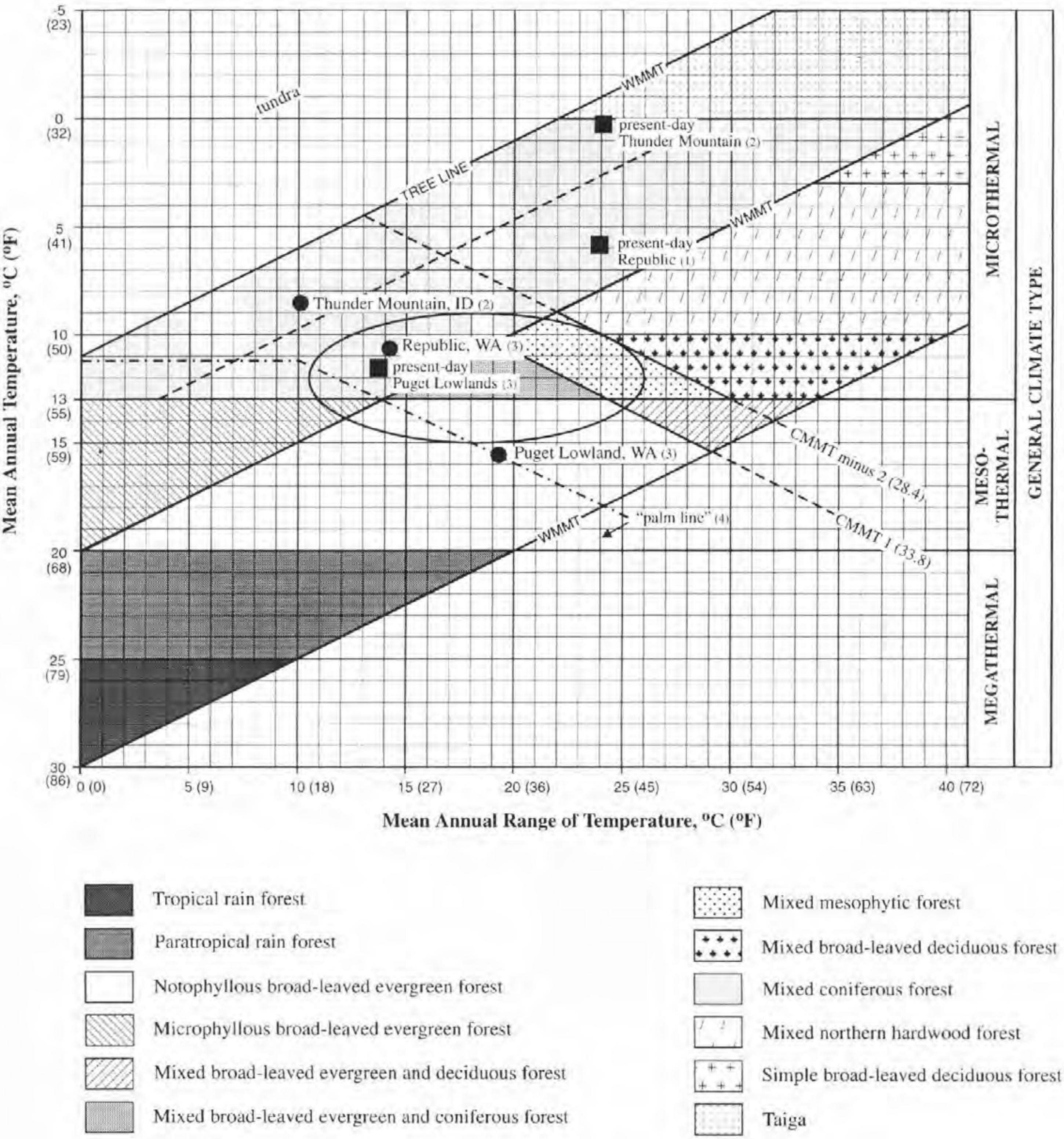

Figure 1. The Puget Lowland, Republic, and Thunder Mountain paleofloras (dark circles) (see Fig. 2) plotted by their inferred temperature requirements. The oval enclosure approximately defines the 'temperature envelope' that contains the majority of the living Northern Hemisphere conifer genera. Present-day temperature plots for the locations of the three fossil flora sites are indicated by squares. This nomograph is redrawn from Wolfe (1979, 1995), with the Mean Annual Temperature scale reversed. This format may make it somewhat easier to visualize the various forest types as they occur in nature. This graph describes tropical conditions in the lower left corner. The vertical and horizontal axes represent progressively cooler and (or) higher habitats. Climates as warm as, or warmer than, the 'palm line' do not experience periods of extended freezing. WMMT, warm month mean temperature; CMMT, cold month mean temperature. (1) from Wolfe (1993); (2) from Axelrod (1990) and Leonard and Marvin (1982); (3) from Wolfe (1994); (4) from Wing and Greenwood (1993).

Schorn, 1992). Second, the generic diversity of the Republic conifers is shown to be richer than in contemporaneous forests that are known on physical evidence to be from either lowlands or areas of higher elevation (Fig. 2). This is comparable to distribution patterns observed in modern forests. For this reason, this type of information helps lend validity to methods

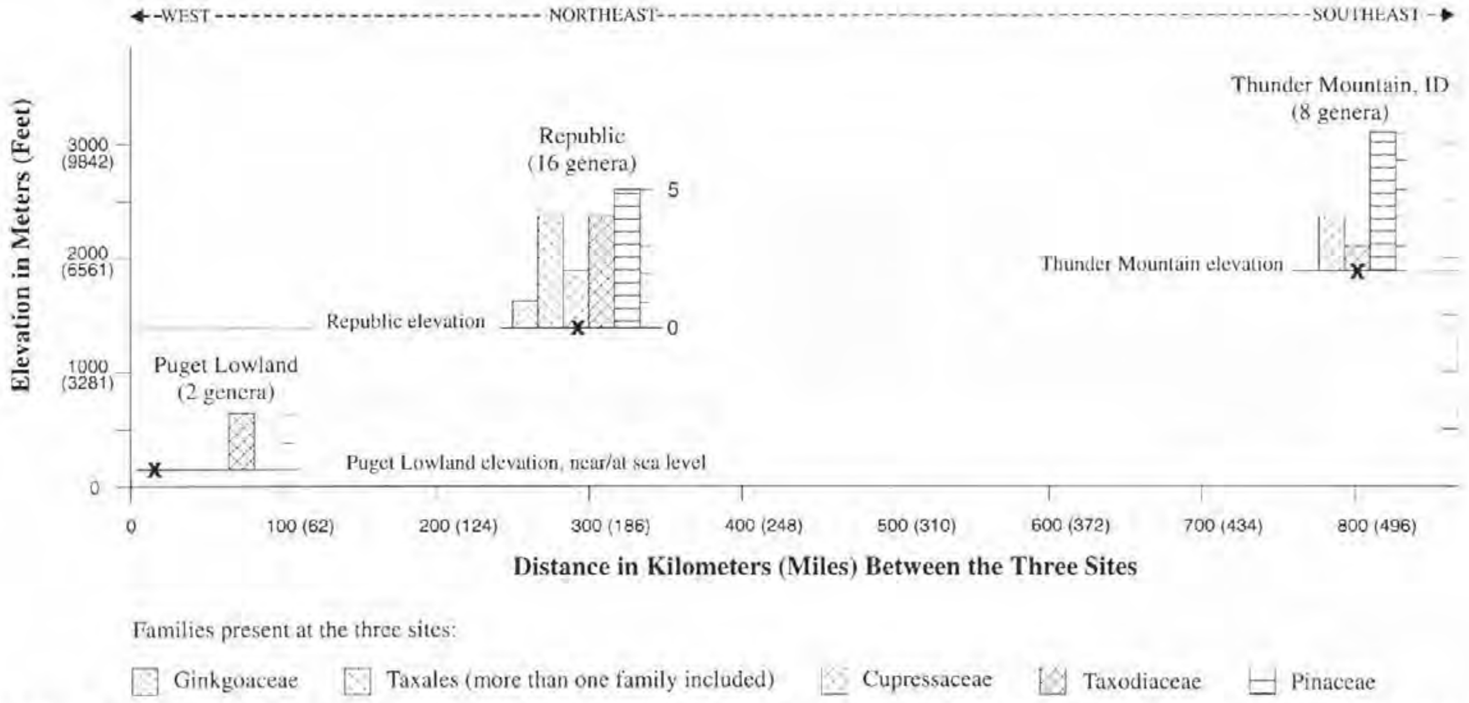

Figure 2. Comparison of generic diversity among the conifers from three Eocene floras that lived at different estimated elevations. Table 1 lists the genera and higher taxonomic groups used here. **X** indicates relative location of the sites.

being developed for evaluating fossil floras (Wolfe, 1993, 1995), and this in turn enhances our confidence and suggests that fossil floras can be used with greater and greater assurance to interpret the habitat, evolution, and other aspects of ancient forests. Third, the greatest generic diversity of extant conifers in the Northern Hemisphere is fairly well concentrated by the temperature values within the oval drawn on Figure 1. Of the some 31–33 conifer genera presently distributed in the Northern Hemisphere, all but perhaps two genera are restricted to, or have some species that live in, areas with temperature ranges that fall within the oval 'temperature envelope'.

In the past, as at present, this temperature domain has acted as the 'cradle' of conifer diversity. As climatic fluctuations (Wolfe, 1994) expanded and (or) contracted the various habitats throughout the Cenozoic, species dispersed into or were eliminated from peripheral temperature domains of generally cooler and (or) more extreme climates. However, throughout these fluctuations the most favorable climates for conifer diversity remained in the warm microthermal to cool mesothermal realm—a relationship already expressed in the early middle Eocene by the Republic flora.

Acknowledgments

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Paleobotanical Significance of Eocene Flowers, Fruits, and Seeds from Republic, Washington

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Fossils from the vicinity of Republic, Washington, provide an important window to the Eocene flora and fauna of the Pacific Northwest. Although the Republic flora is perhaps best known for the diversity of well-preserved leaf impressions (Brown, 1937; Wolfe and Wehr, 1987; Wehr and Hopkins, 1994), plant reproductive structures are also present. Because the classification of many living plants is based largely on their fertile parts, the study of fossil flowers and fruits is particularly useful in comparative studies with modern relatives. Persistent careful collecting of the Republic strata has resulted in a steadily increasing database of flowers, fruits, and seeds. These fossils provide an important supplement to the data available from leaves. Some of the reproductive structures represent genera as yet unknown from leaves, whereas others provide a more complete understanding of the genera known also from leaves.

Because fossil leaves are the most commonly found plant element at many Tertiary localities in Washington, Oregon, and British Columbia, Pacific Northwest paleobotanical work has relied heavily on the fossil leaf record. The historical approach commonly used in west coast fossil plant study has traditionally been floristic and ecological and based primarily on fossil leaves. No matter how competently identified they are, fossil leaves, however, can provide at best only part of the picture. They can, in fact, present a distorted picture of angiosperm evolution. Many fossil leaves, in their general similarity to extant leaves, can give the impression that they represent extant genera. However, some of the fossil flowers, fruits, and seeds found in close association, and more rarely in direct attachment with them, represent extinct genera for which there are no known living counterparts. The reconstruction of the 'whole plant' has become a fundamental approach in contemporary angiosperm paleobotany.

Wehr (1995) provided an overview of the diversity of flowers, fruits, and seeds from Republic and other sites of similar age in the Pacific Northwest, showing the potential for many avenues of systematic research. Approximately 6 species of flowers, 30 species of fruits, and 4 species of seeds are now known from Republic. Currently, about 18 extant genera and at least 14 extinct genera can be recognized. In addition, at least 20 types remain unidentified, types which could include both modern and extinct genera. The current list of Republic fossil flowers, fruits, and seeds (with their common

Table 1. Flowers, fruits, and seeds found at Republic through 1995. Plates 1 and 2 illustrate specimens found or identified since mid-1994

Nymphaeaceae (water lily family)
- *Nuphar* sp. (water lily) seeds, stigmatic disc [Plate, 1, figs. 1 and 2]

Menispermaceae (moonseed family)
- *Calycocarpum* sp. fruit [Plate 1, fig. 3]

Trochodendroid Group
- *Trochodendron* sp. fruits
- *Joffrea* sp. (extinct genus) fruits, seeds, stamens [Plate 1, figs. 4 and 6]
- *Cercidiphyllum* sp. (katsura) clustered pods [Plate 1, fig. 5]
- *Nordenskioldia* sp. (extinct genus) fruits

Sabiaceae (sabia family)
- *Sabia* sp. fruits [Plate 1, fig. 7]
- *Meliosma* sp. (fruit) [Plate 1, fig. 8]

Hamamelidaceae (witch-hazel family)
- *Liquidambar* sp. (sweet gum) seeds

Eucommiaceae (eucommia family)
- *Eucommia* sp. fruit

Platanaceae (sycamore family)
- *Macginicarpa* sp. (extinct genus) fruits

Tiliaceae (linden family)
- *Craigia* sp. fruit

Sterculiaceae (cocoa tree family)
- *Florissantia quilchenensis* Manchester (extinct genus) flowers, stamens [Plate 2, fig. 1]

Ulmaceae (elm family)
- *Ulmus* sp. fruits
- *Cedrelospermum* sp. (extinct genus) fruit [Plate 2, fig. 2]

Fagaceae (oak family)
- *Fagopsis undulata* (Knowlton) Wolfe & Wehr (extinct genus) fruits

Betulaceae (birch/alder family)
- *Alnus parvifolia* (Berry) Wolfe & Wehr (alder) fruits
- *Corylus* n. sp. (hazelnut) fruit in husk (involucre)
- aff. *Corylus* sp. fruit
- aff. *Carpinus* sp. (hornbeam) fruit
- *Palaeocarpinus* sp. (extinct genus) fruits

Juglandaceae (walnut family)
- *Cruciptera* sp. (extinct genus) fruit
- *Carya/Juglans* sp. (hickory or walnut) fruit [Plate 2, fig. 3]

Leguminosae/Fabaceae? (pea/locust family)
- unknown genus fruits [Plate 2, fig. 4]

Myrtaceae (myrtle family)
- *Paleomyrtinaea* sp. (extinct genus) fruit [Plate 2, fig. 5]

Sapindaceae (soapberry family)
- *Bohlenia americana* (Brown) Wolfe & Wehr (extinct genus) fruits
- *Deviacer* ("*Acer*" *arcticum*) (extinct genus) fruits
- *Koelreuteria* sp. fruits

Aceraceae (maple family)
- *Acer* spp. (maple) fruits

Icacinaceae (moonvine family)
- *Palaeophytocrene* sp. (extinct genus) fruit

Vitaceae (grape family)
- *Vitis* sp. (grape) seeds

Rubiaceae (gardenia/coffee/quinine family)
- cf. *Emmenopterys* sp. fruits [Plate 2, fig. 6]

Bignoniaceae (catalpa family)
- genus unknown seeds

Musaceae (banana family)
- *Ensete* sp. (banana) fruits with seeds [Plate 2, fig. 7]

Unknown affinity
- *Pteronepelys wehri* Manchester (extinct genus) fruits
- *Calycites ardtunensis* Crane (extinct genus) fruits
- Undetermined I fruits [Plate 2, fig. 8]
- Undetermined II fruits [Plate 2, fig. 9]

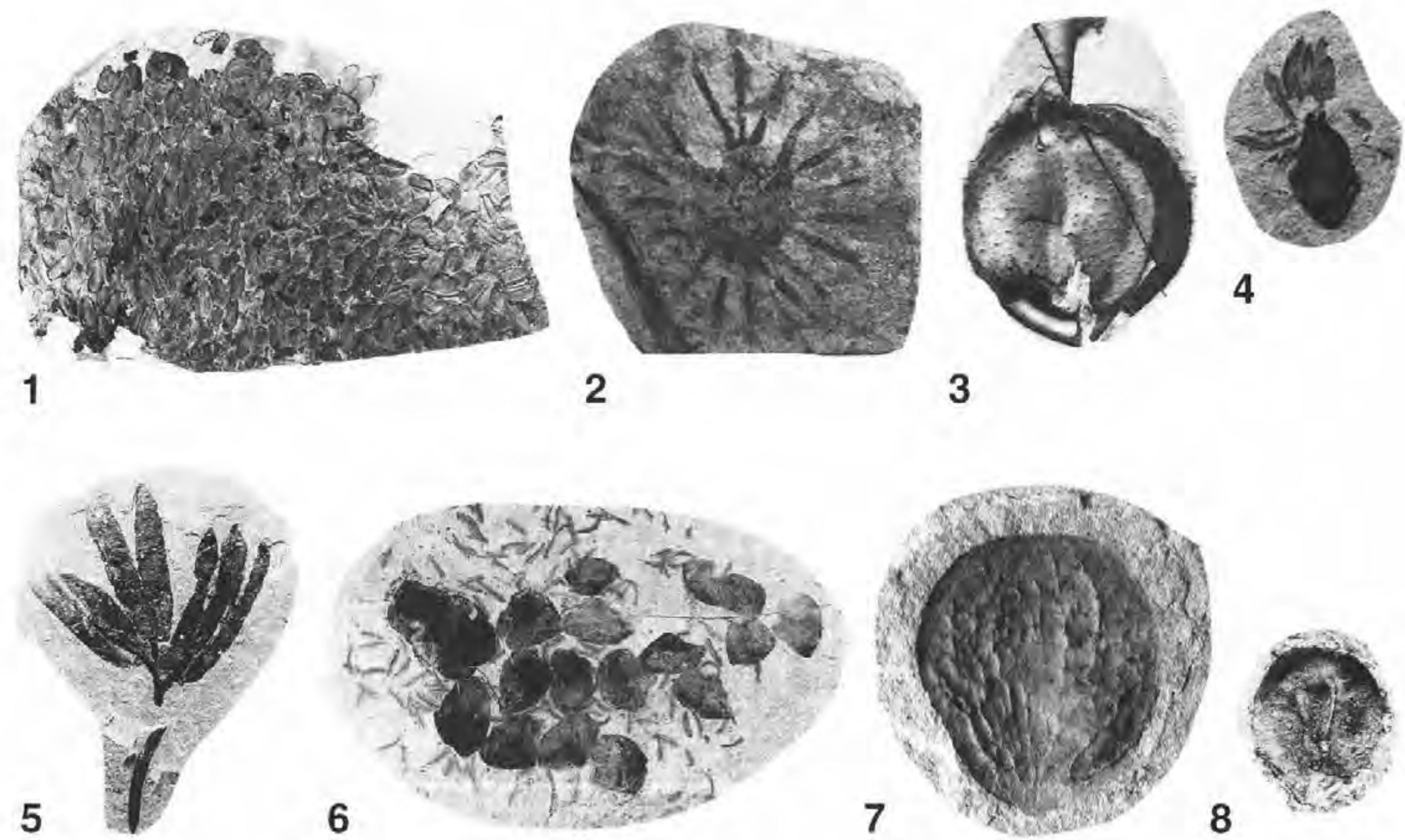

Plate 1. Flowers, fruits, and seeds that have been recognized at Republic since mid-1994. See Wehr (1995) for more illustrations of these kinds of fossils from Republic. UWBM, Univ. of Washington, Burke Museum; SR, Stonerose Interpretive Center. **1.** *Nuphar* sp. seed mass, UWBM 36804, loc. B4131, x1. **2.** *Nuphar* sp. stigmatic disc, SR 95-30-04, loc. B4131, x2. **3.** *Calycocarpum* sp. fruit, UWBM 95537, loc. B2737, x2.5. **4.** *Joffrea* sp. stamens, SR 95-15-11A, loc. B4131, x2. **5.** *Cercidiphyllum* sp. clustered pods, SR 93-9-7, loc. B4131, x1.5. **6.** *Joffrea* sp. stamens, SR 92-14-14, loc. B4131, x1. **7.** *Sabia* sp. fruit, SR 95-30-08, loc. B4131, x4. **8.** *Meliosma* sp. fruit, SR 95-30-12, loc. B4131, x3.

names) is given in Table 1. Thirteen of the families on this list are known also by fossil leaves found at Republic. Ten of the families are known only from their flowers, fruits, or seeds.

To understand the biogeography of the plants, it is helpful to compare the flowers, fruits, and seeds found at Republic with those recorded from other Eocene and Oligocene localities. The middle Eocene Clarno Formation of north-central Oregon has abundant fossil fruit and seed remains (Scott, 1954, Manchester, 1994); some of these taxa are shared with the Republic and British Columbia middle Eocene floras: *Cruciptera*, *Juglans*?, *Florissantia* (although a different species), *Calycites*, *Macginicarpa*, *Deviacer*, *Pteronepelys*, *Meliosma*, *Palaeophytocrene*, *Vitis*, *Palaeocarpinus*, *Craigia*, *Porana*, *Joffrea*, *Sabia*, *Calycocarpum*, *Ensete*, and *Emmenopterys*.

Shared with the Eocene Green River Formation floras of Wyoming, Colorado, and Utah are *Palaeophytocrene*, *Macginicarpa*, *Florissantia*, and vitaceous seeds. Shared with the middle Eocene Messel flora, from near Darmstadt, Germany, are *Cruciptera*, *Cedrelospermum*, and vitaceous seeds.

The Oligocene Bridge Creek flora of central Oregon (Meyer and Manchester, in press) contains, in common with Republic, several genera: *Ulmus*, *Acer*, *Cercidiphyllum*, *Cedrelospermum*, *Craigia*, *Nuphar*, *Florissantia*, and *Palaeophytocrene*.

During the concerted collecting that has been done at Republic, especially since 1977, new and rare varieties of flowers, fruits, and seeds are still being found regularly. These finds are helping us to have a clearer understanding of the paleogeographical distributions of many plants, both modern and extinct. These fossil finds continue to yield new information about the evolution of the flowering plants during the Early Tertiary, a critical time in the appearance and diversification of many angiosperm families and genera.

Acknowledgments

Without the donations of the following collectors, this article would not have been possible: Lisa Barksdale, Bob Geer, Donald Hopkins, Kirk Johnson, Henry Kowalyk, Donald Krom, Allie Kunkel, Chris Luckey, Madilane Perry, Robert Solt, Alex Strong, Peggy Toepel, and Michael Vermillion.

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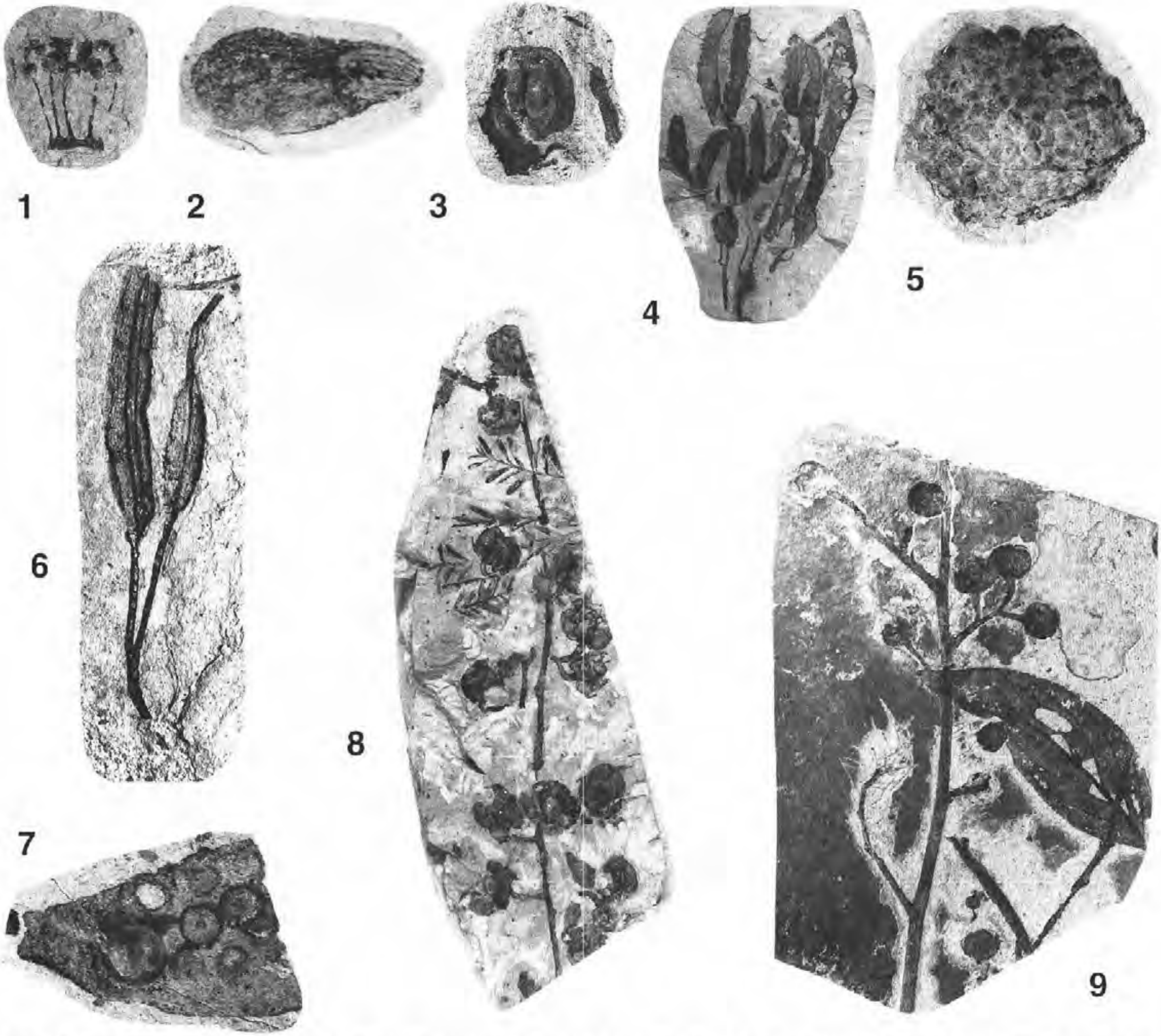

Plate 2. Flowers, fruits, and seeds that have been recognized at Republic since mid-1994. See Wehr (1995) for more illustrations of these kinds of fossils from Republic. UWBM, Univ. of Washington, Burke Museum; SR, Stonerose Interpretive Center. **1.** *Florissantia quilchenensis* Manchester stamens, SR 95-30-07, loc. B4131, x2.5. **2.** *Cedrelospermum* sp. fruit, UWBM 77570, loc. B4131, x5. **3.** *Carya/Juglans* sp. fruit, SR 95-30-03, loc. B4131, x1. **4.** Leguminosae? fruits, SR 92-13-2A, loc. B4131, x1. **5.** *Paleomyrtinaea* sp. (extinct genus) fruit, UWBM 77721A, loc. B2737, x2. **6.** cf. *Emmenopterys* sp. fruits, UWBM 77563, loc. B4131, x3. **7.** *Ensete* sp. fruits with seeds, UWBM 57225, loc. A0307, x3. **8.** Undetermined I fruits, UWBM 78162, loc. A0307, x1. **9.** Undetermined II fruits, UWBM 57473, loc. B4876 (Golden Promise mine), x1.

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Pollen and Spores Characteristic of Eocene Sediments at Republic, Washington

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We processed five samples of organic-rich silty shale from the fossil plant beds of the Klondike Mountain Formation on the north side of Republic, Washington, to investigate the characteristic pollen and spores from this important floral site. Some of these samples also contained fossil leaf remains. In a repeated effort to minimize damage to the fossil pollen, we used various alternative combinations of Schultze Solution, 5 percent potassium hydroxide, hydrofluoric acid, acetylation, sodium hypochlorite bleach, and heavy liquid flotation. However, all our samples yielded only poorly preserved particulate organic matter in which tissues and pollen were badly corroded and retained few morphological features.

Our samples consistently contained abundant charcoal and some poorly preserved pollen grains of the Pinaceae, including *Picea, Pinus, Abies*, and *Tsuga*. Because of the abundance of angiosperm leaf remains, we anticipated pollen of dicotyledonous plants, but we were able to identify only one dicot genus, *Betula*, and there appeared to be many isodiametric pollen/spore grains that were probably angiosperm pollen. Also common were fungal spore remains, and we found a few hyphae and monolete fern spores.

We were surprised at the character of our results, partly because we had gotten some moderately well preserved pollen from the Eocene Princeton locality in British Columbia. (See Pigg and Stockey, this issue.) We know of another site, the Tepee Trail Formation, Wyoming (considered to have been an upland site and which is of late Eocene age), where in spite of fossil monkeys and a small dicot and conifer leaf flora, the pollen obtained were rare and chiefly *Pinus*, with only an occasional grain of *Alnus* pollen. Similarly, the Beaverhead flora of Montana is chiefly composed of Pinaceae pollen while containing a diverse broadleaved woody flora that does not appear to be represented in the pollen record (Leopold and MacGinitie, 1972). Quality of pollen preservation at Republic is considerably worse that at the Tepee Trail or Beaverhead floral sites in the northern Rocky Mountains.

A preliminary pollen study of fossil-bearing lacustrine sediments from the One Mile Creek flora locality at Princeton, British Columbia, has yielded a small but significant list of moderately well preserved pollen. The leaf flora at One Mile Creek is considered to be coeval with the Republic flora and is floristically similar to that at Republic.

The co-occurring reproductive structures, foliage, and pollen of *Abies, Pinus*, and *Tsuga* from the Eocene sediments at Republic and One Mile Creek comprises some of the earliest known well-documented records of these genera. Pollen of *Betula* complements the well-preserved leaves and bracts reported by Wehr (see references cited in other articles, this issue) from the fossil beds at Republic.

Our interpretation of the poor preservation of microspores from Republic is that corrosion and abrasion of pollen and spores, perhaps in transport by surface runoff into the Eocene lake, occurred before deposition, not after. This conclusion is based on the consistently poor preservation of all the contained organic matter. Additionally, the lake may have been shallow enough so that wave action of oxygen-rich water could have degraded the pollen, and considerable movement of the sediments may have abraded it. Because Pinaceae pollen typically is more sturdy than most angiosperm pollen types, our results may be a case of differential preservation by which the more fragile angiosperm pollen is highly degraded.

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Northwest Paleontological Association Activities

August 10: Bill Smith will lead a field trip to the Coal Creek area near Longview to collect from the Cowlitz Formation.

September 7: Wes Wehr will speak about the fossil plants of the Republic area at 1:00 pm in the Burke Room at the Burke Museum, University of Washington.

For more information about these and other trips and lectures or the association, contact Bill Smith (president) at (360) 697-1859.

Natural Resources Teachers Workshop

The Northwest Natural Resources Institute (NNRI) will hold its fourth annual teachers workshop from July 29 through August 2 on the campus of Eastern Washington University (EWU) in Cheney. The five-day course for K–12 teachers will cover topics in the science behind the management of our region's natural resources: water/power, timber, agriculture, and mining. The workshop will include tours and grade-appropriate 'hands-on' teaching aids, as well as lesson-plan ideas for 'making bread in a bag' and 'how to make your own paper'.

The $75 registration fee includes lunch and an evening barbecue for teachers and their families. Two EWU undergraduate credits or one University of Idaho graduate credit will be available along with ESD 101 clock hours. Credit fees are the responsibility of the participant.

For more information, contact Shane Phillips at the NNRI, PO Box 2147, Spokane, WA 99201, (506) 459-4121.

A Checklist of Fossil Insects from Republic, Washington

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In 1992, Standley E. Lewis published an illustrated article and checklist of insects found in the Republic lakebed deposits. Additional finds and identifications allow us to update that list here (Table 1).

Conrad C. Labandeira of the National Museum of Natural History in Washington, DC, is currently studying Republic fossil plant/insect interactions as recorded by many distinctive types of insect damage displayed on the fossil leaves and other plant remains. These trace fossils have added several insect families to the Republic fauna, especially among the Lepidoptera (butterflies, moths).

For the insect identifications, we thank Standley Lewis (St. Cloud Univ.), David Grimaldi (American Museum of Natural History), Conrad C. Labandeira and John D. Oswald (National Museum of Natural History), Rod Crawford and Dennis Paulson (Univ. of Washington, Burke Museum), and Sheila Douglas (Univ. of Alberta).

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Table 1. Middle Eocene fossil insects of Republic, Washington

Ephemeroptera (mayflies)
- Heptageniidae (stream mayflies)

Odonata (dragonflies and damselflies)
- Lestidae
- Megapodagrionidae
- Megapodagrionidae or Platycnemididae
- Euphaeidae

Blattoidea (cockroaches)
- Blattidae (cockroaches)

Orthoptera (crickets and grasshoppers)
- Acrididae (short-horned grasshoppers

Isoptera (termites)
- family unknown

Dermaptera (earwigs)
- Forficulidae (earwigs)

Psocoptera (booklice and barklice)
- family unknown

Hemiptera (bugs)
- Coreidae? (leaf-footed bugs)
- Pentatomidae (stink bugs)
- Corixidae (water boatmen)
- Anthocoridae? (minute pirate bugs)

Homoptera (hoppers and aphids)
- Cercopidae (froghoppers and spittlebugs)
- Aphididae (aphids)
- Flatidae (flatid planthoppers)
- Fulgoridae (plant hoppers)

Neuroptera (lacewings)
- Hemerobiidae (brown lacewings)
- Osmylidae
- Chrysopidae (green lacewings)

Raphidioptera (snakeflies)
- family unknown

Coleoptera (beetles)
- Carabidae (ground beetles)
- Lucanidae (stag beetles)
- Cerambycidae (long-horned beetles)
- Curculionidae (snout beetles)
- Chrysomelidae (leaf beetles)

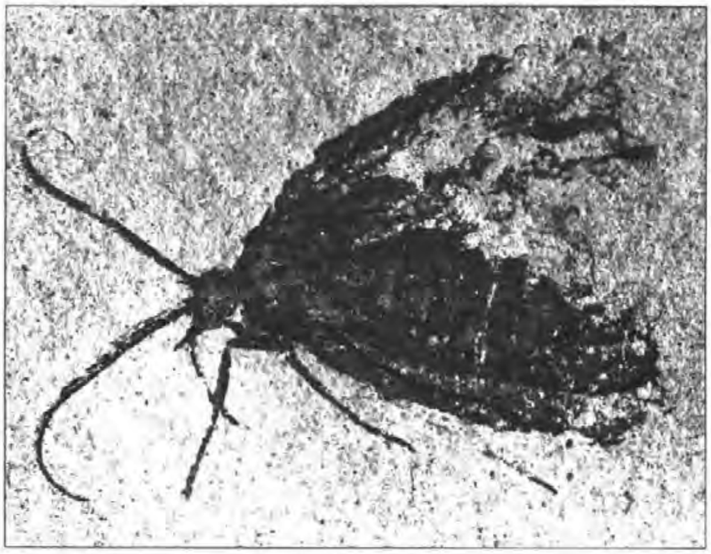
Trichoptera (caddisflies)
- Phryganeidae (large caddisflies)
- Limnephilidae (northern caddisflies)

Lepidoptera (moths and butterflies)
- Arctiidae (tiger moths)

Diptera (flies)
- Tipulidae (crane flies)
- Bibionidae (march flies)
  - *Plecia* sp.
- Mycetophilidae (fungus gnats)

Hymenoptera (sawflies, wasps, ants, and bees)
- Braconidae (braconid wasps)
- Ichneumonidae (ichneumonid wasps)
- Sphecidae (sphecid wasps)
- Megachilidae (leaf-cutting bees)
- Formicidae (ants)

An extinct species of march fly (*Plecia*), about x3.5 (Photo by Lisa Barksdale)



Tiger moth from Republic, the earliest record of the family Arctiidae. Body length ca. 2 cm. UWBM 66000A, loc. B2737. (Photo by Paul Schwartz.)

The Eocene Fishes of Republic, Washington

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Eocene fossil fishes were discovered in the Republic area by J. B. Umpleby during the course of geological surveys early in the century (Umpleby, 1910). Umpleby's specimens were sent to the U.S. National Museum and identified by Eastman (1917) as belonging to the genus *Amyzon* (Family Catostomidae) in a species named by E. D. Cope (1893) on fossils from the Similkameen River area of British Columbia. Another geologist, R. C. Pearson of the U.S. Geological Survey, discovered fossils near Toroda Creek in the 1960s. Fossil fish expert D. Dunkle (as quoted in Pearson, 1967) thought they were related to species known from the Green River Formation of Wyoming. Work by geologists about the same time also cleared up confusion surrounding the age of the fossils, assigning them to the middle Eocene using radiometric dating methods. A third early discovery was made by Republic youth R. Woodruff, who collected fossil fish near the Tom Thumb mine as a hobby; some of his finds were later given to me for the University of Alberta, and new collections were made when I visited Republic in 1977 and 1978. All of these discoveries formed the basis for our early knowledge of Republic fossil fishes.

At least five species of fish lived in the Eocene lakes of the Republic area. Though all of them would appear modern if we could see them alive, all five species are extinct—four represent extinct genera, and one belongs to an extinct family.

The least well known is a species of *Amia* (Family Amiidae, an ancient group whose only living species is the bowfin) usually represented only by its scales. Fish can lose scales and then grow replacements, so the presence of isolated scales does not necessarily imply that the fish had died. Even replacement scales can sometimes be found as fossils. Judging by the size of the *Amia* scales, these fish could have reached 30 cm or more in length. In the Princeton area of British Columbia, a more complete specimen has been found and the species *Amia hesperia* Wilson (1982) named. Finding plentiful amiid scales usually means that the enclosing sediments were deposited in shallow, often weedy water, because amiids usually prefer such habitats.

The family Hiodontidae is another old group; this one has two living species, mooneye and goldeye, both in the genus *Hiodon*, that specialize in eating insects. The Republic hiodontid is in an extinct genus and is called *Eohiodon woodruffi* Wilson (1978), after the Republic youth who found several specimens. A different species, *Eohiodon rosei*, is much more abundant in British Columbia, but both species occur together at Horsefly, BC. Males of both *Hiodon* and *Eohiodon*, when they become (or became) reproductively mature, develop thickened anal fin rays that can be recognized in fossils. The Eocene hiodontids are smaller than either living species, growing to about 15 cm long. The closest relatives of hiodontids occur in Cretaceous rocks of China, but none of the Chinese species is known to have sexually dimorphic anal fins (Wilson and Williams, 1992).

The suckers, Family Catostomidae, are today a prominent part of the North American fauna; in the Eocene they had no competition from minnows and are very common fossils in Eocene lakebeds. Republic's fossil sucker, known from whole skeletons as well as separate bones and scales, is now identified with the species *Amyzon aggregatum* Wilson (1977), which is also common in Eocene deposits of British Columbia and is known to reach more than 20 cm in length.

Perhaps the most significant of Republic's Eocene fish is *Eosalmo driftwoodensis* Wilson (1977) (Fig. 1), first named on specimens from British Columbia. The oldest fossil member of the family Salmonidae (salmon and its relatives), *Eosalmo* has features intermediate between those of subfamily Salmoninae (salmon, trout, charr) and those of subfamily Thymallinae (grayling), indicating that salmon evolved from ancestors with grayling-like features (Wilson and Williams, 1992). Though small as well as larger individuals of most Republic species are commonly found, almost all *Eosalmo* speci-

Figure 1. A specimen of *Eosalmo driftwoodensis*, the Eocene salmonid known from Republic fossil beds and similar deposits in British Columbia. This specimen is in the Miguasha Natural History Museum, Quebec. Note centimeter ruler for scale. (Photo courtesy of the Royal Tyrrell Museum of Palaeontology.)

mens are full-grown; perhaps the young spent most of their time in nearby streams. *Eosalmo* has very modern tail, body, and scales but more primitive skull and jaws, suggesting that advanced features of modern salmonids' body and tail evolved long ago, while changes in their heads happened more recently. The presence of both large and small specimens of *Eosalmo* found together at some localities in British Columbia also seems to confirm the idea that primitive salmonids spent their whole lives in fresh water (like many modern trout), while the habit of running to the sea and returning to spawn, best developed in today's Pacific salmon, evolved later (Stearley, 1993).

The final species is *Libotonius pearsoni* Wilson (1979), first recognized in rocks near Toroda Creek and named after geologist Pearson. Distantly related to the modern trout-perch family Percopsidae but classified in the extinct family Libotoniidae, individuals of *L. pearsoni* were small fish, reaching only about 5 cm long, with small fin spines and flattened heads. The related *L. blakeburnensis* occurs near Princeton, BC. Like amiids, abundant libotoniids seem to indicate deposition in shallow water.

Overall, Republic's fossil fishes are most closely related and comparable in diversity to Eocene fishes from British Columbia. They also have much in common with Eocene fishes from Montana (Kishenehn Formation; Constenius and others, 1989), Colorado (Florissant Formation: Evanoff, 1994), and Wyoming (Green River Formation; Grande, 1984) although the Green River fauna is an order of magnitude more diverse.

The number of species in any one lake is correlated with age and size of the lake and its drainage basin (Smith and others, 1988). On this and other evidence, we believe that the Eocene fish beds in Colorado, Montana, Washington, and British Columbia were deposited in relatively small basins as compared with the Green River Formation. However, the large proportion of Republic's species and genera shared with these other deposits suggests that the drainage basins might have been connected by river systems.

At some localities (such as the roadcut in the center of the town of Republic), most specimens consist of disarticulated skeletons, bones, and scales, suggestive of shallow, warmer, and nearshore conditions. At other localities (such as some sites near the Tom Thumb mine), most of the specimens are complete skeletons, suggestive of deposition in deeper, cooler, offshore, and possibly anaerobic water.

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Amyzon, a common fossil fish (sucker), ca. x2.0. Found by Nathan Shiflett.

The Significance of the Princeton Chert Permineralized Flora to the Middle Eocene Upland Biota of the Okanogan Highlands

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Introduction

The Okanogan Highlands contain a middle Eocene fossil biota of astonishing diversity. Along with those at Messel in Germany and in the Green River Formation of western North America, this fossil biota is among the most informative sources we have on Eocene life. The Republic localities contain one of the most diverse Eocene leaf compression floras in the world, as well as an intriguing array of insects and fish. Because these fossils faithfully preserve such delicate leaf structures as higher order venation and tooth morphology, they document the complex Eocene diversification that occurred in such families as the Rosaceae. Leaf fossils at Republic also show characteristic patterns of insect or fungal damage that demonstrate evidence for interactions that occurred on the plant surfaces.

A second important Eocene plant assemblage of a different type in the Okanogan Highlands is found in the Princeton chert of southern British Columbia. In contrast to the compressed flora of Republic and the essentially coeval leaf floras of British Columbia at Princeton, Quilchena, McAbee, and Driftwood Creek at Smithers, plant and fungal remains from the chert are three-dimensionally preserved. This preservation allows us to compare the internal cellular structure of fruits, seeds, flowers, stems, and leaves of vascular plants and the morphology of fungi with both other fossil and modern forms. While studies of the chert contribute significantly to the record of the dicotyledons (for example, the rose and grape families), they also provide some of the only records of Eocene fungi and monocots (plants such as palms and lilies) for the Okanogan Highlands.

Many of the Princeton chert plants are currently known from only one organ, such as seeds, but others are represented by a collection of plant 'parts'. For example, the taxodiaceous conifer *Metasequoia milleri* (related to modern dawn redwood and bald cypress) is recognized from seed and pollen cones, stems, roots, leaves, pollen, and seeds (Basinger, 1976a, 1981, 1984; Basinger and Rothwell, 1977; Rothwell and Basinger, 1979). Interconnected stems, leaves, roots, and buds are all known for the semiaquatic dicot *Eorhiza* (Robison and Person, 1973; Stockey and Pigg, 1994). Several monocots, including palms, rushes and sedges, and members of the lily family (for example, *Uhlia*, *Ethela*, and *Soleredera* [Erwin and Stockey 1991, 1992, 1994]) are also known from interconnected stem, root, and petiolar remains.

The anatomical structure of cones and flowers provides detailed information about the evolutionary relationships of Eocene plants. Many of the flowers and cones contain their original pollen grains, which further aid in identification. Leaf and stem anatomy is important for classification, especially in monocots (Tomlinson, 1961; Metcalfe, 1971). Even when these plants' reproductive structures are unknown, they can be identified by their leaf and stem structures. Wood from twigs and stems found in the chert provides other important data for classification and ecological interpretation.

In this article, we explore how plant and fungal fossil remains from the Princeton chert relate to those from the Republic localities and how together they provide a detailed view of the high diversity and complex interactions of the middle Eocene plant and fungal biota of the region.

The Princeton Chert

The chert locality is exposed on the east bank of the Similkameen River near the abandoned mining town of Allenby and approximately 8.4 km south of Princeton, BC. Forty-nine separate chert layers are interbedded with coal horizons, and individual layers contain differing plant assemblages. The chert is regarded as middle Eocene (50 million years old) on the basis of palynology, fossil mammals and fish, and potassium-argon dating (Cevallos-Ferriz and others, 1991).

Fossils in the chert are preserved together as a mixture of plant fragments that comprise a sort of fossilized 'compost'. The fossils were formed by silicification, a process in which ground water containing a high concentration of silica (probably of volcanic origin) percolated into mats of plant material in various freshwater lacustrine and fluvial sites. The plant tissues then became supersaturated or 'permineralized' with the mineralized waters, and the silica crystallized, trapping the plant cells in the newly formed rock matrix. This means of preservation thus allows for precise study of cellular anatomy of the plant organs.

The chert blocks are slabbed with a rock saw, and then individual plant organs are identified and studied by techniques that allow for numerous closely spaced serial sections that can be reassembled for three-dimensional reconstruction of the organ being studied. This process allows studies of plant structure much like the 'CAT' scan (tomography) used in medicine today. Because the plants are preserved as fragments, researchers then attempt to reassemble 'whole plants' by finding interconnections and structural similarities among the separate organs.

The chert was first collected in the 1960s by R. F. Boneham, who made a palynological (pollen and spore) study of several Eocene basins in British Columbia. In his study of the cherts and interbedded coals (Boneham's "locality I") he found a high percentage of palynomorph remains of fungal origin (Boneham, 1968). Boneham gave samples of the chert to Chester A. Arnold, of the University of Michigan Museum of Paleontology, who recognized dennstaedtioid ferns (forms related to the modern hay-scented and bracken ferns) in the matrix.

Other early descriptions of plants from the Princeton chert include those of conifer remains by Miller (1973) and of the semiaquatic dicot *Eorhiza* (Robison and Person, 1973). During the 1970s additional studies of the chert produced descriptions of stems, leaves, roots, pollen, and seed cones of *Metase-*

quoia milleri (see, for example., Basinger, 1976a) and the flower *Paleorosa* (Basinger, 1976b).

Since the early 1980s, Ruth A. Stockey, University of Alberta, and her students and associates have described numerous species from this high diversity flora. To date, 36 plants have been recognized from the chert: these include 5 ferns, 6 conifers, 19 dicots, and 6 monocots, as well as 7 types of fungi (Cevallos-Ferriz, and others, 1991; Sun and Stockey, 1991; Erwin and Stockey, 1992, 1994; LePage, and others, 1994, 1995; Stockey, 1984, 1994; Wehr and Hopkins, 1994; Cevallos-Ferriz, 1995; Hill-Rackette and others, 1995; Phipps and others, 1995; Stockey and Wehr, in press; Table 1). At least nine additional dicot wood types, nine additional monocots, and numerous fungi are among the types yet to be described (Stockey, unpublished data).

Fossil Fungi

The presence of fossil fungi as important components of the Princeton chert was recognized in the earliest study by Boneham (1968). He found that more than 80 percent of the palynomorphs present were assignable to the fungal spore genus *Brachysporium* and to the algal, fungal, or bryophyte palynomorph *Inapertisporites*. More recently, fungi have been found in several host plants, including palm leaves, stems of *Eorhiza*, seeds, fruits, and flowers of Lythraceae, seeds of Nymphaeaceae, flowers of Alismatidae, and a dicot flower of uncertain affinity. These fungi represent a diverse assemblage that includes forms similar to those of the major groups of modern higher fungi, including the ascomycetes (sac fungi), the basidiomycetes (club fungi), and members of the form division Fungi Imperfecti. Possible ascomycetes are represented by three forms similar to the order Dothideales, which are found on leaves of the fossil palm *Uhlia* (Erwin and Stockey, 1994). These fungi are the so-called "tar-spot" pathogens that cause damage to leaves in tropical monocots such as palms and screw-pines (Pandanaceae) today (Farr and others, 1989, p. 834; Cannon, 1991; LePage and others, 1994).

A second group of fungi found in the chert, the Hyphomycetes (molds in Fungi Imperfecti), resembles the modern genera *Alternaria* and *Cercospora*. These molds cause blights, fruit and seed rot, and leaf spots in a wide variety of modern plants. In the chert, fungi of this type infect several types of seeds.

Basidiomycetes are represented by the first known fossil smut fungus, found in the anthers of an unnamed flower (Currah and Stockey, 1991). Smuts are fungal agents that today commonly infect crop plants such as corn and wheat. Presumably they had a similar mode of infecting flowers and fruits in the Eocene. Fossil fungi thus provide information not only about their taxonomic diversity but, perhaps more importantly, about their important ecological role in the Eocene biota.

In one study, the sequence of fungal infection of the tissues of the aquatic flower and fruits of *Princetonia allenbyensis*, a dicot of uncertain affinities (Stockey, 1987; Stockey and Pigg, 1991), has been documented (Hill-Rackette and others, 1995). In this pathogenic process, septate hyphae (fungal filaments with internal cross walls) invade the external surfaces of the flowers and fruits, penetrate between carpels to the center of the fruit, then invade the fruit's seeds through their attachment to the fruit axis. Characteristics of this fungus show that it is similar in form and function to the modern coelomycetous fungus *Phoma*. This study indicates that pathogenic relationships were part of the Eocene ecosystem and that these interactions may have been as complex as some today.

More recently, LePage and others (1995) have documented the first fossil evidence of a more beneficial plant/fungus relationship shown by the ectomycorrhizal fungal genus *Rhizopogon* (Boletaceae) in *Pinus* roots. The colonization of fossil pine roots by these fungi resembles mycorrhizal associations of modern pine roots, suggesting that this type of mutualism and its consequent plant adaptations go back least 50 million years.

Monocot Remains

While the Republic flora contains only a few remains of the monocot genera *Smilax* (Smilacaceae, greenbriers) and *Typha* (Typhaceae, cattails) (Wehr and Hopkins, 1994), the Princeton chert has at least five families of monocots, including vegetative remains of Alismataceae, Liliaceae, Juncaceae/Cyperaceae, and Arecaceae, fruits and seeds of Araceae, and probable floral remains of some group of Alismatidae (Erwin and Stockey, 1989, 1991, 1992, 1994; Cevallos-Ferriz and Stockey, 1988b; Cevallos-Ferriz and others, 1991; Stockey, 1994; see Table 1). These fossils add greatly to our understanding of Eocene monocot evolution by providing anatomically preserved examples of families that are otherwise poorly known for that time.

The family Alismataceae, which includes many aquatic and marsh plants such as *Sagittaria* (arrowhead), is represented in the chert by petioles of the genus *Heleophyton helobiaeoides* (Erwin and Stockey, 1989). Liliaceae, the lily family, is also present, as evidenced by stems and attached leaves and roots of *Soleredera rhizomorpha* (Erwin and Stockey, 1991). The families Juncaceae and Cyperaceae, which include the rushes and sedges, respectively, are difficult to distinguish from one another on the basis of vegetative remains. *Ethela sargantiana*, a plant known from stems, attached leaves, and roots, probably represents one of these two families (Erwin and Stockey, 1992).

The Arecaceae, or palm family, has an extensive fossil record. Palms are represented in the Princeton chert by *Uhlia allenbyensis* (Erwin and Stockey 1991, 1994). Stems, attached petioles and roots, mid-ribs, and laminae have been found. These were coryphoid (or fan) palms and indicate a subtropical climate for the middle Eocene at this site.

Although most of the monocot remains in the chert are vegetative, fruits and seeds with embryos are known for *Keratosperma allenbyensis* (Araceae) (Cevallos-Ferriz and Stockey 1988b). These curved embryos show shoot and root apices, as well as one large cotyledon. Among the Princeton fossils are the oldest known seeds of the subfamily Lasioideae, tribe Lasieae, of the large and diverse family Araceae, which includes skunk cabbage, arum lily, and jack-in-the-pulpit.

Flowers that contain the smut fungus discussed above have been compared with the aquatic monocot families in the order Najadales. These flowers share a suite of features with several families including the Aponogetonaceae, Scheuchzeriaceae, Potamogetonaceae, and Juncaginaceae.

Comparison of Princeton Chert and Republic Floras

Part of the value of the Princeton chert is that it independently confirms the presence in the Eocene Okanogan Highlands of families known from the Republic leaf flora. Several important families that were undergoing significant Eocene diversi-

Table 1. Plants from the Princeton chert, British Columbia

Taxon	Some modern relatives	Parts known	References
Osmundaceae			
cf. *Osmunda*	Cinnamon fern, royal fern, interrupted fern	Rachis	G. W. Rothwell, 1996, written commun.
Polypodiaceae			
Dennstaedtiopsis aerenchymata	Hay-scented and bracken ferns	Rhizomes, fronds, sporangia, spores	Basinger & Rothwell, 1977; R. A. Stockey, unpub. data, 1996
Dryopteridaceae			
Diplazium n. sp.	Glade fern	Rhizomes, fronds, sporangia, spores	Rothwell and others, 1994
Onocleoid fern	Sensitive fern	Rhizomes with attached frond bases	G. W. Rothwell, 1996, written commun.
Blechnaceae			
Blechnoid fern	Swamp fern	Rhizomes with attached frond bases	G. W. Rothwell, 1996, written commun.
Pinaceae			
Pinus andersonii	Pines	Leaves	Stockey, 1984
Pinus arnoldii	Pines	Ovulate cones	Miller, 1973; Stockey, 1984
Pinus princetonensis	Pines	Ovulate cones	Stockey, 1984
Pinus similkameenensis	Pines	Leaves, twigs	Miller, 1973; Stockey, 1984
Pinus sp.	Pines	Pollen cone	Phipps and others, 1995
Taxodiaceae			
Metasequoia milleri	Bald cypress, redwood, dawn redwood	Ovulate cones, pollen cones, stems, leaves, roots	Basinger, 1976a, 1981, 1984; Basinger and Rothwell, 1977; Rothwell and Basinger, 1979
Magnoliaceae			
Liriodendroxylon princetonensis	Tulip tree, magnolias	Woody twigs	Cevallos-Ferriz and Stockey, 1990a
Lauraceae			
New taxon	Sassafras, laurel, bay	Inflorescences, fruits, twigs, leaves	Sun and Stockey, 1991; R. A. Stockey, unpub. data, 1996
Nymphaeaceae			
Allenbya collinsonae	Water lilies	Fruit, seeds	Cevallos-Ferriz and Stockey, 1989
Grossulariaceae			
Ribes	Gooseberries, currants	Fruits, seeds	Cevallos-Ferriz, 1995
Rosaceae			
Paleorosa similkameenensis	Rose family	Flowers, pollen, ?embryo	Basinger, 1976b; Cevallos-Ferriz and others, 1993
Prunus allenbyensis	Cherries, apricots, plums	Woody twigs	Cevallos-Ferriz and Stockey, 1990b
Prunus sp. Type 1	Cherries, apricots, plums	Fruits	Cevallos-Ferriz and Stockey, 1991
Prunus sp. Type 2	Cherries, apricots, plums	Fruits	Cevallos-Ferriz and Stockey, 1991
Prunus sp. Type 3	Cherries, apricots, plums	Fruits	Cevallos-Ferriz and Stockey, 1991
Lythraceae			
Decodon allenbyensis	Swamp loosestrife	Fruits, seeds	Cevallos-Ferriz and Stockey, 1988a
cf. *Lythrum*	Purple loosestrife	Fruit, seeds	Cevallos-Ferriz and Stockey, 1988a
Vitaceae			
Ampelocissus similkameenensis	Grape family	Seeds	Cevallos-Ferriz and Stockey, 1990c
Seed type 1	Grape family	Seeds	Cevallos-Ferriz and Stockey, 1990c
Seed type 2	Grape family	Seeds	Cevallos-Ferriz and Stockey, 1990c
Sapindaceae			
Wehrwolfea striata	Soapberry family	Flowers, pollen	Erwin and Stockey, 1990
Myrtaceae			
Paleomyrtinaea princetonensis	Guavas	Fruits, seeds	Pigg and others, 1993
Cornaceae			
Mastixicarpum	Dogwood family	Fruits, seed	Wehr, 1995; R. A. Stockey and B. A. LePage unpub. data, 1996
Dicotyledon			
Eorhiza arnoldii	Unknown	Stem, attached roots, axillary branches, leaves	Robinson and Person, 1973; Stockey and Pigg, 1994
Princetonia allenbyensis	Unknown	Inflorescences, flowers, fruits, seeds, pollen	Stockey, 1987; Stockey and Pigg, 1991
Alismatidae			
New taxon	Unknown	Flowers	Stockey, 1994
Heleophyton helobiaeoides	Arrowhead	Petiole	Erwin and Stockey, 1989
Arecaceae			
Uhlia allenbyensis	Fan palms	Stems, attached petioles and roots, midribs, laminae	Erwin and Stockey, 1991, 1994
Araceae			
Keratosperma allenbyensis	Arum lily, skunk cabbage	Fruits, seeds, embryos	Cevallos-Ferriz and Stockey, 1988b
Juncaceae/Cyperaceae			
Eihela sargantiana	Sedges and rushes	Stems, attached leaves and roots	Erwin and Stockey, 1992
Liliaceae			
Soleredera rhizomorpha	Lily family	Stems, attached leaves and roots	Erwin and Stockey, 1991

fication have strong records in both the leaf and chert floras, for example, the Rosaceae and Sapindaceae. While the Republic flora documents the diversification of more than 50 leaf types representing all four subfamilies of Rosaceae (Wehr and Hopkins, 1994; Wehr, 1995), the Princeton chert provides floral, fruit, and wood evidence of several members of this family.

Paleorosa similkameenensis is the oldest flower of the Rosaceae (Basinger, 1976b; Cevallos-Ferriz and others, 1993). This petrified flower contains the oldest known rosaceous pollen, which is extremely rare. The flower has features that place it in the presumably most primitive subfamily of the Rosaceae, the Spiroideae, but it also has some features of the subfamily Maloideae, which includes the apples, pears, and quinces. A third subfamily of Rosaceae, the Prunoideae, includes the stone-fruits such as cherry, apricot, and peach. This subfamily is represented in the chert by both fossilized *Prunus* wood and fossil endocarps or 'stones' similar to those of modern fruits of this genus (Cevallos-Ferriz and Stockey, 1990b, 1991).

The Sapindaceae (or soapberry family), known in the Republic leaf record, is represented in the Princeton chert by the flower *Wehrwolfea striata* (Erwin and Stockey, 1990). Flowers at two developmental stages with pollen present have been described and are most similar to those of the tribe Dodoneeae, believed to be a primitive group in the family Sapindaceae. A third important family at Republic, the Grossulariaceae, which includes the gooseberries and wild currants, may also be represented in the chert by fruits and seeds of *Ribes* (Cevallos-Ferriz, 1995). These remains are being studied at the present time.

Other dicot families with perhaps less extensive but still significant records are the Magnoliaceae, Lauraceae, Nymphaeaceae, Lythraceae, Myrtaceae, and Vitaceae (Cevallos-Ferriz and Stockey, 1988a, 1989, 1990a, 1990c; Sun and Stockey, 1991; Pigg and others, 1993; Wehr and Hopkins, 1994). For example, tentative determinations of the genera *Decodon* and *Prunus* from the leaf record were strengthened by the presence of anatomically preserved seeds and fruits of these taxa from the chert (Stockey and Wehr, in press).

Plant fossils from Republic, Princeton, and other localities of the Okanogan Highlands, as well as insect, fish, and other animal remains and fungi, give a better view of a past biota than is possible from one source alone. As more is learned from each source, an increasingly detailed understanding will emerge for the middle Eocene world of northwestern North America.

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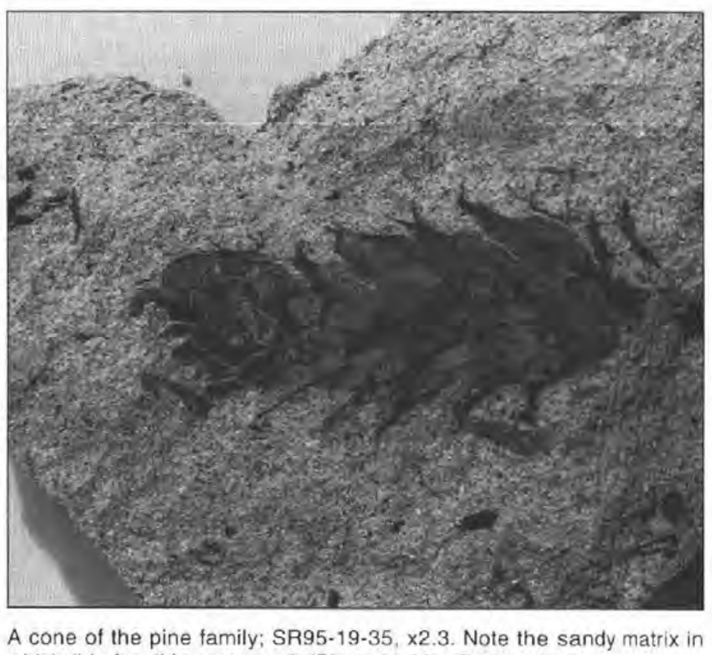
Fossil cone of *Metasequoia;* SR95-13-15, x1.75. (Photo by Lisa Barksdale.)



A cone of the pine family; SR95-19-35, x2.3. Note the sandy matrix in which this fossil is preserved. (Photo by Lisa Barksdale.)

Volcanic Arcs and Vegetation

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Introduction

Many of us who were students of paleobotany during the mid-1980s vividly recall the appearance in 1987 of Wolfe and Wehr's partial monograph of the middle Eocene Republic flora. At Republic, temperate plants (including pine, spruce, fir, gooseberry, blackberry, hawthorn, maple, linden, and many others) co-occurred with extinct members of plant families now limited to the tropics (such as *Barghoornia* in the Burseaceae or torchwood family), confirming that Eocene forests were compositionally unlike any known today.

The Republic flora is also interesting because, despite the almost 50 million years since it grew, many living temperate genera were present. Previously it had been thought that the temperate (or *microthermal*) families, which represent numerical and taxonomic dominants in modern mid-latitude forests, diversified primarily in response to climate cooling during or after the Oligocene (33–24 million years ago). That diverse forms in some of these families grew at Republic during the warmest interval of the Tertiary came as a surprise.

Wolfe (1972, 1977) had long suggested that "uplands" of the Pacific Northwest were refuges for microthermal groups excluded from the "lowlands" during the Eocene Warm Period (roughly 57.5–48 million years ago).

Republic provides the best evidence to date that this was indeed the case and that some of these groups underwent dramatic diversification in the moist upland forests. Where, when, why, and particularly how these lineages diversified so readily and apparently so rapidly remain some of the most intriguing questions in paleobotany.

An understanding of the interaction among geological/geomorphological processes, climate, and evolutionary constraints and advantages of the plant lineages growing at the time may help answer these questions. However, scientists have a much better understanding of the biology of plants and of the pattern of climate change during the Tertiary than they do of the geological and geomorphic processes that shape Earth's landscape. A real need exists for detailed microstratigraphic/sedimentological and taphonomic analysis of paleofloras in order to understand them in the context of landscape-level physical processes and regional settings. Many paleo- botanical publications vastly oversimplify the physical landscape even at the largest and most fundamental scale.

For example, even the term 'upland', as used in the paleobotanical literature, is somewhat vague because it ignores the processes by which topographic features form and change through time. When, as paleobotanists, we think of uplands, we very likely envision mountains, and it is likely that we think of these mountains as essentially static geomorphic features over significant periods of geologic time.

Paleofloras are, of course, not preserved on mountains, but in much lower elevation depositional basins, which are commonly associated with mountains. The paleobotanical record is a direct consequence of geological processes that control the sedimentology and stratigraphy of basin fill. Mountains are dynamic features that form and change quickly in geological time, ultimately erode, and are not preserved in the record, although they have a profound impact on the surrounding environment while they exist. These impacts—on topography, on local climate, and on site ecology both in the mountains themselves *and in the basins surrounding them*—are primary controls on regional vegetation.

One major result of the mountain–basin relationship is that vegetation presumed to have been growing at high elevation rarely makes it into the fossil record. Any understanding of what ancient high-elevation vegetation really looked like should be considered speculative at best. However, paleofloras from certain types of basins associated with volcanic mountain chains of convergent continental margins, including the Republic flora, may fit into the rare category of true 'upland' floras. Some paleofloras of comparable age possibly grew at higher elevations than Republic, but it is at Republic that we see the most dramatic expression of middle Eocene temperate forest richness.

The Interior Arc and Its Vegetation

Volcanic arcs are mountain chains of composite stratovolcanoes (Cascade-type volcanoes), which are produced by the melting of subducted oceanic crust at convergent (subduction) continental margins. All upland middle Eocene paleofloras from western North America, including Republic, occur in basins associated with what is often called the Eocene Interior Arc. This arc extended from central British Columbia, south through eastern Washington (the Republic graben), Idaho (the Challis Group), and western Montana and Wyoming (the Absaroka Group), and ended in northern Utah—essentially the region slightly west of the modern Northern Rocky Mountains Province. It was the dominant topographic feature in northwestern North America between about 50 million and about 40 million years ago, when arc magmatism shifted westward to form the Western Cascade arc.

Because of their intermediate magmatic composition and their characteristic modes of eruption, stratocones tend to be large features that can form quickly (in tens to hundreds of years) and erode rapidly. Basins associated with arcs typically host outstanding fossil plant assemblages because they experience rapid rates of subsidence while simultaneously receiving massive fine sediment input from volcanic sources directly associated with them. Furthermore, arc basins form *within and directly adjacent to* the arc edifices, thus producing the unusual circumstances of depositional basins associated with mountains. The result is a setting optimal for the preservation of delicate plant material and one that potentially includes vegetation from true upland habitats.

What did the Eocene Interior Arc look like? Some of the middle Eocene arc volcanic centers, like the Absaroka volcanic province, included very large and possibly long-lived composite stratocones with moderate-elevation intervening basins. Other centers, like the Clarno volcanic field in central

Oregon, consisted of smaller, short-lived cones on a low-lying landscape (White and Robinson, 1992). The Republic flora was deposited within a graben associated with active volcanoes, which were possibly similar to those of the Clarno field.

In general, most arc settings consist of volcanic edifices with summits on the order of 500 to 1,000 meters above the surrounding landscape. In this respect, the volcanoes resemble higher elevation 'islands' in a lower elevation 'sea'. If the regional landscape has been tectonically uplifted, the intervening 'sea' may lie several thousand meters above actual sea level, although most are at only a few hundred meters in elevation. The Republic graben probably lay between 800 and 1,500 meters during the middle Eocene, which is relatively high for an arc basin.

Only recently have scientists begun to understand the sedimentary record of arc-associated basins (for example, Smith, 1991). It is in the sedimentary record of the arc basins that paleobotanists must look for evidence about the environment in which arc vegetation grew and how the environment and the vegetation that inhabited it changed through time. The arc basin sedimentary sequence is shaped by two primary variables: (1) the size, volume, construction, and persistence through time of the volcanic sediment source, which determines the magnitude, periodicity, and style of volcanic sedimentation in the basins; and (2) the subsidence history of the basin and the distance between the basin and the volcanogenic sediment source, which determines which portion of the available sediment is actually preserved. Of course, plant debris incorporated into the sediment delivery system represents a part of the 'sediment' deposited in the basins. The interpretation of *where* and *when* the basin fill originated with respect to the volcanic sediment source largely determines what information can potentially be obtained from the plant debris enclosed within it. Such work is the province of volcaniclastic sedimentologists and stratigraphers, along with plant paleotaphonomists.

While not always the case, the paleobotanical record of many arc basins is often skewed toward vegetation growing during eruptive epochs (intervals of heightened volcanic activity which may last as long as a few thousand years) and to specific horizons deposited just prior to, during, or immediately after individual eruptions. This is simply because the processes by which sediment is transported and deposited are more favorable for plant preservation during eruptive periods than between them and because the sedimentary pile of many arc basins is dominated by massive amounts of minimally reworked debris stripped from the volcano flanks within a few decades to, at most, a hundred or so years after eruptions.

In arc basins relatively far from the volcanic sediment source (such as the Green River Basin, Utah, or the Republic graben) this material is of fine grain sizes and deposited over many years. In contrast, basins very close to the volcanoes are dominated by coarser, more rapidly deposited debris (for example, the Eocene Copper Basin in Nevada [Axelrod, 1966] and the Germer flora of Idaho [Edelman, 1975]).

While habitats near vents experience frequent and profound devastation from eruptions, more distant habitats are minimally disturbed except in the very largest eruptions. The net effect is to produce a fossil record that is punctuated in time and highly variable over distances on the order of a few kilometers. This heterogeneity reflects both variability in the living vegetational matrix and variability in the processes by which plant debris enters the sedimentary record.

Unless the elevational thermal gradient has changed radically since the Eocene, many stratocones of the Interior Arc must have been high enough to have supported microthermal vegetation on their upper slopes. Recall, though, that the actual arc edifices erode and do not enter the record. What does enter the stratigraphic record is the vegetation growing in the basins adjacent to the volcanoes. If the basins lay at relatively high elevations, they may have supported uniform microthermal forests. However, it is unlikely that many arc basins lay high enough during the Eocene Warm Period.

The diverse forests of Republic include a mix of plants from historically microthermal and megathermal lineages, suggesting that the Republic graben lay somewhere in the ecotone between temperate and tropical vegetation. Presumably, true microthermal forest occupied higher elevation sites while tropical vegetation may have occurred at lower elevations and (or) closer to the ocean.

Most interesting is that at Republic, for the first time in the Tertiary paleobotanical record, one sees the intergradation of microthermal and megathermal vegetation to produce extremely diverse forests composed of plants with disparate and complex vegetational histories. The germane questions are: How did this massive intergradation occur? and Why did some families diversify so readily at this time?

There is some evidence that microthermal floral elements can enter warmer forests as successional colonizers. For example, Wang (1961) found that successional colonizers of disturbed tropical forest in mainland China produce a woody vegetation with a decidedly more 'temperate' composition than minimally disturbed forest of the same region.

The colonizing woody vegetation of the Mount St. Helens debris avalanche deposit includes as dominants alder, willow, blackberry, blueberry, elderberry, maple, and other forms represented in abundance in the Republic flora. (Keep in mind that even 'minimally disturbed' vegetation of coastal Washington is temperate today.) These plants are notable for either their ability to resprout from vegetative fragments or their particularly effective dispersal mechanisms (Viers, 1987). Farther from the vent, similar colonizing woody vegetation occurs within lahar-devastated river channels, whereas the surrounding forest is essentially unaffected. It may be that some microthermal elements from higher, cooler stratocones of the Interior Arc entered the lower arc basins by colonizing volcanically disturbed habitat and that some of these intergraded with the later stage 'climax' vegetation.

My work on the 33.9-million-year-old Cedarville floras of northeastern California (Myers, 1993), provides tantalizing evidence that this may be the case. At Cedarville vegetational and floristic differences between multiple, well-correlated, coeval paleoassemblages are significant. The distribution of vegetational associations is not climatically induced (the thermal and moisture parameters of all sites are essentially identical) but is microsite controlled. Geological evidence suggests that Cedarville microsites colonized by broadleaved, primarily deciduous vegetation (dominated by microthermal elements) were regularly devastated by volcaniclastic debris. Sites farther from the volcanic source supported predominantly evergreen broadleaved vegetation with strong tropical floristic ties and appear not to have been highly disturbed.

Sedimentological and microstratigraphic study at Cedarville reveals cyclical vegetational changes within short stratigraphic sequences. Horizons with a high percentage of juvenile volcanic detritus contain the fossils of ferns. Fern fossils are replaced upsection by a low-diversity vegetation dominated by 'weedy' trees and vines. Moving upward in the section lamina by lamina, one sees the low-diversity 'weedy' trees gradually replaced by a diverse temperate forest not dissimilar to that at Republic. Between four and six cycles of vegetational change have been recognized in a 1-meter-thick sequence of rock.

The predictable cyclicity of vegetational change, and particularly the association of 'fern episodes' with juvenile pyroclastic debris, tempts the suggestion that the vegetational cycles mark repeated events of volcanic devastation and recovery, although other explanations are equally plausible. Hence, while there is some evidence that 'temperate' forest might enter warmer lowland sites through colonization of volcanically disturbed habitat, it is difficult to determine the actual cause of the vegetational relations from the fossil record.

A similar repeated lithological cyclicity occurs in the Republic sequence, although as yet no one has attempted a lamina-by-lamina correlation of lithological changes with changes in associated plant fossils.

Mechanisms of Floral and Vegetational Change in the Interior Arc

From the brief discussion above, it is clear that the formation of plant preservational sites in or adjacent to volcanic centers of the Eocene Interior Arc allowed for the fossilization of vegetation that hitherto had not entered the Tertiary western North American paleobotanical record. While this vegetation may not have been actually growing at high elevation, it would have reflected the landscape dynamics influenced by the arc and would have experienced vegetational exchange with the higher elevation volcanic centers. That voluminous arc volcanism in isolated upland centers would very likely have forced high rates of vegetational change has been suggested previously (Kruckeberg, 1987; Wolfe, 1987; Myers, 1993; Myers and Fisher, 1994).

The formation of a series of volcanic centers in western North America during the Eocene Warm Period would have provided biogeographic and evolutionary opportunities for microthermal lineages restricted from the tropical lowlands. Microthermal groups, like the Rosaceae, almost certainly would have been restricted to cooler habitats of *widely spaced and isolated* volcanic centers. Migration between these centers would have been by chance (by wind or animal vectors or by other means) and perhaps infrequent. The potential for speciation in isolation would have been high. This leads to the suggestion that diverse forests composed of floristic elements with different histories (like that at Republic during the middle Eocene) could evolve and accrue diversity through the continued intermixing of relicts and neoendemics in a geologically complex and dynamic landscape like that of a volcanic arc. While volcanic arcs are not the only environment in which this might happen, the extremely dynamic and unstable geological system of volcanic arcs could be a particularly effective pump driving floristic diversification and vegetational mixing.

One way for paleobotanists to test this idea would be to place arc vegetation into the context of what geologists can interpret about the processes by which volcanism shapes the physical and vegetational landscape, by which vegetation is taphonomically sampled and sorted (with particular emphasis on where and when this occurred with respect to the volcanoes and the timing of eruptions), and by which the basinal sediment pile is formed. Such work is time consuming and must be conducted on a lamina-by-lamina scale at several coeval sites. If combined with careful whole-organism taxonomic and paleoecological analysis, such information could begin to yield a picture of how and why vegetation and lineages changed through time in arc settings.

Given the occurrence of multiple, widely spaced, and well-dated floras at Republic and their unique vegetational and floristic associations, Republic would be an ideal laboratory for this type of integrative study.

Acknowledgments

The ideas proposed here are an outgrowth of Myer's work with Richard V. Fisher, emeritus professor, U.C. Santa Barbara, whose unique insight into the processes by which explosive volcanism shapes the Earth's landscapes and sedimentary record has immense value to paleobotanists.

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The Republic Highlands

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The fossil flora from Republic, Washington, is an extraordinary window on the vegetation of nearly 50 million years ago. It records a time when there were no polar ice caps, when alligators swam in the Arctic Ocean, when broad-leaved evergreen forests grew as far as 60° north, and forests of bald-cypress relatives and deciduous broad-leaved trees grew nearly to the poles. Because of the globally warm climate, this was the time of maximal interchange among floras of North America, Europe, and Asia—even frost-sensitive plant lineages were able to expand their ranges across the North Atlantic and Beringian land bridges.

However, even as warm climates at middle and high latitudes permitted the spread of broad-leaved evergreen forests and frost-sensitive plants, volcanic activity and uplift in the northern Rocky Mountains were creating montane regions with cooler climates. The Republic fossils document this montane vegetation of the Eocene better than any other assemblage in the world.

We know the vegetation at Republic was diverse—more than 200 species have been recorded from the 12 sites there that have been collected. The flora contains a mixture of pine-family conifers, deciduous broad-leaved trees like alder, sassafras, elms, and sycamore relatives, and a few broad-leaved evergreen trees like photinia and members of the tea family.

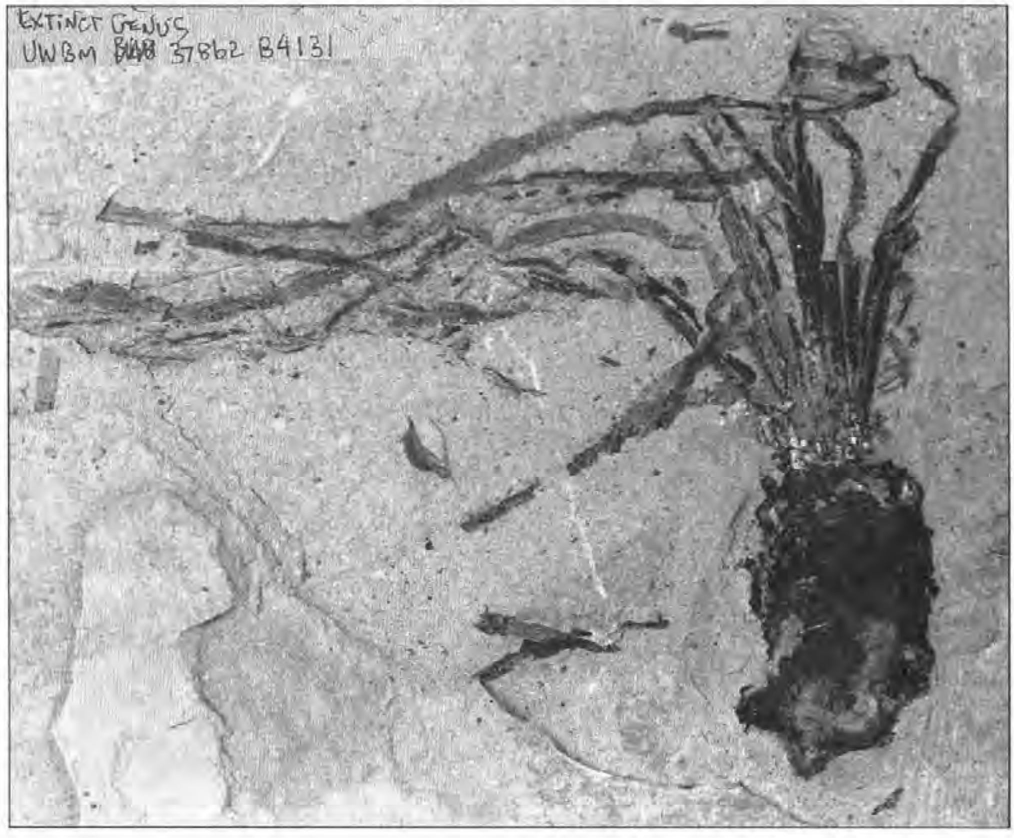
How did the vegetation at Republic differ from what grew at the same time to the east and west? As volcanic highlands developed in eastern Washington, Oregon, Idaho, and western Montana and Wyoming, they began to cast a rain shadow across the interior of North America. The eastern edge of the Eocene volcanic highlands appears to have been in the Yellowstone area, where floras of about the same age as Republic contain many conifers, including relatives of the coast redwood. Fifty-million-year-old floras from farther east in Wyoming, however, share relatively few plant species with Republic and are dominated by broad-leaved evergreen members of tropical and subtropical plant families. These Wyoming floras also have an abundance of species in the legume family, which tends to be diverse in regions with seasonally dry climates.

Floras of about the same age as that at Republic are also found in western Washington. These Pacific coast Eocene floras were highly diverse, composed mostly of evergreen broad-leaved trees, and had leaf shapes and sizes similar to those seen in living wet tropical forests.

Republic plants help to document the existence of highlands that separated the warm, wet floras of the Pacific coast from the warm, but seasonally dry floras of the continental interior.

The effects of the 'Republic highlands' are still seen in the distribution of plants today. The Eocene drying of the interior of the continent confined moisture-loving plants to more coastal areas. This was the initial break in the distributions of plants that had previously grown all across the northern mid-latitudes. Later in the Tertiary, cold climates further restricted the northern ends of many plant ranges, finally producing the well-known 'disjunct' genera that now occur in east Asia and eastern North America but nowhere in between.

The Eocene highlands so well represented by Republic may also have been the cradle of evolution for many of the more cold-tolerant plant lineages that came to dominate temperate forests during the later Tertiary. The plant fossils from Republic uniquely document a critical interval in the development of modern plant distributions and the evolution of important living species. ■



Isoetites (quillwort), extinct genus, corm ca. 1.5 cm wide, UWBM 37862, loc. B4131.

The Role of the Republic Flora in Documenting the Floristic Evolution of the Northern Hemisphere

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The middle Eocene flora recovered from several localities in and around the town of Republic, Washington, provides some of the best evidence for the early evolution of many northern hemisphere plant lineages. First described by Brown in 1935, the Republic flora was for decades considered to be of minor importance.

In 1977, Wes Wehr and Kirk Johnson discovered a new site, known as the 'corner lot', at the intersection of 10th Street and Clark Avenue. Extensive excavation of this site over the next several years proved that the flora was far richer than had previously been thought. Initial description of the flora by Wolfe and Wehr (1987) and further tabulation by Wehr and Hopkins (1994) have shown that Republic is the richest known Eocene floral locality in western North America.

Representing vegetation growing at a moderate elevation during the early middle Eocene, just after the global thermal maximum of the Cenozoic (Wing and others, 1991), the Republic flora contains a mixture of taxa known from higher and lower elevation sites from a time when local floristic diversity was at an all-time high for North America. The flora also contains: relict taxa from the Cretaceous, such as *Metasequoia*, *Cercidiphyllum*, and *Ginkgo*; other groups that diversified during the the Paleocene such as the Betulaceae (birches), Ulmaceae (elms), Fagaceae (oaks, beeches), and Platanaceae (sycamores); and a whole suite of taxa that make their first appearance in the Eocene.

The assemblage as a whole sheds light on the long-known floristic similarity between the forests of eastern North America and eastern Asia. As early as 1750, Linnaeus had recognized generic similarities between the living floras of eastern North America and eastern Asia (Graham, 1972). The similarities became significantly greater with increased botanical exploration, and in 1846 Asa Gray wrote, "It is interesting to note how many of our characteristic genera are reproduced in Japan, not to speak of striking analogous forms." A tabulation of these similarities by Li in 1952 showed that many genera in 59 families occurred in these widely separated regions.

Paleobotanical exploration of the American West, beginning largely with the United States Geological Surveys of the Territories, commenced in the 1860s. These scientists discovered a fossil record that indicated that the extinct floras of the West also contained genera similar to those that were common to the living disjunct floras of eastern North America and eastern Asia.

Detailed descriptions and discussions of these and additional floras over the last 130 years has led to the understanding that the middle Eocene world was characterized by equable climates and by land connections between Alaska and Siberia to the west and Canada, Greenland, and Scandinavia to the east. These conditions allowed relatively unrestricted migration of temperate and even subtropical plant genera between continents and the resulting similarity of floras. Mountain building, continental drift, and climatic cooling resulting in ice ages in the late Cenozoic not only severed these migrations, but also extirpated this vegetation from most of the places where it had previously grown. (See Wing and DiMichele, this issue.)

Its floral list makes Republic one of the more important localities for interpreting the evolution and biogeography of the flora of North America. The Republic flora contains dozens of plant genera that today are known only in eastern Asia and many more that are known only in eastern Asia and eastern North America.

Examples of Eocene plant genera from Republic that survive today only in east Asia or only in east Asia and eastern North America

Republic taxon	Eastern North America	Eastern Asia
Ginkgo (maiden hair tree)		x
Pseudolarix (Chinese golden larch)		x
Cercidiphyllum (katsura)		x
Metasequoia (dawn redwood)		x
Photinia		x
Liquidambar (sweet gum)	x	x
Sassafras	x	x
Lindera (spicebush)	x	x
Gordonia (Carolina bay)	x	x
Koelreuteria (goldenrain tree)		x

Due to the combined forces of its initial deposition and preservation and the ongoing collection and study, the Republic flora provides one of the better data points for understanding the vegetational history of the northern hemisphere. The lesson of Republic is that relentless excavation will uncover material that is simply not obtained by the traditional professional approach of a few seasons' work at a site. The growth of our understanding of this flora is directly related to the diligence and persistence of Wes Wehr, who has worked steadily on the project since 1977. Enlisting dozens of colleagues and friends as rock splitters, Wehr eventually captured the interest of the residents of Republic, and the site was recognized as significant local landmark. The Stonerose Interpretive Center now encourages continuing research and education relating to this flora. (See Perry and Barksdale, this issue.)

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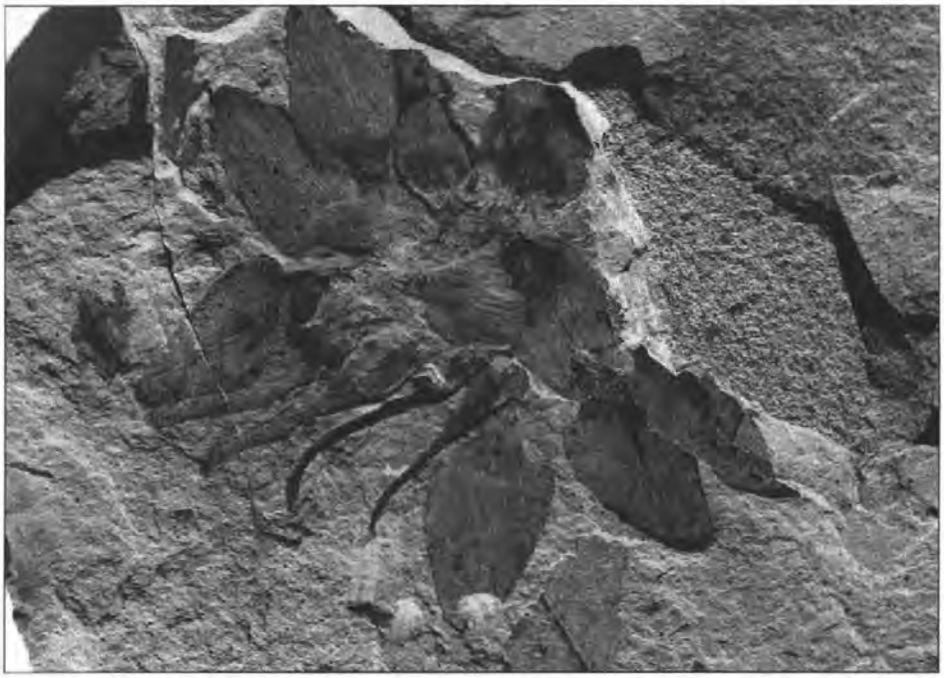
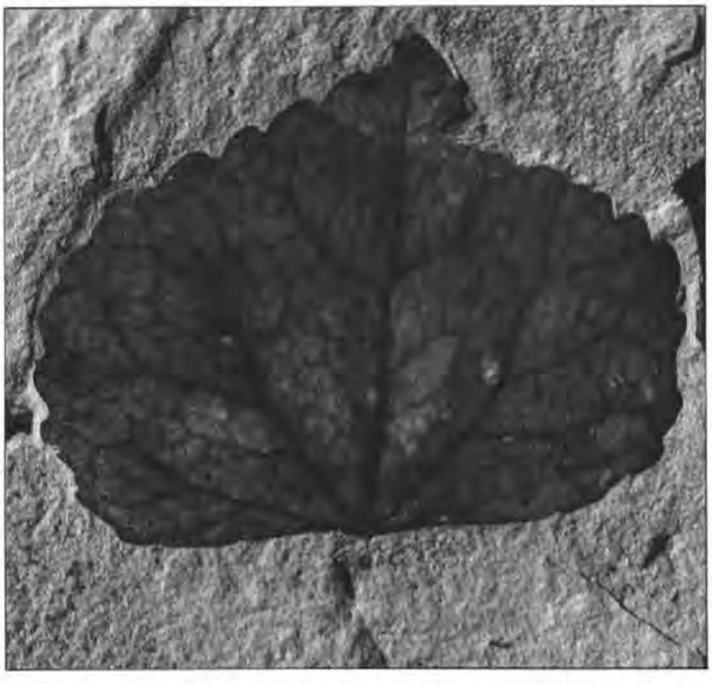
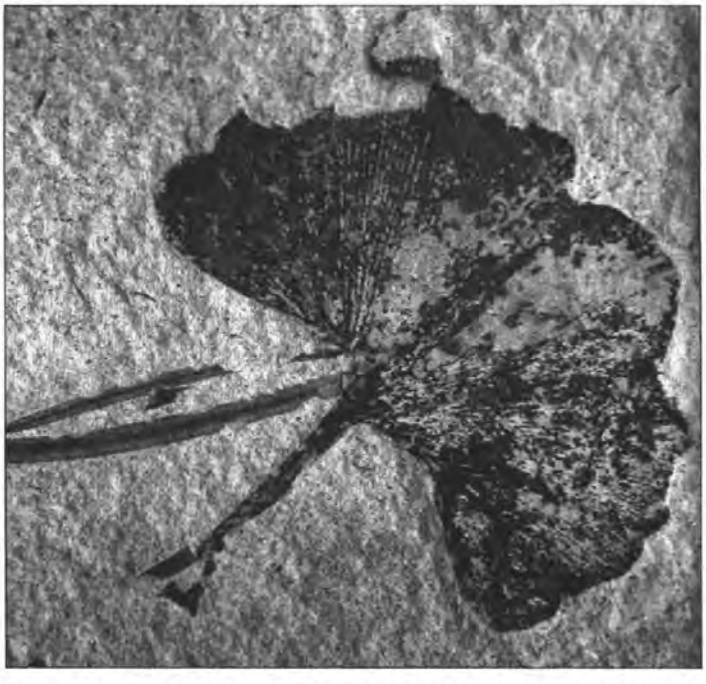


Partially disarticulated cone of *Pseudolarix wehrii* Gooch (golden larch); SR88-73-01, x1.1. (Photo by Lisa Barksdale.)



Fossil leaf of *Cercidiphyllum* (katsura), a genus now native to eastern Asia and a tree commonly planted in cities; SR91-0-14, x1.8. (Photo by Lisa Barksdale.)



Fossil leaf of *Ginkgo adiantoides* (Unger) Heer, whose modern relative is native to eastern Asia; SR87-36-2A, x1.3. Gingko trees have been planted in many communities throughout the United States. (Photo by Sandra Sweetman.)

A Brief History of the Stonerose Interpretive Center

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Washington Geology readers often see 'SR' or 'Stonerose Interpretive Center Collection' below illustrations of Republic's Eocene fossils. Many readers and others have come to the center, but for those who haven't, this short history may serve as an introduction.

The Stonerose Interpretive Center is an educational facility that performs several functions: It promotes popular and scientific interest in local fossils, geology, and related subjects. It collects, preserves, exhibits, and interprets fossils and other objects that illustrate these subjects and encourages research and information exchange. Its program provides a unique opportunity for the public to collect museum-quality fossils and participate in their study.

This would be an unusual situation anywhere. Its existence in a small, economically depressed, mining town is even more remarkable. It is a result of an equally remarkable cooperation among local organizations, several levels of government, educational institutions, and private citizens.

Stonerose's history began with a conversation between Republic City Councilman Bert Chadick and paleobotanist Wes Wehr of the Thomas Burke Memorial Washington State Museum. Collecting at Republic's fossil beds began in 1896, but their significance was barely appreciated before Wehr began work there in 1977. The fossil locality he was investigating is across the street from Republic's city hall.

In the mid-1980s, Chadick crossed the street to ask about the work. Wehr's explanation included the fact that Republic's roadcuts, slicing through layers of ancient lake beds, had exposed a rich Eocene plant fossil deposit. These well-preserved leaf and flower impressions comprise the world's best 'snapshot' of plant development in warm temperate uplands 50 million years ago.

The two men began considering what such a world-class resource might mean to Republic. They envisioned an interpretive center where the public, including students of all ages, could get hands-on experience with fossils and interact with the people who study them. It would encourage tourism and demonstrate to local students that science is a process that can take place literally anywhere. Wehr and Chadick began to work toward making a museum a reality.

The city soon after bought a house near the fossil outcrop and found funds for a modest salary for a curator, some basic equipment, and for modifications of the house. TRICO, a local economic development district, made arrangements for an assistant curator's position through the Washington Service Corps.

Town residents digging for fill rock soon uncovered a more accessible fossil outcrop at the north end of town (Fig. 1). Early in 1987, Madilane Perry, a local resident and anthropology graduate fresh from a single short museology course, heard about the project from Chadick, then the town's mayor. Alarmed at its scope, she cautioned that it was probably impossible, given the area's limited resources. Somehow the conversation ended up with Perry being enlisted as curator of something called 'Stonerose', named for the numerous

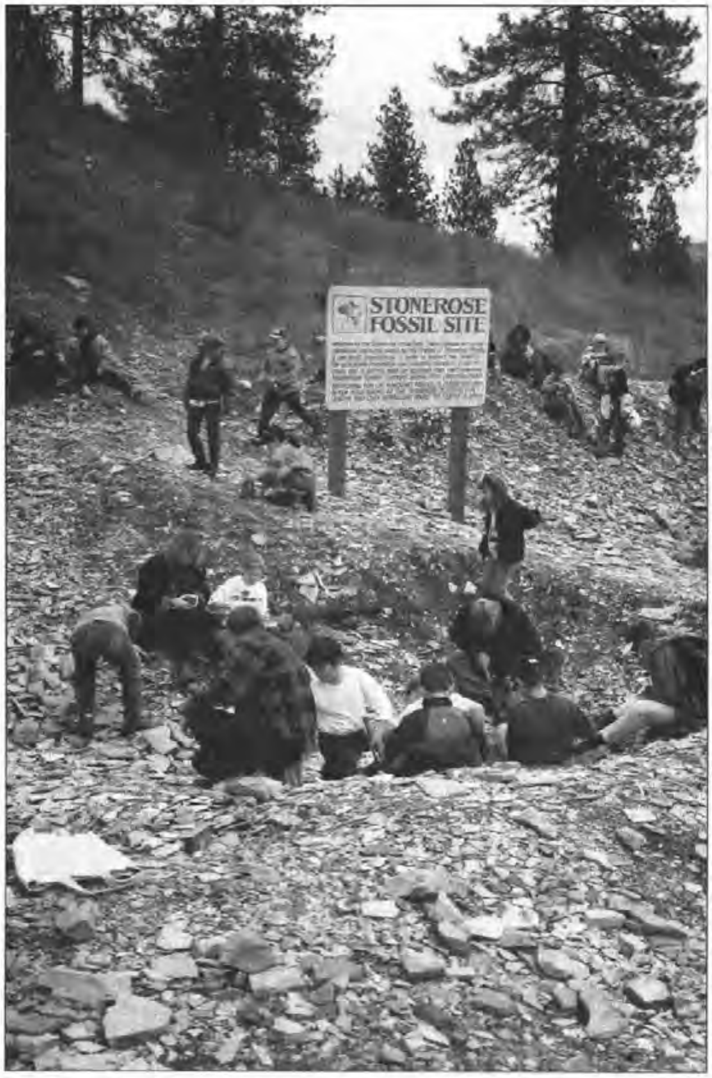

Figure 1. Amateur fossil collectors at the Stonerose site.

Madilane Perry (left), the first curator of the center, and Lisa Phillips, the first assistant curator. (Photo by Sandra Sweetman.)

members of the rose family that are found in the stones there. The Stonerose Interpretive Center was to be part of the City Parks Department.

Getting from the dream to today's center has followed unorthodox, improvised, and fortuitous paths, certainly not the more traditional process of establishing a facility for such important materials. The physical work needed to make Stonerose a reality began in the spring of 1987. This involved cleaning and repairing a rundown, turn-of-the-century house (Fig. 2) and several donated glass cases and organizing the city's small fossil collection for an exhibit. Perry made a quick trip to the Burke Museum, where Wehr provided an intensive cram course in paleobotany and local geology and a great deal of moral support. In August, the facility officially opened to the public.

Since then, under the direction of the present curator Lisa Barksdale, the fossil collection has grown, attendance has increased steadily and dramatically, and visitor fossil collecting has settled into a pattern. Fossils found by visitors are examined by Stonerose staff members and, if possible, identified. Fossils that may represent previously unknown plants or animals are retained by Stonerose to be examined by Wehr or other specialists. Stonerose contacts the collectors with information about the fossils that have been kept; the willingness of visitors to cooperate in the ongoing research is an asset to the center's work.

Figure 2. The first home of the Stonerose Interpretive Center. (Photo by Sandra Sweetman.)

In 1988, a Washington State Department of Community Development (DCD) grant enabled Stonerose to form its own nonprofit support group, the 'Friends of Stonerose Fossils'. The Friends now operate the center and have purchased eight city lots, including about 100 feet of exposed fossil beds. Another DCD grant in 1991 funded an extremely popular university-accredited workshop for teachers about the educational use of fossils.

Since its early days, Stonerose has moved to a more accessible location. The city and Ferry County Historical Society joined forces to purchase a building next to the city park for the center. It houses most of the area's tourism-related organizations and is maintained with city funds earmarked for tourism. Similar county funding goes toward the curator's salary. The Washington Service Corps and, later, Americorps have participated by providing part of the assistant curator's salary. The rest of the center's needs are met by donations, memberships, gift shop sales, and the proceeds of an annual 'Bingo Bash'.

Figure 3. Stonerose Interpretive Center in 1996, with its new expansion.

Stonerose has reissued U.S. Geological Survey Bulletin 1597, which discusses the significance of Republic's plant fossils, and has several other reports about the fossil flora available for visitors.

The center recently received a $50,000 grant from the state legislature to enlarge its physical facilities. The 600-square-foot addition is nearly complete (Fig. 3). The finishing touches are being applied by a crew from the local Job Corps center. This is a continuation of an effective partnership that can serve as a model of interagency cooperation for similar projects elsewhere.

Stonerose attracted more than 9,000 visitors in the summer of 1995, more than Ferry County's entire population. The center is open from May through October, Tuesday through Saturday, 10:00 am to 5:00 pm. From mid-June to mid-September, Stonerose is also open on Sunday. Visitors who want to search for fossils must check in with the center, where they will receive instructions, can rent simple tools, and see examples of the local fossils. ■

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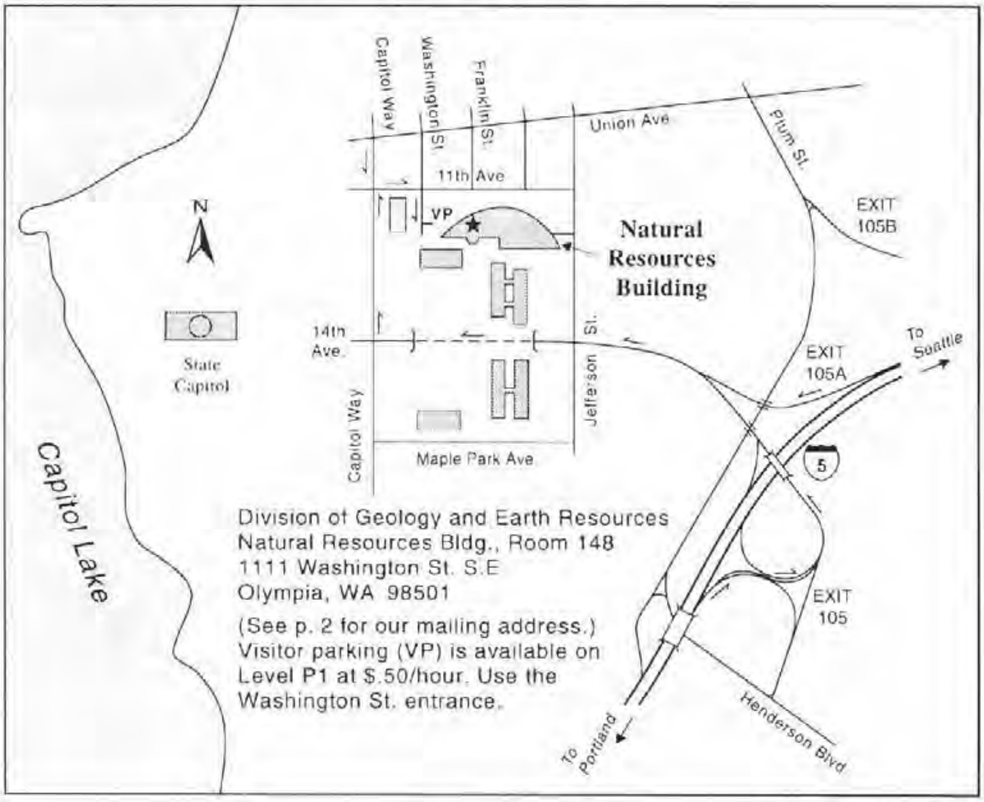

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Division Releases

Bibliography and Index of the Geology and Mineral Resources of Washington, 1986–1990, Bulletin 81, compiled by Connie Manson. This 478-page book contains citations (indexed) for nearly 4,100 items issued from 1986 through 1990 and about 650 items issued before 1986 that were missed in previous compilations. The price is $14.72 + 1.28 tax = $16.00. A preliminary bibliography for 1991 through 1995 is in preparation.

Slope Stability Analysis of the Bluffs along the Washington State Capitol Campus, Olympia, Washington, Open File Report 96-3, by Wendy J. Gerstel, is a review of historic and current stability. The report consists of a 6-page text and seven appendices that present boring logs, cross sections, soil test and inclinometer data, and analytical data, as well as information about the effects of the February 1996 rain storm. The report includes several maps and reproductions of color photographs. This study was done under Department of General Administration contract #FY93-007(4). The price is $11.12 + .88 tax = $12.00.

Association of American State Geologists Earth Science Education Source Book, compiled by Robert H. Fakundiny and Neil H. Suneson, will soon be released as our Open File Report 96-4. This 134-page report briefly describes publications and other materials offered by each state geological survey and indicates suitability for various readers and users. The price is $3.68 + .32 tax = $4.00.

We have reprinted Information Circular 85, **Washington State Earthquake Hazards**. The report is available free, but please add $1.00 to each order for postage and handling.

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Earthquake Information Sources

Earthquake Basics Brief No. 2 (1995, 20 p.) lists organizations that distribute earthquake information and includes each organization's mission statement, strengths, products and services, and Internet resources. Complete contact information is also provided. Free (single copies only). Available from the Earthquake Engineering Research Institute, 499 14th St., suite 320, Oakland, CA 94612-1934; *phone:* (510) 451-0905; *fax:* (510) 451-5411; *e-mail:* susant@eerc.berkeley.edu

USGS Report Being Revised

Water Resources Investigations Report 92-4109, "Hydrology and Quality of Ground Water in Northern Thurston County, Washington", is undergoing revision. The Washington District staff reports that errors were discovered in applying a numerical model to simulate the ground-water flow system. Some of the geohydrologic unit assignments to wells are being reanalyzed and corrected. The revised report will be distributed upon completion. For more information about specific applications of the information in the report, contact Brian Drost or Gary Turney at the Washington District, (206) 593-6510.

Burke Museum Field Trips

The Burke Museum announces the following trips to be led by Liz Nesbitt and Tony Irving of the University of Washington:

North Cascades Loop Trip—fossils, minerals, and geologic history, Aug. 23–25.

San Juan Islands, including Sucia Island—geology and fossils, Oct. 11–13.

For information about costs and to sign up, contact Liz Nesbitt at (206) 543-1856.

CD-ROM Available from Mount Rainier National Park

"Where the Rivers Begin" is a program that incorporates interactive animations, games, slides, and videos that teach users about natural and human history of the park, as well as the social and political concerns affecting its management. The program includes trip activities, worksheets, other resources. It requires a 486/66 PC or better, or Mac System 7 or greater. Also required, for either CPU type, are 8mb of RAM, a 256-color monitor, and a CD-ROM drive. The educator's special price is $10. Contact the Education Office at the park, Tahoma Woods, Star Route, Ashford, WA 98304.

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