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; dates: 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, work-sheets, other resources. It requires a 486/666 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.

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: susan@eerc.berkeley.edu

Earthquake Hazards. The report is available free, but please add $1.00 in each order for postage and handling.

Only Washington State residents must pay tax; out-of-state orders use the price before tax. Please add $1.00 to each order for postage and handling.

Division Releases


Slope Stability Analysis of the Bluffs along the Washington State Capitol Campus, Olympia, Washington. Open File Report 96-3, by Wendy J. Gerstie, is a review of historic and current stability. The report consists of a 6-page text and seven appendixes 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 rainstorm. The report includes several maps and reproductions of color photographs. This study was done under Department of General Administration contract #FY95-0074. The price is $11.12 + $8.38 tax = $19.50.

Association of American State Geologists Earth Science Education Source Book, compiled by Robert H. Fukuda and Neil H. Sisson, 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 + $1.32 tax = $5.00.

We have reprinted Information Circular 85, Washington State Earthquake Hazards. The report is available free, but please add $1.00 in each order for postage and handling.
IN CELEBRATION OF THE REPUBLIC CENTENIAL

Raymond Lasmasins Washington Division of Geology and Earth Resources PO Box 475107, Olympia, WA 98504-7007

O n April 18, 1896, a group of 64 men gathered where the Skookum Creek trail crosses the Duwamish River near the western periphery of Seattle. They were members of the newly organized Washington State Historical Society (WSHS). Their meeting was the first step in the establishment of a statewide organization devoted to the study and preservation of the state's history and natural resources.

The Society was founded in 1896 to commemorate the centennial of the Washington Territory, which had been transferred to the United States from the British Crown in 1846. The Society's founders believed that it was important to document and preserve the state's history and natural resources for future generations.

The Society's early activities included the publication of historical and scientific papers, the creation of a library and archives, and the establishment of a museum. The Society also worked to promote the study of the state's natural resources, including its water, soils, and forests.

Today, the Washington State Historical Society is one of the state's leading cultural institutions. It continues to collect and preserve the state's history and natural resources, and to promote the understanding of these resources through educational programs and exhibitions.

OTHER REPORTS OF INTEREST

Archibald, Bruce. 1995. Some new insects from the interior of British Columbia: Vancouver Paleontological Society, 1 v.

Correspondence Courses Offered By Wright State University

The Center for Ground Water Management at Wright State University offers a number of courses geared toward working professionals interested in specialized training in environmental science. Students use the Interactive Remote Instructional System (IRIS) and are assigned a personal tutor with whom they communicate by fax, e-mail, and phone.

A 20-week course in ground-water hydrology starts July 15. The following 12-week courses begin Aug. 26:

- Site Remediation
- Contaminant Hydrology
- Monitor Well Design and Construction
- Aquifer Test Analysis/Well Hydraulics
- Ground Water Flow Modeling Using MODFLOW

For more information, contact:

- Wright State University
  Center for Ground Water Management
  3640 Colonel Glenn Hwy; 356 Library
  Dayton, OH 45435
  phone: (513) 873-3649; fax: (513) 873-2455
  e-mail: IRIS@desire.wright.edu; home page:
  http://biology.wright.edu/cgwm/cgw_home.html

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Science Summer Camps for Children, Families, and Adults

The Oregon Museum of Science and Industry in Portland offers a wide variety of summer camps for children, families, and adults in Washington and Oregon locations. Activities include biological and geological field trips, museum tours, family science week, and more. For more information, call OMSI at (503) 797-4545.

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Regional Geology of the Republic Area

Eric S. Chenes
Department of Geological Sciences
University of Washington, Box 351310
Seattle, WA 98195-1310

Introduction

This article describes the regional geology of the Republic area and considers more than the Eocene stratigraphic unit that has 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, ancomformity-bound sequences within the larger Chalchis sequence, and (2) rather than having been deposited in a local fault-bounded basin or graben, the formations are preserved in the upper plate of one or more low-angle normal faults as a regional synform between two anomalous metamorphic complexes. These and other concepts are discussed more fully in Cheney and others (1994) and Cheney (1994). However, the information in these articles is not explicitly referenced here.

Figure 1 shows the regional geology of northeastern Washington. East of the Buckhuckle Ridge, Columbia, and Wameta 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 Quentinella, a terrane that accreted to North America in the late Jurassic (about 175 million years ago). Eocene sedimentary and volcanic rocks of the Challis unconformity-bound sequence (55 to 36 million years old) overlie the pre-Challis rocks. The metamorphic core complexes (MCCs) are Eocene antiformal uplifts of crystalline basement unconformity-bound sequence 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 Wallpapi sequence (18 to 2 million years old), unconformably overlies all other rocks. The most voluminous lithostatigraphic unit of the Wallpapi sequence is the Columbia River Basalt Group.

The dominant rocks in the Republic area (Fig. 2) are greenstone-facies quartzite formations, four unconformity-bound formations of the Challis sequence, and the amphibolite-facies metamorphic rocks and granitic plutons of the MCCs.
Table 1. Explanation for geologic and geographic features of Figures 1 and 2

<table>
<thead>
<tr>
<th>MAP UNITS</th>
<th>Metamorphic Core Complexes</th>
<th>NAME ABBREVIATIONS</th>
<th>Towns (RO)</th>
<th>Mines (BC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalk series</td>
<td>T1 Klondike Mountain Formation</td>
<td>E. Eocene Herron Creek quartz monzonite</td>
<td>CO, Colville</td>
<td>KH, Knob Hill</td>
</tr>
<tr>
<td></td>
<td>T2 Eocene felsic plutons</td>
<td>E. Eocene felsic plutons</td>
<td>G, Greentown</td>
<td>L, Lamefoot</td>
</tr>
<tr>
<td></td>
<td>T3 Sanpoil Volcanics rhythems flows</td>
<td>P1m Amphibolite facies Cretaceous orthogneiss and Proterozoic Paleozoic paragneiss</td>
<td>MG, Midway</td>
<td>OL, Overlook</td>
</tr>
<tr>
<td></td>
<td>BM Marron Formation alkali flows</td>
<td>O, Omak</td>
<td>OH, Oroville</td>
<td>P, Phoenix</td>
</tr>
<tr>
<td></td>
<td>TM O'Brien Creek Formation</td>
<td>B, Buried Mountain fault</td>
<td>H, Republic</td>
<td>S, Spokane</td>
</tr>
<tr>
<td></td>
<td>Tm Appalachian tectonic and raffle rocks</td>
<td>T, Trail</td>
<td>T, Trail</td>
<td></td>
</tr>
<tr>
<td>Quesnellia</td>
<td>Mi Granitic to alkalic plutons</td>
<td>Faults</td>
<td>B, BC, Bc, Beacon Creek fault</td>
<td>N, No. 7 fault</td>
</tr>
<tr>
<td></td>
<td>Bc Carboniferous to Permian</td>
<td>Detachment fault — blocks on upper plate</td>
<td>Br, Borehole Mountain fault</td>
<td>Br, Borehole Mountain fault</td>
</tr>
<tr>
<td></td>
<td>Pm Carboniferous to Permian</td>
<td>Gl, Columbia fault</td>
<td>Cl, Clarno fault</td>
<td>Cl, Clarkia fault</td>
</tr>
<tr>
<td></td>
<td>IM Carboniferous to Permian</td>
<td>DF, Deschutes fault</td>
<td>EM, Eagle Mountain fault</td>
<td>EM, Eagle Mountain fault</td>
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<td></td>
<td>Knob Hill Group greenstone, mafic and felsic volcanic rocks, alkali flows</td>
<td>Df, Drop fault</td>
<td>Df, Drop fault</td>
<td>Df, Drop fault</td>
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<td></td>
<td>Knob Hill Group greenstone, mafic and felsic volcanic rocks, alkali flows</td>
<td>Gr, Greenwood fault</td>
<td>Gr, Greenwood fault</td>
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<td></td>
<td>Ultramafic rocks</td>
<td>Hr, Huckleberry Ridge fault</td>
<td>Hr, Huckleberry Ridge fault</td>
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<td></td>
<td>Alkaline plutons</td>
<td>Lc, Lind Creek fault</td>
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<td>Lm, Lambert Creek fault</td>
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<td>Mf, Mount Attwood fault</td>
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<td>Mw, Mount Wright fault</td>
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<td>N, No. 7 fault</td>
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<td>S, Sherman fault</td>
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<td>Sp, Steel fault</td>
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<td>Sc, Scott Creek fault</td>
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<td>Sn, Snowshoe fault</td>
<td>Sn, Snowshoe fault</td>
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<td></td>
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<td>Tm, Thimbles Mountain fault</td>
<td>Tm, Thimbles Mountain fault</td>
<td>Tm, Thimbles Mountain fault</td>
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<td></td>
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<td>Wf, Waneta fault</td>
<td>Wf, Waneta fault</td>
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<td></td>
<td></td>
<td>Wm, White Mountain fault</td>
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</table>

Quesnellia
The best description of the Quesnellia rocks is given in Fyles (1990). The Quesnellia rocks include the Carboniferous to Permian ophiolite 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 volcanlastic rocks, and intermediate to acid rocks (the Attwood Group). Both of these units are unconformably overlain by the Triassic Brooklyn Formation (chert meta-conglomerate, clastic limestone, and argillite). A younger unconformable succession of oceanic to volcanlastic rocks and sedimentary rocks may be part of the Quesnellia rocks of the Quesnellia Group in the upper part of the Quesnellia Formation. (Cheney and others, 1994) as shown in Figure 1 or 2, or both. Although few large-scale, recurrent folds have been mapped in the area of Figure 2, the Quesnellia rocks are significantly folded or faulted. For example, the Attwood Group at the Overlook gold mine northeast of Republic is subhorizontally overturned (Rasmussen, 1994), and the Brooklyn Formation north of Curlew dips 30° northwestward but is overturned.

Figure 2. (right) Geology of the Republic area. Sources of data are A, Morgan (1966); B, the modification of Fyles (1990) shown in Cheney and others (1994); C, our mapping since 1995, and D, Parker and Calkins (1960), Mugaess (1987), and Stoffel and others (1991).

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Hoecker, D. J., and others, 1993, Proposed Lakehead Hills South mining and reclamation plan and planned community development: Draft environmental impact statement: Pierce County Department of Planning and Land Services, 199 p.
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 Barkdale, 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.

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'. 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.

![Figure 2. The first home of the Stonerose Interpretive Center. (Photo by Sandra Swetman.)](image)

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

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.
A Brief History of the Stonerose Interpretive Center

Madeline Perry and Lisa Backdahl
Stonerose Interpretive Center
PO Box 587
Republic, WA 99166

Washington Geology readers often see ‘SR’ or ‘Stonerose Interpretive Center Collection’ below illustrations of Republic area fossils. Most of the readers probably know the collection’s story, but for those who haven’t, the 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 was across the street from Republic’s city hall.

In the mid-1980s, Chadick crossed the street to speak to the work. Wehr explained the significance of the fossil beds. The rock exposures contained ancient lake beds, and the beds posed a rich fossil plant deposit. These well-preserved leaf and flower impressions comprise the world’s best ‘snapshots’ 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 a center that would attract tourists 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 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 a summer assistant. The Interpretive Center became an interpretive center where the public, including students of all ages, could get hands-on experience with fossils and interact with the curator. The interpretive center, in cooperation with the town, continues to attract tourists and local students.

The town residents digging for fossil rock soon uncovered a more accessible fossil outcrop at the north end of town (Figure 1). In 1987, Madeline 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. Asked if it were possible, she cautioned that it was probably impossible, given the area’s limited resources. Somewhat to the conversation ended with Perry being enlisted as curator of something called ‘Stonerose’, named for the numerous


Partially disarticulated cone of Psuedolirion uhali. Glosso (golden larch). SRBB-73-01, x1.5. (Photo by Lisa Barxradale.)

Possibly leaf of Carpodiumum (kalsana), a genus now native to eastern Asia and a tree commonly planted in cities. SRBB-0-14, x1.8. (Photo by Lisa Barxradale.)

Fossil leaf of Gingko aradiatola (Unger) Hara, whose modern relative is native to eastern Asia. SRBB-36-2A, x1.5. Gingko trees have been planted in many communities throughout the United States. (Photo by Sandra Swaves.)

Figure 3. Inter-regional sequence stratigraphy of the Eocene rocks. CHM, Chumack Formation; COW, Cowles Formation; GB, Guide Volcanics; GRV, Gray River Volcanics; KLD, Klondike Mountain Formation; MRM, Marana Formation; NCH, Naches Formation; OBB, O'Brien Creek Formation; ORR, Oak River Formation; RGE, Raging River Formation; ROS, Roslyn Formation; SAN, Sangi Volcanics; SHK, Skaha Formation; SLP, Silver Pass volcanic rocks; SPP, Springbrook Formation; TIA, Tiesa Formation; TIG, 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 Muesig, 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 Sangi volcanics in the Sanpoil valley, shown by Parker and Calkins (1964) and Muesig (1967). The synclines are outlined by the three Chalkis sequences and by considering all of the Queene Hill rocks to be a fourth basin unit (Fig. 2). North of Curlew, the synformal structure is marked by the Knox Hill Group in the Curlew klippe of the No. 7 fault of the Chelan thrust. Thus, much of the structural relief of the Republic 'graben' is synclinal. Because the Sangi syncline has a length, northerly strike, and structural relief similar to that of the adjacent anticlinal MCCs and is largely bounded by the same detachment faults, it is the synclinal counterpart of the anticlinal MCCs. Thus, the Chalkis regional sequences were not deposited in a local 'graben' but, rather, are structurally preserved in the upper plates of detachment faults.

References Cited


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

Raymond Leaheimer
Washington Division of Geology and Earth Resources
P.O. Box 47007, Olympia, WA 98504-7007

The Early Days

The mining history of the Republic District is a tribute to its prospectors, miners, engineers, metallurgists, geologists, and financiers. By February 26, 1892, when William Dwight managed half of the Colville Indian Reservation was opened to claim staking, most of the gold-bearing ledges were already known to local trap- pers, pack train drivers, and other 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. Waring, Ferry County Historical Society, written commun., 1996). On March 5 of that year, two prospectors, Phil Garner and Thomas Ryan, with Mr. W. C. Reddy, located the townsite of Eureka. James Clark of Spokane, located the Republic and Jim Blamey of Delor, financed by provided by Patrick F. (Patsy) Clark, the dis- trict was rapidly developed.

A gold rush ensued, and thousands of claims were staked, encouraged by published accounts during 1891 in the Seattle Post-Intelligencer by 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 most extensive veins known at the time around 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 (Walker and Heuray, 1895). During 1898, the gold-rich town of Eureka was renamed ‘Republic’ after the President of the Republic Reduction 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 the Territory of Colorado. 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 the town of Seattle, the state capital. In the summer of 1902, two railroads reached Republic to serve the mills and mines—the Kettle Valley Railroad and the Great Northern Railway (Heuray, 1895).

In those early days, 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-slop from adits and shafts.

Metallurgy, however, was a problem because the very finely crystalline ore minerals and silica encapsulation of electrum in matrix gold 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, 1922).

Development and mining activity in Republic soon attracted the attention of the state’s geological survey. In his an- nual report for 1895, John V. Amsden described the early evolution of many of the large deposits 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.

In the wake of the Republic District was demonstrated when the Washington Geological Survey published its first bulletin Geology and Ore Deposits of Republic Mining District (Umplcy, 1913). 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 con-clusions about ore deposition, Umply (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 depos- ites. Sigurd H. Lindgren was hired this year to fill a new position on the east coast. In 1901, the USGS published Walderman Lindgren’s exhaustive report on the Silver City and De Lamar, Idaho, gold/silver deposits, which was the USGS Regional Geologic section for precious and semiprecious metals (Graton, 1934).

It was Lindgren who developed an ore genesis model ap- plicable 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 porphyry copper deposits. Lindgren (1934) was the first to explain the origin of these deposits, and he did so by suggesting that the ore deposits were formed in a hydrothermal system. His ideas were based on the fact that the ore deposits are associated with porphyry copper deposits, which are known to be formed in a hydrothermal system. Lindgren’s ideas were later refined by other geologists, and today, the hydrothermal model is widely accepted as the best explanation for the formation of these deposits.

The middle Eocene floras recovered from several localities in and around the town of Republic, Washington, provide significant insights into the early evolution of many of the northern hemisphere plant lineages. First described by Brown in 1935, the Republic flora was for decades considered to be of major importance. In 1977, Wes Wehr and Kirk Johnson discovered a new site, known as the ‘corner lot’, at the intersection of 10th Street and 14th Avenue in Eureka. Upon excavation of this site in the next several years proved that the flora was far richer than what had previously been thought. Initial description of the flora by Wolfe and Wehr (1987) and further publication 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 elevations and lower elevation sites from a time when floristic diversity was at an all-time high for North America. The flora also con- tains elements from the Cretaceous, such as Metasequoia, Cercidiphyllum, and Ginkgo, other groups that diversified dur- ing this Paleocene such as the Betulaceae (birches), Ul- maceae (elm), and 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 Amer- ica and eastern Asia. As early as 1750, Linnaeus had recog- nized the similarity of species between living floras of eastern North America and eastern Asia (Graham, 1972). The similari- ties became significantly greater with increased botanical ex- ploration, 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, begin- ning with Charles B. Kelloff, United States Geological Survey, in the Territories, commenced in the 1860s. These scientists discov- ered a fossil record that indicated 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.

The described descriptions and discussions of these and addi- tional floras over the last 130 years has led to the under- standing that the middle Eocene world was characterized by extensive faunal and faunal connections between Alaska and Siberia to the west and Canada, Greenland, and Scandinavia to the east. These conditions allowed relatively unrestricted mi- gration of temperate and even subtropical plant genera be- tween continents and the resulting similarity of floras. Moun- tain building, continental drift, and climatic cooling resulting in ice ages in the late Cenozoic not only severed these migrati- ons, but also extirpated this vegetation from most of the places that had previously grown. See (Wing and Di- Michele, this issue).

Its floral list makes Republic one of the more important locations for a study of 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 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

<table>
<thead>
<tr>
<th>Republic</th>
<th>Eastern Asia</th>
<th>Eastern North America</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ginkgo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequoia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redwood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnolia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robinia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quercus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tilia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>decidua</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulmus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Betula</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alnus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Populus</td>
<td></td>
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<tr>
<td>Salix</td>
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<tr>
<td>Populus</td>
<td></td>
<td></td>
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<tr>
<td>Salix</td>
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</tbody>
</table>

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 origins 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 tirelessly on this project since 1977. Enduring dozens of col- leagues and friends as rock splitters, Wehr eventually captured the interest of the residents of Republic, and the site was rec- ognized as significant local landmark. The Stonerose Interpre- tive Center now encourages continuing research and education relating to this flora. (See Perry and Barkdale, this issue.)

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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 60º north, and forests of holly-like species were the dominant trees in the poles. Because of the globally warm climate, this was the time of maximal interchange among floras of North America, Europe, and Asia—e.g., 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 300 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 ashes, magnolias, 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 in 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.

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

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forgotten for more than 40 years, probably because the banana ores of epithelial 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 1913 until a 400-ton-per-day cyanide mill went into operation on May 10, 1977 (Lasmasul, 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 (Mueussig, 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 epithelial 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 Figure 1.)

The first indications of a revival of the epithelial model and its implications were in a report by mining geologist Har- rison Schmitt (father of geologist and 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 Yellstone to Lindgren’s epithelial 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 under- ground 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 in behalf of Louton Superi- rior. After a four-year exploration and development program by Canadian Superior, Earth Resources Company, and their consultant, Don 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 mining of the epithelial type associated with Tertiary volcanic activity.

A Unified Model

Suddenly, epithelial gold-silver deposits came into vogue throughout the industry. Both industry and academic research on epithelial 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 Mesozoic hot spring precious metal deposit was published for the first time in 1975. The model for bulk silver-gold deposits in volcanic rocks (Eimon, 1975) was developed. In the Republic Mine, a three-dimensional vertical section was proposed for the Las Torres mine in Mexico (Buchanan, 1979). In 1979, Paul Eimon gave a paper on the epithelial hot spring deposit model for bulk silver-gold deposits in volcanic rocks (Eimon, 1979). In 1979, and then, in 1981, he presented an exploration concept for hot spring epithelial 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 Deposition.” The conference was organized by H. F. Bonham, D. C. Noble, F. J. Sawkins, and R. Sullivan of the MacKay School of Mines in Nevada. Berger published his fully developed model in 1985. The search for epithelial deposits turned into a gold rush when the McLaughlin mine in California started producing gold during March 1985 from a hot spring deposit that was discovered by Homestake in 1978 (Lehrman, 1986).

On October 21, 1981, Hecla Mining Company acquired the operating properties of 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 high-grade 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 1960s and 1970s that led to the discovery of the Golden Promise vein system in 1984 (Lasmasul, 1989). A model of an epithelial precious metal hot spring system for the Republic District was finally published in 1989 (Tschabuday, 1989). It resembles very closely the models of Buchanan (1979) and Berger (1985) and has features that were documented by Lindgren back in 1944.

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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 shown 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 Republic, 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 is a proprietary metallurgical test program to extract gold 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 mi² 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 mill, are operated by Echo Bay Minerals. Echo Bay is a relative newcomer to 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 of four drill holes was produced at the mill in January 1990. 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. Lefebvre and Ballesteros (1987) had given some interesting descriptions of the Overview, Copper Key, and Belcher contact-metamorphic deposits, mentioning that they are gold bearing. Additional drill bit materials of mines and prospects were given by Hunting (1956). Gold there is associated with magnetite, pyrrhotite, and pyrite. Since it was established that the deposits may have a magnetic signature, Echo Bay started to state Division of Mines and Geology Report of Investigations 20 (Hunting Geological Services, Inc., 1960) and noted the large magnetic anomaly under Cooke Mountain near the Key prospects (Fig. 7). Wahl H. Hunt of Echo Bay (oral commun., 1991) attributes the discovery of the large Overview deposit by drilling in 1987 at Cooke Mountain to this Division publication.

Table 1. 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.*

<table>
<thead>
<tr>
<th>Year</th>
<th>Tons</th>
<th>Au oz</th>
<th>Ag oz</th>
<th>Mine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>79,210</td>
<td>80,301</td>
<td>354,077</td>
<td>Metzphi</td>
</tr>
<tr>
<td>1989</td>
<td>81,300</td>
<td>70,591</td>
<td>336,000</td>
<td>Metzphi</td>
</tr>
<tr>
<td>1990</td>
<td>90,000</td>
<td>81,400</td>
<td>326,000</td>
<td>Metzphi</td>
</tr>
<tr>
<td>1991</td>
<td>69,562</td>
<td>77,316</td>
<td>314,445</td>
<td>Metzphi</td>
</tr>
<tr>
<td>1992</td>
<td>71,000</td>
<td>69,531</td>
<td>292,975</td>
<td>Metzphi</td>
</tr>
<tr>
<td>1993</td>
<td>118,846</td>
<td>49,601</td>
<td>267,688</td>
<td>Metzphi</td>
</tr>
<tr>
<td>1994</td>
<td>120,165</td>
<td>39,085</td>
<td>283,326</td>
<td>Metzphi</td>
</tr>
<tr>
<td>1995</td>
<td>nil</td>
<td>3,098</td>
<td>15,320</td>
<td>Metzphi</td>
</tr>
</tbody>
</table>

Mines that have produced for the Echo Bay mill are the Overview, Kettle, Key East, Key West, and currently the Lamefoot. Only the Key is of the epithermal type; the remaining mines are in deposits that were thought to be skarns. Recent studies by G. M. Rasmusson at the animal were demonstrated that the Overview deposit is not a skarn deposit or of a replacement type. Echo Bay geologists did consider a syenitic model, but because the football was limestone, the idea was ultimately rejected. During 1990, E. S. Cheney and Rasmusson noted that the deposit is overturned, thus making it possible to apply a volcanic-sedimentary massif to the model (Rasmusson, 1993).

The application of that model is permissive 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 of a picture of how and why vegetation and lineages changed through time in arc settings.

Mechanisms of Floral and Vegetational Change in the Tertiary Arc

The formation of a series of volcanic centers in western North America during the Eocene Warm Period allowed for the fossilization of vegetation that hitherto had not entered the Tertiary western North American palynological 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 (Kruckenberg, 1987; Wolfe, 1987; Myers, 1993; and Fisher, 1994).

The proposal involves a focus on the historical development of western North America as a volcanic arc system with a considerable record of arc volcanism. The history is complex, involving 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 authors would like to thank an outgrowth of Myers'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.

References Cited


Oregon, consisted of shorter, lived-on cones in a low-lying landscape (White and Robins, 1950). The flora of this area was deposited within and was associated with active volcanoes, which were possibly those to the Channell field.

In general, microfossils in the rocks are well preserved. Because of the high altitude of the volcanic field, the deposits consist of volcanic ashes and lapilli which, in places, may be several meters thick. The volcanic ash and lapilli are composed of glass shards and tiny crystals of flint and quartz. The absence of biologic material indicates that the volcanic deposit is a result of an explosive eruption.

In the area surrounding the volcano, the vegetation is sparse, and the soil is thin. The ground is composed of volcanic rock, and the surface is covered with a layer of ash and lapilli. The area is characterized by a cold, dry climate with long winters and short summers.

The flora of the area includes a variety of plants, including coniferous trees, shrubs, and herbs. The dominant species are Picea engelmannii, Abies lasiocarpa, and Pinus edulis. These species are adapted to the harsh environmental conditions found in the area.

In conclusion, the flora of the area is characterized by the presence of a variety of plants adapted to the cold, dry climate of the region. The absence of biologic material in the volcanic deposit indicates that the deposit is a result of an explosive eruption.
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 of the 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 Burseraceae in the Burseraceae 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/stratigraphical and taphonomic analysis of paleofloras in order to understand them in the context of landscape-level physical processes and regional settings. Many past 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 paleontological 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. This 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 presumably has grown 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, 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 is an 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, stratovolcanoes tend to be large features that can form quickly (in tens of 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 volcanic centers, like the Absaroka volcanic province, included very large and possibly long-lived composite stratovolcanoes with moderate-elevation intervening basins. Other centers, like the Clarno volcanic field in central


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

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Possiliferous, leaf- and insect-bearing sedimentary strata of the middle Eocene Klondike Mountain Formation in the Okangan Highlands of northern Washington and southern British Columbia (Fig. 1) accumulated in a series of north-northeast-trending, on channel grabens and half-grabens that formed during regional extension, platonism, volcanism, and metamorphic core complex emplacement (Muessig, 1962, 1967; Parker and Calkins, 1964; Staats, 1964; Pearson, 1967; Fox and others, 1976; Pearson and Obradowich, 1977; Cheney, 1986; Orr and Cheney, 1987; Fox and Rinehart, 1988; Hansen and Goodge, 1988; Holder and Holder, 1988; Parrish and others, 1988; Holder and others, 1990; Price, 1991; Suydam, 1993; Muessig, 1993). A re-examination and analysis of the Klondike Mountain Formation strata in the Republic and Curlew basins of the Republic graben suggest much of this unit accumulated in relatively limited (<200 km²) sedimentary basins occupying topographic and volcanic- tec tone 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-laden sedimentary deposits in the Okangan Highlands (see, for example, articles by Schorn and Wehr, Wehr and Barkdale, 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 Klondike Mountain, a prominent hill immediately north to Republic, and subdivided the unit into one formal and two informal members (stratigraphic sub-divisions 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 Unglehy (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 units 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 sandstones 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 volcaniclastic sedimentary detritus) and volcanic flow rocks (Gaylord and others, 1988; Gaylord, 1988; Price, 1991) (Fig. 2). Curlew basin deposits are generally similar stratigraphically and lithologically to the Republic basin deposits—withe 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 Sanfol Volcanics.

Overall, the Klondike Mountain Formation strata in the Republic basin consist of a generally coarsening upward sequence of mudstone, sandstone, and conglomerate-dominated deposits unconformably overlying basaltic and andesitic tuffs and volcanic flows. The basaltic part of the Klondike Mountain Formation consists of a 0-50-m thick sequence of breccia, conglomerate, and minor lava flows that unconformably overlie the dacite and andesite flows of the Sanfol Volcanics. Muessig (1967) believed the basal contact of the Klondike Mountain Formation was an angular unconformity. However, detailed examination of strata across the Republic basin reveal essentially concordant bedding attitudes between these two units (Gaylord and others, 1988; Gaylord, 1990).

Figure 1. Index map showing approximate limits of the Republic and Curlew basins. (Geology after Price, 1981, and Suydam, 1983.)
Klondike Mountain Formation
Gaylord and others, this paper
Muegg, 1962, 1967

Upper member
Upper member
Upper member
Middle member
Lower member

Tom Thumb Tuff Member

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 importance to weathering (tied to sediment grain size and color) of the various tuff units which are best preserved in strata from the lower member of the Klondike Mountain Formation. Limits of informal members used in this paper and informal members described by Muegg (1962, 1967) are also indicated.

Sanpoil Volcanics

EXPLANATION
matrix- and glass-supported conglomerate
sandstone
fine gravel
medium gravel
coarse gravel
silt and clay (silt mud)
lava rocks

hydrothermally altered detritus remaining from the earlier hydrothermal eruptions as well as recently eroded Sanpoil Volcanics detritus were transported to the lake from surrounding highlands primarily via sedimentary mass movement (debris flows) and alluvial (stream) reworking. Debris-flow deposits are recognized as poorly sorted, clay- and mud-rich, matrix-supported breccia and conglomerate. Clasts of siliciclastic quartz sand 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 well sorted and relatively sand-rich and exhibit stratification and cross-stratification.

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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 changes in the insects and 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 leaf floras of Republic, the Princeton Chert contains a sort of fossilized 'complex'. The fossils were formed by silicification, a process in which ground water containing a high concentration of silica (probably from local granite) percolated into mats of plant material in various freshwater lacustrine and fluvial sites. The plant tissues then became supersaturated or 'permineralized' with 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 described in detail by Boatright (1981). One or more blocks of chert from different sites can be reassembled for three-dimensional reconstruction of the organism being studied. This process allows studies of plant structure from Mesofossil A. C. T. (M. A. T.) and Boatright (1981) gave samples of the chert to Chester A. Arnold, of the University of Michigan Museum of Paleontology, who recognized dendrocladous ferns (forms related to modern holly ferns) and a new species of Dicksonia. This is the first time that such widespread preservation of intact leaves and ferns in such a dynamic depositional setting. Apparently, leaf fragments were washed into the lake by streams and wind and later settled into deeper parts of the lake where burial was swift and reworking by waves was limited. With this coincidence of factors, the leaves were thinly to thickly laminated, normally graded couplets of fine sand to mud indicates that in many cases the fish, insects, and other organisms that interacted with the frequent turbidity currents that flowed across the lake bottom. Curiously, these fossiliferous strata show only local evidence of bioturbation, suggesting that oxygen levels were too low to support burrowing organisms or that deposition rates often were too rapid to allow significant turnover of the substrate.

Reference Cited


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The Eocene Fishes of Republic, Washington

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The Eocene fossil fishes were discovered in the Republic area by J. B. Umplyle during the course of geological surveys early in the century (Umplyle, 1910). Umplyle's specimens were sent to the U.S. National Museum and identified by Eastman (1917) as belonging to the genus Amynx (Family Catostomidae) in a species named by E. D. Cope (1983) on fossils from the Similkameen River area of British Columbia. Another geologist, R. C. Pearson of the U.S. Geological Survey, discovered fossils near Tokoda Creek in the 1960s. Fossil fish expert D. Dunkle (as quoted in Pearson, 1967) thought they were related to species of the genus Esox, known from the Green River Formation of Wyoming. I 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 Anis (Family Amiidae), an ancient group whose only living species is the bowfin (usualy represented only by its scales). Fish can lose scales and then grow new scales, so the presence of isolated scales does not necessarily imply that the fish died. Even if the scales were lost in such a manner, these scales can sometimes be found as fossils. Judging by the size of the 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 Anis bicepina Wilson (1982) named. Finding gill plates in a fish scale usually means that the enclosing sediments were deposited in shallow, often weedy water, because amids usually prefer such habitats.

The family Hiodontidae is another old living group; this one has two living species, mooney 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 Horseye, BC. Males of both Hiodon and Eohiodon, when they become 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 Amynx aggregatums 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 Eosomolus driftwoodensis Wilson (1977) (Fig. 1), first named on specimens from British Columbia. The oldest fossil member of the family Salmonidae (salmon and its relatives), Eosomolus has features intermediate between those of subfamily Salmoninae (salmon, trout, char) 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 Eosomolus spes-

The leaf floras of the Republic graptolite are a spectacular lot. The possibility was to display take the same to play in fire volatile red 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. Such detailed and preserved preparational conditions are rare, but well known: Florissant and Green River in Colorado, Wind River in Wyoming, and Clarksia in Idaho. In another field, 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) gives us information about the local Eocene ecosys-

Taphonomy is the study of the processes by which fossils and associated materials are preserved and later fossilized. It deals with the interactions between the biological material, the geological environment, and the conditions that dictate whether a fossil will be preserved. The presence of hot mineral springs in the area may have affected 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 impede solubility of the plant 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 embalm the leaves. Rivers carrying larger grain sizes would have some coarse material 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, so a modern parallel might be the weeds along the roadsides. 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.
The Presence of Fagaceae (Oak Family) in Sediments of the Klondike Mountain Formation (Middle Eocene), Republic, Washington

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L. H. Bailey Hortorum
Cornell University
Ithaca, NY 14853-6301

Tear 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 Picea (pine), Pinus (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 cranberry), 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 amorphous (wind-pollinated), some of its elements, such as the understory trees and shrubs, are entomophous (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, 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 Fagoidae, Castanea (chestnuts) in the subfamily Castanoeae. Some authors place Quercus in a subfamily, Quercoidae. Quercus and Fagus are pollinated by wind, whereas all members of the Castanoeae 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 moss colony fossil record ascertainable as belonging to the Fagaceae consists of pollen grains resembling those of the modern Castanoeae 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 Fagus?u?d?kald?a? (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 arrangement along the leaf margin allows Fagus?u?d?kald?a to be identified as belonging to this family because this character is widespread in 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 Fagus?u?d?kald?a. 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 Castanoea (Plate 1, figs. 3 and 4), erected for isolated Castanoea-like fossil leaves, is almost identical in leaf features to the extant genus Castanoea. The shape, margin, high-ordered venation, and areolation resemble the fossil genus Castanoea to modern Castanoea, and for this reason some researchers believe that Castaneoea should be considered a member of the subfamily Castanoeae. 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 Fagaceae and to be considered as belonging to the subfamily Fagoidae. Various fragmented specimens show leaf characters similar to those of the genus Fagus (Plate 1, fig. 7), but any assignment to Fagus 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 Nannamy, Mark Reeves, and Michael Spitz.

An extinct species of march fly (Placioa), about x3.5 (Photo by Lisa Barkdale)

A Checklist of Fossil Insects from Republic, Washington

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In 1993, Stanley 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 (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).

Table 1. Middle Eocene fossil insects of Republic, Washington

<table>
<thead>
<tr>
<th>Family</th>
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<th>Species</th>
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<tr>
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<td>Tettigoniidae</td>
<td>family unknown</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>Hesperoidea</td>
<td>family unknown</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>Tettigoniidae</td>
<td>family unknown</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>Hesperoidea</td>
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</tr>
<tr>
<td>Lepidoptera</td>
<td>Hesperoidea</td>
<td>family unknown</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>Tettigoniidae</td>
<td>family unknown</td>
</tr>
</tbody>
</table>

For the insect identifications, we thank Stanley Lewis (St. Cloud Univ.,) David Grimadi (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.)

Reference cited


Tiger moth from Republic, the earliest record of the family Arctiidae. Body length ca. 2 cm. UWBM 66300A. loc: B2737. (Photo by Paul Schwartz.)
Pollen and Spores Characteristic of Eocene Sediments at Republic, Washington

Edna B. Leopold, Cindy A. Updegrave, and Kaffe Maier
Department of Botany
University of Washington
Seattle, WA 98195

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 fossil 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 Schaeffer Solution, 5 percent potassium hydroxide, hydrofluoric acid, acetylation, sodium hypochlorite bleach, and heavy liquid flotation. However, all our samples yielded only poorly preserved palynologically organic material in which tissues and pollen were badly corroded and retained few morphological features.

Our samples consistently contained abundant charcoal and 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 dicotyle- dontous 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 motile 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 Teppe 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 Teppe 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 tracts 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.

Reference Cited

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, (509) 249-4121.


Northwest Palaeontological 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.

The Conifer Flora from the Eocene Uplands at Republic, Washington

Howard E. Schorn
Museum of Paleobotany
University of California
Berkeley, CA 94720-7040

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 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 Republican conifers 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 through 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 genus 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 needles or nodules, 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 Republican 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 Republican flora is rich in fossil specimens and is very diverse in numbers of different species (Gooch, 1982; 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.


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 Clarino Formation of northern 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: *Craizipetra*, *Iglanuar*, *Florissantia* (although a different species), *Calycites*, *Magnicarpas*, *Devicer*, *Pteronepletoma*, *Melissoma*, *Palaeophytocarpus*, *Vitis*, *Palaeoarchippus*, *Craizipeta*, *Portana*, *Joffren*, *Saba*, *Calycocarpus*, *Esote*, and *Immergenyptes*

Shared with the Eocene Green River Formation floras of Wyoming, Colorado, and Utah are *Palaeophytocarpus*, *Magnicarpas*, *Florissantia*, and vitaceous seeds. Shared with the middle Eocene Mesiel flora, from near Darmstadt, Germany, are *Craizipetra*, *Cedrelaspermum*, 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*, *Ceratophyllum*, *Cedrelaspermum*, *Craizipetra*, *Naphth*, *Florissantia*, and *Palaeophytocarpus*

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, Madeline Perry, Robert Solt, Alex Strong, Peggy Toepel, and Michael Vermillion.

References Cited


Figure 1. The Puget Lowland, Republic, and Thunder Mountain palaeofloras (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 histogram is redrawn from Wolfe (1979, 1990), 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 higher habitats. Climates as warm as, or warmer than, the 'palm line' do not experience periods of extended freezing. WMT, warm month mean temperature; CMT, cold month mean temperature. (1) from Wolfe (1990); (2) from Axtell (1990) and Leonard and Marvin (1980); (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 lends validity to methods.
Paleobotanical Significance of Eocene Flowers, Fruits, and Seeds from Republic, Washington

Wesley C. Wehr
Thomas Burke Memorial Washington State Museum
University of Washington
Seattle, WA 98115

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 material 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 names are:

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

<table>
<thead>
<tr>
<th>Family</th>
<th>Genus</th>
<th>Species</th>
<th>Plate</th>
<th>Fig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nymphadoraceae</td>
<td>Nymphadoranthus</td>
<td>sp.</td>
<td>[Plate 2, Fig. 2]</td>
<td></td>
</tr>
<tr>
<td>Fabaceae</td>
<td>Fabaceae</td>
<td>sp.</td>
<td>[Plate 2, Fig. 2]</td>
<td></td>
</tr>
<tr>
<td>Rosaceae</td>
<td>Rosaceae</td>
<td>sp.</td>
<td>[Plate 2, Fig. 2]</td>
<td></td>
</tr>
<tr>
<td>Salicaceae</td>
<td>Salicaceae</td>
<td>sp.</td>
<td>[Plate 2, Fig. 2]</td>
<td></td>
</tr>
<tr>
<td>Ulmaceae</td>
<td>Ulmaceae</td>
<td>sp.</td>
<td>[Plate 2, Fig. 2]</td>
<td></td>
</tr>
<tr>
<td>Aceraceae</td>
<td>Aceraceae</td>
<td>sp.</td>
<td>[Plate 2, Fig. 2]</td>
<td></td>
</tr>
</tbody>
</table>

Acknowledgments

It is a pleasure to thank Diane M. Erwin, Nancy L. Guoch, and Jeffrey A. Myers for their constructive reviews. Their suggestions, combined with editorial advice from Katherine M. Reed, help make this a better paper.

References Cited


Gosch, N. L., 1992, Two new species of Parascolicia Gordon (Plac.

Gosch) from the middle Eocene of the Pacific Northwest: Paleonto.


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<table>
<thead>
<tr>
<th>Family</th>
<th>Genus</th>
<th>Scientific Name</th>
<th>Fossil Flora</th>
<th>Fossil Fruits</th>
<th>Fossil Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nymphaeaceae</td>
<td>Nymphaea</td>
<td>Nymphaea species</td>
<td>Nymphaea species</td>
<td>Nymphaea species</td>
<td>Nymphaea species</td>
</tr>
<tr>
<td>Ranunculaceae</td>
<td>Ranunculus</td>
<td>Ranunculus species</td>
<td>Ranunculus species</td>
<td>Ranunculus species</td>
<td>Ranunculus species</td>
</tr>
<tr>
<td>Orchidaceae</td>
<td>Dendrobium</td>
<td>Dendrobium species</td>
<td>Dendrobium species</td>
<td>Dendrobium species</td>
<td>Dendrobium species</td>
</tr>
<tr>
<td>Caryophyllaceae</td>
<td>Silene</td>
<td>Silene species</td>
<td>Silene species</td>
<td>Silene species</td>
<td>Silene species</td>
</tr>
<tr>
<td>Fabaceae</td>
<td>Phaseolus</td>
<td>Phaseolus species</td>
<td>Phaseolus species</td>
<td>Phaseolus species</td>
<td>Phaseolus species</td>
</tr>
<tr>
<td>Cucurbitaceae</td>
<td>Cucurbita</td>
<td>Cucurbita species</td>
<td>Cucurbita species</td>
<td>Cucurbita species</td>
<td>Cucurbita species</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asteraceae</td>
<td>Compositae</td>
</tr>
<tr>
<td>Poaceae</td>
<td>Gramineae</td>
</tr>
<tr>
<td>Rosaceae</td>
<td>Rosaceae</td>
</tr>
</tbody>
</table>

Acknowledgments

Without the assistance of the following individuals, this article would not have been possible: Lisa Barksdale, Bob Geer, Donald Hopkins, Kirk Johnson, Henry Kowalyn, Donald Koon, Allie Kunkel, Chris Luckey, Madeline Perry, Robert Solt, Alex Strong, Peggy Toepel, and Michael Vermillion.

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The Conifer Flora from the Eocene Uplands at Republic, Washington

Howard E. Schorn
Museum of Paleontology
University of California
Berkeley, CA 94720-4750

Weirly C. Wehr
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As you collect fossil plants in Republic, and the bright sun of a warm August afternoon begins to bear down upon 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 fir. 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 30 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 Eocene forest. In fact, the Republic flora probably has the richest concentration of conifer genera of any known Tertiary forest. 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 moderating, or more equable, temperate climate that existed at Republic some 30 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 temperate 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: fit (Abies), hemlock (Tsuga), and spruce (Picea) (Wehr and Wehr, 1992).

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

<table>
<thead>
<tr>
<th>Genus</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ginkgoaceae</strong></td>
<td>Ginkgo</td>
</tr>
<tr>
<td><strong>Taxaceae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Gnetum</em>-type</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Tsuga</em>-type</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Taxus</em> (California nutmeg)</td>
<td>1 species</td>
</tr>
<tr>
<td><strong>Cephalotaxaceae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Cephalotaxus</em>-type (plant-wax)</td>
<td>1 species</td>
</tr>
<tr>
<td><strong>Cupressaceae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Chamaecyparis</em> (Port Orford cedar)</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Thuya</em> (arbor-vitae)</td>
<td>1 species</td>
</tr>
<tr>
<td><strong>Tetradeaeae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Cryphonotus</em>-type branches (Japanese cedar)</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Glyptostrobus</em>-type branches (Chinese water pine)</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Sequoia</em> (coast redwood)</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Sequoites</em> (dawn redwood)</td>
<td>1 species</td>
</tr>
<tr>
<td><strong>Pinaceae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Abies</em> (larch)</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Pseudotsuga</em> (golden larch)</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Tsuga</em> (hemlock)</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Picea</em> (spruce)</td>
<td>1 species</td>
</tr>
<tr>
<td><em>Pinus</em> (pine)</td>
<td>2 (3) species</td>
</tr>
<tr>
<td><em>Pinus</em> (Bladen pine)</td>
<td>1 (2) species</td>
</tr>
</tbody>
</table>

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.


Pollen and Spores Characteristic of Eocene Sediments at Republic, Washington

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University of Washington
Seattle, WA 98195

We processed five samples of organic-rich silt 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 florasite. 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 Schulte Solution, 5 percent potassium hydroxide, hydrofluoric acid, acetolysis, sodium hydroxide bleach, and heavy liquid flotation. However, all our samples yielded only poorly preserved palynologically 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 Pinacea, including Pinus, Abies, and Tonga. Because of the abundance of angiosperm leaf remains, we anticipated pollen of dicotyledonous plants, but we were able to identify only one dicot genus, Beilula, 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 zoospore 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 broad-leaved 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 correlative with the Republic flora and is floristically similar to that at Republic. The co-occurring reproductive structures, foliage, and pollen of Abies, Pinus, and Tonga from the Eocene sediments at Republic and One Mile Creek comprises some of the earliest known well-documented records of these genera. Pollen of Beilula complements the well-preserved leaves and bracts reported by Wehr (see references cited in this article, 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 sturdier than most angiosperm pollen types, our results may be a case of differential preservation by which the more fragile angiosperm pollen is highly degraded.

Reference Cited

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, (509) 459-4127.


Northwest Paleontological Association Activities

August 10: Bill Smith will lead a field trip to the Coal Creek area near Longview to collect from the Cowitz 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.
The Presence of Fagaceae (Oak Family) in Sediments of the Klondike Mountain Formation (Middle Eocene), Republic, Washington

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L. H. Bailey Hortorium
Cornell University
Ithaca, NY 14853-6801

Tear 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 Hydrangus, Ribes (wild currant), Prunus (cherry), Coriolus (winter hazel), Phoebe (laurel), Populus (poplar), and Salix (willow). In spite of the fact that most elements of this type of forest are amorphous (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 a large family of both trees and shrubs that has a northern hemisphere distribution. There are nine extant genera of these. Of these, Quercus (oaks) and Fagus (beeches) are placed in the subfamily Fagioideae, Castanea (chestnuts) in the subfamily Castanoeae. Some authors place Quercus in a third subfamily, Quercoideae. Quercus and Fagus are pollinated by wind, whereas all members of the Castanoeae 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 Castanoeae that were found in Lake 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 Fagusopsis umbulata (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 ornamentation on the leaf margin allows Fagus to be identified as belonging to the family Castanoeae because this character is widespread 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 Fagusopsis 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 recorded from the lakebed strata.

The genus Castaneopyllum (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-ordered venation, and areole relation of fossil genus Castaneopyllum to modern Castanea, and for this reason some researchers believe that Castaneopyllum should be considered a member of the subfamily Castanoeae. 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 genera. Fagus is common in the rock record and is an important taxon in the fossil record of the Republic flora.

Acknowledgments

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

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 from the Republic lakebed deposits. Additional finds and identifications allow us to update that list as shown in 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 more 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).

Reference cited


Table 1. Middle Eocene fossil insects of Republic, Washington

<table>
<thead>
<tr>
<th>Insect Order</th>
<th>Family</th>
<th>Genus</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemiptera</td>
<td>Hemipecten</td>
<td>Hemipecten</td>
<td>Pennate (leaf-feeding)</td>
</tr>
<tr>
<td>Hymenoptera</td>
<td>Bembidae</td>
<td>Bembex</td>
<td>Pennate (leaf-feeding)</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>Lepidoptera</td>
<td>Lepidoptera</td>
<td>Pennate (leaf-feeding)</td>
</tr>
<tr>
<td>Coleoptera</td>
<td>Coleoptera</td>
<td>Coleoptera</td>
<td>Pennate (leaf-feeding)</td>
</tr>
</tbody>
</table>

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

An extinct species of march fly (Platia), about x3.5 (Photo by Lisa Barkdale).

Tiger moth from Republic, the earliest record of the family Arctiidae. Body length ca. 2 cm. UWBM 66030A, loc. B7373. (Photo by Paul Schwartz.)
The Eocene Fishes of Republic, Washington

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University of Alberta
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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 foot
man (1917) as belonging to the genus Acanthodid (Family Ca
tostomidae) in a species named by E. D. Cope (1893) on fos
ts from the Similkameen River area of British Columbia. Another geologist, R. C. Pearson of the U.S. Geological Sur
vey, discovered fossils near Toro Creek in the 1960s. Fossil fish expert D. Dunkle (as quoted in Pearson, 1967) thought they were related to species previously known in the Green River For
mation of Wyoming and 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. W. 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 discov
eries 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 represen
t a distinct group, and one belongs to an extinct family. The least well known is a species of Ania (Family Ami
dae, an ancient group whose only living species is the bowfin) usually represented only by its scales. Fish can lose scales and then grow new ones, so the presence of isolated scales does not necessarily imply that the fish had died. Even if scales can sometimes be found as fossils, judging by the size of the average scale, these fish could have reached 30 cm or more in length. In the Princeton area of British Co
lumbia, a more complete specimen has been found and the species Ania hesperia Wilson (1982) named. Finding complete fossils, scales usually mean that the en
closing sediments were deposited in shallow, often weedy water, be
cause amids usually prefer such habitats.

The family Hiodontidae is another old living group; this one has two new living species, mooneye and goldeye, both in the genus Hiodon, that specialize in eating insects. The Republic hiodontid is an extinct genus and is called Eohiodon woodruff Wilson (1976), after the Re

The leaf floras of the Republic graptolites are a spectacular lot. The Cretaceous period is known for its diversity in plant life, and the presence of hot mineral springs in the area may have aided plant preservation in some cases. In modern volcanic en
vironments, mineral deposits have been noted coating leaves with a fine precipitate. This precipitate may prevent bacterial degradation and impart durability to the delicate 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 emmbose the leaves. Rivers carrying larger grain sizes would have been more erosive on the fossils, but this is rare in the deposits from which we have collected the best leaf specimens at Republic. Second, the high plant species richness of the plants and animal tracings in the deposits at Republic indicates that the ecosystem was relatively stable, at least in the short tens of hundreds of years. A limited range of plants and animals can withstand constant perturbation, and plant ranges are thought to be stable over long periods of time. 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.


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.wa.us/dnr/offices/mines/omm.html

The list of links to mines and mining sites can be reached by:
http://dnr.state.wa.us/dnr/offices/mines/mineleys.html

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

Erratum

On page 31 in our previous issue, there are two geologic units mistakenly labeled in the right side of the map. The shape should be Ksn (Mount Spokane granite), and the small unit in that area labeled Ksn is 1Ka (alaskite, pegmatite, aplite).

References Cited


Ammon, a common fossil fish (sucker), ca. x20. Found by Nathan Shifflet.
The Significance of the Princeton Chert Perminalian Flora to the Middle Eocene Upland Biota of the Okanagan Highlands

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Arizona State University
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Introduction
The Okanagan 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 characters of both 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 Okanagan Highlands is found in the Princeton chert of southern British Columbia. In contrast to the compressed floras of Republic and Cretaceous floras of British Columbia at Princeton, Quesnelia, McBride, and Abert-Wood Creek at Smithers, plant and fungal remains from the Princeton 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 associated microbes, as well as 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 ferns and monocots (plants such as palms and lilies) for the Okanagan Highlands.

The Princeton Chert is a series of limestones and sandstones that are currently known from only one outcrop, such as seeds, but others are represented by a collection of plant ‘parts’. For example, the taxodiaceous species Brachyphyllum mulleri (related to modern dawn redwood and bald cypress) is recognized from seed and pollen cones, stems, roots, leaves, pollen, and seeds (Basinger1976a, 1981, 1982; Basilevsky, Rothwell, and Basinger, 1976). Interconnected stems, leaves, roots, and buds are all known for the semiaquatic dicot Eorhiza (Robison and Person, 1983). Fossil palms and leafy members of the Ily family (for example, Uakis, Ethelia, and Soteridera [Erwin and Stockey 1992]) are also known from interconnected stem, root, and petiole remains. The anatomical structure of cones and flowers provides detailed information about the evolution of 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 in understanding the evolution of angiosperms, especially in some Eocene basins in British Columbia. In his study of the chert and interbedded clays (Bonehama’s “locality”) in the northwestern Palaeonotocentrum, who recognized the semiaquatic dicot Eorhiza (Robison and Person, 1983). During the 1970s additional studies of the chert produced descriptions of leaves, stems, roots, pollen, and seed cones of Mesaur...

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References Cited
Klondike Mountain Formation

Gaylord and others, this paper
May 1962, 1967

Upper member

Upper member

Middle member

Lower member

Tom Thumb, Tuff Member

Sapnon Volcanics

Figure 2. Generalized composite stratigraphic section of the Klondike Mountain Formation and uppermost Sapnon Volcanics in the Republic Basin. The graphic profile of the section reflects the relative resistance to weathering (tied to sediment grain size and sorting) of the rocks. Beds are best preserved in strata from the lower member of the Klondike Mountain Formation. Limits of informal members used in this paper and informal members described by Muesing (1962, 1967) are also indicated.

Hydrothermal alteration promoted precambrian-episodic metamorphism and extensively altered older Klondike saprolite (Tschauer, 1989). Topographic and volcanic-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 lake deposits, porcellaneous silica silt (Tschauer, 1989).

Quoia milleri (see, for example, Businger, 1979a) and the flower fossil Pariophyllum as some today. Since the early 1980s, Ruth A. Stockey, University of Alberta, and her students and associates have described numerous fossils described, including... (continued)

Fossil Fungi

The presence of fossil fungi as important components of the Princeton chert was recognized in the earliest study by Boneham (1968). It was found that more than 80 percent of the palynomorphs present were assignable to the fungal spore group Buchspermops and to the algal, fungid, or bryophyte polyhymenomycetes. More recently, fungi have been found in general tan color, including palm leaves, stems of Erythraea, seeds, fruits, and flowers of Lycaglaeae, seeds of Nymphaeaceae, flowers of Alismatales, and a dicot flower of uncertain affinity. These fungi represent a diverse assemblage that includes forms similar to those of the modern group of modern higher fungi, including the ascomycetes (Saccharomyces), the basidiomycetes (Saccharomyces), a possible divinision of the fungi Impertiscipes. Possible ascomycetes are represented by the forms similar to those of the order Dothideales, which are found in the modern public domain or in the subdomain in U. E. 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 (Pandanaeae) today (Erwin and others, 1989). Presumably, these types have a long history, dating back to at least the Paleocene (Erwin and Stockey, 1994).

A second group of fungi found in the chert, the Hymenomycetes, are representative of the modern genera Alternaria and Cercosporella. These molds cause blast, fruit and seed rot, and leaf spots in a wide variety of modern plants. In the chert, fungi of this type infect several species of plants.

Basidiozymes are represented by the first known fossil smut, which infects a flowering plant (Chlorophyllum). Fungi of the family Prorocentrum, are represented by the newly described genus Prorocentrum. These fungi are unusual in that they infect the roots of living plants, and indicate a subtropical climate for the middle Eocene at this site.

Although most of the monocot remains in the chert are vegetative and seeds with embryos are known for Keraosophora allenbensis (Erwin and Stockey, 1991), stems, attached petals and roots, mid-rib, and laminae have been found. These vascular plant fossils (or their modes of preservation) are difficult to distinguish from one another on the basis of vegetative remains. Ekbole sargentiana, a plant known from stems, attached leaves, and roots, probably represents one of these two families (Erwin and Stockey, 1991).

The Arecales, or palm family, has an extensive fossil record. Palms were represented in the Princeton chert by Ulkabea allenbensis (Erwin and Stockey, 1991). In modern public domain, the palms and related genera are found in the southern United States, Mexico, and the Caribbean, and have a subtropical climate for the middle Eocene at this site.

Comparison of Princeton Chert and Republic Floras

Part of the value of the Princeton chert is that it independently confirms the biogeographic history of the region. It is noteworthy that many of the plants known from the Republic leaf flora are also present, although in significantly different proportions, in the plants known from the Princeton chert. Several important families that were undergoing significant Eocene diversification were part of the Eocene ecosystem and that these interactions may have continued into the Recent.
Depositional History of the Uppermost Sanlo Volcanics and Klondike Mountain Formation in the Republic Basin

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Department of Geology, Washington State University, Pullman, WA, 99164-2812

Possiliferous, 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, platonization, volcanism, and metamorphic core complex emplacement (Muessig, 1962, 1967; Parker and Calkins, 1964; Staats, 1964; Pearson, 1967; Fox and others, 1976; Pearson and Obradovich, 1977; Cheney, 1980; Orr and Cheney, 1987; Fox and Rinnehart, 1988; Hansen and Goode, 1988; Holder and Holder, 1989; Parrish and others, 1990; Holder and others, 1990; Price, 1991; Suydam, 1980, 1983). 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 large (<200 km²) sedimentary basins occupying topographic and volcanic-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 Barkdale, 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 Klondike Mountain, a prominent hill immediately north to 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 Ungley (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 units 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 sandstones and conglomerates 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 volcaniclastic) 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 Sanlo 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 basaltic 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 Sanlo 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 (Gaylord and others, 1990, 1994; Price, 1991; Suydam, 1983).
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, 1984; Wehr, 1995), the Princeton chert provides floral, fruit, and wood evidence of several members of this family.

*Paleorsos similamenensis* is the oldest flower of the Rosaceae (Rasinger, 1976b; Cevallos-Ferriz and others, 1993). This petrified flower contains the oldest known rosequaceous pollen, which is extremely rare. The flower has features that place it in the presently most primitive subfamily of the Rosaceae, the Spirioideae, but it also has some features of the subfamily Maloideae, which includes the apples, pears, and quinces. A third subfamily of Rosaceae, the Prunnoideae, 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 *Wehrwoofia striata* (Erwin and Stockey, 1980). Flowerers at two developmental stages with pollen present have been described and are most similar to those of the tribe Dodoneaeae, 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, Nympheaceae, Lyrhracceae, Myrtaceae, and Vitaceae (Cevallos-Ferriz and Stockey, 1988a, 1989, 1990a, 1990b; San and Stockey, 1991; Pigg and others, 1993; Wehr and Hopkins, 1994). For example, tentative determinations of the genera *Dodonopsis* 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 Okanagan Highlands, as well as insects, fish, and other animal remains and fossils, 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.

Acknowledgments

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References


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 of the 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 Bursera, which is the Burseraceae 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 (35–24 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 57.5–44 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/stratigraphic and taphonomic analysis of paleofloras in order to understand them in the context of landscape-level physical processes and regional settings. Many past paleobotanical publications vastly oversimplify the physical landscape even at the largest and most fundamental scale.

For example, even the term "upland," as used in the paleontological 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 extends 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, stratovolcanoes tend to be large features that can form quickly (in tens of 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 volcanoes, like the Absaroka volcanic province, included very large and possibly long-lived composite stratovolcanoes 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 Robbins, 1987). The post-glacial flora was deposited within an area associated with active volcanoes, which were possibly those to the north of the Channeled scablands.

In general, many of the cones consist of arcuate edifices with summit heights of about 500 to 1,000 meters above the surrounding landscape. In this respect, the volcanoes resemble higher elevation "island" cones 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 the embayment consists of arcuate edifices with summit heights of about 500 to 1,000 meters above the surrounding landscape. The Republic graben probably lay between 800 and 1,500 meters during the middle Eocene, which is relatively high for an arc basin.

Recently many scientists began to understand the Eocene.

On the other hand, the paleobotanical record of the Eocene basins shows that many of the Eocene deposits are volcanic and that the vegetation was dominantly composed of coniferous forests. The Eocene paleobotanical record shows a more diverse flora than previous studies have suggested. For example, some studies have suggested that the Eocene paleobotanical record is dominated by coniferous forests, while others have suggested that the Eocene paleobotanical record is dominated by angiosperms. Recent studies have shown that the Eocene paleobotanical record is more diverse than previously thought.

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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 shown in Table 1.

**Table 1. Republic Unit production, Golden Promise mine. Data from annual mineral industry reports by R. E. Derkay in Washington Geology.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Tons</th>
<th>Au (oz)</th>
<th>Ag (oz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>79,210</td>
<td>80,301</td>
<td>354,077</td>
</tr>
<tr>
<td>1989</td>
<td>62,187</td>
<td>52,007</td>
<td>266,000</td>
</tr>
<tr>
<td>1990</td>
<td>90,000</td>
<td>81,400</td>
<td>326,000</td>
</tr>
<tr>
<td>1991</td>
<td>96,562</td>
<td>77,316</td>
<td>311,440</td>
</tr>
<tr>
<td>1992</td>
<td>83,371</td>
<td>58,510</td>
<td>299,057</td>
</tr>
<tr>
<td>1993</td>
<td>110,846</td>
<td>49,601</td>
<td>276,688</td>
</tr>
<tr>
<td>1994</td>
<td>112,260</td>
<td>39,085</td>
<td>283,326</td>
</tr>
<tr>
<td>1995</td>
<td>nil</td>
<td>3,986</td>
<td>15,350*</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Tons</th>
<th>Au (oz)</th>
<th>Ag (oz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>N.A.</td>
<td>83,310</td>
<td>nil</td>
</tr>
<tr>
<td>1991</td>
<td>644,950</td>
<td>602,271</td>
<td>398,603</td>
</tr>
<tr>
<td>1992</td>
<td>657,099</td>
<td>89,848</td>
<td>299,057</td>
</tr>
<tr>
<td>1993</td>
<td>575,460</td>
<td>73,431</td>
<td>nil</td>
</tr>
<tr>
<td>1994</td>
<td>612,260</td>
<td>66,763</td>
<td>283,326</td>
</tr>
<tr>
<td>1995</td>
<td>547,597</td>
<td>10,044</td>
<td>22,800</td>
</tr>
</tbody>
</table>

**Figure 2. Belcher Delta mines and semicircular anomalies. Contours in gamines. (Modified from Hunting Geophysical Services, Inc., 1960.)**

The future is promising for the Republic Unit as it is expected to produce a significant amount of gold and silver in the near future.

**Acknowledgments**

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**References Cited**


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 dogwoods, 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 further 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 distributions 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 eastern 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.

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 grading 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, 1953-1967* (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 Harison Schmitt (father of geologist 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, Wally W. Kolb, on behalf of the USGS. After a four-year exploration and development program by Canadian Superior, Earth Resources Company, and their consultants, 5150 Knob, 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 development of the 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 first time in 1975. In 1983, 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 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. Ronan, 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 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 hot spring 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 1990 (Tschauer, unpublished). It resembles very closely the models of Buchanan (1979) and Berger (1985) and has features that were documented by Lindgren back in 1914.
The Early Days

The mining history of the Republic District is a tribute to its prospectors, miners, engineers, metallurgists, geologists, and financiers. In February 1873, when the northern 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 other 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 Euroka Gulch (M. S. Warring, Ferry County Historical Society, written commun., 1996). On March 5 of that year, two prospectors, Philip Cressey and Thomas Ryan, with the aid of P.C. Reynolds, James Clark of Spokane, located the Republic and Jim Blaine claims. With financing provided by Patrick P. (Patsy) Clark, the district was rapidly developed.

A gold rush ensued, and thousands of claims were staked, encouraged by published accounts during 1873 in the Seattle Post-Intelligencer by K. Hodges, who wrote, "One of the greatest showings of free-milling ore has been made in Euroka 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 from the time and area 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 Euroka was renamed 'Republic' by its new owners, the Republic Reduction Company. The name 'Euroka' had been pre-empted by a post office in business at the time. On February 18, 1899, Governor Rogers signed a bill creating the new town. 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 the town of Lenore, in the Green Belt.

In the summer of 1902, two railroads reached Republic to serve the mills and mines—the Kettle Valley Railroad and the Great Northern Railway (1905). 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 shafts.

Metallurgy, however, was a problem because the very finely crystalline ore minerals and silica encapsulation of electrum in native gold 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 continues 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 1910, J.W. Umpleby described the development and mining activity in the early evolution of many small mines 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.

In the westward advance 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 depositional processes in the United States in an effort to understand the character of gold deposits. In 1900, the USGS published Waldemar Lindgren's exhaustive report on the Silver City and DeLamar, Idaho, gold/silver deposits. It was the first USGS report on the Silver City deposit and important for its documentation of the Silver City district. In 1909, Lindgren published his book Geology of the Silurian of Idaho, which provided an exhaustive study of the geology of the Silver City area.

Lindgren was the first geologist to develop a comprehensive model for the formation of gold deposits. He divided gold deposits into two types: epithermal (low-temperature) deposits and mesothermal (high-temperature) deposits. Epithermal deposits are formed at shallow depths, typically less than 1000 meters, and are associated with magmatic activity. Mesothermal deposits are formed at deeper levels, typically greater than 1000 meters, and are associated with metamorphic activity.

Lindgren's model was based on his studies of the geology of the Silver City deposit in Idaho. The Silver City deposit is a typical epithermal deposit, and Lindgren's model was developed to explain the formation of these deposits. His model was later expanded and modified by other geologists, but it remains the foundation of our understanding of the geology of gold deposits.

The middle Eocene Eocene flora recovered from several localities in and around the town of Republic, Washington, provides some of the clearest 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 Main Street in Republic. This discovery of this floras for 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 elevations and lower elevation sites from a time when local floristic diversity was at an all-time high for North America. The flora also contains taxa from the Cretaceous, such as Medullosa, Cercidiphyllum, and Ginkgo; other groups that diversified during this time such as the Paleocene such as the Betulaeaceae (birches), Ulmaceae (elm), 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 the similarity between the living floral communities of North America and eastern Asia (Graham, 1972). The similarities became significantly greater with increased botanical exploration, and in 1946, 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 in the 1870s, revealed a wealth of fossil plant material in the Tertiary, commenced in the 1860s. These scientists discovered a fossil record that indicated the extinct floras of the late Eocene and early Oligocene were more closely related to those of the late Oligocene and early Miocene than to those of the late Miocene and early Pliocene, and that the early Eocene floras were more closely related to those of the late Miocene and early Pliocene than to those of the late Oligocene and early Miocene.

The Republic flora is an important addition to our understanding of the evolution of the flora in 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 eastern Asia or eastern Asia and eastern North America

<table>
<thead>
<tr>
<th>Republic taxon</th>
<th>Eastern North America</th>
<th>Eastern Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gingko (maiden hair tree)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Perulriden (China golden larch)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Cercidiphyllum (katsura)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Metasequoia (dawn redwood)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Phoebus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Liapilambour (sweet gum)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Sasafo</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Linderia (spinechop)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Haplostegia (Carolina bay)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Koelreutesia (goldenrain tree)</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

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 floras 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 on the project since 1977. Enthusiastic 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 Stonecrop Interpretive Center now encourages continuing research and education relating to this flora. (See Perry and Barksdale, this issue.)

References Cited

Figure 3. Inter-regional sequence stratigraphy of the Eocene rocks. CHM, Chumstick Formation; COW, Cowiche Formation; GBV, Gable Volcanics; GRV, Gray River Volcanic Formation of the Cowiche Formation; KLD, Klondike Mountain Formation; MRM, Marana Formation; MRW, Marano Formation; NCH, Naches Formation; OBR, O'Brien Creek Formation; RFD, Renton Formation; RGE, Raging River Formation; ROD, Roslyn Formation; SAN, Sanpoil Volcanics; SDH, Shanks Formation; SLP, Silver Pass volcanic rocks; SPB, Springbrook Formation; SWA, Spokane Formation; TFD, Tofane Formation; TIG, Tiger Mountain Formation; TUK, Tukwila Formation; WLT, 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 Calcites, 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 River valley, shown by Parker and Calcites (1964) and Muessig (1967). The syncline is outlined by the three Chalina sequences and by considering all of the Quaternary rocks to be a fourth basal unit (Fig. 2). North of Carlew, the synformal structure is marked by the Knob Hill Group in the Carlew klippe of the No. 7 fault of the Chesa Bay 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 antiform MCCs and is largely bounded by the same detachment faults, it is the synformal counterpart of the antiform MCCs. Thus, while the Chalina regional sequences were not deposited in a local "graben" but rather, are structurally preserved in the upper plates of detachment faults.

References Cited
Challis Sequence

The Eocene formations of the Republic area are smaller unconf ormity-bound 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 Marren Formation of alkaline volcanic rocks lies unconformably upon the Kettle River Formation and basalt flows to the south of the border. The Scarpill Volcanics (the now-eroded olivine tholeiite and semimconglomeratic lavas) are the most extensive Challis rocks within 15 km of Republic. However, the paucity of bedding within the Scarpill makes its stratigraphy and structure difficult to assess.

The youngest Challis unconformity-bound 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-bound sequences at Republic extend well beyond the Scarpill/Carley volcanics, they are not developed 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-bound formations also are poorly dated radiometrically.

Metamorphic Core Complexes

In the area of Figure 2, Proterozoic and possibly Paleozoic am phibolite-facies metamorphic gneisses and three suites of Palaeozoic to Eocene granite, plutons are restricted to the MCCs. Only the youngest of the three suites (the Hilette Formation suite of Holder and Holder, 1988) is shown separately in Figures 2, 3, and 4. The three suites are bounded unconformably by their top members, which are marked by 10 m to 110 m of chloritic breccia in the crystalline rocks. Herron Creek rocks are capped by detachment faults in the middle of the Scarpill/Carley valley (cross sections D-D' and E-E' of Figure 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 below Figure 2, the chloritic breccias are underlain by as much as 4 km of mylonitic gneiss.

Considerable rotation may have occurred along detachment faults, either because the faults are listric (decrease in dip downward) and (or) because of extension over ductile Eocene granite plutons in a manner similar to that described by Brain and others (1984). Possible evidence for such structural rotation is that near the Lanefoot 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-veinlet mineralization at Republic is in veins adjacent to the Bacon Creek detachment fault and is in Scarpill 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-aggregate deposits (Malie, 1995). Similar deposits occur along State Route 20 four miles west of the Okanagan/Perry County border. Rock-aggregate deposits in southeastern California mark the uplift of MCCs in that area (Topping, 1993).

The metamorphic core complexes, or the detachment faults that bound them, may have distinctly different ages. The unconformity at the top of the Tom Thumb Tuff Member may be contemporaneous with the Scarpill Creek/Bacon Creek fault. The Herron Creek detachment fault but the Bodie Mountain fault cuts the younger members of the Klondike Mountain Formation and the White Mountain fault. Furthermore, breccia deposits in the Klondike Mountain Formation may be related to the Bodie Mountain fault that cuts the formation: plots of SO4 vs. K2O and of Cr, Ba and Th against TFeO (from Table 2) of the rock avalanche deposits are less like the Herron Creek Empire Lakes plug between the Bodie Mountain and Bacon Creek faults than the Herron Creek/Bacon Creek fault unit of the Grandby 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 (north-eastern arm of the Okanagan 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 Scarpill/Carley valley (the so-called Republic "graben"), are mostly bounded by detachment faults. Younger high-angle NNE-trending faults, the largest of which is the Scarpill Lake detachment fault near which the Tom Thumb Tuff Member is unconformable, but the "graben" is primarily the upper plate of one or more detachment faults. Low-angle faults do occur in the upper plate of the detachment faults. Fyles (1980) mapped several in the Quesnellian and Challis rocks north of the international border (Figure 2). Similar faults have been mapped in small pyrite deposits near the Beltcher 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 mapped faults) and the failure of pyritic unit one of the faults are listric, the highest 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 Scarpill Creek phylloclastics. This phylloclastics is a shallow intrusive suite that extends to the south of the Tom Thumb Tuff Member (Muessig, 1987; Tschauer, 1989). Not only is the Scarpill Creek unit difficult to distinguish texturally from the Scarpill Formation but the Scarpill Formation is resistant to weathering and intrusion rocks so that the intruded rocks are under-represented in outcrops. North of Carley, bodies of Scarpill Creek rocks are cut by the quartz veins of the Carley, the (and possibly adjacent abundant along the trace of the No. 7 fault (Chezov thrust). Thus, the Scarpill Creek may be a tabular body or simply a tabular body of Scarpill Creek, the Scarpill Creek is intruded locally and on all the No. 7 fault and along the NNF high-angle faults that cut the quartz veins. The conditions by Muessig (1986) the Scarpill Creek also is well-jointed along other faults. This minor rejuvenation of faults happened during the waning stage of the MCCs.

The maps of Parker and Calcis (1964) and of Muessig (1967) show that the Scarpill Creek also preferentially intrudes Quesnellian rocks and the O'Brien Creek Formation in the
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 craniomorph 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 curators Lisa Barkdale, 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.

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’.

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 3:30 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.
Table 1. Explanation for geologic and geographic features of Figures 1 and 2

<table>
<thead>
<tr>
<th>MAP UNITS</th>
<th>Metamorphic Core Complexes</th>
<th>NAME ABBREVIATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tl</td>
<td>Eocene Herron Creek quartz monzonite</td>
<td>Town (BO)</td>
</tr>
<tr>
<td>E</td>
<td>Eocene felsic plutons</td>
<td>GO, Colville</td>
</tr>
<tr>
<td>E</td>
<td>Eocene felsic plutons</td>
<td>Colville</td>
</tr>
<tr>
<td>P1m</td>
<td>Amphibolite facies Cretaceous orthogneiss and Porphyroclastic Paleozoic paragneiss</td>
<td>G, Greenwood</td>
</tr>
<tr>
<td>Pm</td>
<td>Amphibolite facies Cretaceous orthogneiss and Porphyroclastic Paleozoic paragneiss</td>
<td>GF, Grand Forks</td>
</tr>
<tr>
<td>M</td>
<td>Amphibolite facies Cretaceous orthogneiss and Porphyroclastic Paleozoic paragneiss</td>
<td>M, Midway</td>
</tr>
<tr>
<td>OH</td>
<td>Amphibolite facies Cretaceous orthogneiss and Porphyroclastic Paleozoic paragneiss</td>
<td>OM, Omak</td>
</tr>
<tr>
<td>S</td>
<td>Amphibolite facies Cretaceous orthogneiss and Porphyroclastic Paleozoic paragneiss</td>
<td>OH, Oroville</td>
</tr>
<tr>
<td>T</td>
<td>Amphibolite facies Cretaceous orthogneiss and Porphyroclastic Paleozoic paragneiss</td>
<td>H, Republic</td>
</tr>
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<td>N</td>
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<td>S, Spokane</td>
</tr>
<tr>
<td>B</td>
<td>Amphibolite facies Cretaceous orthogneiss and Porphyroclastic Paleozoic paragneiss</td>
<td>B, Trail</td>
</tr>
<tr>
<td>Mines (BC)</td>
<td></td>
<td>K, Knob Hill</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L, Lamefoot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OL, Overlook</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P, Phoenix</td>
</tr>
<tr>
<td>Faults</td>
<td>Faults</td>
<td>BCF, Bacon Creek fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BDF, Bfitz Mountain fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CLF, Columbia fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CFS, Cheswauke fault</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>GD, Gold Dog fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GFP, Granby River fault</td>
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<tr>
<td></td>
<td></td>
<td>GRF, Greenwood fault</td>
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<td></td>
<td>HRF, Huckleberry Ridge fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LCF, Lind Creek fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LMF, Lambert Creek fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAF, Mount Aitken fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MWF, Mount Wright fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NF, No. 7 fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SE, Sherman fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SPF, South Peter fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SKF, Skeets Creek fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SBF, Snowshoe fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TMP, Timblin Mountain fault</td>
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<tr>
<td></td>
<td></td>
<td>WNF, Wanea fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBF, White Mountain fault</td>
</tr>
</tbody>
</table>

Quesnellia
The basin is defined as the area encompassing the Quesnellia, a major structural feature in the central Cascades. The Quesnellia is a large, northwest-southeast-trending fault system that marks the boundary between the North American and Pacific tectonic plates. The Quesnellia fault system extends from the Cascades to the Pacific Ocean, and is characterized by a series of faults and folds that define a series of terranes along its length. The Quesnellia fault system is an important conduit for the movement of magmas and fluids, and has played a significant role in the geologic evolution of the region.

Selected Additions to the Library of the Division of Geology and Earth Resources
February 6, 1990

THESYS


OTHER REPORTS ON WASHINGTON GEOLOGY

Benda, L. E., 1993. Geomorphic analysis of the north fork of Green Creek: Published by the author. J.V.


Includes:


Figure 2. (Right) Geology of the Republic area. Sources of data are A. Monger (1968); B, the modification of Fyles (1990) shown in Chevy and others (1994); C, our mapping since 1990, and D, Parker and Calkins (1960); Muessig (1967), and Staffoli and others (1991).
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 stratigraphy area 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, ancomformity-bound sequences within the larger Challes sequence, and (2) rather than having been deposited in a local fault-bounded basin or graben, the formations are preserved in the upper plate of one or more low-angle normal faults as a regional synergent 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 these 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-Challies rocks are the Proterozoic to Paleozoic stratigraphic units native to North America. West of these faults, especially in the Republic area, the pre-Challies rocks are predominantly those of Queenetia, a terrane that accreted to North America in the mid-Jurassic (about 175 million years ago). Eocene sedimentary and volcanic rocks of the Challies unconformity-bound sequence (55 to 36 million years old) overlie the pre-Challies rocks. The metamorphic core complexes (MCCs) are Eocene antiformal uplifts of crystalline basement unmetamorphosed blocks. MCCs underlie most of the major mountain ranges in the area of Figure 1. The Walispa sequence (18 to 2 million years old), unconformably overlies all other rocks. The most voluminous lithostatigraphic unit of the Walispa sequence is the Columbia River Basalt Group.

The dominant rocks in the Republic area (Fig. 2) are greenstone-facies Queenetian rocks, four unconformity-bound formations of the Challies unconformity-bound 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.)

area of map
Area of Figure 1
Pointsallo
Washington
State

157°
117°

Walispaf
Kettle Island

Okanogan Metamorphic Core Complex

 detachment fault
Thrust faults
Pre-Challies Detachment faults
metamorphic core complexes
Priest River Metamorphic Complex

area

50 km

area

50 km

pre-Challies

Challis

area of map

area

46

IN CELEBRATION OF THE REPUBLIC CENTENNIAL

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Washington Division of Geology and Earth Resources
PO Box 47507, Olympia, WA 98504-7007

On April 18, 1896, a group of 64 men gathered where the small creek crossed near Christmas Creek to dedicate 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 been among 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 $1,000,000 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, 1994.)

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 area 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 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, paleobiologists, and other specialists in contributing their expertise to this broad overview.

Reference


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 Burke Museum, University of Washington, Seattle, WA 98195; phone: (206) 543-0495 or fax: (206) 685-3039.

Science Summer Camps for Children, Families, and Adults

The Oregon Museum of Science and Industry in Portland offers a wide variety of summer camps for children, families, and adults in Washington and Oregon locations. Activities include backcountry (marine and upland areas), astronomy, paleontology, and geology. For more information, call OMSI at (503) 797-4545.

HOW TO FIND OUR MAIN OFFICE

Cover Photos: The top photo shows a horse race up Clark Ave., the main street of Republic; the race was the first of the Fourth of July festivities in 1909, a dozen years after the founding of the town whose centennial we celebrate in this issue. The photo is taken from slightly higher up the hill and shows Clark Avenue in 1996.

The 1996 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 Barteck.
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 geology of the history trip, 23-26.

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, work sheets, other resources. It requires a 486/666 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, Tahama Woods, Star Route, Ashford, WA 98304.

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