New Division Releases

Prediction of sediment yield from tributary basins along Huesedonk Ridge, Hob River, Washington, Open File Report 91-7, by R. L. Logan, K. K. Kaler, and P. K. Bigelow. This report describes the results of field investigations and study of aerial photographs to determine the volume of sediment yielded by slope failures in this area on the west side of the Olympic Peninsula. The study was conducted to assist in developing resource management alternatives for Hob River basins. The 14-page report costs $0.93 + .07 tax (for Washington residents only) = $1.00.


Seismic hazards of western Washington and selected areas—Bibliography and index, 1988–1991, Open File Report 92-2, compiled by C. J. Manson. This report continues the previous bibliography (Open File Report 88-4) and includes citations for the entire Cascadia subduction zone. Publication has been supported by the National Earthquake Hazards Reduction Program through the U.S. Geological Survey. This 250-page report is free.

A colored geologic map of Washington at 1:2,250,000 (or 1 in. = approx. 37 mi) is now available free from the Division. This map (8½ x 14 in.) was compiled by J. Eric Schuster. Included are an explanation of the 22 map units and a list of sources used in compilation.

County Bibliographies

A bibliography of geologic information for Okanogan County has been added to this series, bringing the total to 26 counties covered by these compilations in support of the Growth Management Act. Copies are available on paper or disk (IBM-compatible). Paper copies are free, but please include $1 with each order to cover postage and handling. To obtain a disk copy, send us a 5.25-in. or 3.5-in. formatted disk. We will copy the file and return your disk. Please specify whether you want the file in Word Perfect 5.0 or 5.1 or ASCII. The Okanogan file is 190 kilobytes (K), and it is the same file listed below in the full series.

We have recently completed 1991 updates to the series of county bibliographies. The updated material has been appended to paper and disk copies, which are available separately. Write or call us to order paper copies. If you want the file(s) on disk, check the list below to be sure you send us enough disks to contain the file(s).

- Benton County (318K)
- Chelan County (184K)
- Clallam County (111K)
- Clark County (50K)
- Cowlitz County (99K)
- Douglas County (46K)
- Franklin County (71K)
- Grays Harbor County (106K)
- Island County (59K)
- Jefferson County (118K)
- King County (288K)
- Kittitas County (64K)
- KittstatusCode (116K)
- Kitsap County (44K)
- Okanogan County (190K)
- Pierce County (197K)
- San Juan County (73K)
- Skagit County (157K)
- Snohomish County (161K)
- Spokane County (109K)
- Thurston County (89K)
- Walla Walla County (39K)
- Whatcom County (191K)
- Yakima County (136K)

Please add $1 to each order for postage and handling.

Our mailing address, on p. 2 of this publication, has recently been revised—we now have a post office box number. In order to serve you as promptly as possible, we would appreciate having your Zip Code and the four-digit extension for your address with your correspondence.

The 270-ton-per-day mill constructed in 1937 at Hecla Mining Co.'s Republic unit maintains a 95 percent recovery level for gold and 88 percent for silver. Hecla is now undertaking an extensive exploration program for additional ore reserves that, if successful, could lead to increased production and expansion of the mill. See related article, p. 3. Photo by Robert E. Deckey.

In This Issue: Washington's mineral industry—1991, p. 3; Coal activity in Washington—1991, p. 26; Stratigraphic interpretation of the Metalline Formation, p. 27; Central Cascades earthquake of March 7, 1891, p. 36; Policy plan for improving earthquake safety, p. 39.

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Washington Geology is published four times a year by the Washington Division of Geology and Earth Resources, Department of Natural Resources. This publication is free upon request. The Division also publishes bulletins, information circulars, reports of investigations, geologic maps, and open-file reports. A list of these publications will be sent upon request.

DEPARTMENT OF NATURAL RESOURCES
Brian J. Boyle
Commissioner of Public Lands
Art Staaks
Superintendent

DIVISION OF GEOLOGY AND EARTH RESOURCES
Raymond Lasansky
State Geologist
J. Eric Schuster
Assistant State Geologist

Geologists (Olympia)
Matthew J. Brunengo
David K. Norman
Joe D. Dragovich
Stephen P. Palmer
Wendy P. Gantzel
Patrick T. Pringle
Venice L. Goetz
Weldon W. Rau
William S. Lingley, Jr.
Katherine M. Reed
Robert L. (Joe) Logan
Henry W. Schasse
Timothy J. Walsh

(Spokane)
Robert E. Derkey
Charles W. Gulick

Librarian
Connie M. Jones

Library Technician
Rebecca Christie

Research Technician
Rex J. Hapala

Cartographers
Nancy A. Eberle
Keith G. Berndt

Editorial Assistant
Jaretta M. (Jodi) Roffal

Administrative Assistant
Barbara A. Preston

Word Processing Specialist
J. Renee Christensen

Clerical Staff
Noami Hall
Shelley Reisher
Kell Ritzm

Regulatory Clerical Staff
Mary Ann Shawver

Main Office
Department of Natural Resources
Division of Geology and Earth Resources
P.O. Box 47007
Olympia, WA 98504-7007
Phone: 206/459-6372
FAX: 206/459-6380

Field Office
Department of Natural Resources
Division of Geology and Earth Resources
Spokane County Agricultural Center
N. 222 Havana
Spokane, WA 99202-4776
Phone: 509/533-2484
FAX: 509/533-2087

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Minerals and Society
by Raymond Lasansky

"We depend on minerals throughout our lives. In fact, each year an average of 40,000 pounds of new minerals are consumed for each American. At this level of consumption, the average child will need a lifetime supply of 800 pounds of lead, 750 pounds of zinc, 750 pounds of copper, 8,593 pounds of iron, 22,550 pounds of clay, 28,213 pounds of salt, and 1,236,100 pounds of stone, sand, gravel and cement." - James H. Hyneman, Mining Commissioner

Members of the public and students frequently ask what persuaded me to become a geologist. The abbreviated answer is that I knew since my high school days that I wanted to be an economic geologist. By the time I was 12, I was collecting geologic materials and reading books on the subject.

At that time, during the post-World War II period and the Korean War, society was cognizant of the value of minerals. This was reflected in public school curricula, where students were taught the direct relationship between the availability of minerals and our economic well-being, as well as the nation's security. It was only natural, therefore, I decided, to take on the task of helping to protect society's interest, even if that interest was not mine.

As a nation, the United States has achieved the highest standard of living anywhere in the world. In the process, we have somehow lost sight of the fact that our very existence depends on only two sources of materials: either grow it (food or lumber products, for example) or get it out of the ground (minerals or oil). Everything else is manufactured from these raw materials.

Our society is largely illiterate when it comes to knowing what materials go into the construction of a house, a car, or even the highways we drive. During the last year, I have heard statements such as "I didn't know concrete is made up of materials that are mined to the group wanted a report about growth management issues" or "I just don't like mining. Can't it be stopped?" (a common public reaction).

It seems to me that our schools have failed to teach students just what the building blocks of a strong society are. Issues surrounding sand and gravel mining are good examples of the need for education. Urban sprawl has infringed on historical sand and gravel mines. Major conflicts over land uses have resulted and will only escalate. But we can do without sand and gravel. These are used for concrete aggregate, plastic and grout, concrete products, asphalt concrete, road-base cover, fill, soil and ice control, railroad ballast, and filtration/drain fields, to name a few uses. The U.S. Bureau of Mines reports that in Washington in 1990, there were 197 operators who produced 40,250,987 tons of construction sand and gravel from 226 major pits.

With a 1990 population of 4,866,692, each person's share of construction sand and gravel was 8.27 tons or 16.540 pounds. Mine operations have little adverse environmental impact, but they are commonly perceived as a major social nuisance. The result is that costs of these materials are rising as regulatory permitting is delayed and the availability of known resources is restricted by zoning or other means. A more balanced approach should be developed, based on deliberations of an informed public that recognizes that everyone of us is a consumer of mineral resources.


Washington Department of Natural Resources, 1992, Draft environmental impact statement for the proposed forest resources plan;

and appendixes: Washington Department of Natural Resources, 226 p.


MISCELLANEOUS TOPICS


University of Colorado Natural Hazards Research and Applications Information Center, 1991, 16th Annual Hazards Research and Applications Workshop: University of Colorado Natural Hazards Research and Applications Information Center, 1 v.

Northeast Quadrant Map A Winner

The Division's Geologic map of Washington—Northwest quadrant (GM-39) recently won an Award of Achievement in the Technical Reports category of the 1991 Art, Online, and Publications Competition sponsored by the Puget Sound Chapter of the Society for Technical Communication. The map of the southeast quadrant was similarly honored in 1988.

by Robert E. Derkey and Charles W. Gulick

INTRODUCTION
Gold production in Washington increased again in 1991, as it has nearly every year since 1985 (Fig. 1). The value of increased gold production, however, was not enough to offset a decrease in total mineral production for 1991. Production of nonfuel minerals increased from 1990 to 1991. A preliminary value reported by the U.S. Bureau of Mines for 1991 nonfuel mineral production is $442,617,000. This is about 6.5 percent lower than the 1990 value. These preliminary figures for 1991 indicate that production of sand and gravel, crushed stone, and portland cement accounted for slightly more than 50 percent of the value of production. Forty percent of the state’s nonfuel mineral value was split nearly equally between production of precious metals and production of magnesium from dolomite. The remaining 8 percent of the 1991 production value was from clay, diatomite, dimension stone, granite, gypsum, industrial sand and gravel (silica), lime, masonry cement, olivine, peat, lead, and zinc.

Of the five metals mined in 1991, four were producing gold. The state’s major precious-metal mining operations, the Canon mine, the Republic Unit, and the Kettle River Project, produced 320,000 ounces of gold and more than 580,000 ounces of silver in 1991. Along with this increase in production, acquisition of mining properties in the state and expenditures for detailed evaluations of these properties during 1991 appear to have increased relative to 1990 levels. Employment in the nonfuel mineral industries increased in 1990 (the latest year for which figures are available) relative to 1989. An average of 2,681 people were employed in 1990, compared to 2,152 in 1989. A significant proportion of the increase in employment is attributable to the start-up of the Kettle River project near Republic by Echo Bay Minerals Co. This new mining operation provided a healthy expansion of the economy of Ferry County. (See also Joseph, 1991). Despite the slight decrease in nonfuel mineral production in 1991, Washington is expected to experience continued growth in the number of persons employed in minerals-related activities and in the value of production. Therefore, the information in this section about mining for mine names is accompanied by a number. This number permits quick access to property location, which is shown on Figures 2a-d and other mining information. Table 1 summarizes mining and mineral exploration activities in Washington. The majority of this information was obtained from an annual survey of mining companies and individuals. Because not all survey questionnaires were returned, Table 1 is an incomplete measure of Washington mineral industry activity. The table includes a column in which geologic setting at or near the property/mine is briefly described. This information is taken from reports from the Washington Bureau of Mines, Road-to-rock onenear quadrant (Stoffell and others, 1991), the metal mines database (Derkey and others, 1990), and other published reports cited in these reports or listed at the end of this article. The discussion of the metallic mineral industry deposits was prepared by R. E. Derkey. It is organized on the basis of deposit type and deposit geology. The industrial minerals part of this article, prepared by C. W. Gulick, is organized by commodity. Questions about this information can be addressed to the authors at the Spokane office of the Division of Geology and Geophysics. Washington Geology and telephone number are given on p. 2 of this publication.

METALLIC MINERAL DEPOSITS
Epithermal Gold Deposits
Hot springs like those found in Yellowstone National Park produce mineral deposits referred to as epithermal deposits or simply hot spring deposits. Epithermal deposits in the Cascade Range at the Cannon mine and Republic Unit are examples of hydrothermal activity and associated epithermal deposits are commonly found in areas of active volcanism, such as the Cascade Range of Washington. Epithermal deposits indicative of hot-spring activity are extensive in Washington; however, only a few contain minable amounts of gold and silver.

The Cannon mine (no. 74), Washington’s largest gold producer, is located southwest of the city of Wenatchee (Fig. 2a). The Cannon mine is a joint venture between Amhero Minerals (U.S.) Inc. (the operator) and Breakwater Resources Ltd. Holcombe and others (1991) for this epithermal gold deposit (Earth and others, 1986) are Eocene elastic rocks of the Clallam group, which is a major northwest-trending strike-slip basin. Evans and Johnson (1991) reported that 1991 was 152,010 ounces of gold and 271,352 ounces of silver from 538,769 tons of ore. This is an average head grade of 0.282 ounces per ton for gold and 0.54 ounces per ton for silver. During 1991, an exploration drift was being driven to inter-sect mineralization of the “A reef” zone to confirm drift-in-dated reserves. Amhero also continued an extensive exploration program on properties located northwest and southeast of the mine (nos. 75-86). Several other
History of Cooperative Topographic Mapping in Washington
by J. Eric Schuster

The mandate of the Washington State Geological Survey, as passed by the 1901 legislature, included no provision for cooperative investigations with the U.S. Geological Survey (USGS). This was corrected in 1903, when the legislature amended the 1901 act by adding the following:

The said board of geological survey is hereby authorized to make provisions for topographic, geologic, and hydrographic survey of the State of Washington in cooperation with the United States geological survey in such manner as in the opinion of the said board will be of the greatest benefit to the agricultural, industrial, and geological requirements of the State of Washington: Provided, that the Director of the United States Geological Survey shall agree to expend on the part of the United States upon such surveys a sum equal to that expended by the said board.

This legislation remains in effect as RCW 43.92.060. Unfortunately, when the legislature gave the state geological survey this new duty and opportunity, it did not renew its appropriation, and the survey was dormant for several years.

In 1909, the legislature passed a second act authorizing the Washington State Geological Survey to engage in cooperative topographic and hydrographic work with the USGS. They also renewed the survey’s appropriation: $30,000 for the cooperative topographic and hydrographic work, and $20,000 for the survey’s geologic projects.

With new funding available, the Board of Geological Survey, the governing body of the Washington State Geological Survey, held planning meetings on April 16 and May 4, 1909. At the April meeting, they discussed cooperative hydrographic and topographic mapping with J. C. Stevens, District Engineer of the USGS. Stevens had been given authority to arrange for such cooperative work by USGS Director G. O. Smith. The Board authorized Governor M. E. Hay to complete all necessary cooperative arrangements with the U.S. government. On May 4, the Board decided that $10,000 would be used for cooperative hydrographic work and $20,000 for topographic mapping. Governor Hay and State Geologist Henry Landes were to decide which quadrangles were to be topographically mapped.

Quincy Is First Quadrangle Printed

They lost no time. Landes reported to the Board at their November 30, 1909, meeting that USGS field parties had completed work on the Mount Vernon 30’ quadrangle and were three-fourths finished with the Quincy, Morrison (Winchester), Red Rock, and Beverly 15’ quadrangles. The Quincy quadrangle was printed by the USGS in November 1910, the Winchester quadrangle in December 1910, the Mount Vernon and Red Rock quadrangles in January 1911, and the Beverly quadrangle in June 1912.

Cooperative topographic mapping was to go on for 82 years. The same general scheme was followed from start to finish. The state geological survey and its successors supplied one-half of the funds, and the USGS supplied the field parties and did the map preparation and printing.

Many of the early cooperative topographic maps are for areas in the arid central part of Washington. This probably reflects Landes’ interest in irrigation projects. He knew that development of such projects depended heavily on the existence of good topographic maps from which canal routes, the extent of irrigable lands, and possible surface-water sources could be realistically determined.

Production Costs Vary With Relief of Terrain

Topographic mapping continued as a cooperative effort of the USGS and the Washington State Geological Survey and its successors. By 1946, Sheldon Glover, the State Geologist and Supervisor of the Division of Mines and Geology, could state in the biennial report of the Division that 169 quadrangles had been topographically mapped in Washington. These covered 77.83 percent of the state’s land area, and 51 of these quadrangles had been produced cooperatively. He further reported that a topographic map of a mountainous quadrangle, like the Mount Constance quadrangle in the Olympic Mountains, cost about $18,000 to produce; a rolling lowland quadrangle like the Chehalis quadrangle cost about $14,500; and a treeless quadrangle of low relief, like the Connell quadrangle, cost $12,800. These are all 30’ quadrangles; 15’ quadrangles cost approximately twice as much to produce. A purchaser had to pay 20 cents per copy for these maps.

Twenty years later, 80 cooperative topographic quadrangles had been completed or were in preparation. The State’s contribution to the program totaled $499,443. These figures were reported by Marshall T. Hunting, State Geologist and Supervisor of the Division of Mines and Geology, in his biennial report for the period July 1, 1964, to June 30, 1966.

Documents in Division files show that an additional $2,000,000 in topographic cooperative agreements were entered into between July 1, 1966, and June 30, 1981. This brought the total State contribution to $734,443 and the total number of cooperative quadrangle maps completed to about 110.

Budget Cuts End Division Involvement

Budget cuts in 1981 ended the Division’s involvement in cooperative topographic mapping, and by the time finances permitted resumption of the cooperative program, completion of first-time topographic mapping in Washington was in sight, and the relatively small contribution the Division was able to make was not deemed to be needed. Cooperative efforts, however, were being continued by the Division’s parent organization, the Department of Natural Resources.

The Division’s cooperative contributions over the years helped to create a significant fraction of the state’s 30’ and 15’ topographic quadrangle maps and sped the recently celebrated completion of 74’ topographic mapping. ■
Utilities Have Not Addressed Seismic Risk
Only a few of the many water and wastewater utilities in the state have assessed seismic vulnerability. Electric utilities have done some vulnerability assessments. The natural gas companies in Washington have done limited work to address seismic safety.

Now Is The Time To Act
There is no doubt that some time in the future Washington will experience a large and damaging earthquake. It could happen as you read this report, or it could happen next week or next year. When it does occur, there will be deaths, injuries and disruption that could and should have been prevented.

At an early stage, the SSAC concluded that the State should devote its energies to identifying measures which will increase earthquake safety. With every earthquake, we learn more about the behavior of buildings, lifelines and people during these events. There is a huge body of knowledge which we can apply right now to reduce seismic risks in Washington. The primary emphasis of the SSAC has been on identifying how the State can improve seismic safety.

Practical Recommendations For Increasing Seismic Safety
The SSAC emphasized developing policy and action recommendations which are realistic and build on other work that is currently underway. These recommendations are practical, achievable, and a wise investment.

Program Oversight Is Essential
A body providing leadership and oversight is required to ensure that the SSAC's recommendations are acted upon. The SSAC's top priority for immediate legislative action is the authorization in statute of an oversight committee with staff support to oversee implementation of the SSAC's recommendations. This committee will lead a multi-agency program and budget development process.

A Multi-Year Effort Is Required
Improving seismic safety is a long-term proposition. Seismic safety cannot be improved overnight, nor can it be improved by legislation alone. The SSAC has carefully crafted a multi-year work program which, when implemented, will significantly enhance seismic safety in Washington.

Program priorities initiatives which:
- Reduce the risks to life, public safety and property.
- Are realistic and feasible.
- Create momentum for the overall program.

The work program involves a multi-agency and multi-jurisdictional effort and builds on current public and private sector work currently underway.

Priorities For Action
The following are top priority recommendations for action.

I. Establishing seismic safety oversight
   a. Create by legislation an interagency seismic safety oversight committee.
   b. Clarify the liability law for volunteer emergency workers and implement a central registry of trained emergency worker and volunteer personnel.
   c. Prepare and implement a multi-media awareness and education program.
   d. Provide standardized materials to help local jurisdictions more effectively train personnel.
   e. Standardize planning guidelines for local jurisdictions as part of ongoing emergency planning.
   f. Increase awareness of structural and nonstructural earthquake hazards as part of ongoing education.

III. Strengthening buildings
   a. Assess the seismic vulnerability of school facilities and improve seismic safety as part of long-range capital planning.
   b. Develop and submit amendments to the State Building Code Council that require seismic strengthening during planned remodel projects.
   c. Support the review of current Uniform Building Code seismic zone 3 boundaries.
   d. Develop financial incentive programs to assist with seismic strengthening projects.
   e. Support and coordinate the geological mapping of sensitive areas.
   f. Support the implementation of a strong motion instrument program in Washington.

IV. Strengthening our lifelines
   a. Establish statewide policy goals for mitigation of seismic risk to lifelines.
   b. Continue the funding for the current Washington State Department of Transportation bridge retrofit program.
   c. Identify critical lifeline routes that include state and local roads, bridges, transit routes, and port facilities.
   d. Develop a work program for seismic vulnerability assessments of local bridges.
   e. Require seismic vulnerability assessments and adoption of seismic mitigation standards for water and wastewater utilities.
   f. Require post-earthquake response and recovery plans for water and wastewater utilities.
   g. Provide a rigorous program of training in seismic safety for lifeline organizations.
   h. Develop standardized seismic safety guidelines for lifeline emergency plans.

Appendix E: Authorizing Legislation
The Department of Community Development shall create a seismic safety advisory board to develop a comprehensive plan and make recommendations for improving the state's earthquake preparedness. The plan shall include an assessment of and recommendations on the adequacy of communication systems, structural integrity of buildings, including hospitals and public schools, local government emergency response systems, and prioritization of measures to improve the state's earthquake readiness. The Department shall report to the Senate and House of Representatives Committees on energy and utilities by December 1, 1991. An interim report shall be made to the Committees by December 1, 1990.
A Policy Plan for Improving Earthquake Safety in Washington: Fulfiling Our Responsibility*

December 1, 1991

EXECUTIVE SUMMARY

The Seismic Safety Advisory Committee

We all remember the 1989 earthquake near San Francisco...the immediate chaos, the collapsed freeway, the tragedies of death, destruction and homelessness. Washington has experienced earthquakes of similar magnitude and will experience them again. Mindful of our risk, the Legislature mandated the Department of Community Development to establish a Seismic Safety Advisory Committee (SSAC). The SSAC was charged with developing a comprehensive plan and making specific recommendations for improving seismic safety in Washington.

Policy Oriented Mission And Goals

Lengthy reports already exist explaining why Washington needs a seismic safety policy and providing generic information on improving earthquake preparedness. Rather than duplicate other work, the SSAC's goals have emphasized developing and prioritizing practical and realistic strategies and initiatives which the state can begin to implement immediately.

Broad Participation

The SSAC's work program involved the broad participation of state agencies, emergency response personnel, building officials and professional organizations from the beginning. The SSAC's work program used formal committees and individual contacts to maximize statewide involvement. Focus groups and public meetings were held in eastern and western Washington, and a survey was mailed to 2,500 government and private organizations to increase involvement in the policy development process.

Project Approach

The SSAC's work program focused on:

- Reviewing the current status of earthquake readiness.
- Developing strategies to improve readiness.
- Identifying initiatives to implement strategies.

The Earthquake Threat In Washington

Washington has experienced earthquakes as large as the recent event that shook San Francisco. In 1949 Olympia was rocked by a magnitude 7.1 earthquake. Again, in 1965, the Seattle-Tacoma area was rattled by a magnitude 6.5 earthquake.

Serious Earthquake In Your Time? A Definite Possibility

Major earthquakes with magnitudes between 6 and 7.5 can be expected every 30 to 50 years. We do not know when, but we do know that they will occur. Anyone spending half their life in western Washington should expect to live through a major earthquake.

Geologists See The Potential For A Catastrophic Earthquake

This summer Washington's earthquake threat was front page news. The news media reported recent research findings which show that coastal regions of Washington experienced a massive earthquake about 300 years ago, and that geologists see the potential for another great earthquake in the Pacific Northwest. Such an earthquake could be many times more damaging than San Francisco's recent earthquake.

We Should Prepare For A Major Earthquake

The conclusion that the SSAC draws from the earthquake risk is that we must prepare for an earthquake of at least magnitude 7.5, and probably larger, in which:

- People will be injured and die.
- People will be left homeless.
- Lives and communities will be disrupted.
- Business will suffer direct loss from property damage.
- Recovery will take months or years to complete.

Being prepared can reduce all of these adverse impacts.

Our Readiness For An Earthquake

The SSAC reviewed the status of our readiness for an earthquake in Washington. What they found is cause for concern. While some organizations and individuals are prepared, most are not.

Our Emergency Response Capacity Will Be Overwhelmed

The SSAC is concerned that our response capacity will be hampered by inadequate communication systems, a lack of public preparedness, and the low priority placed on local emergency planning.

Schools Are Cause For Concern

There are a great many older, unreinforced masonry school buildings that are at risk. Tentative estimates indicate there are 350 to 400 unreinforced masonry school buildings, containing up to 155,000 children.

Fire And Medical Facilities Are Vulnerable

Many of our older firehouses and hospitals are vulnerable. When an earthquake strikes we need these facilities to be fully operational.

Our Transportation Lifelines Are Not Secure

The Washington State Department of Transportation is seismically strengthening key bridges. This is only a start. We need to know the risks to local bridges, marine facilities, port facilities, highways, transit systems, airports and rail facilities so that we can selectively strengthen crucial routes, staging areas, and airport facilities.

* Raymond Lasnawas was the author of the interim report (delivered Dec. 1, 1991, and from which this has been taken verbatim), as well as co-chairman of the SSAC. Additional copies of the full report are available from the Department of Community Development, MS/GH-51, Olympia, WA 98504-4151.
Do You Know Of Original Accounts Of Earthquakes That Occurred Before 1928?

Diary entries and newspaper accounts of felt earthquakes (felt in Washington, Idaho, Oregon, and Montana) that took place before 1928 are being collected by Ruth Ludwin of the University of Washington Geophysics Program. She needs to know where the diary was written or, for newspaper reports, the name of the newspaper, date and place of publication, as well as the page and column numbers for the earthquake story. If you have such material, she would appreciate having photocopies of it.

Ruth is also searching for newspaper indexes, which have proven to be especially helpful in documenting un-cataloged earthquakes. She needs to know if there is a pre-1930 index to your local paper.

Please address information to Ruth Ludwin, Geophysics Program 4545, University of Washington, Seattle, WA 98195.

Out-of-Print Publications Available

The following publications, long unavailable, can now be purchased from the Northwest Geological Society. For information about cost and mailing of these reprints, contact Dale Kramer at 783-0151 (home) or write to the Northwest Geological Society, 89 NW 50th, Seattle, WA 98107.


Corrections

In Washington Geology, vol. 19, no. 4, the view in the photograph on page 38 is from the northeast; on page 41, left column, second paragraph, the text should read "During the 1991 legislative session...", and the photo credit on page 53 should be Kent Reynolds.

Division Publication Activity—1991

by Renee Christensen

During 1991, the Division of Geology and Earth Resources published one report in the Geologic Map series (GM-39), consisting of text, three large plates in color, and the accompanying topographic map (TM-2). We also published seven open-file reports, four issues of Washington Geology, and bibliographies for 26 counties. These reports total 1,316 pages of information.

Of the publications in all our formal series, we distributed 5,320 copies. Of those formal publications for which we charge, we sold 2,571 and gave away 948 complimentary copies. Of the formal publications that are free, we mailed or gave out over the counter 1,765 copies.

We received orders for 3,312 copies of reports in our open-file series. Only 64 copies of free open-file reports were mailed out or distributed over the counter, but nearly 820 copies of reports in this series were given out on a complimentary basis.

The Division also distributed 4,381 copies of miscellaneous free information packets, brochures, and flyers, such as "Placer gold mining in Washington" and "Gems and minerals of Washington". We also gave away many copies of our list of publications.

The four issues of Washington Geology (formerly the Washington Geologic Newsletter) totaled 180 pages. This publication is mailed to an average of 3,824 addresses; by the end of 1991, there were approximately 4,010 people or institutions on the mailing list. We gave 1,378 copies to visitors or persons requesting particular issues.

During the year, the clerical staff handled orders and requests for 31,471 copies of our printed materials. This averages about 125 items per day being mailed or sold or given to visitors.
Table 1. Extract from the Modified Mercalli Intensity scale developed by Wood and Neumann (1933).

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy, or heavily loaded trucks. Sensation like heavy body striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Cracking of walls, frame, especially in the upper part of the structure.</td>
</tr>
<tr>
<td>II</td>
<td>Felt indoors by practically all, outdoors by most; outdoors direction estimated. Awakened many, or most. Frightened few—slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows—in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors swinging generally or considerably. Knocked pictures against walls, or swung them out of place. Open or closed doors, shutters, ajar. Pendulum clocks stopped, started, or ran fast or slow. Moved small objects, furnishings, the latter to a slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes shaken slightly.</td>
</tr>
<tr>
<td>III</td>
<td>Felt by all, indoors and outdoors. Frightened many, excitement general; some alarm, many ran outdoors. Awakened all. Persons made to move uneasily. Trees, bushes shaken plainly to moderately. Liquid set in strong motion. Small bells ring—church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks; chimneys [sic] in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of bricks-chocks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.</td>
</tr>
<tr>
<td>VI</td>
<td>Felt by all. Persons driving cars disturbed.</td>
</tr>
</tbody>
</table>

Tacona
The bookkeeper noticed the lamp moving, then found that his hand was traveling in a wavering line over the paper. Accompanying this was a feeling that he was moving. The rows of hanging lamps which hang on both sides of the room swung quite violently from one side to another. The lighter of the waves jolted against one another. (Tacona Daily Ledger, March 8, 1893)

"Several hundred felt the shock but thought it was due to blasting..." (Seattle Post-Intelligencer, March 8, 1893)

No damage was done, although articles in china and glassware stores ratted a trifle, and occupants of sixth floors roused from rooms fearing the structures were about to topple. (Oregonian, March 8, 1893)

Modified Mercalli Intensity I-III

Ellensburg
"The shock was [a] light one and a great many failed to notice it." (The Ellensburg Capital, March 12, 1891)

Not reported felt in the Ellensburg Daily Leader.

Monitor
"The house trembled and shook." (From the diary of Helen Margaret Paarish, March 8, 1891, copy contributed by her granddaughter, Betsy Detory)

Admiralty Head Lighthouse
A light shock (Bradfords, 1935).
The Central Cascades Earthquake of March 7, 1891

by T. E. Johnson, R. S. Ludwin, and A. I. Qamar
Geophysics Program, University of Washington

While reviewing newspaper accounts of earthquakes in Washington and Oregon prior to 1938, we have discovered evidence that an earthquake on March 7, 1891 (7:40 P.M. local time), was much larger than previously thought. Before our investigation, this earthquake was known to have been felt only at the lightshouses on Smith Island and at Admiralty Head (Bradford, 1935; Townley and Allen, 1939). It is not included in the Earthquake History of the United States (Coffman and von Hake, 1973), which lists earthquakes with Modified Mercalli intensities (MMI) V or greater. (The MMI scale was developed by Wood and Neumann (1931) to measure felt earthquake effects.)

Through old newspaper reports and a diary entry, we now have evidence that the earthquake had intensities as high as VI, was felt on both sides of the Cascades, and did some minor damage. Figure 1 shows our estimate of the felt area of the 1891 earthquake and the distribution of areas where MMI V and VI were experienced.

The apparent focus of the 1891 earthquake was east of Seattle in the central Cascades, close to Mt. St. Helens where a number of earthquakes have been located in a tight spatial cluster since instrumental coverage began in 1970, and where felt earthquakes of magnitudes 5.6 (Zollweg and Johnson, 1989) and 4.9 (Tom Yelin, U.S. Geologic Survey, written comm., Dec. 11, 1991; coda duration on the Longmire seismograph station) occurred in 1945 and 1963, respectively. For the 1891 earthquake, which had a total felt area of approximately 36,000 km², we estimate a magnitude of 5.0 (Toppenoza, 1970).

INFORMATION FOR RE-EVALUATION OF THE 1891 EARTHQUAKE

Modified Mercalli Intensity V-VI

Roslyn

"The shock was severe enough to rock houses, stop clocks, and shatter crockery. Disturbance caused vertigo and nausea in several persons. Everybody rushed to the street." (Seattle Post-Intelligencer, March 8, 1891)

Snokaulian

"Heavy shock....The rocks from Mount St. Helens came rolling down and made a loud rumbling noise, which was plainly heard."

Seattle Post-Intelligencer, March 8, 1891

ModificatiMercalli Intensity IV

Eagle Gorge

"Eagle Gorge felt three severe shocks." (Seattle Telegraph, March 8, 1891)

Snokomish

"In a number of Snokomish stores the shelves with their contents were given a good shaking up." (Snokomish Daily Sun, March 9, 1891)

Hot Springs

"A loud shock....Things were shaken up, chandeliers swayed and crockery rattled." (Seattle Post-Intelligencer, March 8, 1891)

The hotel and depot shook badly. No damage done." (Seattle Telegraph, March 8, 1891)

Orrington

"People rushed out to find the cause of the disturbance." (Tacoma Daily Ledger, March 8, 1891)

Puyallup

"Light shocks were also felt in...Puyallup and surrounding villages." (Seattle Telegraph, March 8, 1891)

Seattle

"The effect was felt most severely by those in the upper floors of the six and seven story buildings downtown. There the chandeliers swayed sharply and men standing up found it difficult to keep their feet." (Tacoma Daily Ledger, March 8, 1891)

"A vase in her room nearly fell from the mantel over the fireplace...the pendulum of a clock was swinging wildly...the doors and windows rattled against the trees and the hall lamps swung backward and forward like the pendulum of a clock..." (Seattle Post-Intelligencer, March 8, 1891)
<table>
<thead>
<tr>
<th>Loc.</th>
<th>Property</th>
<th>Latitude</th>
<th>Longitude</th>
<th>County</th>
<th>Town</th>
<th>Well/Drill</th>
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**Table 3. Mining and mineral exploration in Washington, 1991 (continued)**

**Loc.** Washington, vol. 20, no. 1

**Table 1. Mining and mineral exploration in Washington, 1991 (continued)**

**Loc.** Washington, vol. 20, no. 1

**Table 2. Mining and mineral exploration in Washington, 1991 (continued)**

**Loc.** Washington, vol. 20, no. 1

**Table 4. Mining and mineral exploration in Washington, 1991 (continued)**

**Loc.** Washington, vol. 20, no. 1

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**Staff News**

The Division has hired Wendy Gerstel as a Geologist 2 in the Environmental Geology section. Wendy received her bachelor's degree from the University of New Hampshire and a master's from Humboldt State University, where she studied glacial and volcanic deposits on Lassen Peak. Along the way, she also studied at the University of Salzburg and the University of Colorado.

Wendy has worked for the U.S. Geological Survey in a variety of mapping projects, and most recently she worked as an engineering geologist with the U.S. Forest Service in the Willamette National Forest. An avid skier, she is a member of the National Ski Patrol.

Wendy's duties with the Division will focus on slope stability and Quaternary geology, as well as compilation of the mapping for the western Olympic Mountains for the state geologic map project.

**Kelli Ristine**

started with the Division in January, replacing Cheryl Hayes as a Clerk Typist 2. Kelli was previously employed by the Transportation Improvement Board, which was her first job with the State.

Kelli will be serving as receptionist, answering the phones and keeping an eye on the counter. She also monitors publication inventories, among other duties. She and her husband, Chris, are expecting their first baby in September.

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**Geological Society of America, Cordilleran Section Meeting**

Hilton Hotel and Conference Center
6th Ave., Eugene, OR, May 11-13

The Cordilleran Section is meeting jointly with the Pacific Coast Section of the Palaeontological Society of America. The meeting will be sponsored by the Department of Geological Sciences, University of Oregon. The pre-registration deadline is April 17.

The meeting features ten symposia, which will cover topics of broad Pacific Northwest significance. Included is the Second Symposium on the Regional Geology of the State of Washington. Conveners are State Geologist Raymond Laemans and Prof. Eric Chevney, University of Washington. This session will be held Tuesday, May 12, and will be followed by a social hour.

Six pre-meeting and four post-meeting field trips are scheduled for areas in Oregon and northern California. Oregon Geology will be publishing some trip guides.

The Washington Division of Geology and Earth Resources is preparing to publish a volume of papers presented at the Washington symposium.

Further information about this meeting can be obtained from Aida Daya, Adjunct, Dept. of Geological Sciences, University of Oregon, Eugene, OR 97403; 503/465-5588, fax 503/465-4692.
is gradational. These gradational contacts range from locally interbedded to irregularly gradational, steeply interdigitate, or ragged and discordant. Locally, particularly near the West Side Pedal Cordlike working areas, the Josephine limestones appear to have been deposited on the step-faulted upper surface of the gray massive lime mudstone limestolites.

Contacts between the Josephine breccia and the various dolostone limestolites are similar to contacts between lithologies within the Josephine. Local discordance is more pronounced at contacts with the gray massive lime mudstone, perhaps because of the uniform character of the lime mudstone and because the lime mudstone is easy to recognize. However, gradational contacts, particularly those between lime mudstone fragments to typical Josephine breccia with dolostone fragments.

In the Pend Oreille mine, the contact between the Josephine breccia and Ledbetter Formation is gradational over an interval several meters thick in some locations, but it is a paper-thin, easily defined, and locally discontinuous surface in others. Although the contact marks a transition from dominantly coarse fragmental carbonates to line siliciclastics and from chaotic, uneven, and irregular bedding to even and planar bedding, lithologic and bedding relations at the contact are similar to those within the breccia and among the Josephine breccias, massive lime mudstone, and various dolostone limestolites. In addition, Carter (1989a) has shown that rocks of both uppermost Josephine and lowermost Ledbetter in the Pend Oreille mine are within the Paraglossopterus tenuicostatus glottolite zone of the uppermost Jurassic. These observations suggest that the contact marks a locally abrupt change in the proportion and character of carbonate and argillite sedimentation but does not represent a significant depositional hiatus.

Many of the peculiar characteristics of the Josephine breccia are common to sediment-gravity-flow deposits known from deep-water environments along modern and ancient continental margins. Two lower Paleozoic examples well documented in the literature are the Cow Head Breccia of Newfoundland (Hubert and others, 1977) and parts of the Hales Formation of New South Wales (Cooke and Tapp, 1977). McCreanor and Anderson (1968) and Addie (1970) proposed a similar origin for Metaline breccias when they suggested that the breccias formed in anoxic waters basinward of an organic reef complex. They envisioned fragmentation and downslope transport of shallow-water deposits by slumps, debris flows, and turbidity currents. Although there is little evidence for organic reefs in the Metaline, detailed lithologic observations from core and mine exposures offer support for the interpretation of sediment-gravity flow as the primary transportation mechanism for many of the Josephine breccias.

In contrast, Mills (1977) considered the breccias immediately adjacent to the Ledbetter/Metcalfe contact as part of a regionally extensive paleokarst and solution-collapse system below the angular unconformity between the Metaline and Metaline Formations. He referred to the system as the “Josephine Breccia” and included in it the breccia of the Josephine sequence as defined by McCreanor and Anderson (1968) along with a variety of other predominantly discordant breccias in the Metaline Formation throughout the region.

Stratigraphic, lithologic, and palaeoecological studies in the district over the past two decades support the original interpretation of the Josephine breccia as marine sedimentary rocks transitional between the Metaline and Ledbetter Formations. Josephine and other Metaline lithologies and, to a much lesser extent, the Ledbetter Formations are cut with, included as fragments within, most of the breccia lithologies that were used in the composite earlier definitions of "Josephine breccia.

Carter’s (1989a) identification of glottolite specimens collected by G. F. Park, Jr., in the central part of the Metaline district in 1937 indicates that the base of the Ledbetter immediately west of the Pend Oreille River is as old or older than the Ongonopterus zone of the Upper Lower Ordovician. Carter and McCreanor concluded that the contact exposed in the Pend Oreille mine just east of the river lies in the Paraglossopterus tenuicostatus zone of Early Middle Ordovician age. On the other hand, Carter (1959) stated that the base of the Ledbetter in the Clagheton Creek area of Stevens County may be as old as the Tetragnathus fractuosus or T. approximatus zones of Early Ordovician age. These differences in age indicate that regional transgression of basinmetallic facies over adjacent and coeval Metaline platform facies was a rapid occurrence in the Early Ordovician. However, in the area now east of the Pend Oreille River, carbonate sedimentation persisted into the Middle Ordovician.

SYNDEPOSITIONAL FAULTING

We consider synsedimentary faulting to have significantly influenced stratigraphic relations in the Metaline Formation in the central part of the Metaline district and in outlying areas, core drilling and mining have exposed linear features in the upper part of the Metaline structure for several hundred meters along strike. The abundance and consistent orientation of linear structures strongly suggest that local block faulting and tilting had occurred during deposition of much of the upper part of the Metaline Formation. In places, the faults are identified by local offset of the top of the gray massive lime mudstone limestolites accompanied by thickening and lithologic changes of the Josephine breccia (without offset of either the Josephine or the Metaline). The fault sets are also identified by a north-northeast-trending stratigraphic fabric in the central part of the district that is paralleled by a pattern of younger normal faulting.

Synsedimentary faults may have magnified the effect of regional subsidence by creating oversteepened and unstable slopes between subtidal uniform environments and deeper basin environments. Faulting and oversteepening would have resulted in a horizontal interfingering or a mosaic of environments along a north-northeast trend, indicating abrupt changes in water depth and depositional conditions. Slope deposits formed by slumping from oversteepened areas were interbedded with lithologic units observed in the Josephine. Actual planes of movement are rarely recognizable, perhaps due to diagenetic reconstitution, so that the only vestiges of the faults may be the abrupt facies changes themselves.

SUMMARY

Stratigraphic relations of Metaline lithologies have been difficult to define because of a lack of continuous exposures, stratigraphic markers, and macrofossils, as well as the effects of mineralization and diagenetic and hydrothermal alteration.
basin. Storms, tidal channels, and slumping may account for cross-beds, intrabedformal folds, troughs, and hummocky and lenticular beds.

**Fish Creek Brecia**

This lithofacies was previously referred to as the intraformational breccia by Yates (1976). Fischer (1983) suggested the name "Fish Creek member of the Metalliferous Formation" for exposures in the Fish Creek area, 13 km northeast of the "Fish Creek breccia" that is used in this paper to convey that, in general, angular fragments are more abundant than rounded fragments in this lithofacies. Yates (1964, 1976), and Hurley (1980) described the lithofacies as a light- to dark-gray, fine- to medium-grained, thin-bedded dolostone that is interbedded with lessoidal sedimentation units of breccias. Breccias consist of angular to subrounded, tabular fragments of thin-bedded dolostone supported by dark-gray to black, fine-grained dolomitic matrix. In places, fragments exhibit contorted bedding. Orientation of fragments ranges from chaotic through subparallel to imbricate. Locally, breccias can be traced laterally into non brecciated bedded dolostone. The lithofacies is almost entirely dolostone, although nodular chaft is abundant locally. Fine-grained pyrite is common in minor amounts, and phosphatic materials occur sparingly as pellets, disseminated grains, and rare fossils. Fischer (1984) noted rare echinoderm plates, but, in general, the Fish Creek breccia is either fossiliferous or nonbioturbated. Yates (1976) noted phosphatic fossils ranging in age from Middle Cambrian through Early Ordovician(?). Much of the lithofacies has a clastic texture in which both normal and reverse graded bedding are common. Sedimentary units are commonly truncated by disconformable surfaces and scour marks are common. Yates and Robertson (1958) and Yates (1964) indicated that in some areas of Stevens County the intrabedformal breccia unit is distinct from the lower Metalliferous Formation, whereas in others it is separated by a transitional sequence of as much as 154 m of interbedded gray limestone and shale, gray to black, black, light gray and dolostone, and dolostone breccia. Where the transitional sequence is absent, the intrabedformal breccia is conformable with and gradational into the "butter" (better Hurley, 1980, Yates, 1964, 1976; Yates and Robertson, 1958). Hurley (1980) and Fischer (1984) noted that parts of the Fish Creek breccias are equivalent in age to some parts of the bedded dolostone and the massive lime mudstone lithofacies. Yates and Robertson (1958) noted a conformable and gradational contact with the bedded dolostone unit in some areas, whereas Fischer (1994) suggested that in northernmost Pend Oreille County, the breccia lies directly on the thin-bedded lime mudstone lithofacies.

The stratigraphic and temporal relations of the Fish Creek breccias are not as clearly known as those of the other lithofacies. As illustrated in Figure 4, it is interpreted to be interbedded with parts of all the other lithofacies, including the Josephine breccia. The two breccia units are considered to be distinct so that they can be finally identifiable tabular fragments in the Fish Creek breccia distinguish it from the Josephine breccia. These stratigraphic relations, in particular the interbedding with all the other lithofacies, were probably caused by the debris flow origin of the breccias. Hurley (1980) and Fischer (1984) had earlier concluded that the Fish Creek breccia likely formed as a result of intermitted submarine slumping and debris flows.

**Josephine Breccia**

The Josephine breccia comprises a wide variety of lithologies, some of which are present in other stratigraphic units. As a result, the Josephine breccia cannot be recognized by the occurrence of a single lithology, but rather by the combination of several distinct lithologies and sedimentary characteristics. The lithofacies was originally described by McConnell and Anderson (1968) and Addie (1970) considered the unit to be present everywhere in the Metalliferous mining district where the top of the breccia is exposed and not disturbed, but a review of outcrops and drill holes indicates that it is most persistent laterally and stratigraphically near the Pend Oreille, Grandview, and Metalliferous mines (Fig. 1). Dings and Whitehead (1965) did not recognize the Josephine as either a discrete lithologic facies or stratigraphic unit, but examination of what appears on their geologic map as "silicified dolomite" indicates that it should be included in the Josephine breccia lithofacies. As defined by McConnell and Anderson (1968), the Josephine is not recognized outside the Metalliferous district.

The thickness of the Josephine breccia generally varies from 0 to 65 m, although in a few areas it may be as much as 165 m thick. In a few locations, the thickness variations are such that they can be seen to result from the fact that the top of the gray massive lime mudstone but that do not offset the Josephine or the Ledbetter/Josephine contact. In most locations, the Josephine breccia grades laterally into and is interbedded with the varicolored dolostone and massive lime mudstone lithofacies. In a few localities, Josephine breccias are contained within the gray massive lime mudstone and variable dolostone units are restricted to a single sharply defined stratigraphic position and are laterally continuous for hundreds of meters. However, in other places, the contact with the gray massive lime mudstone and varicolored dolostone...
Varied Dolostone

In much of northeastern Washington, the Cambrian rocks described as hydrothermally altered, crystalline, and intermixed crystalline and bedded dolomite by Dings and Whitebread (1965) and those referred to in unpublished reports as lower dolomite belong to a distinct stratigraphic unit herein informally named the varied dolostone unit. This lithofacies locally exceeds 900 m in thickness. Although much of its original nature is masked by coarse-grained dolomite replacement, many of the primary depositional features recognizable in the fine-grained parts are substantially different from those of other Metamorphic units. These depositional features include: dominance of hummocky, irregularly lenticular dolomitic concretions, unfoliated, discontinuous dark- and light-gray laminations. The dolostones are lenticular to grey with fine to medium and have a speckled appearance resulting from a variety of grain colors as well as from dark grains in a light matrix. Angular, shard-like fragments of gray to black and irregular, angular clasts of grey to black are locally abundant. Undulating bedding, cross-stratification, poor to good sorting, and graded bedding are common. These clastic dolostones occur in bodies that range from irregular beds and lenses to discontinuous troughs, forming a "waxy" to "sandy" matrix that is easily eroded by water.

Less common rock types in the varied dolostone lithofacies include black massive dolostone, black fenestral dolostone, thin-bedded parallel laminated dolostone, grey massive dolostone, lime mudstone, and oncoid dolostatolite. Black massive dolostone is fine to medium-grained and locally argillaceous and laminated and occurs in both conformable and disconformable beds and masses. In places, discordant bodies of black dolostone separate large blocks of other varied dolostone lithofacies in much the same way that dark matrix separates different lithofacies in the Josephine breccia. Black fenestral dolostone consists of fine- to medium-grained black dolomite with coarse white dolomite spots, many of which are elongate and subparallel to bedding. Several kinds of breccia in discordant as well as concordant beds are also present in the varied dolostone. Some of these bodies resemble breccias in the Josephine. Quartzite and dolomite quartzite sandstone occur rarely in lenses as much a meter thick at various stratigraphic positions within the varied dolostone. 

The varied dolostone lithofacies is not recognized outside the Metamorphic mining district, and a petrographic study of the unit has not been undertaken. It is transitional between gray bedded dolostone, grey massive lime mudstone, and the Josephine breccia lithofacies, and it exhibits characteristics of each of these units. The presence of oncoids, lack of body fossils, and the varied dolostone lithofacies suggest this unit was deposited in a poorly oxygenated, shallow subtidal environment close to a deeper
(1982) added a seventh lithofacies, which is exposed in the Claggett Creek area. The lithotypes are (1) black birdseye dolomite, (2) cryptalgal laminated dolomite, (3) dolomitized, laminated, intrasclerotic floatstone, (4) gray massive dolomite, (5) dolomitized oolitic floatstone, (6) lenticular-beded dolomite, and (7) breccia.

Fischer (1981, 1988) studied the diagenetic fabric of the bedded dolostone and noted that each lithofacies contains depositionally derived features that have been diagenetically altered by several stages of dolomitization. The least altered samples retain a fine grained micritic fabric and contain well-preserved recognizable grains. The more altered samples are composed of a mosaic of dolomite in which constituent crystals range from spheroidal to aspherical and in which only ghosts of depositional grains are recognizable. Fischer (1988) noted that the gray massive dolostone lithofacies is the most altered. It consists of featureless gray dolostone or gray dolomite that contains vugs and pools of white sparry dolomite, zebra dolomite, and, rarely, relict grains. Fischer (1988) concluded that the gray massive dolostone represents a diagenetic fabric and is not, as suggested by Harbour (1978) and Cleveland (1982), a depositional lithofacies.

The bedded dolostone occurs stratigraphically between the thin-beded and the gray massive lime mudstone lithofacies in most areas. However, in other areas it is overlain by the Ledbetter Formation, the varied dolostone, or the Josephine breccia lithofacies. In addition, it is laterally equivalent to parts of the Ledbetter Formation and to the Josephine, Fish Creek, massive lime mudstone, and varied dolostone lithofacies of the Metamorphic rock (Fig. 2).

Aadland (1979), Bush and Fischer (1981), and Bush (1989) correlated the bedded dolostone lithofacies with the upper Lakeview Formation in northern Idaho and the upper Flistrap Formation in western Montana (Fig. 4). The upper Lakeview Formation has been subdivided, from its lowermost unit upward, into a peloidal ooid dolopackstone, a cryptalgal dolobedstone, and an upper cryptalgal dolostone lithofacies (Bush, 1989). The upper Lakeview is highly altered and has a diagenetic history similar to that reported by Fischer (1988) for the bedded dolostone lithofacies.

Harbour (1978) and Cleveland (1982) considered the bedded dolostone lithofacies to have been deposited in a low-energy, shallow subtidal and peritidal mosaic that, according to Bush and Fischer (1980) and Bush and Fischer

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**Figure 4.** Correlation chart comparing Metamorphic rock with other Cambrian-Ordovician units in Idaho and northeastern Montana.

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**Figure 5.** Distribution of lower Paleozoic outcrops in northeastern Washington, northern Idaho, and northwest Montana.
The fossil component of the thin-bedded lime mudstone facies consists of trilobite and echinoderm fragments, oncospheres, Ephydatia, traces of boring algae, and phosphatic inarticulate brachiopods. The laminated units are typically non-fossiliferous, but other intervals contain local concentrations of fossil fragments. In places, trilobite preservation is excellent, and assemblages have been assigned by A. R. Palmer (U.S. Geological Survey) to the Bathysurina-
cus-Eratolina Zone of the Middle and Upper Cambrian (Du-
stro and Gilmour, 1989).

The thin-bedded lime mudstone lithologies generally makes up the lower part of the Metaline (Fig. 2), where it is in gradational contact with the underlying Matten Formation and at most places is in sharp contact with the overlying bedded dolostone unit. Intervals of this lithofacies have also been identified in core samples from the Metaline district within the bedded and varied dolostone lithofacies. The stratigraphic configuration and horizontal extent of these inter-
bedded intervals is not certain. However, the contacts appear to be conformable, and the units extend laterally for a few miles and pinch out north of Metaline Falls.

Lochman-Balk (1971) correlated the thin-bedded lime mudstone lithofacies with the lower Lakeview Formation in northern Idaho (Fig. 4, 5). The lower Lakeview is litholog-
ically similar and consists, from the base upward, of pyritic, dark-colored parallel laminated lime mudstone, black shale, and mottled lime mudstone (Bush, 1989). Trilobite assem-
bles places the boundary between the Bathysurina-
cus-Eratolina and Bolospidella Zones in the upper one-third of the lower Lakeview (Motzer, 1980). The easternmost out-
crop of similar lithologic units that are considered to be of the same age as the thin-bedded lime mudstone is 6 mi east of the Montana-Idaho border near Heron, Montana (Bush, 1989). Figure 4 illustrates regional correlation of the Metaline Formation with sequences of similar ages at Lakeview, Idaho, and in the Libby Trouth, Montana, and Figure 5 shows the distribution of outcrops of lower Paleozoic rocks in north-
eastern Washington and areas to the east.

The bedded dolostone lithofacies ranges to as much as 1,402 ft thick in the Clugston Creek area (Cleveland, 1982) and consists of a monotonous succession of non-fossiliferous gray and black, fine- to medium-grained, parallel bedded dolostone interlayered with massive, gray, featureless, fine-
to-medium-grained dolostone. Dings and Whitebread (1965) originally used the term bedded dolomite for this unit, and Fischer (1981) informally called this unit the middle member. Harbour (1978) studied numerous cores of this lithofacies from the central part of the Metaline mining district in Pend Oreille County, and on the basis of that study he divided the sequence into six laterally discontinuous lithotypes. Cleveland
companies and individuals maintain properties in the Wescott area.

Hecla Mining Co.'s Republic Unit (no. 25), the major revenue-producing property for the company for the past several years, continued to produce from the Golden Promise area of the deposit. The 1993 production from the Republic Unit was 77,736 ounces of gold and 311,445 ounces of silver from 96,562 tons of ore mined. Hecla reports the ore grade at the mine averaged 0.87 ounces of gold per ton.

The highlight of the year for the Republic Unit was completion of the decline-ramp (Fig. 3), which provides more direct access to the Golden Promise orebodies. This allows the use of rubber-tired, diesel vehicles for loading ore and hauling it directly to the surface. Hecla began using the new ramp in August of 1991. The decline also provides access for exploration and development of disseminated orebodies in bedded tuffs of the Eocene Sanpoil Volcanics. Because the new access was completed to the 800 level ahead of schedule and under budget, it was extended to the 1100 level. The new 11-by-13-foot decline is 7,200 feet long and replaces the former method of transporting (tramming) ore more than a mile to the Knob Hill #2 shaft before hoisting it to the surface.

Hecla embarked on an extensive program of underground exploration and development and began remapping the geology of their numerous holdings throughout the district. Recent advances in understanding epithermal, hot-spring-type mineral deposits like that at Republic (Tischendorf, 1989) spurred this program. If Hecla is successful and if considerable reserves are located, the company is likely to increase production and expand the mill (cover photo), which now handles 700 tons per day.

Hecla's Golden Eagle property (no. 26) reportedly contains more than 1 million ounces of gold at a grade of 0.13 ounces per ton (Table 1, 1991). Because of differences between ore from the Golden Eagle property and that of the Golden Promise, the Golden Eagle was put on hold during the past year, and exploration centered on the Golden Promise veins and adjacent mine areas.

Washington's other producing epithermal gold deposit, the Kettle mine (no. 30), located west of Clew, in the Republic district, is projected to be mined in 1992. Total production for the Kettle mine will exceed 80,000 ounces of gold. The deposit, like mineralization in the Republic district, is so near to the Sanpoil Volcanics (Tischendorf, 1989). The mine is part of the Kettle River Project, a joint venture between Echo Bay Metals Co. (operator) and Crown Resources Corp. Approximately 300 tons per day of the Kettle ore is processed at the joint venture's Key mill, located near the Overlook mine northwest of Republic.

Echo Bay/Crown Resources continued exploration on the 30-square-mile K-311, located 2 miles west-southwest of the Kettle mine. This deposit is genetically similar to the Kettle deposit.

Figure 3. Completion of the new decline at Hecla Mining Co.'s Republic Unit signaled the advent of new mining methods at the mine. Pictured is a diesel, rubber-tired, 3.5-mg capacity loader exiting the new decline. This vehicle is used to load 16-ton capacity diesel trucks that haul ore directly to the surface. Previously all ore was dropped to the 1100 level, trammed 7,000 feet by rail to the Knob Hill #2 shaft, and then hoisted to the surface.

Replacement-Type Gold Deposits

The Overlook mine is the model for replacement-type gold deposits found in contact-metamorphosed and metasomatized rocks in northeastern Washington. Host rocks for these replacement-type deposits are volcaniclastic and epithermal rocks that were deposited in and around island arcs adjacent to the North American continent during the Permian and Triassic. These rocks were accreted to the continent in mid-Mesozoic time (Stoffel and others, 1991). Contact metamorphism and metasomatism took place when granitic dikes ranging in age from Jurassic to Eocene intruded the Permian to Triassic rocks. Tischendorf (1989) provides additional details about replacement-type deposits in the Republic graben. (Replacement-type deposits are compared with skarn-type deposits in the next section.)

The Overlook mine (no. 32), the other producing mine in the Kettle River Project, completed its first full year of production in 1991. Throughput at the Key mill, which processes ore from both the Overlook and Kettle mines, ranged from 1,500 to 2,100 tons per day. The majority of the ore for the Key mill is from the Overlook mine, with only about 300 tons per day coming from the Kettle mine. Production from both the mining methods at the mine in 1991 was 90,272 ounces of gold from 644,950 tons of ore with a grade of 0.146 ounces of gold per ton.

Neither the K-311 nor the Overlook project are in the process of obtaining permits to begin mining at the Key East (no. 33) and Key West (no. 34) deposits, located northeast of the Overlook mine. Production will begin once all permits are obtained. The Key East and Key West deposits, like the Overlook, are in Permian rocks. Other Echo Bay Minerals exploration projects in similar Permian rocks include properties in the Cooke Mountain area (nos. 37-38) and at the Lamontel property (no. 35), which became part of the Echo Bay/Crown joint venture at the end of the year. The joint venture partners are seeking permits to drive an exploration drift into the Lamontel deposit and are expected to announce a probable reserve for
this prospect in mid-March. Echo Bay Minerals (the operator) also entered into a joint venture to explore the Leekd property (no. 36), located between the Lametoota deposit and the Overlook mine.

Two properties adjacent to the Lamefoot property were drilled in 1991: the Kellogg (no. 39) and the Wardlaw (no. 40), both operated by Place Dome U.S. Inc. under a joint venture agreement with Equinox Resources Ltd. They are two of the many properties in Permian rocks of the Republic graben (Table 1). Other exploration projects investigating replacement-type deposit characteristics were active in the wedge-shaped area between the Kettle and Columbia Rivers and the Canadian border.

Readers interested in obtaining more information about iron and magnetite deposits (many of which are of the contact metamorphic type) in northwestern Washington should refer to Lucas (1977) and Broughton (1945). Details about Permian, Triassic, and early Jurassic rocks are presented by Holdier and others (1989). The geology of the Republic and Toroda Creek grabens is shown on maps by Muesig (1967), Parker and Calkins (1964), and Pearson (1967). Pearson and Obadiah (1977) compiled information on the Evac intrusive and extrusive rocks in northwestern Washington.

Skarn-Type Gold Deposits

The Crown Jewel deposit is a model for skarn-type gold deposits in Washington and southern British Columbia. Skarn (or tectite) is formed by the contact metamorphism and metasomatism of carbonate rocks. The skarn-type gold deposits are genetically similar to replacement-type gold deposits. The known skarn-type and replacement-type gold deposits in Washington are found in metamorphosed Permian to Jurassic carbonate host rocks or in volcaniclastic and epipetic host rocks, respectively. The contact metamorphism between the two types of gold deposits may be the nature and composition of the original host rocks. Gold (including that at the Crown Jewel deposit) is found in garnet skarn, in porphyry skarn, and in skarn containing iron and copper minerals (Ettlinger and Ray, 1989). Gold at the Overlook replacement-type deposit is found in rocks containing metamorphic iron and copper minerals. Intrusive rocks associated with Washington’s skarn- and replacement-type deposits range in age from Jurassic to Eocene and are commonly granite to diorite.

Extensive drilling during 1991 at the Crown Jewel deposit (no. 52), a joint venture project between Battle Mountain Gold Corp. (the operator) and Crown Resources Corp., centered on locating the margin of gold mineralization for the orebody. (See Hickey, 1992.) The deposit is within the approximate area shown on Figure 4, which covers about 60 acres on and adjacent to Buckhorn Mountain (Fig. 5). Reserves announced in December 1991 are 8.7 million tons of ore at a grade of 0.186 ounces of gold per ton, or a total of more than 1.6 million ounces of gold. Cut-off grade was 0.032 ounces per ton, waste to ore ratio was 9 to 1, and metallurgical recovery is expected to be about 87 percent. Battle Mountain also com-

INTRODUCTION

The Metaline Formation crops out in much of Pend Oreille and Stevens Counties in northeastern Washington (Fig. 1). The formation, named by Park and Cannon (1943) for rocks exposed near Metaline Falls, was assigned a Cambrian age on the basis of trilobites collected from the nearby Lehigh quarry. This thick (1,600 m), predominantly carbonaceous sequence conformably overlies the Mainland Formation and is at most 1500 m thick conformable with the overlying Ledbetter Formation.

Stratigraphic relations within the Metaline are difficult to ascertain because of extensive glacial depositional events and overlying, dense forest, complex folding and faulting, incomplete stratigraphic sections, abrupt facies changes, general absence of marker horizons, and sparse paleontologic control. These factors have contributed to a variety of interpretations of Metaline stratigraphy and deposition (Park and Cannon, 1943; Dings and Whitebread, 1965; Adie, 1970; Mills, 1977; Fischer, 1981).

In recent years there has been considerable research on the Metaline Formation. This work includes biostratigraphic studies (Repettski, 1978; Carter, 1989a, 1989b; Repettski and others, 1989; Schuster and others, 1989), a paleohydrology study (Fischer, 1986), and regional depositional studies (Bush, 1989, 1991).

In the last twenty years mine development and exploration by Resource Finance Inc. (present owner of the Pend Oreille mine), Pinlar Inc., The Burker Hill Company, Gulf Resources and Chemical Exploration Company, and Pend Oreille Mines and Metals have provided opportunities to collect data about the Metaline Formation. Much new and unpublished stratigraphic and structural information has been gained from study of core samples and underground mine exposures in and around the Metaline mining district of Pend Oreille County (Fig. 1).

Several theories about the Metaline Formation have also been completed in the past 13 years, including those by Harbour (1978), Hurley (1980), Fischer (1981), Dansart (1982), Janik (1982), Cleveland (1985), Bending (1985), and Colligan (1986). These studies, as well as the data mentioned above, have led to new interpretations that may help unravel the complicated stratigraphic relations of the Metaline Formation.

Dings and Whitebread (1965) initially subdivided the Metaline into three major stratigraphic units, but they cautioned that these units did not have definite time value or stratigraphic position. They defined a lower thin-bedded limestone-shale, a middle light-gray bedded dolomite, and an upper gray massive limestone unit. Subsequent work has shown that, indeed, these three units are not in a consistent stratigraphic succession, nor do they have time-stratigraphic boundaries. This article uses parts of Dings and Whitebread’s lithologic unit designations, but it avoids the adjectives lower, middle, and upper because they imply lateral continuity and stratigraphic succession. We recommend that the terms lower, middle, and upper not be used to describe Metaline lithologic units.

In addition to the three units originally recognized by Dings and Whitebread (1965), two other Metaline units have been described: intramarginal breccia (Neal, 1964, 1969).
Coal Activity in Washington—1991

by Henry W. Schasse

Washington’s coal activity continued to focus on the state’s two producing coal mines, which are in western Washington. Total production from the two mines was more than 5 million tons for the fourth consecutive year. There were no exploration efforts directed toward finding new coal deposits in Washington in 1991.

The state’s largest coal mine, the Centralia Coal Mine (Fig. 1), is in its second year of production under new ownership and is operated by Centralia Mining Co. The mine, which straddles the border between Thurston and Lewis Counties, produced 4,891,950 short tons in 1991, an increase of about 18,000 short tons over last year’s total. Subbituminous coal is surface mined at Centralia, currently from four pits and 12 coals beds representing eight coal seams and splits of three of those seams. The coal is mined from the middle of the Skookumchuck Formation, a nearshore and nonmarine member of the Eocene Puget Group. Since its fourth year of operation, when production leveled off, the mine has produced an average of 4.5 million tons per year. Production over the 21-year life of the mine has averaged 4.2 million tons. The mine’s sole customer is the Centralia Steam Plant, located about a mile from the mine in Lewis County.

The state’s other coal mine, the John Henry No. 1 open-pit mine, operated by the Pacific Coast Coal Company (PCCC) (Figs. 1 and 2), achieved its design capacity of 250,000 tons per year for the first time since it opened in 1986. The mine is located 2 miles northeast of Black Diamond in south-central King County. With its 150-ton per day beneficiation plant in full operation, the mine produced an all-time high of 251,459 short tons of subbituminous coal during 1991, nearly doubling its 1990 production.

Ninety-nine percent of the John Henry mine’s 1991 production was exported to Japan and Korea for use as steam coal and in cement manufacturing. Use of the remaining one percent of production was divided among public institutional heating, industrial use, and residential heating. PCCC continues to mine from four coal seams of the Franklin coal series (Franklin Nos. 7, 8, 9, and 10), which are stratigraphically near the base of the Eocene Puget Group (unindurated) in nonmarine deltaic-sedimentary rocks. PCCC had considered co-use of the John Henry mine for disposal of construction demolition material and had also considered applying for permits with county and federal authorities. The company abandoned those plans because King County decided to ship demolition material by rail to sites outside the county.

pleated a small excavation to confirm results from drilling (Fig. 6). The companies initiated the permitting process in preparation for mining.

The Crown Jewel deposit is part of an 8,000-plus-acre property package known as the Crown Jewel exploration project (no. 53) that the Battle Mountain/Crown Resources joint venture is evaluating. Several other contacted targets are studying potential skarn-type properties throughout northeastern and north-central Washington (Table 1).

Mississippi Valley-Type Deposits Washington contains many Mississippi Valley-type deposits in the Cambrian-Ordovician Metaline Formation (Mills, 1977; Dings and Whitebread, 1965) in the northeastern corner of the state (Fig. 7). The typical Mississippi Valley deposit contains lead and zinc minerals with, at best, trace amounts of silver as the only precious metal. Zinc generally exceeds lead in these deposits.

Mining and exploration for lead and zinc deposits in Washington have been essentially inactive over the past several years because of depressed prices for lead and zinc. The last operating mine in this type of deposit was the Pend Oreille, which closed in 1977. Increased demand and higher prices for zinc, combined with the proximity of these deposits to the Lummi Nation’s reservation at Trail, B.C., resulted in Equinox Resources Ltd. reopening the Van Stone mine (no. 5) in northern Stevens County. The mine stripped overburden in 1991 in preparation for mining, which began in early 1991 (Fig. 8). Mining progressed until the end of August when, due to depressed zinc prices, it was suspended to await improvements in the economy and higher prices. The mine operated during the summer at a monthly rate of 150,000 tons of ore plus waste. Waste to ore ratio was 7 to 1; the ratio of zinc to lead was approximately 2.5 to 1. On the basis of conversion of the lead content to zinc equivalents, ore grading between 2.5 and 4 percent zinc was sent to a lead smelter site and ore grading more than 4 percent zinc was sent directly to the mill.

The mill (Fig. 9) continued to operate through October using ore from the low-grade stockpile. The mill is capable of producing 950 tons of concentrates per day. When zinc prices recover to about 55 cents per pound, the Van Stone mine will resume production, according to Equinox.

The Pend Oreille mine (no. 1), in another Mississippi Valley-type deposit near Metaline Falls, was the site of underground exploratory drilling by Resource Finance Inc. The target was zinc-rich ores of the Yellowhead zones. Most of the previous production from the Pend Oreille mine was from the upper part of the Josephine breccia lithofacies; however, the zinc-rich ores of the Yellowhead zones have become increasingly important with increased zinc demand. A total of 13 holes were drilled, with no encouraging results, but any further exploration or development apparently awaits recovery of the price of zinc.

Volcanogenic Massive Sulfide Deposits Volcanogenic massive sulfide deposits form when hot springs went onto the seafloor. Present-day examples of this phenomenon have been observed on the Juan de Fuca Ridge off the coast of Oregon, Washington, and British Columbia. Interest in volcanogenic massive sulfide deposits increased with the announcement of the results of drilling on Kennecott Corp.’s Lockwood deposit (no. 97) in Snohomish County. The project is a joint venture among Kennecott (the operator), Island Arc Resources Corp., and Formosa Resources Corp. Intercepts from six drill holes averaged 2 percent copper, 3 percent zinc, 0.05 ounces of gold per ton, and 1.3 ounces of silver per ton over an average thickness of...
40 feet. Extensive bedded pyrite was known from this deposit (Derkey and others, 1990; Cartilliers and Guard, 1945), and it was considered a resource for both iron and sulfur. The recent exploratory drilling, which located associated base- and precious-metal mineralization, is in an area of extensive glacial cover. The geology of the area has been described by Tabor and others (1982).

One other recognized volcanogenic massive sulfide deposit, which has had extensive production, is the Hidden mine (no. 90; Nold, 1983; Sunshine Valley Minerals, Inc.); conducted a preliminary study of the property for possible mining. Other areas that have volcanogenic massive sulfide potential include the Border area (no. 91) and the Copper World area (no. 72), both in Okanogan County.

Other Deposit Types

Several companies expressed renewed interest in Washington’s numerous porphyry-type deposits (Fig. 10), many of which are described in Derkey and others (1990). In the past, these properties were examined for their copper or molybdenum resource potential. Current interest is focused on the potential for precious-metal resources as well. Porphyry-type deposits that were explored in 1991 include the Makanza property (no. 67), where Centurion Mines Corp. embarked on a program to re-evaluate all of the pre-existing data for the property. They also restaked a number of claims and completed a drilling program on the property. Pegassau Gold Corp. obtained an option on the Hot Lake property (no. 66), which is adjacent to the Kelley porphyry deposit (no. 64). Teck Exploration, Ltd., is seeking permits to work on the Margaret deposit (no. 103), and Champion Interna- tional Corp. continued to evaluate their Polar Star property (no. 104), which is near the Margaret deposit. Placer Re- sources Corp. maintained their Black Jack and adjacent prop- erties (no. 105). Kenneth L. Bruhn, Sr., applied for a permit for test mining on his Mountain Springs property (no. 106); however, the permit was not approved.

Two properties on the Cowichan Indian Reservation, the Parmender Creek (no. 62) and Strawberry Creek (no. 63), saw activity in 1991. These are in or adjacent to Tertiary rocks in the southern part of the Republic graben and may be epithermal deposits or peripheral portions of porphyry-type deposits.


Northeast Washington Geological Society

The first 1992 meeting of an informal organization known as the Northeast Washington Geological Society is sched- uled for March 29, when Byron Berger of the U.S. Geo- logical Society will speak on gold deposits in Uzbekistan, including the giant Muruntau deposit. NEWGS speakers present a wide variety of topics of interest to the mineral exploration and mining community of this part of Washington. Meetings are held at the Somewhere Else Banquet Hall in Republic, and the March presentation begins at 7:30; a social hour pre- cedes the talk. For additional information about NEWGS and scheduled events, write to NEWGS, P.O. Box 658, Republic, WA 99166, or phone 509/775-3022.

Northwest Geological Society

A regional association for professionals, students, and other interested persons in the field of geological sciences provides a forum for the presentation and discussion of a wide range of geologic topics, emphasizing those of the Pacific Northwest or of fundamental scientific interest. Meetings are the second Tuesday of the months between October and April. A social hour is held at the Holiday Inn Hotel, 45th St., Seattle. A no-host dinner and bar are followed by a speaker and discussion. Anyone may attend the meetings. Field trips (members only) are in June and September. 1992 membership dues are $20/y (professional) and $5/y (student). For more information and registration form, please contact: Carl Johnson, Science Applications International Corp., 18702 North Creek Parkway, Suite 211, Bothell, WA 98011; 206/485- 2818, Fax 206/485-1473.

Annual Pacific Northwest Mining and Metals Conference

Mining, Exploration and the Environment ‘92
April 6-10, Hyatt Regency, Bellevue, WA
Sponsored by: North Pacific Section of the Society for Mining, Metallurgy and Exploration, with three sessions sponsored by the Association of Exploration Geochmists.
Preconvention Short Courses (April 6-7)
Exploration Geochemistry - Stan J. Hoffman, Prime Geochemi- cal Methods Ltd.
MagmaChem—Metal Series - Stanley B. Keith, MagmaChem Ex- ploration, Inc.
Alkaline Systems - Felix Muttech, Dept. of Geology, Eastern Washington Univ.
Wetlands Design for Bioremediation - John T. Gosney, Knight Parrish and Co.
Technological Sessions (April 8-10)
Exploration and the environment; modern methods of multi-ele- mentic techniques and advances in stream sediment geochemistry; Explo ‘92—exploration strategies for the ‘90s; new discover-ies; case histories; environmental considerations for the ‘90s; re- mediation of mine wastes; acid mine drainage; abandoned mines; extractive metallurgy; heap leach pad and tailings dam; surface and underground mining; controversial geological concepts
Field Trips
Republic-Oroville gold country -- Hecle-Republic Unit B
Alkaline porphyry tour — Southeast B.C.
Trade Show: 24 booths available
For more information and registration form, please contact: Carl Johnson, Science Applications International Corp., 18702 North Creek Parkway, Suite 211, Bothell, WA 98011; 206/485-2818, Fax 206/485-1473.
Silliman

Approximately 18,000 tons of high-quality silicon metal (>96% Si, <0.03% Fe) was produced by Siliconmetal at their Rock Island plant (near Wenatchee). They transport, by rail, 50,000-60,000 tons a year of massive, high-purity (<99.8% SiO₂) quartzite ore from Golden, B.C., to this plant. All three furnaces are operating, and the outlook is improving at Siliconmetal despite the interference of Chapter 11 bankruptcy proceedings. Silicon metal dumping was addressed by Argentinia, Brazil, and China was exposed during 1991, with resultantly increased tariffs being imposed on the Chinese material. Both Siliconmetal and Northwest Alloys are capable of producing ferrosilicon; however, neither have resumed doing so.

Aluminum

Aluminum metal production from Washington-based plants was estimated at 1.24 million metric tons with an approximate value of $1.6 billion in 1991 (Patriaik Plunkett, U.S. Bureau of Mines, oral comm., 1992). The average price declined from 74 cents per pound in 1990 to 59.5 cents per pound in 1991. This was a result of reduced demand combined with increased supply, particularly aluminum from the former Soviet Union.

The value of aluminum metal produced in Washington is appreciable, and if it were included in the Bureau of Mines valuation of total nonfuel mineral production, Washington would jump from its 1991 rank of twenty-fourth in the nation to fourth.

Lime

Continental Lime Inc., a wholly owned subsidiary of Graymont Ltd., continued production of hydrated lime and quicklime at their Tacoma plant. The high-calcium limestone used by Continental is banded from limestone quarries on Texas Island. A slight downturn in sales during 1991 resulted in minor excess capacity and reflects Continental's reliance on oil industry customers. This is expected to be a short-term downturn, as the national trend is toward increased lime consumption. Two major and expanding markets for lime are in the manufacture of calcium soda from sodium carbonate (trona) and for flue-gas desulfurization. As an example, Spokane Power and Energy plant (garbage incinerator) currently consumes 80 tons of lime per week for flue-gas treatment. At the minimum (85 percent) on-line availability of this plant alone, more than 3,500 tons of lime per year will be required to treat the stack gas.

Other lime manufactured in Washington is mainly derived from paper mill effluents and not directly mined. Continental Lime continues to operate a precipitated calcium carbonate (PCC) plant at its Tacoma complex. PCC plants produce crystalline calcium carbonate with higher purity than "acid-free" paper, which has a neutral or alkaline pH. All but one of Washington’s fine-quality paper plants have converted from acid to alkaline paper making. The others are incorporating PCC or ground calcium carbonate as paper coatings and fillers. Pfizer Inc., Specialty Minerals Group, owns the other three PCC plants in Washington, at Camas, Longview, and Wallula. These recently constructed satellite PCC plants are adjacent to the James River, Weyerhaeuser, and Boise Cascade paper manufacturing plants, respectively. Pfizer now operates 21 PCC plants throughout the United States.

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REFERENCES


Figure 10. Locations of porphyry copper/calderonyd deposits in Washington. Descriptions of these deposits are given in Derley and others (1990), 1; Mount Tolman; 2; B-Metalllic; 3; Kelsoy; 4; Starr; 5; Maza; 6; Glacer Peak; 7; Sunrise; 8; Quartz City; 9; Dutch Miller; 10; Clapper; 11; Cooner-Henrickson; 12; Margaret; 13; Black Jack.

1980s and 1970s, respectively. The Gold Mountain deposit is now a joint venture project of Gold Express Corp. and N. A. Degestron Inc. Permits to mine this deposit, which consists of disseminated pyrite and gold in a dike of Shaletuk Creek acidic rocks, were obtained in 1991.

CSS Management Corp. prepared the Apex mine for increased mining of their combined Apex and Damon properties (no. 98). Their principal effort, however, was directed toward research of the "Clarkman" process, which uses a small, pressure-leaching mill to extract metals from ore.

Recognition of a potential for gold in shear zones prompted increased activity in the area west of Oroville and Tonasket in northern Okanogan County. Districts such as the Houghtaw (Ungsep, 1911; Rinchart and Fox, 1972), Palmer Mountains (Rinchart and Fox, 1972), and Cronoully (Rinchart and Fox, 1972, 1976) are attractive for this type of deposit. This area also has potential for volcanicogenic massive sulfide deposits (Copper World area, no. 72), porphyry-type deposits (Kelsoy, no. 64, and Starr Molybdenum, no. 65), and possible skarn-type deposits (Lucky Knock, no. 60). With its relatively high aerial, this area may be the focus of increased activity in the coming year.

INDUSTRIAL MINERALS

Preliminary production statistics for Washington from the U.S. Bureau of Mines suggest that 1991 was, in most re-
volume of both sand and gravel and crushed stone produced in 1991. However, producer figures are imprecise because the Bureau of Mines estimates sand and gravel production for odd-numbered years and stone production for even-numbered years, whereas crushed stone production is surveyed for odd-numbered years and estimated for even-numbered years. Data for the crushed stone produced by Portland cement manufacturers, for example, is drawn from "common variety" crushed rock aggregates for concrete construction and "ground for terrazzo chips, exposed aggregateveneer, landscaping rock, and agricultural applications." Necessarily, these product lines are part of the " beneficiated" minerals under federal mining laws owing to their inherent chemical properties. The finished products derived from them can be further used in various construction materials where their value-added aspect is commonly not represented in industrial-mineral products statistics.

Total production of Portland cement has declined over the past two years following the mid-1990 closure of Laclede Corp.'s cement plant at Metaline Falls. This decline is expected to be reversed in 1992 with the completion and scheduled start-up in May of Ash Grove Cement Co.'s new plant in Seattle. This will be the largest cement plant in the Pacific Northwest and will have a capacity of more than 500,000 tons per year. All the limestone to be used in the manufacture of their Portland cement will be barged from the Ash Grove Cement Co. quarry on Texada Island in British Columbia. Ash Grove is evaluating three Washington sources for the clay component of cement, and the silica will be derived from additional sources. Ash Grove's Superior quarry (No. 233) is located in King County.

Washington's only active portland cement manufacturer is Columbia Portland Cement Co., which currently continues to produce at nearly its full capacity of 500,000 short tons per year. Holman Ideal's limestone is mined on Texada Island and barged to the plant. They mine their clay at the Twin River quarry (No. 239) along the Strait of Juan de Fuca, west of Port Angeles. A second portland cement plant at Bellingham may also be used by Tiltex at times to grind clinker (marble-sized balls of Portland cement as it emerges from a kiln). The cinerker is imported from their Portland cement plant at Westport.

Dolomite, Limestone, and Magnesite Magnesium metal, produced from dolomite by the magnesiotherm process (Joseph, 1990), is the dominant value-added industrial mineral commodity produced in the state. Unlike silicon or manganese, magnesium metal is derived from raw material quarried in Washington. The value of magnesium metal accounted for about one-fifth of the total value of the state's mineral industry during 1991. Northwest Alloys Inc. (No. 209), the sole Washington producer, quarried more than 500,000 tons of dolomite ore for magnesium production each year. Major demand of magnesium on the world market by the former Soviet Union resulted in a 30 percent drop in price at the end of 1991. Consequently, Northwest Alloys could not compete and relented on its parent company, Alcoa, as sole customer. A 50 percent temporary reduction in the total workforce of 500 was announced by the company in December; this will take effect prior to March 31, 1992. L-Bar Industries, located at Chewelah, processes magnesium- and potassium-rich sludge bar residue from the North- west Alloys magnesium plant. The product, Ag-Mag K, is used in the fertilizer industry. L-Bar was temporarily shut down at the end of the year.

Several mineral companies, such as Nanome Aggregates, Inc. (No. 207), present and surveyed by the Bureau of Mines, invested $2 million in 1991 in the Marble Products Co. (No. 214), Chewelah Eagle Mining Co. (No. 204), and Blue Silver Mining (No. 216), produced a total of 34,000 tons of dolomite. The dolomite is crushed or ground for terrazzo chips, exposed aggregateveneer, landscaping rock, and agricultural applications.

Nanome Aggregates, Inc. has invested heavily in reclamation efforts in the Moxcuse Columbia River Basalt Group. The diatomite bed formed from accumulations of the siliceous skeletons of diatoms that lived in freshwater lakes on basaltic-flow surfaces in the Quincy basin.

Silica Three companies produced silica in Washington during 1991. Lane Mountain Silica Co. (No. 204) produced 300,000 tons for glass, golf course sand traps, and other uses. Ash Grove Cement West, Inc., produced 130,000 tons of silica at the Superior quarry (No. 233) for Portland cement. Ash Grove exported 40,000 tons to Lutinay Cement in Delaware, B.C.; however, in 1992 Ash Grove will begin to use much of their silica production in-house at their new Seattle cement plant. Reserve Silica Corp. (No. 235) of Ravenaide mined 60,000 tons of silica sands primarily for cement and glass.

Olivine Olivine Corp. mined 60,000 tons of refractory olivine ore on the Twin Coves (No. 229) for the Alcoa and Pacific Sisters dumpsite (Ragan, 1963). Most of the olivine is sold to AIMCOR and processed into a variety of refractory products at their Hamilton plant (No. 231) in Skagit County. Olivine Corp. continues to utilize a small portion of their refractory mineral production for the manufacture of wood and municipal-waste incinerators, which they market.

Clay production for bricks and ceramic tiles continued on the east and west sides of the state by Mutual Material Co. (No. 202, 236, 237, 241, 242) and the Quarry Tile Co. (No. 237). Although the total output from Holman Ideal's Twin River quarry (No. 239) on the Olympic Peninsula near Port Angeles, from which 109,000 tons of high-aluminum clay from the Eocene Twin River Group sediments was barged to their Portland cement plant in Seattle. Additional clay will be needed in Washington when Ash Grove Cement opens its new plant at Westport.

Building Stone Ashlar, flagstone, rabbble, and veneers were produced during 1991 by at least four companies. Rough construction stones were quarried from andesite, basalt, marble, and quartzite. Three companies, the U.S.B. Gilbert Western Corp., Whistler Stone Co., and Raymond Fossback Masonry, crushed landscaping rock and larger landscaping boulders, crushed and natural river rocks to more rock, and other stone materials were marketed, particularly in the populous, high-growth corridor of western Washington. More detailed information on building stone production will be published in a future issue of Washington Geology.

The Bureau of Mines value of production for the category "stone, clay, and masonry products" obtained from producers of rough construction stone. However, true dimension stone has not been produced in Washington for several years.

Gypsum and Peat Agro Minerals, Inc., of Oroville (No. 226) produced small amounts of gypsum (an earthy form of gypsum) for fertilizer. Two of the state's largest producers, Domtar Gypsum and James Hardie Gypsum, continue to satisfy their requirements for raw materials by importing relatively inexpensive ore from Mexico. At least three peat producers (Nos. 227, 238, 240) were active in widely separated parts of Washington. The primary use of peat for use in horticulture.

COMMODITIES PRODUCED FROM IMPORTED RAW MATERIALS Other valuable nonfuel mineral commodities produced in Washington are lime, silicon, metal, and aluminum metal. Lime production in Washington and the U.S.B. Gilbert Western Corp., Whistler Stone Co., and Raymond Fossback Masonry, of Mines value of nonfuel mineral production in Washington, but aluminum and silicon metals are not. A portion of the lime produced in Washington is imported from imported lime, whereas nearly all of the raw materials for silicon and aluminum metal originate at sites outside the state.
volume of both sand and gravel and crushed stone produced in 1991. However, production figures are imprecise because the Bureau of Mines estimates sand and gravel production for odd-numbered years and sand and gravel production for even-numbered years, whereas crushed stone production is surveyed for odd-numbered years and estimated for even-numbered years. Data for the crushed stone production are more difficult to obtain, and are based on "arsenic" material mined for construction (lime, filter/coating, and metallurgical uses, for example) with "common variety" crushed rock aggregates for concrete construction. The Bureau of Mines refers to this as "arsenic" material federal under mining laws owing to their inherent chemical properties. The finished products delivered from them can be extremely valuable, and value-added aspect is commonly not represented in industrial-mineral products statistics.

Total production of Portland cement has declined over the past two years following the mid-1990 closure of Laclede Corp.'s cement plant at Metaline Falls. This decline is expected to be reversed in 1992 with the completion and scheduled start-up in May of Ash Grove Cement Co.'s new plant in Seattle. This will be the largest cement plant in the Pacific Northwest and has an estimated production capacity of 500,000 short tons per year. All the limestone to be used in the manufacture of their Portland cement will be barged from the Ash Grove Cement Co. quarry on Tenas Island in British Columbia. Ash Grove is evaluating three Washington sources for the clay component of cement, and the silica will be derived from additional sources in the vicinity of Grove's Superior Quarry (no. 233) located in King County.

Washington's only active Portland cement manufacturer is outside the state and for most of 1991 continued to produce at its capacity of 500,000 short tons per year. Holman's Ideal limestone is mined on Tenas Island and barged to Tumwater, where they make their clay at the Tumwater River quarry (no. 239) along the Strait of Juan de Fuca, west of Port Angeles. A second Portland cement plant at Bellingham is being operated by the Washington Portland Cement Co., which mined five-foot beds by grinding at Cominco Ltd.'s Trail, B.C., mill, and used for use in paper coatings and fillers at Columbia River Carbonates' plant at Wallula, Wash.

One of 1991's notable explorations was the Shamrock Lime Company's exploration in the White Rock Lime Company's quarry. The deposit received extensive attention in the late 1980s as a limestone resource for a Portland cement plant at Ellsworth, Wash. The project was granted a permit, and later exploration continued until 1992. In 1993, the Shamrock Lime Company successfully drilled three holes totaling 500 feet during July 1991. The drilling program delineated thick sections of white magnesite with MgO values from 30% to 100% (209, 209). The company has been granted a permit to mine and sell white magnesite.
**Silicon**

Approximately 18,000 tons of high-quality silicon metal (>96% Si, <0.03% Fe) was produced by Silicon Metaltech at their Rock Island plant (near Wenatchee). They transport, by rail, 50,000-60,000 tons per year of massive, high-purity (>99.8% SiO) quartzite ore from Golden, B.C., to this plant. All three furnaces are operating, and the outlook is improving at Silicon Metaltech despite the recession of Chapter 11 bankruptcy proceedings. Silicon metal dumping by Argenta, Brazil, and China was exposed during 1991, with results in improved imports at Silicon Metaltech despite the suspension of Chapter 11 bankruptcy proceedings. Silicon metal dumping by Argentina, Brazil, and China was exposed during 1991, with results in improved imports at Silicon Metaltech despite the suspension of Chapter 11 bankruptcy proceedings. Silicon metal dumping by Argentina, Brazil, and China was exposed during 1991, with results in improved imports at Silicon Metaltech despite the suspension of Chapter 11 bankruptcy proceedings. Silicon metal dumping by Argentina, Brazil, and China was exposed during 1991, with results in improved imports.

**Aluminum**

Aluminum production from Washington-based plants was estimated at 1.24 million metric tons with an approximate value of $1.6 billion in 1991 (Patricia plankert, U.S. Bureau of Mines, oral comment, 1992). The average price declined from 74 cents per pound in 1990 to 59.5 cents per pound in 1991. This was a result of reduced demand combined with increased supply, particularly aluminum from the former Soviet Union.

The value of aluminum metal produced in Washington is appreciable, and if it were included in the Bureau of Mines valuation of total nonfuel mineral production, Washington would jump from its 1991 rank of twenty-fourth in the nation to fourth.

**Lime**

Continental Lime Inc., a wholly owned subsidiary of Greymont Ltd., continued production of hydrated lime and quicklime at their Tacoma plant. The high-calcium lime used by Continental is banded from limestone quarries on Texada Island. A slight downturn in sales during 1991 resulted in minor excess capacity and reflects Continental’s lime reliance on a limited number of customers. The industry is expected to be a short-term downturn, as the national trend is toward increased lime consumption. Two major and expanding markets for lime are in the manufacture of chemical compounds from sodium carbonate (trona) and for flue-gas desulfurization. As an example, Spokand Energy (electric lime) consumes 7000 tons of lime per year for flue-gas desulfurization. At the minimum (85 percent) on-line availability of this plant alone, more than 3,500 tons of lime per year will be required to treat the stack gas.

Other lime manufactured in Washington is mainly derived from paper mill effluents and not directly mined. Continental Lime continues to operate a precipitated calcium carbonate (PCC) plant at its Tacoma complex. PCC plants produce precipitated calcium carbonate (PCC) for "acid-free" paper, which has a neutral or alkaline pH. All but one of Washington’s fine-quality paper plants have converted from acid to alkaline paper making. This is occurring to incorporate PCC or ground calcium carbonate as paper coatings and fillers. Plizer Inc., Specialty Minerals Group, owns the other three PCC plants in Washington, at Camas, Longview, and Wallula. These recently constructed satellite PCC plants are adjacent to the James River, Weyerhaeuser, and Boise Cascade paper manufacturing plants, respectively. Plizer now operates 21 PCC plants throughout the United States.

**REFERENCES**


**Figure 10.** Locations of porphyry copper/molybdenum deposits in Washington. Descriptions of these deposits are given in Delrey and others (1990), 1, Mount Tolmien; 2, Bi-Metallic; 3, Kelsoy; 4, Starr; 5, Mazama; 6, Glacer Peak; 7, Sunrise; 8, Quartz Creek; 9, Dutch Miller; 10, Clipper; 11, Conner-Hotchkiss; 12, Margaret; 13, Black Jack.

**INDUSTRIAL MINERALS**

Preliminary production statistics for Washington from the U.S. Bureau of Mines suggest that 1991 was, in most respects, a typical year for production of industrial minerals. The overall value was slightly lower than in 1990, but two new projects, a cement plant and barite production, along with other projects under development should result in a comparable value for 1992, despite depressed prices for magnesium metal and other rare earth elements.

Following sand and gravel and crushed aggregates, the principal nonmetallic materials quarried in Washington, in approximate descending order of value, are: dolomite and limestone, diatomite, silica, olivine, clay/shale, decorative stone, gemstones, pect, pyram, and barite. Portland cement and lime contribute substantially to the Bureau of Mines figures for total nonfuel mineral value in Washington. However, most of the limestone for production of Portland cement and lime is currently procured from sources outside of the state or country. Commodities wholly produced from imported raw materials, such as silicon and aluminum metals, are not included in the Bureau of Mines tabulation.

**Construction Materials**

Washington produced 40.5 million tons of sand and gravel valued at $135.7 million (preliminary estimate). The state is the fifth largest producer of sand and gravel (round-rock aggregate) in the nation, a position it has held for a number of years. Preliminary statistics for crushed stone are 16.6 million short tons valued at $54.8 million. The Washington Geology, vol. 20, no. 1
40 feet. Extensive bedded pyrite was known from this deposit (Derkey and others, 1990; Carithers and Guard, 1945), and it was considered a resource for both iron and sulfur. The recent exploratory drilling, which located associated base- and precious-metal mineralization, is in an area of extensive glacial cover. The geology of the area has been described by Tabor and others (1982).

One other recognized volcanogenic massive sulfide deposit, which has had extensive production, is the Hidden mine (no. 90; Nold, 1983). Sunshine Valley Minerals, Inc., conducted a preliminary study of the property for possible mining. Other areas that have volcanogenic massive sulfide potential include the Older area (no. 73) and the Copper World area (no. 72), both in Okanogan County.

Other Deposit Types
Several companies expressed renewed interest in Washington's numerous porphyry-type deposits (Fig. 10), many of which are described in Derkey and others (1990). In the past, these properties were examined for their copper or molybdenum resource potential. Current interest is focused on the potential for precious-metal resources as well. Porphyry-type deposits that were explored in 1991 include the Mazama property (no. 67), where Centurion Mines Corp. embarked on a program to re-evaluate all of the pre-existing data for the property. They also restated a number of claims and completed a drilling program on the property. Pegasus Gold Corp. obtained an option on the Hot Lake property (no. 66), which is adjacent to the Keiley porphyry deposit (no. 64). Teck Exploration, Ltd., is seeking permits to work on the Margaret deposit (no. 103), and Champion International Corp. continued to evaluate their Polar Star property (no. 104), which is near the Margaret deposit. Phoenix Resources Corp. maintained their Black Jack and adjacent properties (no. 105). Kenneth L. Bruhn, Sr., applied for a permit for test mining on his Mountain Springs property (no. 106), however, the permit was not approved.

Two properties on the Cowlitz Indian Reservation, the Pemberton Creek (no. 62) and Strawberry Creek (no. 63), saw activity in 1991. These are in or adjacent to Tertiary rocks in the southern part of the Republic graben and may be epithermal deposits or peripheral portions of porphyry-type deposits.

Several deposits in rocks of the Shasket Creek alkalic complex were mined or explored over the past few years. The most notable are the Gold Mountain mine (no. 48) formerly called the Gold Diked (Herdick and Bunney, 1984) and the Lone Star mine (no. 50). These produced in the


Coal Activity in Washington—1991  
by Henry W. Schasse

Washington's coal activity continued to focus on the state's two producing coal mines, which are in western Washington. Total production from the two mines was more than 5 million tons for the fourth consecutive year. There were no exploration efforts directed toward finding new coal deposits in Washington in 1991.

The state's largest coal mine, the Centralia Coal Mine (Fig. 1), is in its second year of production under new ownership and is operated by Centralia Mining Co. The mine, which straddles the border between Thurston and Lewis Counties, produced 8,891,950 short tons in 1991, an increase of about 18,000 short tons over last year's total. Subbituminous coal is surface mined at Centralia, currently from four pits and 12 coals beds representing eight coal seams and splits of three of those seams. The coal is mined from the middle of the Skookumchuck Formation, a nearshore and nonmarine member of the Eocene Puget Group. Since its fourth year of operation, when production leveled off, the mine has produced an average of 4.5 million tons per year. Production over the 21-year life of the mine has averaged 4.2 million tons. The mine's sole customer is the Centralia Steam Plant, located about a mile from the mine in Lewis County.

The state's other coal mine, the John Henry No. 1 openpit mine, operated by the Pacific Coast Coal Company (PCCC) (Figs. 1 and 2), achieved its design capacity of 250,000 tons per year for the first time since it opened in 1986. The mine is located 2 miles northeast of Black Diamond in south-central King County. With its 150 tons per day beneficiation plant in full operation, the mine produced an all-time high of 251,459 short tons of bituminous coal during 1991, nearly doubling its 1990 production.

Ninety-nine percent of the John Henry mine's 1991 production was exported to Japan and Korea for use as steam coal and in cement manufacturing. Use of the remaining one percent of production was divided among public institutional heating, industrial use, and residential heating. PCCC continues to mine from four coal seams of the Franklin coal series (Franklin Nos. 7, 8, 9, and 10), which are stratigraphically near the base of the Eocene Puget Group (unidentified) in nonmarine deltaic-sedimentary rocks. PCCC had considered co-use of the John Henry mine for disposal of construction demolition material and had also considered applying for permits with county and federal authorities. The company abandoned those plans because King County decided to ship demolition material by rail to sites outside the county.

pleated a small excavation to confirm results from drilling (Fig. 6). The companies initiated the permitting process in preparation for mining.

The Crown Jewel deposit is part of an 8,000-acre property package known as the Crown Jewel exploration project (no. 53) that the Battle Mountain/Crown Resources joint venture is evaluating. Several other contacted tons are studying potential skarn-type properties throughout northeastern and north-central Washington (Table 1).

Mississippi Valley-Type Deposits

Washington contains many Mississippi Valley-type deposits in the Cambrian-Ordovician Metaline Formation (Mills, 1977; Dingga and Whitehead, 1969) in the northeastern corner of the state (Fig. 7). The typical Mississippi Valley deposit contains lead and zinc minerals with, at best, trace amounts of silver as the only precious metal. Zinc generally exceeds lead in these deposits.

Mining and exploration for lead and zinc deposits in Washington have been inactive over the past several years because of depressed prices for lead and zinc. The last operating mine in this type of deposit was the Pend Oreille, which closed in 1977. Increased demand and higher prices for zinc, combined with the proximity of these deposits to Moscow's smelter at Trail, B.C., resulted in Equinox Resources Ltd. reopening the Van Stone mine (no. 5) in northern Stevens County. The mine stripped overburden in 1991 in preparation for mining, which began in early 1991 (Fig. 8). Mining progressed until the end of August when, due to depressed zinc prices, it was suspended to await improvements in the economy and higher prices. The mine operated during the summer at a monthly rate of 150,000 tons of ore plus waste. Waste to ore ratio was 7 to 1; the ratio of zinc to lead was approximately 2.5 to 1. On the basis of conversion of the lead content to zinc equivalents, ore grading between 2.5 and 4 percent zinc was sent to a lead smelter and ore grading more than 4 percent zinc was sent directly to the mill.

The mill (Fig. 9) continued to operate through October using ore from the low-grade stockpile. The mill is capable of producing 950 tons of concentrates per day. When zinc prices recover to about 55 cents per pound, the Van Stone mine will resume production, according to Equinox Resources.

The Pend Oreille mine (no. 1), in another Mississippi Valley-type deposit near Metaline Falls, was the site of underground exploratory drilling by Resource Finance Inc. The target was zinc-rich ores of the Yellowhead zones. Most of the previous production from the Pend Oreille mine was from the upper part of the Josephine breccia lithofacies; however, the zinc-rich ores of the Yellowhead zones have become increasingly important with increased zinc demand. A total of 13 holes were drilled, with encouraging results, but any further exploration or development apparently awaits recovery of the price of zinc.

Volcanogenic Massive Sulfide Deposits

Volcanogenic massive sulfide deposits form when hot springs went onto the seafloor. Present-day examples of this phenomenon have been observed on the Juan de Fuca Ridge off the coast of Oregon, Washington, and British Columbia. Interest in volcanogenic massive sulfide deposits increased with the announcement of the results of drilling on Kennecott Corp.'s Lockwood deposit (no. 97) in Snohomish County. The project is a joint venture among Kennecott (the operator), Island Arc Resources Corp., and Formosa Resources Corp. Intercrudes from six drill holes averaged 2 percent copper, 3 percent zinc, 0.05 ounces of gold per ton, and 1.3 ounces of silver per ton over an average thickness of
this prospect in mid-March. Echo Bay Mines (the operator) then entered into a joint venture to explore the Leoknd property (no. 36), located between the Lamefoot deposit and the Overlook mine.

Two properties adjacent to the Lamefoot property were drilled in 1991: the Kellogg (no. 39) and the Wardlaw (no. 40), both operated by Placer Dome U.S. Inc. under a joint venture agreement with Equinox Resources Ltd. They are two of the many properties in Permian rocks of the Republic graben (Table 1). Other exploration projects investigating replacement-type deposit characteristics were active in the wedge-shaped area between the Kettle and Columbia Rivers and the Canadian border.

Readers interested in obtaining more information about iron and magnetite deposits (many of which are of the contact metamorphic type) in northwestern Washington should refer to Lucas (1977) and Broughton (1945). Details about Permian, Triassic, and early Jurassic rocks are presented by Holdier and others (1980). The geology of the Republic and Toroda Creek grabens is shown on maps by Mueggen (1967), Parker and Calkins (1964), and Pearson (1967). Pearson and Obradovich (1977) compiled information on the geology of intrusive and extrusive rocks in northeastern Washington.

Skarn-Type Gold Deposits

The Crown Jewel deposit is a model for skarn-type gold deposits in Washington and southern British Columbia. Skarn (or tectonic) is formed by the contact metamorphism and metamorphism of carbonate rocks. The skarn-type gold deposits are genetically similar to replacement-type gold deposits. The known skarn-type and replacement-type gold deposits in Washington are found in metamorphosed Permian to Jurassic carbonate host rocks or in volcaniclastic and pepticlastic host rocks, respectively. One characteristic between the two types of gold deposits may be the nature and composition of the original host rocks. Gold (including that at the Crown Jewel deposit) is found in garnet skarn, in greisen skarn, and in skarn containing iron and copper minerals (Elliott and Ray, 1989). Gold at the Overlook replacement-type deposit is found in rocks containing metamorphic iron and copper minerals. Intrusive rocks associated with Washington’s skarn and replacement-type deposits range in age from Jurassic to Eocene and are commonly granitic to dioritic.

Extensive drilling during 1991 at the Crown Jewel deposit (no. 52), a joint venture project between Battle Mountain Gold Corp. (the operator) and Crown Resources Corp., centered on locating the margin of gold mineralization for the orebody. (See Hickey, 1992.) The deposit is within the approximate area shown on Figure 4, which covers about 60 acres on and adjacent to Bulkhead Mountain (Fig. 5). Resources announced in December 1991 are 8.7 million tons of ore at a grade of 0.186 ounces of gold per ton, or a total of more than 1.6 million ounces of gold. Cut-off grade was 0.032 ounces per ton; waste to ore ratio was 9 to 1, and metallurgical recovery is expected to be about 87 percent. Battle Mountain also contains some lead and zinc mineralization, but these are not separately mineralized.

INTRODUCTION

The Metalline Formation crops out in much of Pend Oreille and Stevens Counties in northeastern Washington (Fig. 1). The formation, named by Park and Cannon (1943) for rocks exposed near Metalline Falls, was assigned a Cambrian age on the basis of trilobites collected from the nearby Lehigh quarry. This thick (>1,600 m), predominantly carbonate sequence conformably overlies the Mainland Formation and is at most 1,500 m conformable with the underlying Bedder Formation.

Stratigraphic relations within the Metalline are difficult to ascertain because of extensive glacial deposits and overlying cover, dense forest, complex folding and faulting, incomplete stratigraphic sections, abrupt facies changes, general absence of marker horizons, and sparse paleontologic control. These factors have contributed to a variety of interpretations of Metalline stratigraphy and deposition (Park and Cannon, 1945; Dings and Whitebread, 1965; Addie, 1970; Mills, 1977; Fischer, 1981). In recent years there has been considerable research on the Metalline Formation. This work includes biostratigraphic studies (Repetski, 1978; Carter, 1989a, 1989b; Repetski and others, 1989; Schuster and others, 1989), a dolomitization study (Fischer, 1989), and regional depositional studies (Bush, 1989, 1991).

In the last twenty years mine development and exploration by Resource Finance Inc. (present owner of the Pend Oreille mine), Plintar Inc., The Banker Hill Company, Gulf Resources and Chemical Exploration Company, and Pend Oreille Mines and Metals have provided opportunities to collect data about the Metalline Formation. Much new and unpublished stratigraphic and structural information has been gained from study of core samples and underground mine exposures in and around the Metalline mining district of Pend Oreille County (Fig. 1).

Several theories about the Metalline Formation have also been completed in the past 13 years, including those by Harbour (1978), Hurley (1980), Fischer (1981), Dams (1982), Jandik (1982), Cleveland (1982), and Bending (1983), and Colligan (1984). These studies, as well as the data mentioned above, have led to new interpretations that may help unravel the complicated stratigraphic relations of the Metalline Formation.

Dings and Whitebread (1965) initially subdivided the Metalline into three major stratigraphic units, but they cautioned that these units did not have definite time value or stratigraphic position. They defined a lower thin-beded limestone-shale, a middle light-gray bedded dolomite, and an upper gray massive limestone unit. Subsequent work has shown that, indeed, these three units are not in a consistent stratigraphic succession, nor do they have time-stratigraphic boundaries. This article uses parts of Dings and Whitebread’s lithologic unit designations, but it avoids the adjectives lower, middle, and upper because they imply lateral continuity and stratigraphic succession. We recommend that the terms lower, middle, and upper not be used to describe Metalline lithologic units.

In addition to the three units originally recognized by Dings and Whitebread (1965), two other Metalline units have been described: intraformational breccia (Voles, 1964,
companies and individuals maintain properties in the Wenasatche area.
Hecla Mining Co.'s Republic Unit (no. 25), the major revenue-producing property for the company for the past several years, continued to produce from the Golden Promise area of the deposit. The 1991 production from the Republic Unit was 77,736 ounces of gold and 311,445 ounces of silver from 96,562 tons of ore milled. Hecla reports the ore grade at the mill averaged 0.87 ounces of gold per ton.

The highlight of the year for the Republic Unit was completion of the decline ramp (Fig. 3), which provides more direct access to the Golden Promise orebodies. This allows the use of rubber-tired, diesel vehicles for loading ore and hauling it directly to the surface. Hecla began using the new ramp in August of 1991. The decline also provides access for exploration and development of disseminated orebodies in bedded tuffs of the Eocene Sanpoil Volcanics. Because the new access was completed to the 800 level ahead of schedule and under budget, it was extended to the 1100 level. The new 11-by-13-foot decline is 7,200 feet long and replaces the former method of transporting (cramping) ore more than a mile to the Knob Hill #2 shaft before hoisting it to the surface.

Hecla embarked on an extensive program of underground exploration and development and began remapping the geology of their numerous holdings throughout the district. Recent advances in understanding epithermal, hot-spring-type mineral deposits like that at Republic (Tschauker, 1989) spurred this program. If Hecla is successful and if considerable reserves are located, the company is likely to increase production and expand the mill (cover photo), which now has six days of ore.

Hecla's Golden Eagle property (no. 26) reportedly contains more than 1 million ounces of gold at a grade of 0.13 ounces per ton (A.L. Tschauker, 1991). Because of differences between ore from the Golden Eagle property and that of the Golden Promise, the Golden Eagle was put on hold during the past year, and exploration centered on the Golden Promises and adjacent mine areas.

Washington's other producing epithermal gold deposit, the Kettle mine (no. 30), located west of Cle Elum in the Republic district, is projected to be mined out in 1992. Total production for the Kettle mine will exceed 80,000 ounces of gold. The deposit, like mineralization in the Republic district, is at or near the top of the Sanpoil Volcanics. The mine is part of the Kettle River Project, concerned with the development of both Echo Bay Mines (the operator) and Crown Resources Corp. Approximately 300 tons per day of the Kettle ore is processed at the joint venture's Kettle mill, located near the Overlook mine. Northwest of Republic.

Echo Bay/Crown Resources continued exploration on the Kettle Project (Fig. 31), located 2 miles west-southwest of the Kettle mine. This deposit is geologically similar to the Kettle deposit.

Replacement-Type Gold Deposits
The Overlook mine (no. 32), the other producing mine in the Kettle River Project, completed its first full year of production in 1991. Throughput at the Key mill, which processes ore from both the Overlook and Kettle mines, ranged from 1,500 to 2,100 tons per day. The majority of the ore for the Key mill is from the Overlook mine, with only about 300 tons per day coming from the Kettle mine. Products from both the mining methods at the mine in 1991 were 90,272 ounces of gold from 664,950 tons of ore with a grade of 0.146 ounces of gold per ton.

Figure 2. Diagrammatic cross section illustrating relations among lithofacies in the Metaline Formation of northeastern Washington.

LITHOFACIES

Thin-beded Lime Mudstone
This lithofacies consists primarily of thin-beded limestone, interbedded with shale, argillite, phyllite, calcareous phyllite, and dolostone. Dingus and Whitebread (1965) initially referred to this unit as their lower thin-beded limestone-shale, and Fischer (1983) used the term lower member. Dingus and Whitebread (1965) reported a thickness of 290 m in the Metaline district, but Fischer (1983) reported a thickness of only 120 m from measured sections near Metaline Falls. Schuster (1976) estimated the thin-bedded to be 914 m thick in the Clagston Creek area (Fig. 1).

Fischer (1981) further subdivided this lithofacies into five limestone units, which he named the gray mudstone, the gray paleokarst limestone, the black peckstone-blackstone, the black mudstone, and the oosereenite mafic rocks. Although oolitic, intraclastic, and skeletal mudstones, wackestones, and packstones are present, dark-colored thin-bedded and laminated lime mudstone and shale dominate. Pyrite is a minor constituent throughout the lithofacies and, in places, constitutes as much as 4 percent of individual samples (Fischer, 1981).

In addition to the above lithotypic types, breccias within the thin-beded mudstone facies have been noted by Hudley (1980). These breccias typically consist of light-colored angular fragments in a dark fine-grained matrix and commonly occur below black argillites.
The fossil component of the thin-bedded lime mudstone facies consists of trilobite and echinoderm fragments, oncocids, Epichthys, traces of boring algae, and phosphatic inarticulate brachiopods. The darker laminated units are typically nonfossiliferous, but other intervals contain local concentrations of fossil fragments. In places, trilobite preservation is excellent, and assemblages have been assigned by A. R. Palmer (U.S. Geological Survey) to the Bathysurus-Erathina Zone of the Middle and Upper Cambrian (Drum and Gilmour, 1989).

The thin-bedded lime mudstone lithofacies generally makes up the lower part of the Metalev (Fig. 2), where it is in gradational contact with the underlying Mattien Formation and at most places is in sharp contact with the overlying bedded dolostone unit. Intervals of these lithofacies have also been identified in core samples from the Metalev formation within the bedded and varied dolostone lithofacies. The stratigraphic configuration and horizontal extent of these interbedded intervals is not certain. However, the contacts appear to be conformable, and the units extend laterally for a few miles and pinch out north of Metalev Falls.

Lochman-Balk (1971) correlated the thin-bedded lime mudstone lithofacies with the lower Lakeview Formation in northern Idaho (Fig. 4, 5). The lower Lakeview is lithologically similar and consists, from the base upward, of pyrite, dark-colored parallel laminated lime mudstone, black shale, and mottled lime mudstone (Bush, 1989). Trilobite assemblages place the boundary between the Bathysurus-Erathina and Bolaspisella Zones in the upper one-third of the lower Lakeview (Motzer, 1980). Eocene and Oligocene biostratigraphic zonations of the upper part of the Lakeview Formation were studied by the U.S. Geological Survey in Pend Oreille County, and on the basis of that study, the sequence is divided into six lowermost Tertiary biostratigraphic zones.
In 1982, a new lithofacies was added to the list of Cretaceous-Oligocene units in northern Idaho and northwestern Montana. This lithofacies is characterized by the presence of bioturbated micritic limestone, and it has been named the "Bretz Formation." The Bretz Formation is composed of thinly bedded, bioturbated micritic limestone that is typically gray in color. The presence of bioturbation indicates that the sediment was deposited in an environment where organisms were active, such as a shallow marine or estuarine setting.

The Bretz Formation is typically found in the eastern part of Idaho and in parts of Montana. It is overlain by the Coldwater Formation and underlain by the Laclede Formation. The Bretz Formation is an important unit for understanding the sedimentary history of the region and provides insight into the paleo-environmental conditions that prevailed during the Cretaceous-Oligocene transition.

In addition to the Bretz Formation, other important units of the Cretaceous-Oligocene sequence include the Laclede Formation, the Coldwater Formation, and the Clearwater Formation. These units are characterized by a variety of sedimentary facies, including bioturbated micritic limestone, sandstone, and mudstone, and provide a rich record of the sedimentary processes that operated during the Cretaceous-Oligocene transition.

The study of these units is important for understanding the evolution of the region and provides valuable information for paleo-environmental reconstruction. The study of the sediments also has implications for the petroleum industry, as these units may contain hydrocarbons or other valuable resources.
Varied Dolostone

In much of northeastern Washington, the Cambrian rocks described as hydrothermally altered, crystalline, and intermixed crystalline and bedded dolomite by Downs and Whitehead (1965) and those referred to in unpublished reports as lower dolomite belong to a distinct stratigraphic unit herein informally named the varied dolostone unit. This lithofacies is at least 1300 ft in thickness. Although much of its original nature is masked by coarse-grained dolomite replacement, many of the primary depositional features recognizable in the fine-grained parts are substantially different from those of other Metalline units. These depositional features include: dominance of hummocky, irregularly bentillar dolostone, marked lithologic heterogeneity and abundance of shale, and abrupt lateral changes in lithology. Some lithologic units occur as large blocks in which bedding attitudes differ from those of adjacent lithologies.

This lithofacies consists of several types of dolostone. However, gray, massive, clastic, and wavy-laminated dolostone dominate. The massive dolostones are featureless, fine to medium grained, and, in places, texturally similar to parts of the bedded dolostone lithofacies. The wavy-laminated dolostones contain undulatory or lenticular, discontinuous dark- and light-gray laminations. The clastic dolostones are light to dark gray and fine to medium grained and have a speckled appearance resulting from a variety of grain colors as well as from dark grains in a light matrix. Angular, shardlike fragments of gray to black shale and irregular, angular clasts of black chert are locally abundant. Undulating bedding, cross-stratification, poor to good sorting, and graded bedding are common. These clastic dolostones occur in bodies that range from irregular beds and lenses to disconformable trough fillings.

Less common rock types in the varied dolostone lithofacies include black massive dolostone, black fenestral dolostone, thin-bedded parallel laminated dolostone, gray massive dolostone, lime mudstone, and oolitic dolofolostite. Black massive dolostone is fine to medium grained and locally argillaceous and laminated and occurs in both conformable and disconformable beds and masses. In places, discordant bodies of black dolostone separate large blocks of other varied dolostone lithofacies in much the same way that dark matrix separates different lithofacies in the Josephine breccia. Black fenestral dolostone consists of fine- to medium-grained black dolomite with coarse white dolomite spots, many of which are elongate and subparallel to bedding. Several kinds of breccia in discordant as well as conformable bodies are also present in the varied dolostone. Some of these bodies resemble breccias in the Josephine. Quartzite and dolomite quartzite sandstone occur rarely in lenses as much as a meter thick at various stratigraphic positions within the varied dolostone.

The varied dolostone lithofacies is not recognized outside the Metalline mining district, and a petrographic study of the unit has not been undertaken. It is transitional between gray bedded dolostone, gray massive lime mudstone, and the Josephine breccia lithofacies, and it exhibits characteristics of each of these units. The presence of ooloids, lack of body fossils, and the varied dolostone lithofacies suggest this unit was deposited in a poorly oxygenated, shallow subtidal environment close to a deeper
basin. Storms, tidal channels, and slumping may account for cross-beds, intraformational folds, tuffs, and hummocky and lenticular beds.

Fish Creek Breccia

This lithofacies was previously referred to as the intraformational breccia by Hayes (1976). Fischer (1981) suggested the name "Fish Creek member of the Metalline Formation" for exposures in the Fish Creek area, 13 km northeast of the "Fish Creek breccia". This lithofacies is used in this paper to convey that, in general, angular fragments are more abundant than rounded fragments in this lithofacies. Hayes (1976, 1980) and Hurley (1980) described the lithofacies as a light to dark-gray, fine- to medium-grained, thin-bedded dolostone that is interbedded with lenticular sedimentation units of breccia.

Breccias consist of angular to subrounded, tabular fragments of thin-bedded dolostone supported by dark-gray to black, fine-grained dolomite matrix. In places, fragments exhibit contorted bedding. Orientation of fragments ranges from chaotic through subparallel to imbricate. Locally, breccias can be traced laterally into non-brecciated bedded dolostone. The lithofacies is almost entirely dolostone, although nodular chalk is abundant locally. Fine-grained pyrite is common in minor amounts, and phosphatic materials occur sparsely as pellets, disseminated grains, and rare fossils. Fischer (1984) noted rare echinoderm plates, but, in general, the Fish Creek breccia is neither fossiliferous nor bioturbated. Yates (1976) noted phosphatic fossils ranging in age from Middle Cambrian through Early Ordovician(?). Much of the lithofacies has a clastic texture in which both normal and reverse graded bedding are common. Sedimentation units are commonly truncated by disconformable surfaces and some cross-beds are common. Yates and Robertson (1958) and Yates (1964) indicated that in some areas of Stevens County the intraformational breccia unit is disconformable to the Metalline Formation, whereas in others it is separated by a transitional sequence of as much as 154 m of interbedded gray limestone and shale, gray to black, thin-bedded dolostone, and dolomite breccia. Where the transitional sequence is absent, the intraformational breccia is conformable with and gradationally into the Fish Creek breccia; where Fischer (1984) suggested that in northernmost Pend Oreille County, the breccia lies directly on the thin-bedded limestone unit.

The stratigraphic and temporal relations of the Fish Creek breccias are not as clearly known as those of the other lithofacies. As illustrated in Figure 4, it is interpreted to be interbedded with parts of all the other lithofacies, including the Josephine breccia. The two breccia units are considered to be distinct stratigraphically from the dominantly fine-grained tabular fragments in the Fish Creek breccia distinguish it from the Josephine breccia. These stratigraphic relations, in particular the interbedding with all the other lithofacies, were probably caused by the debris flow origin of the breccias. Hurley (1980) and Fischer (1984) had earlier concluded that the Fish Creek breccia likely formed as a result of intermitent submarine slumping and debris flows.

Josephine Breccia

The Josephine breccia comprises a wide variety of lithologies, some of which are present in other stratigraphic units. As a result, the Josephine can not be recognized by the occurrence of a single lithology, but rather by the combination of several distinct lithologies and sedimentary characteristics. The lithofacies was originally described by McGee and Robertson (1960) as noted above. Hurley (1980) and Hayes (1976) noted, "It hardly can be called uniform in its characteristic irregular brecciation and marked diversity of rock types within it...in contrast to the well-developed, thin-bedded lack of brecciation in the other units of the Metalline Limestone." The Josephine lithofacies is distinguished by the following features:

(1) Discontinuous occurrence at the top of the Metalline Formation as a heterogeneous assemblage of pyritic, black- or gray-dark dolostone with minor chalk, lime mudstone, and argillaceous.

(2) Abundance of matrix-supported breccias with varied fragment and matrix lithologies.

(3) Irregular interbedding of breccias and non-breccias, and dominance of undulating, discontinuous, and disconformable bedding surfaces.

(4) Abrupt lateral variation of lithology and character of bedding.

(5) Scarcity of fossils.

(6) Presence of minor pellet phosphates.

The Josephine breccia generally occupies a stratigraphic position at the top of the Metalline Formation directly below the Ledbetter Formation. McConnell and Anderson (1968) and Addicott (1970) considered the unit to be present everywhere in the Metalline mining district where the top of the Metalline is exposed and unfaulted, but a review of outcrops and drill core indicates that it is most persistent laterally and stratigraphically near the Pend Oreille, Grandview, and Metalline mines (Fig. 1). Dings and Whitebread (1965) did not recognize the Josephine as either a discrete lithologic facies or stratigraphic unit, but examination of what appears on their geologic map as "silicified dolomite" indicates that it should be included in the Josephine breccia lithofacies. As defined by McConnell and Anderson (1968), the Josephine is not recognized outside the Metalline district.

The thickness of the Josephine breccia generally varies from 0 to 65 m, although in a few areas it may be as much as 165 m thick. In a few locations, the thickness variations are less than that indicated by the total thickness of the Josephine, suggesting that it is a relatively thin bed or that it is not exposed. In a few occurrences, the breccia is thickest at the top of the Josephine, and is thinning or absent at the base. In general, the Josephine breccia is thickest in the area of known metalliferous deposits, and thinnest in the area of the Western mining belt.

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is gradational. These gradational contacts range from locally interbedded to irregularly gradational, steeply interdigitate, or ragged and discordant. Locally, particularly near the West Side Pend Oreille River workings, the Josephine lithofacies appears to have been deposited on the step-fault upper surface of the gray massive lime mudstone lithofacies.

Contacts between the Josephine breccia and the variably dolostone lithofacies are similar to contacts between lithofacies within the Josephine. Local discordance is more pronounced at contacts with the gray massive lime mudstone, perhaps because of the uniform character of the lime mudstone and because the lime mudstone is easy to recognize. However, gradational or undulose, parallel to the surface of the lime mudstone fragments to typical Josephine breccia with dolostone fragments.

In the Pend Oreille mine, the contact between the Josephine lithofacies and Ledbetter Formation is gradational over an interval of several meters thick in some locations, but it is a paper-thin, easily defined, and locally disconformable surface in others. Although the contact makes a transition from dominantly coarse fragmental to very fine siltclastic, and from chaotic, uneven to even and planar bedding, lithologic and bedding relations at the contact are similar to those within the breccia and among the Josephine breccia, massive lime mudstone, and variable dolostone lithofacies. In addition, Carter (1989a) has shown that rocks of both uppermost Josephine and lowermost Ledbetter in the Pend Oreille mine are within the Paragrapus tentacularus graptolite zone of the early Middle Ordovician. These observations suggest that the contact makes a locally abrupt change in the proportion and character of carbonate and argillite sedimentation but does not represent a significant depositional hiatus.

Many of the particular characteristics of the Josephine breccia are common to sediment-gravity flow deposits known from deep-water environments along modern and ancient continental margins. Two lower Paleozoic examples well documented in the literature are the Cow Head Breccia of Newfoundland (Hubert and others, 1977) and parts of the Tidewater Formation of Nevada (Cox and Tuck, 1977). McNallen and Anderson (1968) and Addie and others (1970) proposed a similar origin for Metaline breccias when they suggested that the lithofacies formed in anoxic waters basinward of an organic reef complex. They envisioned fragmentation and downslope transportation of shallow-water deposits by slumps, debris flows, and turbidity currents. Although there is no evidence for organic reefs in the Metaline, detailed lithologic observations from core and mine exposures offer support for the interpretation of sediment-gravity flow as the primary transportation mechanism for many of the Josephine lithofacies.

In contrast, Mills (1977) considered the breccias immediately adjacent to the Ledbetter/Metaline contact as part of a regionally extensive paleokarst and solution-collapse system below the uppermost Josephine and Metaline Formations. He referred to the system as the "Josephine Breccia" and included it in the breccias of the "Josephine zone" defined by McConnell and Anderson (1968) along with a variety of other predominantly discordant breccias in the Metaline Formation throughout the region. Stratigraphic, lithologic, and paleontologic studies in the district over the past two decades support the original interpretation of the Josephine breccia as marine sedimentary rocks transitional between the Metaline and Ledbetter Formations. Josephine and other Metaline lithofacies, and, to a much lesser degree, the Ledbetter Formation are cut, sliced, and included as fragments within, most of the breccia lithologies that were used in the composite earlier definitions of "Josephine breccia." Carter's (1989a) identification of graptolite specimens collected by C. F. Park, Jr., in the central part of the Metaline district in 1937 indicates that the base of the Ledbetter immediately west of the Pend Oreille River is as old or older than the Oncograptus zone of the Upper Lower Ordovician. Carter concludes that the contact exposed in the Pend Oreille mine just east of the river lies in the Paragrapus tentacularus Zone of early Middle Ordovician age. On the other hand, Carter (1989a) also stated that the base of the Ledbetter in the Claghtong Creek area of Stevens County may be as old as the Tetrarhapus fruticosus or T. approximatus Zones of Early Ordovician age. These differences in age indicate that regional transgression of basinled Metaline facies over adjacent and coeval Metaline platform facies was a rapid occurrence in the Early Ordovician. However, in the area now east of the Pend Oreille River, carbonate sedimentation persisted into the Middle Ordovician.

SYNDEPOSITIONAL FAULTING

We consider syndepositional faulting to have strongly influenced stratigraphic relations in the Metaline Formation. In the central part of the Metaline district and in outlying areas, core drilling and mining have exposed linear features in the upper parts of the Metaline stratigraphic section for several hundred meters along strike. The abundance and consistent orientation of linear structures strongly suggest that local block faulting and tilting along north-northeasterly directions occurred during deposition of much of the upper part of the Metaline Formation. In places, the faults are identified by local offset of top of the gray massive lime mudstone and dolostone lithofacies accompanied by thickening and lithologic changes of the Josephine breccia (without offset of either the Josephine or Tetrarhapus Marker beds). The faults are also identified by a north-northeast-trending stratigraphic fabric in the central part of the district that is paralleled by a pattern of younger normal faulting.

Syndepositional faults may have magnified the effect of regional subsidence by creating steepened and unstable slopes between subtidal conformable settings and deeper, more basin environments. Faulting and oversteepening would have resulted in a horizontal interfingering or a mosaic of environments along a north-northeast trend, indicating abrupt changes in water depth and depositional conditions. Slope deposits formed by slumping from oversteepened areas may have interacted with the lithologic units observed in the Josephine. Actual planes of movement are rarely recognizable, perhaps due to diagenetic reconstitution, so that the only vestiges of the faults may be the abrupt facies changes themselves.

SUMMARY

Stratigraphic relations of Metaline lithofacies have been difficult to define because of a lack of continuous exposures, stratigraphic markers, and macrofossils, as well as the effects of mineralization and diagenetic and hydrothermal alteration.
Staff News

The Division has hired Wendy Gerstel as a Geologist 2 in the Environmental Geology section. Wendy received her bachelor’s degree from the University of New Hampshire and a master’s from Humboldt State University, where she studied glacial and volcanic deposits on Lassen Peak. Along the way, she also studied at the University of Salzburg and the University of Colorado.

Wendy has worked for the U.S. Geological Survey in a variety of mapping projects, and most recently she worked as an engineering geologist with the U.S. Forest Service in the Willamette National Forest. An avid skier, she is a member of the National Ski Patrol.

Wendy’s duties with the Division will focus on slope stability and Quaternary geology, as well as compilation of the mapping for the western Olympic Mountains for the state geologic map project.

Kelli Ristime started with the Division in January, replacing Cheryl Hayes as a Clerk Typist 2. Kelli was previously employed by the Transportation Improvement Board, which was her first job with the State.

Kelli will be serving as receptionist, answering the phones and keeping an eye on the counter. She also monitors publication inventory, among other duties. She and her husband, Chris, are expecting their first baby in September.

Geological Society of America, Cordilleran Section Meeting

Hilton Hotel and Conference Center
6th Ave., Eugene, OR, May 11-13

The Cordilleran Section is meeting jointly with the Pacific Coast Section of the Paleontological Society of America, which is meeting at the University of Oregon. The pre-registration deadline is April 17.

The meeting features ten symposia, which will cover topics of broad Pacific Northwest significance. Included is the Second Symposium on the Regional Geology of the State of Washington. Conveners are State Geologist Raymond Lasans, and Prof. Eric Cheney, University of Washington. The session will be held Tuesday, May 12, and will be followed by a social hour.

Six pre-meeting and four post-meeting field trips are scheduled for areas in Oregon and northern California. Oregon Geology will be publishing some trip guidebooks.

The Washington Division of Geology and Earth Resources is preparing to publish a volume of papers presented at the Washington Symposium.

Further information about this meeting can be obtained from Aral Danna, Director of Geological Sciences, University of Oregon, Eugene, OR 97403, 503/465-5888, fax 503/464-4692.

Table 1. Mining and mineral exploration in Washington, 1991 (continued)

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<th>Property</th>
<th>Commodity</th>
<th>Company</th>
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</thead>
<tbody>
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<td>Ferry</td>
<td>A-33 SE1/4</td>
<td>Eco-Bay Inc.</td>
</tr>
<tr>
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<td>Ferry</td>
<td>A-6 33/4</td>
<td>Etco-Bay Metals, Inc.</td>
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<td>37 Lakes</td>
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<td>Vine</td>
<td>Echo Bay Mining Corporation</td>
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<td>38 Lakes</td>
<td>sec. 22, T2N, R3E</td>
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<td>46 Lakes</td>
<td>sec. 11, T3S, R3E</td>
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35 Washington Geology, vol. 20, no. 1
The Central Cascades Earthquake of March 7, 1891

by T. E. Johnson, R. S. Ludwin, and A. I. Qamar
Geophysics Program, University of Washington

While reviewing newspaper accounts of earthquakes in Washington and Oregon prior to 1928, we have discovered evidence that an earthquake on March 7, 1891 (7:40 P.M.) was much larger than previously thought. Before our investigation, this earthquake was known to have been felt only at the lighthouses on Smith Island and at Admiralty Head (Bradford, 1935; Townley and Allen, 1939). It is not included in the Earthquake History of the United States (Coffman and von Hake, 1973), which lists earthquakes with Modified Mercalli intensities (MMI) V or greater. (The MMI scale was developed by Wood and Neumann (1931) to measure felt earthquake effects.)

Through old newspaper reports and a diary entry, we now have evidence that the earthquake had intensities as high as VI, was felt on both sides of the Cascades, and did some minor damage. Figure 1 shows our estimate of the felt area of the 1891 earthquake and the distribution of areas where MMI IV and V-VI were experienced.

The apparent focus of the 1891 earthquake was east of Seattle in the central Cascades, close to Mt. St. Helens, where a number of earthquakes have been located in a tight spatial cluster since instrumental coverage began in 1970, and where felt earthquakes of magnitudes 5.6 (Zollweg and Johnson, 1989) and 4.5 (Tom Yelin, U.S. Geologic Survey, written commun., Dec. 11, 1991; coda duration on the Longmire seismographic station) occurred in 1945 and 1963, respectively. For the 1891 earthquake, which had a total felt area of approximately 36,000 km², we estimate a magnitude of 5.0 (Toppozada, 1975).

**Information for Re-Evaluation of the 1891 Earthquake**

**Modified Mercalli Intensity V-VI**

Roslyn

"The shock was severe enough to rock houses, stop clocks, and shutter crockery. Disturbance caused vertigo and nausea in several persons. Everybody rushed to the street." (Seattle Post-Intelligencer, March 8, 1891)

Snoqualmie

"Heavy shock...The rocks from Mount St. Helens came rolling down and made a loud rumbling noise, which was plainly heard." (Seattle Telegraph, March 8, 1891)

**Modified Mercalli Intensity IV-VI**

Eagle Gorge

"Eagle Gorge felt three severe shocks." (Seattle Telegraph, March 8, 1891)

Snodmonish

"In a number of Snodmonish stores the shelves with their contents were given a good shaking up." (Snodmonish Daily Sun, March 9, 1891)

Hot Springs

"A lively shock...Things were shaken up, chandeliers swayed and crockery rattled." (Seattle Post-Intelligencer, March 8, 1891)

"The hotel and depot shook badly, no damage done." (Seattle Telegraph, March 8, 1891)

Orring

"People rushed out to find the cause of the disturbance." (Tacoma Daily Ledger, March 8, 1891)

Puysappul

"Light shocks were also felt in Puysappul and surrounding villages." (Seattle Telegraph, March 8, 1891)

Seattle

"The effect was felt most severely by those in the upper floors of the six and seven story buildings downtown. There the chandeliers swayed sharply and men standing up found it difficult to keep their feet." (Tacoma Daily Ledger, March 8, 1891)

"A vase in her room nearly fell from the mantel over the fireplace...the pendulum of a Post-Intelligencer reporter who was writing made a crooked mark, as if someone had pushed his arm...the stones and dwellings rocked to and fro, and hanging lamps swung backward and forward like the pendulum of a clock..." (Seattle Post-Intelligencer, March 8, 1891)
<table>
<thead>
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<th>Location</th>
<th>Activity</th>
<th>Company</th>
<th>Property No.</th>
<th>Property Description</th>
<th>Company No.</th>
<th>Company Address</th>
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<td>Resource Finance</td>
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<td>Mesabi Valley zinc deposit in the Cambrian-Devonian rock succession</td>
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<td>Minneapolis, MN</td>
<td>55401</td>
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<td>Smith Island Lighthouse</td>
<td>Drilling</td>
<td>Pacific Northwest</td>
<td>sec. 30, T, 39N, 40E</td>
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<td>Seattle, WA</td>
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Table 1. Extract from the Modified Mercalli Intensity scale developed by Wood and Neumann (1933).

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>None felt</td>
</tr>
<tr>
<td>II</td>
<td>Felt only by unprepared</td>
</tr>
<tr>
<td>V</td>
<td>Damage to lightweight buildings</td>
</tr>
<tr>
<td>VI</td>
<td>Damage to buildings and structures</td>
</tr>
<tr>
<td>VII</td>
<td>Damage to buildings and structures</td>
</tr>
<tr>
<td>VIII</td>
<td>Damage to buildings and structures</td>
</tr>
<tr>
<td>IX</td>
<td>Damage to buildings and structures</td>
</tr>
<tr>
<td>X</td>
<td>Damage to buildings and structures</td>
</tr>
</tbody>
</table>

V. Fall indoors by many, outdoors by few.
Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience.
Vibration like that due to passing of heavy, or heavily loaded trucks.
Sensation like heavy body striking building or falling of heavy objects inside.
Rattling of dishes, windows, doors; glassware and crockery clink and clash.
Creating of walls, frame, especially in the upper range of this grade.

V. Fall indoors by practically all, outdoors by many or most; outdoors direction estimated.
Awakened many, or most.
Frightened few—slight excitement, a few ran outdoors.
Buildings trembled throughout.
Broke dishes, glassware, to some extent.
Cracked windows—in some cases, but not generally.
Overturned vases, small or unstable objects, in many instances, with occasional fall.
Hanging objects, doors swinging generally or considerably.
Knocked pictures against walls, or swung them out of place.
Open or closed doors, shutters, awnings.
Penumbra clocks stopped, started, or ran fast or slow.
Moved small objects, furnishings, to the latter slight to extent.
Spilled liquids in small amounts from well-filled open containers.
Trees, bushes shaken slightly.

VI. Felt by all, indoors and outdoors.
Frightened many, excitement general; some alarm, many ran outdoors.
Awakened all.
Persons made to move uneasily.
Trees, bushes shaken slightly to moderately.
Liquid set in strong motion.
Small bells ring—church, chapel, school, etc.
Damage slight in poorly built buildings.
Fall of plaster in small amount.
Cracked plaster somewhat, especially fine cracks chimneys [sic] in some instances.
Broke dishes, glassware, in considerable quantity, also some windows.
Fall of brick-knocks, books, pictures.
Overtured furniture in many instances.
Moved furnishings of moderately heavy kind.

VII. Everybody runs outdoors.
Damage negligible in buildings of good construction; slight to moderate in well-built ordinary structures.
Considerable damage in poorly built or badly designed structures.
Some chimneys broken.
Noticed by persons driving cars.

VIII. Damage slight in specially designed structures, considerable in ordinary substantial buildings with partial collapse, great in poorly built structures.
Panel walls thrown out of frame structures.
Fall of chimneys, factories, stacks, columns, monuments, walls.
Heavy furniture overturned.
Sand and mud ejected in small amounts.
Changes in well water.
Persons driving cars disturbed.

Tacoma
The bookkeeper noticed the lamp moving, then found that his hand was traveling in a wavering line over the paper. Accompanying this was a feeling that he was moving. The rows of hanging lamps which hang on both sides of the room swung violently from one side to another. The lighter of the waves jolted against one another. (Tacoma Daily Ledger, March 8, 1893)
Several hundred felt the shock but thought it was due to blasting... (Seattle Post-Intelligencer, March 8, 1893)
No damage was done, although articles in china and glassware stores ruffled a little, and occupants of six floors rooms from fear of rooms feeling the structure were about to topple. (Og flashback: March 8, 1893)

Modified Mercalli Intensity I-III
Ellensburg
The shock was [a] light one and a great many failed to notice it. (The Ellensburg Capitol, March 12, 1893)
Not reported felt in the Ellensburg Daily Leader.

Monitor
The house trembled and shook. (From the diary of Helen Margaret Paarish, March 8, 1893, copy contributed by her granddaughter, Betty Detroy.)

Admiralty Head Lighthouse
A light shock (Bridford, 1935).

Smith Island Lighthouse
A slight shock (Bradford, 1935).

No Feit Reports Found
The earthquake was not reported felt in the Aberdeen Herald, the Hoquiam Washington, the Chehalis Bee, or the Washington Standard, a weekly published in Olympia; nor was it reported felt in the Victoria, B.C., Daily Colonist.

ACKNOWLEDGMENTS
This research was funded under USGS grant 14-08-0001-G1510 on Earthquake Intensities. We thank Betty Detroy for contributing a copy of her grandmother's diary entry, and Chris Triller for calling our attention to this earthquake.

REFERENCES CITED

Washington Geology, vol. 20, no. 1
Do You Know Of Original Accounts Of Earthquakes That Occurred Before 1928?

Diary entries and newspaper accounts of felt earthquakes (felt in Washington, Idaho, Oregon, and Montana) that took place before 1928 are being collected by Ruth Ludwin of the University of Washington Geophysics Program. She needs to know where the diary was written or, for newspaper reports, the name of the newspaper, date and place of publication, as well as the page and column numbers for the earthquake story. If you have such material, she would appreciate having photocopies of it. Ruth is also searching for newspaper indexes, which have proven to be especially helpful in documenting un-catalogued earthquakes. She needs to know if there is a pre-1930 index to your local paper.

Please address information to Ruth Ludwin, Geophysics Program AK-50, University of Washington, Seattle, WA 98195.

Out-of-Print Publications Available

The following publications, long unavailable, can now be purchased from the Northwest Geological Society. For information about cost and mailing of these reprints, contact Dale Kramer at 783-0151 (home) or write to the Northwest Geological Society, 834 NW 50th, Seattle, WA 98107.


Corrections

In Washington Geology, vol. 19, no. 4, the view in the photograph on page 38 is from the northeast; on page 41, left column, second paragraph, the text should read "During the 1991 legislative session...", and the photo credit on page 53 should be Kent Reynolds.

Division Publication Activity—1991

by Renee Christensen

During 1991, the Division of Geology and Earth Resources published one report in the Geologic Map series (GM-39), consisting of text, three large plates in color, and the accompanying topographic map (TM-2). We also published seven open-file reports, four issues of Washington Geology, and bibliographies for 26 counties. These reports total 1,316 pages of information.

Of the publications in all our formal series, we distributed 5,320 copies. Of those formal publications for which we charged, we sold 2,571 and gave away 984 complimentary copies. Of the formal publications that are free, we mailed or gave out over the counter 1,765 copies.

We received orders for 3,312 copies of reports in our open-file series. Only 64 copies of free open-file reports were mailed out or distributed over the counter, but nearly 820 copies of reports in this series were given out on a complimentary basis.

The Division also distributed 4,381 copies of miscellaneous free information packets, brochures, and flyers, such as "Placer gold mining in Washington" and "Gems and minerals of Washington". We also gave away many copies of our list of publications.

The four issues of Washington Geology (formerly the Washington Geologic Newsletter) totaled 180 pages. This publication is mailed to an average of 3,824 addresses; by the end of 1991, there were approximately 4,010 people or institutions on the mailing list. We gave 1,378 copies to visitors or persons requesting particular issues.

During the year, the clerical staff handled orders and requests for 31,471 copies of our printed materials. This averages about 125 items per day being mailed or sold or given to visitors.
A Policy Plan for Improving Earthquake Safety in Washington: Fulfiling Our Responsibility

December 1, 1991

EXECUTIVE SUMMARY

The Seismic Safety Advisory Committee
We all remember the 1989 earthquake near San Francisco...the immediate chaos, the collapsed freeway, the tragedies of death, destruction and homelessness. Washington has experienced earthquakes of similar magnitude and will experience them again. Mindful of our risk, the Legislature mandated the Department of Community Development to establish a Seismic Safety Advisory Committee (SSAC). The SSAC was charged with developing a comprehensive plan and making specific recommendations for improving seismic safety in Washington.

Policy Oriented Mission And Goals
Lengthy reports already exist explaining why Washington needs a seismic safety policy and providing generic information on improving earthquake preparedness. Rather than duplicate other work, the SSAC's goals have emphasized developing and prioritizing practical and realistic strategies and initiatives which the state can begin to implement immediately.

Broad Participation
The SSAC's work program involved the broad participation of state agencies, emergency response personnel, building officials and professional organizations from the beginning. The SSAC's work program used formal committees and individual contacts to maximize statewide involvement. Focus groups and public meetings were held in eastern and western Washington, and a survey was mailed to 2,500 government and private organizations to increase involvement in the policy development process.

Project Approach
The SSAC's work program focused on:
- Reviewing the current status of earthquake readiness.
- Developing strategies to improve readiness.
- Identifying initiatives to implement strategies.

The Earthquake Threat In Washington
Washington has experienced earthquakes as large as the recent event that shook San Francisco. In 1949 Olympia was rocked by a magnitude 7.1 earthquake. Again, in 1965, the Seattle-Tacoma area was rattled by a magnitude 6.5 earthquake.

Serious Earthquake In Your Time?
A Definite Possibility
Major earthquakes with magnitudes between 6 and 7.5 can be expected every 30 to 50 years. We do not know when,

but we do know that they will occur. Anyone spending half their life in western Washington should expect to live through a major earthquake.

Geologists See The Potential For A Catastrophic Earthquake
This summer Washington's earthquake threat was front page news. The news media reported recent research findings which show that coastal regions of Washington experienced a massive earthquake about 300 years ago, and that geologists see the potential for another great earthquake in the Pacific Northwest. Such an earthquake could be many times more damaging than San Francisco's recent earthquake.

We Should Prepare For A Major Earthquake
The conclusion that the SSAC draws from the earthquake risk is that we must prepare for an earthquake of at least magnitude 7.5, and probably larger, in which:
- People will be injured and die.
- People will be left homeless.
- Lives and communities will be disrupted.
- Business will suffer direct loss from property damage.
- Recovery will take months or years to complete.

Being prepared can reduce all of these adverse impacts.

Our Readiness For An Earthquake
The SSAC reviewed the status of our readiness for an earthquake in Washington. What they found is cause for concern. While some organizations and individuals are prepared, most are not.

Our Emergency Response Capacity Will Be Overwhelmed
The SSAC is concerned that our response capacity will be hampered by inadequate communication systems, a lack of public preparedness, and the low priority placed on local emergency planning.

Schools Are Cause For Concern
There are a great many older, unreinforced masonry school buildings that are at risk. Tentative estimates indicate there are 350 to 400 unreinforced masonry school buildings, containing up to 155,000 children.

Fire And Medical Facilities Are Vulnerable
Many of our older firehouses and hospitals are vulnerable. When an earthquake strikes we need these facilities to be fully operational.

Our Transportation Lifelines Are Not Secure
The Washington State Department of Transportation is seismically strengthening key bridges. This is only a start. We need to know the risks to local bridges, marine facilities, port facilities, highways, transit systems, airports and rail facilities so that we can selectively strengthen crucial routes, staging areas, and airport facilities.
Utilities Have Not Addressed Seismic Risk

Only a few of the many water and wastewater utilities in the state have assessed seismic vulnerability. Electric utilities have done some vulnerability assessments. The natural gas companies in Washington have done limited work to address seismic safety.

Now Is The Time To Act

There is no doubt that some time in the future Washington will experience a large and damaging earthquake. It could happen as you read this report, or it could happen next week or next year. When it does occur, there will be deaths, injuries and disruption that could and should have been prevented.

At an early stage, the SSAC concluded that the State should devote its energies to identifying measures which will increase earthquake safety. With every earthquake, we learn more about the behavior of buildings, lifelines and people during these events. There is a huge body of knowledge which we can apply right now to reduce seismic risks in Washington. The primary emphasis of the SSAC has been on identifying how the State can improve seismic safety.

Practical Recommendations For Increasing Seismic Safety

The SSAC emphasized developing policy and action recommendations which are realistic and build on other work that is currently underway. These recommendations are practical, achievable, and a wise investment.

Program Oversight Is Essential

A body providing leadership and oversight is required to ensure that the SSAC’s recommendations are acted upon. The SSAC’s top priority for immediate legislative action is the authorization in statute of an oversight committee with staff support to oversee implementation of the SSAC’s recommendations. This committee will lead a multi-agency program and budget development process.

A Multi-Year Effort Is Required

Improving seismic safety is a long-term proposition. Seismic safety cannot be improved overnight, nor can it be improved by legislation alone. The SSAC has carefully crafted a multi-year work program which, when implemented, will significantly enhance seismic safety in Washington.

This work program prioritizes initiatives which:
- Reduce the risks to life, public safety and property.
- Are realistic and feasible.
- Create momentum for the overall program.

The work program involves a multi-agency and multi-jurisdictional effort and builds on current public and private sector work currently underway.

Priorities For Action

The following are top priority recommendations for action.

I. Establishing seismic safety oversight
   a. Create by legislation an interagency seismic safety policy committee.

II. Improving emergency planning
   a. Conduct a state-level review of emergency communication systems and implement the review recommendations.

b. Clarify the liability law for volunteer emergency workers and implement a central registry of trained emergency worker and volunteer personnel.
c. Prepare and implement a multimedia awareness and education program.
d. Provide standardized materials to help local jurisdictions more effectively train personnel.
e. Standardize planning guidelines for local jurisdictions as part of ongoing emergency planning.
f. Increase awareness of structural and nonstructural earthquake hazards as part of ongoing education.

III. Strengthening buildings
   a. Assess the seismic vulnerability of school facilities and improve seismic safety as part of long-range capital planning.
b. Develop and submit amendments to the State Building Code Council that require seismic strengthening during planned remodel projects.
c. Support the review of current Uniform Building Code Seismic Zone 3 boundaries.
d. Develop financial incentive programs to assist with seismic strengthening projects.
e. Support and coordinate the geological mapping of sensitive areas.
f. Support the implementation of a strong motion instrumentation program in Washington.

IV. Strengthening our lifelines
   a. Establish statewide policy goals for mitigation of seismic risk to lifelines.
b. Continue the funding for the current Washington State Department of Transportation bridge retrofit program.
c. Identify critical lifeline routes that include state and local roads, bridges, transit routes, and port facilities.
d. Develop a work program for seismic vulnerability assessments of local bridges.
e. Require seismic vulnerability assessments and adoption of seismic mitigation standards for water and wastewater utilities.
f. Require post-earthquake response and recovery plans for water and wastewater utilities.
g. Provide a rigorous program of training in seismic safety for lifeline organizations.
h. Develop standardized seismic safety guidelines for lifeline emergency plans.

Appendix E: Authorizing Legislation

The Department [of Community Development] shall create a seismic safety advisory board to develop a comprehensive plan and make recommendations for improving the state’s earthquake preparedness. The plan shall include an assessment of and recommendations on the adequacy of communications systems, structural integrity of public buildings, including hospitals and public schools, local government emergency response systems, and prioritization of measures to improve the state’s earthquake readiness. The Department shall report to the Senate and House of Representatives Committees on energy and utilities by December 1, 1991. An interim report shall be made to the Committees by December 1, 1990.
History of Cooperative Topographic Mapping
In Washington
by J. Eric Schuster

The mandate of the Washington State Geological Survey, as passed by the 1901 legislature, included no provision for cooperative investigations with the U.S. Geological Survey (USGS). This was corrected in 1905, when the legislature amended the 1901 act by adding the following:

The said board of geological survey is hereby authorized to make provisions for topographic, geologic, and hydrographic surveys of the State of Washington in cooperation with the United States geological survey in such manner as in the opinion of the said board will be of the greatest benefit to the agricultural, industrial, and geological requirements of the State of Washington; Provided, that the Director of the United States Geological Survey shall agree to expend on the part of the United States upon such surveys a sum equal to that expended by the said board.

This legislation remains in effect as RCW 43.92.060. Unfortunately, when the legislature gave the state geological survey this new duty and opportunity, it did not renew its appropriation, and the survey was dormant for several years.

In 1909, the legislature passed a second act authorizing the Washington State Geological Survey to engage in cooperative topographic and hydrographic work with the USGS. They also renewed the survey’s appropriation; $30,000 for the cooperative topographic and hydrographic work, and $20,000 for the survey’s geologic projects.

With new funding available, the Board of Geological Survey, the governing body of the Washington State Geological Survey, held planning meetings on April 16 and May 4, 1909. At the April meeting, they discussed cooperative hydrographic and topographic mapping with J. C. Stevens, District Engineer of the USGS. Stevens had been given authority to arrange for such cooperative work by USGS Director G. O. Smith. The Board authorized Governor M. E. Hay to complete all necessary cooperative arrangements with the U.S. government. On May 4, the Board decided that $10,000 would be used for cooperative hydrographic work and $20,000 for topographic mapping. Governor Hay and State Geologist Henry Landes were to decide which quadrangles were to be topographically mapped.

Quincy Is First Quadrangle Printed
They lost no time. Landes reported to the Board at their November 30, 1909, meeting that USGS field parties had completed work on the Mount Vernon 30’ quadrangle and were three-fourths finished with the Quincy, Morrison (Winchester), Red Rock, and Beverly 15’ quadrangles. The Quincy quadrangle was printed by the USGS in November 1910, the Winchester quadrangle in December 1910, the Mount Vernon and Red Rock quadrangles in January 1911, and the Beverly quadrangle in June 1912.

Cooperative topographic mapping was to go on for 82 years. The same general scheme was followed from start to finish. The state geological survey and its successors supplied one-half of the funds, and the USGS supplied the field parties and did the map preparation and printing.

Many of the early cooperative topographic maps are for areas in the arid central part of Washington. This probably reflects Landes’ interest in irrigation projects. He knew that development of such projects depended heavily on the existence of good topographic maps from which canal routes, the extent of irrigable lands, and possible surface-water sources could be realistically determined.

Production Costs Vary With Relief of Terrain
Topographic mapping continued as a cooperative effort of the USGS and the Washington State Geological Survey and its successors. By 1946, Sheldon Glover, the State Geologist and Supervisor of the Division of Mines and Geology, could state in the biennial report of the Division that 169 quadrangles had been topographically mapped in Washington. These covered 77.83 percent of the state’s land area, and 51 of these quadrangles had been produced cooperatively. He further reported that a topographic map of a mountainous quadrangle, like the Mount Constance quadrangle in the Olympic Mountains, cost about $18,000 to produce; a rolling lowland quadrangle like the Chehalis quadrangle cost about $14,500; and a treeless quadrangle of low relief, like the Connell quadrangle, cost $12,800. These are all 30’ quadrangles; 15’ quadrangles cost approximately twice as much to produce. A purchaser had to pay 20 cents per copy for these maps.

Twenty years later, 80 cooperative topographic quadrangles had been completed or were in preparation. The State’s contribution to the program totaled $499,443. These figures were reported by Marshall T. Hunting, State Geologist and Supervisor of the Division of Mines and Geology, in his biennial report for the period July 1, 1964, to June 30, 1966.

Documents in Division files show that an additional $2,355,000 in topographic cooperative agreements were entered into between July 1, 1966, and June 30, 1981. This brought the total State contribution to $734,443 and the total number of cooperative quadrangle maps completed to about 110.

Budget Cuts End Division Involvement
Budget cuts in 1981 ended the Division’s involvement in cooperative topographic mapping, and by the time finances permitted resumption of the cooperative program, completion of first-time topographic mapping in Washington was in sight, and the relatively small contribution the Division was able to make was not deemed to be needed. Cooperative efforts, however, were being continued by the Division’s parent organization, the Department of Natural Resources.

The Division’s cooperative contributions over the years helped to create a significant fraction of the state’s 30’ and 15’ topographic quadrangle maps and sped the recently celebrated completion of 71/4’ topographic mapping.
Selected Additions to the Library of the Division of Geology and Earth Resources

November 1991 through January 1992

THESES

U.S. GEOLOGICAL SURVEY REPORTS
Published Reports

Open-File Reports and Water-Resources Investigations Reports
Sumiaka, S. S., 1991, Quality of water in an inactive uranium mine and its effects on the quality of water in blue creeks. Stevens

by Robert E. Derkey and Charles W. Gulick

INTRODUCTION
Gold production in Washington increased again in 1991, as it has nearly every year since 1985 (Fig. 1). The value of increased gold production, however, was not enough to offset a decrease in total mineral production for the state from 1990 to 1991. A preliminary value reported by the U.S. Bureau of Mines for 1991 nondal mineral production is $442,617,000; this is about 6.5 percent lower than the 1990 value. These preliminary figures for 1991 indicate that production of seed and gravel, crushed stone, and portland cement accounted for slightly more than 50 percent of the value of production. Forty percent of the state's nondal mineral value was split nearly equally between production of precious metals and production of magnesium from dolomite. The remaining 8 percent of the 1991 production value was from clay, diatomite, dimension stone, gemstones, gypsum, industrial sand and gravel (silica), lime, masonry cement, clinker, pect, lead, and zinc.
Of the five metals mined actively in 1991, four were producing. The state's major precious-metal mining operations, the Cannon mine, the Republic Unit, and the Kettle River Project, produced 320,000 ounces of gold and more than 580,000 ounces of silver in 1991. Along with this increase in production, acquisition of mining properties in the state and expenditures for detailed evaluations of these properties during 1991 appear to have increased relative to 1990 levels. Employment in the nondal mineral industries increased in 1990 (the latest year for which figures are available) relative to 1989. An average of 2,681 people were employed in 1990, compared to 2,152 in 1989. A significant proportion of these employees in attributable to the start-up of the Kettle River project near Republic by Echo Bay Minerals Co. This new mining operation provided a healthy stimulus to the economy of Ferry County. (See also Joseph, 1991). Despite the slight decrease in nondal mineral production in 1991, Washington is expected to experience continued growth in the number of persons employed in minerals-related activities and in the value of production. Therefore, this estimate of the number of persons employed in minerals-related activities is accompanied by a number. This number permits quick access to property location, which is shown on Figures 2a-d and other public lands. This table summarizes mining and mineral exploration activities in Washington. The majority of this information was obtained from an annual survey of mining companies and individuals. Because not all survey questionnaires were returned, Table 1 is an incomplete measure of Washington mineral industry activity. The table includes a column in which geologic setting at or near the property/mine is briefly described. This information is taken from the U.S. Geological Survey's Kettle River Project. The classification of "northeast quadrant" (Stoffel and others, 1991), the metal mines database (Derkey and others, 1990), and other published reports cited in these reports or listed at the end of this article.

The discussion of the metallic mineral industry deposits was prepared by R. E. Derkey. It is organized on the basis of deposit type and deposit geology. The industrial minerals part of this article, prepared by C. W. Gulick, is organized by commodity. Questions about this information can be addressed to the authors at the Spokane office of the Division of Geology and Earth Resources. Phone numbers and telephone number are given on p. 2 of this publication.

METALLIC MINERAL DEPOSITS
Epithermal Gold Deposits
Hot springs like those found in Yellowstone National Park produce mineral deposits referred to as epithermal deposits or simply hot spring deposits. These deposits are typically found at the Cannon mine and deposits at Republic are the sub- surface expressions of formations in the applicable geologic basin. Hot spring activity and associated epithermal deposits are commonly found in areas of active volcanism, such as the Cascade Range of Washington and Idaho. Epithermal deposits and the associated hot spring activity are extensive in Washington; however, only a few contain mineable amounts of gold and silver.

The Cannon mine (no. 74), Washington's largest gold producer, is located southwest of the city of Wenatchee (Fig. 2a). The cannon mine is a joint venture between Amasa Minerals (U.S.) Inc. (the operator) and Breakwater Resources Ltd. Hot spring activity for this epithermal gold deposit (Ott and others, 1986) is Eocene elastic rocks of the Chelan-Wenatchee group, which is a major northwest-trending strike-slip basin. Evens and Johnson (1986) noted that the ore in 1991 was 152,010 ounces of gold and 271,352 ounces of silver from 538,769 tons of ore. This is an average head grade of 0.282 ounces per ton for gold and 0.544 ounces per ton for silver. During 1991, an exploration drift was being driven to inter- sect mineralization of the "A reef" zone to confirm drift-in- dicated reserves. Amasa also continued an extensive exploration program on properties located northwest and southeast of the mine (nos. 75-86). Several other
Minerals and Society
by Raymond L. Lammens

"We depend on minerals throughout our lives. In fact, each year an average of 40,000 pounds of new minerals are consumed for each American. At this level of consumption, the average child will need a lifetime supply of 800 pounds of coal, 750 pounds of oil, 1,500 pounds of copper, 5,500 pounds of iron, 26,500 pounds of clay, 21,650 pounds of salt, 1,236,101 pounds of stone, sand, gravel, and cement." - Raymond L. Lammens

Members of the public and students frequently ask what persuaded me to become a geologist. The abbreviated answer is that I knew since my high school days that I wanted to be an economic geologist. By the time I was 12, I was collecting geologic materials and reading books on the subject. At that time, during the post-World War II period and the Korean War, society was cognizant of the value of minerals. This was reflected in public school curricula, where students were taught the direct relation between the availability of minerals and our economic well-being, as well as the nation's security. It was only natural, therefore, I decided, to take on the task of helping to identify why it was a society's benefit.

As a nation, the United States has achieved the highest standard of living anywhere in the world. In the process, we have somehow lost sight of the fact that our very existence depends on only two sources of material—either grow it (food or lumber products, for example) or you get it out of the ground (minerals or oil). Everything else is manufactured from these raw materials. Our society is largely illiterate when it comes to knowing what materials go into the construction of a house, a car, or even the highways we drive. During the last year, I have heard statements such as "I didn't know concrete is made up of a group of minerals" (a report about growth management issues) or "I just don't like mining. Can't it be stopped?" (a common public reaction).

It seems to me that our schools have failed to teach students just what the building blocks of a strong society are. Issues surrounding sand and gravel mining are good examples of the need for education. Urban sprawl has infringed on historical sand and gravel mines. Major conflicts over land uses have resulted and will only escalate. But we can do without sand and gravel. These are used for concrete aggregate, plaster and grout, concrete products, asphaltic concrete, road-base cover, fill, soil and ice control, railroad ballast, and filtration/drain fields, to name a few uses. The U.S. Bureau of Mines reports that in Washington in 1990, there were 197 operators who produced 420,250,917 tons of construction sand and gravel from 226 major pits. With a 1990 population of 4,866,692, each person's share of construction sand and gravel is 0.27 tons or 16,540 pounds. Mine operations have little adverse environmental impact, but they are commonly perceived as a major social nuisance. The result is that these costs are rising as regulatory permitting is delayed and the availability of known resources is restricted by zoning or other means. A more balanced approach should be developed, based on deliberations of an informed public that recognizes that every one of us is a consumer of mineral resources.

Washington Department of Natural Resources, 1992, Draft environmental impact statement for the proposed forest resources plan.

Location of Main Office
Division of Geology and Earth Resources
Rossiere Building
4225 10th Ave. S.E.
Lacey, WA 98503-1024

Northeast Quadrant Map A Winner
The Division's Geologic map of Washington-Northwest quadrant (GM-39) recently reissued an Award of Achievement in the Technical Reports category of the 1991 Art, Online, and Publications Competition sponsored by the Puget Sound Chapter of the Society for Technical Communication. The map of the northeast quadrant was similarly honored in 1988.
New Division Releases

Prediction of sediment yield from tributary basins along Huesedok Ridge, Hoh River, Washington, Open File Report 91-7, by R. L. Logan, K. L. Kaler, and P. K. Bigelow. This report describes the results of field investigations and study of aerial photographs to determine the volume of sediment yielded by slope failures in this area on the west side of the Olympic Peninsula. The study was conducted to assist in developing resource management alternatives for Hoh River basins. The 14-page report costs $0.93 + .07 tax (for Washington residents only) = $1.00.


Seismic hazards of western Washington and selected areas—Bibliography and index, 1988-1991, Open File Report 92-2, compiled by C. J. Manson. This report continues the previous bibliography (Open File Report 88-4) and includes citations for the entire Cascadia subduction zone. Publication has been supported by the National Earthquake Hazards Reduction Program through the U.S. Geological Survey. This 250-page report is free.

A colored geologic map of Washington at 1:2,500,000 (or 1 in. = approx. 37 mi) is now available free from the Division. This map (8½ x 14 in.) was compiled by J. Eric Schuster. Included are an explanation of the 22 map units and a list of sources used in compilation.

County Bibliographies

A bibliography of geologic information for Okanogan County has been added to this series, bringing the total to 26 counties covered by these compilations in support of the Growth Management Act. Copies are available on paper or disk (IBM-compatible). Paper copies are free, but please include $1 with each order to cover postage and handling.

To obtain a disk copy, send us a 5.25-in. or 3.5-in. formatted disk. We will copy the file and return your disk. Please specify whether you want the file in Word Perfect 5.0 or 5.1 or ASCII. The Okanogan file is 190 kilobytes (K), and it is the same file listed below in the full series.

We have recently completed 1991 updates to the series of county bibliographies. The updated material has been appended to paper and disk copies, which are available separately.

Write or call us to order paper copies. If you want the file(s) on disk, check the list below to be sure you send us enough disks to contain the file(s).

- Benton County (316K)
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Our mailing address, on p. 2 of this publication, has recently been revised—we now have a post office box number. In order to serve you as promptly as possible, we would appreciate having your Zip Code and the four-digit extension for your address with your correspondence.

In This Issue: Washington’s mineral industry—1991, p. 3; Coal activity in Washington—1991, p. 26; Stratigraphic interpretation of the Metlak Formation, p. 27; Central Cascades earthquake of March 7, 1891, p. 36; Policy plan for improving earthquake safety, p. 59.

The 270-ton-per-day mill constructed in 1937 at Hecta Mining Co.’s Republic unit maintains a 95 percent recovery level for gold and 88 percent for silver. Hecta is now undertaking an extensive exploration program for additional ore reserves that, if successful, could lead to increased production and expansion of the mill. See related article, p. 3. Photo by Robert E. Deckey.