Division Releases

Liquefaction Features from a Subduction Zone Earthquake: Preserved Examples from the 1964 Alaska Earthquake. Report of Investigations 32, by Timothy J. Walsh, Rodney A. Combrell, and Gerald L. Block. This 80-page report describes results of investigations of four locations in southern Alaska. Liquefaction features, particularly in the eastern part of Turnagain Arm, are illustrated by photographs. Many photos are accompanied by sketches of stratigraphic details. This report was produced in cooperation with the Alaska Division of Geologic and Geophysical Surveys and the Oregon Department of Geology and Mineral Industries and supported by a grant from the U.S. Geological Survey. The price is $3.71 (+ $0.29 tax for Washington residents) = $4.00.

Geologic and Geophysical Mapping of Washington, 1984 through 1995, and Theses on the Geology of Washington, 1986 through 1995, Open-File Report 96-1, compiled by Connie J. Munson. Reports are listed by author, and 9 plates display mapped areas by map scale. This report supersedes OFR 95-2. Earlier mapping is covered in our Information Circulaires 77 (geologic and geophysical mapping; out of print, but available in many libraries) and 80 (theses; still in print). This updated list of maps and theses costs $1.39 + .11 tax (WA residents only) = $1.50.

Flood Basalts and Glacier Floods—Roadside Geology of Parts of Walla Walla, Franklin, and Columbia Counties, Washington, by Robert J. Carlson and Kevin R. Pugh of Whitman College. This report, Information Circular 90, describes the region's general geology and features along a 200-mile loop route that begins and ends in Walla Walla. The many illustrations help readers understand the effects of the Missoula flood eruptions and the glacial outburst floods. The price is $3.24 + .26 tax (WA residents only) = $3.50.

Best Management Practices for Reclaiming Surface Mines in Washington and Oregon, by D. K. Norman, P. J. Wampfler, A. H. Throp, E. F. Schnitzer, and J. M. Roloff, has been produced as a cooperative project by the Department of Natural Resources and the Oregon Department of Geology and Mineral Industries. (The first and last authors are DNR employees.) The report is DNR's Open File Report 96-2 (Oregon's Open-File Report O-96-2) and consists of seven chapters that discuss operating and reclamation techniques for controlling erosion, creating stable slopes, and revegetation, as well as information about satisfying regulatory requirements. The cost is $3.24 + .26 tax (WA residents only) = $3.50.

Our supply of Geologic guidebook for Washington and adjacent areas (Information Circular 86, edited by N. L. Joseph) is very small and consists entirely of copies with covers loose pages. We offer the remaining copies at half price, $4.50; Residents of other states may subtract the 3.33 tax.

GSA Field-Trip Guidebooks Available

Leftover field-trip guidebooks from the 1994 Geological Society of America Annual Meeting in Seattle are available for purchase. For more information, contact Don Swanson 206-553-5587 or Ralph Haugard 206-553-5542 of the U.S. Geological Survey at the University of Washington, Department of Geological Sciences, PO Box 351310, Seattle, WA 98195-1310. The two-volume set is $20 if picked up or $22 if mailed. Make checks payable to GSA Guidebook.
DEPARTMENT'S GUIDING PRINCIPLES AND SURFACE MINING RECLAMATION
Raymond Lasmas, State Geologist
Washington Division of Geology and Earth Resources
PO Box 47007, Olympia, WA 98504-7007

Starting in 1993, Department of Natural Resources (DNR) management developed a series of guiding principles to provide direction. The revised version was endorsed by Commissioner of Public Lands Jennifer M. Belcher on January 20, 1995. One guiding principle is that regulatory programs shall encourage voluntary compliance and collaboration.

Additionally, during 1995, the 54th Legislature passed an Enacted Substitute House Bill 1010, an Act relating to regulatory reform. Section 603 of that Act states in part, "all regulatory agencies shall develop programs to encourage voluntary compliance by providing technical assistance." Consistent with department guiding principles and the Regulatory Reform Act, the Division of Geology and Earth Resources has just released Open File Report 96-2, Best Management Practices for Reclaiming Surface Mines in Washington and Oregon, by David K. Norman, Peter J. Wampler, Allen H. Thropp, Frank Schnitzer, and Jaettra M. Roloff. Concurrently, it is being released by Oregon Department of Geology and Mineral Industries as Oregon Open File Report 95-6.

This report is also a demonstration of the department's five-year goal statement to have DNR recognized as the agency of choice through partnerships with the public, other governments, and other agencies and interests. Open File Report 96-2 is the result of a project partially funded by U.S. Environmental Protection Agency through an agreement among American Petroleum Institute, Washington DNR, and U.S. EPA.

Copies of this report can be obtained from Division of Geology and Earth Resources for $3.50 plus $1.00 for postage and handling. Please address this page and more information about the report on this page about the back page of this issue.

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University of British Columbia Professor Receives Fellowship

Susan Werner Kieffer is one of 24 individuals, and the only geologist, to be awarded a 1995 MacArthur Fellowship, given "in recognition of an exceptional capacity for original and independent work in geology which demonstrate your originality, creativity, capacity for self-direction, and ability to make a contribution to our lives." She will receive $515,000.

Kieffer is a planetary scientist with expertise in meteorites, impacts, volcanics, and mass flows. She has worked for several years at the 1980 blast and pyroclastic flows at Mount St. Helens.


Robert E. Derkey
Washington Division of Geology and Earth Resources
904 W. Riverside, Room 208, Spokane, WA 99201-1031

INTRODUCTION

The review of the nonfuel mineral industry of Washington for 1995 is organized into three commodity "type" categories—metallic, nonmetallic, and industrial minerals. Metallic mineral deposits are those that commonly require the most processing for their intended use. The metal produced typically is compact and volumetrically small and can be economically transported considerable distances. Examples are gold and copper.

Nonmetallic mineral deposits are those that commonly require less processing and are not very different from their original state. Industrial or mineral materials are generally bulkier in their final processed form than are metallic commodities; consequently, they are not transported as far from their source as are metallic commodities. Examples include cement, clay, and lime. Industrial minerals are those minerals that require relatively little processing and are easily recognized in their original form. They are essentially local in that they support local road and building construction industries. Industrial minerals cannot be transported very far before transportation costs outweigh their value. The best examples are sand and gravel and crushed stone.

Washington ranked 20th in the nation in total value of nonfuel mineral production in 1994, the last year for which production figures are available. The value, $556 million, is an estimate and represents a 10 percent increase over 1993. The increase was for magnesium metal and for the basic construction materials—crushed stone, portland cement, and sand and gravel. The value of gold production decreased by 15 percent in 1994 and will have decreased still more in 1995. These values are from the recently closed U.S. Bureau of Mines industrial mineral industry surveys that are now being collected and distributed by the U.S. Geological Survey.

Table 1 (see p. 3–13) summarizes mining and mineral exploration activities in Washington for metallic and nonmetallic commodities in 1995. Numbers following deposit names in this text are keyed to the deposits and properties listed in Table 1 and to their locations on Figures 1A–D (see p. 4–7). Metal mining and exploration projects have numbers below 100 and nonmetallic projects and mines have numbers above 100.

The majority of this volunteered information was obtained from an annual survey of mining companies and individuals. Table 1 lists only those companies that returned questionnaires. It is not a complete listing of mining activities in 1995, many companies and individuals reported maintaining properties, but with little expenditure beyond that required to maintain the property. Additional details about the geology of the metallic mineral deposits and comparisons of activities in previous years in the state are available in reviews of Washington's mineral industry for 1991 through 1994 by Derkey and Gulick (1992), Derkey (1993, 1994, 1995), and Gulick and Lingel (1993). Questions about metal mining activities and exploration can be referred to the Division in the Spokane office. (See page 2 for telephone and fax numbers.)

METALLIC MINERAL INDUSTRY

Production of metallic mineral commodities accounted for approximately 34 percent of the value of Washington's nonfuel mineral production in 1994. The greatest value was for magnesium.

Major changes occurred in Washington's precious-metals mining industry late in 1994—the Canyon mine at Wenatchee closed at the end of 1994, and Hecla Mining Company's Republic Unit operations closed in early 1995. Consequently, production of precious metals has declined considerably. Only 107,000 oz of gold (Fig. 2) and 42,000 oz of silver were produced in Washington in 1995, compared to 232,000 oz of gold and 507,000 oz of silver in 1994. The estimated value of the precious metals produced in Washington in 1995 was $41.3 million, less than half the $91.6 million (estimated) for 1994.

Exploration for precious metals in Washington also continued to decrease. The focus was on precious metals in or near rocks of the Republic and Chiwaukum grabens.

Precious Metals

Gold, because of its natural beauty and durability, has differing importance to people depending on their occupation: to the artist, goldsmith, and jeweler, it is a "metal of superlatives and lasting beauty"; to the industrial artist it is a "metal with unique properties useful in electronics and many other articles," to the numismatist, a "vestige metal with a long and interesting history," to the economist it is a "valua-
Surface Mine Reclamation Awards

The Department of Natural Resources (DNR) is establishing three annual awards to recognize outstanding reclamation of surface mines. These awards will honor permit holders who reclaim mines in an exemplary manner. Awards will also recognize reclamation efforts on sites exempt from the Surface Mine Reclamation Act [RCW 78.44] because of size or because a site was abandoned by earlier mine operators prior to 1971. Criteria for evaluating entrants are described below by award category. If no mine reclamation has occurred that meets the stringent criteria of each category, no award may be granted for that year. Nominations for awards can be made by the public, permit holders, DNR, or other agencies. Nominations received by November 1 will be eligible for that year's award.

Commissioner of Public Lands' Recognition for Reclamation

To receive this award, an operation must meet or exceed the DNR-approved reclamation plan. Exemplary reclamation may include, but it is not limited to:

- Innovation or creativity in reclamation, such as creating unique wetlands or enhancing wildlife and fish habitat or topographic elements.
- Voluntary reclamation of mined land that is exempt from reclamation under the Act.
- Use of native plant species in revegetation.
- Innovative research and approaches to reclamation that can be applied at other mines.
- Attention to water quality and erosion prevention.
- Orderly segmental mine development resulting in high-quality reclamation.
- A consistent long-term commitment to reclamation.
- Methods that enhance the environment and reduce reclamation liability, such as mining to a final slope.
- No significant enforcement actions in the past 10 years.

Commissioner of Public Lands' Recognition for Reclamation for a Small Operation

The criteria are as for the Recognition for Reclamation award, except that the operation is less than 16 acres in size.

Good Neighbor Award

The winner of this award works unselfishly with neighbors and the community in a spirit of cooperation to reflect a positive image of the mining industry. For example, the operator may have developed cooperative projects that benefit the environment and the community.

The Award Process

Winners will be selected by a panel of five judges: the Commissioner of Public Lands or a designee, a representative of the mining industry, two representatives of environmental interest groups, and a representative of state environmental agencies.

DNR surface mine reclamationists will present the candidates to the panel. Because the judges may not have opportunities to visit the nominated operations, 35-mm slides, photos, or videos showing conditions before, during, and after reclamation will help the judges review the nominees. At least two slides and six color photos should be submitted. Written descriptions of site reclamation will help the panel reach their decision. These descriptions may include the history of reclamation, plans for development, partnerships made with neighbors, and direct benefits to the immediate environment, as well as specific information about topsoil handling, slope, revegetation, water control, and other interesting aspects of the reclamation.

Winners will receive an award and public recognition from a press release issued by the Jennifer Belcher, Commissioner of Public Lands. They will also be nominated for national honors. Nominations should be made on the form on the facing page. Please feel free to copy it.

Selected Additions to the Library of the Division of Geology and Earth Resources

November 1995 through January 1996

THESSES


U.S. GEOLOGICAL SURVEY REPORTS

Published reports


RECLAMATION AWARDS
NOMINATION FORM

(Please print or type the information. Nominations must be received by November 1, 1996.)

Please check the category for which you wish to nominate the site:

☐ Commissioner of Public Lands’ Recognition for Reclamation
☐ Good Neighbor Award
☐ Commissioner of Public Lands’ Recognition for Reclamation for a Small Operation (less than 16 acres)
☐ All of the above

Person making the nomination: ___________________________ Phone: ( )

Organization or business nominated: ________________________

Name of site: _____________________________

Location: _____________________________

DNR Reclamation Permit Number (if known): ________________________

Description of reclamation: (You may attach a separate sheet.)

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

Presentation material included with nomination: (We suggest at least 12 slides and 6 color photos.)

☐ 35-mm slides (how many?) ______  ☐ Photos (how many?) ______  ☐ Video

All presentation material becomes the property of the Department of Natural Resources.

Your address: _____________________________

City/State/Zip + extension: _____________________________

Send this nomination form to: Regulatory Section
Division of Geology and Earth Resources
PO Box 47007
Olympia, WA 98504-7007
Symposium on Hydrogeology

and actions to abolish the U.S. Geological Survey. He identified four tasks that ground-water scientists must accomplish:

- Ensure that everyone who needs hydrologic data can quickly and easily get all available information.
- Ensure comparable and high-quality data.
- Disentangle the technical and societal elements of major water issues.
- Educate Washington's citizens about basic hydrology and ground-water processes so that they can make informed choices as they vote.

Goodwin asked ground-water scientists to step out of their comfort zones in the technical arena, to think about water as if they were social scientists, and to be aware of the deep-seated social struggles that are intertwined with major water issues. Barcelona called for skilled and well-trained hydrologists to make critical decisions in practice and policy. He emphasized that stronger interdisciplinary and field training should be provided to college and graduate students by ground-water professionals in higher education.

Keynote Speaker

The keynote speaker was R. Allen Freeze, co-author with John Cherry of the textbook "Groundwater" (published by Prentice-Hall). His talk, "Ground water remediation and its ethical underpinnings"—The question of mass removal and risk reduction in an adversarial regulatory environment"—called for societal and regulatory realization that mass removal approaches are often not a pragmatic means of containing contaminants. Freeze explained that ground water remediation requires flexible approaches, not narrow regulation.

Ground-Water Sampling Workshop

More than 70 scientists took part in the ground-water sampling workshop presented by Barcelona, Mark Varfajen (hydrogeologist and president of Applied Hydrogeologic Research Inc., Seattle, WA) and David Kaminiski (vice president, QED Ground Water Specialists, Walnut, Creek, CA). The emphasis of the workshop was on micro-purging techniques for sampling ground water. The challenge is moving away from the traditional excavation of three well volumes to a new standard practice.

Internet Access

Several of the plenary session presentations and all symposium research abstracts are now available on the Internet by choosing an option from Ecology's home page on the World Wide Web (http://olympus.dis.wa.gov/www/access/ecologi-ecyhome.html). For updates on development of the second symposium, please also refer to this home page.

Editor's note: This article was delayed due to page constraints in the previous issue.
at which water levels were measured (fortuitously) penetrated the same Latah sand as the one indicated at 600-700 ft depth in the representative log hole P-3 (Fig. 7). From these data, total hydraulic heads were calculated and a potentiometric surface determined. The potentiometric surface generally indicates the aquifer’s flow direction from recharge to discharge. (See Table 1.) Because three wells were tested, a 3-point analysis of the potentiometric surface was possible. This analysis indicates a west-northwest slope, approximately paralleling Deadman Creek. Therefore a water recharge area probably lies to the east-southeast and a discharge lies to the west-northwest.

**PRELIMINARY CONCLUSIONS AND TOPICS FOR STUDY**

Further investigation is needed to confirm many of the preliminary observations below. However, several conclusions can be drawn from this 1978 reconnaissance study.

**Aquifers**

Potential aquifers include (shallowest to deepest) Quaternary sands, including the bouldery zone (15-300 ft in thickness), Latah Formation sands (0-230 ft in thickness), and the weathered zone of bedrock or gravel (14-157 ft in thickness). The greatest combined aquifer sand thicknesses appear to lie south of Deadman Creek. Depth to bedrock ranges from 100 to 1200 ft. Helium analysis suggests that all but the deep (basal) Latah aquifer are in hydraulic communication with areas of ground-water recharge.

**Latah Sequences**

The Peone area is remarkable for two reasons: first, it exhibits a thick, uninterrupted sedimentary sequence of the Latah, and second, the sand content (percent sand) of the Latah here is greater than expected. Lobe, fluvial, and deltaic sequences shown on borehole logs in the Latah Formation indicate that extensive interconnectivity of sand deposits probably occurs in the area. Similar sequences are also indicated in the Quaternary sediments. Thick Latah sequences likely extend beneath nearby basalt-covered plateaus. Permeability and porosity of the sands and other materials that compose the aquifers are expected to range far below that of the Spokane Valley aquifer.

Data from this test are insufficient to describe the water supply. Streamflow, runoff, and precipitation data not used here should be studied in conjunction with other well test results. Engineering tests must be made to determine aquifer storativity and transmissivity values. Deep borings should be made in the surrounding area to obtain new borehole data and determine the extent of aquifers.

**Recharge and Discharge**

Hydraulic head testing indicates that recharge areas may lie to the east-southeast and discharge areas may lie to the west-northwest for the deep Latah aquifer. Obtaining hydraulic head data from new and existing borings will clarify this preliminary observation.

**Shallow Clay Aquicludes**

Thick, varved clay-silt layers are located at the surface and at shallow depths across Peone Prairie. If suburban development is considered, the ability of this aquiclue to reject or impede vertical seepage may be a concern and requires further investigation. Storm water runoff in areas with the clay-silt layers at shallow depths present special problems and require further study.

**Water quality**

Preliminary water quality data from wells and springs at Green Bluff and Deadman Creek are insufficient to characterize the prairie area’s drinking water supply. High iron content of water supplies is a common complaint.

**ACKNOWLEDGMENTS**

The authors thank Rexcon Inc. for permission to use borehole data for this report. Many people contributed to the success of this project. Drill-stem test equipment was supplied and operated by Johnston Testers, a division of Schlumberger of Casper, WY. Paul Nordstrom ofScierra collected and analyzed water samples for helium on a mass spectrometer at Whitworth College Physics Department under the direction of the late Prof. Glen Erickson. Jack Roylace originated and directed the project. Don Hunsat suggested the use of the drill-stem testing. Hansen, Gunther Jarre, and John Brehm supervised various aspects of the project. Bill Smallwood, Dave McClure, Dan Wallin, Mike Schuler, Marilyn Pess-Plahuta, Ken Bullis, and Gene Halstead provided geologic and geochemical assistance to the senior author during drilling operations. We also thank D. P. Stradling and E. F. Kier of Eastern Washington University for explanations of glacial and Lake Missoula flood deposit geology of the Spokane area. W. J. Gerastel, DIER, mapped and field checked photogeologic mapping of Quaternary deposits in the Spokane area including part of the map area included here. Bev Lackaff digitized the geologic information for Spokane County and provided the line work on which the geologic map is based. Mitchell Linne of U.S. Bureau of Mines reviewed an earlier version of this article. Robin Peterson, U.S. Bureau of Mines, drafted Figures 5, 7, and 8. Josh Logan and Stephen Palmer of DIER made significant editorial contributions.

**REFERENCES CITED**


plained, and we then discuss interpretations of hydraulic head and helmet results from the 1978 work.

We first used an electric borehole-diameter measuring device (caliper log) to select the positions to place the DST tool across a test interval (Fig. 8). The DST equipment simultaneously isolates the test interval's upper and lower boundaries and opens a valve exposing the formation in the hydraulic environment to the atmosphere, much like a piezometer (a water-level measuring device) tube. Formation water enters the pipe and rises to a point of equilibrium. After 45 to 90 minutes, the pull-down force exerted by the drill rig is released to close the valve and free the packers, the pipe is withdrawn, and the water level reached is recorded as the pressure head. Total hydraulic head is determined by adding test interval elevation to pressure head, that is, the level to which the water has risen in the pipe (Table 1). Area mapping of hydraulic heads defines the potentiometric surface and is important because it will indicate an aquifer's water flow direction and the relative locations of recharge and discharge areas for that aquifer.

Specific conductance of the water was measured to ensure quality control by comparing measurements taken along the various vertical sections of drill pipe. A stabilized low specific conductance indicated that water originated from the formation and not the borehole fluid.

The quality of water from private wells and springs used for domestic purposes on Green bluff, upper Deadman Creek, and Peone Prairie varied considerably. (Sample points are not shown on map.) Eight springs and 45 wells were sampled and the owners interviewed by Paul Nordstrom in 1978. Wells sampled were no deeper than 50 ft. Alkalinity as bicarbonate ranged from 36 to 204 ppm (average 50 ppm), pH ranged from 5.9 to 7.2, and alkalinity as carbonate ranged from 3 to 48 mg/l except in a 95-ml water sample where water had an undesirable taste; that water tested 7,670 mg/l carbonate alkalinity. Sulfurous odor and iron and calcium deposits (as a carbonate or sulfate) on water faucets and in sinks were common. Three of those interviewed noted bopieria problems with their water, a number used water softeners, and two were treating their water with chlorine. Seven wells had turbid water, and eleven had water with a slightly to very unpleasant taste or odor. Quality of water in the Peone Prairie area needs further study.

Helium Analyses

Helium (He) is a radioactive decay product of natural earth materials, principally uranium and thorium. Because He is inert, it can be traced through the hydrogeologic environment and provide valuable insights into water movement. The usefulness of He values is in indicating an aquifier’s relative communication, or lack of it, with recharge and discharge areas, terming dynamic equilibrium (Fetter, 1994). Detecting anomalous He is dependent on knowing the background He content of local recharge waters. To establish a local background value, 62 water-surface-water samples were collected in the Peone Prairie, upper Deadman Creek, and Green bluff areas. Average He was 5.3 ppm (standard deviation 0.21 ppm). Any value exceeding 5.77 ppm (mean plus 2 standard deviations) was considered anomalous.

Deeper Latlah Beds

Water samples analyzed for He came from the DST tool chamber and lowest drill pipe sections. He values from the deeper Latlah aquifer in P-14, P-16, and P-17 are anomalously high (7.90 to 42.79 ppm). Reasons for high He contents in aquifer water remain somewhat esigmatic. High He values are best attributed to the efficient sealing of layers covering this deep Latlah aquifer or the diffusion of the aquifer. High He may also indicate that recharge is low and cannot sufficiently dilute the natural helium flux from the bedrock, suggesting that the aquifer is closed.

A third possible explanation, that a nearby uranium deposit is supplying abnormal quantities of He to the aquifers, can be rejected upon comparing the He values in samples taken from the weathered zone aquifer (P-10, P-13; see Table 1) to those from the basal Latlah aquifers. Furthermore, a highly fractured basement rock at this location can enhance He movement up through the aquifers (Ottoni-Mateus Corp., 1978, p. 1, p. 2. 5). Low He values indicate potential for water supplies from the weathered zone and shallow aquifers. High He in the basal Latlah suggests this aquifer receives little recharge, which may reduce its potential as a water source.

He in the Weathered Zone

He values in the weathered zone aquifer ranged from 5.25 to 5.35 ppm, about the background level. Because the weathered zone is erodingly extensive, follows the pre-Latlah erosional topography, and is enclosed by eroding colluvial layers, recharging of the weathered zone is more likely than for the basal Latlah aquifer. This suggests the weathered zone may contain a useful water supply.

Hydraulic Head Tests

Some preliminary potentiometric results were provided by this reconnaissance exploration. Three boreholes (P-14, P-16, P-17)
A thick, alternating silt and clay sequence in borehole P-3 at 370 to 605 ft depth culminates in a series of horizons that can be positively identified in borehole logs for P-1, P-7, and P-14. This alternating sequence may underlie about one-half the study area and may be similar to clay deposits associated with the Latah sand. The sequence probably acts as an excellent confining layer between shallow and deep Latah sands and likely represents one of the extensive layered deposits.

Less significant Latah sands that lie below the lakebed are:

<table>
<thead>
<tr>
<th>Borehole no.</th>
<th>Depth (ft)</th>
<th>Total thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-1</td>
<td>535-555</td>
<td>20</td>
</tr>
<tr>
<td>P-3</td>
<td>650-700</td>
<td>20</td>
</tr>
<tr>
<td>P-7</td>
<td>600-700</td>
<td>20</td>
</tr>
<tr>
<td>P-14</td>
<td>455-485</td>
<td>30</td>
</tr>
<tr>
<td>P-16</td>
<td>507-545</td>
<td>38</td>
</tr>
<tr>
<td>P-17</td>
<td>540-560, 585-590</td>
<td>25</td>
</tr>
</tbody>
</table>

* Drill stem test interval

Quaternary Units

The Latah was completely removed along the center of the Deadman Creek valley, and this is indicated in borehole logs at P-8, P-9, P-10, and P-15. The thickest section, 300 ft, of Quaternary glaciolacustrine and glaciofluvial sediment occurs at P-10. Of the 5 ft, the Deadman Creek valley, Pleistocene erosion cut a valley nearly 600 ft deep and 1.5 mi wide. The present-day Pne We Prairie is 1.5 mi wide with relief, following refilling of the valley by younger sediments.

Based on qualitative estimations from borehole logs, the Quaternary sedimentary section contains 35 percent (by volume) sand; the specific yield for such material normally ranges from 25 to 40 percent (Fetter, 1994, p. 93). We estimate that the total water volume in this aquifer varies from 9 to 14 percent (by volume). Because Quaternary aquifers are the shallowest, their potential for use is greatest. Likewise, shallow aquifers have the highest likelihood for recharge from surface water sources, including confounded sources.

Aquifers at depths below the water table (or unconfined) aquifer are called confined aquifers. Significant aquifers of the Quaternary confined aquifers occur at the following intervals:

<table>
<thead>
<tr>
<th>Borehole no.</th>
<th>Depth (ft)</th>
<th>Total thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-8</td>
<td>108-122, 200-208</td>
<td>117</td>
</tr>
<tr>
<td>P-9</td>
<td>95-110, 234-234</td>
<td>109</td>
</tr>
<tr>
<td>P-10</td>
<td>120-190, 260-410</td>
<td>220</td>
</tr>
<tr>
<td>P-15</td>
<td>67-92, 111-155</td>
<td>69</td>
</tr>
<tr>
<td>P-16</td>
<td>85-100, 150-190</td>
<td>55</td>
</tr>
</tbody>
</table>

Aquifer sand sizes are dominantly medium to coarse, locally pebbly, and include basalt boulders (in) in boreholes P-6, P-9, and P-13. Boreholes listed above are located near Deadman Creek, so potential for water recharge from surrounding uplands appears good.

The origin and significance of basalt boulders (in) encountered in boreholes remains problematic. They may be either undisturbed flows of basalt mass-wasting (landslide) deposits. Because they occur on a sloping Latah erosion surface and occur sporadically in only three holes, it is hard to imagine the basalt as undisturbed flows. Furthermore, there is no evidence of palagonite or a baked surface. Therefore, we think the basalt intercepted in the three boreholes marks a depositional hiatus between Quaternary and Miocene time and favors the mass-wasting interpretation. A bouldery zone would be an excellent aquifer because it is extremely coarse grained and would have good hydraulic communication with recharge areas.

The Quaternary sediments in the subsurface also include numerous thin, interbedded, repeated lacustrine clay and silt beds. Hosterman (1969) observed varved lakebeds in outcrops and in shallow borings; these can also be seen in roadcuts along Bruce Road (Fig. 3). The thickness of this sequence varies, but this varved clay-silt sequence is prominent in boreholes near Deadman Creek (P-8, 9, 10, 11, 13, 14, 15, and 16). Depths range from 0 to 300 ft. Locally, these beds are interbedded with or overlie the Quaternary aquifer sands. The clay interbeds might significantly restrict vertical water movement (percolation), including water flow from storm-water runoff and seepage from septic systems. Percolation problems and near-surface saturated silts could pose problems for development in the area.

HYDROGEOLOGY

Water Test Procedures

Drill-stem test (DST) equipment, commonly used in oil-well testing, was used to obtain hydraulic head data (Fig. 8). This equipment is designed to sample fluids and determine pressures in specific aquifers. At Pne We Prairie, the DST equipment was connected to the drill pipe and used to obtain eight water samples from selected deep aquifers in six boreholes (Table 1). In the paragraphs below, the procedures are explained.

**Figure 8.** Diagrammatic view of drill-stem test. The drill pipe is attached and the test is operated from the drilling rig at the surface.
Table 1. Mining and mineral exploration in Washington, 1995 (continued)

<table>
<thead>
<tr>
<th>Lec. no.</th>
<th>Property</th>
<th>Location</th>
<th>County</th>
<th>Commodity</th>
<th>Company</th>
<th>Activity</th>
<th>Area geology</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Kelsey</td>
<td>secs. 5-8, 40N, 27E</td>
<td>Okanogan</td>
<td>Cu, Mo, Ag, Au</td>
<td>Wilbur Hallauer</td>
<td>Maintained property</td>
<td>Porphry-type mineralization in Jurassic-Cretaceous Silver Nail quartz diorite</td>
</tr>
<tr>
<td>31</td>
<td>Hot Lake</td>
<td>secs. 17, 18, 40N, 27E</td>
<td>Okanogan</td>
<td>Au, Ag</td>
<td>Wilbur Hallauer</td>
<td>Maintained property</td>
<td>Low-grade gold mineralization adjacent to the Kelsey porphyry-type deposit</td>
</tr>
<tr>
<td>32</td>
<td>Copper World, Copper World Extension</td>
<td>secs. 20, 29, 39N, 26E</td>
<td>Okanogan</td>
<td>Cu, Au, Ag, W, Sn, Fe</td>
<td>Wilbur Hallauer</td>
<td>Geophysics, geologic mapping, opened old adit</td>
<td>Ore lenses in altered anodesite of Permian-Triassic Palmer Mountain Greenstone</td>
</tr>
<tr>
<td>33</td>
<td>Black Bear</td>
<td>NE1/4 sec. 36, 39N, 25E</td>
<td>Okanogan</td>
<td>Au, Ag, Cu</td>
<td>Wilbur Hallauer</td>
<td>Maintained property</td>
<td>Veins in Permian-Triassic Palmer Mountain Greenstone intruded by felsic to intermediate rocks of probable Jurassic-Cretaceous age</td>
</tr>
<tr>
<td>34</td>
<td>Lucky Knoll</td>
<td>sec. 19, 38N, 27E</td>
<td>Okanogan</td>
<td>Au, Sb</td>
<td>Magill &amp; Associates</td>
<td>Soil and rock geochemistry, building repair</td>
<td>Silbine veins and disseminations in fractured and altered limestones of the Permian Spastic Formation (Anarchist Group)</td>
</tr>
<tr>
<td>35</td>
<td>Starr Molydenum</td>
<td>secs. 8, 16, 37N, 26E</td>
<td>Okanogan</td>
<td>Mo, Cu, W</td>
<td>Wilbur Hallauer</td>
<td>Maintained property</td>
<td>Porphry-type mineralization in Cretaceous Aneas Creek quartz monzonite and granodiorite, gold in secondary enriched zone</td>
</tr>
<tr>
<td>36</td>
<td>Golden Zone</td>
<td>sec. 7, 40N, 25E</td>
<td>Okanogan</td>
<td>Au, Ag</td>
<td>El Bravo Gold Mining Ltd.</td>
<td>Maintained property</td>
<td>Vein or shear zone in the Kobau Formation and Similkameen batholith</td>
</tr>
<tr>
<td>38</td>
<td>New Light</td>
<td>sec. 27, 39N, 17E</td>
<td>Whatcom</td>
<td>Au, Ag</td>
<td>Western Gold Mining, Inc.</td>
<td>Maintained property, site rehabilitation</td>
<td>Quartz-carbonate-cemented slate-argillite breccia in the Lower Cretaceous Harts Pass Formation</td>
</tr>
<tr>
<td>39</td>
<td>Minnesota</td>
<td>sec. 2, 37N, 16E</td>
<td>Whatcom</td>
<td>Au, Cu</td>
<td>Seattle-St. Louis Mining Co.</td>
<td>Maintained property, limited exploration</td>
<td>Veins in sedimentary rocks of the Cretaceous Virginia Ridge Formation</td>
</tr>
<tr>
<td>40</td>
<td>Azurite</td>
<td>sec. 30, 37N, 17E</td>
<td>Whatcom</td>
<td>Au, Ag, Cu, Pb</td>
<td>Double Dragon Exploration Inc.</td>
<td>Maintained property</td>
<td>Quartz veins in metasedimentary rocks</td>
</tr>
<tr>
<td>41</td>
<td>Lona Jack</td>
<td>secs. 22-23, 40N</td>
<td>Whatcom</td>
<td>Au, Ag</td>
<td>Diversified Development Co.</td>
<td>Mining, shipped ore to East Hondo, mine development</td>
<td>Laterite developed in peridotite at the base of Eocene sedimentary rocks</td>
</tr>
<tr>
<td>42</td>
<td>South Pass Nickel</td>
<td>secs. 2, 35N, 4E</td>
<td>Whatcom</td>
<td>Sc, Ni, Co</td>
<td>Consolidated Vanadium Resources, Ltd.</td>
<td>Obtained property, planning winter exploration program</td>
<td>Massive sulfide mineralization in accreted terrane (melange?) rocks</td>
</tr>
<tr>
<td>43</td>
<td>Skagit Copper</td>
<td>secs. 1-2, 33N</td>
<td>Skagit</td>
<td>Cu, Zn, Au, Ag, Pt</td>
<td>Cannon Minerals</td>
<td>Trenching on massive sulfide lenses</td>
<td>Kuroko-type volcanogenic massive sulfide mineralization in Jurassic volcanic rocks of the Western melange belt</td>
</tr>
<tr>
<td>44</td>
<td>Lockwood</td>
<td>secs. 25, 30-32, 29N, 9E</td>
<td>Snohomish</td>
<td>Cu, Au, Ag</td>
<td>Island Arc Resources Corp., Formosa Resources Corp.</td>
<td>Maintained property</td>
<td>Shear zone/exhaustive contact metamorphic mineralization in roof pendant of the Tertiary Grotto batholith</td>
</tr>
<tr>
<td>45</td>
<td>Trout Creek property</td>
<td>sec. 20, 27N, 11E</td>
<td>Snohomish</td>
<td>Cu, Au, Ag, Zn, Pb, W, Sn, Pt</td>
<td>Northwest Minerals Inc.</td>
<td>Reconnaissance prospecting, claim staking</td>
<td></td>
</tr>
</tbody>
</table>
Wind-blown sand deposits overlie glaciolacustrine and flood deposits on the western side of the prairie and in the Mead area. Some display cross bedding typical of sand dunes. Sub-rounded sand grains are predominantly lithic fragments. Locally, the sand deposits contain beds of lenses of re-worked Mazama volcanic ash (dated at 6.8 ka), commonly at or near the surface in the Peone Prairie area.

Loess grains are far smaller than sand grains, and thus they are carried great distances by wind. Where hilltops and fairly flat surfaces of the prairie that are still covered by loess are filled for farming, the loess is commonly dark brown; loess has not been preserved on the slopes (Fig. 6). Alluvium, the youngest material on Peone Prairie, occurs along Deadman Creek and other local drainages.

**SUBSURFACE AND AQUIFER GEOLOGY**

We used borehole logs to construct two northwest-southeast, one north-south and one east-west cross section (Fig. 5). These indicate the extent of the various local aquifers. Cross sections show the magnitude of Pleistocene erosion and subsequent sedimentation events. A representative borehole log (Fig. 7) provides an example of the comprehensive and complementary value of information that constitutes the borehole logs used in constructing the cross sections.

Used in combination, borehole samples and borehole geophysical logs (radioactivity, spontaneous potential, resistivity, and caliper) are of enormous value in identifying and describing sedimentary units and in allowing detailed stratigraphic correlation of units and hydrogeologic analysis across the study area. Natural radioactivity and resistance logs are particularly sensitive to changes in grain size and composition of units penetrated. The SP log, in addition to providing lithologic distinctions, signals changes in conductivities of waters between the borehole and formation (Driscoll, 1987, p. 180; Keys, 1989).

Borehole data permit interpretation of the depositional setting of rock and sediment intervals (Fig. 7). Fining-upward and coarsening-upward sequences are indicated from borehole logs. In conjunction with helium data, interpretation of depositional setting can provide important inferences about aquifer geology beyond the borehole site.

**Weathered Granite Aquifer**

At three sites (P-9, 12, 15), buried hills of granite were identified. Interpreted as pre-Lathe weathering surface, these hills were later exposed prior to deposition of the Quaternary lacustrine deposits.

The weathered zone, or crust, overlying granite basement was identified from borehole logs to be soft and possibly friable and subject to fracture and to act as an aquifer. Drills penetrate this zone rapidly, and borehole logs show it has characteristics that differ from those of the sediments above and the basement rock below. Data show the weathered zone varies from 14 to 151 ft thick and averages about 70 ft thick. This zone occurs in all the prairie boreholes and may represent an important aquifer where sections occur at shallow depths, as at boreholes P-9 and P-13.

**Lahate Formation**

The poorly indurated Lahate sands are as widespread as Quaternary sands. Lahate sands that produce water are considered porous and permeable based on qualitative characteristics of drill-stem tests and lower resistance values exhibited on borehole logs and drill penetration rates; however, permeability and porosity tests were not made. Sand composition indicates that expected from erosion of the underlying granitic rocks. Aquifers in the Lahate consist of medium to coarse sands. The geophysical log responses are consistent with deltaic (coarsening upward), fluvial point bar (fining upward), or channel deposits.

The Lahate consists of at least five coarsening-upward, possibly lake-filling cycles (Robinson, 1991). Thickness of the entire Lahate Formation varies from 4 ft in P-15 to 690 ft in P-1, the thickest uninterrupted sediments thickness identified in the area. The average thickness of the Lahate is 350 ft; it is more than 350 ft thick in seven of the boreholes (P-1, 3, 4, 7, 13, 14, 16).

Sand beds determined to be porous and permeable (see above) constitute 25 percent by volume of the Lahate section, indicating significant aquifers may be present. The specific yield for such material normally ranges from 25 to 35 percent (Fetter, 1994, p. 93). Taken together, this indicates that total water volume in this aquifer varies from 6 to 10 percent.

**Figure 6.** View across a tilted field of a portion of Peone Prairie. Surfaces that have low relief (foreground) and hills that generally retain a veneer (typically less than 3 ft) of loess and are dark brown on slopes. Where loess has been eroded, the lighter colored lake beds are exposed.

**Table 1.** Locality, property, area geology, and activity.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Property</th>
<th>Area geology</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>Axon</td>
<td>Co.</td>
<td>GS Management Corp. (GS)</td>
</tr>
<tr>
<td>47</td>
<td>Bone</td>
<td>Log</td>
<td>Gold Mining Co.</td>
</tr>
<tr>
<td>48</td>
<td>Cameron mine</td>
<td></td>
<td>R. M. R. Mining Co.</td>
</tr>
<tr>
<td>49</td>
<td>Windham</td>
<td></td>
<td>Leveda, Inc.</td>
</tr>
<tr>
<td>50</td>
<td>Weatherleather</td>
<td></td>
<td>R. M. R. Mining Co.</td>
</tr>
<tr>
<td>51</td>
<td>Moore Creek</td>
<td></td>
<td>R. M. R. Mining Co.</td>
</tr>
<tr>
<td>52</td>
<td>Mill</td>
<td></td>
<td>R. M. R. Mining Co.</td>
</tr>
<tr>
<td>53</td>
<td>Shale and limestone</td>
<td></td>
<td>R. M. R. Mining Co.</td>
</tr>
<tr>
<td>54</td>
<td>Sandstone</td>
<td></td>
<td>R. M. R. Mining Co.</td>
</tr>
<tr>
<td>55</td>
<td>Shale and limestone</td>
<td></td>
<td>R. M. R. Mining Co.</td>
</tr>
<tr>
<td>56</td>
<td>Sandstone</td>
<td></td>
<td>R. M. R. Mining Co.</td>
</tr>
</tbody>
</table>

**Figure 7.** Locality, property, area geology, and activity.
Table 1. Mining and mineral exploration in Washington, 1995 (continued)

<table>
<thead>
<tr>
<th>Loci no.</th>
<th>Property</th>
<th>Location</th>
<th>County</th>
<th>Commodity</th>
<th>Company</th>
<th>Activity</th>
<th>Area geology</th>
</tr>
</thead>
<tbody>
<tr>
<td>107</td>
<td>Blue Creek quarry</td>
<td>sec. 29, 33N, 40E</td>
<td>Stevens</td>
<td>silica</td>
<td>Northwest Alloys, Inc.</td>
<td>Maintained property</td>
<td>Cambrian Addy Quartzite</td>
</tr>
<tr>
<td>108</td>
<td>Chlewielah Eagle quarry</td>
<td>sec. 5, 32N, 41E</td>
<td>Stevens</td>
<td>dolomite</td>
<td>Chlewielah Eagle Mining Co.</td>
<td>Discontinued mining when Nanime Aggregates discontinued Washington operations</td>
<td>Devonian–Carboniferous(?): metacarbonate rocks</td>
</tr>
<tr>
<td>109</td>
<td>Lana Mountain quarry</td>
<td>sec. 22, 34, 31N, 39E</td>
<td>Stevens</td>
<td>silica</td>
<td>Lana Mountain Silica Co. (division of Hennepin Brothers, Inc.)</td>
<td>Mining, milling</td>
<td>Cambrian Addy Quartzite</td>
</tr>
</tbody>
</table>
| 110      | Nine quarries | — | Stevens | dolomite | Nanime Aggregates, Inc. | Ceased all mining and milling operations in Washington in 1995 | Uniquely colored dolomite or dolomitic marble was mined at nine sites in Stevens County: China White, Black, Lolo Martin, Primavera/Sage Green, Green, Rose/Red, Gray/Charterhouse, Bottle, and Watermar

Figure 5. Geological cross-sections of Priest Rapids Dam. Explanation follows. Unnumbered panels illustrate updated views from Figure 2 for local geology beneath Priest Rapids Dam.
Quaternary Deposits

Quaternary sediments of Peone Prairie consist of Pleistocene glacial lakebeds (unit Qia) (Hostetler, 1969) of predominantly sand, silt, and clay with scattered boulders. The lakebeds commonly occur as terrains in tributary valleys (including Peone Prairie) north of the Spokane Valley and are probably deposits of glacial Lake Columbia (D. F. Strading, Eastern Washington Univ., oral commun., 1995; Wait and Thoron, 1983). Dropstones as large as 2 ft in diameter, presumably carried by glaciers into the glacial lake, occur in some of the lakebeds; several were uncovered during construction of the Mt. Spokane-Mead High School.

Bedding in the lakebeds is obscure; in places it is contorted, which suggests a debris-flow origin. Some fine sand beds range up to 3 ft in thickness; clay beds between 3 and 6 in. in thickness are exposed in roadcuts along Bruce Road (Fig. 3).

Borehole cuttings show that Quaternary lacustrine deposits (unit Qia) are fine to pebbly and consist of metamorphic rock fragments, some basalt fragments, and little quartz. Limonite staining is common. Clay is this unit ranged from yellowish brown to olive-brown to medium gray and are commonly silty. Quaternary sediments contain traces of pyrite and organic matter ranging from 0.5 to 1.5 percent; some samples contain as much as 11 percent.

West of Peone Prairie near Mead (Fig. 2), glacial Lake Missoula flood deposits (unit Qbe) are sparsely interbedded with the lakebeds (Kiver and Strading, 1989; Wait and Thoron, 1983; Wait, 1985). The flood deposits are poorly sorted and commonly range from sand to pebble gravel. Many of these interbeds in the Peone Prairie area may be tributary channel deposits; they are not shown on Figure 2. The flood deposits were probably carried into the area by eddy currents to the main flood channels. Where the Missoula flood currents were stronger, glacial lakebeds are not preserved and flood deposits predominate.

Mass-wasting deposits (unit Qmw) occur in areas adjacent to basaltic remnants. They consist of pebbly-to-block-size gravel and breccia deposits that apparently slumped, slid, or were carried by debris flows into the lake (Fig. 4). They are all underlain by the Lathe Formation in Peone Prairie and likely formed where poorly consolidated deposits of the Lathe Formation were eroded, which resulted in undercutting of overlying basaltic remnants.

**Surficial (Unconsolidated) Deposits**

Unconsolidated deposits of the Peone Prairie area include surficial wind-blown sand (unit Qes) and loess deposits (unit Qel) and alluvium (unit Qal). These deposits are included on the geologic map (Fig. 2) but are not shown on the cross sections (Fig. 5).
able standard against which wealth is measured and an imperishable medium for balancing international accounts,” to the geochronologist it is “a rare metal, the geochemistry of which is intricate and complex,” and finally to the mining engineer and metallurgist it “presents a challenge of extraction from the earth and from its ores” (Boyle, 1987, p. 1).

Gold occurs in two types of deposits—lode and placer. A placer deposit consists of sand, gravel, and other detrital or residual material in which the valuable mineral such as gold has accumulated through weathering and mechanical concentration processes. Lode deposits consist of a vein, a series of veins, or disseminated minerals in rock. Only a small portion of Washington’s gold production has been from placers.

Echo Bay Minerals Co.’s Kettle River operations at Republic were the only major gold mining operation in Washington in 1995. The Kettle River operations produced 100,419 oz of gold and approximately 22,800 oz of silver in 1995 from 547,597 tons of ore processed in its mill near Republic. The head grade was 0.212 oz of gold per ton, and recovery was 86.6 percent.

For the Kettle River operations, ore was mined from the exhalative replacement-type Overlook and Lamfoot deposits. 19 percent came from Overlook, the remainder from Lamfoot. The Overlook mine (no. 17) was reopened in 1994, and deposits at the Overlook were exhausted during 1995. The mine will be closed. Overlook has produced 1,858,181 tons of ore since it was opened in 1989; contained gold in that ore was 285,259 oz. Gold recovery at the Kettle River operations has typically been in the 80 to 85 percent range, which means that the Overlook produced roughly 220,000 to 240,000 oz of gold.

Higher grade ore from the Lamfoot deposit (no. 16) was recovered in Echo Bay’s Kettle River operations breaking the 100,000-oz production level in 1995. In 1993 and 1994, most of the ore milled at the Kettle River operations came from the lower grade, open-pit Key deposits. Mining at Lamfoot began in December of 1994, following receipt of permits to mine above the 7,500-377 ft elevation only. Permits to mine below that elevation were obtained in September 1995. Exploration drilling from the surface suggests that mineralization extends to the north of the deposit now being worked. Echo Bay plans to explore this potential by drilling to it in 1996.

Lamfoot is expected to be the mainstay of Kettle River operations for several years. The company reports proven and probable ore reserves are 1,585,400 tons of 0.207 oz of gold per ton (or 320,000 oz of contained gold). An additional measured and indicated ore reserves include 466,900 tons at 0.164 oz of gold per ton (76,500 oz of contained gold).

Echo Bay continued underground exploration at its K-2 deposit (no. 15). The deposit is near the mined-out Kettle mine, and, like the Kettle, is an epithermal vein-type deposit in Eocene volcanic rocks of the Republic graben. The announced inferred resource at this deposit is 631,000 tons that contains 0.202 oz of gold per ton. The company plans to make a production decision on the K-2 in mid- to late 1996.

Hecla Mining Co.’s Republic Unit produced 3,088,940 oz of gold and 15,320 oz of silver from milling ore mined in 1994 and from cleanup at the mill following shutdown. Most of the production is from activity of the Golden Northwest company. Echo Bay Exploration was active at the Morning Star (no. 12), and N. A. Degerstrom, Inc. and Gold Express Corp.

During the past year Asamara Minerals (U.S.) Inc. (as operator) and Breakwater Resources Ltd. were in the process of dismantling their mill and reclaiming the Cannon mine site (no. 48) at Wanetache. The mine closed at the end of 1994. Production cleanup and dismantling of the mill in 1995 was 2,670 oz of gold and 3,555 oz of silver. The Cannon mine produced 1,248,911 oz of gold and 2,075,077 oz of silver from a total of 4,133,101 dry tonnes of ore from its opening in 1985 through final cleanup in 1995.

The Lone Jack mine (no. 41) operated again in 1995, producing approximately 800 tons of ore that was shipped to a smelter in East Helena, MT. The operators also drove a drift to intersect the vein on a lower level of the mine.

A draft environmental impact statement (EIS) was issued June 30, 1995, for the Crowe Jewel deposit (no. 28), a Buck Mountain Gold (operator) Crown Jewel joint venture. The public comment period for the draft EIS lasting 60 days and ended on August 29, 1995. The Washington Department of Ecology and the Okanogan National Forest are now preparing the final EIS for the project. It is expected in September of 1996. The process of obtaining permits to mine will then begin, issuance of permits is expected to take about a year. Announced reserves at the Crowe Jewel deposit are 8.7 million oz of ore at a grade of 0.186 oz of gold per ton, or more than 1.4 million oz of gold. Per Washington, the gold estimated to be contained in the Crowe Jewel deposit is second in amount only to that at the Republic Unit of Hecla Mining Co.

The most extensive exploration in Washington was for gold from epithermal deposits in Tertiary rocks of the Republic and Chiwaukum grabens. Hecla Mining Co. signed an earn-in agreement with Santa Fe Pacific Gold Corp. in August for its Republic area holdings (no. 21) in the Republic graben. The focus of the acquisition for Santa Fe Pacific is the Golden Eagle deposit (no. 19), on which they were drilling in 1995. The Golden Eagle has a possible resource of 11.3 million oz gold grading 0.1 oz of gold per ton. Santa Fe Pacific will earn a 70 percent interest in the project by spending $7.5 million over a 2-year period and completing a feasibility study.

Echo Bay Exploration Inc. drilled and dropped a property on Graphite Creek (no. 27) in Eocene volcanic rocks of the Toroda Creek graben northwest of the Republic graben. Ramadan Gold USA Inc. continued their activities, including drilling on their Wanetache gold belt project (no. 49) in the Chiwaukum graben near Wanetache. Delano Wind River Mining Co. was mining Wind River deposit (no. 52) and seeking permits to establish a milling operation. Activities on all other properties with potential for epithermal-type gold mineralization (see Table 1) were too limited to maintain the property.

The Hawkeye (no. 15) is the only project/property actively explored for replacement/exhalative-type mineralization in the Republic graben. At all other properties (see Table 1) that have potential for this type of mineralization associated with Permin to Triassic rocks of northeastern and north-central Washington, activity was limited to maintaining of property.

Gold deposits in or near rocks of the Shasket Creek alkalic complex at the north end of the Republic graben were the focus of activity the past year was from the Golden Northwest companies. Echo Bay Exploration was active at the Morning Star (no. 12), and N. A. Degerstrom, Inc. and Gold Express Corp.

Figure 2. Geologic map, with drill hole locations, of the Pooch Panhandle area northeast of Spokane. Geologic cross-sections A–A’–D–D’ are shown in Figure 5.

low-orange silstone, claystone, sandstone, and minor conglomerate. These deposits are thought to span the later stages of a period of Miocene “deep weathering” (Robinson, 1991) and are interbedded with and underlie the local units of the Columbia River Basalt Group. Borehole cuttings indicate the sandstone are arkosic to quartzose, fine to coarse grained and locally pebbly, and olive brown to medium light gray; grays are rounded to angular. Claystone varies from brownish gray to greenish gray to olive gray and is commonly silty. Pyrite and organic matter contents in the formation range from 0 to 0.5 percent and 0 to 1.5 percent, respectively. Latite deposits are extensive and thick in areas interpreted as paleo-depressions (low areas) and pinch out in paleo-higher areas. The topography in Latite time was not unlike that of Spokane today.

Columbia River Basalt
Basalts of the Columbia River Basalt Group (Miocene, Reidel and Fecht, 1978; Griggs, 1976; Swanson and others, 1979) are
INTRODUCTION

Pecon Prairie lies approximately 3 mi northeast of the Spokane city boundary (Fig. 1). A sand, unincorporated area undergoing rapid suburban growth, is located at the west end of Pecon Prairie. Local residents and state and county governments are concerned about water availability and water quality for this rapidly increasing population.

This report describes the various aquifer and confining (or aquitard) units penetrated during drilling and the results of ground-water, geophysical, and oil-field tests made in 1977 and 1978 as part of a mineral exploration venture. The drilling took place on Pecon Prairie in an area 4 mi east-to-west by 3 mi north-to-south. The subsurface geology and hydrology presented in this report are based on results of this drilling and, although the information is adaptable to hydrologic analysis presented here, it may be limited because of the tests were specific to mineral exploration.

PREVIOUS STUDIES

The most relevant geologic mapping in the greater Spokane area consists of two 1:62,500-scale geologic maps of the Greenacres (Weis, 1968) and Mount Spokane (Weissenborn and Wells, 1976) quadrangles. Other maps include the 1:100,000-scale Spokane quadrangle (Joseph, 1990) and a 1:125,000-scale reconnaissance geologic map of the west half of the Spokane 1 x 2 degree sheet (Griggs, 1966). In 1992-94, W. J. Gerstel, C. W. Gullick, and Derkey of the Washington Division of Geology and Earth Resources (DGER) mapped (at 1:24,000 scale) Flatscience and younger deposits of the Lower and Upper Tertiary unconfined and confined aquifers for the Spokane County Water Quality Management Program. Figure 2 is a 1:60,000-scale portion of that map.

The subsurface information and interpretations presented in this paper are based on results of an exploratory drilling program (geophysics and rotary) program (Boleneus, unpublished data). Resistivity and gravity surveys completed in 1977 showed that as much as 1,000 ft of sediments overlies crystalline basement. In 1978, fourteen rotary drill holes were completed and logged electrically using natural radioactivity, spontaneous potential, resistance, and caliper devices. Additionally, samples taken at 10-ft intervals in these holes were described by a geologist on the site. Collectively, these data are referred to as "borehole logs" for this report. Coincident with drilling and logging, geologists made eight drill-stem tests on selected sand intervals in six boreholes from which water levels were recorded; they also took water samples for helium analyses.

GEOLGY

Rock and sedimentary units underlying Pecon Prairie include, from oldest to youngest, metamorphic rocks of the Priest River metamorphic core complex, Mount Spokane granite and skagitite, peamite, and aplite, Latah Formation and Columbia River Basalt Group, glacial lake deposits, and Lake Missoula catastrophic flood deposits.

Older Rocks

Mount Spokane granite (unit Kpm) (Cretaceous) is predominant in outcrops in the hills immediately surrounding the prairie. It is a foliated massive, medium- to fine grained biotite-muscovite granite containing quartz, K-feldspar, plagioclase, muscovite, and biotite (Joseph, 1990). Scattered bodies of Eocene to Cretaceous skagitite, peamite, and aplite (unit Tka) are also present in the hills around the prairie. Both granite rock units intrude high-grade metamorphic rocks of the Priest River metamorphic core complex (Rehrig and others, 1987; Armstrong and others, 1987).

Latah Formation

The Miocene Latah Formation (unit Tl) (Hosterman, 1969; Pardee and Bryan, 1926; Robinson, 1991) consists of poorly indurated lacustrine and fluvial deposits of gray to tan yel- sold the Gold Mountain deposit (no. 11) to Globex Nevada Inc. in late December.

Base Metals

Copper, lead, and zinc are here considered base metals. Many of the larger known copper deposits in Washington are in the porphyry copper category, that is, disseminated copper minerals in gra- nitic to intermediate composition intrusive igneous rocks. Most such deposits are found in the Cascade mountains.

A major source of lead and zinc in Washington is the Mississippi Valley-type (MVT) deposits in the northeastern corner of the state. Washington's MVT de-

Figure 1. Location of the study area in Spokane County. Pecon Prairie is the southeast 1/2 of the Mead quadrangle. The Spokane Valley/Robertson Prairie Aquifer area is represented by the dotted pattern.

Figure 3. Dolomite at Northwest Alloys' dolomite mine at Addy is drilled prior to blasting. After blasting and transport to a crusher, the boulder-size ore material is separated out and sent to the mill (cover photo) to produce magnesium metal.

All magnesium metal production in the state is by Northwest Alloys Inc. (a subsidiary of ALCOA) at Addy (no. 2) from dolomite rock mined from a pit (Fig. 3) adjacent to the plant (cover photo). Electrical energy used in the smelting process is readily available in northeastern Washington. Northwest Alloys uses the Aluminothermic Process, a modifi-

of the European Magnetherrneric Process, to produce magnesium metal. The Aluminothermic Process requires less electrical power than the European process and is adaptable to controlling emissions.

The charge for the electric furnaces, in addition to dolo-

MgO + Fe2O3 + MgO + CaO + 2CO2

The calcined dolomite at this point in the process is referred to as dolime. The ferro-silicon, aluminum, and magnesi-

MgO + 3Fe2O3S + MgO + SiO2 + Fe2O3S + Al2O3

Elemental magnesium produced in the furnace is a gas, which migrates to an adjacent, cooler vessel and condenses. The furnace operates with an argon atmosphere at 70 tare to prevent re-oxidation of the magnesium at the high temperatures in the furnace (1,500°C). The vessel containing ele-

MgO + 3Fe2O3S + MgO + SiO2 + Fe2O3S + Al2O3

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The major use for the magnesium from Addy is alloying with aluminum. For example, two alloys that have different proportions of aluminum and magnesium are used to make beverage cans—one is for the can and the other for the can top.

Some materials for the Addy operation are imported. Ferro-silicon comes from Norway. In past years, ferro-silicon was produced locally—the silica (quartz) was mined from the nearby Blue Creek quarry and the iron came from taconite pellets from Minnesota. The company has found that the Norwegian product is more expensive than the locally produced ferro-silicon. Magnesium for the operation is purchased from China. Northwest Alloys is considering obtaining magnesium from the west of Chewelah; however, because of the relatively small amount consumed, establishing a local magnesium mining operation may make that commodity more expensive than the Russian magnesium. Aluminum in the form of shot is obtained from Kaiser Aluminum Mead Works in Spokane. All of these materials’ costs and a greater result in the production of magnesium, the most valuable metal commodity produced in Washington.

Washington State Nickel (no. 42) prospect in Whatcom County will be the object of exploration activity in early 1966. Samples from the deposit contain considerable scandium. Principal uses of scandium are in high-intensity metal halide lamps, as analytical standards, and in research. Most scandium is recovered as a by-product from processing other ores.

**NONMETALLIC MINERAL INDUSTRY**

Commodities produced by the nonmetallic mineral industry of Washington range from a relatively low unit-volume value to a high unit-volume value. Cement is an example of a low unit-volume value commodity. Commonly cement is not transported great distances because of its bulk and because the materials to make it are relatively widespread. Diatomite, on the other hand, has a high unit-volume value. It has many specialty uses and is found in Washington in ancient lakebed deposits.

Nonmetallic mineral commodities such as portland cement, clays, carbonates, diatomite, olivine, and silica are used for approximately 20 percent of the $556 million total value of nonfuel mineral production for Washington in 1994, the last year for which figures are available.

**Carbonates**

The principal carbonate materials used in Washington are limestone and dolomite. Large amounts are used in construction, agriculture, and the chemical and metallurgical industries. Limestone is used in the manufacture of cement; however, all of the limestone used to produce cement in Washington is from Texada Island, British Columbia. Carbonate rocks are calcined to produce lime, which is required in some chemical and metallurgical industries, as well as a soil conditioner in agriculture. Generally, lime used by chemical industries is of high purity.

**Dolomite**

Dolomite ore reaches the smelter on a conveyor belt and the smelting process begins when it passes through the rotary kiln (center to center) on its way to one of six furnaces. In this stage of the operation, carbon dioxide is driven off to produce a lime product called dolomite.

Northwest Alloys produces agricultural soil conditioners by using reject materials from magnesium metal production at Addy (no. 2). The company is experimenting with using the remaining reject materials at their operation for additional agricultural land conditioners and hopes to market or use their entire production of reject materials by the year 2000. Some of their reject materials could be used to manufacture cement; however, the company has not yet thoroughly explored marketing cement. No other company is reported to have expressed interest in buying their reject material for cement manufacture.

Dolomite use for terrazzo and exposed aggregate suffered a setback when Nanomex Aggregates Inc. (nos. 110 and 108) closed its Washington operations. They had mined various types and colors of dolomite from several different quarries in the Chewelah area. Northwest Marble Products Co. (no. 106), however, is able to supply the same colored dolomite products from that area.

Columbia River Carbonates continued production of carbonate for use as a paper coating and filler from its limestone (marble) quarry (no. 114) southwest of Republic.

Several other companies or quarries (nos. 102, 103, 104, 111, 116) in northeastern Washington also produced carbonates for a variety of uses in 1995.

The only known western Washington carbonate production was of limestone from the Maple Falls quarry (no. 124), owned by Clausen Lime Co.

**Olivine**

Olivine, a silicate containing magnesium and iron, has been used primarily as a foundry sand (Kramer, 1985). However, in recent years the magnesium end-member, forsterite, has been used as a slag conditioner in blast furnace production of pig iron (Teague, 1983).

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**Report on the First Symposium on the Hydrogeology of Washington State**

*Naadine Romero Washington Department of Ecology* PO Box 47600, Olympia, WA 98504-7600

The State of Washington held its first major ground-water science conference in late August 1995 at The Evergreen Seattle Conference in Olympia. More than 360 professionals attended, coming from the Pacific Northwest and beyond. More than 20 presentations and 30 posters were delivered in twohalf-day symposium sessions during the two-and-a-half-day symposium. Theme sessions featured physical hydrology, groundwater modeling, geophysics, geochemistry, applied technology, and groundwater science policy. A ground-water sampling workshop was offered, and a trade and poster exhibition was also presented.

Sponsored by the Washington Department of Ecology, the broad goal of the symposium was to bring together for the first time the ground-water and hydrologic science community to present and discuss current research and the status of Washington's ground water. The success of the symposium was sig-}
mens. Both minerals indicate that oxidizing conditions existed during the final stages of geode filling, in contrast to the more reducing environment that prevailed during the main mineralization episode.

The sporadic occurrence of pyrite at Walker Valley is rather puzzling. Pyrite and siderite both form under similar conditions of Eh and pH (Fig. 9), and the scarcity of pyrite suggests that percolating waters had a low sulfur content, so that iron was unable to crystallize as a sulfide. However, in 1992, the Vandenbergs found geode containing three intergrown pyrite cubes, each about 1 cm in width. Pyrite also occurs as microscopic cubes and pyritohedrons in recrystallizing surfaces of quartz and goethite in the central cavities of some geodes. These occurrences may represent a chemical environment where sulfur was present as a local anomaly, perhaps derived from the adjacent volcanic matrix.

Goethite and pyrite have been observed as inclusions in quartz crystals bordering the central geode cavity. However, these iron minerals more commonly occur as encrustations on the surface of the quartz, indicating that most microcrystalline formation took place after silica deposition had ceased.

Stage 5: Minerals of the brecciated zone

The previous four stages describe the minerals found in geodes and fissures in the zone where fresh, dark-colored andesite occurs. The mineralogy of the brecciated zone shows several important differences. The enclosing host rock has been bleached and oxidized, and mafic minerals have been dissolved. Iron released from this decomposition has led to the precipitation of hydrous iron oxides along fracture zones and as breccia matrix. Siderite that had previously formed in geodes or fissures has been either bleached, oxidized or dissolved to limonite or goethite. Extensive silicification along fractures resulted in the deposition of chalcedony, creating the white, gray, and blue 'seam aggregate' by-products. The presence of yellow crusts of cristobalite (Fig. 12) provides evidence of high-temperature hydrothermal fluid and, more recently (a zeolite) has been identified from X-ray diffraction patterns. However, well-crystallized specimens of any kind are rare, and the mineralogy of the brecciated zone has not been studied in detail.

COLLECTING INFORMATION

The Walker Valley site is managed by the Department of Natural Resources and is leased to the Washington Mineral Council, a nonprofit organization that strives to maintain public access to collecting sites. Commercial collecting at the site is not allowed, and power tools and explosives are both prohibited, but there are no fees or quantity limits. Permission to collect is not required, but visitors are asked to refrain from littering, building fires, or otherwise causing damage.

Geodes are relatively abundant in certain areas of the deposit, but their extraction requires strenuous labor and skilled use of hammers, chisels, and pry bars. Hammering the brittle host rock yields razor-sharp shards, making protective goggles a necessity.

For those with less zeal for hard-rock mining, a large talus slope produces attractive specimens, but rockfall hazards make this site suitable only for small groups.

The site (Fig. 2) can be reached year-round by ordinary passenger vehicles. An easy approach is to leave Interstate Highway 5 at the College Way exit in Mount Vernon and drive east to intersect Highway 9 north of Big Lake. From Big Lake, about 7.5 mi from the freeway, turn east on Walker Valley Road. Follow this paved country road for about 2 mi, then turn right on Peter Burns Road. (In about 1 mi, a side road turns south, crossing old culverts to join a powerline access road. The Fly-by-Night claim and several other agate collecting sites are located along this rough road.) To reach the agate-bearing outcrops, stay on Peter Burns Road, passing the entrance to an off-road vehicle recreation area parking lot in another half-mile. The Mineral Council site is located a half-mile farther, where the road passes a prominent zone of rust-colored cliffs.

The geode-bearing zone can be reached by walking a few hundred feet up a path through the forest on the south side of the outcrop or by driving a quarter-mile farther and turning left on a logging road that ascends one switchback to the top of the quarry.

Acknowledgments

We thank Len Jones, Bob Jones, Dick Rantz, Leonard Schact, and Wes Gannaway for providing specimens and information about collecting history at Walker Valley. Discussions with Ted Brown and our understanding of geology and regional geology, and Scott Babcock, Ray Lasnians, Ray Claude, and Anton Wodzicki provided helpful reviews of the

term clay is ambiguous; it is used as the name for a group of minerals, as the name of a soil (a rock made up of clay-size particles is also referred to as a clay), and for particles of the smallest size known in nature.

Clay mined in eastern Washington in 1995 came from the Mica mine (no. 112) for making bricks and from Quarry Tile Co. (no. 113) for producing ceramic tile. Mutual Materials operates the Mica mine and several quarries in western Washington (nos. 127, 130, 134). Most of the remaining clay production in western Washington (nos. 127, 132, 136) was for the cement industry. Basic Resources Corp. is progressing toward production of cement raw clays (nos. 118, 119) to line irrigation canals and other possible markets.

Diatomite

Diatomite is an opaline silica-rich sedimentary rock made up of the skeletal remains of diatoms, unicellular aquatic plants related to the algae (Kadey, 1983). Diatomite first became abundant in the Late Cretaceous, but most commercial deposits are of Tertiary age (Bates, 1960). After the diatom dies, it sinks to the bottom of the water body in which it was living. A cubic inch of diatomite may contain as many as 40 million "shells" (Bates, 1960). The diatom structure produces a deposit of low bulk density, high absorptive capacity, high surface area, and relatively low abrasiveness.

Processed diatomite has a unique structure and chemical stability that is preferred for some purposes to any other form of silica. Its most important use is as a filter aid. Diatomite is also useful as a filler and extender in paint, paper, rubber, and plastics. It is also used as an anti-caking agent and as a thermal insulating material, catalyst carrier, polish, abrasive, and pesticide extender (Kadey, 1983).

All of Washington’s diatomite production is by Cellite Corp. in central Washington. The company has several quarries (nos. 120-123) that are in various stages of development, ranging from planning to mining. They are also reclaiming exhausted areas.

Barite

Barite has a relatively high specific gravity, and it is relatively inert, that is, it does not break down or react with other materials. For these reasons, it is ground, mixed with drilling fluids, and used as drilling mud when drilling for oil and gas, especially where the drilling company anticipates that it might encounter gas or oil under high pressure. The high density, or weight, of the barite mud can prevent a blowout and consequent loss of control of the drilling operation and environmental damage.

Barite is found in two major deposit types: fissure and replacement vein deposits and bedded or sedimentary deposits. Most of the deposits in Washington occur in the northeast part of the state (for example, no. 105), a few are found in the north central part of the state, and only one in western Washington (Moen, 1964). At the present time, there is little demand for Washington barite. The lack of demand and the limited number of deposit relations to its value precludes transporting it great distances for consumption; other deposits closer to major oilfields and lower priced barite from China are more commonly used sources.

At Washington deposits that have been active in recent years, the property owner either is trying to sell the property or has dropped it.
Table 2. Some rockery and decorative and dimension stone producers in Washington in 1994 and 1995. Not all quarries listed have reported production in 1996.

<table>
<thead>
<tr>
<th>Property</th>
<th>Location</th>
<th>County</th>
<th>Commodity</th>
<th>Company</th>
</tr>
</thead>
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<tr>
<td>Whitestone quarry</td>
<td>sec. 34, 39N, 3E</td>
<td>Stevens</td>
<td>decorative stone</td>
<td>Whitestone Co.</td>
</tr>
<tr>
<td>Moonlight quarry</td>
<td>sec. 24, 30N, 3E</td>
<td>Stevens</td>
<td>decorative stone</td>
<td>Whitestone Co.</td>
</tr>
<tr>
<td>Kifer quarry</td>
<td>sec. 2, 36N, 3E</td>
<td>Ferry</td>
<td>decorative stone</td>
<td>Raymond Fordcast Masonry</td>
</tr>
<tr>
<td>Cactus quarry</td>
<td>sec. 16, 3N, 3E</td>
<td>Franklin</td>
<td>decorative stone</td>
<td>Meridian Aggregates Inc.</td>
</tr>
<tr>
<td>Chilies quarry</td>
<td>sec. 22, 38N, 3E</td>
<td>Chelan</td>
<td>decorative stone</td>
<td>Joe Mahaffey</td>
</tr>
<tr>
<td>Three Rivers quarry</td>
<td>sec. 18, 29N, 3E</td>
<td>Chelan</td>
<td>decorative stone</td>
<td>Two Rivers Sand and Gravel</td>
</tr>
<tr>
<td>Kendall quarry</td>
<td>sec. 16-14, 22-23, 40N, 3E</td>
<td>Whatcom</td>
<td>limestone</td>
<td>Tilbury Cement Co.</td>
</tr>
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<td>Whatcom and Skagit quarry</td>
<td>sec. 6, 39N, 3E</td>
<td>Whatcom</td>
<td>Skagit</td>
<td>Whatcom Skagit Co.</td>
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<tr>
<td>Unnamed quarry</td>
<td>sec. 13, 34N, 3E</td>
<td>Skagit</td>
<td>decorative stone</td>
<td>Island Frontier Landscape</td>
</tr>
<tr>
<td>Pacific quarry</td>
<td>sec. 33, 34N, 3E</td>
<td>Skagit</td>
<td>rockery</td>
<td>Meridian Aggregates Inc.</td>
</tr>
<tr>
<td>Miles Matt quarry</td>
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<td>Jefferson</td>
<td>rockery</td>
<td>Lona Star Northwest</td>
</tr>
<tr>
<td>Iron Mountain quarry</td>
<td>sec. 17, 30N, 3E</td>
<td>Snohomish</td>
<td>rockery</td>
<td>Iron Mountain Quarry Inc.</td>
</tr>
<tr>
<td>Granite Falls quarry</td>
<td>sec. 8, 30N, 3E</td>
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<td>rockery</td>
<td>Meridian Aggregates Inc.</td>
</tr>
<tr>
<td>Cadman Rock quarry</td>
<td>sec. 19, 27N, 3E</td>
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<td>rockery</td>
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<tr>
<td>Alpaca Miller Rock quarry</td>
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<td>rockery</td>
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<td>Marenakos Rock Center</td>
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<td>various</td>
<td>decorative stone</td>
<td>Marenakos Inc.</td>
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<tr>
<td>Minn 11</td>
<td>sec. 11, 21N, 3E</td>
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<td>decorative stone</td>
<td>Palmer Coking Coal Co.</td>
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<tr>
<td>Franklin Rock quarry</td>
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<td>Emmet quarry</td>
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<td>Enumatah Quarry Inc.</td>
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<td>410 quarry</td>
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<td>decorative stone</td>
<td>410 Quarry Inc.</td>
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<tr>
<td>Miller River Quarry</td>
<td>sec. 28, 20N, 3E</td>
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<td>decorative stone</td>
<td>Meridian Aggregates Inc.</td>
</tr>
<tr>
<td>Buckley quarry</td>
<td>sec. 7, 19N, 3E</td>
<td>Pierce</td>
<td>decorative stone</td>
<td>Washington Rock Quarries Inc.</td>
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<td>Wilcoxson quarry</td>
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</tr>
<tr>
<td>Kaposhov quarry</td>
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<td>Pierce</td>
<td>decorative stone</td>
<td>Washington Rock Quarries Inc.</td>
</tr>
<tr>
<td>Lynch Creek quarry</td>
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<td>Pierce</td>
<td>decorative stone</td>
<td>Randles Sand and Gravel Inc.</td>
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<td>Hercules quarry</td>
<td>sec. 37, 16N, 3E</td>
<td>Thurston</td>
<td>decorative stone</td>
<td>Northwest Stone Inc.</td>
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<tr>
<td>Johnson Creek</td>
<td>sec. 24, 16N, 3E</td>
<td>Thurston</td>
<td>decorative stone</td>
<td>Sea Top Rock Co.</td>
</tr>
<tr>
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<td>sec. 25, 18N, 3E</td>
<td>Thurston</td>
<td>decorative stone</td>
<td>Jones Quarry Inc.</td>
</tr>
<tr>
<td>Snow Queen quarry</td>
<td>sec. 36, 14N, 3E</td>
<td>Yakima</td>
<td>decorative stone</td>
<td>Heatherton Inc.</td>
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<tr>
<td>Blackshear house</td>
<td>sec. 6, 8-9, 4N, 1E</td>
<td>Kittitas</td>
<td>decorative stone</td>
<td>D. M. Layman Inc.</td>
</tr>
<tr>
<td>Red Rock quarry</td>
<td>sec. 27, 4N, 1E</td>
<td>Kittitas</td>
<td>decorative stone</td>
<td>Bishop Red Rock Co.</td>
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<tr>
<td>Fisher quarry</td>
<td>sec. 8, 1N, 3E</td>
<td>Clark</td>
<td>decorative stone</td>
<td>Gilbert Western Corp.</td>
</tr>
</tbody>
</table>

Silica
Silica consists of the elements silicon and oxygen; these are most common in the mineral quartz. Although quartz deposits of high purity may have formed in several ways, the most common is as beach sands. Most beach sands, however, contain enough grains of other minerals that they are not pure enough to be used for manufacturing glass. The Addy quartz in northeast Washington, derived from a Cambrian beach sand, and a sandstone of the Eocene Puget Group in western Washington are used for glass manufacture.

Lime Mountain Silica Co. (no. 109) mines Addy quartz for Chewelah, and Reserve Silica Corp. (no. 131) mines Puget Group sands to produce silica, primarily for the manufacture of bottle glass. Ash Grove Cement Co. (no. 133) mines silica for use in the manufacture of cement.

INDUSTRIAL MINERAL INDUSTRY
Industrial mineral commodities, construction sand and gravel, and construction stone accounted for approximately 46 percent of the $556 million total value of nonfuel mineral production for Washington in 1994, the last year for which figures are available. The overall production value of construction sand and gravel, the single most valuable nonfuel mineral commodity in Washington, was $71.4 million.

Construction Sand and Gravel
The value of construction sand and gravel is so high because of the demand to support the construction industry of the state. The Department of Transportation and county road departments use numerous pits for maintaining roads throughout the state. Large private companies use sand and gravel to make concrete for home and business construction. The size of these companies tends to depend on the size of the market in the community. The greater Seattle area, Spokane, the Tri-Cities, and Vancouver have large sand and gravel operations and typically more than one company competing for the concrete business. (See Lingley and Manion, 1992.)

Large road-construction projects require large amounts of sand and gravel. Sand and gravel sources for these projects

Calcite occurs in geode centers in a variety of habits, including white jasper, jasper, and dundrific shapes, large translucent yellowish crystals, and clear crystalline masses showing prominent rhombic cleavage.

Many specimens have an empty central area, created when the circulation of hydrothermal fluids was obstructed after narrow fractures leading to the cavities became completely mineralized. These fractures contain the same minerals found in the adjacent geodes. The effectiveness of this sealing-off process is evident when collectors use hammers and chisels to quarry the anodes—the first hint that a geode is close at hand is often leakage of water that has been trapped inside it for millions of years.

Stage 4: Goethite, pyrite, and hematite as microcrystals
In addition to the large crystals that line the geodes, examination with a binocular microscope reveals a wealth of microcrystals that form as encrustations on the surfaces of the central cavity. Hematite is the most abundant micromineral, generally occurring as radiating sprays of acicular crystals (Fig. 11). Small hexagonal plates of hematite are present in a few speci-
ess that probably accounts for the early phases of mineralization at Walker Valley.

Mineral formation may also occur when ascending hydrothermal waters encounter open fractures, resulting in a drop in pressure that causes fluid saturation. This type of event probably played an important role during the last stage of the mineralization sequence.

The stages of mineralization described below are generalizations based on examination of numerous geodes, but not every specimen shows all of these features.

Stage 1: Hisingerite, quartz, and spheroiderite
Walker Valley geodes typically contain an outermost layer of hisingerite in contact with the adjacent anodesite, providing a brittle parting layer that often allows specimens to be removed from the matrix with relative ease. These layers typically consist of several thin laminae of hisingerite alternating with crystalline quartz. Hemispherical masses of fibrous microcrystalline siderite may occur within the quartz (Fig. 8). Less commonly, the outer wall of the geode consists of a single hisingerite layer as much as 1 cm thick and resembling obsidian in color and luster.

The high ferric iron content of hisingerite suggests that the mineral forms in oxidizing environments, but conditions required for its precipitation have never been experimentally determined. The stability ranges of common iron minerals are shown in Figure 9.

Siderite forms under reducing conditions within a wide pH range, whereas an increase in oxidation potential causes dissolved iron to form as hematite or goethite. The presence of carbonaceous sedimentary rock adjacent to the dike may have contributed to reducing electrochemical conditions in circulating hydrothermal waters by providing a source of reducing agents created during anaerobic decomposition of organic matter.

The initial precipitation of quartz as crystalline crusts provides several clues about the hydrothermal environment. Experimental studies suggest that silica is likely to precipitate as opal at temperatures of 100°C or less. At temperatures of 100–300°C, crystalline quartz forms if levels of dissolved silica are low, but higher silica levels result in precipitation of chalcedony (Krauskopf, 1956; White and Corwin, 1961). At higher temperatures, silica may be deposited as cristobalite.

The oxidation therefore tends to be that early hydrothermal activity involved dilute silica solutions containing iron and carbonate ions flowing through fissures and vesicles at a temperature between 100° and 300°C.

should be fairly close to the construction site because transporting sand and gravel a long distance greatly increases the cost of the project.

Major operators in the greater Seattle area in King County are Cadman, Inc., Stoneway Concrete Co., M. A. Segale, Inc., Miles Sand and Gravel Co., and Lakesides Industries. In Snohomish County, they are Associated Sand and Gravel, Inc., and Cadman, Inc., at the Everett pit, and in Pierce County, Woodworth & Co., Inc., Lone Star Northwest, Cornish Co., and Tim Corliss and Son, Inc. In the Olympia area, a major operator is Nilsson Pacific Ltd. at the Nisqually pit. Gilbert Pacific operates in Clark County at the English pit. Central Precast Concrete Co. operates a plant in Yakima, and Central Pre-Mix and Acme Materials and Construction Co. have large operations at sand and gravel pits in the Spokane and Tri-Cities areas. Several companies may operate from a large, single pit area, and companies may have different pits for specific types of sand or gravel.

The list of major sand and gravel operators in the larger communities in Washington is far from complete. A more extensive list of sand and gravel operators is available in Lingley and Mannon (1992). Smaller operators in these communities, as well as in other communities of the state, commonly can meet local or smaller needs. The "yellow pages" can give an indication of the activity of the local sand and gravel industry.

Construction Stone
Construction stone quarried in Washington can be classified into two major categories by use—dimension stone and crushed stone. Crushed stone is rock that has been broken, crushed, or ground to smaller fragments, and dimension stone is rock that has been trimmed or cut to a desired shape or size (LaFrance, 1975). Building stone in Washington is described in detail by Moon (1967). More recent articles about the building and decorative stone industry in Washington include Gullikson and Fuhrman’s (1992) industry history and Gullikson’s (1993) industry history of Washington’s stone industry.

In Washington, numerous producers (Table 2) quarry various types of rock to produce crushed landscape rock, rockery (rock used to create a non-mortared wall or barrier), veneer, landscape boulders, rubble or fill, rectangular pieces of stone trimmed to essentially rectangular shapes (termed ashlar), exposed aggregate, terrazzo, ragstone, and cinders (Gullikson, 1992). Sand and gravel operators commonly crush oversize rocks, which can then be used instead of round rock aggregate (a term often used for the non-crushed version).

REFERENCES CITED


Erratum
The correct Internet address for the National Center for Earthquake Engineering Research is:
http://nceer.org/buffalo.edu

This was reported incorrectly in the last issue of Washington Geology. Please make a note of the correction. Our apologies to the Center.

Dam Safety Conference
The Canadian Dam Safety Association and the Canadian National Committee of the International Commission on Large Dams will hold a joint conference in Niagara Falls, Ontario, from October 6 to 10, 1996. Session themes include the economics of dam safety and tailings dams. A poster session is part of the program for this meeting.

For more information, contact Grant Smith in Toronto:
Phone: 416-592-5359; Fax: 416-592-4446, or E-mail: grant.fsmith@hydro.on.ca.

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Washington's Coal Industry—1995

Henry W. Schese
Washington Division of Geology and Earth Resources
PO Box 47007, Olympia, WA 98504-7007

In 1995, Washington's two coal mines, the Centrailia mine in north-central Lewis County and the John Henry No. 1 mine in south-central King County, together produced 4,856,769 short tons, down a mere 11,000 tons from 1994.

The state's largest mine, the Centrailia Coal Mine, is operated by the Centrailia Mining Company, a division of Pacific Corp. The mine is located 5 miles northeast of the city of Centralia (Fig. 1). Its sole customer is the Centrailia thermoelectric plant, situated about a mile from the mine.

The mine completed its 25th year in 1995, producing 4,626,756 short tons of subbituminous coal. This amount is only 8,000 tons less than for the previous year. The mine's average annual production for the past 5 years has been 4.7 million tons; average annual production over the mine's lifetime is 4.3 million tons.

Coal production in 1995 came from four open pits. Coal beds mined were the Big Dirty, Little Dirty and two splits of this coal bed, Smith, Lower Thompson, Upper Thompson, Tono No. 1, Tono No. 2, and Penitentiary. These coals are part of the Skookumchuck Formation, which is composed of near-shore marine and nonmarine sedimentary rocks. The formation is a member of the Eocene Puget Group.

Washington's other producing coal mine, the John Henry No. 1, is located 2 miles northeast of the town of Black Diamond (Fig. 1). It produced 230,013 short tons of bituminous coal in 1995, down only 3,000 short tons from 1994. The John Henry No. 1 completed its ninth full year of production in 1995. The mine is operated by the Pacific Coast Coal Company (PCCC), a joint American and Japanese venture.

PCCC made 54 percent of its sales to the local industrial market, where coal is used largely in the manufacturing process to produce cement and lime in the Puget Sound area. A small amount of those sales were to local public institutions for space heating. The industrial sales value was up from 38 percent of total sales a year ago.

Of the remaining tonnage, 46 percent was exported to South Korea for steam coal. A tiny amount was sold to local residential customers for space heating.

In 1995, PCCC mined coal at its Pit No. 1 (Fig. 2) from four coals beds, the Franklin Nos. 7, 8, 9, and 10. (See also Fig. 3.) The Franklin coals beds are stratigraphically near the base of the undeveloped Eocene Puget Group in nomenclature of the Puget Sound area. A small amount of those sales was sold to local residential customers for space heating.

During the past year PCCC extended its workings to the southwest.

4. An explosive hydrothermal event related to faulting

Early stages of mineralization were caused by hot water that gently trickled through fractures and vessels. However, a later hydrothermal episode behaved quite differently, causing extensive brecciation and alteration within the dike (Fig. 7). The triggering mechanism for this hydrothermal event may have been an episode of seismic activity that created new fissures within the outcrop area, providing a conduit for superheated hydrothermal solutions that arrived with explosive force. At temperatures above the 374°C critical point, water exists as a very dense gas, and a sudden decrease in confining pressure would have caused an abrupt phase change, generating violently boiling liquid and a huge volume of steam capable of shattering the surrounding rock.

This hydrothermal event created an extensive breccia zone. The transition between the fractured material and the adjacent unaltered dike rock is fairly abrupt, a pattern of alteration that suggests that the previous mineralization event filled the original fractures and vessels so thoroughly that later generations of hydrothermal fluids were unable to penetrate andesite adjacent to the breccia. The contact between bleached breccia and unaltered andesite can be traced upfll from the main collecting site for at least a kilometer, suggesting the possibility that geods may occur well beyond the present zone of discovery. Although this Washington Department of Natural Resources land is open to exploration by rockhounds, the rugged topography and extensive soil cover create difficult collecting conditions.

5. Continued regional uplift exposed the dike to the surface

Erosion of the surrounding sedimentary rock left the more resistant andesite as a ridge. Weathering, soil development, and luxuriant plant growth eventually obscured all surface evidence of the contact zone between the dike and its host rock.

MINERALOGY

Minerals precipitate from aqueous solutions because of a variety of physical and chemical factors, including temperature, pressure, acidity (pH), oxidation-reduction potential (Eh), and the concentration of dissolved elements. Successive mineral layers in Walker Valley geodes provide clues that allow us to reconstruct the hydrothermal history of the deposit. Precipitation can be triggered due to a temperature drop caused by contact of the hydrothermal solution with cool wall rock, a proc-
caused the sticky lava to yield in a series of rips and tears. Agate-filled "thunder eggs" from central Oregon provide classic examples of this phenomenon (Ross, 1941).

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Eventually the molten rock chilled enough that it became solid, producing hard, brittle andesite. During the final stages of cooling, shrinkage caused the development of narrow fractures that intersected the vesicles. These cracks allowed warm mineral-laden water to percolate through the dike, precipitating various minerals as veins and cavity fillings. This episode of epithermal activity probably involved solutions at fairly low temperatures and circulating at a crustal depth of less than 1 km (Guilbert and Park, 1986).

Analysis of fluids trapped in microscopic inclusions provides a potential method for determining temperature and pressure at the time of crystallization, but the half-dozen polished slices of quartz and calcite that we examined contained no fluid inclusions. More persistent efforts might be more successful. However, the high degree of transparency typical of Walker Valley crystals is related to the scarcity of microscopic inclusions.

The hydrothermal solutions likely originated when surface water penetrated into the rocks along fractures and porous zones. Water expelled during compaction of adjacent sedimentary rocks may have made an additional contribution. Heat generated by a local body of magma warmed this ground water, causing a decrease in density that promoted upward flow. This ascending plume of hot water leached mining coals near the crest of the anticline within the mine and along the southeast limb of the structure. In early January 1996, PCCC was mining the Franklin Nos. 7, 8, and 9 coals along the southeast limb where these coals occur stratigraphically close to each other (Fig. 2). PCCC also mines a clay bed between the Franklin Nos. 9 and 10 coals. The clay is blended with high alumina clay for manufacturing Portland cement.

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SR 504, the Spirit Lake Highway, is still open as far as Coldwater Ridge Visitor Center. Anyone planning field trips or touring in the Mount St. Helens area should stay aware of road conditions by checking at visitor facilities.

Figure 1. A major washout on the Cispus River Road (FR 23).

Figure 2. John Henry Pit No. 1 in January 1996. In this view to the east, the Franklin No. 8 coalbed is exposed just above the fill on the northern flank of the anticline near its crest in the left half of the photo. Franklin Nos. 7 and 8 coalbeds are buried beneath the fill. Franklin Nos. 9 to 11 (exposed above the right edge of ponded water) and 11 (exposed just beneath the upper half of the photo) are the next two seams higher in the stratigraphic section.

Figure 3. Elaine Mustoe collecting geodes in dark-colored andesite. The contact with bleached, brecciated andesite is at the base of the cliff on the left side of the photo.

Figure 4. Stickerskies in brecciated andesite in the upper level of the road-cut quarry.

Figure 5. Sketch of the outcrop.
The Minerals of Walker Valley, Skagit County, Washington

George E. Mustoe
Geology Department
Western Washington University
Bellingham, WA 98225

INTRODUCTION

In the late 1960s, spectacular mineral specimens were discovered in an outcrop of hydrothermally altered volcanic rock in the Cascade foothills in western Skagit County. A portion of the site has subsequently been quarried as a source of road fill, uncovering a large area of bedrock that was previously obscured by soil and vegetation.

Prized collector’s items include large geodes containing crystals of clear quartz, amethyst, calcite, and siderite (Fig. 1), accompanied by seams and nodules of pen-quartz agate. Located about 15 km east of Mount Vernon (Fig. 2), the Walker Valley collecting site has been described in magazines and guidebooks (Jackson, 1978; Jackson and Jackson, 1974, 1975; Hadley, 1975, 1976, 1990; Pladur, 1977; Partie, 1985; Ream, 1985; Gannaway, 1993; Claude, 1995), but the geology of the deposit has received little attention. In this article, we review the physical and chemical processes that were responsible for the origin of the various minerals.

GEOLOGIC SETTING

The geology of the Walker Valley area is shown in Figure 2. Geodes occur in a body of volcanic rock that strikes N75°E and dips 65°W. Contacts with other units are not exposed, but the relatively gentle inclination of sedimentary strata at several nearby locations suggests that the igneous material originated as a dike rather than as a surface flow. To casual observers, the outcrop appears to be a 100-m-wide mass of brecciated rhyolite bordered on either side by unaltered black basalt (Fig. 3). However, thin sections and chemical analyses indicate that the rock consists of andesite of fairly uniform composition and that the brecciated central zone was caused by later hydrothermal alteration. Atomic absorption spectrophotometric analysis of a typical sample of dark rock indicated the composition to be:

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<tr>
<th>Component</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>61.42%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12.32%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>11.2%</td>
</tr>
<tr>
<td>MgO</td>
<td>8.3%</td>
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<td>Total iron calculated as Fe₂O₃</td>
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The Walker Valley site is the only place in these volcanic units where geodes have been found (Fig. 4). Their presence at this particular location is the result of episodes of hydrothermal activity that did not affect neighboring igneous bodies.

Regional mapping led geologists to infer that the host rocks at this site are part of the Chuckanut Formation (Martin, 1991; Whetten and others, 1988). This interpretation was confirmed in 1994 when quarrying exposed a 1-m-thick lens of carbonaceous siltstone within the brecciated andesite.

The geology and mineralogy of the Walker Valley locality suggest that the following sequence of events was responsible for the development of the geode zone:

1. Deposition of Early Tertiary andesitic ash

Sandstone, conglomerate, and siltstone of the Chuckanut Formation were deposited on a flood plain bordering a meandering river that existed from about 55 million to 40 million years ago, prior to the rise of the North Cascades. These sedimentary strata are separated from the older metamorphic basement rock by faults or unconformities.

2. Formation of andesitic dikes

Slickensided surfaces in the outcrop indicate that magma intruded along a fault that developed when sedimentary rocks of the Chuckanut Formation were uplifted during the rise of the North Cascades range (Fig. 5). This zone of crustal weakness can be traced for at least 2 km in an east-west direction, suggesting that its origin is related to activity along the Devils Mountain strike-slip fault zone, a major structural feature of the region (Craus, 1975; Tabor, 1994).

Although geodes occur only where the fault zone is associated with igneous activity, brecciation and silicification of host rock at other locations along the fault has produced deposits of gem-quality agate, the best known of these being the Fly-by-Night claim located along the power line access road about 2 km west of the geode site (Jackson, 1987; Claude, 1995).

The age of the Walker Valley dike has not been determined, but nearby igneous rocks of similar composition have ankyroxenous-track ages of 39.9 ± 2.4 to 52.7 ± 2.5 ma (Whetten and others, 1988).

As the molten rock began to cool, the release of water vapor and other gases caused vesicles to develop. These cavities range in diameter from about 0.5 to 50 cm (Fig. 6). Their smooth walls and spherical or ovoid shapes are evidence that the host material was relatively fluid. In contrast, gas bubbles in viscous rhyolitic lavas and welded tuffs typically have star-shaped cross-sections, formed when expanding gas vapor

Figure 1. Quartz-filled geode from the Walker Valley site in Skagit County.

Figure 2. Geologic map of Cascade foothills in western Skagit County. No pattern, unconsolidated Quaternary deposits. Heavy lines are faults.

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<td>CaO</td>
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Two samples of light-colored rock gave approximately the same results for all elements except iron. Total Fe₂O₃ in these samples was 10.83 percent and 11.89 percent. These decreased iron values were caused by the partial dissolution of férrogious minerals during hydrothermal alteration. Light and dark rocks both plot as andesite on the total alkali-silica diagram of LeBas and others (1986) and the International Union of Geological Sciences classification diagram (Le Maitre, 1989).

Thin sections of the dark rock reveal phenocrysts of plagioclase and clinopyroxene in a glass-rich matrix. In some samples, much of the glass has been altered in situ to produce microscopic blebs of amorphous hisingerite, a rare hydrous iron silicate.

In thin sections of light-colored samples, plagioclase laths occur along with siderite, sericite, chlorite, and clays, the latter minerals all having formed as alteration products. Hisingerite is no longer present, individual masses having been dissolved or oxidized to limonite.

Basement rocks in this area consist of a complex tectonic melange of Paleozoic and Mesozoic rocks that were brought together when pieces of oceanic crust collided with the western edge of North America. These folded and faulted metamorphic rocks are locally overlain by the Early Tertiary nonmarine Chuckanut Formation and nearshore marine conglomerates and sandstones of the Bulson Creek sedimentary unit. Other Cenozoic rocks include eight outcrops of rhyolite and andesite that originated as volcanic flows, welded tuff beds, or intrusive dikes.

The Walker Valley site is the only place in these volcanic units where geodes have been found (Fig. 4). Their presence at this particular location is the result of episodes of hydrothermal activity that did not affect neighboring igneous bodies.

Regional mapping led geologists to infer that the host rocks at this site are part of the Chuckanut Formation (Matus, 1991; Whetten and others, 1988). This interpretation was confirmed in 1994 when quarrying exposed a 1-m-thick lens of carbonate siltstone within the brecciated andesite.

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During the past year, PCCC extended its workings to the southwest, elements from the enclosing host rock in proportions that reflect the chemical composition of this crustal material. The Walker Valley hydrothermal deposits primarily contain minerals composed of silica, calcium, and iron, three of the most common rock-forming elements.

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Early stages of mineralization were caused by hot water that gently trickled through fractures and vesicles. However, a later hydrothermal episode behaved quite differently, causing extensive brecciation and alteration within the dike (Fig. 7). The triggering mechanism for this hydrothermal event may have been an episode of seismic activity that created new fissures within the outcrop area, providing a conduit for superheated hydrothermal solutions that arrived with explosive force. At temperatures above the 374°C critical point, water exists as a very dense gas, and a sudden decrease in confining pressure would have caused an abrupt phase change, generating violently boiling liquid and a huge volume of steam capable of shattering the surrounding rock.

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Minerals precipitate from aqueous solutions because of a variety of physical and chemical factors, including temperature, pressure, acidity (pH), oxidation-reduction potential (Eh), and the concentration of dissolved elements. Successive mineral layers in Walker Valley geodes provide clues that allow us to reconstruct the hydrothermal history of the deposit. Precipitation can be triggered due to a temperature drop caused by contact of the hydrothermal solution with cool wall rock, a proc-

Figure 1. Coal-producing areas and districts, western Washington.

Figure 2. John Henry No. 1 coal mine, Pit No. 1, in January 1996. This view to the northeast shows mining on the southeast limb of the anticlinal structure. Light-colored "bare rock" material to the left of the large tracks forms the floor of the Franklin No. 7 coalbed. The Franklin Nos. 7, 8, and 9 coalbeds merge in this part of the mine; very little sedimentary rock separates the coal. The Franklin No. 10 coalbed is exposed in the highwall at the right out of view.

Figure 6. Anhydrite exposure showing quartz-filled cavities. The white circular shapes near the hammer are quartz-filled geodes.

Figure 7. Breccia composed of clasts of bleached anhydrite in a terrigenous matrix.
should be fairly close to the construction site because transporting sand and gravel a long distance greatly increases the cost of the project.

Major operators in the greater Seattle area in King County are Cadman, Inc., Stoneway Concrete Co., M. A. Segalos, Inc., Miles Sand and Gravel Co., and Lakesides Industries. In Snohomish County, they are Associated Sand and Gravel, Inc., and Cadman, Inc., at the Everett pit, and in Pierce County, Woodworth and Co., Inc., Lone Star Northwest, Corliss Co., and Tim Corliss and Sons, Inc. In the Olympia area, a major operator is Nielsen Pacific Ltd. at the Nisqually pit. Gilbert Pacific operates in Clark County at the English pit. Central Pre-Mix Concrete Co. operates a plant in Yakima, and Central Pre-Mix and Acme Materials and Construction Co. have large operations at sand and gravel pits in the Spokane and Tri-Cities areas. Several companies may operate from a large, single pit area, and companies may have different pits for specific types of sand or gravel.

The list of major sand and gravel operators in the larger communities in Washington is far from complete. A more extensive list of sand and gravel operators is available in Lingley and Manson (1992). Smaller operators in these communities, as well as in other communities of the state, commonly can meet local or smaller needs. The "yellow pages" can give an indication of the activity of the local sand and gravel industry.

Construction Stone

Construction stone quarried in Washington can be classified into two major categories by use—dimension stone and crushed stone. Crushed stone is rock that has been broken, crushed, or ground to smaller fragments, and dimension stone is rock that has been trimmed or cut to a desired shape or size (Langer, 1973). Building stone in Washington is described in detail by Moon (1967). More recent articles about the building and decorative stone industry in Washington include Guilk (1992) and Abou'Saad's (1995) brief histories of Washington's stone industry.

In Washington, numerous producers (Table 2) quarry various types of rock to produce crushed landscape rock, rockery (rock used to create a non-mortared wall or barrier), veneer, landscape boulders, rubble or fill, rectangular pieces of stone trimmed to essentially rectangular shapes (termed ashlar), exposed aggregate, terrazzo, flagstone, and cinders (Guilk, 1992). Sand and gravel operators commonly crush oversize rocks, which can then be used instead of round rock aggregate (a term often used for the non-crushed version).

REFERENCES CITED


Erratum

The correct Internet address for the National Center for Earthquake Engineering Research is: http://nceer.eng.buffalo.edu

This was reported incorrectly in the last issue of Washington Geology. Please make a note of the correction. Our apologies to the Center.

Dam Safety Conference

The Canadian Dam Safety Association and the Canadian National Committee of the International Commission on Large Dams will hold a joint conference in Niagara Falls, Ontario, from October 6 to 10, 1996. Session themes include the economics of dam safety and tailings dams. A poster session is part of the program for this meeting. For more information, contact Grant Smith in Toronto:

Phone: 416-592-5359; Fax: 416-592-4444, or E-mail: grant.fsmith@hydro.ca.
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**Silica**

Silica consists of the elements silicon and oxygen; these are most common in the mineral quartz. Although quartz deposits are high purity may have formed in several ways, the most common is as beach sands. Most beach sands, however, contain enough grains of other minerals that they are not pure enough to be used for manufacturing glass. The Addy quarry in northeastern Washington, derived from a Cambrian beach sand, and a sandstone of the Eocene Puget Group in western Washington are used for glass manufacture.

**Lime Mountain Silica Co. (no. 109)** mines Addy quarry and Chewelah, and Reserve Silica Corp. (no. 131) mines Packer Group sands to produce silica, primarily for the manufacture of bottle glass. Ash Grove Cement Co. (no. 133) mines silica for use in the manufacture of cement.

**INDUSTRIAL MINERAL INDUSTRY**

Industrial mineral commodities, construction sand and gravel, and construction stone accounted for approximately 46 percent of the $556 million total value of nonfuel mineral production in Washington in 1994, the last year for which figures are available. The overall production value of construction sand and gravel, the single most valuable nonfuel mineral commodity in Washington, was $174 million.

**Construction Sand and Gravel**

The value of construction sand and gravel is so high because it is used to support the construction industry of the state. The Department of Transportation and county road departments use numerous pits for maintaining roads throughout the state. Large private companies use sand and gravel to make concrete for home and business construction. The size of these companies tend to depend on the size of the market in the community. The greater Seattle area, Spokane, the Tri-Cities, and Vancouver have large sand and gravel operations and typically more than one company competing for the concrete business. (See Lingley and Manion, 1992.)

Large road-construction projects require large amounts of sand and gravel. Sand and gravel sources for these projects include:

- **Stage 2: Cubicold quartz and amethyst**
  Subsequent mineral layers show a gradual shift in the conditions of crystallization. Many geodes contain coarse crystalline quartz linings, and a few contain clear quartz crystals in the form of stalactic columns as wide as several centimeters in diameter. A particularly spectacular example is displayed at the Thomas Burke Memorial Washington State Museum at the University of Washington in Seattle. Amethyst crystals in light to medium shades line the central cavities of many geodes, occurring as purple terminations on quartz crystals that are otherwise colorless. Amethyst's color is caused by Fe³⁺ ions present as an interstitial impurity. This Fe³⁺ is evidence of shallow crustal depth, because quartz formed at deeper levels contains titanium iron in the Fe²⁺ valence state (Cohen, 1995). The presence of amethyst provides an indication of dissolved iron within the hydrothermal fluids, even after the previous stages of crystal growth. Clear quartz, resulting from this process, produces a pattern that rockshounders call 'sagenite'.

![Figure 10](image10.png)

**Calcite occurs in geode centers in a variety of habits, including white jasper (Fig. 10), dendirite forms, large translucent yellowish crystals, and clear crystalline massesshowing prominent rhombic cleavage.**

Many specimens have an empty central area, created when the flow of hydrothermal fluids was obstructed. Narrow fractures leading to the cavities became completely mineralized. These fractures contain the same minerals found in the adjacent geodes. The effectiveness of this sealing off process is evident when collectors use hammers and chisels to pry open the geode and see the colors—often the first hint that a geode is close at hand is the occasional breaking of water that has been trapped inside it for millions of years.

**Stage 3: Siderite and calcite**

While siderosite is found in the outermost goethite layers, ordinary siderite occurs in the central zone of some goethites as brown or amber-colored crystals, generally as columnar masses of stacked plates, radiating rods, or jasper arrangements. In some geodes, these crystals have been encased by clear quartz, producing a pattern that rockshounders call 'sagenite'.

![Figure 11](image11.png)

**Calcite occurs in geode centers in a variety of habits, including white jasper (Fig. 10), dendritic forms, large translucent yellowish crystals, and clear crystalline masses showing prominent rhombic cleavage.**

Many specimens have an empty central area, created when the flow of hydrothermal fluids was obstructed. Narrow fractures leading to the cavities became completely mineralized. These fractures contain the same minerals found in the adjacent geodes. The effectiveness of this sealing off process is evident when collectors use hammers and chisels to pry open the geode and see the colors—often the first hint that a geode is close at hand is the occasional breaking of water that has been trapped inside it for millions of years.

**Stage 4: Goethite, pyrite, and hematite as microcrystals**

In addition to the large crystals that line the geode, examination with a binocular microscope reveals a wealth of microcrystals present as encrustations on the surfaces of the central cavity. Goethite is the most abundant microcrystal, generally occurring as radiating sprays of acicular crystals (Fig. 11). Tiny hexagonal plates of hematite are present in a few speci-
The sporadic occurrence of pyrite at Walker Valley is rather puzzling. Pyrite and siderite both form under similar conditions of Eh and pH (Fig. 9), and the scarcity of pyrite suggests that percolating waters had a low sulfur content, so that iron was unable to crystallize as a sulfide. However, in 1992, the Vandenbergs found a goede containing three intergrown pyrite cubes, each about 1 cm in width. Pyrite also occurs as microscopic cubes and pyritohedrons on the fracture surfaces of quartz and goethite in the central cavities of some of these goedes. These occurrences may represent a chemical environment where sulfur was present as a local anomaly, perhaps derived from the adjacent volcanic rocks.

Goethite and pyrite have been observed as inclusions in quartz crystals bordering the central goede cavity. However, these iron minerals more commonly occur as encrustations on the surface of the quartz, indicating that most microscopic formation took place after silica deposition had ceased.

Stage 5: Minerals of the brecciated zone

The previous four stages describe the minerals found in goedes and fissures in the zone where fresh, dark-colored anodesite occurs. The mineralogy of the brecciated zone shows several important differences. The enclosing host rock has been bleached and oxidized, and mafic minerals have been dissolved. Iron released from this decomposition has led to the precipitation of hydrous iron oxides along fracture zones and as breccia matrix. Siderite that had previously formed in goedes or fissures has been either replaced by hematite or oxidized to limonite or goethite. Extensive silification along fractures resulted in the deposition of chalcedony, creating the white, gray, and blue ‘steam agate’ prized by collectors. The presence of whitish crusts of cristobalite (Fig. 12) provides evidence of high-temperature hydrothermal fluid, and mordenite (a zeolite) has been identified from X-ray diffraction patterns. However, well-crystallized specimens of any kind are scarce, and the mineralogy of the brecciated zone has not been studied in detail.

COLLECTING INFORMATION

The Walker Valley site is managed by the Department of Natural Resources and is leased to the Washington Mineral Council, a nonprofit organization that strives to maintain public access to collecting sites. Commercial collecting at the site is not allowed, and power tools and explosives are both prohibited, but there are no fees or quantity limits. Permission to collect is not required, but visitors are asked to refrain from littering, building fires, or otherwise causing damage.

Geodes are relatively abundant in certain areas of the deposit, but their extraction requires strenuous labor and skilled use of hammers, chisels, and pry bars. Hammering the brittle host rock yields razor-sharp shards, making protective goggles necessary.

For those with less zeal for hard-rock mining, a large talus slope produces attractive specimens, but rockfall hazards make this site suitable only for small groups.

The site (Fig. 2) can be reached year-round by ordinary passenger vehicles. An easy approach is to leave Interstate Highway 5 at the College Way exit in Mount Vernon and drive east to intersect Highway 9 north of Big Lake. From Big Lake, about 7.5 mi from the freeway, turn east on Walker Valley Road. Follow this paved road for about 2 mi, then turn right on Peter Burns Road. In about 0.5 mi, a side road turns south, crossing old cleats to join a powerline access road. The Fly-by Night claim and several other agate collecting sites are located along this rough road. To reach the goede-bearing outcrops, stay on Peter Burns Road, passing the entrance to an off-road vehicle recreation area parking lot in another half-mile. The Mineral Council site is located a half-mile farther, where the road passes a prominent zone of rust-colored cliffs.

The goede-bearing zone can be reached by walking a few hundred feet up a path through the forest on the south side of the outcrop or by driving a quarter-mile farther and turning left on a logging road that ascends one switchback to the top of the quarry.

Acknowledgments

We thank Len Jones, Bob Jones, Dick Rantzi, Leonard Schacht, and Wes Gannaway for providing specimens and information about collecting history at Walker Valley. Discussions with Red Brown, our understanding of petrography and regional geology, and Scott Babcock, Ray Lasmanis, Ray Claude, and Anton Wodzicki provided helpful reviews of the clay.

Clays

"Clay is a natural, earthy, fine material composed largely of a group of crystalline minerals known as the clay minerals" (Patterson and Murray, 1983). Clay is among the leading industrial minerals in terms of the tonnage produced and total value (Patterson and Murray, 1983). Some uses for clays include: making bricks and tiles; as an ingredient essential in cement and kiln firers and other absorbent granules; as a filler in many items, including plastics and paper; and to line and seal irrigation canals. Patterson and Murray further state that the term clay is ambiguous; it is used as the name for a group of minerals, as the name of a soil (a rock made up of clay-sized particles is also referred to as a slake), and for particles of the smallest size known in nature.

Clay mined in eastern Washington in 1995 came from the Mica mine (no. 112) for making bricks and from Quarry Tile Co. (no. 113) for producing ceramic tile. Mutual Materials operates the Mica mine and several quarries in western Washington (nos. 122, 130, 134). Most of the remaining clay production in western Washington (nos. 127, 132, 136) was for the cement industry. Basic Resources Corp. is progressing toward production of bentonite clay (nos. 118, 119) to line irrigation canals and other possible markets.

Diatomite

Diatomite is an opaline silica-rich sedimentary rock made up of the skeletal remains of diatoms, unicellular aquatic plants related to the algae (Kadey, 1983). Diatoms first became abundant in the Late Cretaceous, but most commercial deposits are of Tertiary age (Bates, 1960). After the diatom dies, it sinks to the bottom of the water body in which it was living. A cubic inch of diatomite may contain as many as 40 million “shells” (Bates, 1960). The diatom structure produces a deposit of low bulk density, high absorptive capacity, high surface area, and relatively low abrasiveness.

Processed diatomite has a unique structure and chemical stability that is preferred for some purposes to any other form of silica. Its most important use is as a filler aid. Diatomite is also useful as a filler and extender in paint, paper, rubber, and plastics. It is also used as an anti-caking agent, an insulating material, catalyst carrier, polish, abrasive, and pesticide extender (Kadey, 1983).

All of Washington’s diatomite production is by Cellite Corp. in central Washington. The company has several quarries (nos. 120-123) that are in various stages of development, ranging from planning to mining. They are also reclaiming exhausted areas.

Barite

Barite has a relatively high specific gravity, and it is relatively inert, that is, it does not break down or react with other materials. For these reasons, it is ground, mixed with drilling fluids, and used as drilling mud when drilling for oil and gas, especially where the drilling company anticipates that it might encounter gas or oil under high pressure. The high density, or weight, of the barite mud can prevent a blowout and consequent loss of control of the well and environmental problems.

Barite is found in two major deposit types: fissure and replacement vein deposits and bedded or sedimentary deposits. Most of the deposits in Washington occur in the northeast part of the state (for example, no. 105), a few are found in the north central part of the state, and only one in western Washington (Moen, 1964). At the present time, there is little demand for Washington barite. The lack of markets for the barite and its relations to its value precludes transporting it great distances for consumption; other deposits closer to major oilfields and lower priced barite from China are more commonly used resources. At Washington deposits that have been active in recent years, the property owner either is trying to sell the property or has dropped it.

The major use for the magnetism from Addy is alloying with aluminum. For example, two alloys that have different proportions of aluminum and magnetism are used to make beverage cans—one is for the can and the other for the can top.

Some materials for the Addy operation are imported. Ferro-silicon comes from Norway. In past years, ferro-silicon was produced locally—the silica (quartz) was mined from the nearby Blue Creek quarry and the iron came from taconite pellets from Minnesota. The company has found that the Norwegian product is more effective than the locally produced ferro-silicon. Magnetite for the operation is purchased from China. Northwest Alloys is considering obtaining magnetite locally from Ellensburg.

Northwest Alloys is producing a considerable output. Principal uses of silicate are in high-intensity metal halide lamps, as analytical standards and, in research. Most scandium is recovered as by-product from processing other ores.

**NONMETALLIC MINERAL INDUSTRY**

Commodities produced by the nonmetallic mineral industry of Washington range from a relatively low unit-volume value to a high unit-volume value. Cement is an example of a low unit-volume value commodity. Common cement is not transported great distances because of its bulk and because the materials to make it are relatively widespread. Diatomite, on the other hand, has a high unit-volume value. It has many specialty uses and is found in Washington in ancient lakede deposits.

Nonmetallic mineral commodities such as portland cement, carbonates, clayes, diatomite, olivine, and silica together accounted for approximately 20 percent of the $556 million total value of nonfuel mineral production for Washington in 1994, the last year for which figures are available.

**Carbonates**

The principal carbonate materials used in Washington are limestone and dolomite. Large amounts are used in construction, agriculture, and the chemical and metallurgical industries. Limestone is used in the manufacture of cement; however, all of the limestone used to produce cement in Washington is from Texas Island, British Columbia. Carbonate rocks are calcined to produce lime, which is required in some chemical and metallurgical industries, as well as a soil conditioner in agriculture. Generally, lime used by chemical industries is of high purity.

**Olivine**

Olivine, a silicate containing magnesium and iron, has been used primarily as a foundry sand (Kramer, 1985). However, in recent years, the high-magnesium end-member, forsterite, has been used as a slag conditioner in blast furnace production of pig iron (Teague, 1983).

**REFERENCES CITED**


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**Report on the First Symposium on the Hydrogeology of Washington State**

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Washington Department of Ecology
PO Box 47600, Olympia, WA 98504-7600

The State of Washington held its first major ground-water science conference in late August 1995 at The Evergreen State College in Olympia. More than 360 professionals attended, coming from the Pacific Northwest and beyond. More than 30 posters and 30 presentations were delivered in concurrent sessions during the two-and-a-half-day symposium. The theme sessions featured physical hydrology, ground-water modeling, geophysics, geochemistry, applied technology, and ground-water science policy. A ground-water sampling workshop was offered, and a trade and poster exhibition was also presented.

Sponsored by the Washington Department of Ecology, the broad goal of the symposium was to bring together for the first time the ground-water and hydrologic science community to present and discuss current research and the status of Washington’s ground water. The success of the symposium was indicated by the large turnout and response from more than 150 environmental consulting firms, government agencies, tribes, and universities. After the compilation of evaluations and commentary on this first gathering, a second symposium is being considered for the Evergreen State College in August 1997.

**Opening Remarks**

Mary Riverland, Director of the Department of Ecology; Carl Ross, University of Washington; John Dupuy, Washington State Geologi- cal Survey’s Water Resources Division; Tacoma; and Michael Barcelona, Director of Field Operations and Research and Adjunct Professor of Civil Engineering, University of Michigan. Anita Arber, presented the opening remarks. Goodwin described the tremendous challenges that scientific agencies face with legislators, citing the recent proposal

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Introduction

Pecon Prairie lies approximately 3 mi northeast of the Spokane city boundary (Fig. 1). Mead, an unincorporated area undergoing rapid suburban growth, is located at the west edge of Pecon Prairie. Local residents and state and county governments are concerned about water availability and water quality for this rapidly increasing population.

This report describes the various aquifer and confining (or aquitard) units penetrated during drilling and the results of ground-water, geophysical, and soil-field tests made in 1977 and 1978 as part of a mineral exploration venture. The drilling took place on Pecon Prairie in an area 4 mi east-to-west by 3 mi north-to-south. The subsurface geology and hydrology presented in this report are based on results of this drilling, and although the information is adaptable to the hydrologic analysis presented here, it may be limited because some of the tests were specific to mineral exploration.

Previous Studies

The most relevant geologic mapping in the greater Spokane area consists of two 1:62,500-scale geologic maps of the Greencars (Weis, 1968) and Mount Spokane (Weisennborn and Weis, 1976) quadrangles. Other maps include the 1:100,000-scale Spokane quadrangle (Joseph, 1990) and a 1:125,000-scale reconnaissance geologic map of the west half of the Spokane 1 x 2 degree sheet (Griggs, 1966). In 1992-94, W. J. Gershel, C. W. Gillick, and Derkey of the Washington Division of Geology and Earth Resources (DGER) mapped (at 1:24,000 scale) Flusseocene and younger deposits of the Spokane valley and the adjacent areas of the Spokane County Water Quality Management Program. Figure 2 is a 1:60,000-scale portion of that map.

The subsurface information and interpretations presented in this paper are based on results of an exploratory drilling (ground geophysics and rotary program) (Boleman, unpublished data). Resistivity and gravity surveys completed in 1977 showed that as much as 1,000 ft of sediment overlies crystalline basement. In 1978, fourteen rotary drill holes were completed and logged electrically using natural radioactivity, spontaneous potential, resistance, and caliper devices. Additionally, samples taken at 10-ft intervals in these holes were described by a geologist on the site. Collectively, these data are referred to as "borehole logs" for this report. Coincident with drilling and logging, geologists made eight drill-stem tests on selected sand intervals in six boreholes from which water levels were recorded; they also took water samples for helium analysis.

Geology

Rock and sedimentary units underlying Pecon Prairie include, from oldest to youngest, metamorphic rocks of the Priest River metamorphic core complex, Mount Spokane granite and alaskite, pegmatite, and aplite, Latlum Formation and Columbia River Basalt Group, glacial lake deposits, and Lake Missoula catastrophic flood deposits.

Older Rocks

Mount Spokane granite (unit Kpm) (Cretaceous) is predominantly in outcrops in the hills immediately surrounding the prairie. It is a foliated granite, medium- to fine-grained biotite-muscovite granite containing quartz, K-feldspar, plagioclase, muscovite, and biotite (Joseph, 1990). Scattered bodies of Eocene to Cretaceous alaskite, pegmatite, and aplite (unit Tka) are also present in the hills around the prairie. Both granite rock units intrude high-grade metamorphic rocks of the Priest River metamorphic core complex (Rehrig and others, 1987; Armstrong and others, 1987).

Latlum Formation

The Miocene Latlum Formation (unit Tq) (Hosterman, 1969; Purdie and Bryan, 1926; Robinson, 1991) consists of poorly indurated lacustrine and fluvial deposits of gray to tan to yellow clay, silt, and sandy clays.

Alluvial deposits consist of boulder, cobble, and gravel. The boulder size ranges from 1 to 10 ft in diameter, and the gravel size ranges from 0.1 to 1 ft in diameter.

Figure 3. Dolomite at Northwest Alloys dolomite mine at Addy is drilled prior to blasting. After blasting and transport to a crusher, ball-clay size ore material is separated out and sent to the smaller (cover photo) to produce magnesia metal.

All magnesia metal production in the state is by Northwest Alloys Inc. (a subsidiary of ACLOA) at Addy (no. 2) from dolomite rock mined from a pit (Fig. 3) adjacent to the plant (cover photo). Electrical energy used in the smelting process is readily available in northeastern Washington. Northwest Alloys uses the Aluminothermic Process, a modification of the European Magnetothermic Process, to produce magnesia metal. The Aluminothermic Process requires less electrical power than the European process and is adaptable to controlling emissions.

The charge for the electric furnaces, in addition to dolomite, includes aluminum (in the form of shot), magnetite, and ferro-silicon. The process begins with heating crushed dolomite from the mine to drive off carbon dioxide (Fig. 4). The reaction is:

$$\text{CaMg(CO}_3\text{)}_2 + \text{MgO} + \text{CaO} + 2\text{CO}_2$$

The calcined dolomite at this point in the process is referred to as dolime. The ferro-silicon, aluminum, and magnesite are added to the dolime in the furnace to promote reduction of MgO to elemental magnesia metal. The reaction in the furnace is:

$$\text{3MgO} + \text{2FeSi}_2\text{O}_5 + \text{6Mg} + \text{SiO}_2 + \text{Fe}_2\text{Si}_5\text{O}_5 + \text{3Al}_2\text{O}_3$$

Elemental magnesia produced in the furnace is a gas, which migrates to an adjacent, cooler vessel and condenses. The furnace operates with an argon atmosphere at 70 torr to prevent oxidation of the magnesium metal at the high temperatures in the furnace (1500°C). The vessel containing elemental magnesia is cooled with a jacket filled with magnesium chloride solutions. The magnesium chloride solutions cool to 100°C when heated. The magnesium chloride solutions are released to the atmosphere when heated. The magnesium chloride solutions cool to 100°C when heated.
able standard against which wealth is measured and an imperishable medium for balancing international accounts,” to the geochemist it is a “rare metal, the geochemistry of which is intricate and complex,” and finally to the mining engineer and metallurgist it “presents a challenge of extraction from the earth and from its ores” (Boyle, 1987, p. 1).

Gold occurs in two types of deposits—lode and placer. A placer deposit consists of sand, gravel, and other detrital or residual material in which the valuable mineral such as gold has accumulated through weathering and mechanical concentration processes. Lode deposits consist of a vein, a series of veins, or disseminated minerals in rock. Only a small portion of Washington’s gold production has been from placers.

Echo Bay Minerals Co.’s Kettle River operations at Republic was the only major gold mining operation in Washington in 1995. The Kettle River operations produced 100,419 oz of gold and approximately 22,800 oz of silver in 1995 from 547,597 tons of ore processed in its mill near Republic. The head grade was 0.212 oz of gold per ton, and recovery was 86.6 percent.

For the Kettle River operations was mined from the exhalative-replacement-type Overlook and Lamefoot deposits; 19 percent came from Overlook, the remainder from Lamefoot. The Overlook mine (no. 17) was reopened in 1994, and reserves at the deposit were exhausted during 1995. The mine will be closed. Overlook has produced 1,858,181 tons of ore since it was opened in 1989; contained gold in that ore was 285,250 oz. Gold recovery at the Kettle River operations has typically been in the 80 to 85 percent range, which means the Overlook produced roughly 220,000 to 240,000 oz of gold.

Higher grade ore from the Lamefoot deposit (no. 16) resulted in Echo Bay’s Kettle River operations breaking the 100,000-oz production level in 1995. In 1993 and 1994, most of the ore milled at the Kettle River operations came from the lower grade, open-pit key deposits. Mining at Lamefoot began in December of 1994, following receipt of permits to mine above the 7,500-ft elevation only. Permits to mine below that elevation were obtained in September 1995. Exploration drilling from the surface suggests that mineralization extends to the north of the deposit now being worked. Echo Bay plans to explore this potential by drilling to it in 1996.

Lamefoot is expected to be the mainstay of Kettle River operations for several years. The company reports proven and probable ore reserves are 1,585,400 tons at 0.207 oz of gold per ton (or 320,000 oz of contained gold). An additional measured and indicated ore reserve includes 466,900 tons at 0.164 oz of gold per ton (76,500 oz of contained gold).

Echo Bay continued underground exploration at its K-2 deposit (no. 13). The deposit is near the mined-out Kettle mine, and, like the Kettle, is an epithermal vein-type deposit in Eocene volcanic rocks of the Republic Group. The announced inferred resource at this deposit is 631,000 tons that contains 0.202 oz of gold per ton. The company plans to make a production decision on the K-2 in mid-to late 1996.

Hecla Mining Co.’s Republic Unit produced 3,098,000 oz of gold and 15,320 oz of silver from milling ore mined in 1994 and from cleanup at the mill following shutdown. Most of the production in previous years was from the Golden Promise mine (no. 20), which was closed on January 2, 1995; the mill operated until mid-February, when processing of gold ores was completed.

During the past year Asamera Minerals (U.S.) Inc. (as operator) and Breakwater Resources Ltd. were in the process of dismantling their mill and reclaiming the Cannon mine site (no. 48) at Wenatchee. The mine closed at the end of 1994. Production cleanup and dismantling of the mill in 1995 was 2,670 oz of gold and 3,565 oz of silver. The Cannon mine produced 1,248,911 oz of gold and 2,075,077 oz of silver from a total of 4,133,101 dry tonnes of ore from its opening in 1985 through final cleanup in 1995.

The Lone Jack mine (no. 41) operated again in 1995, producing approximately 800 tons of ore that was shipped to a smelter in East Helena, MT. The operators also drove a drift to intersect the vein on a lower level of the mine.

A draft environmental impact statement (EIS) was issued June 30, 1995, for the Crown Jewel deposit (no. 28), a Back Mountain Gold (operator)/Crown Jewel Joint venture. The public comment period for the draft EIS lasted 60 days and ended on August 29, 1995. The Washington Department of Ecology and the Okanogan National Forest are now preparing the final EIS for the project. It is expected in September of 1996. The process of obtaining permits to mine will then begin; issuance of permits is expected to take about a year. Announced reserves at the Crown Jewel deposit are 8.7 million oz of ore at a grade of 0.186 oz of gold per ton, or more than 1.6 million oz of gold. For Washington, the gold estimated to be contained in the Crown Jewel deposit is second in amount only to that at the Republic Unit of Hecla Mining Co.

The most extensive exploration in Washington was for gold from epithermal deposits in Tertiary rocks of the Republic and Chiauwakum grabens. Hecla Mining Co. signed an earn-in agreement with Santa Fe Pacific Gold Corp. in August for its Republic area holdings (no. 21) in the Republic graben. The focus of the acquisition of Santa Fe Pacific is the Golden Eagle deposit (no. 19), on which they were drilling in 1995. The Golden Eagle has a possible resource of 11.3 million oz, 73% of grading 0.1 oz of gold per ton. Santa Fe Pacific will earn 70 percent interest in the project by spending $7.5 million over a 3-year period and completing a feasibility study.

Echo Bay Exploration Inc. drilled and dropped a property on Graphite Creek (no. 27) in Eocene volcanic rocks of the Toroda Creek graben northwest of the Republic graben. Ramrod Gold USA Inc. continued their activities, including drilling on their Wenatchee gold belt project (no. 49) in the Chiauwakum graben near Wenatchee. Deluto Wind River Mining Co. was mining Wind River deposit (no. 52) and seeking permits to establish a milling operation. Activities on all other properties with potential for epithermal-type gold mineralization (see Table 1) were held or terminated.

The Hawkeye Project (no. 15) was the only project property actively explored for replacement/sedimentary-type mineralization in the Republic graben. At all other properties (see Table 1) that have potential for this type of mineralization, which is associated with Pennsian to Triassic rocks of northeastern and north-central Washington, activity was limited to maintaining the properties.

Gold deposits in or near rocks of the Shasket Creek alkalic complex at the north end of the Republic graben were the focus of activity for many years from the Golden Promise company. Echo Bay Exploration Co. was active at the Morning Star (no. 12), and N. A. Degerstrom, Inc. and Gold Express Corp. low orange silstone, claystone, sandstone, and minor conglomerate. These deposits are thought to span the later stages of a period of Miocene “deep weathering” (Robinson, 1991) and are interbedded with and underlie the local units of the Columbia River Basalt Group. Bedrock cuttings indicate the sandstones are arkosic to quartzose, fine to coarse grained and locally pebbly, and olive brown to medium light gray; grains are rounded to angular. Claystone varies from brownish gray to greenish gray to olive gray and is commonly silty. Pyrite and organic matter contents in the formation range from 0 to 0.5 percent and 0 to 1.5 percent respectively. Latite deposits are extensive and thin in areas interpreted as paleo-depressions (low areas) and pinch out in paleo-higher areas. The toponography in Latite time was not unlike that of Spokane today.

Columbia River Basalt

Basalts of the Columbia River Basalt Group (Miocene, Reidel and Fecht, 1987; Griggs, 1976; Swanson and others, 1979) are
Quaternary Deposits

Quaternary sediments of Peone Prairie consist of Pleistocene glacial lakebeds (unit Qia) (Hustermen, 1969) of predominantly sand, silt, and clay with scattered boulders. The lakebeds commonly occur as terrains in tributary valleys (including Peone Prairie), north of the Spokane Valley and are probably deposits of glacial Lake Columbia (D. F. Stradling, Eastern Washington Univ., oral commun., 1995; Waitt and Thorson, 1983). Drop stones are large as 2 ft in diameter, presumably carried by icebergs into the glacial lake, occur in some of the lakebeds; several were uncovered during construction of the Mt. Spokane-Mead High School.

Bedding in the lakebeds is obscure; in places it is contorted, which suggests a debris-flow origin. Silt and fine sand beds range up to 3 ft in thickness; clay beds range between 3 and 6 in. in thickness are exposed in roadcuts along Bruce Road (Fig. 3).

Borehole cuttings show that Quaternary lacustrine deposits (unit Qia) are fine to pebbly and consist of metamorphic rock fragments, some basalt fragments, and little quartz. Limonite staining is common. Clays in this unit range from yellowish brown to olive-brown to medium gray and are commonly silty. Quaternary sediments contain traces of prytie and organic matter ranging from 0.5 to 1.5 percent; some samples contain as much as 11 percent.

West of Peone Prairie near Mead (Fig. 2), glacial Lake Missoula flood deposits (unit Qe) are sparsely interbedded with the lakebeds (Kiver and Stradling, 1989; Waitt and Thorson, 1983; Waitt, 1985). The flood deposits are poor sorted and commonly range from sand to pebble gravels. Many of these interbeds in the Peone Prairie area may be tributary channel deposits; they are not shown on Figure 2. The flood deposits were probably carried into the area by eddy currents tributary to the main flood channels. Where the Missoula flood currents were stronger, glacial lakebeds are not preserved and flood deposits predominate.

Mass wasting deposits (unit Qmm) occur in areas adjacent to basalt rocks. They consist of pebble- to block-size gravel and breccia deposits that apparently slumped, slid, or were carried by debris flows into the lake (Fig. 4). They are all underlain by the Lahar Formation in Peone Prairie and likely formed where poorly consolidated deposits of the Lahar Formation were eroded, which resulted in undercutting of overlying basalt rocks.

Surficial (Unconsolidated) Deposits

Unconsolidated deposits of the Peone Prairie area include surficial wind-blown sand (unit Qes) and loess deposits (unit Qel) and alluvium (unit Qal). These deposits are included on the geologic map (Fig. 2) but are not shown on the cross sections (Fig. 5).
Wind-blown sand deposits overlie glaciolacustrine and flood deposits on the western side of the prairie and in the Mead area. Some display cross bedding typical of sand dunes. Sub- to well-rounded sand grains are predominantly lithic fragments. Locally, the sand deposits contain beds of lenses of re-worked Mazama volcanic ash (dated at 6.8 ka), commonly at or near the surface in the Peone Prairie area.

Loess grains are far smaller than sand grains, and thus they are carried great distances by wind. Where hilltops and fairly flat surfaces of the prairie that are still covered by loess are tilted for farming, the loess is commonly dark brown; loess has not been preserved on the slopes (Fig. 6).

Alluvium, the youngest material on Peone Prairie, occurs along Deadman Creek and other local drainages.

**SUBSURFACE AND AQUIFER GEOLOGY**

We used borehole logs to construct two northwest-southeast, one north-south and one east-west cross section (Fig. 3). These indicate the extent of the various local aquifers. Cross sections show the magnitude of Pleistocene erosion and subsequent sedimentation events. A representative borehole log (Fig. 7) provides an example of the comprehensive and complementary value of information that constitutes the borehole logs used in constructing the cross sections.

Used in combination, borehole samples and borehole geophysical logs (radioactivity, spontaneous potential [SP], resistivity, and caliper) are of enormous value in identifying and describing sedimentary units and in allowing detailed stratigraphic correlation of units and hydrogeologic analysis across the study area. Natural radioactivity and resistance logs are particularly sensitive to changes in grain size and composition of units penetrated. The SP log, in addition to providing lithology distinctions, signals changes in conductivity of waters between the borehole and formation (Driscoll, 1987, p. 180-201; Keys, 1989).

Borehole data permit interpretation of the depositional setting of rock and sediment intervals (Fig. 7). Fining-upward and coarsening-upward sequences are indicated from borehole logs. In conjunction with helium data, interpretation of depositional setting can provide important inferences about aquifer geology beyond the borehole site.

**Weathered Granite Aquifer**

At three sites (P-9, -12, -15), buried hills of granite were identified. Interpreted as the pre-Latoh weathering surface, these hills were again exposed prior to deposition of the Quaternary lacustrine deposits.

The weathered zone, or grus, overlying granite basement was identified from borehole logs to be soft and possibly friable and subject to fracturing to act as an aquifer. Drills penetrating this zone rapidly, and borehole logs show it has characteristics that differ from those of the sediments above and the basement rock below. Data show the weathered zone varies from 14 to 151 ft thick and averages 70 ft thick. This zone occurs in all the prairie boreholes and may represent an important aquifer where these sections occur at shallow depths, as at boreholes P-9 and P-13.

**Latoh Formation**

The poorly indurated Latoh sands are as widespread as Quaternary sands. Latoh sands that produce water are considered porous and permeable based on qualitative characteristics of drill stem tests and lower resistance values exhibited on borehole logs and drill penetration rates; however, permeability and porosity tests were not made. Sand composition indicates that this is from erosion of the underlying granitic rocks. Aquifers in the Latoh consist of moderate to coarse sands. The geophysical log responses are consistent with detrital (coarsening upward), fluvial point bar (fining upward) or channel deposits.

The Latoh consists of at least five coarsening-upward, possibly lake-filling cycles (Robinson, 1991). Thickness of the entire Latoh Formation varies from 4 ft in P-15 to 650 ft in P-1, the thickest uninterrupted sedimentary thickness identified in the region. The average thickness of the Latoh is 350 ft; it is more than 350 ft thick in seven of the boreholes (P-1, -3, -6, -7, -13, -14, -16).

Sand beds determined to be porous and permeable (see above) constitute 25 percent by volume of the Latoh section, indicating significant aquifers may be present. The specific yield for such material normally ranges from 25 to 35 percent (Fetzer, 1994, p. 93). Taken together, this indicates that total water volume in this aquifer varies from 6 to 10 percent.

Thickness and depth of significant shallow Latoh sands are:

<table>
<thead>
<tr>
<th>Borehole no.</th>
<th>Depth (ft)</th>
<th>Total thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-1</td>
<td>200-250</td>
<td>280-300</td>
</tr>
<tr>
<td>P-3</td>
<td>180-250-275-315-330-370</td>
<td>150</td>
</tr>
<tr>
<td>P-13</td>
<td>150-190</td>
<td>40</td>
</tr>
<tr>
<td>P-14</td>
<td>265-283-311-370</td>
<td>77</td>
</tr>
<tr>
<td>P-16</td>
<td>285-305-359-371*</td>
<td>52</td>
</tr>
</tbody>
</table>

* Drill-stem test interval; see p. 36
A thick, alternating silt and clay sequence in borehole P-3 at 370 to 605 ft depth can also be positively identified in boreholes P-1, P-7, and P-14. This alternating sequence may underlie about one-half the study area and may be similar to clay deposits correlatable across the Latala basin (Robinson, 1991). The sequence probably acts as an excellent confining layer between shallow and deep Latala sands and likely represents some of the extensive lacedeep deposits.

Less significant Latala sands that lie below the lacustrine deposits are:

<table>
<thead>
<tr>
<th>Borehole no.</th>
<th>Depth (ft)</th>
<th>Total thickness (ft)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-1</td>
<td>535-555</td>
<td>20</td>
<td>Basalt channel sand</td>
</tr>
<tr>
<td>P-3</td>
<td>680-700</td>
<td>20</td>
<td>Basalt (?) sand</td>
</tr>
<tr>
<td>P-3</td>
<td>728-757</td>
<td>29</td>
<td>Basalt fluvial sand</td>
</tr>
<tr>
<td>P-5</td>
<td>480-520</td>
<td>40</td>
<td>Basalt fluvial sand</td>
</tr>
<tr>
<td>P-7</td>
<td>670-700</td>
<td>40</td>
<td>Basalt fluvial sand</td>
</tr>
<tr>
<td>P-14</td>
<td>455-485</td>
<td>30</td>
<td>Basalt fluvial sand</td>
</tr>
<tr>
<td>P-16</td>
<td>307-345</td>
<td>38</td>
<td>Basalt channel sand</td>
</tr>
<tr>
<td>P-17*</td>
<td>560-580, 385-590</td>
<td>25</td>
<td>Basalt fluvial sand</td>
</tr>
</tbody>
</table>

Quaternary Units

The Latala was completely removed along the center of the Deadman Creek palaeo-valley; this is indicated by borehole logs at P-8, P-9, P-10, and P-15. The thickest section, 600 ft, of Quaternary glaciolacustrine and glaciolacustrine sediment occurs at drill site P-8, P-10, and P-17 near Deadman Creek (and perhaps nearest the center of the paleo-Deadman Creek valley). Pleistocene erosion cut a valley nearly 600 ft deep and 2 mi wide. The present-day Poo Brae is 3 mi 30 ft below relief, following refilling of the valley by younger sediments.

Based on qualitative estimates from borehole logs, the Quaternary sedimentary section contains 35 percent (by volume) sand; the specific yield for such material normally ranges from 25 to 40 percent (Fetter, 1994, p. 93). We estimate that the total water volume in this aquifer varies from 9 to 14 percent (by volume). Because Quaternary aquifers are the shallowest, their potential for use is greatest. Likewise, shallow aquifers have the highest likelihood for recharge from surface water sources, including confined springs.

Aquifers at depths below the water table (or unconfined) aquifer are called confined aquifers. Significant sands of the Quaternary confined aquifers occur at the following intervals:

<table>
<thead>
<tr>
<th>Borehole no.</th>
<th>Depth (ft)</th>
<th>Total thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-4</td>
<td>103-122, 200-208</td>
<td>117</td>
</tr>
<tr>
<td>P-9</td>
<td>95-106, 234-238</td>
<td>139</td>
</tr>
<tr>
<td>P-10</td>
<td>120-190, 260-410</td>
<td>220</td>
</tr>
<tr>
<td>P-15</td>
<td>67-92, 111-155</td>
<td>69</td>
</tr>
<tr>
<td>P-16</td>
<td>85-100, 150-190</td>
<td>55</td>
</tr>
</tbody>
</table>

Aquifer sand sizes are dominantly medium to coarse, locally pebbly, and include basalts (boulders?) in boreholes P-6, P-9, and P-13. Boreholes listed above are located near Deadman Creek, so potential for water recharge from surrounding uplands appears good.

The origin and significance of basalts boulders? encountered in boreholes remains problematic. They may be either undisturbed flows of basaltal mass-wasting (landslide) deposits. Because they occur on a sloping Latala erosion surface and occur sporadically in only three holes, it is hard to imagine the basalt as undisturbed flows. Furthermore, there is no evidence of palagonite or a baked surface. Therefore, we think the basalt intercepted in the three boreholes marks a depositional hiatus between Middle and Quaternary time and favors the mass-wasting interpretation. A boulder zone would be an excellent aquifer because it is extremely coarse grained and would have good hydraulic communication with recharge areas. The Quaternary sediments in the subsurface also include numerous thin, interbedded, repeated lacustrine clay and silt beds. Hosterman (1969) observed varved lakebeds in oolites and in shallow borings; these can also be seen in roadcuts along Bruce Road (Fig. 3). The thickness of this sequence varies, but the varved clay-silt sequence is prominent in boreholes near Deadman Creek (P-8, 9, 10, 13, 14, 15, and 16). Depths range from 0 to 300 ft. Locally, these beds are interbedded with or overlie the Quaternary aquifer sands. The clay interbeds might significantly restrict vertical water movement (percolation), including water flow from storm-water runoff and seepage from septic systems. Percolation problems and near-surface saturated clays could pose problems for development in the area.

**HYDROGEOLOGY**

**Water Test Procedures**

Drill-test stem (DTS) equipment, commonly used in oil-well testing, was used to obtain hydraulic head data (Fig. 8). This equipment is designed to sample fluids and determine pressures in specific aquifers. At Poo Brae, the DTS equipment was connected to the drill rig and used to obtain eight water samples from selected deep aquifers in six boreholes (Table 1). In the paragraphs below, the procedures are explained.
**Table 1. Summary of hydraulic head and water analysis data.**

<table>
<thead>
<tr>
<th>Boring</th>
<th>Surface elevation (ft)</th>
<th>Test Interval (ft)</th>
<th>Formation</th>
<th>Hydraulic head</th>
<th>Pressure head (ppm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-10</td>
<td>1,870</td>
<td>594-626</td>
<td>granite rocks</td>
<td>**</td>
<td>68</td>
<td>5.25</td>
</tr>
<tr>
<td>P-11</td>
<td>1,908</td>
<td>128-167</td>
<td>Latah</td>
<td>**</td>
<td>125</td>
<td>2.05</td>
</tr>
<tr>
<td>P-12</td>
<td>1,855</td>
<td>310-344</td>
<td>**</td>
<td>192</td>
<td>5.27</td>
<td>2.63</td>
</tr>
<tr>
<td>P-13</td>
<td>405-436</td>
<td>granite rocks</td>
<td>**</td>
<td>271</td>
<td>5.34</td>
<td>5.35</td>
</tr>
<tr>
<td>P-14</td>
<td>1,830</td>
<td>449-496</td>
<td>Latah</td>
<td>**</td>
<td>1,521</td>
<td>7.90</td>
</tr>
<tr>
<td>P-16</td>
<td>1,875</td>
<td>380-386</td>
<td>Latah</td>
<td>**</td>
<td>252</td>
<td>9.58</td>
</tr>
<tr>
<td>P-16</td>
<td>500-554</td>
<td>395</td>
<td>Latah</td>
<td>**</td>
<td>1,770</td>
<td>27.72</td>
</tr>
<tr>
<td>P-17</td>
<td>1,860</td>
<td>520-566</td>
<td>Latah</td>
<td>**</td>
<td>1,662</td>
<td>24.06</td>
</tr>
<tr>
<td>P-17</td>
<td>583-606</td>
<td></td>
<td>Latah</td>
<td>**</td>
<td>522</td>
<td>27.91</td>
</tr>
</tbody>
</table>

*Sum of test interval elevation and pressure head*

plained, and we then discuss interpretations of hydraulic head and helium results from the 1978 work.

We first used an electric borehole-diameter measuring device (caliper log) to select the positions to place the DST tool across a test interval (Fig. 8). The DST equipment simultaneously isolates the test interval’s upper and lower boundaries and opens a valve exposing the formation in hydraulic environ-ment to the atmosphere, much like a piezometer (a water-level measuring device) tube. Formation water enters the pipe and rises to a point of equilibrium. After 45 to 90 minutes, the pull-down force exerted by the drill rig is released to close the valve and free the packers, the pipe is withdrawn, and the water level reached is recorded as the pressure head. Total hy-draulic head is determined by adding test interval elevation to pressure head, that is, the level to which the water has risen in the pipe (Table 1). Area mapping of hydraulic head defines the potentiometric surface and is important because it will in-duce an aquifer’s water flow direction and the relative loca-tions of recharge and discharge areas for that aquifer.

Specific conductance of the water was measured to ensure quality control by comparing measurements taken along the various vertical sections of drill pipe. A stabilized low specific conductance indicated that water originated from the forma-tion and not the borehole fluid.

The quality of water from private wells and springs used for domestic purposes on Green bluff, upper Deadman Creek and Peone Prairie varied considerably. (Sample points are not shown on map.) Eight springs and 45 wells were sampled and the owners interviewed by Paul Nordstrom in 1978. Wells sampled were as deep as 500 ft. Alkalinity of bicarbonate ranged from 36 to 204 ppm (average 50 ppm), pH ranged from 5.9 to 7.2, and alkalinity as carbonate ranged from 3 to 48 mg/l except in a 95 well where water had an undesirable taste; that test yielded 7.670 mg/l carbonate alkalinity. Sulfurous odor and iron and calcium deposits (as a carbonate or sulfate) on water faucets and in sinks were common. Tests of those interviewed noted bacterial problems with their water, a num-ber used water softeners, and two were treating their water with chlorine. Seven wells had turbid water, and eleven had water with a slightly to very unpleasant taste or odor. Quality of water in the Peone Prairie area needs further study.

**Helium Analyses**

Helium (He) is a radioactive decay product of natural earth materials, principally uranium and thorium. Because He is in-ert, it can be traced through the hydrogeologic environment and provide valuable insights into water movement. The use-fulness of He values is in indicating an aquifer’s relative com-munication, or lack of it, with recharge and discharge areas, termed dynamic equilibrium (Fetter, 1994). Detecting anoma-lous He is dependent on knowing the background He content of local recharge waters. To establish a local background value, 62 water samples were collected in the Peone Prairie, upper Deadman Creek, and Green bluff areas. Average He was 5.35 ppm (standard deviation 0.21 ppm). Any value exceeding 5.77 ppm (mean plus 2 standard deviations) was considered anomalous.

**Deeper Latah Beds**

Water samples analyzed for He came from the DST tool cham-ber and lowest drill pipe sections. He values from the deeper Latah aquifer in P-14, P-16, and P-17 are anomalously high (7.90 to 42.79 ppm). Reasons for high He contents in aquifer water remain somewhat enigmatic. High He values are best attributed to the efficient sealing of layers enclosing this deep Latah aquifer to He diffusion in the aquifer. High He may also indicate that recharge is low and cannot suf-ficiently dilute the natural helium flux from the bedrock, sug-gest that the aquifer is isolated.

A third possible explanation, that a nearby uranium deposit is supplying abnormal quantities of He to the aquifers, can be rejected upon comparing the He values in samples taken from the weathered zone aquifer (P-10, P-13; see Table 1) to those from the basal Latah aquifers. Furthermore, a highly fractured basement rock at this location can enhance He movement up-ward to aquifers (Martin’s East Corp., 1978, p. 1, p. 2- 5). Low He values indicate potential for water supplies from the weathered zone and shallow aquifers. High He in the basal Latah suggests this aquifer received little recharge, which may reduce its potential as a water source.

**He in the Weathered Zone**

He values in the weathered zone aquifer ranged from 5.25 to 5.35 ppm, about the background level. Because the weathered zone is erally extensive, follows the pre-Latah erosional to-pography, and is enclosed by leaky confining layers, recharg-ing of the weathered zone is more likely than for the basal Latah aquifer. This suggests the weathered zone may contain a useful water supply.

**Hydraulic Head Tests**

Some preliminary potentiometric results were provided by this reconnaissance exploration. Three boreholes (P-14, P-16, P-17) were cored and sampled, with the deepest part of the cores cored intact.
at which water levels were measured (fortuitously) penetrated the same Latah sand as the one indicated at 600–700 ft depth in the representative log borehole P-3 (Fig. 7). From these data, total hydraulic heads were calculated and a potentiometric surface determined. The potentiometric surface generally indicates the aquifer’s flow direction from recharge to discharge. (See Table 1.) Because three wells were tested, a 3-point analysis of the potentiometric surface was possible. This analysis indicates a west-northwest slope, approximately paralleling Deadman Creek. Therefore a water recharge area probably lies to the east-southeast and a discharge lies to the west-northwest.

**PRELIMINARY CONCLUSIONS AND TOPICS FOR STUDY**

Further investigation is needed to confirm many of the preliminary observations below. However, several conclusions can be drawn from this 1978 reconnaissance study.

**Aquifers**

Potential aquifers include (shallower to deepest) Quaternary sands, including the boudery zone (15–300 ft in thickness), Latah Formation sands (0–230 ft in thickness), and the weathered zone of bedrock or grus (14–151 ft in thickness). The greatest combined aquifer sand thicknesses appear to lie south of Deadman Creek. Depth to bedrock ranges from 100 to 831 ft. Helium analysis suggests that all but the deep (basal) Latah aquifer are in hydraulic communication with areas of ground-water recharge.

**Latah Sequences**

The Peone area is remarkable for two reasons: first, it exhibits a thick, uninterrupted sedimentary sequence of the Latah, and second, the sand content (percent sand) of the Latah here is greater than expected. Labeled, fluvial, and deltaic sequences shown on borehole logs in the Latah Formation indicate that extensive interconnectivity of sand deposits probably occurs in the area. Similar sequences are also indicated in the Quaternary sediments. Thick Latah sequences likely extend beneath nearby basalt-covered plateaus. Permeability and porosity of the sands and other materials that compose the aquifers are expected to range far below that of the Spokane Valley aquifer.

Data from this test are insufficient to describe the water supply. Streamflow, runoff, and precipitation data not used here should be studied in conjunction with other well test results. Engineering tests must be made to determine aquifer storativity and transmissivity values. Deep borings should be made in the surrounding area to obtain new borehole data and determine the extent of aquifers.

**Recharge and Discharge**

Hydraulic head testing indicates that recharge areas may lie to the east-southeast and discharge areas may lie to the west-northwest for the deep Latah aquifer. Obtaining hydraulic head data from new and existing borings will clarify this preliminary observation.

**Shallow Clay Aquicludes**

Thick, varved clay-silt layers are located at the surface and at shallow depths across Peone Prairie. If suburban development is considered, the ability of this aquiclude to reject or impede vertical seepage may be a concern and requires further investigation. Storm-water runoff in areas with the clay-silt layers at shallow depths present special problems and require further study.

**Water quality**

Preliminary water quality data from wells and springs at Green Bluff and Deadman Creek are insufficient to characterize the prairie area’s drinking water supply. High iron content of water supplies is a common complaint.

**ACKNOWLEDGMENTS**

The authors thank Rexcon Inc. for permission to use borehole data for this report. Many people contributed to the success of this project. Drill-stem test equipment was supplied and operated by Johnston Testers, a division of Schlumberger of Casper, WY. Paul Nordstrom of ScienTerra collected and analyzed water samples for helium on a mass spectrometer at Whitworth College Physics Department under the direction of the late Prof. Glen Erickson. Jack Roylance originated and directed the project. Don Hansen suggested the use of the drill-stem testing. Hansen, Gunther Jarre, and John Brehm supervised various aspects of the project. Bill Smallwood, Dave McClure, Dan Wallis, Mike Schuler, Marilyn Pau-Plueta, Ken Bullis, and Gene Halsted provided geologic and geophysical assistance to the senior author during drilling operations. We also thank D. F. Stratford and E. F. Riker of Eastern Washington University for explanations of glacial and Lake Missoula flood deposit geology of the Spokane area. W. J. Gerastel, DOER, mapped and field checked photogeologic mapping of Quaternary deposits in the Spokane area including part of the map area included here. Backlaff digitized the geologic information for Spokane County and provided the line work on which the geologic map is based. Mitch Linne of U.S. Bureau of Mines reviewed an earlier version of this article. Robin Peterson, U.S. Bureau of Mines, drafted Figures 5, 7, and 8. Josh Logan and Stephen Palmer of DOER made significant editorial contributions.

**REFERENCES CITED**


Symposium on Hydrogeology  Continued from page 29

and actions to abolish the U.S. Geological Survey. He identi- fied four tasks that ground-water scientists must accomplish:

1. Assure that everyone who needs hydrologic data can quickly and easily get all available information.
2. Ensure comparable and high-quality data.
3. Disentangle the technical and societal elements of major water issues.
4. Educate Washington’s citizens about basic hydrology and ground-water processes so that they can make informed choices as they vote.

Goodwin asked ground-water scientists to step out of their comfort zones in the technical arena, to think about water as if they were social scientists, and to be aware of the deep-seated social struggles that are intertwined with major water issues. Barcelona calls for skilled and well-trained hydrologists to make critical decisions in practice and policy. He emphasized that stronger interdisciplinary and field training should be provided to college and graduate students by ground-water professionals in higher education.

Keynote Speaker

The keynote speaker was R. Allen Freeze, co-author with John Cherry of the textbook "Groundwater" (published by Prentice-Hall). His talk, "Ground water remediation and its ethical conundrums"—The question of mass removal and risk reduction in an adversarial regulatory environment" called for societal and regulatory realization that mass removal approaches are often not a pragmatic means of containing contaminants. Freeze explained that ground water remediation requires flexible approaches, not narrow regulation.

Ground-Water Sampling Workshop

More than 70 scientists took part in the ground-water sampling workshop presented by Barcelona, Mark Varlien (hydrogeologist and president of Applied Hydrogeologic Research, Inc., Seattle, WA) and David Kaminski (vice president, QED Ground Water Specialists, Walnut Creek, CA). The emphasis of the workshop was on micro-purging techniques for sampling ground water. The challenge is moving away from the traditional evacuation of three well volumes to a new standard practice.

Internet Access

Several of the plenary session presentations and all symposi um research abstracts are now available on the Internet by choosing an option from Ecology’s home page on the World Wide Web (http://olympus.dis.wa.gov/www/access/ecology/ecohome.html). For updates on development of the second symposium, please also refer to this home page.

Editor’s note: This article was delayed due to page constraints in the previous issue.
RECLAMATION AWARDS NOMINATION FORM

(Please print or type the information. Nominations must be received by November 1, 1996.)

Please check the category for which you wish to nominate the site:

☐ Commissioner of Public Lands' Recognition for Reclamation
☐ Good Neighbor Award

☐ Commissioner of Public Lands' Recognition for Reclamation for a Small Operation (less than 16 acres)
☐ All of the above

Person making the nomination: __________________________ Phone: ( )

Organization or business nominated: __________________________

Name of site: __________________________

Location: __________________________

DNR Reclamation Permit Number (if known): __________________________

Description of reclamation: (You may attach a separate sheet.)

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Presentation material included with nomination: (We suggest at least 12 slides and 6 color photos.)

☐ 35-mm slides (how many?) ______  ☐ Photos (how many?) ______  ☐ Video

All presentation material becomes the property of the Department of Natural Resources.

Your address: __________________________

City/State/Zip + extension: __________________________

Send this nomination form to: Regulatory Section
Division of Geology and Earth Resources
PO Box 47007
Olympia, WA 98507-7007
Surface Mine Reclamation Awards

The Department of Natural Resources (DNR) is establishing three annual awards to recognize outstanding reclamation of surface mines. These awards will honor permit holders who reclaim mines in an exemplary manner. Awards will also recognize reclamation efforts on sites exempt from the Surface Mine Reclamation Act (RCW 78.44) because of size or because a site was abandoned by earlier mine operators prior to 1971. Criteria for evaluating entrants are described below by award category. If no mine reclamation has occurred that meets the stringent criteria of each category, no award may be granted for that year. Nominations for awards can be made by the public, permit holders, DNR, or other agencies. Nominations received by November 1 will be eligible for that year’s award.

Commissioner of Public Lands’ Recognition for Reclamation

To receive this award, an operation must meet or exceed the DNR-approved reclamation plan. Exemplary reclamation may include, but is not limited to:

1. Innovation or creativity in reclamation, such as creating unique wetlands or enhancing wildlife and fish habitat or topographic elements.
2. Voluntary reclamation of mined land that is exempt from reclamation under the Act.
3. Use of native plant species in revegetation.
4. Innovative research and approaches to reclamation that can be applied at other mines.
5. Attention to water quality and erosion prevention.
6. Orderly segmental mine development resulting in high-quality reclamation.
7. A consistent long-term commitment to reclamation.
8. Methods that enhance the environment and reduce reclamation liability, such as mining to a final slope.
9. No significant enforcement actions in the past 10 years.

Commissioner of Public Lands’ Recognition for Reclamation for a Small Operation

The criteria are as for the Recognition for Reclamation award, except that the operation is less than 16 acres in size.

Good Neighbor Award

The winner of this award works unselfishly with neighbors and the community in a spirit of cooperation to reflect a positive image of the mining industry. For example, the operator may have developed cooperative projects that benefit the environment and the community.

The Award Process

Winners will be selected by a panel of five judges: the Commissioner of Public Lands or a designee, a representative of the mining industry, two representatives of environmental interest groups, and a representative of state environmental agencies.

DNR surface mine reclamationists will present the candidates to the panel. Because the judges may not have opportunities to visit the nominated operations, 35-mm slides, photos, or videos showing conditions before, during, and after reclamation will help the judges review the nominees. At least twelve slides and six color photos should be submitted. Written descriptions of site reclamation will help the panel reach their decision. These descriptions may include the history of reclamation, planned development, partnerships made with neighbors, and direct benefits to the immediate environment, as well as specific information about topsoil handling, sloping, revegetation, water control, and other interesting aspects of the reclamation.

Winners will receive an award and public recognition from a press release issued by the Jennifer Belcher, Commissioner of Public Lands. They will also be nominated for national honors.

Nominations should be made on the form on the facing page. Please feel free to copy it.

Selected Additions to the Library of the Division of Geology and Earth Resources

November 1995 through January 1996

THESES


U.S. GEOLOGICAL SURVEY REPORTS

Published reports


WASHINGTON

DEPARTMENT'S GUIDING PRINCIPLES AND SURFACE Mine RECLAMATION

Raymond Lasnusis, State Geologist
Washington Division of Geology and Earth Resources
P.O. Box 47077, Olympia, WA 98504-7077

Starting in 1993, Department of Natural Resources (DNR) management developed a series of guiding principles to provide direction for the department. These guiding principles were endorsed by Commissioner of Public Lands Jennifer M. Belcher on January 20, 1995. These principles are that regulatory programs should encourage voluntary compliance and collaboration. Additionally, during 1995, the 54th Legislature passed an

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WASHINGTON GEOLoGY
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Washingon Geology (ISSN 1058-231X) is published four times each year by the Washington State Department of Natural Resources, Division of Geology and Earth Resources. This publication is free of charge. 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.

Washington Divisiom of Geology and Earth Resources

Sag River: The magnesium metal-producing operation of Northwest Alloys Inc. at Anacortes has operated here for many years, mining dolomite typically adjacent to the complex. Some areas near the use in being backfilled during mining. Water for the operation is stored in and reused from the pond (lower left); no water is released to the lake. The site is attractive to bird life and known for the diversity of plants in the area. Future use could include a nature center or bird sanctuary.


Division Releases

Liquefaction Features from a Subduction Zone Earthquake: Preserved Examples from the 1964 Alaska Earthquake. Report of Investigations 32, by Timothy J. Walsh, Rodney A. Combellick, and Gerald L. Black. This 80-page report describes results of investigations of four locations in southern Alaska. Liquefaction features, particularly in the eastern part of Turnagain Arm, are illustrated by photographs. Many photos are accompanied by sketches of stratigraphic details. This report was produced in cooperation with the Alaska Division of Geologic and Geophysical Surveys and the Oregon Department of Geology and Mineral Industries and supported by a grant from the U.S. Geological Survey. The price is $3.71 (+29 tax for Washington residents) = $4.00.

Geologic and Geophysical Mapping of Washington, 1984 through 1995, and Theses on the Geology of Washington. 1986 through 1995, Open File Reports 96-1, compiled by Connie J. Munson. Reports are listed by author, and 11 plates display mapped areas by map scale. This report supersedes OFR 95-2. Earlier mapping is covered in our Information Circulars 77 (geologic and geophysical mapping; out of print, but available in many libraries) and 80 (theses; still in print). This updated list of maps and theses costs $1.39 + .11 tax (WA residents only) = $1.50.

Flood Basalts and Glacial Floods—Roadside Geology of Parts of Walla Walla, Franklin, and Columbia Counties, Washington. by Robert J. Carson and Kevin R. Pugoe of Whitman College. This report, Information Circular 90, describes the region's general geology and features along a 200-mile loop route that begins and ends in Walla Walla. The many illustrations help readers understand the effects of the Mosquito fissure eruptions and the glacial outburst floods. The price is $3.24 + .26 tax (WA residents only) = $3.50.

Best Management Practices for Reclaiming Surface Mines in Washington and Oregon. by D. K. Norman, P. J. Wampier, A. H. Throop, E. F. Schintzer, and J. M. Roloff, has been produced as a cooperative project by the Department of Natural Resources and the Oregon Department of Geology and Mineral Industries. The first and last authors are DNR employees. This report is DNR's Open File Report 96-2 (Oregon's Open File Report O-96-2) and consists of seven chapters that discuss operating and reclamation techniques for controlling erosion, creating stable slopes, and revegetation, as well as information about satisfying regulatory requirements. The cost is $3.24 + .26 tax (WA residents only) = $3.50.

Our supply of Geologic guidebook for Washington and adjacent areas (Information Circular 86, edited by N. L. Joseph) is very small and consists entirely of copies with covers but loose pages. We offer the remaining copies at half price, $4.50; Residents of other states may subtract the 3.33 tax.