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BIBLIOGRAPHY OF THE GEOLOGY OF THE COLUMBIA BASIN AND SURROUNDING AREAS OF WASHINGTON

Washington State Department of Natural Resources
Division of Geology and Earth Resources

Open-File Report OF 79-5

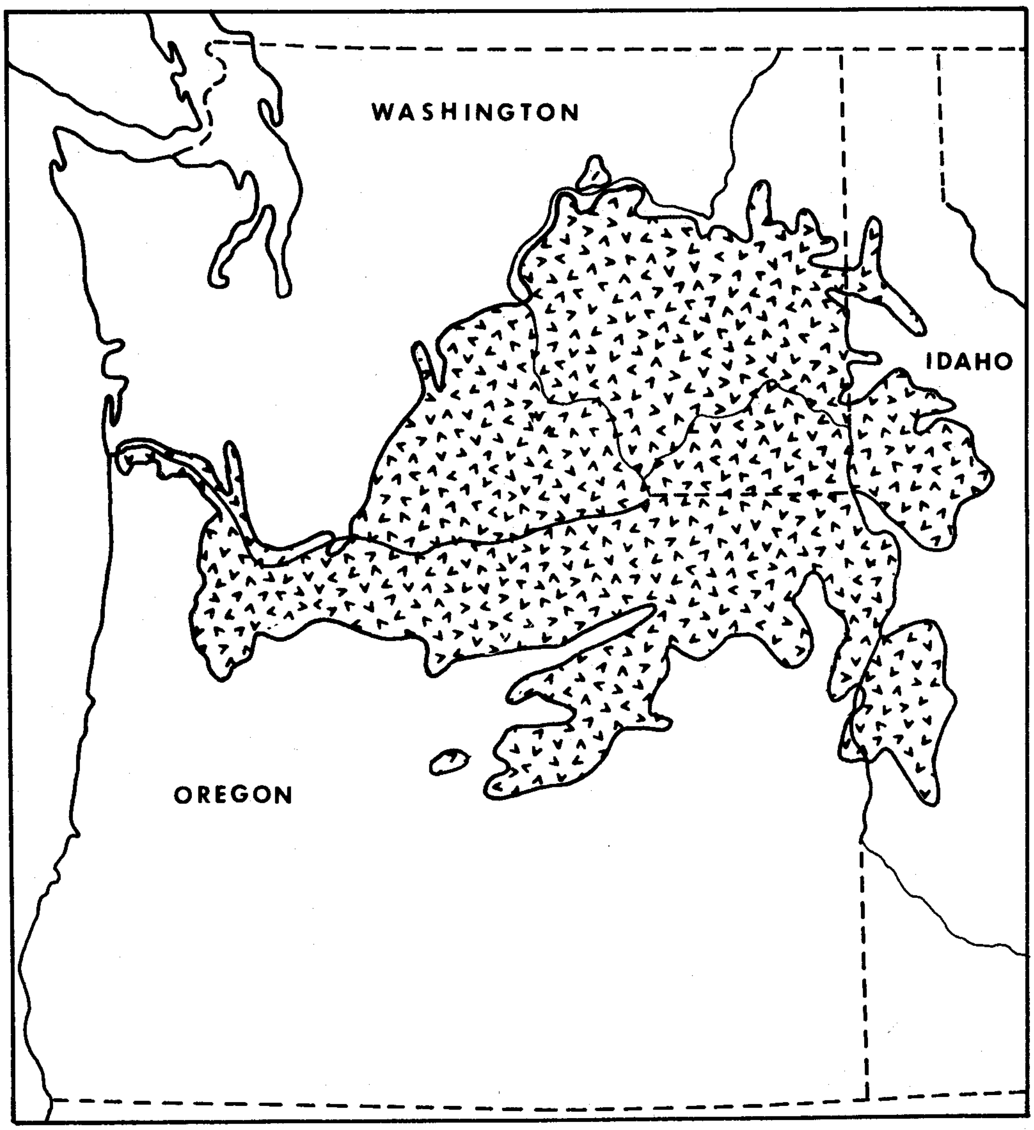
by

Glennda B. Tucker and James G. Rigby

Revised by

Glennda B. McLucas

July 1979



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Under Contract Number EY-77-C-06-1030

NOTICE

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This document is preliminary and has not been edited or reviewed for conformity with Washington Division of Geology and Earth Resources or Rockwell Hanford Operations standards and nomenclature

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INTRODUCTION

In the fall of 1977, the Washington State Department of Natural Resources, Division of Geology and Earth Resources (WDGER), entered into a contract with the U.S. Department of Energy, administered by Rockwell Hanford Operations (Rockwell) in Richland, Washington, as a principal contributor to a geologic study of feasibility of storing radioactive waste within Columbia River basalt. WDGER's responsibility was the production of this bibliography and a reconnaissance geologic map of the sediments overlying the Columbia River Basalt Group in the State of Washington. An outline of WDGER's study area appears on Figure 1.

A thorough review of all previous geologic investigations in the Columbia Basin was the initial objective of the WDGER study. In response to this objective, the first draft of the bibliography was published by Rockwell in March 1978. Within the following year, it was decided that the first draft required extensive revision and updating. In the meantime, the Washington Department of Ecology, Pacific Northwest Laboratories, the Oregon Department of Geology and Mineral Industries, and the Idaho Bureau of Mines and Geology completed bibliographies dealing with, respectively, hydrologic, remote sensing, Oregon, and Idaho aspects of Columbia Basin geology. Since the original WDGER bibliography contained sections dealing with these subjects, they were removed during the revision. Approximately 500 new citations were added as a result of geologic investigations that were completed within the year and the inclusion of reference material that had been overlooked during the original compilation. July 1, 1979, was used as the cut-off date for the inclusion of new citations. An author index was added and the index map series was updated and redrafted.

This bibliography is a compilation of all known published, unpublished, and open-file references dealing with geology and geophysics of the Columbia Basin of eastern Washington. The citations were obtained primarily from the WDGER and Washington State libraries; the "Geo-Ref" bibliographic system was also utilized. Because the WDGER portion of the study included preparation of a reconnaissance geologic map of surficial deposits in the Columbia Basin, available references dealing with this subject have been annotated. Many abstracts in the annotated section are quotations and have been copied directly from their respective publications.

An index map series dealing with geologic and geophysical maps, cross sections, columnar sections, type sections, and mineral resources in the Columbia Basin of Washington is included with the bibliography. The index maps are folded into the back of the bibliography and are accompanied by citation compilations in Appendices A, B, and C. The index maps have been produced from Army Map Service 1 degree by 2 degree base maps (scale 1:250,000) of the Okanogan, Ritzville, Spokane, Wenatchee, Yakima, Walla Walla, Pullman, The Dalles, and Pendleton. Instructions on the use of the index maps and compilations appear in the following Bibliographic Format Section.

Entries in the index map compilations represent all known published, unpublished, and open-file reference material, available to the author, containing geologic maps and sections and geophysical surveys. Leona Boardman's Index to Geologic Mapping in Washington and William H. Reichert's Compilation of Geologic Mapping in Washington through 1968 were used extensively. Some of the maps from these sources were not included because they were outdated, schematic, or had been superseded by a published map of the same area. Appendix D contains a separate list of these excluded map references.

Map Sheet T, Mineral Resources of the Columbia Basin, was adapted from the Washington Division of Geology and Earth Resources GM-22, Mineral Resources of Washington, By Wayne S. Moen (1978). For additional information regarding nonmetallic mineral resources in the Columbia Basin, please consult Washington Division of Geology and Earth Resources Bulletin 37, Inventory of Washington Minerals, Part 1, Nonmetallic Minerals, by Marshall T. Huntting (1960).

Some maps referenced in the index map compilation are unpublished WDGER field maps on file in the division library. While many of these maps have no known author or date, they represent valuable reference material.

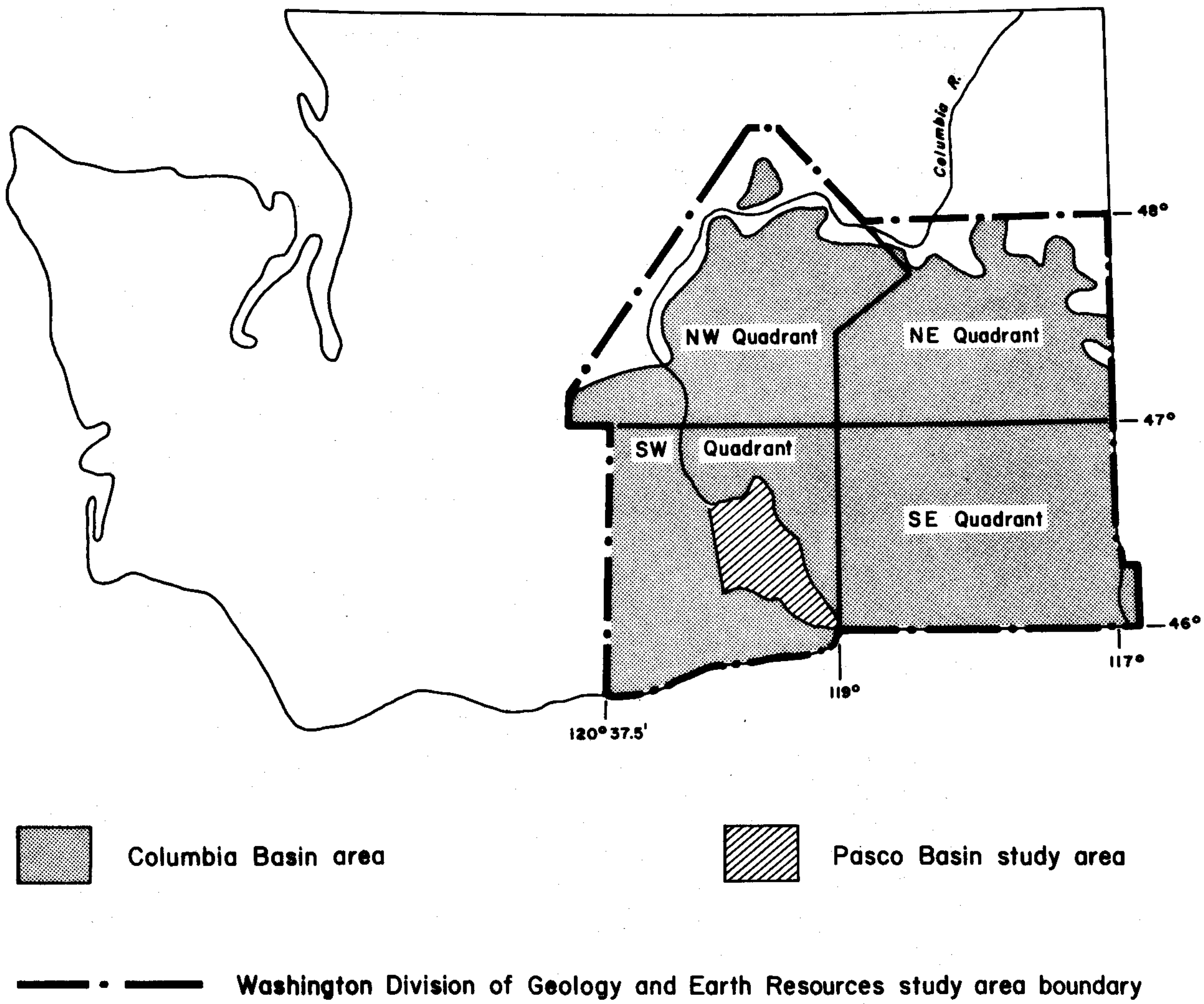

Figure 1. Study Area.

BIBLIOGRAPHIC FORMAT

The bibliography is presented in topical format, alphabetized by the author's last name within each category. Refer to the Table of Contents for a listing of the categories and to the Author Index for page numbers of entries by specific authors.

The alpha-numeric notations following some citations refer to geologic or geophysical maps or sections contained in the publication and included in the appended indices to geologic and geophysical mapping. To find a specific map or section, select the citation from the text or from the appropriate appendix, then note the alpha-numeric symbol at the right margin of the citation (e.g., Hanson, L. G., 1970, The origin ...., A-3). The capital letter represents the index map sheet (e.g., Map Sheet A, Okanogan) and the number represents the geologic map or section that is being sought.

Citations in the Surficial Geology category have been annotated and provide information according to the following format:

1. Location of study area;
2. Geologic units involved;
3. Method of investigation;
4. Type of information gathered;
5. Illustrations (geologic maps, sections, tables, charts);
6. Abstract.

AUTHOR INDEX

REFERENCES TO COLUMBIA BASIN GEOLOGY

SURFICIAL GEOLOGY (ANNOTATED)

Sedimentary Units

Alwin, J. A., 1970, Clastic dikes of the Touchet Beds, southeastern Washington: Washington State University M.S. thesis, 87 p.

1. Yakima, Benton, Franklin, Columbia, Garfield, Asotin, Whitman, and Walla Walla Counties, Washington.
2. Touchet Beds.
3. Each dike studied individually, its characteristics noted and recorded during field observation. Strike and dip recorded. Material subjected to sieve analysis and heavy minerals separated. Mineralogy determined by X-ray and optical methods.
4. Origin and nature of clastic dikes.
5. No geologic map. Built flume to simulate conditions of formation of original dikes with similar results. Photos of individual clastic dikes. Pole plot of 50 major dikes.
6. Touchet Beds are cyclic lacustrine sands and silts of Pleistocene age in southeast Washington. Many clastic dikes crosscut the beds from a few inches to 100 feet deep. Strike random; dip vertical. Width varies from less than 1 inch to several inches, mostly compounded to form vertically stratified dikes to 80 inches wide. Common features: claywall linings with chevrons, cross-stratification, graded beds, oriented grains. Primary structures indicate downward filling of dike crevices by sand and silt. Dikes represent fillings of perma-frost-related crevices.

Ames, K.; Fryxell, R., 1973, Two glacial tills at Grand Coulee Dam, Washington (abs.): Northwest Scientific Assoc., Abstracts of Papers, 46th annual meeting, p. 1.

1. Crown Point near Grand Coulee Dam, Washington.
2. Two glacial tills representing two glacial advances of Cordilleran Ice Sheet.
3. Field observation, sieving of till, X-ray diffraction of clay.
4. Sedimentary beds overlying Columbia River Basalt.
5. No geologic map or sections; field and lab data.

6. Superposed lodgment tills representing two different glacial advances of the Cordilleran Ice Sheet are exposed at Crown Point near Grand Coulee Dam. The lower till appears slightly more oxidized, contains more striated pebbles, fewer granitic clasts, more fragments 2-9 mm in diameter, and has a finer matrix than the upper till. X-ray diffraction peaks indicate montmorillonite is the dominant clay in the lower till, but is absent from the upper till; little illite and no vermiculite were found in the lower till, although both occur in the upper one. Striae on bedrock show both tills were deposited by easterly advancing ice.

Antevs, E., 1929, Maps of Pleistocene glaciations (excerpts): Geol. Soc. America Bull., v. 40, no. 4, p. 631-720. Washington, p. 648, 650, 653.

1. Excerpts of Washington State.
2. Pleistocene ice extent, drift borders.
3. Compilation of existing maps on extent of Pleistocene glaciation of northern and southern hemisphere.
4. See title.
5. Maps including Washington State showing Pleistocene mountain glaciation and borders of ice-sheets in southern Canada and U.S. west of 112th Meridian, scale 1:60,000,000.
6. Excerpt on Washington State: In northern Washington, Spokane and Vashon (Wisconsin) drift sheets are recognized. The Spokane drift, according to Alden, should probably be correlated with the Iowan. The Spokane border has been mapped through Spokane west-northwestward to the Columbia River (Bretz, 1928, plate 5). Here it seems to disappear under the Wisconsin drift. At about latitude 47° 50' north, longitude 119 1/2° west, its border inside the Wisconsin boundary has been relocated by Bretz.

   The Wisconsin drift border in the eastern part of Washington is compiled from data supplied by Stewart (1913, page 428), Pardee (1918, page 51), Anderson (1927), Bretz (1928), Salisbury (1901, page 722), and Russell (1900, page 169). Its course is not well known. In the Cascade Mountains there was a network of glaciers that was more or less confluent with the ice-sheet. The differentiation between these glaciers and the ice-sheet, especially on the east side of the mountains, is difficult to determine from the data now at hand.

The course of the drift border west of the Columbia River is unknown. On the west side of the Cascades the extreme limit of the last ice-sheet, the Puget Sound Glacier, is somewhat better known. On the lowland of Puget Sound and farther west the limit of the last continental glacier is satisfactorily established (Leighton, 1918; Bretz, 1920).

Barker, P. A., 1968, Glaciation of the Chelan Trough: Washington State University M.S. thesis, 52 p. D-1-65

1. Chelan Trough, Washington.
2. Glacial features in trough--especially terraces lining slopes at lower end of Lake Chelan. Basalt erratics also observed and measured. Moraines mapped, drumloidal topography, coulees, and small Pleistocene drainage ways noted.
3. All observable glacial features measured, sampled, and mapped.
4. Sedimentary and glacial beds and features overlying or adjacent to Columbia River basalt.
5. Description and map of glacial features as well as photos of individual features. Profiles of major north-side and south-side terraces.
6. Lake Chelan occupies classic glacial trough, created by Cascade glaciers, on east side of North Cascades. It was further modified by southwest trending continental Okanogan Glacier. Pleistocene sequence repeated in valleys west and north of Chelan Valley. Evidence for Okanogan Glacier is terraces (mostly kame) built alongside glacier, sloping uplake (west) and descending to lake level. At least 12 terraces on lower valley create giant staircase, more developed on north side of valley. The few basalt fragments and several basalt erratics were brought to area from continental glacier passing over terrain east of Columbia River.

Barksdale, J. D., 1941, Glaciation of the Methow Valley: Jour. Geology, v. 49, no. 7, p. 721-737, illus., incl. index maps; (abs.) Northwest Sci., v. 15, no. 4, p. 100.

1. Methow Valley, northeastern Cascade Range, Washington.
2. Glacial erosional and depositional features.
3. Field observations and measurements and discussion of previous literature.
4. Description of stages and extent of glaciation in Methow Valley from field evidence.
5. Location map of Methow River drainage; location map showing relation of upper Methow tributaries to those of the Pasayton; Methow quadrangle map showing glacial features and relationships.

6. Ice from the Methow drainage joined with ice of the Okanogan lobe during a glacial maximum, to form an almost continuous blanket covering all but the highest peaks of the northern Okanogan Mountains and the eastern Cascade Range. A true valley glacier occupied the Methow during a late phase of the glaciation, building moraines as far south as Libby Creek, but it did not join the Okanogan ice at the mouth of the Methow. The evidence does not warrant saying whether the maximum and the valley glaciation represent two separate stages or one stage with very slow retreat. Much glaciation of the Methow ice originated outside the Methow drainage area and was contributed southward through the present north-flowing Middle and West forks of the Pasayten River.

Beck, G. F., 1940, Late Tertiary stratigraphy and paleontology of south-central Washington and adjacent Oregon (abs.): Geol. Soc. America Bull., v. 51, no. 12, pt. 2, p. 2018.

1. South-central Washington.
2. Ellensburg Formation, Ringold Formation, Columbia River Basalt.
3. & 4. Paleontological study of plant and animal collections from south-central Washington to revise interpretations of late Tertiary geology of area.
5. ---
6. Recent fossil plant and animal collections, especially of vertebrates, from East-Selah, Buena, Snipes Mountain, Toppenish Ridge, Roosevelt, Arlington, Boardman, Taunton, and Othello, promise to revise interpretations of the late Tertiary geology of the areas cited. Whereas originally the Columbia lavas and superjacent sediments were accepted as a unit in time (middle Miocene), it now appears they accumulated without essential interruption throughout much of the late Tertiary.

   The post-lava Tertiary faunas now seem divisible into a western Lower Pliocene sequence and an eastern Upper Pliocene sequence without requiring a corresponding unconformity in the associated sediments. It is suggested that the sediments encroached upon the lavas progressively from west to east, with primitive hipparions at the upper basalt boundary in the Ellensburg (western) province and the plesippus appearing directly above the basalts in the Ringold (eastern) province.

As early as late Miocene, palagonite phases with associated entombed raft forests suggest a general subsidence in the basalts of the Ellensburg province. In about mid-Pliocene, sedimentation seems to have begun a shift toward the east. Thus the Ellensburg beds typically intercalate among the upper Columbia lavas, while the Ringold do not. Both are conformable with the basalt.

At least local peneplanation seems to have truncated Columbia lavas, Ellensburg sediments, and Ringold beds. Upon this erosion surface a distinctive caliche zone has been developed.

______, 1966, The Yakima Basalt and Ellensburg Formation of south-central Washington: U.S. Geol. Survey Bull. 1224-G, 15 p. Figure 2, 1:7,000,000.

1. Ellensburg-Yakima area between T. 12 N. - T.18 N. and R. 17 E. - R. 24 E., Kittitas and Yakima Counties, Washington.
2. Columbia River Basalt Group and Ellensburg Formation.
3. Field observations, measurement and designation of type sections.
4. Stratigraphic description of Columbia River Basalt Group and Ellensburg Formation.
5. Composite stratigraphic sequence in the northwestern Columbia Plateau; location of type sections of Yakima Basalt; descriptions of members.
6. The uppermost part of the Yakima Basalt - herein assigned to the Columbia River Basalt Group - has the following largely conformable units (from oldest to youngest): lower basalt flows; the Vantage Sandstone Member; the Frenchman Springs Member, which locally includes the Squaw Creek Diatomite Bed; the Roza Member; the Priest Rapids Member, which locally includes the Quincy Diatomite Bed; and the Saddle Mountains Member. Sedimentary deposits of the Ellensburg Formation interfinger with basalt flows of the youngest member of the Yakima Basalt.

   The maximum thickness of the Yakima Basalt is not known, but the formation is about 4,500 feet thick at a test well drilled in the Odessa area, and is probably much thicker toward the center of the Columbia Plateau. The part described herein has a composite thickness of about 1,200 feet above the Vantage Sandstone Member. The overlying and interfingering Ellensburg Formation is as thick as 2,000 feet in the type area, and the Beverly Member, which represents the lower part of the Ellensburg in the Sentinel Gap area, is as thick as 300 feet.

The Yakima Basalt is late Miocene and early Pliocene in age, as determined from the flora and fauna in the underlying Mascall Formation in Oregon, the intrabedded sedimentary rocks and the interbedded and overlying Ellensburg Formation.

Birkeland, P. W.; Crandell, D. R.; Richmond, G. M., 1971, Status of correlation of Quarternary stratigraphic units in the western conterminous United States: Quaternary Research, v. 1, no. 2, p. 208-227.

1. Rocky Mountains to Pacific Coast in western conterminous U.S.
2. Quaternary deposits including those of Snake River Plain, Idaho, western Washington, and Cascade Range, Washington.
3. Correlation (on charts) of representative sequences of deposits of Quaternary environment based on published and unpublished work; radiocarbon, K/Ar, and U-series dating; rock magnetism; fossil ages; and key volcanic horizons used in correlation.
4. Correlation of representative sequences of Quaternary deposits from a variety of environments.
5. Charts showing status of correlation between stratigraphic units of early to middle Quaternary age in western U.S.
6. Deposits of Quaternary age from the Rocky Mountains to the Pacific Coast in the western conterminous U.S. represent a great variety of environments. The deposits include those of continental and alpine glaciers, glacial meltwater streams, non-glacial streams, pluvial lakes, marine environments, eolian environments, and mass-wasting environments. On two charts we have attempted to correlate representative sequences of deposits of many of these environments, based on published sources and recent unpublished investigations. Evidence for correlation is based mainly on stratigraphic sequence, soil characteristics, the amount of subsequent erosion and interlayered volcanic ash beds identifiable as to source. Chronologic control is based on numerous radiocarbon dates. U-series dates on marine fossils, and K-Ar dates on volcanic rocks. The Bishop volcanic ash bed and one of the Pearlette-like volcanic ash beds appear to represent significant regional key horizons, respectively about 700,000 and 600,000 years old. Rock magnetism is shown to suggest the paleomagnetic polarity at the time of rock deposition. Assigned land-mammal ages of included fossils help to put limits on the age of some units.

Blinman, E.; Mehringer, P. J., Jr.; Sheppard, J. C., 1977, Pollen influx and the depositional chronologies of Mazama and Glacier Peak tephra (abs.): Geol. Soc. America Abs. with Programs, v. 9, no. 7, p. 901.

1. Pacific Northwest.
2. Pollen in tephra deposits.
3. Analysis of pollen content in lake sediment and tephra deposits.
4. See title.
5. ---
6. Pollen content of lake sediments and tephra can be used to estimate the duration of short term depositional events. When pollen influx estimates are applied to volcanic ash they may also provide information on the season and ecological effects of ash falls.

   At Lost Trail Pass Bog, Montana, two distinct layers of Glacier Peak ash were separated by 7.5 mm of lake sediment containing 10-20 years of average pollen for the vegetation at that time. The later fall of 7.3 cm of Mazama ash contained nearly 3 years of pollen as compared with the average pollen influx of adjacent lake sediments. Subsampling of Mazama ash revealed that it first fell in autumn and nearly 4.9 cm were deposited before spring. The remaining 2.4 cm fell sporadically during the next two years.

   Sediments from a scabland lake of eastern Washington contain a different and more complex record of the Mazama ash fall. Here, two ash layers are separated by 24 cm of organic sediments. The low pollen and low detritus contents of the lower portion of each ash are indicative of two distinct airfalls. Nearly 6 m of secondary Mazama ash were deposited during the 1200 years following the second ash fall.

Blissenbach, E., 1954, Geology of alluvial fans in semi-arid regions: Geol. Soc. America Bull., v. 65, no. 2, p. 175-189.

1. Semi-arid regions, including southeastern Washington.
2. Alluvial fan sediments.
3. Field observations.
4. See title.
5. --
6. An alluvial fan is a body of detrital sediments built up at a mountain base by a mountain stream. Bold relief is essential, moderately arid to semi-arid climate favorable for the development of fans. The depositing agents are sheet floods, stream floods, and streams. Compound alluvial fans result from lateral coalescence of single fans.

Development of alluvial fans is affected by changes in the course of a cycle, varying base level, climatic changes, tectonic movements, and slumping of fan deposits. Telescoped or superimposed structure may be developed.

Fan deposits are arkosic or graywacke. Sorting and roundness of particles range widely. The matrix is primary or secondary. In general, alluvial-fan deposits are stratified. Channel cut-and-fill is pronounced. Individual strata in fans are up to 20 feet thick. Particles in stream deposits are inbricated.

Talus-slope deposits at the apex of a fan, and floodplain deposits at its base, can be separated from those of an alluvial fan by particle sizes, angularity and orientation of fragments, sorting, and original dip of strata. Mudflow deposits in an alluvial fan indicate certain climatic conditions during its formation.

Many ancient fan deposits may have escaped recognition because of the common misconception that fan deposits are necessarily unstratified, composed of angular fragments, poorly sorted, and without distinctive sedimentary structures.

Borchardt, G. A.; Harward, M. E.; Schmidt, R. A., 1971, Correlation of volcanic ash deposits by activation analysis of glass separates: Quaternary Research, v. 1, no. 2, p. 247-260.

1. Cascade Mountains, Pacific Northwest.
2. Volcanic ash: Glacier Peak, Mazama, Mount St. Helens, Newberry.
3. Neutron activation analysis and computer program analysis.
4. See title.
5. Location map of volcanic ash sampling sites; mean elemental compositions of glassy separates from several volcanic ash sources in Cascade Range; coefficients of variation for regional ash samples.
6. Volcanic ash deposits whose source is the Cascade Mountains area were correlated on the basis of 19 elemental abundances obtained by instrumental neutron activation analysis (INAA). After activation of glassy separates in a TRIGA reactor, gamma ray spectra were obtained and analyzed with computer programs. The elements Na, Sm, Sc, Fe, Ce, Hf, and Th were determined with relative standard deviations less than 5%; the precision for La, Co,

Eu, Yb, Cs, Ba, and Lu was less than 17%; larger errors were obtained for Rb, Ta, Nd, Tb, and Cr. A statistical method was developed for correlation on the basis of relative elemental compositions unique to the ash deposits. Elemental abundances of Mazama glassy separates were independent of distance for the source. The site to site chemical variability of crystal rich Glacier Peak and St. Helens ash layers was greater than for Mazama and Newberry ashes. The Rb, Yb, Lu, Th, and Ta contents in Newberry glass were more than twice those in Mazama glass. The concentrations of trace elements in Glacier Peak and St. Helens ashes generally were less than one-half those in Mazama glass. The presence of Mazama ash has been confirmed at sites in Oregon, Washington, Alberta, and in sediments of the Pacific Ocean.

Bretz, J H., 1919, The late Pleistocene submergence in the Columbia Valley of Oregon and Washington: Jour. Geology, v. 27, p. 489-506.

1. Columbia Valley, Washington and Oregon.
2. Pleistocene sediments and glacial features.
3. Review and reinterpretation of previous literature and presentation of new evidence.
4. Data to substantiate Pleistocene submergence of Columbia Valley including descriptions of gravel terraces, lacustrine sediments, foreign boulders, and debris.
5. Figure showing areal extent of submergence.
6. Article reviews previous references to a Champlain submergence in the lower drainage of Columbia River, eliminates erroneous interpretations and correlates data belonging to the subject, presents more evidence in support of submergence, correlates this with the Pleistocene history of northwestern Washington, and raises unanswered questions.

______, 1923, Glacial drainage on the Columbia Plateau: Geol. Soc. America Bull., v. 34, no. 3, p. 573-608.

1. North Columbia Plateau, Washington.
2. Glacial depositional and erosional features.
3. Field investigations.
4. See title.
5. Maps of: glacial drainage features of east-central Washington; glacial ice and drainage near Spangle, Washington; part of Drumheller Channels Plexus; The Potholes.

6. Geological history of northern part of Columbia Plateau and discussion of erosive force of glacial streams over large tracts of land far from ice front. Discussion of topography and drainage physiography and glaciation of region. Spokane glaciation is discussed in terms of Spokane River, Palouse River, Crab Creek drainage, and Moses Coulee. Wisconsin glaciation in region also discussed.

______, 1924, The age of the Spokane glaciation: Am. Jour. Sci., 5th Ser., v. 8, p. 336-342, 1 fig.

1. Northern portion Columbia Basalt Plateau, Washington.
2. Columbia River Basalt as cliffs along stream channels.
3. Solution to problem of the relative lapse of time since Spokane glaciation by determining the ratio of height of talus to height of cliff and working out a mathematical model.
4. Same as above.
5. ---
6. In order to determine the age of Spokane glaciation, author finds the relative lapse of time since each glaciation (Spokane and Wisconsin) by studying the ratio of height of talus (accumulated at bottom of stream channel basalt cliffs in eastern Washington) to height of cliffs. Conclusion is that the times of fill are directly proportional to the squares of the heights filled. Angles of repose and densities of fills do not vary with ratios obtained. The result is that the lapse of time since Spokane glaciation is 2.25 times as great as that since Wisconsin glaciation. This makes the Spokane equivalent to the Iowan or early Wisconsin.

______, 1929, Valley deposits immediately east of the Channeled Scabland of Washington, 1-11: Jour. Geology, v. 37, p. 393-427, and 505-541, 6 fig.; (abs.) Revue de Geologie et des Sciences Connexes, v. 10, no. 8, p. 308, 1929.

1. East of Channeled Scablands, southeast Washington.
2. Pleistocene valley flood deposits.
3. Field observations, measurements and correlations of Scabland flood deposits in support of Spokane flood.
4. Same as above.
5. Figure showing location of valley deposits east of Scabland.

6. Forty-one valleys whose drainage enters the eastern margin of scabland spillways are known to contain deposits made by glacial waters. Thirty-nine of these valleys never have carried drainage from glaciated areas, and the glacial waters in them must have been backed up from the scabland. These deposits possess such extraordinary features and relations that they, like the scabland topographic forms, are considered unique.

    1. Each separate area of backwater is recorded by a widespread mantle of silt containing abundant grains of unweathered basalt (the country rock) and pebbles of foreign rock.
    2. In each, this mantle extends up to a definite upper limit on the valley slopes and along the valley lengths.
    3. These upper limits in each case agree closely with the upper limit of scabland where the valley enters.
    4. The altitudes of the upper limits, constant throughout any one back-water area, vary with different pondings, forming a descending series from north to south along the scabland gradient.
    5. Remarkable large mounded gravel deposits in the tributary valley debouchures possess foreset strata which dip out of the scabland and up the valleys. The composition, topography, topographical relations, structure, and size of these deposits are inexplicable without great reverse currents.
    6. In no case could these reverse currents continue through and escape from the valleys they entered. They are simply a record of the rapid backflow into these valleys.

    It is concluded that these glacio-aqueous deposits cannot be explained by conditions associated with ordinary glacial ablation or by a sequence of several Pleistocene epochs. They require the volume and rapid rise of glacial rivers across the plateau, which the writer has previously read from the scabland itself.

______, 1930, Valley deposits immediately west of the Channeled Scabland: Jour. Geology, v. 38, no. 5, p. 395-423, 14 fig.; (abs.) Revue de Geologie et des Sciences Connexes, v. 11, no. 11, p. 519-520, 1930.

1. Western margin of scabland, both in Columbia Valley and Yakima Valley, Washington.

2. Columbia River Basalt, Swauk shale and sandstone, glacial and other sedimentary beds overlying basalt.
3. Field observations, measurements and correlation of glacial and fluvial features in support of the Spokane Flood theory.
4. Same as above.
5. Cross-section of Yakima Valley through Chandler Narrows; contour map of Yakima Valley.
6. If a "Spokane Flood" ever occurred, and if the valley system of eastern and central Washington was already in existence, these valleys must have become channels and abnormal deposits of great magnitude must have been formed. This paper calls attention to such deposits along the western margin of the scabland, both in Columbia Valley, a main discharge route, and in Yakima Valley, a capacious tributary valley entering from an area unaffected by the flood. Three extraordinary situations are given especial attention: the mouth of Moses Coulee, the Columbia Valley deposits near Trinidad, and the truly astounding features in lower Yakima Valley. The conclusion is reached that nothing short of a catastrophic flood can explain these features. Skepticism can be justified only by the construction of workable alternatives.

Brown, D. J.; Brown, R. E., 1958, Subsurface eolian deposit at the Hanford Project, Washington (abs.): Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1676-1677.

1. Hanford Reservation, Pasco Basin, Washington.
2. Eolian deposit overlying Ringold Formation.
3. Mineral composition and mechanical properties analyses and grain size analysis.
4. Stratigraphic relationship, age, and origin of eolian deposit.
5. ---
6. A subsurface eolian deposit of silt and clay occurs at the Hanford Project in the Pasco Basin of Washington. It is buried beneath a mantle of glacial outwash and materials correlated with the Touchet beds and was found and explored by extensive drilling during investigations for Hanford's waste-disposal program. The deposit is believed to be of eolian origin, similar to the main body of the Palouse Formation of eastern Washington. It lies directly over the Ringold Formation close to the Ringold type locality at White Bluffs and appears to have been derived from that formation.

If this subsurface eolian deposit is equivalent to the Palouse loesses, additional evidence will be established to indicate that at least part of the Palouse Formation was likewise derived from the Ringold Formation. Supporting the eolian origin of the deposit at Hanford are characteristics similar to eolian deposits elsewhere. These include (1) a high quartz, mica, and chlorite content in contrast to the composition of adjacent, underlying and overlying deposits, (2) all particles of a size characteristic of wind-blown material, and (3) quartz and feldspar grains subangular and slightly frosted.

Inasmuch as this deposit overlies the Ringold Formation and underlies the glacial sediments, it is post-Ringold and pro-latest glaciation in age. This stratigraphic position supports the general concept that at least part of the equivalent Palouse loess was deposited before the close of the latest glacial age.

Brown, D. J., 1959, Subsurface geology of the Hanford separation areas: Hanford Atomic Products Operation Report HW-61780, 21 p.

1. Hanford atomic works, Richland, Washington.
2. Ringold Formation, Columbia River Basalt, glaciofluviatile sediments, Palouse Formation, Ellensburg Formation.
3. & 4. Field investigations and well-log interpretations leading to summary of subsurface geology of part of the Hanford Works.
5. Several cross sections, map showing contours of basalt bedrock and Ringold Formation.
6. Five geologic units are known beneath the region in which Hanford's chemical processing plants are located. In ascending order these include the Columbia River basalts and the interbeds of the Ellensburg Formation in the upper part of the basalt series, the Ringold Formation, Palouse soil, and a thick deposit of fluviatile and glaciofluviatile sediments.

The Columbia River basalts form the bedrock beneath the separation areas. Overlying the basalts and largely conformable with them are several hundred feet of lacustrine and fluviatile sediments known as the Ringold Formation. Three lithologic zones of the Ringold Formation are characterized by their designation of: lower

"blue clay" zone; middle conglomerate zone; and upper silt zone. Capping most of the Ringold Formation is a thick layer of calcium carbonate or caliche, representing an old land surface. Unconformably overlying the Ringold Formation in the western part of the areas is an eolian deposit correlated to the Palouse soil of eastern Washington. Above this deposit, and also unconformable with the Ringold Formation, are several hundred feet of glaciofluviatile sediments. These are coarse materials made up largely of sands, gravels, and boulders.

The basalts, interbasalt sediments, and the Ringold Formation are measurably though not greatly tectonically deformed.

______, 1960, An eolian deposit beneath 200-West area: Hanford Atomic Products Operation Report HW-67549, 11 p.

1. 200-west area, Hanford, 4 miles east of Yakima Ridge.
2. Eolian sediments overlying Ringold Formation and underlying Touchet sediments.
3. Earth samples were collected from wells drilled in region surrounding 200-west area, mechanical analyses, cation exchange studies, and mineral composition studies performed.
4. Cation exchange capacity, mineral and mechanical analyses of Touchet sediments, the eolian deposit, and the Ringold Formation were determined and origin of eolian deposits therefore determined.
5. Distribution and thickness of eolian deposit beneath 200-west, tables showing cation exchange capacity, mineral composition, and mechanical analyses of Ringold Formation, eolian deposits, and Touchet sediments; table showing average heavy mineral frequencies of the 50-100M size fraction from Palouse, eolian deposit, Touchet, Ringold Formation and Ellensburg Formation 50:1 profiles.
6. Physical examination of materials from geologic strata underlying 200-west area show bed of eolian loess to 70 feet deposited on Ringold Formation erosional surface. Cation exchange capacity of loess 50 to 70% higher than other material lying above water table is factor governing volume of radioactive waste dischargeable to ground without creating radiological hazard. This uniform, fine-grained material would be expected to influence pattern of downward percolation of wastes discharged to ground.

______, 1962, Geology underlying Hanford Reactor Areas: Hanford Atomic Products Operation Report HW-73337, p. 212-218.

1. Hanford Atomic Works, south-central Washington.
2. Ringold Formation, glaciofluviatile sediments, Columbia River Basalt.
3. & 4. Interpretation of geologic environment from well-log data and field investigations.
5. Contour maps of surface of Ringold Formation and basalt in study area, several schematic cross sections, and contour map of water table.
6. There are three distinct geologic units beneath the reactor areas: The Columbia River basalt, the Ringold Formation, and the glaciofluviatile sediments. The Columbia River basalt series forms the bedrock beneath the reactor areas and is generally compact, hard, and dense. The surface of the basalt series reflects the structure of the flows and is only locally modified by erosion. The Ringold Formation overlies and is largely conformable to the basalt. This formation is an extensive lacustrine and fluviatile deposit of sand, silt, gravel, and clay. The three members of the Ringold Formation distinguishable elsewhere on the Hanford Project are not readily differentiated beneath the reactor areas. Unconformably overlying the Ringold Formation to a maximum depth of 170 feet is a sedimentary deposit of fluviatile and glaciofluviatile outwash sands and gravels. This unit is referred to at Hanford as glaciofluviatile sediments. The coarse materials of this deposit which are more abundant in the northwestern section of the project, grade into finer materials to the east and south.

   The structure of the materials underlying the reactor areas reflects the deformation which has been going on essentially continuously for the last several million years. The lower beds of the Ringold Formation exhibit the greatest degree of conformity with the basalt with successively higher beds showing less and less deformation. Contours of the basalt surface and the Ringold surface reflect this orogeny in that the topographic highs on the basalt surface lie in the same position as the highs on the Ringold surface.

   The contour of the water table in the region underlying the reactor areas reflects strongly the contact between the Ringold Formation and the

glaciofluviatile sediments. The most rapid ground-water movement rates were noted in glaciofluviatile-filled channels incised in the Ringold sediments.

Brown, D. J.; Brown, R. E., 1962, Touchet clastic dikes in the Ringold Formation: Hanford Atomic Products Operation Report HW-SA-2851, 11 p.

1. Northwestern end of type Ringold Formation locality at the White Bluffs on the Columbia River, Washington.
2. Clastic dikes in Ringold Formation and the Touchet material of which they are composed.
3. Field observation.
4. Field measurements of size and location of dikes.
5. Photographs of dikes.
6. Undoubtedly many different processes were involved in the formation of the clastic dikes in the Columbia Basin region. It is possible that these different processes and combinations of them varied from time to time and from place to place creating a multiplicity of dike forms. At least one of these processes, however, must account for the presence of clastic dikes within the Ringold sediments as they cannot be explained by filling of landslide fissures or fissures caused by slumping of the basalt bedrock, as in the case of the Clarkston deposits. It is suggested that surface earthquake waves moving through the Ringold Formation and saturated Touchet sediments could provide the mechanism of forming the fissures in the Ringold and injecting the Touchet sediments downward.

______, 1965, Problems associated with the extension of the stratigraphic units of south-central Washington: Part 1, The late basalt flows, Ellensburg and lower Ringold Formations: Battelle Memorial Institute Pacific Northwest Laboratory Report BNSA-1365, 11 p.

1. South-central Washington.
2. Ellensburg and lower Ringold Formations, late basalt flows.
3. Review of existing stratigraphic descriptions and nomenclature for the above rock units for purposes of regional correlation.
4. Same as above.
5. Two figures showing stratigraphic sequences and showing thickening section toward the Pasco Basin.
6. Paper attempts to consolidate and interpret geological studies at Hanford of last 18 years and relate

it to classical stratigraphic units within and without the plant area. The Pasco Basin, lying at the structural and topographic low point of eastern Washington and at the stratigraphic high point, is the meeting ground for many of the geologic units of eastern Washington. The Columbia River has traversed the Pasco Basin for many millions of years so that some record of all geologic events in its drainage basin in that time period are there recorded. Report summarizes recent work and attempts and evolutionary solution.

______, 1965, Problems associated with the extension of the stratigraphic units of south-central Washington; Part 2, The post basalt sediments: Battelle Memorial Institute Pacific Northwest Laboratory Report BNSA-135, 10 p.

1. South-central Washington.
2. Ringold Formation, Palouse soil, Touchet beds, glacial outwash gravels.
3. Compilation of new field evidence to correlate the post-basalt sediments in south-central Washington.
4. Extensions and definitions of units at type localities followed by simplified correlations throughout region.
5. Historical geology of south-central Washington; review of previous formational descriptions, stratigraphy and nomenclature.
6. Paper describes the four principal stratigraphic units as found in Pasco Basin and presents possible chronological sequence of events to explain various relationships observed between each unit at that site. Several published descriptions of stratigraphic units discussed to show problems of correlation of these sediments.

Brown, D. J., 1965, Correlation of sediments overlying the Columbia River Basalt in southeastern Washington (abs.): Geol. Soc. America Spec. Paper 82, p. 321.

1. Southeastern Washington.
2. Fluvial, glaciofluvial, lacustrine, and eolian deposits overlying Columbia River basalt, e.g., Ellensburg and Ringold Formations, Palouse soil.
3. Field observations and development of geologic history of southeastern Washington.
4. See title.
5. ---
6. New evidence makes possible the correlation of the fluvial, glaciofluvial, lacustrine, and eolian

deposits which overlie the Columbia River basalt in southeastern Washington. These correlations suggest that during the Pliocene, with gradual cessation of volcanic activity, the region existed as a broad and very shallow basin. Small lakes dotted much of the region, and streams and rivers flowed into the basin from the west, north, and east. At the close of the Tertiary, tectonism significantly altered the drainage pattern of the basin. Most of the fluvial sediments in the western portion of the basin (Ellensburg Formation) became isolated and in the central portion of the basin (Pasco Basin), a shallow inland lake or floodplain was created. Lacustrine and fluvial sediments continued to accumulate on top of the Ellensburg deposits in the Pasco Basin and gave rise to the Ringold Formation. Continued tectonism formed the Lewiston Basin to the east. Following an interglacial age a thick wedge of sands and gravels which later became cemented was deposited in the Pasco and Lewiston Basins. Evidence suggests that at the beginning of an interglacial age, thick deposits of eolian sediments accumulated (Palouse soil). Many of the smaller lakes were filled in, and the longitude hills of eastern Washington were created. At the close of the last glacial age, a layer of glaciofluvial sediments was deposited over parts of southeastern Washington. In slackwater areas, finer-grained sediments accumulated (Touchet beds), and the remaining portion of the region was covered by the outwash gravels. Consideration should be given to reconciling the differences which exist in the names and descriptions of these sedimentary deposits.

Brown, R. E.; McConiga, M. W., 1960, Some contributions to the stratigraphy and indicated deformation of the Ringold Formation: Northwest Sci., v. 34, no. 2, p. 43-54.
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1. Ringold Formation type locality, western Franklin County, Washington, 12 miles north of Richland.
2. Ringold Formation.
3. Five beds were traced and surveyed. Recorded data of earlier work were then correlated and reconciled as necessary. Continuous red silt bed used.
4. Accurate detailed stratigraphic sequence of beds of type Ringold Formation and their attitudes.
5. Longitudinal section through Ringold Formation in White Bluffs from Saddle Mountains to Yakima River-Columbia River junction. Well log information.
6. Ringold beds dip westward, at angles less than 1 degree, at type locality. Dip directions of

Ringold beds in Pasco Basin generally parallel those of underlying basalt and are radially inward toward center of Pasco Basin toward axis of Pasco syncline. Suggests these variations from horizontal attitude are not depositional dips. Deformation by differential compaction cannot be ruled out; however, parallelism of dip direction of Ringold sediments and the basalts, the general agreement in order of magnitude of angle of dip, conformity of conglomerate with basalts in the Yakima River outcrop, and dips of the blue clays up to 20° NE, question whether roles played by deposition and compaction are more than locally significant. Newcomb shows that Ringold conglomerate was deposited by southeastward-flowing stream. Local westward to northwestward dips (upstream) in that conglomerate, substantiated by comparable dips in higher and lower beds, indicate post-depositional warping. Proof that type Ringold beds are not necessarily flat-lying favors the acceptance that tilted Ringold-type beds, mapped by others in surrounding area, are Ringold. Sedimentary sequence, traced across Pasco Basin, helps assure this. Gradual general decrease in dips upward in Ringold section favors continuous deformation throughout Pasco Basin during period of depositon. Interpretation requires neither sudden cessation of deformation that produced latter part of 2-stage impoundment of Newcomb, nor deformation localized to anticlinal ridges alone. Deformation, according to this interpretation, could still be continuing.

Brown, R. E., 1960, An introduction to the surface of the Ringold Formation beneath the Hanford Works area: Hanford Atomic Products Operation Report HW-66289, 10 p.

1. Hanford Works area, Washington.
2. Ringold Formation surface.
3. Interpretation of well logs.
4. Concept of extensively channeled, highly irregular erosion surface on Ringold Formation beneath Hanford Works.
5. Description of topography of the Ringold surface.
6. Distinction between Ringold Formation sediments and recent fluviatile gravels, on the basis of properties affecting waste behavior, was made and these data were geologically correlated to the lithologic evidence, resulting in evidence that the surface of the Ringold Formation is extensively and irregularly eroded. This surface was formed by the Columbia River prior to deposition of the

recent fluviatile gravels. A network of river channels crosses the Hanford area and dissects what was an earlier extensive erosional or land surface sloping gently from the hills toward the Columbia River. Many of the channels now bottom beneath the current groundwater table. Where this occurs, groundwater flow toward the Columbia River is at least potentially at quite rapid rates through the highly permeable fluviatile gravels.

Brown, R. E.; Brown, D. J., 1961, The Ringold Formation and its relationships to other formations: Hanford Atomic Products Operation Report HW-SA-2319, 17 p. F-2-154

1. Southeast Washington.
2. Ringold Formation and relationship to Ellensburg Formation, Palouse soil, upper basal flows, Touchet beds, and glaciofluvial deposits.
3. Literature review and field observations.
4. See title.
5. Geologic cross-section-Hanford Works; geologic map of the Ringold Formation surface beneath Hanford Works.
6. The Ringold Formation in the Pasco Basin, Washington, is the key to resolving the Pleistocene history of eastern Washington. It also is important in waste-disposal operations of the General Electric Company at the Hanford Works. The formation is divisible into three generally recognizable lithologic members. These grade from the underlying interbasalt sediments of Miocene-Pliocene age into overlying late Pleistocene to Recent(?) sediments. Lowermost beds of the Ringold sequence are generally conformable to folded older basalt flows and interbasalt sediments and appear to be alluvial fan deposits equivalent to upper Ellensburg beds. Higher beds are progressively less folded. Two erosion periods followed Ringold Formation deposition. Caliche caps remnants of the older unconformity and is overlain by eolian silts, probably equivalent to Palouse soil. The younger unconformity locally truncates the older. It formed during excavation of Washington's channelled scablands before deposition of the latest glaciofluviatile sediments. Downward extension of the Ringold section to the basalt series, its continuity with Miocene-Pliocene sediments, and the unconformities separating it from late Pleistocene to Recent(?) sediments suggest that it more probably is early rather than late Pleistocene in age.

Brown, R. E., 1966, The relationships between the Ellensburg and Ringold Formations in the Pasco Basin: Northwest Sci., v. 40, no. 1, p. 37.

1. Pasco Basin, Washington.
2. Ellensburg Formation and Ringold Formation.
3. & 4. Description of geologic history of Pasco Basin.
5. ---
6. Final solution of the Ellensburg-Ringold Formations relationship now appears most nearly possible through the regional geologic history.

Downwarping of south-central Washington was under way by late Miocene time. Basalt flows, emanating from northern Oregon, repeatedly flooded the basin and kept pace with downwarping. The oldest Ellensburg Formation sediments formed sheetlike deposits extending into the basin where they interfingered with the basalt flows.

Anticlinal uplift began in earliest Pliocene time, concomitant with less frequent outpouring of basalt flows and greater emission of volcanic debris of the Ellensburg Formation sediments. These sediments accumulated in the synclinal valleys, in places burying the anticlinal ridges. The Columbia River, flowing southwestward east of Yakima, was diverted farther eastward as flow emission decreased, the basin continued to subside, and the Ellensburg fans accordingly grew eastward. Lowermost Ringold Formation beds were deposited in quiet water east of the main Columbia River simultaneously with deposition of some of the Ellensburg Formation farther west. Downwarping of the basin, especially along north-south axes, and the continued rise of the Horse Heaven Hills further ponded the Columbia River, which continued to flow over those low hills, however. More widespread deposition of the Ringold Formation sediments and consequent overlap or transgressive relationships resulted from the increasing closure of the basin.

Erosion of Wallula Gap was speeded by the steepening dip on the south limb of the fold. As base level lowered in spite of continued rise of the anticline, by mid-Pleistocene time much of the Ringold Formation had been removed by the Columbia River flowing west of its current course, and a widespread angular unconformity was created. Further scouring of the formation in latest Pleistocene and early Recent times by the glacial meltwaters and floodwaters immediately preceded deposition of the scabland gravels, glaciofluvial deposits, and Touchet beds.

The indicated history of the Pasco Basin is of a long period of essentially continuous evolutionary development. The major hiatus of deposition appears to lie between Ringold time and the deposition of the glaciofluvial deposits.

Basining and anticlinal uplift appear to be still under way.

______, 1970, Some effects of irrigation in the Pasco Basin, Washington (abs.): Geol. Soc. America Abs. with Programs, v. 2, no. 5, p. 326-327.

1. Pasco Basin, Washington.
2. Ringold Formation and other post-basalt sediments.
3. Field observations, literature review.
4. Information about geological effects of irrigation such as landslide activity, changes in water table, flooding, washouts, as well as climatic changes.
5. ---
6. Sixty inches of irrigation water, applied each irrigation season, simulates a gross climatic change in the semi-arid Pasco Basin. Roads locally have washed out, some land is flooded, many landslides have formed, the groundwater table locally has risen more than 100 feet, and more than six miles from irrigation sites the water table is rising between one half and two feet per year. Low lying residential areas are threatened and problem areas are enlarging.

   Landslides occur with increasing frequency. They form in the floodplain deposits of the Pliocene Ringold Formation where pore pressure, increased by perched water, is reduced along bluffs, coulees and canyons. Some old slides evidently were caused by the glacial Lake Missoula and related floods of 50,000 to 10,000 years ago. Some probably were caused by the well-demonstrated more humid climatic in Pleistocene time, which deposited perhaps 20 inches of precipitation. Many landslides are being reactivated.

   Sensitive instruments on and adjacent to the Hanford Reservation have not detected earthquakes at the time of recent slides. Nor have large quarry blasts in several sites resulted in slides. Some old slides may have been caused by earthquakes but the assumption that they were is without sound supporting evidence. Irrigation is beneficial. Long-term addition of large amounts of water to

ground, however, causes effects which must be identified long in advance to avoid conflicts of interest.

______, 1971, Environmental changes by irrigation in the Pasco Basin, Washington: American Soc. Mining Engineers Preprint No. 71-AG-310, 8 p.

1. Pasco Basin.
2. Post-basalt sediments.
3. Observations of changes in water table level, landslides, road washouts.
4. Same as above.
5. ---
6. The Pasco Basin had developed in response to an overall increasingly arid climate over the last several millions of years. Temporary but significant climatic changes during that time have produced appreciable environmental changes. Artificial climatic changes induced by extensive irrigation can be expected to and are producing comparable environmental changes. Foremost among these are many and large landslides resulting from greatly raised ground water tables and the formation of perched water bodies. Data do not yet indicate that an equilibrium has been reached, hence an at least local worsening of the situation can be expected.

Campbell, N. P., 1975, A geologic road log over Chinook, White Pass, and Ellensburg to Yakima highways: Washington Div. Geology and Earth Resources Inf. Circ. 54, 82 p.

1. Eastern Washington.
2. Includes Ellensburg Formation, glacial debris, landslide deposits, and alluvium.

3. & 4. Roadside geologic guidebook information and observations.

5. Informal stratigraphic column of pertinent rock units; schematic cross sections.
6. ---

Chappell, W. M., 1937. Glaciation of Columbia Valley in the Wenatchee-Chelan District: Geol. Soc. America Proc. 1936, p. 344.

1. Wenatchee-Chelan district, Washington.
2. Gneiss and granodiorite boulders, flood-plain gravels, loess.
3. Glacial deposits and features observed and measured to determine presence or extent of glaciation in region.

4. Same as above.
5. ---
6. Huge angular boulders of gneiss and granodiorite in the valley of the Columbia near Wenatchee, Washington, were attributed by I. C. Russell to ice action. Morainal topography between Wenatchee and the mouth of Moses Coulee is ascribed by Bretz to a glacier that came down the Wenatchee Valley or the Columbia, possibly both.

   The rounded forms of gneiss and granodiorite protruding through the flood-plain gravels of the Columbia between Wenatchee and Chelan are characteristic of glacial sculpture; there are grooves and striae on several of these, two miles north of Wenatchee. The Okanogan lobe of the last, or Wisconsin, ice sheet ended 30 miles above Wenatchee, as shown by A. C. Waters. Glacial features below this limit demonstrate that an earlier tongue extended at least as far as the mouth of Moses Coulee, 45 miles south of the Wisconsin front. No evidence of glaciation has been found in lower Wenatchee Valley; therefore, in all probability, the ice came down the Columbia Valley. Definite correlation of this early glaciation with established stages is not yet possible, nor is it known whether it represents only one stage or several. Furthermore, no southern limit of the earlier continental ice sheet can be set. The region is largely covered with loess, but some old drift is known.

Cochran, B. D., 1976, Holocene alluvial chronology in east-central Washington (abs.): Geol. Soc. America Abs. with Programs, v. 8, no. 3, p. 362-363.

1. Johnson Canyon, Washington.
2. Holocene alluvium.
3. Radiometric dates, stratigraphic correlations, volcanic ash and soil time-stratigraphic markers, and cultural remains.
4. Holocene alluvial chronology.
5. ---
6. Alluvial stratigraphy in Johnson Canyon, Washington, indicates a sequence of geologic events consisting of three flood-plain depositions and three erosional episodes. The chronology is based on radiometric dates, stratigraphic correlations, volcanic ash and soil time-stratigraphic markers, and cultural remains. The early flood plain began before 7,000 years before present and terminated before

5,500 years before present. The mid-postglacial flood plain, contained in channels, represents an intense but short-lived depositional phase which began about 5,500 years before present. Late flood plain deposition was within large channels cut into older alluvium. Cultural remains contained in these sediments suggest initial deposition began between 2,000 and 3,500 years ago and ended about 200 years before present. There have been extensive erosion and deposition since. Field evidence suggests that this sequence is typical of many drainage basins in central and eastern Washington. Fluctuating postglacial climate appears to be a controlling factor for the alluvial history of streams in this region. Consideration of local controls, which have greatly modified regional events, is necessary to prevent inclusion of spurious events in a regional chronology.

______, 1978, Late Quaternary stratigraphy and chronology in Johnson Canyon, central Washington: Washington State Univ. M.A. thesis, 81 p. 0-6

1. Central Washington.
2. Holocene sediments.
3. Stratigraphic investigations and radiometric dating.
4. See title.
5. Several stratigraphic columns; table showing stratigraphic columns from 5 widely separated areas in central and eastern Washington; table showing generalized geochronology and events in eastern Washington in last 13,000 years; table comparing Holocene alpine glacial fluctuations, pollen influx, temperature variation and alluvial events in Washington.
6. Stratigraphic investigations combined with radiometric dates revealed cyclic episodes of erosion, deposition, and soil formation during the Holocene in the Johnson Canyon-Vantage region of central Washington. A major period of erosion spanned the Pleistocene/Holocene boundary. It roughly postdated the last Missoula Flood (ca. 13,000 years B.P.) and ended some time before 8,400 years B.P. The first major interval of aggradation began about 8,400 years B.P. and terminated before 6,800 years B.P. This was followed by an episode of erosion which began before 6,800 years B.P. Alluviation after 6,800 years B.P. included the time of the Mazama ash fall (ca. 6,700 years B.P.) and continued to some time before 5,500 years B.P. Downcutting, which began before 5,500 years B.P., was succeeded by an interval of deposition

dated between 5,500 to 2,000 years B.P. A period of erosion occurred shortly before 1,700 years B.P. and was followed by an interval of aggradation which began about 1,700 years B.P. and ended some time after 500 years B.P., probably about 200 years ago. This last major period of deposition was followed by historic erosion, downcutting, and deposition of valley-sheet-flood sediments.

The alluvial sequence in Johnson Canyon is correlative to other alluvial chronologies established in central and eastern Washington. Regional correlation of alluvial events is based on radiometric dates and time stratigraphic marker horizons (volcanic ash layers and paleosols).

Establishment of a regional alluvial chronology implies that there are dominant forces controlling stream processes. When comparing Holocene alluvial sequences to alpine glacier fluctuations, an inferred temperature curve, and rock fall in caves, it is apparent that climate was a major factor controlling stream regimens in central and eastern Washington.

Conners, J. A., 1976, Quaternary history of northern Idaho and adjacent areas: Univ. Idaho Ph.D. thesis, 504 p.
M-4, M-9

1. Northern Idaho, northeastern Washington.
2. Glacial and flood features.
3. Field investigations.
4. See title.
5. Topographic map of study area, cross-sections, topographic profiles.
6. During the Pleistocene, several large lobes of the Cordilleran Glacier Complex pushed southward from Canada into the Pend Oreille-Spokane area of northern Idaho and northeastern Washington. Although it is probable that extensive pre-Wisconsin glaciers were present in parts of the study area, no conclusive evidence for such early glaciations was found. The "Bull Lake till" described by previous investigators near Hayden Lake is reinterpreted as deeply weathered Tertiary colluvial and alluvial deposits. In addition, such Tertiary developments as lava extrusions and associated drainage adjustments resulted in sediment accumulations and landforms, such as terrace remnants and spillways, which may closely resemble Quaternary glacial phenomena.

Pleistocene events and deposits are grouped chronologically by their relation to the last catastrophic flood of Glacial Lake Missoula, which occurred about 19,000 years ago during Pinedale time. Local glaciers probably attained maximum extent in pre-Pinedale time, when sublobes of the Pend Oreille River, Priest River, and Purcell Trench Lobes merged in northern Rathdrum Prairie and flowed south, then west along the Spokane Valley to Spokane. The evidence does not support a similar ice occupation of the Little Spokane Valley north of Spokane. West of Spokane, the Colville and Columbia River Lobes dammed the west-flowing drainage from the study area resulting in higher base levels and associated deposition in the Spokane region during pre-Pinedale glacial maxima. These deposits persist today in sheltered areas, usually at relatively high elevations where they escaped subsequent erosion. During pre-flood Pinedale glaciation, thick valley train deposits from ice lobes immediately to the north accumulated in the Spokane-Rathdrum and Little Spokane valleys. This outwash dammed tributary valleys along the Spokane-Rathdrum valley producing a series of shallow lakes, many of which persist today ; e.g., Coeur d'Alene, Newman, Liberty, and Hayden Lakes.

The Purcell French Lobe in northern Idaho dammed the northwest-flowing Clark Fork forming Glacial Lake Missoula. The last catastrophic flood of this lake removed large quantities of preexisting outwash from the Spokane-Rathdrum and Little Spokane valleys, eroded bedrock along the valley sides and in constricted areas, and left behind a complex sequence of surficial deposits and associated landforms, including giant ripple marks and large-scale scour features. An abundance of new evidence documenting the erosional and depositional effects of the flood, the nature and characteristics of the flood deposits, and the paths taken by the flood is presented. Possible triggering mechanisms of the flood include water flow over or through the ice dam, plastic ice deformation, flotation, glacial surges, and earthquakes.

Relatively little modification of flood-produced features has occurred in the southern part of the area. Post-flood drainage of the Pend Oreille region flowed west to Newport, then south along the Scotia Canyon Sluiceway to the Spokane River. Glaciers occupied the Lake Pend Oreille and Cocolalla valleys during and following the Missoula Flood. The Pinedale ice which occupied Hoodoo Valley had apparently melted by the time of the flood. Glacial phenomena, including ice-marginal meltways and deposits, crag and tail features, ice-terminal amphitheaters, ice-stagnation moraines, large stagnant-ice basins (including Pend Oreille Lake basin), and outwash terraces, are abundant north of Rathdrum Prairie and the Little Spokane valley. Evidence of major post-flood advances is lacking.

A remarkable example of river capture and drainage reversal occurred in the long north-south segment of the Pend Oreille River valley between Newport, Washington, and the Canadian border. Of key importance in understanding this reversal was the presence of a large mass of very slowly downwasting ice which lingered for many centuries in the broad southern part of the valley northwest of Newport. This ice mass blocked southward drainage from the northern part of the valley, causing these waters to find an outlet to the north in the Z Canyon area near the Canadian border. By the time the ice in the southern part of the valley had melted and through-drainage established, the northern outlet had been eroded to a lower elevation than the southern outlet (Scotia Canyon Sluiceway), resulting in the north-flowing river of today.

The report concludes with brief chapters on alpine glaciation, postglacial events, and suggestions for future geomorphic investigations in the area.

Coombs, H. A., 1941, Hornblende and magnetite heavies in the Ellensburg of central Washington: Jour. Sed. Petrology v. 11, p. 142-144.

1. Central Washington.
2. Ellensburg Formation.
3. Mineralogical study of Ellensburg mineral assemblage.
4. Same as above.
5. Sketch map showing sample localities and distribution of Ellensburg Formation. Histogram of samples.
6. The mineral assemblage in the Ellensburg Formation is unusual in many respects. The heavies are restricted exclusively to hornblende and magnetite. The lights are essentially glass and plagioclase. All of the minerals are remarkably euhedral although evidence points to sources up to 50 miles or more from their present position. The uniform mineral content persists over an area of many hundreds, if not thousands, of square miles and may prove to be an aid in working out the stratigraphy of central Washington.

Crandell, D. R.; Meier, M. F.; Mullineaux, D. R.; Sigafoos, R. S., 1965, Quaternary geology of the route between Mount Rainier National Park and Yakima, Washington. In Internat. Assoc. for Quaternary Res., 7th Congress, Guidebook for Field Conf. J, Pacific Northwest: Nebraska Acad. Sciences, Lincoln, Neb., p. 27-34.

1. Mt. Rainier to Yakima, Washington.
2. Quaternary geology.
3., 4., 5. ---
6. Field trip guidebook.

Culver, H. E., 1937, Ellensburg Formation (abs.): Geol. Soc., America Proc. 1936, p. 317.

1. Southeast Washington.
2. Ellensburg Formation.
3. Review of literature and re-study of Ellensburg Formation.
4. Same as above.
5. --
6. A re-study of the Ellensburg Formation, now underway, brings out evidence that the upper part of the formation in the type area is stratigraphically separable. Original descriptions by Smith apply satisfactorily only to the lower portion.

   The essential reduction of the term Ellensburg to interbasalt beds may mean a relatively limited area of disposition. Similar deposits at many places in the Columbia River basalts may be interpreted as remnants of a widespread formation or as discontinuous deposits that may not have been contemporaneous. The latter concept is favored. Consideration is also given to the question of correlation of other continental beds in the area, such as the Latah of Spokane.

______, 1937, Extensions of the Ringold Formation: Northwest Sci., v. 11, no. 3, p. 57-60.

1. Southeast Washington.
2. Ringold Formation.
3. Field observations and literature review.
4. See title.
5. ---
6. The Ringold may be looked upon as extending much more widely than suggested by Merriam and Buwalda. It appears to have been a general filling of the Columbia Basin. Sedimentary materials appear to be from all sides with the recently uplifted rocks along the west margin furnishing the major portion.

The usual continental agencies of erosion and deposition appear to have been operative. Ringold deposition preceded uplift of Frenchman Hills and Saddle Mountains, but the formation has subsequently been trenched by streams of late glacial time, probably those by Bretz to his Scabland Flood. Still later, and continuing today, the original Ringold deposits appear to have been furnishing most of the material making up the substance of the Palouse soil.

Czamanske, G. K.; Porter, S. C., 1965, Titanium dioxide in pyroclastic layers from volcanoes in the Cascade Range: Science, v. 150, p. 1022-1025.

1. Pacific Northwest.
2. Pyroclastic layers.
3. X-ray emission techniques.
4. Determination of TiO_2 in volcanic ash for purposes of correlations and identification of pyroclastic units from Cascade volcanoes.
5. Chemical data tables.
6. Rapid determinations of titanium dioxide have been made by X-ray emission techniques to evaluate the potentiality of using the TiO_2 content of samples for checking field correlations and assisting in identification of pyroclastic units from Cascade volcanoes. Preliminary data suggest that the two most widespread units have characteristic ranges of TiO_2 content and that other, less extensive layers have ranges which, though characteristic, often overlap the ranges of the more widespread layers. Relative to fresh samples, weathered samples from B and C soil horizons are enriched in TiO_2.

Davis, O. K.; Kolva, D. A.; Mehringer, P. J., Jr., 1977, Pollen analysis of Wildcat Lake, Whitman County, Washington: The last 1000 years: Northwest Sci., v. 51, no. 1, p. 13-30.

1. Southeast Washington.
2. Holocene lake sediments.
3. Field and laboratory study.
4. Interpretation of Holocene climate and vegetation.
5. Photos of pollen, core description.
6. Examined 4 meters of lake sediments to detect variations in microfaunal and organic content. These variations, spanning the last 1000 years, reflect changes in the aquatic and terrestrial environment. Most significant event found resulted from introduction of livestock accompanied with

destruction of natural vegetation and erosion.

Dawson, W. L., 1898, Glacial phenomena in Okanogan County, Washington: Am. Geologist, v. 22, no. 4, p. 203-217.

1. Central Washington.
2. Glacial phenomena.
3. Field observations.
4. Description of glacial history in study area.
5. ---
6. Field descriptions of glacial depositional and erosional events and features in study area.

Dobie, J. L., 1926, The "clastic dike" at Pullman: Washington State College B.S. thesis, 11 p.

1. Pullman, Washington.
2. Clastic dike in basalt.
3. Field observations and measurements of dike and physical, mineralogical and chemical laboratory examination of components of dike (chiefly sand and clay).
4. Same as above.
5. ---
6. A clastic dike in a quarry at Pullman, Washington, was studied. It is 2 feet wide and extends from the top of the quarry to an undetermined distance below quarry floor. It is composed chiefly of light-colored sand mixed with clay. Basalt fragments and quartz pebbles are also scattered throughout the dike. Weathering along a joint plane, combined with stream deposition in the joint and slumping of the basalt, might result in formation of such a dike.

Easterbrook, D. J., 1976, Quaternary history of Washington (abs.): Geol. Soc. America Abs. with Programs, v. 8, no. 3, p. 370-371.

1. Washington State.
2. Quaternary sediments and events.
3. Field observations and literature review.
4. Glacial and volcanic events.
5. ---
6. Fluctuations of continental glaciers in the Puget Lowland, eruption of volcanoes in the Cascade Range, and catastrophic glacial flooding across the Columbia Plateau characterize the Quaternary of Washington. Evidence of early and middle Pleistocene glaciations are restricted to a few exposures in the southern Puget Lowland. Elsewhere, deposits of this age have been removed by erosion

or buried by younger sediments. The early to middle part of the Wisconsin Glaciation consists of at least two stages and two interstades. An ice advance older than 50,000 years B.P. was followed by a phase of ice retreat in the interval between 35,000 and 50,000 or older. A re-advance of Cordilleran ice occurred between about 30-35,000 years B.P. The Olympia Interstade was the last nonglacial interval preceding the last major glaciation of the lowland. Radiocarbon dates indicate an age between about 19,000 and 30,000 years B.P. The Fraser Glaciation, constituting the last major advance of Cordilleran ice into the lowland, is divided into two stades and one interstade which encompass the time between about 10,000 and 20,000 years B.P.

Throughout a significant portion of the Pleistocene, volcanoes in the Cascade Range erupted lava and pyroclastic material. Volcanic ash from these volcanoes serves as important stratigraphic markers. Glaciation in eastern Washington and adjacent parts of Idaho and Montana provided the setting for creation of ice-dammed lakes which served as sources for immense floods across the Columbia Plateau upon bursting of the ice dams. An impressive array of glacial landforms marks the site of occupancy of Vashon age ice on the Waterville Plateau.

Easterbrook, D. J.; Rahm, D. A., 1976, Quaternary geology of the Pacific Northwest. <u>In</u> Mahaney, W., ed., Quaternary Stratigraphy of North America: Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa., p. 441-457.

1. Includes Columbia Basin, eastern Washington.
2. Glacial and flood features.
3. Field observations, literature review.
4. See title.
5. Map showing position of Okanogan lobe, Vashon maximum and channeled scablands on Columbia Plateau; map showing morainal flood, and outwash deposits in Moses Coulee and Dryfalls Cataract.
6. The Columbia Plateau underwent glaciation by the Okanogan Lobe from the same parent ice sheet as the Puget Lobe. Although moraines, eskers, drumlins, and kames allow good reconstruction of the last glaciation, evidence for earlier glaciations is generally lacking. Damming of the Clark Fork River by an ice lobe near the Idaho-Montana border created glacial Lake Missoula. Repeated bursting of the ice dam during times of ice

retreat caused immense volumes of water to be suddenly released across the plateau and resulted in the scouring of the channeled scablands.

Easterbrook, D. J.; Baker, V. R.; Waitt, R. B., 1977, Glaciation and catastrophic flooding of the Columbia Plateau, Washington (Field Trip No. 13): In Geological Excursions in the Pacific Northwest: Geological Society of America 1977 Annual Meeting, Seattle, Washington, p. 390-414.

1. Columbia Plateau, Washington.
2. Glacial and flood features, including those of Okanogan lobe of Vashon glacier.
3. Field observations.
4. Interpretation of glacial and catastrophic flood geology.
5. Schematic maps and photos of glacial and flood features.
6. Field trip guidebook that examines location, nature, and significance of Withrow Moraine, outwash terrace, giant flood bars, Moses Coulee, Dry Falls cataract, Grand Coulee, Quincy Basin, Ephrata bar, and giant current ripples in Lind Coulee.

Farkas, S. E., 1972, Structural relationships of folds and faults in Yakima Basalt and Ellensburg Formation, central Washington (abs.): Geol. Soc. America Abs. with Programs, v. 4, no. 6, p. 375-376.

1. Central Washington.
2. Yakima Basalt and Ellensburg Formation.
3. Field observations.
4. Structural relationships of folds and faults.
5. ---
6. High angle reverse faults are found to be associated with Umtanum Ridge and Selah Butte in Yakima, Kittitas, and Benton Counties, Washington. Similar structural relationships of overthrust rocks are found on the north flank of Umtanum Ridge and the south flank of Selah Butte. Yakima Basalt in the major allochthonous plate overrode the core of the Umtanum Ridge anticline, near Priest Rapids Dam. Several sheared minor allochthonous plates were also overridden as the major allochthonous plate moved over the core of the anticline along a high-angle reverse fault. This fault rapidly flattens out to assume low-angle and reversed dips on the crest and north flanks of the fold, respectively.

Rocks of the Ellensburg Formation exposed along new highway cuts near the crest of Selah Butte in Yakima County show a somewhat similar relationship. Here, however, minor normal faulting is clearly shown to have followed severe compression of the rocks. Sharply deformed Ellensburg Formation, sands, shales, and basalt are found on the south limb of the fold and override flat-lying units of a similar nature to the north. Here again, a high-angle reverse fault rapidly flattens out to assume overthrust characteristics as it overrides the crest of the fold.

Field, R. F., 1936, Glacial-till borders of Washington (abs.): Pan-American Geologist, v. 65, no. 3, p. 240.

1. Eastern Washington.
2. Glacial till.
3. Field observations.
4. Glacial till borders, relationship to Scablands.
5. ---
6. It has been generally considered that there are three glacial drifts in eastern Washington and northern Idaho. Recent work there seems to indicate that there were only two glaciations of this region. The ice appears to have had the character of a piedmont glacier formed from a number of valley ice-tongues. The southern margin of glaciation is deeply lobate, and the interlobate ridges do not show evidence of being glaciated. The relationships of the glacial margin to the peculiar scablands seem to demonstrate that the picturesque catastrophic hypothesis of scabland erosion, advanced by Bretz, is altogether untenable. The so-called Old Till, Spokane drift-sheet, proves to be a product of the last glaciation. No correlation is attempted of the two drifts with the the glacial drift-sheets of the Great Plains.

Flint, R. F., 1934, Glaciation in the Okanogan region (abs.): Geol. Soc. America Proc. 1933, p. 81.

1. Okanogan region, Washington.
2. Glacial stratified drift, silt terraces, and moraines.
3. Field observations.
4. Extent of piedmont glaciation in eastern Washington, description of two silt terraces in Columbia trench above Grand Coulee Dam.
5. ---
6. The Okanogan region in northern Washington and southern British Columbia was overrun two or more

times by an extensive piedmont glacier, formed in the Interior Plateau of British Columbia by the coalescence of numerous valley glaciers emerging from the Rocky Mountain system to the east and from the Coast Ranges to the west. It has long been recognized that during the last glaciation, the Okanogan lobe of this piedmont glacier crossed the Columbia trench in northern Washington and pushed south across the basalt of the Columbia Plateau, damming the Columbia and forcing it to spill south through the Grand Coulee, a capacious canyon excavated during an earlier glaciation. Extensive deposits of laminated silt, forming two rather distinct terraces, have been described in the Columbia trench above the dam.

It is suggested that the higher silt terrace records a lake controlled by a rock threshold of scabland type in the Grand Coulee, and that the lower silt terrace records a later and lower profile, partly lacustrine and partly fluvial, along which the water, having abandoned the high-level Grand Coulee route, escaped via the Columbia trench, its course being much obstructed both by residual ice and by great volumes of stratified drift (constituting the "Great Terrace" of Russell) washed in through the tributary Okanogan trench.

______, 1934, Geomorphic fractures of the Okanogan region (abs.): Geol. Soc. America Proc. 1933, p. 81.

1. Okanogan region, Washington.
2. Geomorphic features.
3. Field observations.
4. Geomorphologic data including uplift, downwarp, and stream changes.
5. --
6. The Okanogan region in northern Washington and southern British Columbia exhibits an undulating past-mature highland surface developed in resistant rocks, uplifted and dissected by deep valleys. Before the uplift, the surface appears to have been deformed into a downwarp flanked upwards, with north-south axes. The long, south-flowing Okanogan River may be consequent on the downwarp, but the southeast-flowing Similkameen appears to be older, antecedent to the upwarp controlled by minor structures.

   The southern part of the warped surface has been covered by the basalt of the Columbia Plateau.

Although initially localized by the basalt margin in a roundabout route, the Columbia River now follows a shorter route through a deep gorge that cuts off a large salient of basalt. This and other stream courses in various parts of the region are attributed to glacial derangement of drainage. The inferred warping in the Okanogan region is related to the movements that brought the Cascade region into prominence.

______, 1935, Glacial features of the southern Okanogan region: Geol. Soc. America Bull., v. 46, no. 2, p. 169-194, 2 figs. incl. map, 6 pls.; discussion by O. D. von Engeln, p. 2016-2017.

1. Southern Okanogan region, Washington.
2. Glacial erosional and depositional features.
3. Field investigations.
4. Discussion of relationships between glacial features in lower Okanogan trench and east up the Columbia River from mouth of the Okanogan.
5. Index map of southern Okanogan region, block diagram of region east and north of mouth of Okanogan River.
6. The wasting of the Okanogan lobe of the last ice invasion gave rise to vast quantities of stratified drift, the distribution of which shows that the ice wasted off the highlands while it remained in the chief valleys.
   The Nespelem silt records a deep and extensive late-glacial lake in the Columbia canyon, ice-dammed near the Grand Coulee intake. The lake drained southward over a scabland threshold in the Grand Coulee. As the dam wasted, the lake extended itself down the Columbia, and eventually the water found outlet via the present drainage route, over residual ice. Below the mouth of the Okanogan, wasting ice and accumulating sediments gave rise to a lake, or lakes, in which the "Great Terrace" sediments were accumulated. The accumulation, together with the stream terrace graded with respect to it (i.e., the 1400-foot terrace of Pardee), was stream-dissected while buried ice still lingered in the canyon.

______, 1936, Stratified drift and deglaciation of eastern Washington: Geol. Soc. America Bull., v. 47, no. 12, p. 1849-1884, 8 pls. incl. geol. map, 2 figs. incl. geol. map; (abs.), Revue de Geologie et des Sciences Sciences Connexes, v. 17, no. 11, p. 693, 1937.

1. Eastern Washington.
2. Pleistocene glacial sediments and landforms.
3. Field investigations.
4. Description of glacial events and deposits in eastern Washington.
5. ---
6. Drift, stratified and antedating the main outwash, occurs in two large areas north and northwest of Spokane. Stratified drift is found on the plateau west of Spokane and the river. Main outwash deposits are in the valleys of the Columbia River and its tributaries, coarse near Spokane and finer down the valley to Coulee Dam; then along the river down to a loop moraine and up a tributary above Mold beyond which an overflow channel occurs at Coulee City. Other overflow channels are known south of Spangle and south of Marshall; and loop moraines across the valleys are known down the Spokane River below Alameda, also across Sanpoil River, and several other streams coming in from the north. Outwash is in two episodes, one represented by extensive fills in the valleys of gravel, sand, and silt, and the other by many remnants of terraces older and above these great plains. Strand lines are noted in several parts of the region which do not agree in level. Warping is suggested but not proven. Loess and dune sands are found on the valley floors and rarely on the drift areas. The outwash is deeply and broadly stream dissected and the stream has encountered rocks frequently causing falls and rapids.

______, 1937. Pleistocene drift border in eastern Washington: Geol. Soc. America Bull., v. 48, no. 2, p. 20, p. 203-232, 5 plates, including geologic map, 1 figure; (abs.) Geol. Soc. America Proc. 1935, p. 77, 1936; (abs.) Revue de Geologie et des Sciences Connexes, v. 17, nos. 7-8, p. 460, 1937.

1. Northeastern Washington.
2. Pleistocene glacial material.
3. Field investigations and literature review.
4. Description of drift border in Washington.
5. ---
6. The glaciation of northeastern Washington and northwestern Idaho is attributed to a piedmont glacier, fed by many valley glaciers chiefly in British Columbia, and somewhat lobate at its southern margin opposite the Rathdrum, Little Spokane, Colville, Columbia, Sanpoil, and Okanogan

Valleys. The tops of the intervening ranges were not glaciated. All the lobes except the Sanpoil lobe emerged from the highland onto the Columbia Plateau.

Viewed broadly, the drift border is bi-convex, indicating that the piedmont ice was fed laterally from the Rockies and the Cascades, rather than by direct precipitation upon its own surface. Measurement of the drift border along ice-free mountain ranges shows that the upper surface of the ice was concave-up along north-south profiles, supporting the same conclusion. The "old till" of the Spokane district consists of fresh and weathered foreign stones in a matrix of reworked "Palouse Soil" (the material underlying the district). Hitherto it has been considered old because of the weathered matrix. The weathering however, is pre-till, and this drift is correlated with the last glaciation of this district. The ice on the Plateau advanced over an irregular surface on weak material, modifying the topography very little. The relation of the drift border to the scabland on the Plateau indicates a modification of the catastrophic view of scabland origin.

______, 1938, Summary of the late-Cenozoic geology of southeastern Washington: Am. Jour. Sci., Series 5, v. 35, p. 223-230.

1. Southeast Washington.
2. Columbia River lava, Ellensburg Formation, Latah Formation, interbedded sediments, post-basalt sediments.
3. Compilation of existing published data on subject and author's unpublished observations.
4. See title.
5. ---
6. Summary of existing data through 1938 on late Cenozoic geology of southeastern Washington as well as author's own observations. Includes descriptions of Columbia River lava, sediments interbedded with basalt (Ellensburg, Latah Formations), and post-basalt sediments (Ringold Formation, Palouse soil, glacial sediments, and post-scabland eolian deposits). Also lists structures and drainage patterns in the Columbia Basin.

Flint, R. F.; Irwin, W. H., 1939, Glacial geology of Grand Coulee Dam, Washington: Geol. Soc. America Bull., v.

50, no. 5, p. 661-680, 6 plates, 1 figure, index map.

1. Grand Coulee Dam, Washington.
2. Glacial stream and lake deposits.
3. Field investigations.
4. Study of sections of glacial fill in Columbia canyon and of stratigraphy and morphology of related downstream features to record behavior of Okanogan glacier lobe during last glaciation.
5. Map of regional relations of Grand Coulee Dam; cross section of fill in Columbia River Canyon at dam site.
6. Sections of the fill in Columbia canyon near Grand Coulee Dam, together with the stratigraphy and morphology of related features downstream, record the expansion and later shrinkage of the Okanogan glacier lobe during the last glaciation. Three stratigraphic zones are recognized: 1) a basal sequence of lacustrine fines interbedded with fluvial sediments, recording oscillatory ponding of the Columbia River as the glacier dammed it downstream. At first the lake was shallow and drained west around the ice margin. Later it was more effectively dammed, deepened, and forced to discharge south through Grand Coulee; 2) a till zone, recording the arrival of ice, with fluctuations, at Grand Coulee Dam during the glacial climax; 3) later deposits stratigraphically (but not everywhere vertically) overlying the till zone, recording oscillatory deglaciation, accompanied by transition from lacustrine to fluvial conditions.

   The San Poil glacier lobe entered the lake-filled Columbia canyon at Keller Ferry, 15 miles upstream from Grand Coulee Dam, and contributed sediment to the lake. The maximum of this lobe appears to have been approximately contemporaneous with the maximum of the neighboring Okanogan lobe.

   While residual ice was still present locally in Columbia canyon downstream, drainage abandoned Grand Coulee and resumed its former (and present) course. Thereafter, grading of the long profile of Columbia River preceded both by erosion of the lake fill and by deposition in depressions partly of ice-block origin and was marked by at least one delay recorded by a particularly conspicuous stream terrace.

Flint, R. F., 1971, Glacial and Quaternary geology: John Wiley and Sons, Inc., New York, 892 p. (Includes section on Western North America.)

Foley, L. L., 1976, Slack water sediments in the Alpowa Creek drainage, Washington: Washington State Univ. M.A. thesis, 55 p. G-185, Q-2

1. Southeastern Washington.
2. Slack water sediments, Mount St. Helens tephra.
3. & 4. Sedimentological and stratigraphic study of slack water sediments in the field and laboratory.
5. Tables showing petrographic characteristics and electron microprobe data for tephra samples; stratigraphic columns for 3 type sections; geologic map of study area.
6. Six geologic units in the Alpowa drainage, Washington are described in terms of stratigraphic position, geomorphic expression, sedimentary structures, estimated particle size, lithology, and elevation. Two episodes of "slack water" deposition are recognized in the Alpowa drainage. The Upper Slack Water Unit is attributed to floodwaters moving up tributary canyons from the Snake River some time after 13,000 B.P. and before the earliest known human occupation in the Lower Snake River canyon at approximately 10,000 B.P. Prior to deposition of the Upper Slack Water Unit, mass wasting on the canyon walls, deposition of large coalescent alluvial fans, and aggradation by tributary streams predominated. High floodplain terraces are found in the Alpowa drainage only above 1,200 feet (366 meters) A.S.L. A radiocarbon date obtained from charcoal deposited in these floodplain sediments is 14,300$\pm$200 B.P. (WSU-1499). Similar alluvium in Steptoe canyon was dated at 13,000$\pm$220 B.P. (WSU-1615). Tephra found in the floodplain alluvium stratigraphically below the Upper Slack Water Unit in Steptoe canyon is tentatively correlated with Mount St. Helens set S. An early episode of slack water deposition is represented by the Lower Slack Water Unit. The structure, particle size, and geomorphic expression of this unit suggest, a floodplain environment environment; however a floodplain environment cannot be dismissed. Tephra layers found in the Lower Slack Water Unit have allowed correlation of this unit at six localities in the Alpowa drainage. Stratigraphic position, petrographic characteristics, and chemical composition of these tephra are different from the tephra found in Steptoe canyon,

suggesting that they belong to distinct Mount St. Helens tephra sets. Tephra contained in the Lower Slack Water Unit is tentatively correlated with the Mount St. Helens unnamed set which is older than 18,000 B.P. (Mullineaux, Hyde, and Rubin 1975).

The mid-Pinedale lacustrine deposits in the lower Palouse River canyon reported by Fryxell and Keel (1969), Marshall (1971) and Gustafson (1972) were not found in the Alpowa drainage. However, an explanation for the lack of archaeological sites which predate 10,000 B.P. in the Lower Snake River canyon is presented on the basis of the stratigraphic sequence and geochronology of the Alpowa drainage. Waters which deposited the Upper Slack Water Unit would have destroyed any early archaeological sites located below 1,200 feet (366 meters) A.S.L.

Foxworthy, B. L., 1962, Geology and ground-water resources of the Ahtanum Valley, Yakima County, Washington: U.S. Geol. Survey Water-Supply Paper 1598, 97 p., 11 figs, map, scale 1:62,500.

1. Ahtanum Valley, Yakima County, Washington.
2. Yakima Basalt and overlying sediments.
3. & 4. Investigation of geology and ground-water resources of study area.
5. Geologic map and sections of Ahtanum Valley with well locations; hydrographs and other well data.
6. The Ahtanum Valley covers an area of about 100 square miles in an important agricultural district in central Yakima County, Washington. Because the area is semiarid, virtually all crops require irrigation. Surface-water supplies are inadequate in most of the area, and ground water is being used increasingly for irrigation. The purpose of this investigation was the collection and interpretation of data pertaining to ground water in the area as an aid in the proper development and management of the water resources.

   The occurence and movement of ground water in the Ahtanum Valley are directly related to the geology. The valley occupies part of a structural trough (Ahtanum-Moxee subbasin) that is underlain by strongly folded flow layers of a thick sequence of the Yakima basalt. The upper part of the basalt sequence interfingers with, and is conformably overlain by, sedimentary rocks of the Ellensburg

Formation which are as much as 1,000 feet thick. These rocks are in turn overlain unconformably by cemented basalt gravel as much as 400 feet thick. Unconsolidated alluvial sand and gravel, as much as 30 feet thick, form the valley floor.

Although ground water occurs in each of the rock units within the area, the Yakima basalt and the unconsolidated alluvium yield about three-fourths of the ground water currently used. Wells in the area range in depth from a few feet to more than 1,200 feet and yield from less than 1 to more than 1,000 gallons per minute.

Freeman, O. W., 1926, Scabland mounds of eastern Washington: Science, new ser., v. 64, p. 450-451.

1. Columbia Plateau, Washington.
2. Loess-like mounds on Columbia River Basalt.
3. Field observations.
4. Size, occurrence, and origin of mounds.
5. ---
6. Thousands of nearly circular mounds are found on top of bare basaltic rock of Columbia Plateau. They are different sizes, from a few feet across to over 100 feet, with an average of 30 to 40 feet, and 3 or 4 feet in height at the center. The material of which they are composed is loess-like and appears to be deposited by the wind, probably derived from the soft lake beds of the Ellensburg Formation and the finest outwash material of the glacial period. Almost always they occur above a depression in the basalt. The catastrophic flooding in the region plucked pot-holes from the basalt surface; the mounds are only found in places where the basalt's surface contains depressions. Their absence from the surface of crystalline rock is accounted for by the fact that such rock is denser and potholes were not worn into its surface. Sediment accumulated first in the depressions, followed by vegetation that grew in the sediment and retained wind-blown material until the entire depression was surrounded by a mound. The fine material of the mounds holds moisture and promotes vigorous plant growth. The mounds are of economic importance because they provide the best available grazing and cultivated plant environment. Due to their limited size, however, it is not economically feasible to cultivate them on a large scale.

______, 1933, Stagnation of the Okanogan lobe of the Cordilleran Ice Sheet and the resulting physiographic effects: Northwest Sci., v. 7, no. 3, p. 61-66.

1. Okanogan Highlands, Washington.
2. Pleistocene glacial sediments and landforms.
3. Field observations.
4. Documentation of glacial drainage changes.
5. ---
6. The Okanogan lobe of the Cordilleran ice sheet during the last glaciation covered all of Washington to a thickness of 2,000 feet north of Spokane and Columbia Rivers crossing the Columbia near Big Bend. The Okanogan lobe deposited a mile-wide terminal moraine on the Waterville Plateau. Toward the close of the Wisconsin epoch the ice sheet stagnated and slowly wasted away, proof provided by eskers in sub-glacial streams and kames deposited in holes in the ice. Almost all of the melt water from the ice sheet on the Waterville Plateau drained into Moses Coulee. The Okanogan glacier completely filled the Columbia River canyon for a distance of 20 to 30 miles and formed a glacial lake to the east of the ice dam. This lake overflowed the divide and created Grand Coulee. All of the Okanogan Highlands was covered by ice except for the highest peaks. An outstanding feature of the Okanogan Valley is the great level terraces, some hundreds of feet high. The rest of the article describes glacial-draingage changes in the Okanogan Highlands, associated with stagnation of the ice of the region.

______, 1940, Glacial drainage changes north of the Columbia Plateau (abs.): Geol. Soc. America Bull., v. 51, no. 12, part 2, p. 2021-2022.

1. Columbia Plateau, Washington.
2. Stream channel changes, stream depositional, and erosional features.
3. Field observations.
4. Documentation of glacial drainage channels.
5. Map showing location of glacial drainage channels.
6. The Okanogan Highlands and other ranges of northeastern Washington were covered by glacial ice that moved southward from the intermontane plateau of Canada. The southward extension of the ice sheet has been mapped by Bretz and Flint, who have also given their interpretations for the origin of the scablands that were eroded by glacial melt waters.

North of the area they describe are dozens of glacial drainage channels and other features such as marginal lakes and associated spillways that were developed during the melting and wasting of the ice sheet. Since the glaciers were thickest in the major valleys, the drainage channels generally form a braided sort of pattern on both sides of such north-south-trending trenches. The character of deposits made by the melt water during the glacial period is briefly mentioned. A map showing the location of the glacial drainage channels of Washington accompanies the paper.

______, 1944, Glaciation and some human relationships at Lake Chelan, Washington: Northwest Sci., v. 18, no. 3, p. 59-62.

1. Lake Chelan, Washington.
2. Glacial sediments and landforms.
3. Field observations.
4. Glacial relationships and origin of Lake Chelan and glacial landforms.
5. ---
6. Lake Chelan, a fiord-like body, extends 60 miles from Columbia Valley northwest into the northern Cascade Mountains of Washington. Official depth is 1,510 feet, making it the second deepest lake in United States. Average width is 1 to 2 miles. Originated as result of a combination of glacial erosion throughout upper and middle parts of the lake and deposition at the outlet of the lake. Pre-glacial Chelan Valley had a length of 75 miles represented now by Lake Chelan and the Stehekin River. Bedrock consists mostly of granite of Mesozoic age or older. Columbia Plateau basalt flows do not occur in drainage basin of Lake Chelan. A thickness of over one mile is indicated for the Chelan Glacier. Important tributary valleys are Agnes Creek, Park Creek, Horseshoe Basin, and Bridge Creek. Chelan Glacier may have extended nearly to the junction of the Columbia Valley but did not remain there long. The largest side feeder to Chelan Glacier came from Railroad Creek to the north. The Okanogan-Columbia Valley lobe of the Cordilleran Ice Sheet blocked the Chelan Valley and created a lake between the two. Two former outlets and numerous terraces of the high-level glacial lake exist between the foot of Lake Chelan and Twenty-Five Mile Creek. When the outlet of the Chelan River had become blocked with debris from receding ice, a new course was established between the deposits and the south wall of the valley.

Fryxell, R., 1960, Problems in glacial chronology of northern Washington (abs.): Geol. Soc. America Bull., v. 71, no. 12, part 2, p. 2060-2061.

1. Northern Washington.
2. Glacial sediments and landforms.
3. Review of previous literature and field observations.
4. Relationships and ages of ice advances.
5. ---
6. Studies of continental glaciation in northern Washington have utilized a variety of criteria for establishing the age of various episodes. Depending on the availability of field evidence, different workers have used stratigraphy, weathering, erosion, physiographic expression, rate of talus accumulation, relationship to units in the Palouse loess, bedrock topography, and radiocarbon analysis. Weathering, topographic expression, and radiocarbon dating support correlation of the last major glacial advance as Wisconsin. However, substage correlations result in major inconsistencies: 1) the last advance in Puget Sound has been referred to as Tazewell (13,700 B.P.), while its apparently equally weathered and supposedly synchronous counterpart across the Cascades, the Okanogan lobe, has been designated Mankato (10,000 B.P.?); 2) restricted valley glaciers a few hundred feet thick, sharing the catchment divide in southern British Columbia of the mile-thick Okanogan lobe, have also been dated as Mankato (post 11,300 B.P.); 3) the Spokane lobe has been suggested to be early or pre-Wisconsin although north of its terminus it merged with the Okanogan lobe; 4) east of Grand Coulee the stratigraphic evidence is almost lacking, and nearly every ice margin so far suggested has been disputed; little agreement exists here or in northern Idaho as to whether recognizable moraines are terminal or recessional. Until the precise relationship of ice advances within northern Washington itself can be established, correlation at the substage level with Midwestern chronology cannot be satisfactory. Present attempts fail because of insufficient field work, lack of stratigraphic information, and scarcity of radiocarbon dates.

______, 1963, Limits of continental glaciation, north-eastern Washington: The XI Transactions of Sigma Gamma Epsilon, XI Chapter, Washington State Univ., v. 1, no. 1, p. 25.

1. Northeast Washington.
2., 3., 4., Field trip guidebook
5. Map showing limits of continental glaciation in northeastern Washington.
6. Guide to places in northeastern Washington where glacial features can be seen.

Fryxell, R., Daugherty, R. D., 1963, Late glacial and post-glacial geological and archaeological chronology of the Columbia Plateau, Washington: interim report: Washington State Univ. Lab. Anthropology Rept. Invest. 23, 22 p.

1. Columbia Plateau, Washington.
2. Late and post-glacial sediments.
3. Field and laboratory study of archaeological site stratigraphy; geological field mapping and regional correlation to determine relationships of cultural horizons to late and post-glacial sediments; development of chronology of geologic events for late and post-glacial time.
4. Development of integrated late and post-glacial geoarchaeological chronology for the Columbia Plateau, Washington.
5. Geographic distribution map and listing of sites for which detailed geologic, stratigraphic, and pedologic information is available. Schematic geological and archaeological chronology for eastern Washington and related areas.
6. Discovery at Lyons Ferry, Washington, of oldest (to date) human remains dated with certainty in Pacific Northwest found in context of a complete sequence of geological and cultural stratigraphy to Anathermal climatic period.

   C-14 dating of organic material collected from scabland flood gravel at Wanapum Dam as 32,700 ± 900 years B.P., provides first radiocarbon dating for glacial chronology in Washington and provides maximum limiting date for late Wisconsin scabland flooding. Date also synchronizes Okanogan lobe maximum with Puget lobe and shows eastern Washington to be free of ice by 12,000 years B.P. Alignment of prehistoric population centers along major drainage in eastern Washington makes them of prime archaeological importance. Alluvial history of the lower Snake River and middle Columbia River are discussed and a regional history of cave and rockshelter sites is given. Paleo-climatic implications are made and volcanic ash deposits are discussed.

Fryxell, R.; Cook, E. F., 1964, A field guide to the loess deposits and channeled scablands of the Palouse area, eastern Washington: Washington State Univ. Lab. Anthropology, Report Invest. 27.

1. Eastern Washington.
2. Palouse loess and catastrophic flood features.
3. & 4. Field trip guidebook.
5. Several schematic diagrams.
6. Field trip guidebook including road log to loess and scablands of the Palouse area and summaries of articles by Flint, Allison, and Bretz concerning origin of the scablands. Summary of post glacial history of the Columbia Plateau.

Fryxell, R., 1964, Regional patterns of sedimentation recorded by cave and rock-shelter stratigraphy in the Columbia Plateau, Washington (abs.): Geol. Soc. America Special Paper 76, p. 273.

1. Columbia Plateau, Washington.
2. Cave rockfalls, eolian sediments, organic debris.
3. Field observations and radiocarbon dating.
4. Data to substantiate a general stratigraphic sequence from Okanogan Highland to north Oregon and from west Idaho to Cascade foothills.
5. ---
6. Stratigraphic records from archaeological excavations at more than 20 cave and rock shelters show that a general stratigraphic sequence, with modifications reflecting local conditions, is present from the Okanogan Highlands to north-central Oregon, and from western Idaho to the eastern foothills of the Cascade Range. Stratigraphy of these sites may be described in terms of three major types of sedimentation: 1) accumulation of rockfall from the cave ceiling; 2) deposition of eolian sediment; and 3) buildup of organic debris.
   Alternate dominance or shift in relative importance of these processes, in the above order, are interpreted as reflecting control by regional climatic conditions. Thus coarse rockfall at the base of this sequence records a cool, moist environment accompanied by vigorous frost activity until about 8000 years ago; next followed a time of relative aridity, lessened frost activity, and increased eolian sedimentation; beginning about 4000 to 2000 years ago conditions gradually shifted toward those of the present, resulting in moderately renewed frost-rockfall activity, moderating eolian deposition and increasing accumulation of organic debris.

Two major pumicite marker horizons commonly are found within this sequence. Field evidence and radiocarbon dating establish the more recent of the two as dating from the eruption of Mt. Mazama at Crater Lake, Oregon, about 6500 years ago and suggest that Glacier Peak in the northern Cascades may have been the source for the earlier pumicite. Analysis of combined geological and archaeological stratigraphy confirms human occupation at several of these sites over a period of 8000 years or longer.

Fryxell, R.; Neff, G. E.; Trimble, D. E., 1965, Scabland tracts, loess, soils, and human pre-history. In INQUA, Guidebook for Field Conference E, northern Rocky Mountains: Nebraska Acad. Sci., Lincoln, Nebr., p. 79-89.

(Annotated under Catastrophic Flood Features.)

______, 1965, Ephrata to Pullman. In Schultz, C. B.; Smith, H. T. U., eds., Guidebook for Field Conf. E., Northern and Middle Rocky Mountains; Internatl. Assoc. Quaternary Research, 7th Congr., Nebraska Acad. Sci., Lincoln, Nebraska, p. 79-90.

1. Ephrata to Pullman, Washington.
2. Pleistocene flood gravels, Ringold Formation, Columbia River basalt; loess.
3. & 4. Field trip guidebook.
5. Stratigraphy of loess deposits and associated buried soils in central Columbia Plateau; correlation of post-glacial climatic events with stratigraphy and cultural sequence at Marmes Rock shelter; precipitation map, vegetation map, and distribution map of great soil groups for Columbia Plateau: map of relationships of loess, soils, and vegetation in Palouse Hills.
6. ---

Fryxell, R., 1965, Mazama and Glacier Peak volcanic ash layers; relative ages: Science, v. 147, no. 3663, p. 1288-1290; (abs.) Geomorphological Abstracts, no. 27, p. 300, 1965.

1. Pacific Northwest.
2. Glacier Peak and Mt. Mazama tephra.
3. Physiographic and stratigraphic correlation and C-14 dating.
4. Regional correlation of Mt. Mazama and Glacier Peak ashes.

5. ---
6. Physiographic and stratigraphic evidence supports the regional correlation of two volcanic ash layers with extinct Mt. Mazama at Crater Lake, Oregon and Glacier Peak in the northern Cascade Range of Washington. A radiocarbon age of 12,000 ± 310 years confirms geological evidence that ash derived from the Glacier Peak eruption is substantially older than ash from the Mazama eruption of 6600 years ago.

______, 1967, Ice-flow pattern reconstructed for the Okanogan lobe of the Cordilleran ice-sheet, north-central Washington (abs.): Northwest Sci., v. 41, no. 1, p. 50.

1. North-central Washington.
2. Glacial features.
3. Field mapping and use of topographic maps and air photos.
4. Direction of ice-flow for Okanogan lobe of Cordilleran ice sheet.
5. ---
6. Directions of ice flow for the Okanogan lobe of the Cordilleran ice sheet can be inferred from several types of field evidence: glacial striae, glacial plucking, bedrock fluting and large-scale bedrock grooves, drumlinoid smear features (some with bedrock cores), boulder trains, indicator lithologies, and loops of moraine draped asymmetrically around nunataks. Mapping of these features in the field, from topographic maps, and from vertical air photos shows close alignment with trends of bedrock topography in the Okanogan Valley except at high elevations, where striae and grooves cross drainage divides. South of the Okanogan Highlands, these features fan out on the surface of the Okanogan and Waterville plateaus to form a radial pattern which terminates moraine of the Okanogan Lobe. Within this pattern, which is not seriously disrupted by the Columbia River, bearings of striae shift in regular eastward progression from south-southwesterly (at the base of the Cascade Range) to due east (six miles north of Grand Coulee Dam). Thus, until the ice had advanced far enough south to escape confinement by the Okanogan Valley, only the upper portions of the Okanogan Ice lobe moved independently of bedrock control. The lobe then spread fan-like across the basalt plateau after completely overriding the Columbia River Canyon. Within the

canyon, local control of ice flow is recorded by striae transverse to the general trend of ice movement. Stratigraphic and topographic relationships show that most of these features represent an ice advance of mid-Pinedale age.

______, 1972, Relationship of the late Quaternary volcanic ash layers to geomorphic history of the Columbia Basin, Washington (abs.): Geol. Soc. America, Abs. with Programs, v. 4, no. 3, p. 159.

1. Columbia Basin, Washington.
2. Mt. Mazama, Glacier Peak and Mt. St. Helens tephra and glacial sediments.
3. Field observations and lab analyses of ash.
4. See title.
5. ---
6. Interpretation of Quaternary history in the Columbia Basin requires establishment of relationships between distinctive and extensive volcanic ash layers, and their geomorphic setting and events. Coarse Glacier Peak ash occurs at many localities on till and recessional outwash of the Okanogan Ice Lobe, demonstrating its retreat nearly to the Canadian border by 13,000 years ago. During ice retreat, the Great Terrace of the Okanogan and Columbia Rivers was graded, well beyond the terminal moraine, to about 1250 feet elevation, suggesting that its base level was an extensive lake of approximately the same elevation. At Vantage and at other localities, lacustrine sediments as high as 1150 feet contain pairs or triplets of cummingtonite-bearing ash of unknown source. The lake sediments, the cummingtonite-bearing ash layers, and the Great Terrace all pre-date the Glacier Peak eruption, for coarse Glacier Peak ash fell subaerially on a bench cut into lake sediments at an elevation of about 1000 feet near Chelan after base level had been lowered and the Terrace dissected. Slack water remained to an elevation of at least 600 feet at Marmes Rockshelter in southeastern Washington, where lacustrine sediments contain fine Glacier Peak ash (identified petrographically by R. E. Wilcox). Archaeological evidence and radiocarbon dates show that the lake was drained by 11,000 years ago. Subsequently, Mazama ash (6700 B.P.) was deposited on surfaces graded to present river levels or lower. Post-Mazama alluvium and other deposits (all younger than 5000 B.P.) contain ash layers correlated with eruptions Y, P(?), W, and T of Mount St. Helens.

______, 1973, Salvage of geochronological information in the Wells Reservoir area, Washington (1964-1972): A report to the National Park Service in completion of Contract No. 14-10-0434-1505, Washington State Univ., 35 p., physiographic diagram, 1:125,000.

1. North central Washington.
2. Surficial deposits.
3. Field observations.
4. Geologic information concerning glacial and flood history and human occupation of study area.
5. Regional ice-flow map reconstructed for area covered by last major advance of Okanogan Lobe of Cordilleran Ice Sheet; table showing sequence of major glacial and post glacial events in vicinity of Wells Reservoir.
6. Surficial deposits in the Wells Reservoir area at the confluence of the Okanogan and Columbia Rivers record late glacial and postglacial geologic events of significance to a much larger area due to regional importance of the two drainages. Except for buried blocks of stagnant ice, glacial retreat almost to the Canadian border had occurred before the Glacier Peak ashfall of 12-13,000 years ago. During deglaciation, construction of the "Great Terrace" of these river valleys occurred in response to changes in base level downstream, but dissection of the fill already had begun by the time of the ashfall. A surface of intermediate age and intermediate elevation, the Osoyoos terrace, lies between the Great Terrace and the level of the postglacial floodplain. Sediments of the floodplain comprise two sets of overbank deposits separated by an erosional unconformity and soil profile. The inactive portion of the floodplain is overlain by volcanic ash of the Mazama eruption of 6,700 years ago, which is absent from the active modern floodplain. The hiatus in deposition reflects a period of less effective precipitation than now, and the more recent sediments record human occupation of the area during at least the past 4,000 years. Greater antiquity is probable for man in the area, but early sites lie in sediments both older and topographically higher than those in which salvage excavations in the reservoir area were conducted.

Gresens, R. L., 1975, Geologic mapping of the Wenatchee area: Washington Division Geol. and Earth Resources Open-File Report, no. OF-75-6, scale 1:1,000.

Griggs, A. B., 1965, Stratigraphic relationships between the Columbia River basalt and the Latah Formation in Spokane area, Washington (abs.): Geol. Soc. America Spec. Paper 82, p. 328.

1. Spokane, Washington.
2. Columbia River basalt, Latah Formation.
3. Field investigation.
4. See title.
5. ---
6. The Latah Formation of Miocene age was originally thought to have been laid down prior to the outpouring of the Columbia River basalt in the Spokane area. In neighboring regions to the east and southeast, however, investigators found much of the Latah sedimentary rocks intercalated with flows of the Columbia River basalt. Data from well logs and from current geologic mapping by the U.S. Geological Survey show that the same interlayered relationships between sedimentary rocks and lava flows hold true in the Spokane area also. The basalt flows exposed within the Spokane Valley are at vertical intervals similar to those of flows penetrated by well holes drilled from atop the adjacent plateau. The flows exposed within Spokane Valley are now considered to be part of the Columbia River basalt rather than remnants of much later valley filling flows that were extruded after the Spokane Valley had been exhumed.

______, 1966, Reconnaissance geologic map of the west half of the Spokane quadrangle, Washington and Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map 1-464, 1:125,000.

______,1973, Geologic map of the Spokane quadrangle, Washington, Idaho and Montana: U.S. Geol. Survey Misc. Geol. Inv. Map 1-768, map and text on one sheet, 1:250,000.
C-57

Grolier, M. J.; Bingham, J. W., 1965, Geologic map and sections of parts of Grant, Adams and Franklin Counties, Washington: U.S. Geol. Survey Open-File Report, scale 1:60,000.

______, 1978, Geology of parts of Grant, Adams, and Franklin Counties, east-central Washington: Washington Div. Geol. and Earth Res. Bull. 71, 91 p.

1. East-central Washington.
2. Columbia River Basalt Group, Ringold Formation,

Ellensburg Formation, glaciofluvial deposits, and Palouse Formation.

3. & 4. Geologic field investigations of study area.
5. Generalized land-surface altitudes within project area; physiographic features; stratigraphic sequence and relationship of principal rock units; schematic cross sections; outcrops, subsurface extent, and structure of the Ringold conglomerate.
6. The study area, which is coextensive with the Columbia Basin Irrigation Project area, covers 3,635 square miles within the northern part of the Columbia Plateau, in the arid to semiarid part of east-central Washington. The area generally has low relief except where the regional southwestward slope is interrupted by canyons and anticlinal ridges. Two main ridges, Frenchman Hills and Saddle Mountains, separate the project area into three principal basins: the Quincy, Othello, and Pasco Basins.

   The geologic events that produced the present landforms of the project area began during late Cenozoic time. Large volumes of highly fluid basaltic magma were extruded and spread in successive layers over large areas. The lava accumulated to an overall thickness that exceeded 5,000 feet, and possibly 10,000 feet in the central part of the Columbia Plateau. During intervals between lava extrusions, fluvial and lacustrine sediments were deposited in depressions on the basalt surface and across areas along margins of the flows.

   The entire sequence of lava flows and associated sedimentary interbeds has been termed the Columbia River Basalt Group. The top several thousand feet of the group in this area has been called the Yakima Basalt of late Miocene and early Pliocene age. Within that formation, the top 1,200 feet includes five separate and largely conformable members, defined (from oldest to youngest) as follows: the Vantage Sandstone Member; the Frenchman Springs Member, which locally includes the Squaw Creek Diatomite Bed; the Roza Member; the Priest Rapids Member, which locally includes the Quincy Diatomite Bed, and the Saddle Mountains Member, which interfingers with the Beverly Member of the Ellensburg Formation. The basalt members, each of which consists of one to four lithologically similar flows, are correlated in the field by their frequency and size of phenocrysts, color, jointing habits, texture, vesicularity, and stratigraphic position. The sedimentary materials that are interbedded with the basalt flows were deposited in lakes and streams. Each deposit was spread widely over the surface of the preceding basalt flow.

Most folding in the project area occurred after extrusion of the Yakima Basalt and created several shallow basins in which sedimentary materials were deposited, in some places to maximum thicknesses of about 1,000 feet. These deposits, in part named the Ringold Formation, consist of interbedded lacustrine clay, silt, and sand; fluviatile sand and gravel; eolian sand and silt, and alluvial-fan deposits, with varying amounts of pyroclastic debris.

The topography of the project area was greatly affected by melt-water runoff and catastrophic flooding associated with the continental glaciations that extended into northern Washington several times during late Pleistocene time. Many gorges were cut where floodwaters were diverted across the area, subfluvial gravels were deposited as bars in channel-ways, and deltaic and lacustrine deposits accumulated in temporary lakes that occupied the Quincy, Othello, and Pasco structural basins.

After recession of the continental glaciers from the area, a dry, windy climate prevailed and promoted widespread deposition of loess and sand. The material was derived primarily from fine-grained parts of the glaciofluvial deposits.

Gustafson, C. E., 1976, An ice age lake in the Columbia Basin: new evidence (abs.): Geol. Soc. America, Abs. with Programs, v. 8, no. 3, p. 377.

1. Columbia Basin, Washington.
2. Lacustrine deposits, volcanic ash, flood and glacial sediments.
3. Field evidence.
4. Evidence to determine origin of late Quaternary slack-water deposits in eastern Washington.
5. ---
6. Controversy concerning the origin of late Quaternary slack-water deposits in eastern Washington has been partially alleviated by recent field evidence which suggests that some deposits resulted directly from scabland flooding whereas others represent

different, later events. The later sediments occur throughout the Columbia Basin and probably were deposited in one or more widespread lakes. Regional correlation of sediments from one stand of the lake(s) is possible through stratigraphic relationships and through the presence of volcanic ash layers having distinctive physical and chemical characteristics. The lacustrine deposits can be traced to elevations of about 1300 feet throughout their range. Freshwater Mollusca, including articulated bivalves, abound in laminated sediments at the higher elevations. Their presence in large numbers near a former lake margin habitat suggests the lake was not ephemeral, but existed long enough for molluscan fauna along with the fish necessary as intermediate hosts for the larval stage of the fingernail clam (Pisidium) to develop. Additional faunal remains include rodents, rabbits, extinct bison and mammoth. Clastic dikes and ice-rafted erratics are common. The erractics especially have proved useful for tracing former shorelines where deposits are mixed and not well-laminated. Archaeological sites stratigraphically above slack-water sediments are at least as old as 10,000 years B.P. Thus the lake must be older than the archaeological materials, and it certainly is younger than the last major episode of Scabland flooding for lacustrine deposits unconformably overlie sediments unquestionably related to catastrophic flooding.

Hammatt, H. H., 1976, Late Quaternary stratigraphy and archaeological chronology in the Lower Granite Reservoir, lower Snake River, Washington: Washington State Univ. Ph.D. thesis, 272 p.

1. Snake River, southeastern Washington.
2. Missoula flood gravels, Palouse loess, tephra, and soil.
3. Field investigations.
4. See title.
5. Geologic maps of Lower Granite Reservoir area and Silcott Bar with location of archaeological sites.
6. The Lower Granite Reservoir includes 32 miles of the Snake River between Lewiston, Idaho, and Lower Granite Dam. The constricted river edge landscape of point bar terraces contains over 100 archaeological sites with evidence of human occupation spanning 10,000 years.

   During the Pinedale (Late Wisconsin) upstream rushing scabland floodwaters deposited high pendant bars in the main canyon, eddy bars in steep tributaries and slackwater deposits both in tributaries and the main canyon. Tributary valley fill deposits underlying slackwater sediments contain tephra referable to the Mount St. Helens S set and charcoal dating to 14,000 and 13,000 B.P. These provide a lower limiting date for the last scabland flood at least 8,000 years later than previous estimates.

The post-flood early alluvium indicates aggradation from 10,000 to 8,000 B.P. and forms a high terrace. A soil developed on this alluvium after 8,000 B.P. and before the Mazama ash fall (6,700 B.P.) is separated from the ash by locally occurring pre-ash aeolian sand. Overlying aeolian mixed ash and ash rich loess accumulated on the high terrace and stabilized about 5,000 years ago. The middle alluvium (4,000 to 2,500 B.P.) indicates renewed aggradation and forms a low terrace. Soil formation on this terrace was followed by aeolian deposition (aeolian sand II) until after 1,000 B.P. After brief stability aeolian activity resumed (aeolian sand I) and has continued to the present.

Cultural layers from 15 archaeological sites are relatable to this geologic sequence. The time depth of earliest recorded occupation within canyon is probably limited by scabland flooding. Windust Phase (10,000-8,000 B.P.) cultural material occurs within a gravel lag deposit below the early alluvium as well as within it. The top part of the alluvium and the directly overlying pre-ash sand contain early Cascade subphase (8,000-6,700 B.P.) cultural material. Late Cascade subphase (6,700-4,500 B.P.) material occurs within the mixed ash and ash rich loess. Cultural layers of the Tucannon Phase (2,500 B.P.-A.D. 1750) are found within aeolian sand II. The overlying aeolian sand I contains Numipu Phase (A.D. 1750-1900) cultural material.

The geologic record reflects changing physical and biological environments within the canyon. Changes were chiefly controlled by the hydrologic regime of the Snake River which determined dominant geological processes as well as ground water tables and probably vegetation. The pattern of successive alluvial deposition, soil formation, terrace abandonment and aeolian activity occurred twice during the last 10,000 years and records two alluvial cycles. At the beginning of each phase of aggradation geologic conditions for preservation of cultural layers were unfavorable. Stable land surfaces and the extent of riparian vegetation were at a maximum toward the end of each phase of aggradation. Geologic conditions for the preservation of cultural layers were favorable. Apparent settlement densities reflected in the archaeological record were lowest toward the beginning of aggradation and highest toward the end of aggradation. Environmental change reflected in geologic evidence has affected the cultural past as well as our perception of that past through the archaeological record.

Hammatt, H. H.; Foley, L. L.; Leonhardy, F. C., 1976, Late Quaternary stratigraphy in the lower Snake River canyon: toward a chronology of slack water sediments (abs.): Geol. Soc. America, Abs. with Programs, v. 8, no. e, p. 379.

1. Lower Snake River Canyon, southeastern Washington.
2. Slack-water sediments.
3. Field observations.
4. Evidence to support chronology of slack-water sediments.
5. ---
6. The origins of slack-water sediments in southeastern Washington and their relationship to catastrophic flood sediments have long been controversial. One interpretation is that the fine textured sediments represent slack-water phases of the floods; the second interpretation, the "Ancient Lake Lewis" hypothesis, holds that there were impoundments of water postdating the last major flood. Late Quaternary deposits in the lower Snake River canyon include at least two slack-water units of different age and origin and at least three gravel units which relate to scabland floods. The earlier slack-water unit, characterized by fine bedding, generally silty texture, and Mt. St. Helens tephra layers unconformably overlies the uppermost known flood gravel. This unit was likely deposited in standing water over a long period of time. The later slack-water unit, characterized by sandy texture, rhythmic bedding, and erratic pebbles and striated cobbles, unconformably overlies the earlier unit and probably represents a slack-water phase of a later scabland flood. The earlier deposits may date at least 20,000 years B.P.; the later deposits may date to 14,000 years B.P. To account for the stratigraphic

sequence and the regional distribution of slack-water sediments we must postulate differing episodes of slack-water deposition and one scabland flood postdating the standing water (Ancient Lake Lewis) episode. At present no gravel unit can be correlated with the upper slack-water sediments which represent this postulated flood.

Hammatt, H. H., 1977, Late Quaternary geology of the Lower Granite Reservoir area, Lower Snake River, Washington: Geol. Soc. America Map MC-18.

Hansen, H. P., 1947, Chronology of postglacial volcanic activity in Oregon and Washington (abs.): Geol. Soc. America Bull., v. 58, no. 12, p. 1252.

1. Pacific Northwest.
2. Glacier Peak, Mount Mazama, Mt. St. Helens, Newberry Crater, and Devils Hill tephra and peat bog pollen.
3. Pollen profile studies.
4. Chronology of volcanic activity using pollen profiles.
5. ---
6. The chronology of volcanic glass and pumice strata interbedded in many peat bogs in the Pacific Northwest has been determined indirectly by pollen profiles from the peat sections. The postglacial climatic trends interpreted from the pollen profiles and correlated with chronological data from several sources provide a basis for segregating the post-glacial into a series of time intervals. The stratigraphic position of the volcanic ejecta in relation to the climatic stages serves to date both relatively and approximately some of the volcanic activity. The eruption of Mount Mazama, which formed the caldera holding Crater Lake, occurred about 10,000 years ago, or before the warm, dry period of 8000 to 4000 years ago. The position of Newberry pumice above Crater Lake pumice in Summer Lake basin of south-central Oregon reveals that Newberry Crater erupted after Mount Mazama, but before the late Wisconsin lakes had become entirely desiccated. It is dated between 9000 and 8000 years ago. The stratigraphic position of a layer of volcanic ash in Washington peat columns, attributed to Glacier Peak, suggests that the eruption took place about 6000 years ago. A pumice stratum in peat sections of the northern Willamette Valley is believed to have come from Mount St. Helens and is dated at about 5000 years. The most recent volcanic activity recorded in peat sections that were analyzed was that of Devil's

Hill in the Three Sisters region, and it is dated at about 4000 years.

Harrison, J. E., 1976, Dated organic material below Mazama(?) tephra: Elk Valley B.C.: Canadian Geol. Survey Paper no. 76-IC, p. 169-170

1. Elkford, B.C.
2. Mazama tephra and underlying organics.
3. Carbon-14 dating techniques.
4. See title.
5. ---
6. A horizontal organic layer, 1 cm thick, north of Elkford, B.C., was dated by C-14 techniques. It underlies white volcanic ash believed to be Mazama. Two dates were obtained: 11,900 $\pm$ 100 years B.P. and 12,260 $\pm$ 160 years B.P.

Hershey, O. H., 1912, Some Tertiary and Quaternary geology of western Montana, northern Idaho, and eastern Washington (abs.): Geol. Soc. America Bull., v. 23, p. 75.

1. Eastern Washington.
2. Glacial sediments and landforms.
3. Field observations.
4. Descriptions, locations, and mode of origin of glacial features in eastern Washington, Idaho, and Montana.
5. ---
6. Evidence of two stages of glaciation in Deer Creek Valley, Montana, are given and brief reference is made to the latest glaciation in the Coeur d'Alene Mountains of Idaho. A system of river terraces distributed for 30 miles along the valley of the South Fork of the Coeur d'Alene River is described in detail. The 1,150-foot terrace is probably early Miocene in age, but merely marks a vicissitude in the erosion of a valley 4,000 feet deep. In middle Miocene time the Columbia River lava obstructed the valley and produced a lake in which were deposited white and variegated silts and the delta gravels of the river, filling the old valley 500 feet deep, to the level of the 600-foot terrace. A new valley 400 feet deep, partly on a new course, was trenched in early Quaternary time down to the 200-foot terrace. A remarkable distribution of granitic and gneissic boulders on this terrace is attributed to icebergs in a lake produced by the glacial damming of the valley at some point not determined; this is considered evidence of very early glaciation somewhere in northern Idaho. The 60-foot terrace is a gravel-capped rock bench, but the 30-foot

terrace was built by the river and is tentatively correlated with the first glacial stage in Deer Creek Valley. Physiographic features of the Clearwater region and the lake plateau of eastern Washington are discussed, and Coeur d'Alene Lake and the Post and Spokane falls are explained as the result of the deposition of glacial overwash gravels in the broad Spokane Valley during the last glacial stage.

Hobbs, W. H., 1943, Discovery in eastern Washington of a new lobe of the Pleistocene continental glacier: Science, v. 98, no. 2541, p. 227-230, illus.; (abs.) Geol. Soc. America Bull., v. 54, no. 12, p. 1825, 1943.

1. Northeastern Washington.
2. Glacial sediments, ice, and features.
3. Field observations.
4. New field evidence for extension of the Cordilleran Ice Sheet in the form of a "Scablands" glacial lobe.
5. ---
6. A hitherto unsuspected southwestward extension of the Cordilleran glacier of late Pleistocene time has been established by studies in 1943. This extension of nearly 4,000 square miles is the area of so-called "Scablands" in eastern Washington. Hitherto the glacier front was thought to have been in the latitude of Spokane. The newly discovered extension is heart-shaped and is called the Scablands glacial lobe. On the east this lobe blocked an ancestor of the Spokane River, which was much swollen by glacial melt water, to impound the waters over an area of some 3,000 square miles as Glacial Lake Spokane. This lake had an outlet along the eastern and southern border of the lobe, and successive spillways into the Columbia and Snake Rivers were through Esquatzel Coulee and Devils and Palouse Canyons. Six major recessions of the lobe have been made out with the new outlets for Lake Spokane successively westward through other canyon spillways into the Columbia River.

   The main outwash apron of the Scablands lobe was the eastern portion of the Columbia Basin. Out side and peripheral to it is the contemporaneous apron of loess, which studies of the Greenland glacier have shown should always be found within the periglacial area of a continental glacier.

   Complete evacuation of the ice of the Scablands with the retirement of the glacier front behind the Spokane and Columbia Rivers brought about an expansion of Lake Spokane down the canyons of these rivers. This has been named Glacial Lake Leverett. It was blocked by ice below the site of Coulee Dam and it cut an outlet through the Grand Coulee This outlet is a double cataract gorge like that of Niagra, but five times as high and many times as wide - the greatest feature of the kind anywhere known.

______, 1945, Scabland and Okanogan lobes of the Cordilleran glaciation, and their lake histories (abs.): Geo. Soc. Am. Bull., v. 56, no. 12, pt. 2, p. 1167.

1. Eastern Washington.
2. Glacial and flood sediments.
3. Field observations.
4. Evidence for Scabland lobe in Spokane area and associated glacial and flood events and deposits.
5. ---
6. In the summer of 1943 evidence was found of a lobe of the Cordilleran glaciation which in late Wisconsin time occupied the "Scabland" region of Eastern Washington. Its area had been about 4000 square miles. Along its front was a peripheral zone of outwash gravels; this is surrounded by a much wider zone of silt (loess), today rich wheatlands.

   The Scabland Lobe blocked the Upper Spokane Valley and impounded its great volume of glacier meltwater, then further augmented by the floods which poured in through the Clark Fork outlet of Glacial Lake Missoula in Montana. Lake Spokane had outlets into the Snake, first as border drainage to the lobe; but later into the Snake or the Columbia through successively unblocked channels which had been under the lobe.

   When the Scabland Lobe had been liquidated and the glacier front stood north of the Spokane valley, Lake Spokane expanded far down the Columbia Canyon to where it was then blocked by the retiring Okanogan Lobe at Bridgeport above the "Big Bend." This ice dam produced Glacial Lake Leverett, which was more than 300 miles in length with outlets through the Grand and the Moses coulees.

   With the retreat of the glacier front westward across the Okanogan valley, Glacial Lake Okanogan, entirely within that valley, succeeded Lake Leverett. It was blocked, not by the glacier itself, but by the heavy moraines which cross the valley at Chelan.

______, 1947, The glacial history of the Scabland and Okanogan Lobes, Cordilleran Continental Glacier: In J. W. Edwards, ed., Glacial Studies of the Pleistocene of North America: Ann Arbor, Michigan, 36 p.

1. Eastern Washington.
2. Glacial and catastrophic flood features.
3. Field investigation.
4. See title.
5. Map and profiles of glacier aprons of outwash and loess; map of glacial formations of Columbia Basin. Maps of glacial lakes Leverett and Missoula; maps showing retreat of Scabland lobe; delta plains of Latah Creek; map of Grand Coulee and vicinity.
6. Discussion of the glacial history of eastern Washington. Attributes all landforms, such as the Scablands, to glacial activity rather than flood activity.

Hodge, E. T., 1931, Exceptional morainelike deposits in Oregon: Geol. Soc. Bull., v. 42, p. 985-1010. H-201

______, 1940, Glacial history of southeastern Washington (abs.): Geol. Soc. America Bull., v. 51, no. 12, part 2, p. 2024; (abs.) Geol. Soc. Oregon Country Geological News Letter, v. 6, no. 16, p. 135, 1940.

1. Southeastern Washington.
2. Glacial sediments and features.
3. Field observations.
4. Glacial history of southeastern Washington including drainage patterns and changes, formation of glacial topographic features, distribution of glacial sediments.
5. ---
6. The basin of southeastern Washington was drained by westward and northward flowing streams. The former were dammed by Pleistocene volcanics, and the latter by the Continental ice sheet. Ponded waters filled the valleys of the Columbia Mountain system but did not submerge the higher ridges; they spilled over cols in the Sanderson-Cheney divide, deepened them, and so directed the course of ice lobes from the advancing ice-front. The glaciated cols produced the coulees, such as Grand and Moses. The ice reached as far south as Ephrata and Ritzville and over the area plucked the highly fractured basalt to make great gravel deposits and left holes filled with ice which are now sheer-walled undrained basins. Loess and gravel were spread over the greater part of the area, burying ridges and forming a lake-bed surface with an initial south-sloping

surface. The lake was drained by an overspill at Wallula Gateway. As the glaciers melted, streams flowed southward over this surface. Some were superposed over ridges, such as Horse Heaven, Rattlesnake, Frenchman, and Waterville-Adrina. These streams were often choked and dammed by ice-floes, and forced out of channel. Repeated damming of diversion channels produced complex anastomosing channels incised in basalt. Erratics rafted were stranded over area and along Columbia and Willamette valleys in Oregon. Similar events followed a second and third advance.

Holmgren, D. A., 1968, Yakima-Ellensburg unconformity, central Washington (abs.): Northwest Sci., v. 42, p. 34-35; Univ. of Washington M.S. thesis, 69 p., Plate 1, 1:142,560; Plate 2, 1:42,768; Plate 3, 1:96,000, 1967.

1. Central Washington.
2. Ellensburg Formation and Yakima Basalt.
3. Field observations of stratigraphic relationships and restriction of Ellensburg Formation to Beverly Member, Pomona Basalt Member and upper sedimentary member.
4. Same as above.
5. Regional geologic map; detailed map of Selah Gap and Kelley Hollow; table showing previous treatment of area; opposing views of Yakima Basalt and Ellensburg relationships; cross-section of platy joints showing location and orientation of phenocrysts in Roza and Frenchman Springs flows; stratigraphic sections Selah Gap; stratigraphic section of Selah Butte anticline; structure map; several petrographic formation photos.
6. The Pliocene Ellensburg Formation unconformably overlies the Miocene Yakima Basalt in the Yakima region; thus, these two formations are not mutually intertongued as interpreted by Smith (1903) and subsequent investigators.

   The angular relationship is clearly exposed on the south flank of the Yakima anticline east of Selah Gap, where the basal Ellensburg beds truncate three Yakima Basalt flows. Map patterns show that basal Ellensburg oversteps the Frenchman Springs-Roza-Priest Rapids succession of the Yakima Basalt from Wenas Valley eastward to Connell, rests on pre-Vantage Sandstone flows west of Ellensburg, and completely truncates the Yakima Basalt to rest on John Day (?) strata, 30 miles west of Yakima.

This significant unconformity calls for restriction of the Ellensburg Formation to exclude the Vantage Sandstone, Squaw Creek, Quincy Diatomite, and other intra-Yakima sedimentary units. Thus restricted, the Ellensburg of this type area consists of a basal sedimentary (Beverly) member, Pomona Basalt Member, and an upper sedimentary member. These relationships imply that the earliest Cascadian uplift in this region was post-Yakima.

Hopkins, K. D., 1966, Glaciation of Ingalls Creek Valley, east-central Cascade Range, Washington: Univ. of Washington M.S. thesis, 79 p.

1. See title.
2. Glacial erosional and depositional features.
3. Field observations; statistical treatment of granite-weathering ratios and surface-boulder frequencies.
4. Description of glaciation of study area including glacial-erosional features, surficial geology, discrimination and relative ages of drift, correlation and age, and snowline relations.
5. Altitudes of cirque floors in Ingalls Creek drainage; reconstructed long profiles of Ingalls Creek and glacier limits of drift sheets in Ingalls-Peshastin Creeks drainage; till fabric from older drift and remnants of erosional terraces along Peshastin Creek, abandoned channels of Peshastin Creek of post-intermediate driftage; late-glacial and neoglacial features in the Ingalls Creek drainage and adjoining valleys; correlation of Ingalls-Peshastin Creeks; glacial sequences; several photos.
6. Comparison of quantitative weathering parameters on glacial drift permits delineation of three distinct drift bodies along a single valley in the east-central Cascade Range, Washington. Marked differences in granite-weathering ratios, surface-boulder frequencies, and thickness of weathering profiles, as well as the degree of modification by erosion and mass wasting, suggest that the drifts represent three separate major glacial episodes. Relative ages based on weathering parameters agree with those determined from such time-independent criteria as morainal position and relative heights of outwash terraces graded to moraines. Contrasts in weathering parameters and erosional modification are greatest between two older drifts suggesting that the earlier of the two nonglacial intervals was of the greater magnitude. The latest glacial episode is correlated with the Fraser Glaciation of the Puget Lowland in western Washington and with the classical Wisconsin

Glaciation of central North America. The intermediate episode is correlated tentatively with Salmon Springs Glaciation of Puget Lowland; oldest is considered pre-Salmon Springs. Moraines and terrace remnants within the youngest drift, together with weathering data, permit subdivision of the latest glacial episode into three, maybe four separate advances or recessional stands. Outwash of the first recessional stand is overlain by postglacial fan gravels containing a layer of volcanic ash (Mazama - 6,600 years old). Other occurrences of Mazama ash in alluvial fans are indicative of widespread alluviation during the Hypsithermal interval. Several inactive rock glaciers in high cirques of adjacent valleys probably formed during neoglaciation.

Hosterman, J. W.; Scheid, V. E.; Allen, V. T.; Sohn, I. G., 1960, Investigations of some clay deposits in Washington and Idaho: U.S. Geol. Survey Bull. 1091, 147 p. Figure 3, 1:380,160; Plate 3, 1:12,000.

1. Eastern Washington, northern Idaho (Palouse Hills).
2. Clay deposits.
3. Mineral composition studies; X-ray and differential thermal determinations.
4. Determination of distribution, quantity and quality of deposits.
5. Geologic map of Latah City clay deposits, the Excelsior, Bovill, Deary, Olson, Stanford, Canfield-Rogers, and Stockton deposits; section of Olson and Bovill deposits; many chemical data tables.
6. The clay deposits of eastern Spokane County occur along the eastern and northeastern margin of the Columbia Plateau, where the basalt flows lap onto the older igneous and metamorphic rocks. Five genetic types of clay are available for making clay products, and three of the five types are possible future sources of alumina. The five types are: 1) white residual clay derived from pre-Tertiary igneous and metamorphic rocks, 2) bluish-gray residual clay derived from Columbia River Basalt (Tertiary), 3) residual and transported clay beds in the Latah Formation (Miocene), 4) brown clayey silt and silty clay of the Palouse Formation (Pleistocene), and 5) light-greenish-gray silty clay of the glacial lake deposits. Residual clays, derived from igneous and metamorphic rocks, and clays from the Latah Formation would be best for refractory products, filler uses, and as an ore of aluminum. Residual clay

derived from basalt would be useful only in an ore of aluminum with a possible byproduct of titanium. The best use of clay from the Palouse Formation and lake deposits is in making building brick. Five clay minerals have been identified by X-ray diffraction in samples from these deposits. Kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) is found in all types of clay, except residual clay derived from basalt. Halloysite ($Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$) is found primarily in the residual clay derived from basalt, and traces are found in the residual clay derived from pre-Tertiary rocks. Montmorillonite and illite do not ocur in residual clay derived from basalt, but do occur in varying amounts in all other types of clay. Nontronite (a high iron montmorillonite) is found only in the residual clay derived from basalt.

______, 1969, Clay deposits of Spokane County, Washington: U.S. Geol. Survey Bull. 1270, 96 p.

1. Spokane County, Washington.
2. Clay deposits.
3. X-ray diffraction, X-ray fluorescence; chemical and mineralogic composition; auger-drilling sampling of clay deposits; ceramic properties studies.
4. Information on distribution, quality and quantity of clay deposits in study area.
5. Chemical tables; stratigraphic sections; geologic map of pre-Palouse of Mica-Manito-Saxby area, Washington-Idaho.
6. The clay deposits of eastern Washington and northern Idaho, known as the Palouse Hills, are at the eastern edge of the Columbia Plateau physiographic province. Three types of clay occur in the area: residual clay derived from the Columbia River basalt of Tertiary age; residual clay derived from the granodiorite and related intrusive rocks of the Idaho batholith of late Jurassic or Cretaceous age; and transported clay, an erosional product of the granodiorite and related intrusive rocks, deposited as part of the Latah Formation of Tertiary age. The two types of residual clay were formed during an interval of weathering called the "Excelsior weathering period" that occurred between flows of the Columbia River basalt, when the land surface had a low to moderate relief and the climate was warm and humid with good oxidation conditions.

   The mineral composition of a few samples has been studied in detail. X-ray and differential thermal determinations on these clays show that kaolinite and halloysite (hydrated) are the principal clay minerals. The residual clay derived from basalt is composed of white halloysite commonly colored blue, gray, or black by ilmenite and occasionally stained brown by limonite or green from nontronite. The residual clay derived from granodiorite and related intrusive rocks contains both halloysite and kaolinite, and the transported clay is predominantly kaolinitic. The latter two types of clay are very similar in physical appearance; both are white and both contain abundant quartz grains and mica flakes--but the residual clay retains a relict granitic texture and is not bedded. It is estimated that about 300,000 tons (dry) of clay containing more than 20 percent available alumina occurs in eastern Washington and northern Idaho. About 90 percent of this tonnage is in four major deposits in Latah County, Idaho; Bovill clay deposits, Olson high-alumina clay deposits, Canfield-Rogers clay deposits, and Benson clay deposits.

Huntting, M. T.; and others, 1961, Geologic map of Washington: Washington Div. Mines Geol., scale 1:500,000, 2 sheets.

Izett, G. A.; Wilcox, R. E.; Powers, H. A.; Desborough, G. A., 1970, The Bishop ash, a Pleistocene marker bed in the western United States: Quaternary Research, v. 1, p. 121-132.

1. Eight localities from California to Nebraska.
2. Pleistocene Bishop ash, Green Mountain Reservoir ash, Pearlette-like ash in alluvial and lacustrine deposits.
3. Field observations and sampling; radiometric dating; petrographic and chemical analyses; stratigraphic correlation.
4. Confirmation of extent, age, and stratigraphic relationship of Bishop and other ashes in western United States.
5. Sample localities map; generalized stratigraphic section showing relations of ash beds; summary of petrographic characteristics of ash beds of this report, table of electron microprobe, and an analysis of glass from report.
6. Biotite-bearing chalky-white rhyolitic ash, here called the Bishop ash bed, occurs in middle Pleistocene alluvial and lacustrine deposits at eight localities scattered from California to Nebraska and is correlated with the basal air-fall lapilli of the Bishop Tuff, an ash flow of eastern

California, radiometrically dated about 0.7 million years. Correlation of the Bishop ash bed with the air-fall lapilli is made on the basis of similar petrography and on chemistry as determined by electron microprobe, atomic absorption, and emission spectrographic analyses. At five localities the Bishop ash bed lies stratigraphically below a Pearlette-like ash. As more occurrences of the Bishop ash bed are found, it should become an increasingly important dated stratigraphic marker relating middle Pleistocene deposits and events across several geomorphic provinces.

Another biotite-bearing chalk-white ash, here called the ash of Green Mountain Reservoir, occurs at three other localities and is distinguishable from the Bishop ash bed by small differences in chemical composition of the glass.

The ash of Green Mountain Reservoir is younger than the Bishop ash bed, as shown by the fact that at one locality it lies stratigraphically above the aforementioned bed of Pearlette-like ash.

Jenkins, O. P., 1924, Unconformity between the Ringold and Ellensburg Formations, Washington: Univ. of California Publications in Geological Sciences, v. 15, no. 2, p. 45-47, 1 fig., 1 plate.

1. White Bluffs, Washington.
2. Ringold and Ellensburg Formation.
3. Field observations.
4. Observations of angular unconformity between Ringold and Ellensburg Formations.
5. ---
6. Exposure of angular unconformity between Ringold and Ellensburg Formations in White Bluffs of south-central Washington (500-foot dissected cliff). Ellensburg Formation is Miocene; Ringold Formation is possibly late Pliocene or early Pleistocene. Lower shales and sandstone dip at a marked angle in northeast direction into bluffs. Ringold Formation overlies them in horizontal layers. Dip of lower beds conforms with general direction of dip of basalt beds on west side of river, indicating that, in the folding of the basalt, these sedimentary beds, which appear to overlie the lava, were folded with it. The anticline formed in basalt runs in general east-west direction, plunging eastward and bending southeast, forming the mountain range south of Priest Rapids, which breaks into isolated hills

such as Gable Butte, Gable Mountain, etc. These hills are surrounded by extensive alluvial deposit formed by Columbia River and are composed of basaltic beds which form the north flank of the anticline, the axis of which probably passes through the alluvial area a few miles south of Hanford. Character of lower beds in White Bluffs differs from Ringold, in that former show more lacustrine nature, consisting of shales (diatomaceous), with local arching. Hanford quadrangle shows irregularity in topography of bluffs in this locality and a high terrace along which number of depressed contour lines are indicated. This bench is on older tilted sedimentary beds (Ellensburg). Terrace formed by differential erosion combined with some landsliding.

______, 1925, Clastic dikes of eastern Washington and their geologic significance: Am. Jour. Sci., 5th series, v. 10, p. 234-246.

1. Eastern Washington.
2. Clastic dikes in Touchet beds.
3. Field observations.
4. Origin, age, composition of clastic dikes.
5. Pictures of dikes.
6. Study of clastic dikes in alluvial deposits near Walla Walla, Washington. Presence of unconformity between limonitic clay dikes and overlying glacial drift, occurring in surface exposures above extensively oxidized lead ore chimneys in Electric Point mine, shows oxidation of lead ore chimneys is pre-glacial in age. Geological significance is that at Pullman, a former sedimentary deposit, now eroded away, is indicated by the preservation of entrapped portion. In Touchet sand pit evidence is preserved of former seismic disturbances of great magnitude. All clastic dikes are ramifying in form, having many branching arms. Shorter dikes die out at depth. Within some, a few nearly horizontal layers of cross-bedded structure were observed. Some show no apparent regular structural arrangement of the materials. In most, a banded form of sorted materials was found parallel to length of dike, following twisted waviness of dikes themselves. Materials derived from above or from wall rocks. Dikes represent filled fissures. Gravity had most to do with material getting into fissures in the presence of water. Banded character indicates material was forced into fissures under pressure although they may have been compressed after formation. It appears then that

fissures are first formed, and fragmental material dropped, washed, or pressed into them from above, below or from the side. This takes place at surface in open fissures, under water in fissures on sea bed or other bodies of water, and far below surface of Earth in consolidated rocks. Filling from below comes about by pressure - probably hydrostatic.

______, 1925, Clastic dikes of southeastern Washington (abs.): Geol. Soc. America Bull., v. 36, no. 1, p. 202.

1. Southeastern Washington.
2. Post-glacial clastic dikes in Touchet beds.
3. Field observations.
4. Description, age, and possible origin of clastic dikes.
5. ---
6. Many curious sand and dust dikes occur in southeastern Washington, especially in a region west of Walla Walla. Those near Touchet occupy fissures in loess deposits and in stream terraces of cross-bedded sands and gravels. The dikes are structurally arranged in layers which lie parallel to the walls of the fissures. Some of the dikes are as thin as paper, while others are several feet thick, and all have a tendency to branch. Their materials are of water-worn basaltic sand and volcanic glass dust. The fissures might have been formed by earthquakes and their subsequent filling undoubtedly came from above. Their age is postglacial.

Judson, S.; Ritter, D. F., 1964, Rates of regional denudation in the United States: Jour. Geophys. Research, v. 69, no. 16, p. 3395-3401.

1. Includes Columbia Basin, Washington.
2. Surface sediments.
3. Mathematic models of stream loads and surface denudation.
4. Measurements of stream sediment loads to calculate regional rates of land denudation.
5. Tables showing suspended sediment loads by estimates of annual chemical denudation; and rates of regional denudation; comparison between regional denudation rates reported in this study and others; relation by regions between detrital load and dissolved load.
6. Data, in large part collected since World War II, allow a recalculation of the rates of regional erosion in the United States. These data indicate a rate of denudation for the United States as a

whole of 2.4 in./1000 years, or about twice that of older estimates. The most rapid rate, 6.5 in./1000 years, is recorded from the Colorado drainage. The slowest rate, 1.5 in./1000 years is found in the Columbia basin. Other drainage areas and their rates are the Pacific slopes, California, 3.6 in./1000 years; the western Gulf of Mexico, 2.1 in./1000 years; the Mississippi River watershed, 2.0 in./1000 years; the South Atlantic and the eastern Gulf of Mexico, 1.6 in./1000 years; and the North Atlantic, 1.9 in./1000 years.

Kaatz, M. R., 1959, Patterned ground in central Washington: A preliminary report: Northwest Sci., v. 33, no. 4, p. 145-145, illus.

1. Manatash Ridge and portions of Kittitas Valley and Yakima County, central Washington.
2. Patterned ground in surficial sediments.
3. Field observations.
4. Description and mode of origin of patterned ground.
5. ---
6. Intensive frost action during a periglacial climate has been more significant in the development of patterned ground in central Washington than formerly recognized. Water (running) has had some significance in shaping the patterned ground, as has polygonal jointing in basalt, especially in the initiation of the pattern of stone nets in some situations. These are of secondary importance when compared with frost action.

Keyes, C. R., 1935, Glacial origin of the Grand Coulee: Pan American Geologist, v. 63, no. 3, p. 189-202, 5 plates incl. geol. map, 1 figure geol. map.

Kittleman, L. R., 1973, Mineralogy, correlation, and grain-like distributions of Mazama tephra and other postglacial pyroclastic layers, Pacific Northwest: Geol. Soc. America Bull., v. 84, no. 9, p. 2957-2980.

1. Pacific Northwest.
2. Mazama tephra and other unidentified tephras.
3. Mineralogical and grain-size analyses.
4. See title.
5. Selected radiocarbon ages reported for Mazama tephra; refractive indices for natural glass and artificial glass for mazama tephra; median grain-size distribution diagrams.
6. Mazama air-fall tephra is a pumiceous pyroclastic deposit dispersed over almost a million square kilometers by an eruption about 7,000 years ago of

ancient Mount Mazama, the precursor of Crater Lake caldera, Oregon. The tephra layer is valuable as a stratigraphic marker and for what it reveals about the production and dispersal of tephra.

The tephra is characterized by its minerals, which include plagioclase (73.1 $\pm$ 1.2 percent), hypersthene (9.4 $\pm$ 0.5 percent), magnetite (10.2 $\pm$ 1.1 percent), hornblende (3.9 $\pm$ 0.4 percent), and clinopyroxene (2.8 $\pm$ 0.3 percent). Mean refractive index of glass is 1.508 $\pm$ 0.001. Mineral abundances and refractive index are homogeneous, and over the region sampled the variances of these properties are no greater than in a single fragment of pumice. Within about 300 km of Crater Lake, the abundance of discrete mineral grains increases, but the proportion of heavy minerals does not change with increasing distance.

Tephra at 14 localities can be correlated with Mazama tephra mineralogically. The localities are at Blue Mountains, Columbia Gorge, and China Hat Butte in Oregon; Curelom Cirque in Utah; and at archaeologic sites at Fort Rock Cave, Paisley Cave, Connley Cave, Three Sheep Rockshelter, Everyone, Hobo Cave, Wildcat Canyon, and Big Eddy in Oregon; and Nightfire Island in California.

Other tephra layers in the region studied contain assemblages of mineral similar to the Mazama assemblage, perhaps because all have sources among volcanoes of the Cascade Range. This makes discrimination difficult, and no layers could be definitively correlated or identified with a specific source.

Mazama tephra has heterogeneous size-frequency distributions that fit Rosin's distribution. Heterogeneity is caused by intermingling of coarse pumiceous fragments and finer crystalline grains; however, if grain size is expressed as terminal velocity, then frequency distributions are log-normal and homogeneous; grains of disparate size or density occur together because they have equivalent terminal velocities. Phi median diameter varies curvilinearly with distance from Crater Lake, but the relation is not readily interpreted in terms of mechanism of deposition. Median terminal velocity, however, varies as $V_t{*}=K_3D^{-r}$, where $V_t{*}$ is median terminal velocity and D is distance. The parameters K_3 and r may characterize individual eruptions and facilitate understanding of the production and dispersal of air-fall tephra.

Krynine, P. D., 1937, Age of till on "Palouse Soil" from Washington: Am. Jour. Sci., 5th ser., v. 33, no. 195, p. 205-216.

1. Southeast Washington.
2. Palouse soil, till.
3. & 4. Method of differentiation between "Palouse soil" and till is discussed.
5. Mechanical analyses and chemical data tables.
6. The so-called "ancient" till of Washington, said to be of Pre-Wisconsin age, is shown by petrographic analysis to be really a late-glacial deposit whose weathered and "ancient" appearance is due to the fact that it contains much reworked and incorporated "Palouse soil," an old and decayed pre-late-glacial loess. Methods of diferentiation between "Palouse soil" and till contaminated with even very large amounts of "Palouse soil" are offered. Finally, the apparent and real effects of the admixture of volcanic ash in "Palouse soil" and recent superficial loess are described.

Large, T., 1922, The glaciation of the Cordilleran region: Science, v. 56, p. 335-336.

1. Spokane, Washington.
2. Glacial deposits and features.
3. Field observations.
4. Observations concerning glaciation of Spokane region.
5. ---
6. Evidence of glaciation on basalt plateau about Spokane four or five hundred feet above the train of the valley glacier in Spokane Valley. The prairies occupying the plateau bore evidence, in form of erratic boulders, gravel, sand and clay to depths of 15 feet, of ground ice on the level tops of the plateau. Hangman Creek valley holds deposits 500 to 600 feet deep. The Spokane Valley was completely dammed, impounding waters of entire Columbia drainage basin. In gap between Mica Peak and Moran Peak, south of Spokane, at 2,460 feet, two outlets for this body of water were found. Hangman Creek was obstructed also. This glaciation was followed by a period when stream erosion cleared valleys of Spokane River and Hangman Creek and eroded Spokane Valley 200 feet below present floor. Some evidence of

glacier almost reaching Spokane from north by way of valley of Little Spokane River; evidence of three periods of glaciation here. Long time period has elapsed since cutting of great trench through Palouse soil. As yet eolian deposits have not covered bare rocks of its floor, though for 8 miles between North Pine Creek and Hangman Creek there is no stream sufficient to account for removal of deposits.

______, 1922, Glacial border of Spokane, Washington: Pan American Geologist, v. 38, no. 5, p. 359-366.

1. Spokane, Washington.
2. Glacial deposits and landforms.
3. Field observations.
4. Description and explanation of glacial features around Spokane.
5. --
6. Discusses location of tills and various moraines in and around Spokane and speculates on the number of glacial epochs northeastern Washington has witnessed. Mentions Palouse Formation and its possible origin as impounded lake sediments resulting from basalt-flow damming of local streams. Discusses formation of Lake Spokane by ice sheet damming Spokane Valley, and the Mica outlet.

______, 1943, Confusion over glacial Lake Spokane: Science, v. 98, no. 2556, p. 560-561.

1. Spokane region, Washington.
2. Palouse Formation, glacial deposits.
3. Field observations.
4. Evidence for glacial lake.
5. ---
6. Evidence for glacial lake in Spokane River Valley (Lake Spokane) formed by ice dam made by lobe of Cordilleran Ice Sheet approaching Spokane from the north to 20 miles south of city. Eastern margin was marked by moraine. This lake collected all water from eastern British Columbia, western Montana and northern Idaho. Represented major interruption of drainage and its outlets through two channels at Mica, Washington, 12 miles southeast of Spokane. Lake level assumed 2,500 feet at lowest level giving depth of 500 feet at Spokane. Mentions Bretz's Lake Latah formed by blockage by glacier of the Mica channels and Latah (Hangman) Creek near Spangle. Also mentions Hobb's larger Lake Spokane. States case for Palouse Formation being older than the last glaciation and flood.

Laval, W. N., 1948, An investigation of the Ellensburg Formation: Univ. of Washington M.S. thesis, 52 p.
D-1-50, N-7, O-7

1. Ellensburg-Yakima region (Mount Stuart and Ellensburg quadrangles).
2. Ellensburg Formation.
3. Channel samples collected throughout study area, then size graded and screened and viewed through petrographic microscope.
4. Field and petrographic studies to classify beds mapped as Ellensburg Formation in the Mount Stuart and Ellensburg quadrangles.
5. Geologic map of Ellensburg area and structure cross-sections.
6. Classification of Ellensburg Formation in Mount Stuart and Ellensburg quadrangles into five separate stratigraphic units. Three units at Ellensburg: 1) upper beds deposited by Wilson Creek as alluvial fan; 2) cobble conglomerate; 3) pebble conglomerate. Latter two units deposited by Yakima River. All three units stratigraphically younger than typical Ellensburg exposed to north and south. In Naches-Wenas occurrences are two units regarded as most typical Ellensburg: 1) beds above Wenas basalt and 2) beds below Wenas basalt. Other occurrences in two quadrangles have been found to correspond to these units. Other units exist which can't be classified at this time: 1) beds on south end of mesa north of Ellensburg, which may correspond to one of the units at Ellensburg, 2) and 3) two interbasalt units on Taneum Creek, neither of which seem to correspond to the beds below the Wenas basalt, 4) the beds in the Cowiche Mountain-Ahtanum Ridge area which are petrographically dissimilar to the typical Ellensburg.

______, 1956, Stratigraphy and structural geology of portions of south-central Washington: Univ. of Washington Ph.D. thesis, 208 p.

1. South-central Washington.
2. Yakima Basalt, Selah Formation, Wenas Basalt Formation, Ellensburg Formation.
3. & 4. Field and laboratory investigations concerning stratigraphy and structural geology of region.
5. Landform map; structure sections and geologic maps for 8 map areas.
6. In the southwestern part of the Columbia Basin Mio-Pliocene and Pleistocene formations are exposed. The Mio-Pliocene units have distinctive

lithologies that can be correlated over hundreds of square miles, thus facilitating detailed structural mapping. The Mio-Pliocene formations are, from oldest to youngest, as follows: the Yakima Basalt, the Selah, the Wenas basalt, and the Ellensburg. This sequence comprises a part of two mutually inter-fingered lithosomes - one of sedimentary rocks and the other of flood lavas. The Yakima Basalt sheets and interbedded fluviatile, aeolian, and lacustrine sediments, including diatomite, record regional downwarping and mild localized warping during accumulation. The Selah formation consists essentially of fluviatile and aeolian clastics of volcanic origin derived from the present mountain areas to the west and probably to the north of the Columbia Basin. It also contains clastics apparently derived from erosion of the northern Columbia River drainage area. The Wenas basalt consists of one or two flood lava flows. Locally these flows are arbitrarily assigned to the Selah and Ellensburg formations. The basalt part of the Ellensburg formation is similar to the Selah formation. Upper Ellensburg sediments consist largely of debris derived from rising anticlinal ridges. The Pleistocene Ringold formation overlies the Mio-Pliocene succession unconformably.

Petrographically the lavas are tholeiitic and are characterized by andesitic basalts and basaltic andesites. The volcanic-derived clastics of the Selah and Ellensburg formations and of the sedimentary interbeds in the Yakima Basalt consist overwhelmingly of hornblende andesite. The non-volcanic sediments are quartzose sands, and conglomerates containing pebbles of quartzite, basalt and other rock types. Mixtures of volcanic and quartzose lithologies occur in the sedimentary lithosome and in the Ringold formation.

The anticlinal structures mapped are of three general types: (1) single, convex upward flexures; (2) broad arches with subsidiary flexures; (3) monocline-like structures bounded on one or both sides by subsidary flexures and locally thrust to the north. In addition to thrust faulting, transverse and normal faults are associated with the rise of the anticlines. More recent normal faults have slightly lowered the structural relief of some of the ridges. Two possible modes of genesis for the folding are suggested: (1) folding free of the basement, or (2) folding in direct response to deformation of the basement.

The indicated sequence of events is as follows: (1) accumulation of flood lavas and minor sedimentation accompanied by general downwarping; (2) localized mild differential warping and the accumulation of great volumes of adesitic detritus along with continued lava outpouring and non-volcanic sedimentation; (3) rise of anticlinal ridges and integration of the drainage system into essentially its present form; (4) continued or renewed differential warping and deposition of the Ringold formation; (5) upwarping of that formation to the north and perhaps nearly contemporaneous antithetic faulting.

Ledbetter, M. T., 1977, Duration of volcanic eruptions: Evidence from deep-sea tephra layers (abs.): Geol. Soc. America Abs. with Programs, v. 9, no. 7, p. 1067.

1. Eastern Pacific.
2. Worzel ash.
3. Model developed to predict distribution of tephra particle sizes as function of duration of eruption and settling time of particles.
4. See title.
5. ---
6. An instantaneous volcanic eruption produces a range of particle sizes which, in turn, are carried downwind and deposited on the sea surface. The differential settling times of these particles in the water column produces a size fractionation that creates a graded bed (fining upward) on the seafloor. A volcanic eruption of a few days or weeks produces a similar range of particle sizes, however, the style of grading is quite different. A model has been developed which predicts the distribution of particle sizes within the graded tephra deposit as a function of the duration of the eruption and the settling time of the particles. If we assume that the range of particle sizes remains constant during the eruption, then there is a zone of coarse particles near the base of the ash layers which results from the faster settling velocity of the largest particles. The top of this coarse zone should include the last large particle ejected at the end of the eruption and also much smaller particles which were ejected earlier but were overtaken while settling. The smallest particle deposited at the top of the coarse zone which was ejected in the initial phase of eruption would be still settling. Since both the coarsest and finest particles arrived together at the seafloor, then the difference in settling time is a measure of the duration of the eruption.

The model has been tested on an ash layer in two Trident deepsea cores from the eastern Pacific. The ash layer is correlated with the Worzel ash (layer D). The mean duration of the volcanic event that resulted in the 8 cm ash layer in both cores is 21 days ± 5 days. The apparently long duration is consistent with the greater ash thickness relative to the observed ash thickness from historical eruptions.

Leverett, F., 1917, Glacial formations in the western United States (abs.): Geol. Soc. America Bull., v. 28, p. 143-144.

1. Western U.S. - excerpts from Puget Sound region, Washington, northeast Washington and Yakima Valley, Washington.
2. Glacial deposits.
3. Field observations.
4. Comparison of western glacial features with eastern.
5. ---
6. In northeastern Washington, the occurrence of a very old drift, probably Kansan, was established by the discovery of till and striated stones on a high divide southwest of Spokane in the vicinity of Cheney. Boulders had been observed in this region and the possibility of glaciation had been suggested by M. R. Campbell in the Northern Pacific Guide Book. In Yakima Valley, the distribution of erratic boulders has been referred to floating ice by earlier students. It seems an open question, however, whether this region, like that near Spokane, may have been glaciated in early Pleistocene time.

   Discussion by G. F. Wright: The glacial accumulations near Spokane, so far from the recognized glacial area, are certainly of great significance. A similar isolated accumulation of glacial material has just been reported 40 or 50 miles south of generally recognized limits of Kansan drift. All this indicates that the "attenuated border" is much more attenuated than we have been accustomed to suppose. It is, however, well known that this attenuated border occasionally has large areas where glacial material is absent.

______, 1922, Old glaciation in the Cordilleran region: Science, New Ser., v. 56, p. 388.

1. Cheney, Washington.

2. Kansan drift.
3. & 4. Field observations.
5. ---
6. To the Editor of Science: The communication by Thomas Large on the above subject in the September 22 issue of Science prompts me to write that in 1916 I found till with striated boulders and pebbles in the brickyard near the normal school at Cheney, Washington, beyond the limits here reported by Large. I brought this matter to the notice of the Geological Society of America at the Albany meeting in December, 1916, and the following brief statement concerning it appears in the proceedings of that meeting. (Bull. Geol. Soc. America, Vol. 28, p. 143):

   In northern Washington the occurrence of a very old drift, probably Kansan, was established by the discovery of till and striated stones on a high divide southwest of Spokane, in the vicinity of Cheney. Boulders had been observed in this region, and the possibility of glaciation had been suggested by M. R. Campbell in the Northern Pacific Guide Book.

Lillie, J. T.; Tallman, A. M.; Caggiano, J. A., 1978, Preliminary geologic map of the late Cenozoic sediments of the western half of the Pasco Basin: Rockwell Hanford Operations, Informal Report RHO-BWI-LD-8, 16 p.

F-1-149

1. Pasco Basin, Washington
2. Surficial deposits including Ringold Formation, Hanford formation and sand dunes.
3. Compilation of existing geologic mapping and original field observations.
4. See title.
5. Preliminary geologic map of late Cenozoic sediments in 13 quadrangles.
6. The surficial geology of the western half of the Pasco Basin was studied and mapped in a reconnaissance fashion at a scale of 1:62,500. The map was produced through a compilation of existing geologic mapping publications and additional field data collected during the spring of 1978. The map was produced primarily to: 1) complement other mapping work currently being conducted in the Pasco Basin and in the region by Rockwell Hanford Operations and its subcontractors; and 2) to provide a framework for more detailed late Cenzoic studies within the Pasco Basin. A description of procedures used to produce the surficial geologic map and geologic map units is summarized in this report.

Livingston, E., 1977, Torrential deposits in southern B.C. and northern Washington (abs.): Geol. Assoc. Canada; Mineralogical Assoc. Canada; Soc. Econ. Geologists; Canadian Geophys. Union 1977 Annual Meeting, Abs. with Programs, v. 2, p. 33.

1. South British Columbia and northern Washington.
2. Torrential deposits.
3. Field observations.
4. Descriptions of torrential deposits.
5. ---
6. Torrential deposits have been recognized in the Okanogan Valley between Okanogan Falls, B.C. and Brewster, Washington. Similar deposits are found intermittently along the Similkameen River Valley upstream from Keremeos, B.C.

   Typical torrential landforms such as boulder bars, streamlined mounds of gravel, giant ripple marks and scooped-out closed depressions are present. The torrential deposits in the Okanogan Valley are associated with rapid drainage of a large glacial lake extending from south of Okanogan Falls to the Shuswap and Kamloops areas. The source of torrential flow in the Similkameen is not clear. Rough calculations based on valley gradient and water depth indicate a very high rate of flow in the Okanogan Valley.

   The presence of the torrential deposits poses many questions about the glacial lake in the Okanogan area, particularly the location of the dam or dams at the south end, how it was formed, and when it was drained.

Livingston, V. E., Jr. Tucker, G. B.; Rigby, J. G., 1978, Regional mapping of late Cenozoic sediments, Columbia Basin, Washington: <u>In</u> Rockwell International Basalt Waste Isolation Program Annual Report - Fiscal Year 1978, Richland, RHO-BWI- 78-100, p. 49-54.

1. Columbia Basin, Washington.
2. Late Cenozoic sediments.
3. Field mapping.
4. Stratigraphy and structures involving surficial geologic units.
5. Table showing stratigraphy of surficial units in Columbia Basin.
6. Report of progress concerning field mapping and map compilation leading to surficial geologic map of Columbia Basin, Washington.

Long, W. A., 1951, Glacial geology of Tieton Valley, south-central Washington: Northwest Sci., v. 25, no. 3, p. 142-148.

1. Tieton Valley, south-central Washington.
2. Ice-contact deposits, landforms.
3 Field observations.
4. See title.
5. Map of Tieton Valley, south-central Washington.
6. The Tieton Valley, a tributary to the Naches Valley, which joins with lower Yakima Valley in south-central Washington, contains deposits of two late Pleistocene glaciations. The older glacier advanced down Tieton Valley and terminated 3 miles beyond the town of Rimrock. Weathering in the older till has resulted in a zone of oxidation extending through an average depth of 20 feet.

   Erosion has almost completely destroyed the original glacial features of the moraines. The younger glacier reached one-fourth mile beyond Rimrock. Weathering has progressed to a depth of about 5 feet in the younger till, and the glacial topography of the moraines is almost entirely preserved.

______, 1951, Glacial geology of the Wenatchee-Entiat area, Washington: Northwest Sci., v. 25, no. 1, p. 3-16.

1. Wenatchee-Entiat area, Washington.
2. Glacial deposits and topography.
3. Field observations.
4. See title.
5. ---
6. Valley glacial deposits in central and southern Chelan County, north-central Washington, suggest two successive late Pleistocene glaciations. The older, more extensive glaciers occupied the Wenatchee Valley and tributaries, the Entiat Valley, and the Wenatchee Mountains. The older glacier deposits are oxidized through an average depth of 20 feet and are partially blanketed by later deposits of sand and silt. They form prominent lateral moraines against Boundary Butte Ridge; elsewhere, the deposits are limited to materials rather than to topography. The younger glaciers occupied the same valleys as did their predecessors but were unable to advance as far. Their deposits are fresh, unaltered, and retain much moraine topography.

______, 1968, High gravels of Wenatchee River below Leavenworth, Washington (abs.): Northwest Sci., v. 42, no. 1, p. 37-38.

1. Leavenworth to Cashmere, Washington.
2. Preglacial river gravels.

3. Field observation and mapping of river gravels and relationship to lower terrace gravels.
4. Same as above.
5. ---
6. High, unconsolidated preglacial river gravels at two levels were observed and mapped on the Wenatchee River between Leavenworth and Cashmere. The upper-level gravels cap high hills and flat ridge spurs 500-700 feet above the river; the lower-level gravels occur on benches at 200-250 feet. These high gravels are unrelated in weathering characteristics, areal extent, and altitude above the river to the Pleistocene terrace gravels, which at much lower levels border the river and are closely related to repeated valley glacier advances.

______, 1969, A preliminary report on the glaciation of the middle Entiat Mountains, Washington (abs.): Northwest Sci., v. 43, no. 1, p. 39.

1. Middle Entiat Mountains, Washington.
2. Glacial features and deposits.
3. Field observations of features indicative of extent and age of glaciation of middle Entiat Mountains, Washington.
4. Same as above.
5. ---
6. The broad, rolling 5,000 to 6,500-foot high upland of the middle Entiat Mountains was occupied by a small Pleistocene ice cap with at least four outlet glaciers. Marble Creek and Mad River glaciers deposited well-defined end moraines; Tommy Creek and Three Creek glaciers joined a 34-mile-long valley glacier built on an end moraine on the Entiat River.

   The principle products of glaciation on the Entiat upland are well-rounded rock bosses and widely scattered patches of smoothed and striated bedrock, which spatial distribution confirms that an ice cap lay on its surface.

   One episode of glaciation is recognized; it is considered Wisconsin and predates Glacier Peak volcano pumice-ash which is widespread on the upland and is on all moraines.

Lupher, R. L., 1940, Origin of clastic dikes in the Lewiston Basin, Washington and Idaho (abs.): Geol. Soc. America Bull., v. 51, no. 12, part 2, p. 2027.

1. Lewiston Basin, Washington and Idaho.

2. Clastic dikes in Pleistocene sediments and Columbia River basalt.
3. Field observations.
4. See title.
5. ---
6. Numerous clastic dikes penetrating Pleistocene sediments have long been known in southeastern Washington. They occur also in the Lewiston region in gravels, sands, and silts related to glacial stages, and even in the basalt lavas beneath. The dikes are composed of clay, silt, sand, gravel, and basalt rubble. Dikes and enclosing deposit are rarely alike in grain size. Many dikes are of a multiple character, showing repeated opening and filling of small fissures. The dikes are almost invariably bounded by thin laminated clay layers representing the accumulation from muddy water. Many lines of evidence show that most fissures were filled from above. More than one process of filling is indicated, but most commonly running water dropped sediment into a water-filled fissure. The sediment accumulated upon the "foot-wall" of the fissure and, reaching the top of the upbuilding dike, it commonly assumed the angle of repose oblique to the fissure walls and produced stratification which reflected the fluctuations of current and materials in the running water above. Some dikes were filled with infalling material without the aid of running water.

   Strong evidence shows that the fissures are not the result of earthquakes. On the contrary, a very gentle opening process is required. Some fissures, particularly those that reach into the bedrocks, are related to slumping, but there is some evidence that settling resulting from the melting of buried ice may have been the most common origin.

______, 1940, Pleistocene history of the Lewiston basin of Washington and Idaho (abs.): Geol. Soc. America Bull., v. 51, no. 12, part 2, p. 2027-2028.

1. Lewiston Basin, Washington and Oregon.
2. Columbia River basalt, Ringold Formation, Pleistocene stream sediments.
3. Field observations.
4. See title.
5. ---
6. The Lewiston-Clarkston region reveals a sequence of Pleistoene events which has some bearing on the

development of scablands and related features in central and southeastern Washington.

Camas Prairie is not far outside the definitely known area of Pleistocene Cordilleran glaciation, and a temporary influx of water across its northern rim might have been caused by an ice dam in the outlet of the neighboring Little Bitterroot Valley. Camas Prairie is also within the area flooded by an arm of glacial Lake Missoula, and the topographic relations of this basin are such that a rapid draining of the lake might have caused, for a brief time, a huge current to flow across it. Certain gravel deposits inside gulches along narrows in Clark Fork Valley nearby may be explained as bars formed by large rapid outflowing currents.

_______, 1944, Clastic dikes of the Columbia Basin region, Washington and Idaho: Geol. Soc. America Bull., v. 55, p. 1431-1462.

1. Columbia Basin, Washington and Idaho.
2. Clastic dikes in lake and stream deposits.
3. Field observations.
4. Evidence for mode of origin, age, and composition of clastic dikes.
5. Sketches of clastic dike sections to illustrate structures and materials.
6. Pleistocene lake and stream deposits of southeast Washington and the adjacent portion of Idaho are cut by innumerable clastic dikes of an unusual kind. Dikes are most abundant in the Touchet beds and scabland deposits, a few are present in the earlier Clarkston deposits, and rarely, they enter the Columbia River basalt. The processes of formation were long-continued and concurrent with proglacial deposition. An analysis of the sedimentary environment indicates that ice played an important role in deposition of dike-bearing deposits.

   Many dikes occur in compound units of several or many individuals lying parallel in the same major fissure; they were formed by repeated filling of growing fissures. Fissures were filled from streams, lake currents, and waves, some collapsed from fissure walls or poured in from unconsolidated surficial deposits, a small amount was carried by underground currents, and films of clay and silt were spread upon fissure walls in several ways. Wind-borne sediments are indicated but not proven. Two or more processes generally operated together

or alternately to fill each fissure; dike material, ranging from clay to fine gravel, may be sorted or unsorted, stratified or unstratified, and the stratification may be horizontal, inclined, or vertical. Any or all possible combinations of the variables may be present even in individual dikes.

Five processes of fissure development are recognized: (1) uneven settling and cracking through melting of buried ice, (2) gravity sliding and faulting on inclined zones of subsurface melting, (3) formation of cavities where ice blocks and layers melted, (4) erosion by underground streams, and (5) faulting and fissuring by landslides in the Columbia River basalts.

Lupher, R. L.; Warren, W. C., 1945, Clarkston stage of the northwest Pleistocene: Jour. Geology, v. 53, no. 5, p. 337-338. G-191

1. Lewiston Basin region on lower Snake River, Washington.
2. Pleistocene stream gravels.
3. Field observatiosn, descriptions of gravels, mapping.
4. Description of the "Clarkston stage" in its type area.
5. Map of Lewiston Basin region.
6. An episode of proglacial aggradation, here named the "Clarkston stage," is recorded in the Lewiston Basin region on the lower Snake River. Stream gravels accumulated to a depth of more than 400 feet in the Snake River canyon and in the lower portions of most tributary canyons. One or two tributary streams were ponded by the fill of the main canyon. The deposits are characterized by considerable cementation, weathering of basalt and granitic stones, and iron oxide stain. Two-story canyons were formed by cessation of erosion beneath the fill, prolonged lowering of slopes above, and later excavation of the fill. The Clarkston stage followed earlier Pleistocene deposition, deformation, and dissection but antedated the Wisconsin stage.

Mackin, J. H., 1941, Mounded fans in the Columbia Plateau area, Washington (abs.): Northwest Sci., v. 15, no. 4, p. 80.

1. Columbia Plateau.
2. Mounded fans.
3. Field observations.

4. Description and mode of origin of mounded fans.
5. ---
6. Alluvial fans along the sides of coulees in the Columbia Plateau exhibit two types of surface form, one type being the smooth radial slopes of the conventional fan, and the other being characterized by small hillocks or mounds on the fan surface. In general, large low-gradient fans tend to be mounded, but there are intergradations, and both types of surface form may occur on different radial segments of the same fan. The mounds may attain a height of six feet, are generally elongate with the steeper end down the slope, and are made up largely of angular blocks of basalt.

   The following hypothesis for the origin of the mounds is offered: Small channels in the uplands become partly filled by slope wash and by mass movements of loessic upland soils during the long intervals between times when they carry running water. When runoff occurs, especially when thawing surface soils rest on frozen sub-soil, mud flows may originate both in the stream channels and on soil mantled slopes.

   The pasty mass, carrying with it angular blocks of basalt, moves out onto the fan and terminates as a steep-ended tongue of mud on the fan surface. The mud flow phase may or may not be followed by a phase of running water. Rain falling directly on the fan subsequently washes away the fine mud, leaving a mound of angular basalt rocks.

   Such mud flows, terminating on fans, are of very infrequent occurrence, but the mounds of basalt, once formed, are long lived. They may be destroyed only by burial or by the active cutting of a relatively large stream of water. For this reason they are common only on small fans which apex in valleys with restricted drainage area, and are rarely seen on the fans of larger upland streams.

______, 1961, A stratigraphic section in the Yakima Basalt and the Ellensburg Formation in south-central Washington: Washington Div. Mines and Geology Report Invest. 19, 45 p.

1. South-central Washington.
2. Yakima Basalt and Ellensburg Formation.
3. Field observations; review of existing literature.
4. See title.
5. Columnar sections of lower part of Ellensburg Formation in Sentinal Gap - Priest Rapids area;

stratigraphic sequences in lower part of Ellensburg Formation.

6. Purpose of paper is to formalize the nomenclature associated with stratigraphic units in the Columbia Plateau. The Ellensburg Formation consists of fluvial and lacustrine sediments from several different sources, and intercalated basalt flows. The stratigraphic contemporaneous complexity is increased by contemporaneous folding. Several sections are described and correlations made. Term Beverly Member is redefined. Basalt flows in Ellensburg Formation are described. The Selah Member of the Ellensburg Formation is designated and described. Problems of correlation are discussed. Changing patterns of sedimentation and erosion are discussed. States that Selah and Beverly Members are correlative. Emphasizes effects of folding and spreading of detritus from the west on localization of drainage lines and erosional and depositional activities on rivers in south-central Washington during late Cenozoic subsidence of Columbia Plateau also considered.

Markham, D. K., 1971, Quaternary loess deposits of Douglas County, central Washington: Univ. of Washington M.S. thesis, 23 p.

1. Douglas County, Washington.
2. Quaternary loess.
3. Field methods; sampling of loess deposits and laboratory work with samples.
4. Same as above.
5. Geologic map of the Waterville Plateau region; idealized loess profile; isolines of average grain-size diameter.
6. Theory proposed that katabatic winds off the Okanogan ice lobe are responsible for loess deposits on the Waterville Plateau. The average grain size diminishes with distance from the Withrow moraine which marks the maximum extent of Pinedale glacial advance on the plateau. As ice front receded north of Columbia River, the Badger Mountains and the Columbia River Gorge inhibited the prevailing southwest winds from carrying alluvium onto the plateau; little additional loess has been deposited in the region. Pumice from Glacier Peak eruption is integrated with loess reflecting continuous animal and wind reworking. A buried B clay peak and associated caliche layer may be pre-Bull Lake remnants. Three hypotheses can be considered to explain the absence of loess until Pinedale time, as dated by the pumice

incursion. Either 1) the loess was deposited but was flushed away by the Missoula floods, 2) the rate of deposition was very slow when the Okanogan lobe failed to cross the Columbia River, and sizeable amounts of loess were deposited only in the Pinedale, or 3) the caliche formed under different climatic conditions than the Palouse and thus is much younger than pre-Bull Lake.

McConiga, M. W., 1955, Deformation of the Ringold Formation: Hanford Atomic Products Operations Report HW-36373, 6 p.

1. White Bluffs, Western Franklin County, Washington.
2. Ringold Formation.
3. & 4. Telescope leveling of formation to determine deformation.
5. ---
6. The Ringold Formation is shown by careful levelling to have undergone significant deformation at the type locality. The presence of deformation here disproves prior reports which state that the Ringold Formation has not been subjected to orogeny. Recognition of this assists in dating the age of the Ringold Formation and the age of the last orogeny in the region and aids in the correlation of the geologic conditions across the project region.

McKnight, E. T., 1923, The White Bluffs Formation of the Columbia: Univ. of Washington B.S. thesis, 22 p.

1. White Bluffs, Washington, region.
2. White Bluffs (Ringold) Formation.
3. Field observations.
4. Stratigraphic and structure, extent, description.
5. ---
6. A close examination of the White Bluffs, 2 miles north and 4 miles south of town of White Bluffs. White Bluffs have an elevation of 300-500 feet and extend along Columbia River 35-40 miles from 12 miles above Pasco to Wahluke. Ringold exposed widely to east and north of Saddle Mountains. The surface extending several miles eastward from Hanford, is a plane 950 feet above sea level, a surface of aggradation. Ringold only occurs on east side of Columbia River. Sediments are soft, very fine grained sandy shale, somewhat coarser sands, shales, travertine, volcanic ash and coarse gravels. Lower part of section is shale, while upper part more sandy. Underlying shale is massive in detail though stratified in thick beds, light gray, fractured in all directions. Sandy

shales at top well-stratified horizontally, block-jointed and creamy yellow. Wherever stratified and undisturbed, Ringold beds are horizontal. The high bluff is topped by travertine and provides the sharp rim of the bluff, protecting underlying sediments from erosion. Gravel beds are common along summit of bluff and were deposited by Columbia River. Gypsum occurs in lower shales. Mentions some landslides, the largest across the river from Hanford. Obtained numerous fish, shark, turtle, bird, mammal and fresh-water molluscan remains. Determined age to be approximately Pleistocene and fluviatile or lacustrine in origin.

Mehringer, P. J., Jr.; Blinman, E.; Petersen, K. L., 1977, Pollen influx and volcanic ash: Science, v. 198, no. 4314, p. 257-261.

1. Pacific Northwest.
2. Mount Mazama and Glacier Peak tephra.
3. Pollen influx (estimate of amount of pollen grains incorporated into sediments within a particular time and with a particular surface area.)
4. Pollen content of Mazama and Glacier Peak ashes to reveal depositional chronologies.
5. Figure showing pollen percentages and total pollen content of 8 Mazama ash samples.
6. Pollen influx can be used to estimate the duration of short-term depositional events. When applied to volcanic ashes, it may also provide information on the season and ecological effects of ash-fall. In our initial application of the method to volcanic ashes from Lost Trail Pass, Bitteroot Mountains, Montana, we have illustrated that (1) two falls of Glacier Peak ash, which occurred about 11,250 C-14 years ago, were separated by 10 to 25 years; and, (2) volcanic ash from a major eruption of Mount Mazama (about 6700 C-14 years ago) first fell in the autumn and 4.6 centimeters of ash were deposited before the following spring. We also believe there is a reasonable probability that (1) about 1 centimeter of ash fell during the following year and about 1.7 centimeters fell the year after; (2) in all, the sporadic primary Mazama ashfall lasted for nearly 3 years; (3) Mazama ash resulted in low lake productivity, as measured by the occurrence of Botryococcus and Pediastrum; (4) Mazama ash, perhaps through a mulching effect, may have produced increased vigor and pollen production in some sagebrush steppe genera; and (5) as measured by the records of

fossil pollen and acid-resistant algae, effects on the aquatic and terrestrial eco-systems were short-lived. With refinement of the methods and broader geographic application, pollen influx studies may prove valuable for separating the regional and chronological details of tephra attributed to Mazama, Glacier Peak, and other Cascade Range volcanoes.

Meinzer, O. E., 1918, The glacial history of Columbia River in the Big Bend region (abs.): Washington Acad. Sci. Jour. v. 8, no. 12, 411-412.

1. Big Bend region, central Washington.
2. Cataracts and other glacial features in Yakima Basalt.
3. Automobile reconnaissance.
4. See title.
5. ---
6. In glacial epoch a lobe of ice sheet was pushed down the valley of Okanogan River, and across Columbia River, diverting waters of Columbia over upland of central Washington, cutting precipitous gorges several hundred feet deep, developing 3 cataracts, forming a large lake in Quincy Valley, and carrying boulders many miles and gouging out holes 200 feet deep.

   Region underlain by Yakima Basalt. Where the diverted water reached the monoclinal fold in basalt that causes the descent into Quincy Valley, they apparently formed a cataract which retreated about 17 miles, cutting through the basalt a gorge several hundred feet deep. As an agent of erosion, the Pleistocene Columbia had two great advantages over the Niagara: 1) It fluctuated much more and in heavy floods carried three times as much water as the maximum modern Niagara: 2) It was much better provided with tools for erosion than the Niagara, shown by large quantity and size of boulders in glacial outwash below mouth of gorge. At the mouth of the gorge the ancient river discharged, in the early part of its history, into a lake which occupied Quincy Valley, as is indicated by the topography, by fossiliferous stratified deposits, by erratic glacial boulders of granite and quartzite which must have been carried to present positions by icebergs, and by two ancient water falls along the present gorge of Columbia River obviously caused by the overflow of the lake.

Merriam, J. C.; Buwalda, J. P., 1917, Age of strata referred to the Ellensburg Formation in the White Bluffs of the

Columbia River: Calif. Univ. Dept. Geol. Sci. Bull., v. 10, no. 15, p. 255-256, plate 13.

1. North Yakima, Washington and White Bluffs near Hanford and Ringold.
2. Ellensburg Formation and Ringold Formation.
3. Collection of vertebrate remains from the formation, field observations of stratification section and physiography and structure.
4. Paleontological evidence to determine age of Ringold Formation and relation to Ellensburg Formation.
5. Estimated section of Ringold Formation in White Bluffs below Hanford.
6. Determination of age of Ellensburg Formation through vertebrate remains. The genus Hipparion (horse type) was found in the type area (Pleistocene) and from the White Bluffs area (Ringold). The genus Equus was represented (Pleistocene). Evolution stages of the horses belong to different periods of which White Bluffs stage (Ringold) is later. Ellensburg Formation is Miocene to early Pliocene; White Bluffs area (Ringold) is distinct and later stage in history of sedimentation of eastern Washington. The collection of fossils included Megalonyx, Equus or Pliohippus, Camelid, Cervid, Leporide, Testudo and fish vertebrae. Includes description of Ringold Formation and proposes that name for it. Beds not sharply stratified, strata not indurated and exposures assume roundness and subdued topography. Strata lie parallel to Columbia River water surface and deformation is due to land sliding. Bluffs follow Columbia River 30 miles from 10 miles north of Pasco then northwestward and have elevation of 500 feet. Ringold Formation deposited in a basin bordered by Yakima Range on west, Saddle Mountains on north, and lava plateaus on east and south, by Columbia River in a flood plain environment. It covers an area up to 600 square miles. It is suggested that the Ringold unconformably overlies the Ellensburg Formation.

Merriam, J. C., 1934, Nature and extent of Tertiary Formations immediately following the Columbia lava flows of the Northwest (abs.): Science, new series, v. 80, no. 2085, p. 550-551.

1. Eastern Washington and Oregon.
2. Ellensburg Formation.
3. Field observations.
4. See title.

5. ---
6. In description of the series of formations in the John Day valley of eastern Oregon, published in 1901, the writer described under the name of the Mascall Formation a series of deposits in a depression formed by the down-folded Columbia lavas. It was noted that the dip of the lower Mascall is approximately the same as that of the lavas upon which it rests. Reference was made to the fact that the Ellensburg beds of central Washington are probably in part of the same age as the Mascall, and that a similar formation occurs in the Crooked River region to the south. There has been question as to the original extent of the Mascall and discussion of its possible extension over a considerable part of the Columbia lava region east of the Cascades in Oregon and Washington. The purpose of the present note is to call attention to the fact that as studies have been extended by geologists and paleontologists in eastern Oregon and Washington the number of localities representing beds of the Mascall type has gradually increased. It is now important to have a study of the whole area with mapping of the beds of the Mascall stage and careful paleontological determination of the horizons. There is reason to believe that beds of the type of the Mascall may have existed over a considerable part of the Columbia lava region in the latter part of Miocene time. The present occurrences of Mascall may be due to post-Mascall depressions through which certain areas have been subject to relatively less intensive erosion, leaving relics of this formation to be covered in part by later accumulations.

Merrill, D. E., 1966, Glacial geology of the Chiwaukum Creek drainage basin and vicinity: Univ. of Washington M.S. thesis, 36 p. D-3-100

1. Central Cascades, Chiwaukum Creek drainage basin, northwest of Leavenworth.
2. Ice contract deposits and landforms and ice-scoured bedrock.
3. Field observations.
4. See title.
5. Hatchery Creek moraine system; correlation of glacial deposits of region; glacial geologic map; generalized bedrock map; glacier profiles.
6. Deposits of three distinct glacial advances are present in Chiwaukum Creek drainage basin, and a possible older advance is present in the surrounding area. The deposits can be differentiated on the basis of granite-weathering ratio 5, surface-

boulder frequence, depth of oxidation, and the sharpness of their morphology.

The oldest deposits, which are patches of ground moraine in the Wenatchee River valley, suggest that ice from the Wenatchee drainage once entered Tumwater Canyon. Ice from the Chiwaukum drainage probably coalesced with the Wenatchee Glacier near the mouth of the Canyon. An end moraine, possibly associated with this advance, lies along the south fork of Hatchery Creek.

The next youngest ice advance left a series of well-preserved, sharp-crested morainal ridges in Hatchery Creek and an arcuate end moraine at the mouth of Chiwaukum Canyon. The only ice to reach Tumwater Canyon during this advance was the outlet glaciers draining an upland ice cap west of the Canyon.

Young glacial deposits are present in the valley heads and probably are due to neoglacial and pre-Hypsithermal advances. An inactive rock glacier in Chiwaukum Canyon probably is neoglacial in age.

The glacial sequence of the Chiwaukum drainage is broadly comparable to those of the Ingalls - Peshastin Creek area and the Leavenworth area, where three major glacial episodes are recognized. The drainage pattern of the Chiwaukum Creek drainage basin is controlled primarily by foliation and a prominent joint set at nearly right angles to the foliation.

Mills, H. H., 1977, Textural characteristics of drift from some representative Cordilleran glaciers: Geol. Soc. America Bull., v. 88, no. 8, p. 1135-1143, illus.

1. Cascade Range, northern Washington - southern British Columbia.
2. Glacial drift.
3. Particle-size analysis.
4. See title
5. Ranges of cumulative particle-size distributions of drift from various glaciers, ranges of graphic statistics for various grain-size samples.
6. Particle-size analyses of more than 300 samples of drift from Nisqually, Paradise, and South Cascade glaciers in the Cascade Range of Washington, from Athabasca Glacier in Alberta, Canada, and from other alpine glaciers show that textural differences exist both between glaciers and between

glacier subenvironments. Differences between glaciers probably reflect bedrock terrane and are shown by the percentage of silt + clay in the <-1.00 ø fraction, which increases in the following order: Nisqually and Paradise (volcanic bedrock), South Cascade (metamorphic and plutonic bedrock), and Athabasca (sedimentary bedrock). Differences between subenvironments are shown best by analyses of samples which include clasts as large as -6.67 ø; average frequency curves of these samples show that basal tills lack dominant modes in the coarse fraction and may have dominant modes in the fine fraction at about 4.00 ø, whereas sediments of other subenvironments possess dominant modes in the coarse fraction at or above -5.00 ø. Mean size and sorting increase, and percentage of silt + clay decreases in the following order: basal till, recessional-moraine till, end-moraine till, ablation drift, and stratified drift. Skewness, but not kurtosis, also varies with subenvironment.

A comparison of alpine drift with continental ice-sheet drift from Ontario shows that, in general, alpine drift is coarser, but that alpine basal till is comparable to ice-sheet basal till. When comparing nonglacial diamictons to alpine drift, it may be possible to distinguish the former from the sediments of one glacier sub-environment but not from those of another.

Moodie, C. D; Okazaki, R.; Smith, H. W.; Kittrick, J. A., 1966, A note on the clay mineralogy of four samples from the Ringold Formation: Northwest Sci., v. 40, no. 2, p. 43-45, table.

1. Central Washington.
2. Ringold Formation.
3. X-ray diffraction of 4 samples of clay.
4. See title.
5. Table showing clay minerals in size separates.
6. Four samples of horizons within the Ringold Formation were collected to assay the clay mineral assemblage. Sample locations are described. Samples freed of organic matter and iron and size separated, then examined by X-ray diffraction. Minerals with 18A spacings recorded as montmorillonite and 10A spacing as illite. Results are summarized in a table. The dominant presence of montmorillonite in the Ringold accounts for its use by the Bureau of Reclamation for lining canals.

Moody, U. L., 1976, Late Quanternary stratigraphy of the Lind

Coulee and surrounding area: Northwest Scientific Assoc., Programs, Abs. p. 18.

1. Grant County, southeast Washington.
2. Late Quaternary flood sediments.
3. Field observations.
4. See title.
5. ---
6. Lower Lind Coulee, Grant County, Washington, was a major drainageway for Late Quaternary floods. Three distinct levels of flood gravels are preserved on Saddle Mountain. Remnant "slack water" sediments containing a triple-banded St. Helens volcanic ash sequence reflect Spokane flood deposition rather than sedimentation in a large "Lake Lewis." These sediments were eroded and topped by younger overbank silts and sand, the Lind Coulee sediments. An erosional episode cuts the overbank deposits and reworked Mazama Ash and aeolian material cap this. Chronology from 6700 B.P. to 18,000 B.P. is established by petrographic and microprobe analysis of volcanic ash. A new limiting radiocarbon date has been established for St. Helens J volcanic ash.

______, 1977, Correlation of flood deposits containing St. Helens Set S ashes and the stratigraphic position of St. Helens Set J and Glacier Peak ashes, central Washington (abs.): Geol. Soc. America Abs. with Programs, v. 9, no. 7, p. 1098.

1. Central Washington.
2. Mt. St. Helens and Glacier Peak tephra.
3. Field relationships and petrographic and chemical analyses.
4. See title.
5. ---
6. Volcanic ashes found in water-laid deposits were studied from 12 sites in central Washington from Crescent Bar to Wallula Gap. The purpose of the study was to correlate flood associated sediments and establish a chronology for St. Helens Set J and Glacier Peak ashes. Field relationships along with petrographic and chemical analyses were used for the correlations. Triple banded ash layers were found in fine clastic sediments and associated flood deposits in six sites north of the Saddle Mountains. Similar sediments to the south contain an ash couplet which corresponds to the upper and lower ashes of the triplet. These ashes appear to correlate with the upper and middle St. Helens Set S. The presence of these ashes in gravels of the

last major scabland flood indicates that the age of this flood was about 13,000 B.P (Mullineaux and others, this symposium). One site on the Lind Coulee Wasteway contains 11 ash layers in floodplain deposits. The lower ashes correlate with a St. Helens J ash and the upper ashes correlate with Glacier Peak. Stratigraphically above this section there are floodplain sediments with another St. Helens J ash dated at 8700 B.P. The Glacier Peak ashes were bracketed by two St. Helens Set J ashes.

______, 1978, Microstratigraphy, paleoecology and tephrochronology of the Lind Coulee site, central Washington: Washington State Univ. Ph.D. thesis, 273 p.

1. Central Washington.
2. St. Helens Set J tephra.
3. Tephrochronologic studies and radiometric dating.
4. Dating of archaeologic site by tephrochronologic and radiometric methods.
5. Microstratigraphic cross-sections of several localities.
6. The Lind Coulee Site, located 5 miles (8 Km) northwest of Warden, Washington, contains the most complete record yet known of man's early occupation away from the major river systems of the Columbia Basin. The initial excavations, conducted in the early 1950's, and the more recent excavations of the 1970's utilized an interdisciplinary approach involving archaeology, geology and ecology.

   This site provides evidence of occupation during at least seven spring seasons, approximately 9,000 years ago. The environment around the Lind Coulee Site during occupation was more moist and possibly cooler than at present. The inhabitants of the site were nomadic hunters and gatherers who were utilizing both large herbivores and medium-sized animals. The principal faunal remains from the site consist of muskrat, beaver, badger, elk and bison. A high percentage (37%) of the bison remains found during the excavations were full-term fetal or newborn, which might suggest that a bison calving area was in close proximity to the site. The artifacts, including projectile points, scrapers and bone needles, plus the split phalanges and long bones suggest that the site was utilized for many purposes, including skin processing and food preparation.

Tephrochronological studies were completed on volcanic ash layers at 13 localities. A tephra unit, similar to an upper St. Helens J ash, was found within the culture bearing sediments at the Lind Coulee Site. At another locality this ash dates at about 8,600 years ago. Furthermore, the ash studies make possible a general chronology for the area for times both preceeding and following the Lind Coulee occupations. This tephrochronology, together with several radiometric results from site materials, place the occupation at approximately 8,600-9,000 years ago.

The thesis documents microstratigraphic and stratigraphic relationships at the Lind Coulee Site. This microstratigraphy allows study of horizontal concentrations of bones and artifacts, affording data for investigation of important co-occurences. Finally, there is a discussion of the place of the Lind Coulee Site in Northwestern Prehistory.

Mullineaux, D. R., 1964, Extensive recent pumice lapilli and ash layers from Mt. St. Helens volcano, southern Washington (abs.): Geol. Soc. America Special Paper 76. p. 285.

1. Southern Washington.
2. Mt. St. Helens tephra.
3. Field observations and measurements.
4. See title.
5. ---
6. Three distinct layers of pumice from Mount St. Helens, separated by tuff and lithic sand, extend generally northeastward from the volcano. Two of these layers, called layers Y and W by Crandell, Mullineaux, Miller, and Rubin in the Mount Rainier area, are about 3200 and 300 years old, respectively; these are the "older" and "younger" Mount St. Helens pumices of Carithers. The third layer, here called layer T, probably is the 1802 lapilli deposit described by Lawrence. Other pumices on Mount St. Helens apparently have relatively small areal extent.

   Layer T is 8 feet thick, locally, on Mount St. Helens; 25 miles northeast it is about 5 inches thick and contains lapilli 20 mm across. Layer W is 20 feet thick on the volcano; 25 miles northeast it is 12 inches thick, locally, and contains lapilli 8 mm across. Layer Y predates the modern volcano but is thick just north-northeast of it;

50 miles north-northeast it is 1.5 feet thick locally and contains lapilli 8 mm across.

Each pumice can be distinguished by color or content and character of Fe-Mg phenocrysts. Most lumps of Y pumice have thin light-brown oxidation rinds, whereas the other pumices are white. In the Y pumice light and dark hornblende phenocrysts are abundant, and pyroxene is rare. Both W and T pumices contain abundant orthopyroxene and dark hornblende; however, orthopyroxene from W pumice has a high refractive index than does orthopyroxene from T pumice, and T pumice contains clinopyroxene, but W pumice does not.

Mullineaux, D. R.; Hyde, J. H.; Rubin, M., 1972, Preliminary assessment of upper Pleistocene and Holocene pumiceous tephra from Mount St. Helens, southern Washington (abs.): Geol. Soc. America Abs. with Programs, v. 4, no. 3, p. 204-205.

1. Pacific Northwest.
2. Mt. St. Helens tephra.
3. Chemical analyses, including prominent Fe-Mg minerals.
4. Division of St. Helens ash into 7 sets, each having characteristic suite of Fe-Mg minerals.
5. ---
6. Within the last 35,000 years, vents at the site of Mount St. Helens have erupted more than 40 voluminous pumice deposits. Most of these deposits can be grouped into 7 sets, each having a characteristic suite of Fe-Mg phenocrysts; cummingtonite in 3 sets appears to distinguish them from tephra derived from other Cascade volcanoes.

Set	Approximate age	Prominent Fe-Mg Minerals	Distribution
T---	150-200 years	hy, hb, augite	NE
W---	450	hypersthene(hy), hornblende(hb)	NE to S
P---	3,000-2,000	hy, hb	NE to E
Y---	4,000-3,000	cummingtonite(cm), hb	NE to SE
J---	<12,000,>8,000	hy, hb	NE to SE
S---	<18,000,>12,000	cm, hb	NE to E
Unnamed---	>35,000 -18,000	cm, hb, biotite	E to S

Each set except T includes several pumice beds. The unnamed set probably can be subdivided further. Pumice in Set J is similar in composition to the "Glacier Peak" tephra about 12,000 years old. The most voluminous layers in set Y from a NE-trending lobe, a NNE-trending lobe known as Mount Rainier

50 miles north-northeast it is 1.5 feet thick locally and contains lapilli 8 mm across.

Each pumice can be distinguished by color or content and character of Fe-Mg phenocrysts. Most lumps of Y pumice have thin light-brown northwestern United States and adjacent parts of Canada.

______, 1975, Widespread late glacial and postglacial tephra deposits from Mount St. Helens volcano, Washington: Jour. Res. U.S. Geol. Survey, v. 3, no. 3, p. 329-335.

1. Pacific Northwest.
2. Mt. St. Helens tephra.
3. Descriptions of tephra Sets S, J, Y, and W; discussion of use of tephra layers for dating a correlation; study of content of ferromagnesian materals in Mt. St. Helens pumice; data on stratigraphy, description and age of four tephra sets.
4. Same as above.
5. Table listing age and Fe-Mg phenocrysts content of tephra sets; diagrammatic section showing stratigraphic positions of some key C^{14} samples to determine tephra set ages; columnar section of sets; minimum distribution inferred from known occurrences of layers Yb, Yn and Ye; columnar section of Set Y, J, and W; minimum distribution of layers Wn and We.
6. Pumice layers composing four different groups of tephra beds (termed "sets"), whose stratigraphy, age, and trend away from Mount St. Helens are fairly well known, are potentially valuable stratigraphic markers in the northwestern United States and adjacent parts of Canada. All four tephra sets are less than about 18,000 years old. The oldest set described (Set S) is between about 18,000 and 12,000 years old; the most extensive pumice layers of the set, however, probably are no more than about 13,000 years old. Relatively voluminous layers in the next younger tephra unit (Set J) probably range from slightly less than 12,000 to slightly more than 8,000 years old; in the overlying Set Y, the most extensive layers range from about 4,000 to 3,400 years old. The largest tephra layers in the youngest tephra set described, Set W, are apparently all about 450 years old. All the extensive tephra deposits were carried chiefly east of Mount St. Helens, and the bulk of them form an arc which extends from northeast of the volcano clockwise around to the southeast.

Mullineaux, D. R.; Wilcox, R. E.; Ebaugh, W. F.; Fryxell, R.; Rubin., M., 1977, Age of the last major scabland flood of eastern Washington, as inferred from associated ash beds of Mount St. Helens Set S (abs.): Geol. Soc. America Abs. with Programs, v. 9, no. 7, p. 1105.

1. Eastern Washington.
2. Mount St. Helens tephra in fine-grained sediments.
3. C-14 dating; Fe-Mg mineral suites, chemical composition, refractive indices.
4. See title.
5. ---
6. Four groups of upper Pleistocene pumice layers from Mount St. Helens, called Sets C (oldest), M, K, and S (youngest), are mineralogically similar to certain cummingtonite-bearing ash beds of the channeled scabland flood. Fe-Mg mineral suites and refractive indices and chemical compositions indicate that Set S pumice layers are the near-source equivalents of "couplet" and "triplet" ash beds exposed near Vantage and Wanapum Dam along the western margin of the scabland. These data confirm earlier tentative correlations of Set S with scabland ash beds by us and several other investigators.

   Near Mount St. Helens, Set S is dated by radiocarbon as about 13,000 years old. Thus, the last major scabland flood is also 13,000 years old, in contrast to most previous estimates of about 20,000 years or older. The younger age, however, is consistent with an age estimate of possibly 14,000 years for a scabland flood by H. H. Hammatt, L. L. Foley, and F. C. Leonhardy in 1976. It is also consistent with an age of less than 13,500 (?) years estimated for the last flood by R. B. Waitt, Jr., in 1977, from relations of flood and glacial deposits marginal to the scabland. In addition, an age of about 13,000 years for the last scabland flood is supported by a radiocarbon date of 13,080 $\pm$ 350 years (W-3404) we obtained for peat that directly overlies the Portland delta of J H. Bretz, which is a down-valley deposit of that flood.

Newberry, J. S., 1885, Notes on the surface geology of the country bordering the Northern Pacific Railroad: New York Acad. Sci. 3d Ser. v. 30, p. 337-346.

Newcomb, R. C., 1958, Ringold formation of Pleistocene age in type locality, the White Bluffs, Washington: American Jour. Sci., v. 256, no. 5, p. 328-340; Washington Div. Mines and Geol. Reprint no. 1, p. 328-340, Figure 1, 1:1,013,760. F-2-153, P-4

1. White Bluffs, Washington.
2. Ringold Formation.
3. Field observations and measurements; well-log

analyses; general composition, origin, and stratigraphy of sediments.
4. Same as above.
5. Map showing outcrop of Ringold Formation in type area, several geologic sections.
6. The type section of the Ringold formation in the White Bluffs of the Columbia River consists of a stratigraphic thickness of about 620 feet of horizontally bedded continental sediments lying between river level and the tops of the bluffs, from about 340 to 960 feet in altitude. The beds are of middle to late Pleistocene age.

   The uppermost 505 feet of the type section, between 455 and 960 feet in altitude, is composed largely of lacustrine sand and silt. The lower part, extending upward from river level at 340 feet to the base of the lacustrine deposits, at 455 feet, is composed of a weakly indurated conglomerate member that was deposited by river currents. The conglomerate member extends also below river level, down to an altitude of about 290 feet. It is underlain by 100 to 290 feet of lacustrine silt, clay, sand, and some gravel beds. This lower lacustrine composite, a part of Ringold, is commonly called the "blue clays" section and lies, in turn, upon the basalt bedrock, whose surface is somewhat irregular but is near sea level in the central part of a broad syncline.

   The succession of lithologic types is believed to indicate two stages in the relative uplift of the drainage rim, the Horse Heaven Ridge, in a total amount of about 1,000 feet. The Horse Heaven Ridge is believed to have been a part of the impounding rim. Its main uplift must have been more or less contemporaneous with the deposition of the lower part of the Ringold Formation and must have preceded the deposition of the upper part in middle to late Pleistocene time.

______, 1961, Age of the Palouse Formation in the Walla Walla and Umatilla River basins, Oregon and Washington: Northwest Sci., v. 35, no. 4, p. 122-127, illus.

1. Walla Walla and Umatilla River Basins, Oregon and Washington.
3. Field observation of sediments and their stratigraphic relationships and determination of ages.
4. See title.
5. ---
6. The typical Palouse Formation of the Walla Walla

Valley is considered by the author to be middle to late Pleistocene.

The greatest deposition of the Palouse Formation closely followed, or accompanied, the deposition of the Ringold Formation and preceded the Wisconsin Glacial Stage. This dating agrees in general with the age findings of Culver (1937, p. 60), is slightly younger than the age assigned by Scheid (1940, p.57), and narrows a broader time interval given by Bryan (1927, pp. 37 and 45).

If younger eolian deposits that have been termed Palouse soil, especially those in the western parts of the Walla Walla and Umatilla River basins, are to be included in the Palouse Formation, the age would be middle Pleistocene to Recent.

The evidence in these basins suggests that the whole Palouse soil problem would be clarified by restriction of the term "Palouse" to the pre-Wisconsin loess.

______, 1962, Hydraulic injection of clastic dikes in the Touchet beds, Washington, Oregon, and Idaho (abs.): Geol. Soc. Oregon Country Geol. News Letter, v. 28, no. 10, p. 70

1. Washington, Oregon, Idaho.
2. Touchet beds.
3. Field observations.
4. Description of and origin of clastic dikes in Touchet beds.
5. ---
6. Dikes composed of silt, sand and gravel cut generally vertical, with great variety of size and spacing, in the Touchet beds, which are the lake-floor sediments of proglacial Lake Lewis. The Touchet beds occur in places widely distributed below 1,150 feet altitude in the Columbia River basin above Hood River. The dikes are the main part of those described by Lupher, whose basic observations are augmented by 6 groups of evidence bearing on the origin. 1) In plan, the dikes occur as large polygonal networks with distances across the cells ranging generally from 50 to 400 feet. 2) Dikes occur most profusely at places within the altitude zone 400-800 feet and are weak above 1,000 feet. 3) Dikes are most numerous where Touchet beds overlie highly permeable material. 4) The vertical section of a typical dike includes an irregular and an involved "root" part at the bottom, a central

"trunk" part, and an uppermost 10 or 20 feet of branches that disperse and taper out. 5) Dikes cut all but uppermost 10 or 20 feet of the thickest sections of the Touchet beds. 6) Silt, laminae on the walls, are filter cake attesting to outward filtration of sedimentary-carrying fluids from each successive dike lamina. Clastic dikes resulted from upward injections of groundwater, each caused by bank-storage effluent when pressure difference caused by lowering of Lake Lewis. Lowering occured after a deterioration of impounding dam and might have been repeated. First lowering produced hydraulic lift and injection of water into equidimensional system of fractures. Later injections used mostly the established transverse dike planes and produced many laminae of dikes.

______, 1971, Geologic map of the proposed Paterson Ridge Pumped-Storage Reservoir, south-central Washington: U.S. Geol. Survey Misc. Geol. Inv. Map I-653, 1:31,680, sections, explanatory text, 4 p.

______, 1971, Relation of the Ellensburg Formation to extensions of The Dalles Formation in the area of Arlington and Shutler Flat, north-central Oregon: Ore Bin, v. 33, no. 7, p. 133-142.

1. Arlington and Shutler Flat, Oregon.
2. Ellensburg and The Dalles Formations.
3. & 4. Field observations and mapping of region, including extension of Ellensburg Members to Shutler flat, basalt below the Selah Member, Dalles Formation as extended to this area; determination of age of units.
5. Type stratigraphic columns in south-central Washington and north-central Oregon.
6. The top flows of the Yakima Basalt taper southward into the Ellensburg Formation near Arlington much as they do westward in the Yakima Valley.

The extension of the Selah Member, and possibly of the Rattlesnake Ridge Member, for many miles beyond the end of its capping besalt flows, requires that large areas be mapped as Ellensburg Formation, a new experience for mappers in Oregon.

The relation of the lower part of the sedimentary facies of the "Dalles Formation extended" to the Rattlesnake Ridge Member is not yet clear and the possibility that the two are in part contemporaneous has not been ruled out.

The Ellensburg Formation and the "Dalles Formation extended" comprises the materials that have been referred to in reconnaissance studies as "Arlington Lake Beds" and "Shutler Formation," terms that are no longer needed.

The discrepancies still exist between early Pleistocene age in the type area of the Dalles Formation and middle Pliocene age for the supposed correlative strata ("Dalles Formation extended") in the Arlington area.

Norgren, J. A.; Borchardt, G. A.; Harward, M. E., 1970, Mount St. Helens Y ash in northeastern Oregon and southcentral Washington (abs.): Northwest Sci., v. 44, no. 1, p. 66.

1. Oregon and Washington.
2. Mt. St. Helens tephra.
3. Stratigraphy, mineralogy, and particle-size data, C-14 dating.
4. Information that ascribes ash deposit to an easterly extension of the "4" ash layer from Mount St. Helens.
5. ---
6. Stratigraphy, mineralogy, and particle-size data are presented for a volcanic ash deposit which occurs in forest soils and bogs along a transect between Mount St. Helens and Enterprise, Wallowa County, Oregon. The above information, plus a radiocarbon date of approximately 3,000 years B.P. leads to the conclusion that this deposit is a significant easterly extension of the "Y" ash layer previously described northeast of Mount St. Helens.

Okazaki, R.; Smith, H. W.; Gilkeson, R. A.; Franklin, J.; 1972, Correlation of West Blacktail ash with pyroclastic layer T from the 1800 A.D. eruption of Mount St. Helens: Northwest Sci., v. 46, no. 2, p. 77-89.

1. Pacific Northwest.
2. Mt. St. Helens and West Blacktail ash.
3. Stratigraphic study of ash at sample localities and mineralogic analysis.
4. See title.
5. Soil monoliths with Mount St. Helens layer T and (D) with West Blacktail ash.
6. We recently described a thin, intermittent, but pedologically distinctive volcanic ash layer, the West Blacktail ash, that occurs in northern Idaho as well as in adjacent Washington and Montana (Smith and others, 1968). Later, while considering pyroclastic layers as general contributors to soils in the Pacific Northwest, we observed the mineralogical similarity between this ash and young

ejecta from Mount St. Helens, called the lapilli deposit of 1800 A.D. by Lawrence (1954), but renamed layer T by Mullineaux (1964). In this paper we report (1) the occurrence of layer T in the Cascade Range in Washington, beyond the fallout area recognized during the field conference of INQUA in the Pacific Northwest (Schultz and Smith, 1965); (2) our current information on the distribution of West Blacktail ash; (3) some bases for correlating layer T and West Blacktail ash; and (4) relationships between these pyroclastic layers and soil horizonation.

Fallout from the 1800 A.D. eruption of Mount St. Helens, in southwestern Washington, was traced 185 km toward the northeast. This pyroclastic layer T correlates in terms of age, particle size distribution, and mineralogy with the West Blacktail ash, which occurs in northeastern Washington, northern Idaho, and northwestern Montana. There is a 160-km gap between the known areas of occurrence of these two layers. Recognition of the A2 horizons in Spodosols is enhanced by the presence of thin layers of these pyroclastic materials.

Olson, T. M., 1975, The geology and ground water resources of part of the Hangman and Marshall Creek drainage basins, Spokane County, Washington: Eastern Washington State College M.S. thesis, 70 p. C-46

1. Spokane, Washington.
2. Includes Latah Formation, Palouse Formation, landslide debris, glacial deposits and alluvium.
3. & 4. Field study to evaluate size and extent of water-bearing rock units.
5. Geologic map and sections
6. Includes discussion of the geology and water-bearing properties of Palouse Formation, landslide deposits, alluvium and glacial deposits.

Page, B. M., 1939, Multiple alpine glaciation in the Leavenworth area, Washington: Jour. Geology, v. 47, p. 685-815 D-2-124, 136

1. Leavenworth, Washington.
2. Alpine glacial till.
3. & 4. Field investigations leading to description of the nature, source and extent of the Leavenworth, Peshastin and Stuart tills and outwashes.
5. Map of Quaternary deposits near Leavenworth; map of Chiwaukum Butte moraine.
6. In this area there is evidence for three successive

Pleistocene glaciations, each of which was less extensive than the preceding one. The first two glaciations were separated by a long interval. The third is fairly well established as a distinct event but may possibly represent a phase of the preceding stage. In any case the third glaciation is undoubtedly equivalent to all or to a part of the Wisconsin stage.

Pardee, J. T., 1922, Glaciation in the Cordilleran region (Spokane area, Washington): Science, new ser., v. 56, p. 686-687.

1. Spokane area, Washington.
2. Glacial depositional and erosional features.
3. Field observation.
4. Observations of occurrence of glacial drift in previously unknown areas west and southwest of Spokane.
5. ---
6. During May and June, 1922, author found glacial drift including till with striated stones similar to that mentioned by Leverett at many other places on the Columbia Plateau west and southwest of Spokane. The writer expects to study the region further and to publish the results later on, but the information now at hand is sufficient to warrant the statement that during one or more comparatively early stages of the Pleistocene ice from the north advanced over the Columbia Plateau in a southwesterly direction far beyond what heretofore has been regarded as the southern limit of glaciation. The evidence at hand tends to show that the ice extended at least over large parts of Spokane, Lincoln, and Adams Counties, and less complete information suggests the possibility that the glaciation extended much farther.

   Concerning the glacial drift, which by the way is not the only evidence the region affords that land ice was formerly present, the alternative ideas that it was brought to place by floating ice or running water have been considered and rejected. Large patches of the drift may be seen southwest of Cheney, west of Lantz, and in the neighborhoods of Winona, Lacrosse and, and Kahlotus, these occurrences being selected for mention at random and not because they are more typical than scores of others scattered throughout the region.

   The writer wishes to point out that he does not herein attempt to correlate or otherwise define the relations between the glaciation described and the glaciations already known to have covered the plateau west of the Grand Coulee or an ice stream which, as shown by recent observations, traversed the coulee itself.

Pardee, J. T.,; Bryan, K., 1925, Origin of fossiliferous Latah clays and associated basalts near Spokane (abs.): Pan-American Geologist, v. 43, no. 5, p. 369-370.

1. Spokane, Washington.
2. Latah clays and associated basalts.
3. Field observations.
4. Historical geological account of the Spokane region from the pre-basalt flows to the present.
5. ---
6. Historical geology of the Spokane region from the rugged pre-basalt terrain, through the lava flows, glaciation to the present. Describes formation of Spokane Falls and stream action that is returning the area to the pre-basalt surface. Casual mention of leaf-bearing shales.

______, 1926, Geology of the Latah Formation in relation to the lavas of the Columbia Plateau near Spokane, Washington: U.S. Geol. Survey Prof. Paper 140-A p. 1-17.

1. Spokane, Washington.
2. Latah Formation and Columbia River Basalt.
3. Field observation.
4. See title; paleontological record of Latah Formation; stratigraphic descriptions of Latah Formation and pre-Latah surface.
5. Geologic cross section from Sunset Prairie to Manito Prairie, Washington and from Manito Prairie to ridge north of Little Spokane River.
6. The name Latah Formation is proposed for a series of beds consisting mostly of clay and shale and of fresh-water origin that are found near Spokane, Washington, and that contain an abundant middle or lower Miocene flora. The formation is found in Latah Creek valley for 10 miles south of Spokane, on tributaries of Little Spokane Valley for 8 miles northwest and 5 miles east of the city. It occurs also in at least one place in the broad, open valleys of the mountains near Coeur d'Alene, Idaho. These beds rest upon a rough surface of granitic and schistose rocks of unknown age, attain a maximum thickness of 1,500 feet, and are overlain by "rim rock" basalt flows, probably Miocene; "valley" flows, probably later Tertiary; and gravel of Pleistocene age. Sills and dikes, which represent some of the conduits through which the "rim rock" basalt rose to the surface, cut

and to a small extent deform the Latah beds, which otherwise retain their original horizontal attitude.

During the Latah time the lava floods of the Columbia Plateau, advancing from the west, were held back from the Spokane area by a ridge, the highest part of which now forms the hills near Cheney, Marshall, and Medical Lake. The drainage outlet of this area was thus gradually obstructed by lava, and the sediments here described were accumulated. Eventually the lava piled up until the "rim rock" flows were enabled to cross the protecting ridge and to overspread the area of Latah sediments.

The "rim rock" flows consist of olivine basalt that shows very conspicuous columnar jointing. They are considered to be of Miocene age but are doubtless younger than the Yakima Basalt. West of the submerged ridge they are apparently indistinguishable from the great series of flows that make up the Columbia Plateau.

After a time interval measured by the cutting of valleys through a "rim rock" basalt and to a known depth of 800 feet into the Latah Formation another series of basalt flows, referred to as "valley" flows, were extruded. These flows occupy parts of the erosional valleys and rest unconformably upon the Latah, exhibiting at the contact "pillow structure" and other characteristic features. They are distinguished from the "rim rock" flows largely by their topographic position, by a more varied jointing, and by the absence of olivine.

Pavish, M., 1973, Stratigraphy and chronology of Holocene alluvium between the Cascade crest and the Columbia River in central Washington: Univ. of Washington M.S. thesis, 38 p.

1. Central Washington.
2. Holocene alluvium.
3. Field observations of Holocene alluvial deposits and tephra layers; lab analysis of alluvial sediments and buried soils.
4. Same as above.
5. Particle-size distribution for Hansel Creek alluvial-fan sediments; stratigraphic sections; selected soil properties at Bock Spring Gully and Rye Grass Coulee.
6. Holocene alluvial deposits exposed in gully walls and cuts in alluvial fans have been examined in central Washington between the Cascade crest and

the Columbia River. Mazama and St. Helens Y tephra provide chronologic control in some exposures. A sequence of depositional units, erosional surfaces, and buried soils were analyzed and evaluated in terms of existing climatic and hydrologic conditions. Inferences as to the past climatic and hydrologic conditions were made on basis of evidence reflecting particular environmental conditions. Alternate hypotheses of including effects of human activity and various climatic and vegetational effects. Alluvial-fan sediments derived from areas undisturbed by man record a sequence of degradational and aggradational events similar to those inferred for the gullies. Consequently, man's activities may be ruled out as major stimulus to changes in stream regimen in this area. A dynamic relationship exists between hydrologic and climatic variables and the gradational history of a stream reflects a response to changes in one or more variables.

Petrone, A., 1970, The Moses Lake sand dunes: Washington State Univ. M.S. thesis, 89 p.

1. Moses Lake, Washington.
2. Sand dunes.
3. Field observations, detailed descriptions of dunes; measurement of dunes and movement; effects of water table; comparison with other dunes; sieve analysis.
4. Same as above.
5. Table of results of sieve analysis, graphs of frequency percentage curves and cumulative frequency curves of grain sizes in various dunes.
6. The Moses Lake sand dunes are located in the semi-arid Quincy Basin, central Washington. Most are concentrated south of Moses Lake. Barchans, transverse, and parabolic dunes are found within the area. Modified and regular barchans are dominant types at leading edge of dune fields. West of these barchans, double barchans and transverse dunes are most common. Farther westward parabolic dunes are prevalent. Sieve analysis of dune sand near the Columbia River showed an average grain size of 2.02 Ø. Sand from a leading dune is 2.22 Ø. Sorting values show change in down-wind direction, with sands showing a decreasing sorting down-wind. A mineralogical change is realized with more heavy minerals in sands at the leading tongue. These observations provide evidence for two source areas: the Columbia River sands and the sandy soil covering the Quincy Basin. Direction of dune movement is N 64°E. Actual distance travelled by each dune depends on its size and location within the dune field. With

construction of O'Sullivan Dam and rising water table, movement of dunes has been reduced in some areas and totally halted in others.

Piper, C. V., 1905, The basalt mounds of the Columbia Lava: Science, new series, v. 21, p. 824-825.

1. Columbia Plateau, Washington.
2. Basalt mounds.
3. Field observations.
4. Origin, composition, size and positions of basalt mounds.
5. ---
6. Examples of these mounds occur near Spangle, Medical Lake, Winona and generally on north walls on crests of all canyons hewn out by streams in the basalt. They average 4 feet in height and 10-20 feet in diameter. They occur only where there has been running water. Where they occur at crests of canyons, there is a single series; where they occur in beds of broad shallow streams there are acres of them, evenly scattered and close together. The soil in them is the same as surrounding basalt derived soil. They are the result of decaying basalt caps from which flowing water has previously worn the softer surrounding rock. The mounds on south walls are buried by fine soil, blown in by prevailing southwesterly winds, and therefore less discernible. The occurrence of mounds only on crests of canyons is due to greater effect of erosion on slopes.

Porter, S. C., 1965, Quaternary geology of the route between Yakima and Seattle via Ellensburg. In Int. Assoc. for Quat. Res., 7th Congress, Guidebook for Field Conf. J. Pacific Northwest: Nebraska Acad. Sciences, Lincoln, p. 34-50.

1. Yakima - Seattle, Washington.
2. Quaternary sediments and landforms.
3. ---
4. ---
5. Axis of principal anticlinal ridges crossed by Yakima River; early Wisconsin glacial features in the vicinity of Lookout Mountain; late Wisconsin moraines and outwash trains near Cle Elum; end moraines and outwash trains beyond Keechelus and Kachess Lake; late Wisconsin glacial features near Snoqualmie Pass.
6. ---

Porter, S. C.; Denton, G. H., 1967, Chronology of neoglaciation in the North American Cordillera: Am. Jour. Sci., v. 265, p. 177-210.

1. Western North America.
2. Ice-contact deposits, glacial landforms.
3. Geological, botanical and historical evidence and C-14 dates to reconstruct history of glacier fluctuations in western North America.
4. Same as above.
5. Generalized curve of glacier fluctuations during neoglaciation; many radiocarbon dates.
6. Geological, botanical, and historical evidence, together with critical radiocarbon dates, permit reconstruction of a reasonably comprehensive picture of glacier fluctuations in western North America during the last three millennia. These fluctuations largely postdate the Hypsithermal interval as defined by Deevey and Flint (1957), and fall within the cool geologic-climate unit widely referred to as neoglaciation. Following recession and disappearance of many residual Wisconsin-age alpine glaciers during the warmest part of the Hypsithermal, resurgence of glacier activity led to a possible widespread early neoglacial advance close to 4600 years ago and to a major advance that culminated 2600 to 2800 years ago throughout the Cordilleran region. A long period of milder climate followed, during which most glaciers probably diminished in size; dated moraines deposited during this interval are restricted to Alaskan coastal glaciers, and their regional significance is not yet known. Glaciers throughout western North America again experienced marked neoglacial positions. Recession has been general and rapid since the early 20th century, although local minor readvance and related glacier growth in recent years reflect a response to somewhat cooler and wetter conditions in the 1940's and 1950's. Glaciers in other parts of the world show broadly similar histories, indicating probable world-wide synchrony of glacier fluctuations in response to climatic change.

Porter, S. C., 1969, Pleistocene geology of the east-central Cascade Range, Washington: Pacific Coast Friends of the Pleistocene 3rd Field Conference Guidebook, 54 p.

______, 1975, Weathering rinds as a relative-age criterion: Application to subdivision of glacial deposits in the Cascade Range: Geology, v. 3, p. 101-104.

1. Cascade Range, Washington.
2. Teanaway basalt.

3. Measurement of basalt weathering rinds.
4. Weathering rinds used to construct relative time-distance curves for Cascade glaciers.
5. Geologic map of upper Yakima River drainage basin showing boundaries of principal drift sheets and distribution of Teanaway basalt; relative time-distance curves for glaciers in upper Yakima River drainage basin based on weathering rind data.
6. The thickness of weathering rinds on surface and near-surface clasts of Teanaway basalt form alpine drift sheets in the southeastern North Cascade Range varies systematically with age of deposit. The rinds, which can be measured to the nearest 0.1 mm, result from oxidation of mafic minerals and mineraloids. Rind thicknesses for outermost moraines of three principal Pleistocene drift sheets are 1.96 $\pm$ 0.24 mm. 1.10 $\pm$ 0.11 mm, and 0.71 $\pm$ 0.12 mm. Sample variance may result from differences in composition and texture of clasts, microclimatic differences at sample sites, and incorporation of previously weathered stones. Weathering rinds can be used to construct relative time-distance curves for Cascade glaciers, but because rate of rind formation appears to be nonlinear, the true age of drift sheets cannot be obtained unless the weathering rate is calibrated by radio-metric dating.

______, 1976, Stratigraphy and distribution of tephra from Glacier Peak (of 12,000 years ago) in the northern Cascade Range, Washington: U.S. Geol. Survey Open-File Report 76-186, map and text on one sheet, February 1976.
D-1-55

1. North-central Washington.
2. Glacier Peak tephra.
3. Field observations.
4. Stratigraphy and distribution of Glacier Peak tephra.
5. Map showing distribution, thickness and maximum size of tephra.
6. Glacier Peak is a dormant volcano that is situated immediately west of the crest of the Cascade Range about 100 km (62 miles) northeast of Seattle, Washington. Although the summit of Glacier Peak stands 3209 m (10,451 ft.) above sea level, well above the general height of the surrounding mountains, it is perched on a high bedrock ridge and the volcanic rocks of the peak are only a few thousand feet thick. The volcano is made up of lava flows with a predominantly pyroxene-dacite composition, all of which probably were extruded within the last 700,000 years (Crowder and Tabor, 1969, p. 24-28).

The most recent series of eruptions, approximately 12,000 years ago (Fryxell, 1965, p. 1288), produced immense quantities of pumice that were blown far downwind from the volcano. Although the pumice, here referred to as tephra, is found west of the Cascade crest only in the immediate vicinity of Glacier Peak, it has been found east of the volcano at distances up to 1000 km (625 miles).

Carithers (1946), studied the tephra in the vicinity of Glacier Peak and found two layers in many places. Present studies indicate that the tephra deposits consist of at least seven distinct layers that can be distinguished in the field on the basis of particle size, thickness, and stratigraphic position. The tephra generally rests directly on late-glacial drift that lacks any discernible weathering profile. The seven informally designated layers are listed in Table 1.

One tephra unit, identified as layer G by major-element analysis, reaches southern Alberta (Westgate and others, 1970). Another layer (layer B), probably is the same as that found overlying late-glacial sediments of the Yellowstone basin (Richmond and others, 1965, p. 49).

Preliminary studies indicate that eruptions that produced layers B and C were of approximately equal volume, whereas the layer M eruption was of lesser volume. Isopleth maps depicting maximum particle size are presented for layers B and G. An isopach map has not been prepared for layer M because in most outcrops the layer showed evidence of substantial reworking.

The reader is referred to the list of additional readings for discussions of hazards which are associated with volcanic eruptions and which might result from future large-scale eruptions of Glacier Peak. The effects might include damage to or destruction of vegetation by deposition of tephra downwind from the volcano, passage of hot ash flows or lahars (volcanic mudflows), or both, down valleys heading at Glacier Peak, and contamination of streams and lakes by widespread erosion of pumice for many years after an eruption.

______, 1976, Pleistocene glaciation in the southern part of the North Cascade Range, Washington: Geol. Soc. America Bull., v. 87, no. 1, p. 61-75. D-1-41

1. North Cascade Range, Washington.
2. Ice contact deposits, landforms.
3. Drift sheets distinguished on basis of stratigraphic relationships, differences in morphology, weathering characteristics, and soil profile development.
4. Same as above.
5. Glacial geologic map of upper Yakima drainage basin and south fork of Snoqualmie River; Quaternary glacial-stratigraphic, rock stratigraphic, and soil stratigrahic units of upper Yakima River drainage basin; principal terraces along Yakima River; long profiles of same terraces; size-frequency distribution and mean values of weathering rinds developed on basalt clasts in principal drift sheets; long profiles of Pleistocene glaciers between North Bend and Ellensburg; sub-surface stratigraphic section between Cle Elum Lake and Indian John Hill; profile data for post-Kittitas and post-Lakedale soils; time-distance curve of glacier fluctuations along transect across southern North Cascade Range during past 25,000 years.

6. Three major Pleistocene drift sheets preserved along a transect across the southern North Cascade Range are distinguished on the basis of stratigraphic relationships and differences in morphology, weathering characteristics, and soil-profile development. The two youngest drifts have been further subdivided into members representing second-order fluctuations of glacier termini. Deposits of former southeast-flowing valley glaciers in the upper Yakima River drainage basin can be traced across a low divide at Snoqualmie Pass to the west-draining valley of the South Fork of the Snoqualmie River where alpine drift is interstratified with deposits of the Puget lobe of the Cordilleran Ice Sheet. Preliminary paleomagnetic measurements indicate that the deeply weathered and extensively eroded oldest drift (Thorp) antedates the Bruhnes-Matuyama reversal (700,000 years). Relative-age criteria suggest that the time elapsed between deposition of Thorp drift and the intermediate drift (Kittitas) was substantially longer than that between the intermediate drift and the youngest drift (Lakedale). Soil developed on Kittitas Drift showed pronounced clay enrichment in the B horizon, in marked contrast to the weakly developed post-Lakedale soil, suggesting that the Kittitas ice advances antedate the last interglaciation of the global marine record and therefore are more than 120,000 years old. On the basis of reconstructed ice gradients, the next-to-youngest member (Domerie)

of the Lakedale Drift is believed to correlate broadly with Vashon Drift that was deposited during the last major expansion of the Puget lobe between 15,000 and 13,500 years ago. Two more-extensive, pre-Domerie advances of Lakedale glaciers (Bullfrog and Ronald) preceded the maximum stand of the Puget lobe, as indicated by stratigraphic relationships and reconstructed glacier profiles. A late Lakedale readvance led to deposition of the Hyak member prior to 11,050 years ago in valley heads draining high-altitude source areas.

______, 1977, Present and past glaciation threshold in the Cascade Range, Washington, U.S.A.; Topographic and climatic controls, and paleoclimatic implication: Jour. Glaciology, v. 18, no. 78, p. 101-116.

1. Cascade Range, Washington.
2. Glacial ice.
3. Field investigations concerning configuration of glaciation thresholds.
4. Same as above.
5. ---
6. Isoglacihypses depicting the configuration of the glaciation threshold (= "glaciation limit") in Washington, broadly parallel the crest of the Cascade Range and curve around the west an south flanks of the Olympic Mountains. In both uplands the glaciation threshold rises inland (eastward) with a mean gradient of 10-12 m/km. However, the gradient in the Cascades is more variable (7-25m/km) due to five east-trending troughs in the glaciation threshold surface that coincide with topographic depressions along the range crest and that apparently result from greater eastward penetration of moist maritime air.

   Mean accumulation-season precipitation correlates strongly (r2 = 0.86) with altitude of the glaciation threshold with altitude of the July freezing isotherm, determined from the calculated July lapse rate within the mountains, is much weaker (r2 = 0.40). Multiple regression analysis relating independent climatic variables that affect the height of the glaciation threshold indicates that 90.4% of variance is explained by accumulation-season precipitation and estimated mean annual temperature at the glaciation threshold.

   The glaciation threshold during the greatest ice advance of the last (Fraser) glaciation in the southern North Cascade Range (c. 18,000-22,000 years B.P.) was 900 $\pm$ 100 m below that of the present. Depression of the glaciation threshold by this amount most likely resulted from a change in accumulation-season precipitation of no more than 30% from present values and a decrease in mean ablation-season temperature of 5.5 $\pm$ 1.5 degrees.

______, 1977, Relationship of Glacier Peak tephra eruptions to late-glacial events in the North Cascade Range, Washington (abs.): Geol. Soc. America Abs. with Programs, v. 9, no. 7, p. 1132.

1. North Cascade Range, Washington.
2. Glacier Peak tephra.
3. Field relationship of tephra layers and C-14 dating.
4. Field observations to show relationship of tephra eruptions from Glacier Peak to late-glacial events in Northern Cascades.
5. ---
6. Nine layers of pumiceous tephra from Glacier Peak volcano mantle much of the eastern North Cascade Range. Three major layers, designated G (oldest), M, and B, are separated by thinner layers of pumiceous ash. Layer M forms a south-trending lobe having an axis that lies close to the crest of the range, whereas layer B trends east and layer B south-east. Layer G rests directly on moraines and outwash deposited about 14,000 years ago by Cascade Valley glaciers; in some drainage basins the unit has been traced to within 1 or 2 km of valley heads. However airfall tephra has not been found throughout most of the lower Methow Valley and part of the lower Okanogan valley, both of which lie within the inferred fallout zone of layer G. This relationship implies that glacier ice still covered those areas at the time of the first major Glacier Peak eruption.

   Although layer M is found near the heads of east-draining valleys south of Glacier Peak, it apparently is lacking on the surface of late-glacial moraines of the Rat Creek advance near Stevens Pass, a locality that lies well within the fallout area of this unit. Radiocarbon dates indicate that layer M was deposited before about 11,250 years ago but after about 12,750 years ago. A minimum limiting date of 11,050 $\pm$ 200 years has been obtained for a moraine at Snoqualmie Pass that is correlated with moraines of the Rat Creek advance farther north., Therefore, the late-glacial advance of Cascade valley glaciers apparently was broadly in phase

with the Sumas readvance of the Cordilleran Ice Sheet in the Fraser Lowland of British Columbia which Armstrong (1975) considers to have culminated between about 11,400 and 11,800 years ago.

Powers, H. A.; Wilcox, R. E., 1964, Volcanic ash from Mt. Mazama (Crater Lake) and from Glacier Peak: Science, b. 144, no. 3624, p. 1334-1336.

1. Pacific Northwest.
2. Mazama and Glacier Peak tephra.
3. Detailed petrographic and chemical study from late and post-glacial deposits of region and parallel study of lump pumice from Cascade volcanoes.
4. Same as above.
5. Table of refractive indices of constituents in Mazama and Glacier Peak pumices; table of chemical compositions of glass from typical pumice and ash.
6. New petrographic and chemical data indicate that the great Mount Mazama eruption at Crater Lake, Oregon, about 6000 years ago was the source of most ash which has been called "Glacier Peak" and some ash called "Galata." Glacier Peak volcano in Washington was itself the source of an older ash deposit, perhaps very late glacial or early post-glacial in age.

Rahm, D. A., 1969, Post-Miocene erosion of basalt in south-eastern Washington (abs.): Northwest Science, v. 43, no. 1, p. 42; (abs.). In Columbia River Basalt symposium 2d, 1969, p. 328, East Washington State Coll. Press, Cheney.

1. Southeastern Washington
2. Columbia River basalt.
3. Field observations.
4. See title.
5. ---
6. Field evidence from the Lewiston Monocline suggests stripping of basalt flows in a manner reminiscent of the Great Denudation of the Colorado Plateau. The rimrock flow above the Lewiston Basin can be traced into the stratigraphically lowest of a series of flatirons above which a section at least 940 feet thick projects into the air. The crest of the Blue Mountain anticline to the south has been stripped of all but a few residual buttes and resistant dikes that persist as cockscomb ridges. The steptoes of south-eastern Washington appear therefore to be exhumed features.

Randle, K.; Goles, G. G.; Kittleman, L. R., 1971, Geochemical and petrological characterization of ash samples from Cascade Range volcanoes: Quat. Research, v. 1, p. 261-282.

1. Pacific Northwest.
2. Tephra from Cascade Range volcanoes.
3. See title.
4. Distinguishing among ash from different source volcanoes.
5. Table showing elemental abundances of ash from known and unknown sources; ternary diagrams for abundances of different minerals from different collection site.
6. Twenty-nine samples of volcanic ash from the Pacific Northwest were analyzed by instrumental neutron activation techniques, with the aim of distinguishing among ashes from different sources. Preliminary results of petrographic studies of 42 ash or pumice samples are also reported. Geochemical characteristics of Mazama ash are defined, and problems induced by winnowing of crystalline material during transport and by weathering are discussed. Contents of La, Th, and Co, and La/Yb ratios are shown to be good discriminants. Data on refractive indices and on proportions of crystalline materials also aid in distinguishing among the various volcanic ashes studied. Ash and pumices found in archaeological contexts at Fort Rock Cave, Paisley Cave, Wildcat Canyon and Hobo Cave are all from Mount Mazama, presumably from the culminating eruption of 7000 years ago.

Richardson, D., 1968, Glacier outburst floods in the Pacific Northwest: U.S. Geol. Survey Prof. Paper 600-D, p. 79-86.

1. Pacific Northwest.
2. Floods and flood deposits.
3. Field observations.
4. See title
5. ---
6. Glacier outburst floods, not uncommon in the Pacific Northwest in late summer or fall, are sometimes triggered by heavy rain but may occur even during a rainless period. Associated mudflows often compound the destruction downstream. Outburst floods are particularly hazardous at Mount Rainier, Washington, where debris flows are reported to occur at a rate of one in 3-10 years. Several floods witnessed at Mount Rainier were much larger than expected from direct storm runoff or release of water temporarily impounded by landslides. The principal source of those floods is believed to have been the large volumes of water that are stored at times within and beneath glaciers.

At present there is no known way of predicting glacier outburst floods. Conceivably, their imminence might be indicated by measurements of englacial water pressure, and their potential size would be indicated by determinations of volume of water stored in glaciers.

Richmond, G. M.; Fryxell, R.; Neff, G. E.; Weis, P. L., 1965, The Cordilleran Ice Sheet of the Northern Rocky Mountains, and related Quaternary history of the Columbia Plateau. In Wright, H. E.; Frey, D. G., eds., The Quaternary of the United States: Princeton Univ. Press, Princeton, New Jersey, p. 231-242.

1. Columbia Plateau and Northern Rocky Mountains.
2. Quaternary ice-contact deposits and landforms.
3. Compilation of other work and author's own observations.
4. See title.
5. Map of Cordilleran Ice Sheet and related features in Northern Rocky Mountains and on Columbia Plateau; correlation table of deposits and events of the Cordilleran region and Columbia Plateau.
6. The Columbia Plateau of eastern Washington is underlain by vast flows of Miocene and Pliocene(?) Columbia River basalt. At the eastern margin of the plateau, these flows intertongue with lake beds of the Latah Formation and rest unconformably on deeply dissected granitic terrain. The surface of the plateau is covered extensively by intermittently accumulated Quaternary loess including that of the Palouse Formation; its western part is also covered by the older predominantly lacustrine and alluvial sediments of the Ringold Formation.

   Near the maximum of each glacial advance, ice dammed the Clark Fork River at Lake Pend Oreille to form Glacial Lake Missoula, and blocked the Columbia River at Grand Coulee to form Glacial Lake Columbia. At times it also blocked the Spokane River east and west of Spokane, forming Glacial Lakes Coeur d'Alene and Spokane.

   The ice dam that impounded Lake Missoula collapsed at least three times, releasing catastrophic floods of enormous magnitude, which swept through the Spokane area and southwestward across the Columbia Plateau. The last of these floods followed the early maximum of the last or Pinedale Glaciation. Two additional earlier floods from unknown sources spilled eastward across the western part of the plateau.

Rigby, J. G., 1979, Preliminary geologic map and report of the Late Cenozoic Geology of the Columbia Basin, Washington: Washington Div. Geology and Earth Resources Open-File Report 79-3, 99 p.

Rigg, G. B.; Gould, H. R., 1957, Age of Glacier Peak eruption and chronology of post-glacial peat deposits in Washington and surrounding areas: Am. Jour. Sci., v. 255, no. 5., p. 341-363, illus.

1. Washington State.
2. Glacier Peak tephra.
3. & 4. Field and laboratory examination of tephra deposits to determine source, distribution, composition and age.
5. Index map showing peat bog sampling sites; sections showing sedimentary and petrographic features of ash layer; chart showing average thickness of peat and mean rates of peat sedimentation in Washington bogs.
6. Volcanic ash, which occurs as a single layer in more than 200 post-glacial peat bogs in the State of Washington, is correlated with a similar layer of volcanic ash in alluvium and bogs of Idaho, Montana, southern Alberta and southern British Columbia. Based on the known localities of ocurrence, the ash at the time of deposition covered an area of at least 180,000 square miles. Vertical and horizontal grading of the layer show that the eruption that produced the ash was single and short. The source of the ash, as demonstrated by the distribution of occurrences, petrographic similarity and horizontal grading of the particles, is Glacier Peak, an obscure volcano of the Cascade Range in north-central Washington.

   The ash is composed of 85 percent glass and 15 percent crystals, the latter of which consists of plagioclase, hypersthene, hornblende, magnetite and a trace of augite. A progressive decrease in particle size, improvement of sorting and decrease in crystal and heavy mineral content with increasing distance from Glacier Peak preclude the possibility of any source for the ash other than Glacier Peak.

   The age of the ash layer, as determined by radiocarbon dating of peat immediately underlying the ash at two localities, is 6,700 years. This age is of particular significance as it serves as a prime reference for establishing an absolute chronology of post-glacial events over a wide area in the Pacific Northwest.

Additional radiocarbon analyses of peat resting on glacial outwash at the bottom of two bogs and in the bottom sediments of Lake Washington in the Puget Sound Lowland place the withdrawal of the Vashon ice sheet from west-central Washington at more than 13,650 years ago. Owing to a considerable time lapse between ice retreat and deposition of the peat dated by C-14, we can conclude only that the Vashon recession is pre-Mankato in age. Precise assignment of the Vashon glaciation to one of the pre-Mankato substages of the Wisconsin glaciation recognized elsewhere must await the results of further radiocarbon dating in the Puget Sound area.

Ringe, L. D., 1976, Glacial geology of the Waterville Plateau, north-central Washington (abs.): Geol. Soc. America Abs. with Programs, v. 8, no. 3, p. 403.

1. Waterville Plateau, Washington
2. Glacial landforms and deposits.
3. Field observations.
4. See title.
5. ---
6. The Okanogan Lobe of the ice sheet which covered the Waterville Plateau, the northwestern corner of the Columbia Plateau, left an exceptional array of erosional and depositional features. These landforms remain well exposed because the semi-arid climate has curtailed erosion and limited vegetative cover. The end moraine, commonly known as the Withrow Moraine, has about 60 m of relief in some places. West of Moses Coulee the former terminus of the glacier is approximated by Dutch Henry Draw, a pro-glacial stream channel. Topographic lineations and glacial striae indicate that the main thread of flow crossed the Columbia River a few miles east of Bridgeport and then fanned over the plateau.

   North of the end moraine the Waterville Plateau is mostly covered by ground moraine. Drumlins are found in a few places, but the principal features are the stagnant ice landforms - kames, kettles, eskers, crevasse fillings - and the large basalt erratics locally called haystack rocks. While eskers are scattered over much of the area north of the end moraine, there is considerable concentration in and around T. 27 N.- R. 27 E. Most of the isolated hills, such as Barnes Butte, Ragged Butte, and Lone Butte are large kames. Multiple kame terraces occur along the Columbia River, especially on the east side of the channel between

Wells Dam and Chelan. This area of the plateau also has the greatest concentration of haystack rocks. The terraces also indicate that the glacier extended some distance down the Columbia River channel south of Chelan.

Runner, J. J., 1921, Origin and history of Lake Chelan (abs.): Geol. Soc. America Bull., v. 32, p. 87-88.

1. Lake Chelan, Washington.
2. Glacial features.
3. & 4. Observations concerning origin and changes of the Chelan.
5. ---
6. The Chelan Basin, in north-central Washington, exhibits many striking effects of the work of glacial ice. Its linear form, abrupt, smooth slopes, and great depth have for some time been attributed to the erosive action of a large valley glacier. At its maximum development, the Chelan Glacier and its tributaries had a surface area probably exceeding 400 square miles. Its length was nearly 80 miles and its thickness throughout a considerable portion of its length doubtless exceeded 4,000 feet. For nearly 15 miles in its mid-section the bottom of the lake lies near to or below sealevel and its depth exceeds 1,000 feet. Data are now at hand to show that in this section several tributary hanging valleys that doubtless once entered the main valley at accordant levels now enter at elevations over 2,000 feet above the bottom of the latter. Locally, then, the amount of glacial erosion exceeded 2,000 feet, for these tributary valleys were glaciated and their floors lowered by a considerable but unknown amount. The deepest section of the lake occurs in the stretch where the valley is narrowest, which in turn coincides with the portion in which the structure of the rock is most favorable for down-cutting. Above the narrow, deep section the bedrock is dominantly granite and gneiss; below it is largely a complex of various fine-grained, igneous intrusives, while within this section the valley runs parallel to the strike of a steeply dipping series of schists and slates. Along the valley walls at the eastern end of the lake occur minor terraces marking the levels of small lakes that lay between valley spurs at the sides and the glacier in front.

   Following the Chelan glaciation, after an unknown interval, came an invasion of the Cordilleran Ice

Sheet into the lower valley from the east. This blocked the natural drainage channel eastward to the Columbia River and caused the lake to rise first to an elevation of 1,800 feet and flow out through Navarre Coulee southward. Then, as the ice-tongue receded, the lake found a lower outlet through Knapp Coulee, at an elevation of 1,430 feet, and finally through the lower Chelan Valley, over the drift-dam, at 1,120 feet above tide. Since that time the level of the lake has been lowered by erosion of the outlet to 1,080 feet. The preglacial channel of Chelan River may be clearly seen one mile above the station of Chelan Falls. The elevation of bedrock at this point and of striated bedrock in the Columbia River Valley nearby is approximately 700 feet. Nearly 400 feet of the water of Lake Chelan, then, is held in by a drift-dam and the remainder lies in a rock basin.

Russell, I. C., 1897, A reconnaissance in southeastern Washington: U.S. Geol. Survey Water Supply Paper 4, p. 96.

1. Southeastern Washington.
2. Columbia lava and interbeds, wells and alluvium.
3. Field observations.
4. See title.
5. Schematic cross sections of lava flow and lake beds at Spokane.
6. Geologic history of study area. Description of topography and drainage. Discussion of geologic formations, irrigation and artesian water supply.

______, 1898, The great terraces of the Columbia and other topographic features in the neighborhood of Lake Chelan, Washington: American Geologist, v. 22, p. 362-369.

1. Lake Chelan, Washington.
2. Great Terrace of Columbia.
3. Field observations and measurements.
4. A review of a publication by W. L. Dawson on glacial phenomena in Okanogan County, Washington.
5. ---
6. Discussion of elevation of terrace, its origin and aerial extent. Discusses origin in terms of a Lake Lewis that occupied the basin-like portion of southeastern Washington. The Columbia River discharged into Lake Lewis, building a delta of coarse material that was dissected by the river when the lake water was withdrawn, forming the Great Terrace. Discusses the extent of glacial ice that occupied the Methow River valley.

Discusses Antwine and Knapp Coulees and denies that it was ever occupied by a glacier.

Salisbury, R. D., 1901, Glacial work in the western mountains in 1901: Jour. Geology, v. 9, p. 718-731.

1. Includes section on western side of Rockies, including eastern Washington.
2. Glacial landforms.
3. Field observations.
4. Observations concerning Pleistocene problems in western North America.
5. ---
6. Summary of field observations of field parties studying the general conditions of glaciation at several localities, leading to interpretation of glacial history of region. The section dealing with eastern Washington includes notes on the glacial ice lobes (and associated depositional and erosional features) of the Okanogan, Columbia and Kootenai River valleys. Question posed as to whether or not the glaciers were marginal lobes of a single continuous ice sheet.

Saunders, E. J., 1915, Relation between the Tertiary sedimentaries and lavas in Kittitas County, Washington (abs.): Geol. Soc. America Bull., v. 26, p. 137.

1. Kittitas County, Washington.
2. Tertiary sediments and lavas.
3., 4., 5. ---
6. "Doctor Branner asked as to the occurrence of coal in relation to the formations described. Doctor Meriam asked if the base of the Keechelus were older than the Ellensburg basalt. Mr. Weaver suggested that the Keechelus may there represent part of the series, due to overlapping. In reply to question by Professor Lawson as to size of dikes, the author stated that they ranged from about 3 to 40 feet thick, and the space occupied by them may represent 10,000 to 20,000 feet. The mechanism by which this amount of space was made available was not clear. The dikes lie across the axes of the folds."

Schmincke, H. U., 1964, Petrology, paleocurrents, stratigraphy of the Ellensburg Formation, and interbedded Yakima Basalt flows, south-central Washington: The Johns Hopkins Univ., Ph.D. thesis, 426 p.

1. South-central Washington.
2. Yakima Basalt, Ellensburg Formation.

3. & 4. Study of the petrography and petrology of the four uppermost Yakima Basalt flows and of the interbedded sedimentary rocks and, by applying these results, to add further details to the origin, stratigraphy and deformation of the upper basalt flows and interbedded sediments in south-central Washington.

5. Comparison tables of terminology used by different authors for four uppermost Yakima Basalt flows and interbedded sediments of lower part of Ellensburg Formation and a summary of their characteristics; figure showing common structures of post-Vantage basalts.

6. The four youngest Yakima Basalt flows intertongue with volcaniclastic and arkosic sediments of the Ellensburg Formation in much of south-central Washington. They are, from oldest to youngest: Umatilla basalt, Pomona basalt, Elephant Mountain basalt, and Ward Gap basalt. The flows differ in their primary structures, textures, and modal, mineralogic, and chemical compositions. The basalts flowed toward the west-northwest. The minimum areal extent of the Pomona flow is 7,000 miles.

   The Selah Member separates the Umatilla and Pomona flows, and the Rattlesnake Ridge Member lies between Pomona and Elephant Mountain flows.

   The volcaniclastic detritus was derived from active volcanoes in the ancestral Cascade Range west of the area and was deposited chiefly as conglomerates, tuffs and lahars. The plutonic and metamorphic debris was carried southward by rivers into the area from northern Washington, as indicated by current directions, pebble size changes and heavy minerals.

   A vitric tuff forms the bulk of the Selah Member. The tuff was commonly welded at the contact by the heat and weight of the Pomona flow which in many places burrowed into it forming a peperite.

   Most of the sediments were deposited in down-sagging synclinal basins--separated by low anticlinal swells--at least as early as Selah time. The coincidence of Selah and Sentinel Gap watergaps with synclines, and the abundance of Selah Member conglomerates within them, suggest that the courses of Yakima and Columbia Rivers are structurally controlled at these places.

Metaquartzite pebbles occur in conglomerates of the Selah and Rattlesnake Ridge members, but are most abundant in a conglomerate that overlies the Ward Gap and Elephant Mountain flows between Sentinel Gap and lower Yakima Valley. They indicate the south-southwestward course of an ancestral Columbia River. After deposition of this conglomerate, the river shifted eastward from lower Yakima Valley.

______, 1967, Graded lahars in the type sections of the Ellensburg Formation, south-central Washington: Jour. Sed. Petrology, v. 37, no. 2, p. 438-448, illus., tables.

1. South-central Washington.
2. Ellensburg Formation.
3. Field observations and measurements; morphology and grain-size distribution studies; petrographic analyses; description of source, transport, and deposition of lahars.
4. Same as above.
5. Map showing regional distribution of Ellensburg sediments; stratigraphic column of Ellensburg at type section; cross section through lahars; abundance of heavy minerals in different fractions.
6. The volcaniclastic Miocene-Pliocene Ellensburg Formation west of Yakima contains up to about 15 lahars. These are massive, sheet-like deposits with an average thickness of 2-5 m (6-15 feet). The lahars are characteristically graded, having a thin fine-grained (medium sand) basal layer which abruptly grades into a massive, coarse, poorly sorted central portion that may contain blocks up to 3 m (9 feet) in diameter. This part grades into a bedded or cross-bedded top zone (fine to medium-grained sand, partly pebbly) that may be transitional to horizontally bedded tuffs. Clay and silt-sized fractions form less than 10 percent of all three zones. Heavy minerals, chiefly hornblende, hypersthene, and magnetite are abundant in the 125-200 γ fraction and may constitute as much as 20 percent of the weight of this fraction. Most lahars are predominantly composed of fragments of a pink to light violet hypersthene-hornblende dacite. The lahars probably originated on the flanks of explosive volcanoes in an ancient Cascade chain at least 60 km (40 miles) to the west. They seem to have moved partly as inertia type flows which would explain the inverse grading: pebbles and blocks moved upward during transport, leaving a layer of medium sand at the base.

Shedd, S., 1923, Topography and geology of the Okanogan Highlands and Columbia Plateau of Washington (abs.): Geol. Soc. America Bull., v. 34, no. 1, p. 75.

1. Okanogan Highlands and Columbia Plateau, Washington.
2. Surface features and geology of eastern Washington.
3. Field study.
4. See title.
5. ---
6. A general discussion of the surface features and geology of the eastern part of Washington. The Okanogan Highlands constitute a large area of metamorphic rocks, part of which was probably originally sedimentary and part igneous. The Columbia Plateau, as used in this paper, refers to that part of the great lava field, in the northwestern part of the United States, which lies within the State of Washington. The surface features of parts of this area are very interesting and are a result, partly at least, of the action of the wind.

______, 1925, Geologic map of Pasco and Prosser quadrangles, Washington: Washington Dept. Conservation and Development, Div. of Geol., Bull. 32, Plate 1.

______, 1926, Abstract of report on geology and resources of the Pasco and Prosser quadrangles: Washington Div. Geology Report Invest. 1, pl. 1, 1:125,000.

1. Southeastern Washington.
2. Ellensburg and Ringold Formations, alluvium, Yakima Basalt.
3. Field investigation.
4. See title.
5. Geologic map of Pasco and Prosser quadrangles.
6. The study of the Pasco-Prosser quadrangles was planned as a basis for a detailed report on the general geology, attention having been drawn to the area through the discovery of gas and the prospect of oil in the Rattlesnake Hills which border the Yakima Valley on the north.

   The sedimentary rocks of the area include but two formations older than the alluvium of the present valleys. The older of these, the Ellensburg Formation, is interbedded with the basalt in a few places, but is entirely absent elsewhere so far as outcrops show. From the distribution of the known Ellensburg it is probable that it is a remnant of an originally widely distributed formation. It outcrops in but three places: (Pl. 1) T. 10 N. R.

27 E. Secs. 8, 18 and 19; T. 8 N. R. 25 E. Sec. 6; T. 9 N. R. 25 E. Sec. 14 and 23. Without exception these exposures of Ellensburg show it to be fine, sandy and pumiceous, composed largely of glass. In one other locality, Sec. 26, T. 12 N. R. 23 E., is a limited outcrop of relatively unconsolidated sediment which is tentatively considered to be Ellensburg. Its relation to the basalt is not known, nor is it lithologically identical with the other exposed beds.

The younger formation is known as the Ringold. This outcrops over a rather wide area in the northeastern part of the Pasco quadrangle, from the east bank of Columbia River to the margin of the upland eight to ten miles to the east. It is a deposit of slightly consolidated sand, distinctly bedded, which is, in the main, light yellow or gray, of fine grain, somewhat clayey in part, distinctly calcareous. It includes some gray limestone and more or less calcareous, sandy clays, and volcanic ash. From its character and position it is believed to have originated on the flood plain of an early Columbia River during the Pleistocene period.

The alluvium of present streams is composed of fine river silts with sands and gravels. This material covers the surface of the Columbia Valley outside of the uplands known as the Rattlesnake Hills, and also up the Yakima Valley above the vicinity of Prosser. Windblown sands and silts, with some volcanic ash and soil, cover practically the whole area under discussion. These, with loose material, effectually conceal outcrops of all rocks except in the rougher parts of the quadrangles.

Of the igneous rocks, the whole area is underlain by the Yakima Basalt of Miocene age, which is more than 2000 feet thick in places. This rock, where fresh, is dark, nearly black, developing brownish discoloration on weathering. The texture varies from very dense to porphyritic. The more dense portions are essentially glass while locally the matrix of the porphyritic portion is fine crystalline. There is no information available from these quadrangles as to the character of the pre-basalt surface. By inference from other portions of the Columbia Plateau, it is probable that the underlying surface is one of erosion on old metamorphic and igneous rocks, above the level of the uppermost basalt flows. While there is no reason to doubt that the relief of this pre-basalt surface is rather great, amounting to several thousand feet, in the absence of any data on its elevation in the Pasco-Prosser district, it is impossible to estimate what local relief or roughness would appear. No reported drilling records have penetrated the pre-basalt strata.

Smith, D. G. W.; Westgate, J. A.; Tomlinson, M. C., 1969, Characterization of pyroclastic units - a stratigraphic application of the microprobe. In Proceedings of the 4th National Conference on Electron Microprobe Analysis, p. 33-34.

1. Pacific Northwest.
2. Glacier Peak, Mazama, St. Helens Y, and Bridge River tephra.
3. Electron microprobe analyses.
4. Characterization of pyroclastic units.
5. Table showing glass and magnetic compositions.
6. Pyroclastic layers, essentially representing time planes, have long been recognised as having great potential for long distance stratigraphic correlation -- provided that they are widespread and distinctive. Much effort has consequently been expended in developing characterization techniques. With reference to Quaternary pyroclastics, attention has particularly centered on optical methods (e.g. Wilcox, 1965), but they have achieved only partial success. Bulk ash chemistry has proved unreliable, composition varying from locality to locality within individual layers as a result of detrital contamination, post-depositional alteration and winnowing effects during deposition. C^{14} dating of associated organic matter is again only suggestive of the affinities of an ash and is useless in old Quaternary deposits.

   Refractive index measurements suggest the volcanic glass composition should be characteristic of an ash. However, it is impossible to separate from most pyroclastic materials glass that is completely free of phenocryst fragments and microlites; thus the chemistry of such glass cannot be investigated in bulk. The microprobe was therefore used to analyze pure, inclusion-free glass from individual shards, thereby avoiding problems facing bulk analysis. Shards and pumice fragments (relatively free of bubbles and inclusions) were concentrated by heavy liquids, mounted in epoxy and polished.

Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, Cl, P and F were determined to establish the potentialities of each for discriminating between certain recent ashes from widespread localities in northwestern U.S. and southwestern Canada. Initially, 14 different samples confidently identified by various workers as "Mazama" ash were investigated to establish the consistency and range of variation to be expected of one bed (Smith and Westgate, 1969). Results were then obtained from Glacier Peak, St. Helens "Y" and Bridge River ashes: their compositions are clearly resolved by the technique; in fact, as few as 3 elements (e.g. Na, K and Fe) serve to distinguish all unequivocally.

Average compositions have now been obtained for the glasses by a refined technique involving, among other things, counting 50 shards for 20 secs. each; in some cases (e.g. Glacier Peak) these differ significantly from analyses available in the literature. Furthermore, these refinements make possible the distinction of fine structure in the chemistry of the ashes; thus it appears that Glacier Peak and possibly Bridge River ashes may have resulted from a series of closely spaced eruptions. The Waskana Creek ash from southern Saskatchewan (Christiansen, 1961) proves to be rhyolitic and completely distinct from well documented dacitic or rhyodacitic ashes of the High Cascades. The coarse grain size of this ash, which underlies a glacial till, and its thickness in Saskatchewan (well away from areas of Quaternary volcanism) suggest that it should be widespread and potentially very useful in correlation. Preliminary work on ashes from the Yukon (Table 1) shows that these are also readily distinguishable.

The technique is much quicker than optical methods of characterization and undoubtedly more precise. However, separation of concentrates of unaltered glass may be time-consuming, particularly when an ash is composed largely of pumiceous fragments riddled with bubbles and inclusions. Alternative methods have therefore been sought which retain the microprobe's advantages of selectivity and rapidity but eliminate separation difficulties. These methods are based on the composition of phenocrysts from the ashes and thus might be applicable to older pyroclastics where the glass has started to devitrify and perhaps change in composition. Magnetite is most easily separated and as it precipitates early from many dacitic or rhyolitic magmas, it is a common constituent of most ashes. Furthermore, as there are significant variations in Ti, Mg and Al in the glasses, it might be expected that concentrations of these elements in magnetites would also vary from ash to ash. Magnetite was therefore extracted from a series of ashes, mounted in epoxy and polished. The compositions reported in Table 1 show that in each case the magnetite is distinctive. Again, however, a considerable scatter was noted in results from Bridge River ashes. Ilmenites which coexist with the magnetites are being analyzed to provide further data for characterization and also with a view to determining temperatures and oxygen fugacities immediately prior to eruption.

Smith, D. G. W.; Westgate, J. A., 1969, Electron probe technique for characterizing pyroclastic deposits: Earth and Planetary Sciences Letters, p. 313-319.

1. Pacific Northwest.
2. Mazama, Glacier Peak, St. Helens and Bridge River tephra.
3. Electron microprobe analyses.
4. See title.
5. ---
6. A rapid electron probe technique has been developed for characterizing pyroclastic deposits by the composition of their volcanic glass. Samples of Mazama ash (6600 years old) from northwestern U.S. and southwestern Canada were used to test the compositional variability of the clear unaltered glass shards. The electron probe analyses show that the glass composition is remarkably consistent, even though some sample locations are several hundred miles apart. The glass composition of Glacier Peak ash (about 12,000 years old), St. Helens "Y" ash (about 3,000 years old) and Bridge River ash (about 2,500 years old) were also determined and found to be distinctive. Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, Cl and F were determined to investigate the usefulness of each in characterizing these ashes. It was found that as few as three key elements, for example, Ca, F and K and Fe or Ca, K and Na, serve to identify any one of these ashes.

Smith, G. O., 1901, Geology and water resources of a portion of Yakima County, Washington: U.S. Geol. Survey Water Supply Paper 55, 68 p.

1. Yakima County, central Washington.
2. Yakima Basalt, Ellensburg Formation.
3. & 4. Field investigations of geology and ground water resources of study area.
5. Geologic map of Yakima area.
6. The basin of Yakima River described here forms an intermediate zone between the Columbia Plains on the east and the Cascade Range on the west, and geologically it possesses many features of each. The geologic formations are chiefly those of the Columbia Basin, but the structure is more nearly related to that of the Cascade Range. The rock formations are folded into arches and troughs, but the structure is simple and readily understood by even the railway traveler passing up Yakima River.

The rock seen everywhere along this river is the black basalt, but in certain valleys on the flanks of the ridges white sandstone is visible.

______, 1903, Geologic folio of the Ellensburg quadrangle, Washington: U.S. Geol. Survey Geol. Folio 86, 7 p. 3 maps, scale 1:125,000.

______, 1903, Contributions to the geology and physiography of central Washington: U.S. Geol. Survey Prof. Paper 19, p. 9-39. E-1-107

1. Central Washington.
2. Includes Yakima Basalt, Ellensburg Formation, later lavas, Pleistocene deposits.
3. Field observations.
4. Geologic mapping of study area.
5. Geologic map of Mount Stuart and Ellensburg quadrangles; geologic section of Yakima Canyon; physiographic sketch map of part of the Ellensburg quadrangle.
6. Includes section on Miocene and later events in central Washington. Describes origin and nature of Yakima Basalt, Ellensburg Formation and Pleistocene deposits, and discusses structure and physiography in the Ellensburg quadrangle.

Smith, H. W.; Okazaki, R.; Knowles, C. L., 1975, Electron microprobe analysis as a test of the correlation of West Blacktail ash from Mount St. Helens pyroclastic layer T: Northwest Sci., v. 49, no. 4, p. 209-215.

1. Pacific Northwest.
2. Mount St. Helens and West Blacktail tephras.
3. Electron microprobe analysis.

4. See title.
5. Electron microprobe data for Ca, K, and Fe in a phase diagram.
6. Scanning electron micrographs illustrate the morphology of vesicular glass shards from the West Blacktail ash. These contrast sharply with shards having tubular voids. Electron microprobe analysis of the glass for content of Ca, K, and Fe shows no difference between this ash and Mount St. Helens pyroclastic layer T. The correlation of the two tephra layers is supported.

______, 1977, Electron microprobe analysis of glass shards from tephra assigned to Set W, Mount St. Helens, Washington: Quaternary Research, v. 7, no. 2, p. 207-217, illus.

1. Pacific Northwest.
2. Mount St. Helens tephra.
3. Electron microprobe analysis.
4. Extension of fallout area for Set W; stratigraphic and petrographic observations and chemical analysis.
5. Phase diagrams, chemical analysis tables.
6. We have extended the fallout areas for each of two members of tephra-set W, erupted from Mount St. Helens about 1500 A.D. by several hundred kilometers beyond the limits mapped in 1975. We traced one member (We) east into Idaho, and the other (Wn) northeast into British Columbia. After using stratigraphic and petrographic observations to assign more than 100 tephra samples to Set W., we found 26 of these selected for chemical analysis, to be closely similar in content of Ca, Fe, and K in glass shards. But improved homogeneity was evident when the 26 sampling localities for tephra W were segregated geographically, east vs. northeast of the volcano. When Ca:Fe:K proportions were plotted on a ternary diagram, there was no overlap of the plotting areas for these two groups of tephra W samples. Without such data, tephra layers We and Wn are currently separable only from stratigraphic and geographic information. Partial glass analysis is also an aid, along with stratigraphic position and petrographic characteristics, in distinguishing tephra W from associated tephra layers. These include tephra layers T and Yn from Mount St. Helens, as well as older tephra layers from Mount Mazama and Glacier Peak.

______, 1977, Electron microprobe data for tephra attributed to Glacier Peak, Washington: Quaternary Research v. 7, no. 2, p. 197-206.

1. Pacific Northwest.
2. Glacier Peak tephra.
3. Electron microprobe analysis.
4. See title.
5. ---
6. Reference samples of three prominent pumice units of Glacier Peak tephra collected east of the volcano within a distance of 100 km are similar petrographically to units described by earlier workers. Glass shards isolated from these samples were analyzed by electron microprobe to determine the content of Ca, Fe, and K.

   Resulting data, plus those published for two other references samples, provide a basis for attributing certain outlying tephra layers from 14 locations in eastern Washington, Idaho, Wyoming, and Montana to eruptions of Glacier Peak. Ten of the samples have properties of both Glacier Peak tephra and Mount St. Helens Set J tephra, but proportions of Ca:Fe:K in glass shards indicate that 9 of the 10 outlying samples came from Glacier Peak, whereas one is assigned to Mount St. Helens set J. The remaining six outlying samples, all from southeastern Washington, contain cummingtonite phenocrysts and are chemically similar to some parts of Mount St. Helens tephra sets that are older than 12,000 B.P.

______, 1977, Discrete tephra layers in the Holocene/Pleistocene loess of southeastern Washington (abs.): Geol. Soc. America Abs. with Programs, v. 9, no. 7, p. 1180.

1. Southeastern Washington.
2. Mount St. Helens and Mt. Mazama tephra.
3. Analyses of phenocryst suites, and morphology, refractive index and Ca:K:Fe proportions of glass shards.
4. All of above to characterize tephra samples taken from loess in study area.
5. ---
6. Phenocryst suite and such properties of glass shards as morphology, refractive index, and Ca:K:Fe proportions characterize the tephra samples collected from cut banks of loess. Each exposure used contains from one to six tephra layers. We correlate some samples with tephra already known in the Pacific Northwest: (1) from

Mt. St. Helens, tephra W-east, 450 years B.P., and one or more parts of the "Unnamed" set, 37,600-18,000 years B.P., and (2) from Mt. Mazama (Crater Lake), 6,600 years B.P. We segregate samples older than the "Unnamed set, but of unknown origin, into three groups. Only one phenocrystic sample represents the youngest of these groups. Hypersthene, augite, and magnetite are common (5-20%), and green hornblende is common to abundant (20-50%). Glass shards have a dominant index of 1.509-1.514, and a Ca:K ratio of 1.7. Seven samples in the middle group are phenocrystic, but variable. Hypersthene is common to abundant, green and brown hornblendes are abundant to sparse (1-5%), and magnetite is abundant to sparse. Some samples have sparse augite, ilmenite, and enstatite. Glass shards have a dominant refractive index of 1.502-1.512, and a variable but intermediate Ca:K ratio of 1.3-0.6. Three samples assigned to the oldest group are deficient in phenocrysts; hornblende, hypersthene, augite, and magnetite are sparse to rare (1%). Glass shards have a dominant refractive index of 1.500-1.508, and a distinctively low Ca:K ratio of 0.3.

Steen, V. C.; Fryxell, R., 1965, Mazama and Glacier Peak pumice glass: Uniformity of refractive index after weathering: Science, v. 150, p. 878-880.

1. Pacific Northwest.
2. Mt. Mazama and Glacier Peak tephra.
3. Laboratory methods to determine effects of weathering on refractive indices of volcanic glass.
4. Same as above.
5. Refractive index ranges of values chart.
6. Weathering has had little differential effect on modal values of the index of refraction of pumice glasses from the eruptions of Mount Mazama and Glacier Peak thousands of years ago. Confidence is thus increased that the ranges of values for the index of refraction are reliable characteristics by which the two glasses may be distinguished from one another.

Steen, V. C., 1965, Effects of weathering environment on the refractive index of pumice glass from Glacier Peak, Washington and Mount Mazama (Crater Lake), Oregon: Washington State Univ. M.S. thesis, 147 p.

1. Glacier Peak, Washington, Mt. Mazama, Oregon.
2. Glacier Peak and Mt. Mazama tephra.

3. Laboratory investigations and field observations.
4. Sources of volcanic ejecta, weathering of volcanic glass and soil formation, relationship of weathering to refractive index of glass, laboratory methods.
5. ---
6. Petrographic examination of pumice glass shows Mt. Mazama and Glacier Peak glasses have different values of modal refractive index (modal refractive index of physically cleaned Glacier Peak samples = 1.501 (+) - 1.504: for Mazama = 1.510 - 1.512). No gross correlation was found between refractive index of clean shards of Glacier Peak and Mazama glass and weathering environment although significant variation in modal n (range of refractive index) occurs between major soil horizons at one sample site. Concluded that refractive index of Glacier Peak and Mt. Mazama pumice glass collected from the B and C soil horizons is little affected by topography, climate and vegetation at the collecting site, and that coarse (1 mm [+]) pumice from the two eruptions can be distinguished solely by refractive index of the pumice glass. Found that the A2 soil horizon was unreliable for use.

Stevenson, R. E., 1942, Petrology of the Ringold in the Palouse area: Washington State College M.S. thesis, 43 p.

1. East-central Washington.
2. Ringold Formation.
3. Field and laboratory work consisted of systematic collection and examination of Ringold samples from the Palouse region; mineral analysis.
4. Mineral analysis of Ringold Formation.
5. Several stratigraphic sections; map showing mineral contours of andesine in Palouse area.
6. There is an eroded sedimentary mantle overlying the Columbia basalts in east-central Washington. This mantle appears largely unstratified; however stratification has been found at several localities, although not occurring in the same manner as Treasher found them. These shaly and laminated deposits are not widespread and in most instances are characterized by a higher percentage of clay than the other localities. The "caliche" layers are local accumulations of calcium carbonate. Lithologically, the Ringold in the Palouse area is a clay-silt (average grain size approximately 0.014 mm.) consisting of unweathered, slightly rounded crystalline fragments of hornblende,

hypersthene and some plagioclase, rounded grains of quartz and othoclase, and mica flakes imbedded in a matrix of brown clay minerals. A comparison of the Ringold with Middle Western and Chinese loess shows that it has a higher percentage of clay and smaller percentage of silt. A much weathered boulder and several weathered pebbles were found imbedded in unstratified Ringold at one locality. Such indefinite results were obtained in the examination of the mineral contour maps with one exception, the andesine map, that one could only guess from what direction the material had come. It seems probable that in the case of the others, the material was brought from all directions.

Strand, J. R.; Hough, J., 1952, Age of the Ringold Formation: Northwest Sci., v. 26, p. 152-154.
1. White Bluffs north of Pasco, Washington.
2. Ringold Formation.
3. Fossil collection and identification to set age of Ringold at middle or late Pleistocene.
4. Same as above.
5. ---
6. Condensed account of fossil collections and identifications that confirm a Pleistocene age for these deposits.

Formation is 490 feet high. Lower 90 feet are iron-stained pebble and conglomerate with few sand lenses and is resistant to reerosion; above this is clay, sand, sandstone, siltstone, with thin beds of ash, diatomite, gravel; uppermost part is thick caliche zone in a sandy siltstone. Fossils described: caribou found at top of conglomerate; camel in thin gravel bed higher in formation; others in siltstone beds. Found a ground sloth, peccary and mastadon also. Fossil identifications and descriptions included, as well as locations.

Swanson, D. A., 1964, Graded subaerial and subaqueous pyroclastic flows, Bethel Ridge, south-central Washington (abs.): Fourth Annual Graduate Student Symposium in the Geological Sciences, Univ. California, Los Angeles, Program, p. 15-16.

Tabor, R. W.; Waitt, R. B., Jr.; Frizzell, V. A., Jr.; Swanson, D. A.; Byerly, G. R., 1977, Preliminary geologic map of the Wenatchee 1:100,000 quadrangle, Washington: U.S. Geol. Survey Open-File Report 77-53, 24 p., 1 plate, 4 figures.

Tallman, A. M.; Lillie, J. T; Caggiano, J. A., 1978, The late Cenozoic geology of the western Pasco Basin. In Basalt Waste Isolation Program Annual Rept., Fiscal Year 1978: Rockwell Hanford Operations Report, RHO-BWI-78-100, p. 78-81.

1. Western Pasco Basin, Washington.
2. Ringold Formation, Hanford Formation, dune sand.
3., 4, 5. ---
6. Review of mapping accomplishments in Pasco Basin concerning late Cenozoic sediments. Review of literature and well data was conducted and a reconnaissance surficial geologic map was done.

Theisen, A. A.; Harward, M. E.; Schmitt, R. A., 1968, Neutron activation for distinguishing Cascade Range pyroclastics: Science, v. 161, p. 1009-1011.

1. Pacific Northwest.
2. Cascade Range tephras.
3. Neutron activation analysis.
4. See title.
5. Chemical composition tables.
6. Neutron activation of glassy separates of volcanic ash resulted in 21 nuclides measurable with instrumental techniques. The relative activities of most of the nuclides distinguish samples from Mount Mazama, Newberry Crater, and Glacier Peak. The usefulness of the technique was assessed by comparing the values for known sources with those from fine ash of uncertain origin. The data strongly suggest Mount Mazama as the source.

Thompson, J. P., 1936, Some relationships between the soil canyons of certain southeastern Washington valleys and summer-fallow cultivation: Northwest Sci., v. 10, no. 1, p. 8-11.

1. Southeastern Washington.
2. Alluvium in basalt canyons.
3. Field investigation.
4. See title.
5. ---
6. The events discussed in this paper may be summarized as follows: (1) There existed in the region of the soil canyons youthful pre-silt stream valleys; (2) These valleys were subjected to conditions of deposition which built flood plains distinguished by: a) Massive, even-textured strata; b) Abundance of enclosed vegetative remains; c) Absence of coarse alluvium; d) The lithologic similarity of valley accumulations over great distances in the

Northwest; and, e) The gradual uniform regional erosion which the flood plain deposits suggest; and (3) Summer-fallow cultivation and destruction of the protected valley channels initiated accelerated erosion, because streams were required to handle more water and handle it in a shorter time than before.

Treasher, R. C., 1925, Geology of the Pullman quadrangle, Washington: Washington State College M.S. thesis, 74 p. Plate 1, 1:125,000.

1. Pullman, Washington.
2. Palouse Formation, alluvium, Yakima Basalt, granite and quartzite.
3. & 4. Field investigation.
5. Geologic map of Pullman quadrangle, including cross sections.
6. Report led to preparation of geologic map of Pullman quadrangle by author. Geologic units described and geologic history of region reviewed. Snake River cut through loess and basalt during uplift of region. Basalt cut by numerous dikes.

Trimble, D. E., 1954, Geology of the Haas quadrangle, Washington: U.S. Geol. Survey Geol. Quad. Map GQ-43, 1:62,500.

Tucker-McLucas, G. B., 1977, Morphologic parameters of Mount Mazama and Glacier Peak tephras: a scanning electron microscope study: Univ. of Washington M.S. thesis, 108 p.

1. Pacific Northwest.
2. Mt. Mazama and Glacier Peak tephras.
3. Scanning electron microscope investigation.
4. Characterization of Glacier Peak and Mt. Mazama tephras using morphologic parameters.
5. ---
6. Samples of tephra from Mount Mazama (Crater Lake, Oregon) and Glacier Peak, Washington were studied using a scanning electron microscope (SEM) to measure and compare the following morphological parameters: vesicle maximum diameter; vesicle minimum diameter; vesicle length; wall thickness, and vesicle density. Sample means (X) from 27 different localities exhibit considerable variations for both tephra suites. At one standard deviation, the vesicle parameter values for the two source volcanoes overlap. Consequently, tephra morphology, by itself, does not appear to constitute a reliable criterion for distinguishing between the two tephras. No obvious relationship

was found between distance of transport and any of the five morphological parameters investigated. However, the SEM does provide a rapid and reliable method for characterizing vesicle morphology of tephra units.

Twiss, S. N., 1933, Stratigraphy of the Saddle Mountains, Washington: Washington State College M.S. thesis, 36 p. Plate 1, 1:62,500.

1. Central Washington..
2. Columbia River Basalt, Crab Creek and Beverly Formations, and granite conglomerate.
3. & 4. Field observations.
5. Geologic map of parts of Corfu, Beverly, and Smyrna quadrangles.
6. In summary, we note the following relationships and similarities between the Ellensburg vicinity and the Saddle Mountains: (1) One of several anticlinal mountain ridges on the Ellensburg quadrangle has its eastern extension in Saddle Mountains Ridge. They doubtless form a structural and topographic unit. (2) The anticlinal mountain ridges are so recent in origin that topography is in most cases, indicative of structure. Dip slopes are the rule rather than the exception. (3) The ridges are composed, in large part, of basalt. (4) But one sedimentary formation in each area is conformable with the basalt. (5) In both areas the sediments mentioned in (4) occur at and near the top of the basalt formation. (6) The age of the sediments in question in the Ellensburg district is Miocene, the age of the sediments in Saddle Mountains is pre-Pleistocene. It is evident that sedimentation took place in both areas at approximately the same time. It has been indicated that there is some, but probably not significant, similarity of rock types between the two areas, and it was indicated that an exposure in Badger Pocket might well be the connecting link between the two formations.

   The relationship of the Beverly Formation to the basal (Miocene) beds of the Ellensburg Formation has been demonstrated by the following: (1) Proof of the pre-Pleistocene age of the Beverly Formation by reference to the Ringold Formation; (2) Occurrence of the Ellensburg and Beverly beds in the same stratigraphic position in relation to the basalt; (3) Similar relationship of the two formations to structure; (4) Indications of a

gradation from one formation to the other.

Considering the above, the opinion seems justified that the Beverly Formation is the eastward extension of the basalt beds of the Ellensburg Formation.

U.S. Dept. of War, 1934, Columbia River and minor tributaries-letter from the Secretary of War, v. 2: Cong. Doc., 73d Cong., 1st sess., House Doc. 103, 1845 p.

1. U.S. Congressional Document.
2. See title.
3. See title.
4. ---
5. Field reconnaissance.
6. Extensive study of Columbia River and tributaries on the general geology (pre-Cambrian-Recent), climate, topography, soils, stream flow, population, transportation, industry, power, irrigation of the area, and papers on proposed dam sites investigating the geology at the sites.
7. Various maps, tables.
8. ---

U.S. Geological Survey, 1966, Spokane and vicinity, Washington, 1950-63: U.S. Geol. Survey, 1 sheet, 1:24,000.

Ver Steeg, K., 1926, Drainage changes in northeastern Washington, Univ. of Chicago M.S. thesis, 116 p.

1. M.S. thesis.
2. See title.
3. See title.
4. Geomorphological stream changes.
5. Reconnaissance field observations.
6. See title.
7. Maps showing several drainage and drainage changes; geologic map of Colville Indian Reservation showing Omak trench; map of the channeled scablands and relation to associated features; map of limit of Wisconsin moraine.
8. Broadly generalized description of the geography and geology of region and a discussion on glaciation and its effects on the area in terms of drainage changes.

Waitt, R. B., Jr., 1972, Geomorphology and glacial geology of the Methow drainage basin, eastern North Cascade Range, Washington: Univ. of Washington Ph.D. thesis, 154 p.

______, 1977, Guidebook to Quaternary geology of the Columbia River, Wenatchee, Peshastin, and Upper Yakima Valleys, west-central Washington: U.S. Geol. Survey Open-File Report 77-753, prepared for Geol. Soc. America 1977 Annual Mtg. (Seattle) Field Trip No. 13, Nov. 1977, 25 p.

1. West-central Washington.
2. Glacial features.
3. & 4. Field trip guidebook.
5. ---
6. Discussion of Quaternary geologic events in Yakima, Peshastin and Wenatchee valleys and the Columbia River Valley.

______, 1978, Post-Miocene stratigraphy and the tectonism of parts of the Great Columbia Plain and adjacent Cascades, Washington: Tectonics and Seismicity of the Columbia Plateau Workshop, Feb. 14-16, 1978, meeting volume: Rockwell Hanford Operations, Richland, Washington.

______, 1979, Late-Cenozoic deposits, landforms, stratigraphy and tectonism in Kittitas Valley, Washington: U.S. Geol. Survey, Prof. Paper 1127, 18 p.

1. Kittitas Valley, Yakima River Valley, Washington.
2. Yakima Basalt subgroup, Ellensburg Formation, Thorp Gravel, Pleistocene till and outwash.
3. Field observations, review of literature.
4. See title.
5. Tectonic map of south-central Washington; geologic map of Kittitas Valley area; correlation chart of map units; geologic map of part of northern Kittitas Valley; composite section of Thorp Gravel; fission track ages on zircon from Thorp Gravel tephra layers.
6. Kittitas Valley, a structurally determined wide segment of the Yakima River Valley, is partly filled with the Pliocene Thorp Gravel and with Pleistocene till, outwash, and related sediment that accumulated during three glaciations. The Thorp Gravel, whose age according to fission-track dating is about 3.7 m.y., forms a conspicuous fill terrace locally as high as 130 m. Bodies of drift, all younger than the Thorp Gravel, form nested fill terraces along the Yakima River. The massive moraines, intermediate morpho-stratigraphic position and well-developed soil of the Kittitas Drift suggest its correlation with the penultimate northern-hemisphere glaciation of about 0.13 m.y. ago. The Lakedale Drift, which composes a single outwash terrace in Kittitas Valley, evidently correlates with the classical late Wisconsin Glaciation. The newly named Lookout Mountain Ranch Drift, which forms moraines at higher

altitudes than and is older than the Kittitas Drift, lacks an attendant valley train.

Three faults disrupt the Thorp Gravel but apparently not the Kittitas Drift, and therefore probably are between 0.13 and 3.7 m.y. old. The eastward trend and up-to-the-basin throw of the faults probably reflect reverse faulting due to a regional north-south compression that uparched several east-trending anticlines in central Washington. The southeast trend of the dextrally echelon arrangement of the faults apparently is due to a right-lateral couple across a zone parallel to the Olympic-Wallowa lineament.

Waldron, H. H.; Gard, L. M., Jr., 1951, Preliminary report on the geology of part of the lower Snake River Canyon, Washington: U.S. Geol. Survey Open-File Report, 66 p. Plate 1, 1:24,000.

1. Southeast Washington.
2. Columbia River basalt, interbasalt sediments, Palouse Formation, Snake River gravel, other sediments, silts and sands.
3. & 4. Field investigation and mapping of study area and summary of and feasibility of engineering projects.
5. Geologic maps of Lower Snake River Canyon.
6. The lower Snake River, throughout its length, flows within the Columbia Plateau physiographic province and has cut a deep canyon into the eastern part of the plateau. This report describes the geology of a three mile wide strip of the canyon between river miles 43 and 102 in southeastern Washington.

   The formations of the area are readily divisible into two groups. The older group, comprising the bedrock of the entire area, consists of over 1,000 feet of Columbia River lavas, some interbedded sediments and pyroclastics of Miocene age, and some younger canyon lava flows of Pliocene or early Pleistocene age. The second group comprises the surficial deposits and consists of unconsolidated Pleistocene eolian and fluvioglacial deposits, and Recent sediments.

   In general, the basalt flows and the plateau surface controlled by them are tilted gently westward with dips of less than one or two degrees. Some minor folding, faulting and fracturing probably accompanied this westward tilting, as

the present courses of the Snake River and many of its tributaries strongly suggest control by regional lines of weakness.

The geologic history of the area is incompletely known but records successive periods of pre-Pleistocene volcanism and canyon cutting, accompanied by some minor deformation. The Pleistocene and Recent epochs record several periods of aggradation, degradation and ponding.

Geologically, the lower Snake River canyon is ideally suited, in many ways, for the construction of dams. Excellent foundations and copious quantities of easily excavated construction materials exist at many places throughout the length of the canyon. Geologic structures are simple, and no seismic activity has been recorded in the area. Existing slopes are relatively stable, and no evidence was observed of large landslides.

______, 1954, Geology of the Hay quadrangle, Washington: U.S. Geol. Survey Geol. Quad. Map GQ-56, 1:62,500.

______, 1955, Geology of the Penewawa quadrangle, Washington: U.S. Geol. Survey Geol. Quad. Map GQ-56, 1:62,500.

Walker, E. H., 1967, Varved lake beds in northern Idaho and northeastern Washington: U.S. Geol. Survey Prof. paper 575-B, p. 83-87.

1. Northern Idaho, northeastern Washington.
2. Varved lake beds.
3. Field observations; measurements and descriptions of beds.
4. Descriptions of beds and repetition of clay-sand-silt-clay sequence in representative section; discussion of weather and climate inferred by beds, rate of accumulation and ground water in beds.
5. Section of glacial-lake deposits in Priest River Valley; map of extent of late glacial lake in Pend Oreille and Priest River valleys.
6. Thick deposits of fine-grained sediment underlie the floors of the Purcell Trench, the Pend Oreille Valley and adjacent lowlands, and the Priest River Valley in northern Idaho and northeastern Washington. The deposits formed in a late glacial lake while ice blocked the north-flowing stretch of the Pend Oreille River. Sheets of clay, distinctly varved in places, are interbedded with sheets of sand and

silt. The sheets of sand and silt are interpreted as drainage varves that were deposited when the lake burst out past the ice dam at about 12- to 65-year intervals. The sheets of sand in the lowlands underlain by lake deposits provide small, but in most places adequate, water supplies for domestic and stock needs.

Walker, F. C.; Irwin, W. H., 1954, Engineering problems in Columbia Basin Washington varved clays: Am. Soc. Civil Engrs. Proc., v. 80, Separate no. 1515, 18 p.

1. Columbia Basin, Washington.
2. Varved clays.
3. Discussion of engineering problems - see title.
4. Same as above.
5. ---
6. In many places clay deposits are found which have definite laminated structure. The individual layers or varves represent seasonal deposition in lakes resulting from annual inflows. Consequently, each separate layer contains a wide range of grain sizes, but exhibits a gradation from coarsest grains near the base of the layer to finest near the top. The Nespelem deposits are predominantly of this type and were developed during the end of the last Glacial era when the Columbia River was dammed by ice and its flow diverted through high level channels such as the Grand Coulee. The Nespelem deposits are therefore confined to the pond created by the glacial dam. The thinness of the layers and their total depth indicate that sedimentation in this pond continued for many hundreds of years and produced a material that has had a profound effect on engineering problems in this area.

   Undisturbed deposits show some of the characteristics of sedimentary rocks but, once disturbed, they reassume all the worst engineering characteristics of freshly deposited alluvial and lacustrine clays. As a consequence, test results both in the field and the laboratory are very deceptive. The varved nature of the undisturbed materials, the occurrence of old landslides, and the usually saturated condition of both disturbed and undisturbed materials make the testing and interpretation of results extremely difficult.

   Once the ice dam was removed, the river entrenched itself into these valley deposits, leaving over-steepened slopes along the sides of the valley with treacherous combinations of undisturbed deposits, landslide debris, and reworked sediments. Landslides continue to be of frequent occurrence. Overburden excavation for Grand Coulee Dam and the new high water levels of the reservoir activated many slides. These entailed many difficult construction problems and right-of-way problems along the reservoir rim.

The solution of the engineering problems of structures found in varved clays has run the entire gamut of accepted practice and has required the introduction of considerable ingenuity in the solution of specific cases. These range from freezing the material in place, through minimizing disturbance of the deposits, to avoidance, loading or unloading, and various types of drainage, including taking advantage of subsurface bedrock configuration and gravel zones.

Experiences with the Nespelem varved clays have served to emphasize the deficiencies in classical design and testing procedures. In particular they have demonstrated the need for thorough and critical appraisal of the nature of such soils using to the utmost the arts of Geology and Soil Mechanics in evolving solutions to engineering problems. These experiences have also served to develop a procedure for the analysis of other types of foundations now generally followed by the Bureau of Reclamation.

Walters, K. L.; Grolier, M. J., 1960, Geology and ground water resources of the Columbia Basin Project area, Washington: Washington Div. Water Resources Water-supply Bull. 8, v. 1, 542 p., plate 3, 1:205,670.

1. South-central Washington.
2. Columbia River Basalt, Ringold Formation, Palouse Formation glacial outwash sand and gravel, dune sand.
3. Interpretation of well logs, geologic mapping.
4. See title.
5. Basalt surface map; well location map.
6. Primarily a report concerned with ground water resources of study area. Discusses geologic setting and rock units and their water-bearing characteristics.

Walters, K. L.; Glancy, P. A., 1969, Reconnaissance of geology and ground water occurrence and development in Whitman County, Washington: Washington Dept. Water Resources, Water-Supply Bull. 26, 169 p. C-47

1. Whitman County, Washington.
2. Yakima Basalt, Palouse Formation, Scabland deposits, alluvium.
3. Field investigations.
4. Geology and water resource information derived from well log interpretations.
5. Reconnaissance geologic map and cross-section of Whitman County; maps showing well locations.
6. Whitman County covers about 2,200 square miles in south-eastern Washington, adjacent to the Washington-Idaho boundary. Average annual precipitation in the county ranges from about 14 to 20 inches. Much of the county is underlain by a thick sequence of basalt flows mantled by loess. Locally, older nonbasaltic crystalline rocks are exposed, principally in the eastern part of the county.

   The crystalline rocks normally contain very little water. Where they are fractured, however, they may contain enough water to meet domestic needs. Elsewhere, deposits of coarse-grained materials weathered from crystalline rocks may yield several hundred gallons per minute to individual wells.

   Basalt of the Columbia River Group is the principal consolidated rock exposed in Whitman County. The Picture Gorge Basalt is exposed in the area south of Uniontown; elsewhere in the county only the Yakima Basalt is exposed. The maximum total thickness of basalt in the county is not known but probably exceeds 5,000 feet. In this study, only the Roza Member of the Yakima Basalt was differentiated. The yield of large-diameter wells that penetrate several hundred feet of basalt in Whitman County is about 125 to 200 gpm (gallons per minute) for every 100 feet of saturated basalt penetrated.

   Adequate yields of water for domestic and stock supplies are commonly obtained from loess or from the contact between the loess and the underlying basalt. Pleistocene gravel deposits and Recent alluvium characteristically yield little water. Locally, however, yields of several hundred gallons per minute are obtained from wells that penetrate the gravel, or the alluvium in the Snake River Valley.

Waring, G. A., 1913, Geology and water resources of a portion of south-central Washington: U.S. Geol. Survey Water Supply Paper 316, 46 p.

1. South-central Washington.
2. Yakima Basalt, Ellensburg Formation, surficial deposits.
3. Field investigation.
4. See title.
5. Reconaissance map of study area showing geology and well locations.
6. Reconnaissance study of water resources of region including utilization of surface and underground water by canals and wells and a general study of rock characters and structural conditions in their relation to further development of underground sources.

Warren, C. R., 1939, The Hood River conglomerate in southern central Washington: Yale Univ. Ph.D. thesis, 285 p.

1. South-central Washington.
2. Hood River conglomerate.
3. Field observations.
4. Description, age, origin of Hood River conglomerate; course of Columbia River through time; petrographic study on Columbia River basalts.
5. Plate showing distribution of the Hood River conglomerate.
6. The Hood River conglomerate is a fluvial conglomerate resting stratigraphically and probably conformably on the Columbia River basalt in southern central Washington. It is interbedded with sandstone from which late Miocene or early Pliocene fossils have been collected, and is traced in the field into the Ellensburg and Dalles Formations, both of which are late Miocene and early Pliocene.

   The conglomerate occurs in a zone extending from the Columbia River near Priest Rapids southwest past Sunnyside and Goldendale, Washington, to the type locality at Hood River, Oregon, adjacent to the Columbia River. The pebbles in the conglomerate resemble lithologically those in the gravel carried by the Columbia River today, and differ markedly from rock types indigenous to the region or to the drainage basin or any of the other streams of the region. This fact, in conjunction with the probably conformity on the basalt, is believed to indicate that the conglomerate marks the course followed by the Columbia River at the end of the period of accumulation of the Columbia River Basalt.

Waters, A. C.; Flagler, C. W., 1929, Origin of the small mounds on the Columbia River Plateau: Am. Jour. Sci., 5th ser., v. 18, no. 105, p. 209-224, 8 figs.

1. Southwestern portion Columbia River Plateau, Oregon.
2. Basalt mounds.
3. Field observations.
4. See title.
5. ---
6. Mounds are polygenetic in general, but areas of mound topography on Columbia River Plateau have had common origin, being the erosional remnants of a once continuous layer of volcanic ash. Large unmodified areas of this ash have survived erosion at many localities. Mound topography was developed only where ash was deposited directly upon basaltic surface, the basic condition being that subsoil be less movable than upper soil. Mounds developed on slope sufficient to permit run-off. Mounds elongated in direction of slope, the amount a function of steepness of slope. Local irregularities in slope reflected in production of irregularly shaped mounds. If ash is of uniform thickness, mound areas pass with decrease of slope into area completely mantled by ash. With increase in slope, may pass into area where ash has been completely stripped. Height of mounds equal to, or less than, thickness of adjacent undissected parts of ash blanket. Mound topography not seen where ash blanket more than 7 feet thick. Areas between mounds form definitely integrated and minutely adjusted drainage system, the symmetry of this system influenced by columnar jointing of ash. Mounds do not indicate climatic change. They were carved from material that was deposited rapidly at time of a period of explosive volcanic activity.

Waters, A. C., 1932, Glacial features along Columbia River near Lake Chelan (abs.): Pan-American Geologist, v. 57, no. 5, p. 372; (abs.): Geol. Soc. America Bull., v. 44, no. 1.

1. Lake Chelan area, Washington.
2. Glacial features.
3. Field observations.
4. See title.
5. ---
6. At the time of the last glaciation in north-central Washington, a broad expanse of ice known as the Okanogan lobe occupied the area immediately east of the northern part of the Cascade Range. This lobe crossed Columbia River and rode out upon

the northwestern part of the broad, flat Columbia Plateau. In the spurs of the Cascades west of the river it encroached upon a region of serrate topography and buried peaks and ridges that rise 4,000 feet above the adjacent streams. The deposits left by the ice in the two regions are striking and distinctive. On the Plateau there is a huge moraine dotted with hundreds of erratic basalt boulders many of which measure 60 feet on a side. Stratified till is very rare. In the region of rough topography, on the other hand, moraines and other deposits of till are only locally found, but numberless terraces composed of stratified glacial drift are conspicuous elements of the scenery. Most of the terrace material shows deltaic structures, and appears to have been deposited during the period of deglaciation in temporary lakes which were dammed by the ice. Suites of these terraces block each tributary valley of the Columbia upstream from the lowermost limit of the ice in Columbia canyon. Their form and association with other topographic features indicate that they were built in lakes dammed in the tributary valleys by an ice tongue that still occupied the main Columbia trough. These lakes were drained by streams flowing along the margin of the ice-tongue. Locally the marginal streams crossed rock spurs between adjacent tributaries and excavated precipitous walled spill-ways which were subsequently abandoned upon withdrawal of the ice. The majority of the spill-way notches are less than 50 feet in depth, but in the case of a few a prodigious amount of rock excavation was accomplished. The most remarkable is Alta coulee, a narrow cliff-walled slot cut 500 feet into fresh granodiorite by a marginal glacial stream.

______, 1933, Terraces and coulees along the Columbia River near Lake Chelan, Washington (abs.): The XI Transactions of Sigma Gamma Epsilon, XI Chapter, Washington State Univ., v. 1, no. 1, p. 24; (abs.) Geol. Soc. America Bull., v. 44, no. 1, p. 150, 1933; (abs.) Revue de Geologic et des Sciences Connexes, v. 16, no. 5, p. 212, 1936. B-12

1. Lake Chelan area, Washington.
2. Glacial features.
3. Field observations.
4. See title.
5. ---
6. A long series of glacial features is described both such as occur on a plateau surface and such

as occur in more rugged mountains. Great erratic moraines, terraces, marginal channels, and ice carvings occur. The author shows that system can be had from this wealth of features by postulating a broad lobe of ice, spreading in the ice age over much of north-central Washington, across the Columbia Canyon, diverting the river, and covering serrate topography 4,000 feet above the major streams. Marginal lakes received the deposits which subsequently became the terraces. After the ice withdrew the river took its former course and bore great floods which left visible surface down the Columbia Canyon.

Weis, P. L., 1960, Geology of the Greenacres quadrangle and adjacent area: U.S. Geol. Survey unpub. reconnaissance map, 1:380,160.

Weis, P. L.; Richmond, G. M., 1965, Maximum extent of late Pleistocene Cordilleran glaciation in northeastern Washington and northern Idaho. In Geological Survey Research 1965: U.S. Geol. Survey Prof. Paper 525-C, p. C128-132, illus.

1. Northeastern Washington and northern Washington.
2. Ice-contact deposits, landforms, and ice-modified bedrock.
3. Field observation of above.
4. See title.
5. Map of Late Pleistocene ice margins in vicinity of Spokane, Washington.
6. Late Pleistocene glaciers in northeastern Washington and northern Idaho were considerably less extensive than has been previously supposed. Ice which was part of a single large sheet farther north formed a number of lobes that were for the most part valley glaciers near their southern margins. Ice-contact deposits, landforms, and ice-modified bedrock were used as criteria for determining the outermost position of the ice margins. Deposits south of those margins that were once considered to be till are now thought to have formed as a result of the catastrophic floods from glacial Lake Missoula.

Weis, P. L., 1968, Geologic map of the Greenacres quadrangle Washington: U.S. Geol. Survey Quad. Map GQ-734, 1 sheet accompanied by 4 pages of text, map 1:62,500.

Weissenborn, A. E.; Weis, P. L.; Fryklund, V. C., Jr., 1960, Reconnaissance geology of eastern Washington: Washington Div. Geology and Earth Resources, 3 sheets

(Spokane Newport and Chewelah quadrangles), scale 1:125,000.

Weissenborn, A. E., 1969, Geologic map of Washington, Lat. 46° to 49°, long. 118° to 124°: U.S. Geol. Survey Misc. Geol. Div. Map I-583, scale 1:2,000,000.

______, 1974, Geologic map of the Mount Spokane quadrangle, Washington and Idaho: U.S. Geol. Survey Open-File Report 74-211, map and text on one sheet, 1:31,680.

Weissenborn, A. E.; Weis, P. L., 1976, Geologic map of the Mount Spokane quadrangle, Spokane County, Washington, and Kootenai and Bonner Counties, Idaho: U.S. Geol. Survey Quad Map GQ-1336, map and text on one sheet, scale 1:62,500.

Whetten, J. T.; Kelley, J. C.; Hanson, L. G., 1969, Columbia River sediment sources (abs.): Geol. Soc. America Spec. Paper 121, p. 576-577.

1. Columbia River, Washington.
2. Columbia River sediments.
3. Mean grain - size measurements, heavy mineral, clay mineral and bulk mineral composition, major and trace element composition.
4. See title.
5. ---
6. Sediment carried on the bed of the Columbia River increases in mean grain size with distance downstream to the mouth. Other measured variables (heavy mineral, clay mineral, and bulk mineral composition; and major and trace element composition) also show consistent changes along the river. In general, discrimination is marked between sediments of Grand Coulee, Ice Harbor, and the three downstream reservoirs (McNary, The Dalles, Bonneville), whereas differences among the downstream reservoirs are small and inconsistent.

   Most of the textural, mineral, and chemical changes in the Columbia River sediments are correlated with changes in source materials. Sediments of the upper Columbia are derived largely from the reworking of generally nonvolcanic glacial and eolian surficial deposits and eroded basalt. The sediments contributed by tributaries to the lower Columbia contain large quantities of volcanic materials derived from the erosion of Cascade volcanoes and Tertiary sedimentary rocks of volcanic origin. Some lower Columbia tributaries contribute quartz-free sediment.

The relatively large quantity of coarse sediment contributed by lower Columbia River tributaries dilutes the sediment contributed by the upper Columbia. Bedload sediment at the mouth therefore appears to be largely of volcanic origin.

Wilcox, R. E.; Powers, H. A., 1963, Petrographic characteristics of Recent pumice from volcanoes in the Cascade Range: Geol. Soc. America Abs., 1963, Spec. Paper 76, p. 232.

1. Pacific Northwest.
2. Cascade Range tephra.
3. Petrographic study including spindle stage and focal-masking techniques.
4. See title.
5. ---
6. Siliceous pyroclastic rocks of Recent age from particular volcanoes in the Cascades show many similarities, but detailed petrographic study, facilitated by the spindle stage and "focal masking" techniques, reveals small but consistent differences. Thus the glass from the Mazama eruption of Crater Lake has refractive index characteristically ranging from 1.500 to 1.511, and, among the phenocrystic minerals, the abundant zoned hornblende has principle refractive index ranging from 1.658 to 1.669. Both ortho- and clinopyroxene are present. The glass from Glacier Peak Volcano, on the other hand, has from 1.495 to 1.500 (rarely as low as 1.486), and the abundant zoned hornblende has an index from 1.644 to 1.655. Phenocrystic orthopyroxene is present, but clinopyroxene is absent. The glass from Newberry Crater has an index from 1.493 to 1.496, and the rare hornblende has an index from 1.668 to 1.674. Ortho- and clinopyroxene are rare. Glass from the pumice of the Bridge River area of British Columbia has an index from 1.496 to 1.501, and the abundant strongly zoned hornblende has an index from 1.640 to 1.658. Phenocrystic ortho- and clinopyroxene are present, and biotite is common.

   Similarly, one or more unique characteristics have shown up on the material of each of the other Recent vents so far studied, and these are reflected in several cases by recognizable differences in the chemistry of the glasses. Such specific petrographic data on material known to have been erupted from a particular major Recent vent provides a basis for identification of the corresponding ash deposit among the several

prominent layers of volcanic ash in the Recent sediments of the Pacific Northwest, and for more confident use of this layer as a stratigraphic marker.

Wilcox, R. E., 1965, Volcanic-ash chronology. In The Quaternary of the United States, H. E. Wright, Jr.; D. G. Frey, eds. p. 807-816.

1. Western United States.
2. Volcanic ash.
3. Discussion of volcanic ash chronologic techniques.
4. Same as above.
5. Location map of Quaternary volcanoes in Western U.S.
6. Several extensive ash-fall layers provide useful time-stratigraphic markers in the Quaternary deposits of western United States. The Mazama ash, erupted from Crater Lake, Oregon, about 6,000 years ago, mantled much of northwestern United States and adjacent parts of Canada. To it belongs most of the ash previously called "Glacier Peak" in Washington and "Galata" in Montana. The ash fall that actually had its source at Glacier Peak Volcano is about 12,000 years old, and it covered a broad zone to the east and southeast. Pearlette ash fall (or ash falls) of late Kansan age spread over the Great Plains, and very similar ash has been found in middle Quaternary deposits in the Rocky Mountains and as far west as Nevada. Valles caldera in New Mexico and the Yellowstone Park region have been suggested as sources for the Pearlette ash fall, but further study appears necessary to establish which, if either, is the source and whether the Pearlette as now used is only one ash fall.

   Many more Quaternary ash layers await investigation and application as time-stratigraphic markers. Some, such as the ash fall associated with the Bishop Tuff eruption in California, dated by potassium-argon methods, are probably extensive but are still to be traced outward from their sources. Satisfactory identification of individual ash beds requires detailed field investigation of the stratigraphic relations and through laboratory determinations of petrographic characteristics of the ash, supplemented in some cases by chemical analysis.

______, 1969, Airfall deposits of two closely spaced eruptions in late glacial time from Glacier Peak

volcano, Washington (abs.): Geol. Soc. America Abs. with Programs 1969, part 5, p. 88-89.

1. East of Glacier Peak, northern Cascades.
2. Glacier Peak tephra.
3. Petrographic analysis; stratigraphic analysis.
4. See title.
5. ---
6. Two units are recognized in the thick airfall pumice lapilli a few miles east of their source, Glacier Peak volcano, in the northern Cascades: A lower coarse gray lapilli and an upper coarse buff-stained lapilli, separated at some localities by a thin parting of crystal-rich ash. Petrographic characteristics of the two lapilli units are similar: Vesicular glass of refractive index near 1.500 enclosing abundant phenocrysts and microlites of plagioclase, orthophroxene, hornblende, and magnetite. Traced east and southeast into Idaho and western Montana, the deposits maintain their twofold character, although as progressively thinner layers of finer-grained material. A C-14 age of 12,750 $\pm$ 350 years (W-1644) was obtained from snails out of associated silt at a locality in western Montana. Locally the two clean ash layers are separated by ordinary detrital sediment as much as several feet thick, and it seems obvious that the two layers represent separate eruptions but closely spaced in time. Commonly these ash layers, either paired or alone, are found in deposits of proglacial lakes or glacially fed streams, consistent with conditions presumed to have prevailed during the last withdrawal of glacial ice. An idea of the position of the ice margins at that time is obtained from the northerly limits of known occurrences of Glacier Peak ash.

Williams, H.; Goles, G. G., 1968, Volume of the Mazama ashfall and the origin of Crater Lake Caldera. In Dole, H. M., ed., Andesite Conference Guidebook: Oregon Dept. Geology and Mineral Industries Bull. 62, p. 37-41.

1. Pacific Northwest and Crater Lake, Oregon.
2. Mt. Mazama tephra.
3. Mathematical models, using measurements of thickness of ash deposits at various distances from vent, to determine volumes of ash-falls.
4. Same as above.
5. Distribution map of Mazama ash; Mazama air-fall ash contour along N. vector.

6. Paper corrects miscalculation by Williams (1942) of volume of ash blown from Mt. Mazama during initial phase of climatic eruption and volume of Mazama that collapsed. The volume of Mazama ash that fell between 60-1000 miles from Crater Lake was 5.7 cubic miles (23 km^3) and was greater than the volume of ash that fell closer to vent. Beyond 1000 miles is a few hundredths of a cubic mile. Content of crystals and lithic fragments in ash diminishes rapidly away from source while pumiceous particles and glass shards increase until only vitric dust is found near limits of fallout. Volume of material blown from Mazama before top collapsed is 13.3-17.3 cubic miles.

It is now believed that Mazama summit was less than 12,000 feet and that less than 17 cubic miles of the top fell - more like 15 cubic miles. The discrepancy between the volume of material ejected from the volcano and the volume of the mountain top that collapsed is suggested to be provided by subterranean withdrawal of magma and may have triggered the explosive eruptions that led to engulfment.

Woodward - Clyde Consultants, 1978, 1872 Earthquake studies, Washington Public Power Supply System Nuclear Project Nos. 1 and 4, Paleomagnetic measurements of the Ringold Formation and loess units near Hanford, Washington and evaluation of age dating potential of Quaternary deposits near Hanford, Washington: Prepared for United Engineers and Constructors, Inc., San Francisco, Woodward-Clyde Consultants, 2 volumes.

Yeaton, W. J., 1923, Geology of the Zillah quadrangle, Washington: Univ. of Chicago M.S. thesis, 88 p., map, 1:125,000.

1. South-central Washington.
2. Ellensburg Formation, Satsop Formation, alluvium and glacial sediments, Yakima Basalt, Wenas Basalt.
3. Field observations.
4. Stratigraphy, structure, geologic history, mineral resources, hydrology and geologic mapping of study area.
5. Geologic map and cross sections in Zillah quadrangle.
6. Geologic field investigations of the Zillah quadrangle including surficial deposit.

CATASTROPHIC FLOOD FEATURES

Allison, I. S., 1933, New version of the Spokane Flood: Geol. Soc. America Bull., v. 44, no. 4, p. 675-722.

1. Eastern Washington.
2. Physiographic features.
3. Field observations.
4. Different interpretation of Bretz's Spokane Flood.
5. Sketch maps; table describing glacial erratics in Umatilla quadrangle.
6. It may be noted that the writer agrees with Bretz that there was a Spokane Flood, and that the erratics, the scabland, the diversion channels, and certain perched gravel deposits and sidehill rubble heaps are authentic records of it. The writer's interpretation differs from that of Bretz, however, in many particulars, among them: (1) That the distribution of all glacial erratics is definitely assigned to the flood; (2) that erosion by the flood below Wallula Gateway was local and limited in volume; (3) that most of the gravels near Umatilla, Hood River, White Salmon, Lyle, Carson, and Portland are older than the flood; (4) that the flood attained a uniform level from the Wallula Gateway to the Columbia River Gorge through the Cascade Range; (5) that this uniformity and the pebbly silts on the uplands and in tributary valleys record a general ponding of the flood; and especially, (6) that ice, rather than mere volume, was the critical factor in the flood. Accordingly, our conceptions of the flood, and particularly its cause, its mechanics, its geologic effects, its volume, and its duration differ widely. Perhaps this revision will make the idea of such a flood more generally acceptable.

______, 1933. Revision of the Spokane Flood (abs.): Geol. Soc. America Bull., v. 44, no. 1, p. 68.

1. Yakima Valley scablands, Washington.
2. Columbia River basalt and flood deposits.
3. Field observations.
4. See title.
5. ---

6. Steep-walled buttes beside deep, narrow channels in the scabland of Chandler Narrows in Yakima Valley are considered inconsistent with a "gigantic bore" type of flood. Instead, the scabland is better explained as the product of water repeatedly diverted around a growing ice jam. Such diversions present an epitome of the flood on the Columbia plateau.

   New data indicate that the flood rose to a consistently high level from the Wallula Gateway to the Columbia River Gorge through the Cascade Range that it left slack-water deposits both in tributary valleys and on the uplands, and hence was virtually ponded. The writer, therefore, proposes a new version of the flood: that the ponding was produced by a blockade of ice in the Columbia River Gorge, that the rise of the river to abnormally high levels began at the gorge and not on the plateau of eastern Washington, that the blockade gradually grew headward until it extended into eastern Washington, that as the waters were dammed to progressively higher levels they were diverted around the ice and into a succession of routes across secondary drainage divides at increasing altitudes, producing scablands and perched gravel bars along the diversion routes, distributing berg-rafted erratics far and wide, and depositing pebbly silts in slack-water areas. This interpretation does not require a short-lived, catastrophic flood, but explains the scablands, the gravel bars, diversion channels, and divide crossings as the effects of a moderate flow of water, now here and now there, over an extended period of time.

______, 1941, Flint's fill hypothesis of origin of scabland: Jour. Geol., v. 49, no. 1, p. 54-73.

1. Eastern Washington scablands.
2. Scabland features.
3. Field observations.
4. Difference of opinion concerning origin of scabland features as opposed to R. F. Flint's fill hypothesis.
5. Photographs.
6. Flint's fill hypothesis is explanation of the scabland features of eastern Washington, which bases the deposition-excavation sequence upon the rise and decline of glacial Lake Lewis, has the advantage of reducing the events and conditions to terms of streams of moderate size but, nevertheless, has serious shortcomings which make it unacceptable.

These considerations lead us to conclude that Flint's fill hypothesis (1) imposes a task on the eroding streams which requires decidedly abnormal, if not impossible, behavior of the several strands of current; (2) involves a misinterpretation of the ages of certain gravel deposits relative to that of the Touchet beds; (3) fails to consider adequately the rounded and sloping forms of some of the gravel deposits; and (4), as it is not applicable to Wallula Gap and other scabland areas, it is not a general solution of the scabland problem. On the other hand, none of these objections are prejudicial to the idea that these scabland features were developed under conditions of glacial drainage clogged by ice jams.

Baker, V. R., 1971, Paleohydrology of catastrophic Pleistocene flooding in eastern Washington (abs.): Geol. Soc. Am. Abs. with Programs, v. 3, no. 7, p. 497.

1. Eastern Washington.
2. Flood deposit and scour features.
3. Field observations and measurements and mathematical models.
4. See title.
5. --
6. The early Pinedale (22,000 years B.P.) breakout of Glacial Lake Missoula probably involved the largest discharges of fresh water that can be documented in the geologic record. This flood left considerable high-water mark evidence in the form of (1) eroded channel margins, (2) highest flood gravel, (3) minor divide crossings, and (4) ice-rafted erratics. Reconstructed water surface gradients and channel geometry provide input data for the slope-area and contracted-opening hydraulic calculation procedures. Maximum discharges through scabland channels ranged from 752 x 10^6 cubic feet per second in the Rathdrum Prairie to 17.5 x 10^6 cubic feet per second in Rocky Coulee. The flood's duration was probably only a week or two.

   Bed forms produced by the early Pinedale flood are preserved at over 60 locations. Chords for these "giant current ripples" vary from 60 to 425 feet. Mean ripple heights vary from 1.5 to 22 feet. Ripple dimensions correlate to depth, depth-slope product, mean flow velocity, and stream power. Correlation coefficients generally exceed 0.7. Correlation coefficients greater than 0.9 occur for the regressions of ripple chord versus depth-slope and ripple chord versus stream power. These empirical relationships only allow the prediction of hydraulic parameters for the narrow range of flow conditions which characterized the flood reaches containing the giant current ripples.

______, 1973, Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington: Geol. Soc. America Spec. Paper 144, 79 p.; Univ. of Colorado Ph.D. thesis, 152 p.

1. Columbia Plateau, eastern Washington.
2. Flood erosional and depositional features.
3. Field observations and mathematical models of flood discharge rates and volume.
4. Description of flood features, number and time of flood events, and mathematical calculations of sediment transport and flood water volumes.
5. Map of modern and ancient drainage on Columbia Plateau; several stratigraphic sections and water surface profiles.
6. The Missoula floods probably involved the largest discharges of fresh water that can be documented in the geologic record. The Columbia Plateau of eastern Washington contains evidence for flooding in pre-Bull Lake, Bull Lake, and early Pinedale time. Stratigraphic relationships between flood deposits and loess, relict soils on the flood gravel, and radiocarbon dates provide the means for the relative dating of these events.

   The early Pinedale flood was the most extensive and left considerable high-water mark evidence in the form of (1) eroded channel margins, (2) highest flood gravel, (3) minor divide crossings, and (4) ice-rafted erratics. The water surface gradients and channel geometry provide input data for the slope-area and contracted-opening hydraulic calculation procedures. Maximum discharges through scabland channels ranged from 752 x 10^6 cubic feet per second in the Rathdrum Prairie to 17.5 x 10^6 cubic feet per second in Rocky Coulee. At these discharges, the ponding of flood water by the Wallula Gap constriction required about a day. The flood's duration was amazingly short. Even with gradually waning flows, the early Pinedale flood probably only lasted a week or two.

   The competence of the scabland flood flows is best expressed in terms of critical tractive force or dimensionless shear (Shields' Parameter). Competence is difficult to express in terms of velocity because of the problem of relating the mean velocity predicted by the hydraulic formulae to the competent bottom velocity responsible for boulder movement. Boulders, which moved through constrictions, such as Lenore Canyon, were probably put into a state of quasi-suspension by kolks.

The Greenacres reach, near Spokane, provides the closest approximation to an "alluvial reach," required for the Einstein bedload calculation. The predicted unit rate of sediment transport, 3300 lbs/sec/ft-width, is probably too high. This may arise because the laboratory flume studies, on which the Einstein procedure is based, cannot be adequately extrapolated to the huge depth-to-grain-size ratios which characterized the scabland channel geometries.

Flood sediments occur as channel deposits and slackwater deposits. The channel deposits include three main types:

1) Pendant bars - streamlined mounds of relatively well-sorted, foreset-bedded flood gravel; often associated with giant current ripples.
2) Eddy bars - mounds of poorly-sorted flood debris deposited by eddies which formed in alcoves and tributary mouths.
3) Expansion bars - foreset-bedded gravels deposited by the decelerating flows just downstreamm from a constriction; often showing armoring and scour features.

The slackwater deposits occur as a sequence of silts and sands in valley-tributary to the main scabland channels. Slackwater deposits in the Tucannon River alley show primary sedimentary structures which suggest deposition by turbidity flows initiated by transient surges up the tributary valley.

60 trains of giant current ripples are recognized in the study area. Mean ripple chords vary from 60 to 425 feet. Mean ripple heights vary from 1.5 to 22 feet. Ripple dimensions correlate to depth, depth-slope product, maximum size of armor, mean flow velocity, and stream power. Correlation coefficients generally exceed 0.7. Correlation coefficients greater than 0.9 for the regressions of ripple chord versus depth-slope and ripple chord versus stream power. These empirical relationships only allow the prediction of hydraulic parameters for the narrow range of flow conditions which characterized the flood reaches containing the giant current ripples.

______, 1974, Erosional forms and processes for the catastrophic Pleistocene Missoula floods in eastern Washington: In Morisawa, Marie, ed., Fluvial Geomorphology: Binghamton, New York, State Univ. Publ. in Geomorphology, p. 123-148.

Baker, V. R.; Patton, P. C., 1976, Missoula flooding in the Cheney-Palouse scabland tract: Terrestrial analogue to the channeled terrain of Mars? (abs.): Geol. Soc. America Abs. with Programs, v. 8, no. 3, p. 351-352.

1. Cheney-Palouse area, eastern Washington.
2. Flood deposits, loess, and calcic horizons; scour features in basalt.
3. Field observation.
4. See title.
5. --
6. At least two episodes of catastrophic Pleistocene flooding are recorded in the Cheney-Palouse scabland tract. An older flood gravel is everywhere capped by brown loess (Palouse Formation) on which is developed a 30-60 cm petrocalcic horizon. The gravel contains boulders of deep red loess stained by manganese dioxide (pre-Bull Lake loess). At Marengo this gravel is covered by three loess units, each separated by calcic horizons, which are overlain by flood gravel of the last catastrophic flood (approximately 18,000-20,000 years B.P.; early Pinedale Stade).

   Flood erosion and deposition by the early Pinedale event were largely determined by the locations of residual loess "islands" within the main flood channel. Irregular scabland was produced by scour in constricted reaches between the islands, and deposition, often as pendant bars and giant current ripples, was favored in channel expansions. Sizes of macroturbulently transported boulders decrease rapidly (1) downstream from resistant basalt ledges, (2) laterally toward the margins of a channel, and (3) in the lee of loess islands, which have depositional "tails" of cobble- to granule-sized material. Relatively smooth, scoured basalt with occasional large basalt blocks (4x3x2.5 m) is common immediately below depositional reaches.

   Mariner 9 imagery of the Chryse Planitia region of Mars shows streamlined forms of striking similarity to the loess islands and pendant bars of the Cheney-Palouse scabland tract. Because the Chryse region is the Viking A prime landing site for summer, 1976, the analogy may actually be tested. If correct, however, localized zones of deposited boulders and

scabland scour would pose a hazard to the delicate Viking lander.

______, 1978, New evidence for pre-Wisconsin flooding in the channeled scabland of eastern Washington: Geology, v. 6, p. 567-571.

1. Cheney-Palouse area, eastern Washington.
2. Flood gravel, loess.
3. Field observations.
4. See title.
5. Stratigraphic sections at Old Maid Coulee, Marengo, MaCall, and Revere.
6. Flood-gravel deposits capped by loess sequences that display well-developed argillic, calcic, and petrocalcic paleosols indicate pre-Wisconsin catastrophic flooding in the Cheney-Palouse tract of the channeled scabland, eastern Washington. The most complete stratigraphic exposure reveals two flood-gravel units, one of pre-Wisconsin age and the other representing the last major phase of scabland flooding (late Wisconsin). The two gravel units are separated by three loess units. Each period of loess deposition was followed by a soil-forming interval. The older of the two flood-gravel units contains cobbles of an early pre-Palouse Formation (that is, pre-Bull Lake) loess. It is capped by a loess unit displaying superimposed argillic and petrocalcic soil horizons. Above the petrocalcic horizon are two younger layers of loess (the Palouse Formation), each of which displays a paleosol having a weakly developed argillic B horizon and a calcic C horizon. These units are overlain by gravel from the last major phase of scabland flooding, which is, in turn, overlain by late Wisconsin and Holocene loess. The earliest flood probably carved part of the Cheney-Palouse scabland morphology during a glaciation prior to that responsible for the Palouse Formation.

Baker, V. R.; Nummedal, D., 1978, The channeled scabland: a guide to the geomorphology of the Columbia Basin, Washington: Prepared for the Comparative Geology Field Conference in the Columbia Basin, June 5-8, 1978, for Planetary Geology Program, National Aeronautics and Space Administration, 186 p., illus.

Baker, V. R., 1979, The Spokane Flood controversy and the Martian outflow channels: Science, v. 202, no. 4374, p. 1249-1256.

1. Columbia Plateau, eastern Washington.

2. Missoula flood erosional and depositional features.
3., & 4. Description of Missoula flood and comparison of flood topography to that of Mars.
5. Geomorphic map of portion of Martian surface; map showing regional pattern of Scabland as mapped from orbital photographs.
6. In a series of papers published between 1923 and 1932, J H. Bretz described an enormous plexus of proglacial stream channels eroded into the loess and basalt of the Columbia Plateau, eastern Washington. He argued that this region, which he called the Channeled Scabland, was the product of a cataclysmic flood, which he called the Spokane flood. Considering the nature and vehemence of the opposition to his hypothesis, which was considered outrageous, its eventual scientific verification constitutes one of the most fascinating episodes in the history of modern science. The discovery of probable catastrophic flood channels on Mars has given new relevance to Bretz's insights.

Booth, C., 1971, An investigation of sedimentary stratigraphy near Lamona, Washington, and its relation to the Bretz hypothesis for the development of the channeled scabland topography of the Columbia Plateau (abs.): Assoc. Pacific Coast Geographers Yearbook, v. 33, p. 176.

1. Eastern Washington.
2. Catastrophic flood deposits, marsh sediments, ash.
3. Trenching enclosed basin, dating.
4. Organic material, working out stratigraphy.
5. --
6. Stratigraphy uncovered by an exploratory trench excavated in a small enclosed basin within the Channeled Scablands yields additional data for the elucidation of the geomorphic history of the Scablands which was postulated by J H. Bretz.

   Both dateable organic deposition (dates pending) and the stratigraphic position of two ash layers believed to be Mazama (6,700 B.P.) and Glacier Peak (12,000 B.P.) exposed in the trench lend significance to the entire stratigraphic sequence as an interpretative element for the late Quaternary history of the region.

   The Lamona Trench stratigraphy may be significant archeologically in that it contains dateable strata with a potential of being older than 12,000 years--contiguous to a probable site of antiquity --a rarity on the Columbia Plateau. It is geographically significant in that it is supplemental to

the geomorphic history of the Channeled Scablands in late Quaternary time.

Bretz, J H., 1923, The channeled scablands of the Columbia Plateau: Jour. Geol., v. 31, p. 617-649.

1. Columbia Plateau, eastern Washington.
2. Catastrophic flood deposits.
3. Field observations.
4. Nature and origin of scablands.
5. Map of the channeled scablands and their associated features.
6. Article describes physiographic relations of scablands and gives a generalized statement of their origin. Gives description of basalt plains north of the scablands and the mature topography. Details scabland surface and gives altitudes and gradients of the scabland tracts. Discusses the depth of glacial stream erosion and the volume of and deposits made by the glacial streams. The depths of the Snake and Columbia River Valleys during the epoch is reviewed. Describes evidence for Spokane glaciation and its effect on the Columbia Plateau.

______, 1925, The Spokane Flood beyond the channeled scablands: Jour. Geol., v. 33, no. 2, p. 97-115; no. 3, p. 236-259, 17 figures: (abs.) Pan-American Geol., v. 43, no. 2, p. 146, 1925.

1. Columbia Plateau, Washington.
2. Channeled scablands physiographic features.
3. Field observations.
4. Field evidence for flood dimensions at Wallula Gap and beyond.
5. --
6. Channeled scablands of the Columbia Plateau, in Washington, are extensive, elongate, denuded tracts of basalt, deeply scored by huge, high gradient, glacier-born rivers. As physiographic features, the scablands are unique, as were the conditions which produced them.

   Field evidences indicate that the Columbia River Valley, below the confluence of Snake River, carried a flood which at Wallula Gateway was 2 miles wide and reached 750 feet above present river-level, and at Portland was nearly 20 miles wide and 350 feet above present river-level.

______, 1927, Channeled scabland and the Spokane Flood (abs. with discussion): Wash. Acad. Sci. Jour., v. 17, no. 8, p. 200-211.

1. Eastern Washington.
2. Erosional and depositional landforms.
3. Field observations.
4. Interpretation of landforms as result of catastrophic Spokane Flood.
5. --
6. Bretz hypothesizes the origin of the scabland tracts and then summarizes the more significant features and relationships: (1) Canyons of the scabland including rock basins in canyons, plexus groupings of canyons and cataracts; (2) areas surrounded by channeled scabland tracts including aligned scarps of loess facing scablands and small isolated loessial hills on the scabland; (3) trenched divides; (4) deposits of the scabland and in Snake and Columbia valleys including gravel bar forms, deltaic bars, and Quincy basin; (5) anastomosis of entire scabland tract on Plateau; (6) Wallula Gateway high-level scabland; (7) Columbia Valley below Wallula Gateway including Portland delta and bars in mouths of tributaries.

   Discussions by W. C. Alden, J. Gilluly, E. T. McKnight, G. R. Mansfield, D. E. Meinzer, and J. T. Pardee. Bretz replies to discussion.

______, 1927, The Spokane Flood; a reply (origin of physiographic features, Washington): Jour. Geology, v. 35, no. 5, p. 461-468.

1. Eastern Washington.
2. Ringold Formation and flood erosional and depositional features.
3. Field observations.
4. See title.
5. --
6. Reply to McKnight's discussion of the Spokane Flood including several criticisms and new field evidence.

______, 1927, What caused the Spokane Flood? (abs.): Geol. Soc. America Bull., v. 38, no. 1, p. 107; Pan-American Geologist, v. 47, no. 1, p. 64, 1927.

1. Columbia, Plateau, Washington.
2. Channeled scablands, flood gravel deposits.
3. Field observations.
4. Theoretical hypothesis for basalt flows underlying

glacial ice as cause of Spokane Flood.
5. --
6. New data will be presented on the distribution and character of channeled scabland and associated gravel deposits on the Columbia Plateau. They indicate that the Spokane Flood was an even greater affair than previously thought. Studies in Washington and British Columbia north of the scabland strongly suggest that basaltic flows which were extruded beneath the Cordilleran ice sheet produced the great flood. The field has not yet been sufficiently studied to justify a definite affirmative. The paper is a report of progress in following up a promising clue.

______, 1928, Alternative hypotheses for channeled scabland, Part I and II: Jour. Geol., v. 36, no. 3, p. 193-223, 6 figs.; no. 4, p. 312-341, 4 figs.

1. Columbia Plateau, Washington.
2. Scabland features.
3. Field observations.
4. See title.
5. --
6. This paper begins with a summary statement of the features of scabland and of the writer's explanation of their origin. In the body of the paper, various criticisms and suggestions are considered on the light of significant field data. Revision of some of the writer's ideas is indicated. The second half of the paper deals with the question of simultaneous development of all channels of the scabland pattern and with proposed tests of the writer's hypothesis.

______, 1928, Bars of channeled scabland (abs.): Geol. Soc. America Bull., v. 39, p. 643-701. F-1-174, H-198

1. Columbia Plateau, Washington.
2. Gravel deposits of abandoned channels.
3. Field observations.
4. Evidence to substantiate origin of bars.
5. --
6. The noteworthy denudation of limited tracts on the Columbia Plateau in Washington, confined to an extraordinary anastomosing pattern, is the product of glacial streams of high gradient. Descriptions already published indicate that these streams operated under very unusual conditions. This paper is an attempt to portray the gravel deposits of the abandoned channels with sufficient definiteness to show that they can be explained only as

stream-bars. If this explanation be accepted, the magnitude, composition, and topographic setting of these deposits lead unavoidably to the conclusion that the streams far transcended in volume any other known glacial dischargeways.

______, 1928, The channeled scabland of eastern Washington: Geog. Rev., v. 18, no. 3, p. 446-477, 27 figs., map.

1. Columbia Plateau, Washington.
2. Scabland features.
3. Field observations.
4. See title.
5. Geologic sketch map of Potholes Cataract and Drumheller Channels; hypsometric map of Drumheller Channels.
6. It is difficult to convey by words and pictures a visualization of the observable relationships of channeled scabland. Such terms as "canyon," "cataract," "scarp," "gravel deposit," calling up images of the usual topographic forms, suggest the usual explanation, which involves far less water and far more time than the writer's hypothesis demands. Put a glacial Columbia first in one channel, then in another, then in a third, instead of running all of them at the same time; use more than one glacial episode if necessary; upwarp the transected divides to give the present high altitudes above valley floors. Procedures such as described here are unheard of. Other ice sheets have come and gone and left no such record. How could such quantities of water be yielded from so small a front and with so little retreat?

   It may be that there are other significant facts yet to be discovered. But the writer is convinced that the relations outlined in this paper do exist and that no alternatives yet proposed by others or devised by himself can explain them.

   That unique assemblage of remarkable physiographic forms on the Columbia Plateau in Washington, described here as the channeled scabland system or complex, records a unique episode in Pleistocene history. Special causes seem clearly indicated. But what these causes were is yet an unsolved problem.

______, 1929, Valley deposits immediately east of the channeled scabland of Washington, I and II: Jour. Geology, v. 37, p. 393-541.

1. Eastern Washington.
2. Missoula flood erosional and depositional features.
3. Field investigations.
4. See title.
5. Map showing valleys east of channeled scablands.
6. Forty-one valleys whose drainage enters the eastern margin of scabland spillways are known to contain deposits made by glacial waters. Thirty-nine of these valleys never have carried drainage from glaciated areas, and the glacial waters in them must have been backed up from the scabland. These deposits possess such extraordinary features and relations that they, like the scabland topoghraphic forms, are considered unique.

   1) Each separate area of backwater is recorded by a widespread mantle of silt containing abundant grains of unweathered basalt (the country rock) and pebbles of foreign rock.
   2) In each, this mantle extends up to a definite upper limit on the valley slopes and along the valley lengths.
   3) These upper limits in each case agree closely with the upper limit of scabland where the valley enters.
   4) The altitudes of the upper limits, constant throughout any one backwater area, vary with different pondings, forming a descending series from north to south along the scabland gradient.
   5) Remarkable large mounded gravel deposits in the tributary valley debouchures possess foreset strata which dip <u>out</u> of the scabland and <u>up</u> the valleys. The composition, topography, topographical relations, structure, and size of these deposits are inexplicable without great <u>reverse currents</u>.
   6) In no case could these reverse currents continue through and escape from the valleys they entered. They are simply a record of the rapid backflow into these valleys.

   It is concluded that these glacio-aqueous deposits cannot be explained by conditions associated with ordinary glacial ablation or by a sequence of several Pleistocene epochs. They require the volume and rapid rise of glacial rivers across the plateau, which the writer has previously read from the scabland itself.

______, 1930, Lake Missoula and the Spokane Flood (abs.): Geol. Soc. America Bull., v. 41, no. 1, p. 92-93.

1. Eastern Washington.

2. Flood deposit and scour features.
3. Field observations.
4. See title.
5. --
6. It is suggested that bursting of an ice-barrier, which confined a large glacial lake among the mountains of western Montana, suddenly released very great volumes of water which escaped across the plateau of eastern Washington and eroded the channeled scablands. There is very little field evidence which can be interpreted as a record of such escaping waters between the lake basin and the scabland channels.

______, 1930, Relation of Yakima Valley to the channeled scabland (abs.): Geol. Soc. America Bull., v. 41, no. 1, p. 93.

1. Yakima Valley, Washington.
2. Scabland flood features.
3. Field observations.
4. Relationship of Yakima Valley to scabland flooding.
5. --
6. Yakima River enters Columbia River near the southern and lower limit of the plateau scabland. Yakima Valley is a group of structural depressions connected structurally or by short canyons across separating upfolds. The convergence of two anticlinal folds produces a noteworthy narrowing of the valley just above its junction with the Columbia. Glacial silts and berg-transported erratics occur throughout this valley up to 1,100 feet A. T. The maximum depth of the water recorded was 600 feet. Evidence will be presented to show that the water was backed up the Yakima from the scabland, that in the narrows near the mouth it possessed tremendous current up the valley floor gradient and that much of the erratic material came from the Rocky Mountains in northern Montana and Idaho.

______, 1932, History of Grand Coulee: Pan-American Geologist, v. 58, no. 2, p. 158-159.

1. Grand Coulee, Washington.
2. Scabland flood scour features.
3. Field investigations.
4. See title.
5. ---
6. Dry Falls is part of much larger cataract with five member falls with collective width of 3 1/8 miles. Castle Lake, 1 mile south of Coulee City,

is a member. An ancient Upper Grand Coulee cataract, contemporaneous with other members, 4 miles north of Coulee City, retreated through Waterville Plateau until it destroyed itself, creating Upper Coulee. It possessed a dozen smaller lateral falls through the 30 miles of recession; they are now abandoned and hang on the margins of the Upper Coulee as Northrup and Barker Canyons, Martin Falls, and Hubbard Creek. Upper Coulee floor is a series of shallow basins lying in an elongate plunge pool eroded 20 feet below present floor. Width of gorge cut by receding waterfall determined by width of fall itself. Upper coulee is 2 miles wide at southern and northern extremes. In vicinity of Steamboat Rock, it widens to 5 miles, an expression of greatest discharge during the Spokane Flood. The flood was preceded and followed by normal glacial Columbia River. During flood, Steamboat Falls (now gone) was 5 miles wide and 900 feet tall and eroded a plunge pool 200 feet deep. Lower Grand Coulee lies in a "coulee monocline" of tilted basalt. Preglacial Lower Coulee was 1 mile east of Lake Lenore, but 200-400 feet higher. It was occupied by glacial Columbia River while Upper Coulee was being developed by cataract recession. With Spokane Flood, preglacial route was overflooded so that torrents attacked monoclinal basalt. With its greater weakness, the deepest place in the flood channel was developed. When the flood subsided, the normal glacial Columbia River abandoned its former Lower Coulee course and located where Lake Lenore now lies. Dry Falls took origin near head of Park Lake and are a product of glacial Columbia River after flood subsided.

______, 1932, Channeled scabland: 16th Internat. geol. cong. guidebook 22. B-13

1. Eastern Washington.
2. Columbia River Basalt.
3. --
4. Annotated guidebook for the scabland and Grand Coulee.
5. Geologic map of Grand Coulee, Washington; diagrammatic representation of channeled scabland and glacial lakes Missoula and Coeur D'Alene.
6. General description of geologic history of Columbia Plateau, Washington with annotated guide to: Great cataract group at head of lower Grand Coulee; Lower Grand Coulee; Coulee monocline and

cliff summit west of Lake Lenore; Quincy Basin near Ephrata; Scabland and bars (?) of Crab Creek; Scabland and distributary canyons east of lower Grand Coulee; Hartline Basin scabland and gravel; Scabland and bars of High Hill anticline; upper Grand Coulee; Route to Spokane over Sunset Highway.

______, 1932, The Grand Coulee: American Geog. Soc. Spec. Publ. 15, 89 p.

Bretz, J H.; Smith, H. T. U.; Neff, G. E., 1956, Channeled scabland of Washington: New data and interpretations: Geol. Soc. America Bull., v. 67, no. 8, p. 957-1059. Plate 1, 1:506,880. B-31

1. Columbia Plateau, Washington.
2. Scabland erosional and depositional features.
3. Field observation, topographic map interpretation.
4. See title.
5. Map of channeled scabland of eastern Washington; map of Trail Lake anticline and vicinity; map of main portion of Quincy Basin; map of Moses Lake and vicinity; topographic map and profiles across Drumheller Channels; map of bars in upper Crab Creek valley; profiles of scabland on Palouse-Snake divide; map of Glacial Lake Missoula and channeled scabland.
6. The existence of four different interpretations of that extraordinary assemblage of erosional and depositional land forms of eastern Washington, the "Channeled Scabland," indicates that rigorously definitive diagnostic characters had not been found. This study, dealing with new data, largely from extensive excavations and detailed topographic maps made by the U.S. Bureau of Reclamation in developing the great Columbia Basin Irrigation Project, returns to the earliest of the four interpretations: that channeled scabland is almost wholly the consequence of catastrophic flooding of glacial water across this part of the Columbia Plateau which remade preglacial valleys into an anastomosing complex of great river channels with huge cataracts, deep rock basins, and bars attaining magnitudes unknown elsewhere on earth.

   The new evidence is held to establish firmly the following points:
   (1) Some structural basins of the region did not have exterior drainage prior to arrival of glacial water.

(2) The gravel hills called bars by Bretz (1928a) have the shapes, surface markings, structures, and topographic situations possible only for subfluvial constructional deposits. In magnitudes and bouldery composition they are sui generis.
(3) Several episodes of catastrophic discharge have occurred across this part of the Columbia Plateau.
(4) The Columbia Valley skirting the plateau has had comparable floods in which the scabland complex did not share.
(5) Successive floods have been differentiated only by topographic relations of their records, not by differential weathering and erosion.
(6) Bretz did not overestimate the magnitude of the erosion by glacial waters.
(7) The existing scabland features contradict the three later interpretations.

Bretz, J H., 1959, Washington's channeled scablands: Washington Div. Mines and Geology Bull. 45, 57 p. Plate 1, 1:570,240; Plate 3, 1:342,144.

1. Eastern Washington.
2. Scabland flood erosional and depositional features.
3. Field observations.
4. Documentation of flood hypothesis.
5. Physiographic diagram of scablands; block diagram and map of great cataract group in Hartline basin; topographic map of Potholes Cataract; Quincy Basin distributary channels; sketch map of region at mouth of Palouse River; cross section through Shoulder Bar (mouth Palouse River); map of Glacial Lake Missoula and channeled scabland; plates of channeled scabland, Dry Falls system, Grand Coulee and upper Crab Creek valley.
6. A summary of results of Bretz' many years of study on channeled scabland. Includes 8 general features of channeled scabland, Grand Coulee, Quincy Basin and its outlets, Lower Crab Creek, and Othello Channels, Moses Coulee, Upper Crab Creek, Cheney-Palouse Scabland tract, and Pasco Basin.

______, 1969, The Lake Missoula floods and the channeled scabland: Jour. Geology, v. 77, no. 5, p. 505-543.

1. Columbia Plateau, Washington.
2. Scabland erosional and depositional features.
3. Field investigations and measurements.
4. Review of evidence for scabland flood behavior.
5. Map of glaciated and flooded areas on Columbia

Plateau; outline map of Lake Missoula; map of giant current ripples north of Plains, Montana; table of tentative correlations of events in Grand Coulee System; map of the Narrows, Oregon and environs; structural features involved in history of Grand Coulee floods.

6. This paper reviews the outstanding evidence for (1) repeated catastrophic outbursts of Montana's glacially dammed Lake Missoula, (2) consequent overwhelming in many places of the preglacial divide along the northern margin of the Columbia Plateau in Washington, (3) remaking of the plateau's preglacial drainage pattern into an anastomosing complex of floodwater channels (Channeled Scabland) locally eroded hundreds of feet into underlying basalt, (4) convergence of these flood-born rivers into the Columbia Valley at least as far as Portland, Oregon, and (5) deposition of a huge delta at Portland. Evidence that the major scabland rivers and the flooded Columbia were hundreds of feet deep exists in (1) gravel and boulder bars more than 100 feet high in mid-channels, (2) subfluvial cataract cliffs, alcoves, and plunge pools hundreds of feet in vertical dimension, (3) back-flooded silts high on slopes of preglacial valleys tributary to the scabland complex, and (4) the delta at Portland. Climatic oscillations of the Cordilleran Ice Sheet produced a succession of Lake Missoulas. Following studies by the writer, later investigators have correlated the Montana glacial record with recurrent scabland floods by soil profiles and a glacial and loessial stratigraphy, and have approximately dated some events by volcanic ash layers, peat deposits, and an archaeological site. Several unsolved problems are outlined in this paper.

Brown, D. J., 1965, The flood that changed the face of Hanford: Hanford Project news 1:14.

1. Pasco Basin, Washington.
2. Ringold Formation, catastrophic flood deposits, dune sand.
3. & 4. Popular account of Missoula flood.
5. Block diagrams of Hanford area showing evolution of landscapes.
6. Popular account of development of landscapes around Hanford works in last 20,000 years. Mostly discusses catastrophic Missoula flood.

Brown, R. E., 1973, The Glacial Lake Missoula floods in the Pasco Basin (abs.): Northwest Scientific Association Abstracts of Papers presented at the 46th annual meeting, p. 6.

1. Pasco Basin, Washington.
2. Flood sediments, tephra, scour features.
3. Field observations.
4. Sedimentary record of scabland flooding.
5. ---
6. The Pasco Basin contains a complete but unappreciated sedimentary record of the Glacial Lake Missoula and related floods.

   The oldest floods pre-date 45,000 years. Minor floods preceded a gigantic flood of probably 18-20,000 years ago. Scouring was followed by a flood crest to about 1200 feet altitude and deposition of distinctive sediments. The Glacier Peak ash lies within deposits of a later flood that peaked at about 900 feet altitude.

   Terrace remnants and alluvial plains, correlated to the flood deposits, identify periodic basin fill levels. Erosion and shifting of the Columbia River in the last 12,000 years is identifiable.

______, 1975, Groundwater and the deposits of the Glacial Lake Missoula floods in the Pasco Basin: EOS (Am. Geophys. Union, Trans.), v. 56, no. 8, p. 532.

1. Pasco Basin, Washington.
2. Pasco gravels, Ringold Formation, Columbia River basalts, Touchet beds.
3. Explanation of irrigation techniques in terms of geological history of basin.
4. Discussion of geological knowledge required to develop irrigation in Pasco Basin.
5. ---
6. Irrigation development of the Pasco Basin requires geological knowledge to degrees not earlier needed. Low to moderate permeability of the basalt and Ringold Formation respectively leaves only the Pasco gravels (coarse flood deposits) as high yield aquifers. Knowledge of the sites and extent of erosion and deposition, and altitudes of deposits are vital in planning but are ignored by most. Best irrigation wells lie in the basin center where basalt and the Ringold Formation were downfolded and the Ringold Formation was scoured then buried by the graded Pasco gravels. Outward, yields decrease and coulees provide the major

supplies. Locally coulees are filled with Touchet beds (fine-graded deposits) but buried alluvial fans provide water. Drainage problems in west Pasco formed where subsurface scour channels lie athwart groundwater flow paths and groundwater levels are rising owing to extensive use of Columbia River water. An industrial disposal site was sited at an optimum location with regard to irrigation, groundwater flow paths and protection of domestic wells. A sewage lagoon, constructed without due regard for the nature of the deposits, leaked and contaminated numerous domestic wells.

Easterbrook, D. J.; Baker, V. R.; Waitt, R. B., 1977, Glaciation and catastrophic flooding of the Columbia Plateau, Washington (Field Trip No. 13). In Geological Excursions in the Pacific Northwest: Geol. Soc. America 1977 Annual Meeting, Seattle, Washington, p. 390-414.

(Annotated under Sedimentary Units section)

Flint, R. F., 1938, Origin of the Cheney-Palouse Scabland Tract, Washington: Geol. Soc. America Bull., v. 49, no. 3, p. 461-563; (abs.) Geol. Soc. America Proceedings 1936, p. 72, June 1937. F-1-170, F-2-170

1. Columbia Plateau, Washington.
2. Scabland erosional and depositional features.
3. Field observations and measurements.
4. Opposing view of Bretz: origin of Cheney-Palouse Scabland Tract.
5. ---
6. Flint's thesis on scabland channels is that it can be explained by normal erosion rather than cataclysmic flood. Gives the order of events by Flint. Discusses scabland sediment in terms of grain size, sorting, etc. Riparia Lake on Snake River is discussed, as are Touchet beds. Summary and conclusions follow:

   The order of events inferred from the features of the Cheney-Palouse Tract and the Pasco Basin may be summarized as follows:

   (1) Advance of glacier ice lobes across the Spokane-Columbia canyon at the northern margin of the plateau, to the divide between drainage north to the canyon and drainage south on the plateau. If the Okanogan lobe or the Columbia lobe (Flint, 1936; 1937) reached the plateau before the Little Spokane Lobe, a lake may have been formed in the canyon, and an overflow

spill established down the Cheney-Palouse Tract, before the encroachment of actual glacier ice south of the divide.

(2) Occupation of preglacial valleys and erosion of basalt in them, by the melt-water flow.

(3) Rise of Lake Lewis in the Pasco Basin, causing aggradation in the tributary valleys to form a thick fill, growing vertically upward and also headward.

(4) Cutting of Palouse scarps by lateral planation and development of lateral distributaries from the principal routes as the streams rose on their own fills. Sedimentation in Lake Lewis, progressively overlapping stream deposits in the mouths of tributaries.

(5) Draining of Lake Lewis, accompanied by progressive dissection of the fill into cut terraces, together with the cutting of more Palouse scarps and terraces and the erosion of more basalt, chiefly by stream channels superposed from the fill. Offlap deposits built into receding Lake Lewis, most of this secondary sediment later eroded and carried off down the Columbia.

(6) Backwasting of the glacier ice margin beyond the divide in the Spokane district, shutting off the supply of melt water and causing the Cheney-Palouse Tract to run dry except for the through drainage of the modern Palouse River-lower Snake River system.

(7) During the whole sequence of events, showers of volcanic ash fell at many different times, and the ash was incorporated in the growing fill, and in the deposits of Lake Lewis and the Riparia Lake.

A hypothesis of filling followed by dissection demands no more than one glaciation for the general development of such a scabland tract, but certain features brought out in this discussion seem to indicate that more than one glaciation, with melt-water flow, did, in fact, control the evolution of the Cheney-Palouse Tract. The key to the latest fill in the tract is Lake Lewis. If this water body had not come into existence, temporarily providing an abnormally high base level, the glacial record in the scabland tract probably would have consisted of thinner fill in the form of a valley train, slightly dissected by post-glacial streams, instead of a thick fill greatly dissected by melt-water streams.

Again, if Lake Lewis had maintained its high level until after the withdrawal of the glacier ice from the area south of Spokane, the fill would still be essentially non-dissected, except in Snake River canyon, and would form broad valley floors contrasting little with the adjacent surface of the "Palouse soil."

Foley, L. L., 1976, Slackwater sediments in the Alpowa Creek drainage, Washington: Washington State Univ. M.A. thesis.

(Annotated under Sedimentary Units section)

Freeman, O. W., 1926, Scabland mounds of eastern Washington: Science, new ser., v. 64, p. 450-451.

1. Columbia Plateau, Washington.
2. Loess-like mounds on Columbia River Basalt.
3. Field observations.
4. Size, occurrence, and origin of scabland mounds.
5. ---
6. On the channeled scablands of eastern Washington are found thousands of nearly circular mounds composed of different material than would be formed from the weathering of the basalt that is the chief bedrock of this region. The mounds only occur on top of the bare basaltic rock of the Columbia Plateau. They never occur on granite, schists or quartzite that occasionally outcrops. Neither do they occur on the loessial hills of Palouse soil or in peat swamps scattered through the scablands.

   Careful measurements failed to show any greater elongation in one direction than another. The highest point of the mounds is the center. The mounds are of all sizes, from a few feet across to over one hundred feet and average around thirty to forty feet in diameter. They rarely exceed three or four feet in height above the scabrock. The material appears to have been brought in from elsewhere and deposited by the wind, the source was probably the soft lake beds of the Ellensburg Formation of south-central Washington and the finest outwash material of the glacial period. They practically without exception occur above a depression in the basalt, sometimes shallow, making the cross-section of a mound lens-like; in other cases it has steep sides like a pothole. In either case the basalt under the mound is very little weathered and makes a sharp contact with the mound. Such weathering as occurred resulted in chipping off small fragments of the basalt from the sides of the depression which are scattered through some of the mounds, chiefly in their lower part.

The work of Bretz on the channeled scablands shows that the Spokane flood from a rapidly melting ice sheet removed the surface soil from the basalt and by the suction of the swirling torrent plucked out from the stream beds great chunks of the jointed lava, leaving its surface in a highly pitted condition. We only find the mounds in places where the basalt's surface contains depressions. The mounds are found in the midst of level areas, on the sides of hills, at the edge of rock terraces and even on top of small isolated hills of basalt. They occur both in the timbered and treeless parts of the scablands. In fact, they may occur anywhere on the bare basaltic rock and never elsewhere in this region. In the bottom of the depression there may be gravel and a few boulders washed in by the Spokane flood and some chips of basalt from the weathering of the sides; aside from this the depression is filled with the loess that composes the mound that rises above it. Some of the depressions are shallow with gentle slopes, others are many feet deep with steep sides.

Apparently at the close of the Spokane flood the basaltic lava was left with a decidedly pitted surface, the depressions of which had about the same dimensions in various directions. Sediment accumulated first in such depressions. Vegetation started growing on the sediment and retained the wind-blown material until the entire depression was surrounded and surmounted by a mound. The fine material of the mounds holds moisture better than the scabrock and the depression beneath is a storehouse of moisture which helps to promote a vigorous plant growth. It seems probable that the mounds were chiefly formed soon after the glacial period, although the much more luxuriant growth of grass on them to day than that on the bare basalt would permit additional wind-blown material to be caught and retained. Mounds have been reported outside the channeled scablands on the basalt of the Columbia Plateau but have not been examined by the writer.

______, 1933, Origin and economic value of the scabland mounds of eastern Washington: Northwest Sci., v. 6, no. 2, p. 37-40.

1. Eastern Washington.
2. Scabland mounds (volcanic ash on basalt depressions).
3. Field observations.
4. See title.
5. ---
6. Tens of thousands of mounds occur in scablands. Mounds are stationary and oval elongated downslope, without regard to wind direction. Diameter from few to a hundred feet. Elevation from few inches to 4 feet. Occur in depressions above basalt material and are composed of volcanic ash. Scabland flooding pitted surface of basalt bedrock by the plucking action of running water. Depressions contained clay, sand, gravel, and basalt chips after water disappeared. Sediments in depressions provided place for first vegetation to grow after flooding. After flood a layer of ash covered eastern Washington. Vegetation in depressions pushed through ash and protected it from erosion. Wind also helped accumulate ash around plants and into depressions. Areas between pits couldn't retain ash so that it was swept away.

   Comments on effect of mounds on agriculture and economics of eastern Washington.

______, 1937, Grand Coulee and neighboring geological wonders: Published by O. W. Freeman, Cheney, Wash., 20 p.

Fryxell, R., 1962, A radiocarbon limiting date for scabland flooding: Northwest Sci., v. 36, no. 4, p. 113-119.

1. Wanapum Dam, eastern Washington.
2. Datable material in scabland flood gravels.
3. C^{14} dating.
4. See title.
5. ---
6. Radiocarbon dating of organic material collected from scabland flood gravel at Wanapum Dam as 32,700±900 years B. P. represents the first available carbon-14 date for glacial chronology in eastern Washington. This figure represents the age of interstadial organic material picked up and redeposited by catastrophic discharge into the Columbia River over Frenchman Springs cataract before the furthest advance of the Okanogan lobe, and thus provides a maximum limiting date for late Wisconsin scabland flooding.

Fryxell, R.; Cook, E. F., 1964, A field guide to the loess deposits and channeled scablands of the Palouse area, eastern Washington: Washington State Univ. Lab. Anthropology, Rept. Inv. 27, 32 p.

1. Eastern Washington.
2. Loess deposits and scabland features.
3. Description of observations made on field trip.
4. See title.
5. Stratigraphy and physiographic distribution of eolian deposits in eastern Washington; map of aligned topography in southwest Palouse; block diagrams showing evolution of ideal scabland tracts and schematic geoarchaeological chronology for eastern Washington.
6. Field trip guide to eastern Washington taking in topics such as: origin of Palouse loess, southern extent of Pleistocene glaciation, chronology of Pleistocene events, and the origin of the channeled scablands.

Fryxell, R.; Neff, G. E., 1965, The origin of Grand Coulee. <u>In</u> INQUA, Guidebook for Field Conference E, northern Rocky Mountains: Nebraska Acad. Sci., Lincoln, Nebraska, p. 77-79.

1. Grand Coulee, Washington.
2. Scabland erosional and depositional features.
3. Field observations.
4. Evidence for Pleistocene ice sheet dam across Columbia River as origin of Grand Coulee.
5. Stratigraphy on east wall of Columbia River showing lacustrine, outwash and glacial deposits of two stades of Pinedale glaciation; inferred velocities of Lake Missoula Flood.
6. Discusses formation of the Grand Coulee through glacier and flood action at two stops of the field trip.

Fryxell, R.; Neff, G. E.; Trimble, D. E., 1965, Scabland tracts, loess, soils, and human prehistory. <u>In</u> INQUA, Guidebook for Field Conference E, northern Rocky Mountains: Nebraska Acad. Sci., Lincoln, Nebr., p. 79-89.

1. Columbia Plateau.
2. See title.
3. Field observation.
4. See title.
5. Stratigraphy of loess deposits and buried soils in central Columbia Basin; correlation of post-glacial climatic events with stratigraphy and

cultural sequence at Marmes Rock Shelter; precipitation, vegetation, soils map for Columbia Plateau; cross-section showing loess, soils and vegetation relationships in Palouse Hills.

6. Discusses stratigraphic relationships, distribution, and formation of various scablands, loesses, and soils between Ephrata and Pullman. Mentions Marmes Rock Shelter, human occupation, dating, and climatic conditions recorded.

Hanson, L. G., 1970, The origin and development of Moses Coulee and other scabland features on the Waterville Plateau, Washington: Univ. Washington Ph.D. thesis, 137 p. A-3

1. Moses Coulee, Waterville Plateau, Washington.
2. Catastrophic flood erosional and depositional features.
3. Field observations.
4. See title.
5. Map showing principal relief features and scabland channels of Waterville Plateau; general geology and structure sections of Waterville Plateau; stratigraphy of Yakima Basalt, Moses Coulee; surficial geology, Moses Coulee mouth area; structure contour map, Vantage Horizon, Moses Coulee area; cross-profile Moses Coulee.
6. Moses Coulee incised along the line of a major preexisting drainage of the Waterville Plateau. This drainage occupied primarily downwarped northeast-trending folds which began to form during the time of extrusion of the post-Vantage Yakima Basalt. The drainage was maintained across the later rise of the Badger Mountain anticline which was initiated in latest Yakima or post-Yakima Basalt time. Moses Coulee was cut by one or more catastrophic floods exceeding discharge of 40 million cubic feet per second. This flood was routed to present coulee site as sheet of water several miles wide and less than 100 feet deep. Water spilled across broad low-relief tract of northeast corner of Waterville Plateau. This tract was carved into complex of shallow scabland channels in short time. Late Wisconsin Okanogan lobe of Withrow advance extended no more than few miles onto plateau at time of flood and effected diversion of flood waters to coulee. A portion of this flood was channeled from Waterville Plateau to Grand Coulee area to begin cutting of that coulee. Floor of coulee was back-filled with several hundreds of feet of coarse gravel in broad trains, which surfaced locally by wave forms. Many huge gravel bars hundreds of feet high formed down-

stream of bedrock obstructions to flood flow. A massive delta-alluvial fan was built into Columbia Valley at mouth of coulee. Foster and Horse Lake Coulees pre-date cutting of Moses Coulee but relate to diversion of melt water from Columbia River by Okanogan lobe. Withrow advance overrode northern scablands but modified them little. Withrow terminal moraine was built during two stadial events. At same time outwash train developed on flood gravels of coulee. Glacier then retreated leaving ice-stagnation features and 13 moraines. Coulee was obscured by landsliding and events of alluvial fan and minor floodplain building during late and post-glacial time. Badger Mountain anticline uplifted during this time also.

Hodge, E. T., 1934, Origin of Washington scablands (abs.): Pan-American Geologist, v. 62, no. 2, p. 155; (abs.) Internat. Geological Congress, 16th, U.S., 1933 Report, v. 2, p. 1105, 1936; Northwest Sci., v. 8, p. 4-11, 1934.

1. Eastern Washington scablands.
2. Ice-scoured landforms and glacial sediments.
3. Field observations.
4. See title.
5. ---
6. The phenomenal and unique geomorphic scabland forms, unlike the rest of the arid West, resulted from glacial advances, partly into a closed basin and onto a basalt and lake-bed surface. The first advance produced two great united lakes, which spilled across the Cascade Range and then produced the integrated Columbia River from many ancestral streams. Ice-lobes dammed the Columbia River and eroded Moses and Grand Coulee and Rock Basin lakes. Stagnant ice produced water-falls, pot-holes, and kames. Ice-jams produced scablandy and anastomosing channels. Melting ice produced loessal deposits, gravel plains, gravel terraces, and upstream bars. Recessional ice permitted the entrenchment and superposition of the Columbia River canyon. A second advance dammed the Columbia River canyon and produced great falls, recessed from its canyon where diverted water spilled into it. All three advances enhanced the scabland features and dispersed erratics by floating icebergs that reached the Willamette Valley. The third advance repeated the same effects, and the retreat of the ice left many stagnant ice features in the valley entering the scabland area. The scablands and

contiguous territory give no evidence of a catastrophic flood but resulted from glacial influences on a peculiar surface effective throughout the Pleistocene.

Hoffman, A. D.; Search, M. A.; Hoffman, M. G., 1931, The geology of Moses Coulee: Washington Div. Mines and Geology Report, 23 p.

1. Moses Coulee, Washington.
2. Clastics (Latah Formation?), Wenas basalt, recent sands, gravels, and glacial tills.
3. Field investigation.
4. General geology of area.
5. ---
6. Describes the structure, Miocene history and basalt series in the area from the Columbia River on southwest, northeastward to Jameson Lake and from 2 to 10 miles in width. Length of the coulee was traversed with plane table and alidade and outline located by triangulation. Lowest formation exposed is a 35' section of clastics in Douglas Canyon, 1/2 mile north of the coulee, believed to be Latah. Resting conformably over this is a 1900' section of basalts, unconformably overlying them are gravels, sands, silts, and glacial tills. Identified the basalts as Wenas. Basalt petrography discussed.

Howard, A. D., 1938, Review of Origin of the Cheney-Palouse scabland tract, Washington, by R. F. Flint, 1938: Geog. Rev., v. 28, no. 3, p. 490-491.

Howell, P.W., 1968, The great glacial floods of the Columbia River: Geol. Soc. Oregon Country Geol. Newsletter, v. 34, no. 5, p. 133-137.

1. Eastern Washington scablands.
2. Scabland scour features and flood deposits.
3. & 4. Popular account of scabland flooding.
5. Map of Glacial Lake Missoula and channeled scablands; map of Willamette flood impoundment.
6. Popular account of scabland flooding. Breach in ice dam at north end of Bitterroot Range started flood. It progressed down Coeur d'Alene Valley, turned west across Spokane and ran into Okanogan lobe of Cordilleran Ice Sheet. It thereupon glanced off ice dam and went down Grand Coulee. The rest backed up and overflowed rim of plateau all the way back to Spokane. The water sloshed southwestward across Columbia Plateau ripping away Palouse soil and bedrock as it went. Part of

water went to Snake River, part to Columbia River, and part toward Pasco. When the water hit the rivers, it temporarily went upstream, but eventually it all converged on Wallula Gap, the only low passageway through the Horse Heaven Hills, 1-1/2 miles wide and 800 feet deep. Here the water velocity was 120 mph. Four hours later the water reached the mouth of the Columbia Gorge. Seven floods occurred in like fashion.

Jenkins, O. P., 1921 and 1922, Geological investigations of the Grand Coulee: Washington Div. Geology Report, illus., 1 plate, 21 p.

1. Grand Coulee, Columbia Plateau.
2. Granite basement, plateau basalts, terrace sands and gravels.
3. Field investigation.
4. Damsite study and general geology information.
5. ---
6. Discusses feasibility of damming north and south ends of Grand Coulee and geological factors relative to placement of dams.

Kaatz, M.R., 1963, Scabland mounds of Washington--depositional or erosional? (abs.): Northwest Sci., v. 37, no. 4, p. 158-59.

1. Channeled scablands, Washington.
2. Silt mounds.
3. Areal reconnaissance and aerial photo interpretation.
4. See title.
5. ---
6. Silt mounds, 10-40 feet across and 2-4 feet high, are widely distributed in the Channeled Scablands. Reconnaissance study of the region together with examination of aerial photographs indicates that, contrary to the findings of Olmsted, the mounds are not an early stage in the restoration of a loess mantle.

   Mound occurence is not restricted to submound depressions. Mounds are generally elongated downslope rather than downwind; they are not encroaching on the intermound surfaces; and climatic records do not indicate conditions favorable to mound growth today.

   On the other hand, the frequent occurrence of periglacial phenomena such as stone nets and stripes, solifluction scars, and talus deposits reflects a past climate more severe than today's.

The mounds originated under such a climate when, as in Alaska today, the erosion of frost crack or ice-wedge polygons resulted in the dissection of a former more or less continuous loess mantle. Today's silt mounds are the erosional remnants of that mantle.

Keyes, C.R., 1935, Glacial origin of the Grand Coulee: Pan-American Geologist, v. LXIII, p. 189-202; (abs.) Revue de Geologie et des Sciences Connexes, v. 17, no. 1, p. 28-29, 1937.

1. Grand Coulee, Washington.
2. See title.
3. Field observations.
4. See title.
5. ---
6. The Grand Coulee, of northern Washington State, is, as is well known, one of the scenic spots of Earth. As canyons go, it is also unique. Its one-time water falls appear to have surpassed in magnitude and drop all others of which we know. The genesis of this noble gorge, or canyon is usually ascribed to the work of a swollen Columbia River, when thwarted in its normal course through damming by a great glacier. But the Grand Coulee does not seem to be the former effect of fluviatile activities of our Columbia since when it was chiefly formed the Columbia River valley was buried deeply beneath glacier-mass. When present-day Columbia River rose again from its icy grave, the Grand Coulee was already an accomplished fact, much as we see it today. Development of Grand Coulee is really not nearly so simple as it has been commonly pictured, and the origin of its grand canyon is not the simple corrosive work of our mighty Columbia.

   For the mechanism of Grand Coulee formation we have to look to far away Iowa, where, recently, deep gorges, newly gashed in the illimitable prairie along the axes of one-time ice-lobes of a fast vanishing ice-sheet, mark the line of post-glacial streams, and give clue to what must have happened at the Grand Coulee, when the Columbia River was not around. Grand Coulee is particularly interesting in this connection as revealing one stage of the development of which the distant eastern relative gives no inkling. It is therefore doubly instructive.

   The <u>modus operandi</u> of the development of a perfectly new drainage line upon an elevated plain never before trenched by stream, during an ice-sheet retreat, is lately revealed and described in considerable detail in the instance of the Des Moines River in Iowa, and the James and Cheyenne Rivers in the Dakotas, which streams were developed, de noro, on the axes of waning ice-lobes and excavated deep gorges for their bed in the tills-plains round about, while the ice-sheet till formed the upper parts of the local canyon-walls.

A great opportunity now awaits at Grand Coulee for determining glacial successions, and till-body relationships. The field is still a virgin one. In a few weeks' time more may be learned concerning the behavior, work, and interactions of Cordilleran glaciers than was accomplished in the Alps in a whole century. A new Eludes sur les Glaciers written in Washington and British Columbia will as far surpass the first great exposition under that title as Agassiz's did all previous literature. A monumental Opus beckons.

Livingston, V. E., Jr., 1964, Origin of Dry Falls: Washington Div. Mines and Geology Report, 4 p.

1. Dry Falls, Grand Coulee, Washington.
2. Yakima Basalt.
3. Field observations.
4. See title.
5. ---
6. Popular account of Miocene and Pliocene history of Columbia basin, and formation of Grand Coulee and Dry Falls by melt water from ice-lobe blocking Columbia River at Coulee Dam.

McKnight, E. T., 1927, The Spokane Flood; a discussion: Jour. Geology v. 35, no. 5, p. 453-460.

1. Eastern Washington.
2. White Bluffs-Ringold Formation.
3. Reconnaissance field observations.
4. See title.
5. ---
6. Records of glacial history left on surface of Ringold Formation in area south of Saddle Mountains is discussed in terms of a non-catastrophic development. Concludes that lateral planation by Columbia has been dominant factor in physiographic development of White Bluffs region based on: (1) relation of present area of Ringold to its former extent; (2) hanging character of normal valley at

north end of White Bluffs; (3) landslide topography of present White Bluffs; and (4) widespread gravel deposits on west side of river, most of planation post-glacial in age.

McMacken, J. G., 1925, Lake Lewis due to flood waters of Spokane ice (abs.): Northwest Sci. Abs. Papers, p. 40.

1. Eastern Washington.
2. Glacial and scabland features.
3. Field observations.
4. See title.
5. --
6. The paper first reviews the conditions on the Columbia Lava Plateau following its building up by the successive floods of lava. It describes briefly the formation of the canyons by the rivers in the basalt and the warpings to produce the divides and structural basins. The outline of Lake Lewis is described as indicated by berg dropped erratics, gravel deposits, and some poorly defined shorelines.

   Several hypotheses for the formation of the lake by different geologists are then taken up. It describes the extent of the great ice front of the Spokane ice. It offers as an explanation of the source of the mighty floods from the melting ice that filled all the old river channels and structural basins to overflowing, the melting due to the short hot summers and the milling caused by the enormous pressure due to the great depth of the ice which covered all but high peaks and caused the ice, when in the lower valleys, to melt and the waters to issue as immense floods from beneath the ice front. It takes up the different channels of these floods as they swept southward to produce the channeled scablands as described by Bretz. It reviews the measurement of these flood waters by Bretz and brings out the fact that old drainage lines were all too small to carry them and that they flooded back into the Hartline, Quincy, Pasco, John Day, and Willamette Basins to produce the temporary bodies of water known as Lake Lewis. The lack of shorelines of This lake is explained on the basis of the seasonal character of the glacial floods which would cause the elevation of its shorelines to change greatly from winter to summer.

______, 1931, Grand Coulee of Washington: Pan-American Geologist, v. 55, no. 2, p. 81-92, 5 plates.

1. Grand Coulee, Washington.
2. Glacial erosional and depositional features.
3. & 4. Geologic history of Grand Coulee region.
5. ---
6. Geologic history of Grand Coulee region from pre-lava floods through lava floods; regional deformation of basalt, glaciation, and post-glacial modifications of landscape.

______, 1937, Vicissitudes of Spokane River in late geologic times: Pan-American Geologist, v. 68, no. 2, p. 111-132, 8 plates.

1. Spokane area, northeastern Washington.
2. Basalt, glacial till, Latah Formation.
3. Field observations, literature review.
4. Discussion of origin and development of the Spokane River.
5. Cross-section of Spokane River Valley, at Spokane; map showing drainage relations of Spokane River; maps showing present-day drainage of upper Columbia River Basin, probable drainage of Columbia River Basin previous to great lava flows, and preglacial drainage of Columbia River Basin.
6. Summary of origin of the Spokane River and its development through time in response to the geologic events that took place in its proximity.

Milton, D. J.; Baker, V. R., 1974, Erosion by catastrophic floods on Mars and Earth: Icarus (New York), v. 23, no. 1, p. 27-41.

Mullineaux, D. R.; Wilcox, R. E.; Fryxell, R.; Ebaugh, W. F.; Meyer, R.F., 1977, Age of the last major scabland flood of eastern Washington, as inferred from associated ash beds of Mount St. Helens Set S (abs.): Geol. Soc. America Abs. with Prog., v. 9, no. 7, p. 1105.

1. Eastern Washington.
2. Mt. St. Helens Set S tephra.
3. Lab investigations of Fe-Mg mineral suites, refractive indices and chemical compositions, radiocarbon dating.
4. See title.
5. ---
6. Four groups of upper Pleistocene pumice layers from Mount St. Helens, called Sets C (oldest), M, K, and S (youngest), are mineralogically similar to certain cummingtonite-bearing ash beds of the channeled scabland. The scabland ash beds occur as closely spaced "couplets" and "triplets" in

fine-grained sediments associated with gravels of the last major scabland flood. Fe-Mg mineral suites and refractive indices and chemical compositions indicate that Set S pumice layers are the near-source equivalents of "couplet" and "triplet" ash beds exposed near Vantage and Wanapum Dam along the western margin of the scabland. These data confirm earlier tentative correlations of Set S with scabland ash beds by us and several other investigators.

Near Mount St. Helens, Set S is dated by radiocarbon as about 13,000 years old. Thus, the last major scabland flood is also about 13,000 years old, in contrast to most previous estimates of about 20,000 years or older. The younger age, however, is consistent with an age estimate of possibly 14,000 years for a scabland flood by H. H. Hammatt, L. L. Foley, and F. C. Leonhardy in 1976. It is also consistent with an age of less than 13,500(?) years estimated for the last flood by R. B. Waitt, Jr., in 1977, from relations of flood and glacial deposits marginal to the scabland. In addition, an age of about 13,000 years for the last major scabland flood is supported by a radiocarbon date of 13,080±350 years (W-3404) we obtained for peat that directly overlies the Portland delta of J H. Bretz, which is a down-valley deposit of that flood.

Olmsted, R. K., 1963, Silt mounds of Missoula flood surfaces: Geol. Soc. America Bull., v. 74, no. 1, p. 47-53.

1. Geological journal.
2. See title.
3. Columbia Plateau.
4. See title.
5. Field observations and measurements.
6. Clarification of contradictions in theories of origin for mounds and assemblage of additional data.
7. ---
8. The small natural mounds of the Missoula Flood channels are a result of the transportation of wind-borne dust across the region. Dry air is cooled and becomes moist as it is forced up the slope of the plateau. The dust becomes heavy by absorption of water from the air and settles in a thin mantle. Over most of the denuded area the removal of dust by drier winds keeps pace with deposition, and the surfaces remain barren. Dust has accumulated in shallow

depressions in the surface. Vegetation, ground water, or a combination of these retard dust loss in these places. Over a period of a few thousand years mounds have grown above the sites of these depressions. The mounds retain ellipsoidal shapes, their major axes aligned with the prevailing wind because of differential rates of dust removal by the wind. The mounds constitute an early stage in the restoration of the loess mantle.

Olson, E., 1969, Introduction to J Harlen Bretz's paper on "The Lake Missoula Floods and the Channeled Scabland": Jour. Geol., v. 77, p. 503-504.

1. Geological journal.
2. See title.
3. Columbia Plateau.
4. Scabland depositional and erosional features.
5. Introduction.
6. --
7. --
8. Discusses, in general terms, the catastrophic hypothesis Bretz used to explain the scablands and the reluctance of the rest of the geologic community to accept his ideas.

Pardee, J. T., 1910, The Glacial Lake Missoula: Jour. Geology v. 18, p. 376-386.

1. Northwestern Montana.
2. Geologic features associated with Glacial Lake Missoula.
3. Field observations and literature review.
4. Nature and origin of Glacial Lake Missoula.
5. --
6. Article provides evidence for existence of Glacial Lake Missoula by describing wave-cut terraces on several slopes. Also discusses location and lithology of glacial erratics. Gives high level of lake as 4,200 feet above sea level, 1,000 feet over Missoula. Discusses extent of lake and says the damming agent was glacial ice.

______, 1942, Unusual currents in Glacial Lake Missoula, Montana: Geol. Soc. America Bull., v. 53, p. 1569-1600, 8 pls., 9 figs.

1. Glacial Lake Missoula, Montana.
2. Flood features.
3. Field investigation.

4. Topography and geology of Lake Missoula; description of and evidence for unusual currents.
5. Map of Glacial Lake Missoula; geologic maps of southern part of Plains Basin, Eddy Narrows, Thompson Falls Valley, Quinn and Perma Narrows, and Paradise Narrows; topography and geology of Markle Pass, North Camas Prairie Basin and Rainbow Lake Pass.
6. The area submerged by Glacial Lake Missoula includes several intermontane basins and constricted interconnecting valleys or "narrows" that drain to a single outlet, the Clark Fork River. A sudden failure of the ice dam that blocked this valley, near the Idaho-Montana State line, caused unusually large and rapid currents through the narrows and wind gaps in the partly submerged rim of Camas Prairie basin. Evidences of such currents include commensurate, but otherwise ordinary, effects of streams confined to rocky channels and the unique giant ripple marks. At its high stage the lake is roughly estimated to have held more than 500 cubic miles of water of which nearly three-fourths was stored above a constricted part of the Clark Fork Valley called the Eddy Narrows. Calculations based on available incomplete data indicate a flow through the Eddy Narrows that reached a maximum of 9.46 cubic miles per hour. Whether the lake was completely drained at that time has not been determined, but a later set of beaches testified that the basin held a lake soon after the rapid outflow. Apparently the final draining was gradual.

Patton, P. C.; Baker, V. R., 1978, New evidence for pre-Wisconsin flooding in the channeled scabland of eastern Washington: Geology, v. 6, no. 9, p. 567-571.

1. Cheney area, eastern Washington.
2. Flood-gravel deposits, Palouse loess.
3. Field investigations.
4. Presentation of new stratigraphic evidence for pre-Wisconsin flood history of channeled scabland.
5. Four measured stratigraphic sections.
6. Flood-gravel deposits capped by loess sequences that display well-developed argillic, calcic, and petrocalcic paleosols indicate pre-Wisconsin catastrophic flooding in the Cheney-Palouse tract of the channeled scabland, eastern Washington. The most complete stratigraphic exposure reveals two flood-gravel units, one of pre-Wisconsin age and the other representing the last major phase

of scabland flooding (late Wisconsin). The two gravel units are separated by three loess units. Each period of loess deposition was followed by a soil-forming interval. The older of the two flood-gravel units contains cobbles of an early pre-Palouse Formation (that is, pre-Bull Lake) loess. It is capped by a loess unit displaying superimposed argillic and petrocalcic soil horizons. Above the petrocalcic horizon are two younger layers of loess (the Palouse Formation), each of which displays a paleosol having a weakly developed argillic B horizon and a calcic C horizon. These units are overlain by gravel from the last major phase of scabland flooding, which is, in turn, overlain by late Wisconsin and Holocene loess. The earliest flood probably carved part of the Cheney-Palouse scabland morphology during a glaciation.

Quinn, R., 1972, The origin and chronology of the scabland channels of the Columbia Plateau of eastern Washington: Unpublished paper by the author, 17 p.

1. Columbia Plateau, Washington.
2. Glacio-fluvial deposits in the Channeled Scablands.
3. & 4. Geologic history of the Columbia Plateau's channeled scablands.
5. Geologic maps showing Bull Lake and Pinedale glaciations and loess.
6. A chronologic presentation of geologic thought concerning the development of the Channeled Scablands.

Richmond, G. M.; Fryxell, R.; Weis, P. L.; Neff, G. E.; Trimble, D. E., 1965, Glacial Lake Missoula, its catastrophic flood across the Columbia Plateau and the loesses and soils of the Columbia Plateau, Pt. F. In Guidebook for Field Conference E, Northern and Middle Rocky Mountains, Internat. Assoc. Quaternary Research, 7th Cong., USA, 1965: Lincoln, Nebr., Nebraska Acad. Sci., p. 68-69, illus.

1. Dixon to Clark Fork to Coeur d'Alene to Grand Coulee Dam to Ephrata to Pullman, Washington.
2. Loess, soils, and catastrophic flood features.
3. ---
4. ---
5. Maps: Giant current ripples in Montana; successive paths of flood from Glacial Lake Missoula near Spokane; surface elevations of high-velocity flood water from Lake Missoula to Portland, Ore.; inferred velocities of Lake Missoula flood;

stratigraphy of loess deposits and associated buried soils in central Columbia Plateau; correlation of post-glacial climatic events with stratigraphy and cultural sequence at Marmes Rock Shelter; several stratigraphic sections; precipitation, vegetation, and distribution of great soil groups for Columbia Plateau.
6. Field trip guidebook.

Thomsen, D. E., 1974, The day the dam burst: similarities between giant erosion features in Washington (scabland) and on Mars, considered evidence of catastrophic flooding: Sci. News (Wash., D. C.), v. 106, no. 16, p. 250-257.

1. Eastern Washington.
2. Catastrophic flood features.
3., 4., & 5. --
6. Interpretation of Martian satellite photography as basis for comparison of Martian and Channeled Scabland physiography.

U.S. Geological Survey, 1973, The Channeled Scablands of eastern Washington--The geologic story of the Spokane Flood: U.S. Govt. Printing Office, Stock no. 2401-2436, 24 p.

1. Columbia Plateau, Washington.
2. Scabland depositional and erosional features.
3. Field observations.
4. See title.
5. Photographs, sketches, map of advance of glacial ice and corking of Clark Fork River and Channeled Scablands, satellite photograph of Channeled Scablands.
6. Popular account of scabland flooding, summarizing the sequence of geologic events that culminated in the Spokane Flood.

Waitt, R. B., Jr., 1972, Revision of Missoula flood history in Columbia Valley between Grand Coulee Dam and Wenatchee, Washington (abs.): Geol. Soc. America Abs. with Programs, v. 4, no. 3, p. 255-256.

1. Columbia River Valley, Washington.
2. Flood erratics and other flood and glacial deposits.
3. Field observations; mathematical models concerning amount of flood water impounded at Grand Coulee by Lake Missoula flood.
4. See title.
5. ---

6. In lower Methow Valley erratics of Columbia provenance rest on late Wisconsin till of Cascade provenance; in Antione Creek stratified gravel with upvalley-dipping foreset beds underlies an anomalous flat valley floor at altitude 2000 feet; in East Wenatchee a broad calichified early- or pre-Wisconsin terrace separates an unweathered 100-foot erratic from its only potential upslope source. These and other anomalous Columbia Valley deposits, as giant boulder fields, giant expansion and eddy bars, and Columbia-provenance erratics up tributaries, are evidence of an iceberg-laden late Wisconsin flood surge 1200 feet deep through Columbia Valley.

   Catastrophic discharge of a late-glacial lake ice-dammed at Grand Coulee (spillway altitude 1550 feet) is inadequate to explain higher effects of flood downvalley; the Missoula flood crest (2665 feet at Spokane) is adequate. Although erratics rafted downvalley indicate residual preflood Columbia ice, distribution of deglacial Great Terrace requires confinement of valley ice below 1500 feet.

   At a surge head of altitude 2500 feet, the combined cross-sectional areas of Grand Coulee and ice-choked Columbia Gorge at Coulee Dam approximately equal the cross-sectional area of the channel above Coulee Dam. Therefore, if mean velocity through all conduits was equal, only after ponding to 2500 feet altitude could discharge out of Columbia and Grand Coulee conduits have equalled flood inflow.

   The Missoula Flood, thus hydraulically ponded at Coulee Dam, produced a 1200-foot surge that abruptly terminated the late Wisconsin glacial history of Columbia Valley.

______, 1977, Missoula Flood *sans* Okanogan lobe: Geol. Soc. America Abs. with Programs, v. 9, p. 770.

1. Columbia Valley.
2. Flood deposits and scour features.
3. Field observations.
4. Proof of catastrophic flooding of area (Wenatchee-Rock Island segment of Columbia Valley) previously believed to be protected by Okanogan lobe of Cordilleran Ice Sheet.

5. ---
6. The Wenatchee-Rock Island segment of Columbia Valley, historically presumed to have been isolated by the Okanogan lobe from the downvalley surge of the Missoula flood, contains unweathered bedload gravel to altitude 440 m, or 255 m above the river. The gravel contains boulders as large as 5 m, displays downvalley-dipping foreset beds in sets at least 15 m thick, and is embellished by giant current ripples whose lee slopes face downvalley and whose mean chord spacing is 100 to 250 m. Unweathered ice-rafted erratics occur to altitude 525 m, or 340 m above the river--higher than the surface of "Lake Columbia" (of depth 200 m and surface altitude 500 m), which therefore was not the floodwater source of these Columbia Valley deposits. The flood surface profile in Columbia Valley projects nicely upvalley to Bretz' 820 m flood-surface altitude near Coulee Dam, and downvalley to Neff's 445 m flood surface altitude in Quincy Basin. The Columbia Valley flood, evidently identical to the last Missoula flooding of the Channeled Scablands, occurred after the Okanogan lobe of Cordilleran ice had largely retreated from Columbia Valley (13,500 B.P.?), but before the eruption of the Glacier Peak about 12,000 B.P.

Deposits from the Columbia Valley flood underlie and are mixed with Missoula flood deposits that issued westward from Quincy Basin: floodwater surged into Quincy Basin first via the Columbia conduit, later via the Scablands. Reversal of flood currents in Quincy Basin from eastward inflow to westward outflow may reflect a late-flood increase in Scabland discharge owing to completion of the Grand Coulee by cataract retreat.

Webster, G. D.; Baker, V. R.; Gustafson, C. E., 1976, Channeled Scabland of southeastern Washington, a roadlog via Spokane-Coulee City-Vantage-Washtucna-Lewiston-Pullman: Geol. Soc. America Cordilleran Section Meeting, Pullman, Washington Field Guide No., 2.

Washington Department of Conservation, 1959, Washington's Channeled Scabland: Washington Dep. Conserv., Div. Mines and Geology Bull., no. 45, 57 p.

Weis, P. L. 1976, Erosional and depositional features of the Spokane Flood (abs.): Geol. Soc. America Abs. with Programs, v. 8, no. 3, p. 419.

1. Channeled Scablands, Washington.
2. See title.
3. Field and aerial reconnaissance.
4. See title.
5. ---
6. The catastrophic emptying of Glacial Lake Missoula had a profound and nearly instantaneous effect on the environment that lay within reach of the flood. The water produced a wide range of unusual erosional and depositional features within the lake basin in western Montana and in the channels that lay downstream to the west, in the path of the suddenly released flood. Although many features of the Spokane flood are well documented, few geologists have had the opportunity to visit them. Fewer still have had the opportunity to see these features from the air, where their magnitude and significance can be best appreciated.

   Giant ripple marks and high eddy gravels in the glacial lake basin in western Montana give evidence of the current velocities. Giant ripple marks, streamlined gravel bars, lag gravel, and bedrock scour are the result of currents in Spokane Valley. Denuded and deeply eroded basalts are evidence of the flood on the lava plateau of eastern and central Washington. On the plateau, some channels contain island-like remnants of Palouse loess, and an abrupt loess scarp forms the channel margin. Satellite photos provide an overall view that might well have settled the controversy of the channel origins if these photos had been available 50 years ago.

Whitmer, J. H., 1974, The channeled scabland of Washington--Part 1 and 2: Geol. Soc. of the Oregon Country Geol. Newsletter, v. 40, no. 3 and 4, p. 18-19, 28-29.

1. Eastern Washington.
2. Flood scour features and deposits.
3. Description of and explanation for channeled scablands region of eastern Washington.
4. Description of and explanation for channeled scablands region of eastern Washington.
5. Geological map of channeled scablands.
6. Description of, and geologic history of, eastern Washington and in particular the channeled scablands. A list of 11 major points of interest are given.

SOILS

Bechtel Corp., 1971, Final soil investigation report for the Fast Flux Test Facility, Richland, Washington (prepared for Wedco Corp., Richland, Washington): Bechtel Corp., San Francisco, California, 195 p.

Borchardt, G. A., 1970, Neutron activation analysis for correlating volcanic ash soils: Ph.D. thesis, Oregon State University, Corvallis, Oregon. 219 p. (Diss. Abstr., v. 30, no. 11, Pub. No. 70-7917).

1. Pacific Northwest.
2. Volcanic ash soils.
3. Neutron activation analysis.
4. Correlation of volcanic ash soils.
5. ---
6. The objectives of this study were: 1) To determine the trace element differences between sample sites and between deposits of Mazama, Newberry, Glacier Peak, and St. Helens volcanic ash in the Pacific Northwest, 2) to correlate volcanic ash in peat bogs with volcanic ash from upland sites, 3) to verify Mazama ash as parent material of soils occurring along a 450 km transect in Oregon, and 4) to determine the trace element composition of clays derived from volcanic ash.

Bryan, K., 1927, The "Palouse soil" problem, with an account of elephant remains in wind-borne soil on the Columbia Plateau, Washington: U.S. Geol. Survey Bull. 790, p. 21-45, 4 plates; Wash. Acad. Sci. Jour., v. 17, no. 5, p. 120-121.

1. Columbia Plateau, Washington.
2. Palouse soil.
3. Historical review of Palouse soil, field observations, description of elephant remains.
4. New data to clarify issues in Palouse soil problem.
5. ---
6. 1) The soil that is useful in agriculture (Palouse, Ritzville, Helmer series, etc., as defined by the Bureau of Soils) consists of a top skin, or veneer, that is largely wind borne throughout the plateau and rests on material of various sorts. 2) Where the unconsolidated material, or so-called "Palouse

soil," is thick, the inner core of the hills composing the intricate topography is largely unknown. At various places this inner core consists of (a) laminated silt, (b) almost structureless reddish compact silt with limey concretions that may be a loess, (c) yellow clay and clay silt that seem with little doubt to be loess, (d) ancient glacial till (older than the intermediate till of this region), and (e) very doubtfully, a soil derived from basalt. 3) In the western part of the plateau there is in numerous valleys a well-defined terrace in part underlain by gravel. The valleys and the terrace antedate the great coulees formed by glacial waters. 4) The soil on these terraces is a definite wind-deposited material, as shown by the arrangement of the bones of an extinct elephant. 5) The soil on the terraces is younger than the unknown inner core of the adjacent "Palouse soil" hills but is of Pleistocene age. 6) In the eastern part of the plateau thin and discontinuous layers of gray to green-gray material, residual from basalt, underlie yellow clay composed of minerals foreign to the basalt and having all the characteristics of loess. 7) In one place at least, the top layer of soil or veneer contains volcanic ash. 8) The present rate of deposition of dust in the vicinity of Spokane is an accelerated rate induced by the cultivation of immense areas of loessial soil to the west and south. 9) Deposition of loess since the Wisconsin and intermediate bodies of till were laid down has been moderate in amount, and the great period of deposition of wind-borne soil antedates these later advances of glacial ice.

Caldwell, H. H., 1961, The Palouse in diverse disciplines: Northwest Sci., v. 35, no. 4, p. 115-121.

1. Southeast Washington.
2. Palouse soil.
3. & 4. Collection and composite of views regarding definition and geographic boundaries of "Palouse."
5. Map showing core area and proposed extensions to geographic boundaries of "Palouse."
6. Attempt to define what "Palouse" means as regional phenomena and to indicate on a map the area conceived as representing the Palouse. Depending upon the discipline, the "Palouse" is considered to be a unique regional landform shaped by wind, snow, and stream action, and to reflect a particu-

lar climate, soil, prairie vegetation, and land use, or a bunch-grass ecologic community with associated climate and soil that developed on eolian materials, or a regional agricultural land-use type that reflects the topography, climate, vegetation, soils, and eolian materials. There is nearly universal agreement of the position of the eastern border but the most disagreement involves the southern border. Historical account of term "Palouse" is given. Due to the common agreement on "core" area boundaries, it is proposed that unadorned term "Palouse" be applied to denote a natural region and other names represent limited-factor areas, elements, dimensions, or extensions of the core area.

Calkins, F. C., 1903, Soils of the wheat lands of Washington (abs.): Science, new series, v. 17, no. 434, p. 668.

1. Eastern Washington.
2. Soil.
3. & 4. Study of physical and chemical properties of soil and lack of transition between soil and underlying rock.
5. ---
6. The soil covering the higher portions of the Columbia plains has generally been considered to be residuary, and derived from the underlying Miocene basalt. Recent observations, however, have led the author to believe that this soil is an eolian deposit. The argument for the eolian hypothesis is based on the physical and chemical properties of the soil and the complete lack of transition between it and the underlying rock. The wind-blown material is supposed to come from the soft volcanic sediments that overlie the basalt in the southern portion of the Columbia plains.

Carmichael, V. W., 1956, The relationship of the "soils" of the Palouse to the Columbia River basalt: Compass of Sigma Gamma Epsilon, v. 34, no. 1, p. 6-28, illus.

1. Southeast Washington.
2. Palouse soil and Columbia River basalt.
3. Study of configuration of basalt surface beneath soil.
4. See title.
5. ---
6. The major problem of this thesis was to determine the relationship of the "Palouse soil" to the Columbia River basalt. A minor problem considered

was the possibility of finding a method for predicting depths from soil surfaces to basalt by an examination of the "soil."

In an effort to obtain solutions to the above problems the basalt surface of an area approximating 50 square miles in Whitman County, Washington, and adjoining Latah County, Idaho, was mapped and a number of samples of "Palouse soil" and basalt were chemically analyzed.

The surface of the basalt shows considerable decomposition between elevations of 2550 and 2650 feet above sea level in many places within the area of study. Considerable dissection of the basalt has taken place and sinuous valleys have been eroded into its surface. In some places there is a complete lack of accordance of the surface topography of the "soil" with the basalt surface. In other words, valleys in the basalt are in some places overlain by Palouse hills.

Chemical analyses of "soils" and basalt show that the Palouse soil is not genetically related to the basalt, but that there is a mixture of residual basaltic soil and "Palouse soil" in a relatively thin zone at the contact between the two materials. Decomposition of the "soil" advances in degree toward the bottom of the "soil" layer. The decomposition of the basalt increases in an upward direction. Alumina content of "Palouse soil" is higher than that of other loessal deposits throughout the United States.

The results of this study and a review of the literature suggest that: (1) There has been one or more long periods of erosion between extrusions of groups of basalt flows. (2) Although much of the Columbia River basalt was extruded from the Grande Ronde region of northeastern Oregon, the marginal plateau basalt in the region between Moscow and St. Joe, Idaho, probably came from a different source. (3) Although the major portion of the Columbia River basalt dips centripetally toward the Pasco, Washington, region the marginal plateau basalt has been only locally deformed in post-Miocene time. (4) A thickness of basalt approaching 800 feet may have been removed by erosion in some areas along the eastern margin of the Columbia Plateau before the deposition of the "Palouse soil" parent material. (5) The parent material of the "Palouse soil" was probably

loess, a portion of which may have been pumicite from the Cascade region.

Chapin, R. W., 1968, General soils map, State of Washington: U.S. Soil Conservation Service, 1:1,500,000.

Culver, H. E., 1937, New version of the Palouse problem (abs): Geol. Soc. America Proc. 1936, p. 338-339.

1. Palouse region, southeast Washington.
2. Palouse soil and topography.
3. Reconnaissance field observations.
4. See title.
5. ---
6. Shapes of the Palouse hills, with their prominent steeper northerly slopes, the dendritic drainage pattern characteristic of the region, the wide range of lithologic character shown by the unconsolidated material lying above the Columbia basalt, and the prevailing southwesterly winds, together with a number of other items, have been scrambled, during the past half century, into a mass of apparently conflicting data from which a varied set of hypotheses of origin and development have been derived. Reconnaissance studies over practically all parts of the Columbia Plain in Washington, together with some detailed work, have suggested a concept under which many, if not all, the data now available can be harmonized.

   The eastern scabland channels cross Columbia Plain near the west margin of the recognized "Palouse country," thus suggesting a boundary where in reality none exists. Extension of the Ringold Formation rather generally over southeastern Washington, suggested in previous papers by the writer, may explain the presence of the two types of deposits in the hills of the Palouse region, and at the same time may account for the present topographic character of the area. In parts of eastern Washington, erosion of the Ringold after its deformation may well have provided much of the material now composing the uppermost portion of the "Palouse formation," thus repeating the relationship believed to obtain locally between the Ringold and the Ellensburg Formations. It seems doubtful that the term "Palouse" should be retained as a formation name.

Cunningham, R. L., 1964, Genesis of the soils along a traverse in Asotin County, Washington: Washington State University Ph.D. thesis, 158 p.

1. Asotin County, Washington.
2. Soils.
3. Laboratory analyses; morphological studies; and studies of pH, partical size distribution, morphology of sand and clay, and electron microscopy of fine particles.
4. Explanation of occurrence of different soils on Anatone plateau, along a traverse where soil characteristics changed due to differing soil forming factors.
5. Soils map on aerial photograph mosaic; soil monoliths; mineral distribution in soil horizons; X-ray diffraction traces for soil samples; electron micrographs of soil samples.
6. An explanation of the occurrence of the different soils on the Anatone plateau is the purpose of this study. A traverse was selected along which soil characteristics changed because of differing soil forming factors. Soils were sampled at eight sites along the 7-mile traverse in order that laboratory analyses might be used in conjunction with morphological studies to infer the genesis of the soils. The soils at sites 1 through 8 are characterized in terms of their morphology, pH, particle size distribution, mineralogy of the very fine sand and clay, and the appearance of the fine particles in electron micrographs.

Dobie, J. L., 1924, The origin of the Palouse soils: Washington State College A.I.M.E. Paper, Department of Geology, State College of Washington, 22 p.

1. Palouse region, eastern Washington.
2. Palouse soil.
3. Field observations.
4. Palouse soil.
5. Map of Pullman quadrangle.
6. Determination of origin of Palouse soil by comparison of conditions there with other areas. Discussion of geology in Pullman quadrangle. Results: (1) discovery of faulting and other disturbances pre-dating present soil deposition; (2) discovery of clastic dikes representing former formation on top of basalt, now destroyed; (3) realization that present soil will be eroded away, leaving barren scabland of mesa type.

Donaldson, N. C.; Giese, L. D., 1968, Soil survey of Spokane County, Washington: U.S. Soil Conservation Service in cooperation with the Washington Agricultural Experiment Station, 143 p., plus 148 map sheets.

Fryxell, R.; Neff, G. E.; Trimble, D. E., 1965, Scabland tracts, loess, soils, and human prehistory. In INQUA, Guidebook for Field Conference E, northern Rocky Mountains: Nebraska Acad. Sci., Lincoln, Nebr., p. 79-89.

(Annotated under Catastrophic Flood Features section).

Garber, L. W., 1965, Relationship of soils to earthflows in the Palouse: Jour. Soil and Water Conserv., v. 20, no. 1, p. 21-23, illus.

1. Eastern Washington and northern Idaho.
2. See title.
3. Field investigations.
4. Description of soils in Palouse region; discussion of physical forces contributing to earthflows and some preventions.
5. Cross-section of typical Palouse hill showing excavation of footslope by plowing, and percentage range in slopes.
6. One striking form of soil erosion in the Palouse region of the Pacific Northwest is the earthflows that occur during the spring of the year. Several hundred tons of soil may move downslope in large earthflows. In this article, a soil scientist describes the properties of soils on which earthflows are likely to occur and relates these properties to physical forces operative in the soils. Also treated are management techniques that can be used to prevent earthflows.

Gentry, H. R., 1974, Geomorphology of some selected soil-landscapes in Whitman County, Washington: Washington State University M.S. thesis, 130 p.

(Annotated under Physiographic Features section)

Gilkeson, R. A., 1958, Washington soils and related physiography -- Columbia Basin Irrigation Project: Washington State Agricultural Experiment Station Circular, 9 p.

______, 1965, Ritzville series; benchmark soils of Washington: Washington Agricultural Experiment Station Bull. 665, 18 p.

Hajek, B. F., 1966, Soil survey, Hanford project in Benton County, Washington: Battelle Memorial Institute, Pacific Northwest Laboratory Report BNWL-243, 18 p.

1. Benton County, Washington
2. Soils.

3. Soil classification, field verification, no lab work.
4. Soil mapping and descriptive report of Hanford Project soils.
5. Soil map of Hanford Project, Benton County, Washington.
6. Soil map and descriptive report of Hanford Project soils classification scheme based on morphologic and genetic characteristics. Soil descriptions include: Ritzville silt loam, Rupert sand, Hezel sand, Koehler sand, Burbank loamy sand, Kiona silt loam, Warden silt loam, Ephrata sandy and stony loams, Scootney stony silt loam, Pasco silt loam, Esquatzel silt loam, Riverwash, Dune sand, and Lickskillet silt loam.

Harrison, E. T.; Donaldson, N. C.; McCreary, F. R.; Ness, A. C., 1964, Soil Survey of Walla Walla County, Washington: U.S. Dept. Agri., Soil Conserv. Serv., 138 p., incl. soils maps 1:31,680.

Holmes, J. G., 1902, Soil survey of the Walla Walla area, Washington: U.S. Dept. Agri., p. 711-728, incl. soil map 1:63,360.

Johnson, L. C.; Papendick, R. I., 1968, A brief history of soil erosion research in the United States and in the Palouse, and a look at the future: Northwest Sci., v. 42, no. 2, p. 53-61.

1. Palouse region, Washington.
2. Soils.
3. & 4. See title.
5. ---
6. Summary of effects of different tillage and cropping practices on soil surface conditions and effects on runoff and soil erosion in Palouse region.

Kaiser, V. G., 1967, Soil erosion and wheat yields in Whitman County, Washington: Northwest Sci., v. 41, no. 2, p. 86-91.

1. Whitman County, Washington.
2. Palouse soil.
3. & 4. Documentation of soil erosion and crop yields.
5. Cross-section of typical Palouse hill.
6. Documents wheat production and soil loss record from 1939-1965. Includes description of Palouse soil and typical Palouse hill. During 27 years of study, erosion moved an average of 0.7 ton of soil off steep cultivated slopes for each bushel

of wheat produced. Areas of typical hill where erosion is most critical are also lowest wheat-producing areas. Cumulative effects of erosion reduces wheat-producing capacity of soil -- eroded soils produce 32 percent of the yield that non-eroded soils produce.

Klock, G. O., 1969, Forest and range soils research in Oregon and Washington, a bibliography with abstracts from 1964 through 1968: Pacific Northwest Forest and Range Experiment Station Report No. FSRP-PNW-90, 31 p.

Kocher, A. E.; Strahorn, A. T., 1919, Soil survey of Benton County, Washington: U.S. Dept. Agri., 72 p.

______, 1922, Soil survey of the Wenatchee area, Washington: U.S. Dept. Agri., 91 p. incl. soil map 1:62,500.

Kraszewski, S., 1952, Morphology and development of Palouse and related series: Washington State College Ph.D. thesis, 105 p.

1. Walla Walla and Columbia Counties, Washington.
2. Palouse Formation.
3. Soil profiling and sampling; lab investigations, including bulk density, mechanical analysis, chemical composition and other standard soil tests.
4. Soil investigations.
5. Descriptions of soil profiles; four diagrams showing how clay, water, organic carbon, and total nitrogen vary with depth of soil profiles; figure showing climatic conditions that prevail near sampling sites.
6. An evaluation of most active soil-forming processes involved in development of soils. Determination of degree of development of Ritzville, Walla Walla, Athena and Palouse soils. Correlation of degree of development with morphological characteristics. Characterization of morphological features of these representative soils.

Krynine, P. D., 1937, Age of till on "Palouse soil" -- Washington: Am. Jour. Sci., 5th ser., v. 33, no. 195, p. 205-216, 2 figs.

1. Columbia Plateau, Washington.
2. Till, Palouse soil.
3. Petrographic analysis.
4. See title.
5. ---
6. The so-called "ancient" till of Washington, said

to be of pre-Wisconsin age, is shown by petrographic analysis to be really a late-glacial deposit whose weathered and "ancient" appearance is due to the fact that it contains much reworked and incorporated "Palouse soil," an old and decayed pre-late-glacial loess. Methods of differentiation between "Palouse soil" and till contaminated with even very large amounts of "Palouse soil" are offered. Finally, the apparent and real effects of the admixture of volcanic ash in "Palouse soil" and recent superficial loess are described.

Lenfesty, C. D.; and others, 1967, Soil survey of Adams County, Washington: U.S. Dept. of Agriculture, Soil Cons. Service, in coop. with the Wash. Agri. Exp. Sta., 110 p., plus 160 map sheets.

Lotspeich, F. B., 1952, A study of the Palouse catena: Washington State College M.S. thesis, 70 p.

1. Southeastern Washington.
2. Palouse, Athena, and Thatuna soils of Palouse catena.
3. Morphological, physical, chemical, and mineralogical studies.
4. Using information gained to draw inferences concerning soil-forming processes involved in development of soils and degree of homogeneity of their parent materials.
5. ---
6. Study of Palouse, Athena, and Thatuna series of Palouse catena including physical, chemical, and mineralogical properties.

Lotspeich, F. B.; Smith, H. W., 1953, Soils of the Palouse loess, Pt. 1, The Palouse Catena: Soil Sci., v. 76, p. 467-480.

1. Southeastern Washington
2. Palouse soil.
3. Profile descriptions and sample collections, particle-size distribution study, petrographic analyses, standard lab soil tests.
4. Discussion of three Palouse soils.
5. Cross-section of Palouse hill showing extent, depth, and sequence of horizons; figure of distribution of sand, silt and clay in profiles of three soils.
6. Physical, chemical, and mineralogical properties of three members of the Palouse catena, Palouse, Athena, and Thatuna soils, were investigated. The conclusions reached are applicable to an area

restricted both geographically and topographically.

Variation in microclimate, due to exposure and localized accumulation of snow, has been dominant in determining soil differences. The zonal prairie soil, Palouse silt loam, is found only on the relatively gentle south-facing slopes. A profile with chernozem morphology, Athena silt loam, is on the dry ridges. On the locally wet lee slopes a claypan soil, Thatuna silt loam has developed. Soil-forming materials are similar throughout the catena, except that the lee north slopes have accumulated a blanket of loess plus volcanic dust, younger than the underlying Palouse loess. Although the microclimate and associated changes in vegetation have determined the general course of soil formation in members of the catena, this layering of the soil-forming material has determined the position of the A-B break in the Thatuna profile, through its influence on the rate of water movement.

Mangum, A. W.; Van Duyne, C.; Westover, H. L., 1913, Soil survey of the Quincy area, Washington: U.S. Dept. Agri., 64 p., incl. soil map 1:62,500.

Maytin, I. L.; Starr, W. A., 1960, Soils of Yakima County, State of Washington Engineering Soils Manual; Wash. State Univ., Pullman, 158 p.

Maytin, I. L.; Gilkeson, R. A., 1962, Soils of Spokane County, State of Washington Engineering Soils Manual: Wash. State Univ., Pullman, 198 p., plus soils map.

______, 1962, Soils of Walla Walla County, State of Washington Engineering Soils Manual: Washington State Univ., Pullman, 122p.

McCreery, R. A., 1954, Mineralogy of Palouse and related series: Washington State College Ph.D. thesis, 120 p.

1. Palouse region, southeast Washington.
2. Palouse soil and loess.
3. Mineralogical methods.
4. Mineralogy of Palouse soil to determine its relation to soil morphology.
5. ---
6. Based upon the mineralogy of the heavy fraction of the very fine sand, the loess from which the soils in the area have developed is identical with the Ringold Formation modified by the addition of

pumicite. The Ringold Formation is thus a probable source of the loess in this area, but it cannot be considered as the source of the main body of loess. Volcanic derived minerals occur to considerable depth in the areas sampled. Vertical variation in the material deposited is evident from the mineral histograms presented.

Illite is the predominant clay mineral found. Mica intermediates make up a significant portion of the clay from profiles of the drier area. Montmorillinite seems to be closely associated with exchangeable magnesium. Little kaolin is present in soils of the Palouse loess.

McGee, D. A., 1972, Soil survey of Clark County, Washington: U.S. Dept. Agri. Soil Conserv. Svc., in cooperation with Wash. Agri. Exper. Sta., 113 p., with soils maps.

McHenry, J. R., 1957, Properties of soils of the Hanford Project: Hanford Works unclassified report HW-53218.

McMacken, J. G., 1925, Eolative soils of Washington wheatlands: Pan-American Geologist, v. 43, p. 177-184.

1. Southeast Washington.
2. Palouse Soils.
3. & 4. Field observations concerning origin of Palouse soils.

5. --
6. These Washington wheat soils are mainly residual in origin, formed by the decaying of the lava with its interbedded layers of clay, ash, and silt, but they are modified and moved by wind-action and are covered with thin layers of wind-borne dust from the Big Bend country and an ash from the western volcanoes. Clays from the flood-waters of the Spokane glaciation are also mingled.

Discusses geologic history of eastern Washington.

Michelson, J. C., 1954, Buried soil zones in the Palouse loess, eastern Washington (abs.): Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1345.

1. Eastern Washington.
2. Palouse loess.
3. Field observations of buried soil zones.
4. See title.
5. ---

6. The Palouse loess is dominantly a silt with lesser amounts of fine sand and clay-size particles. In most instances it shows little or no bedding or lamination although locally it has the characteristic bedding and sorting of silts, sands, and gravels deposited in standing and/or moving waters.

The Palouse loess is characterized by a near absence of fauna which makes it most difficult to assign a definite age to the deposit. Physical relationships indicate a Pleistocene age and probably late Pleistocene. Within the main body of the Palouse loess are two quite well-defined buried soil horizons. The upper buried soil horizon occurs 4 to 10 feet below the surface and conforms to the present topography, with a high percentage of pumicite above. Lower in the loess section is another well-defined buried soil profile that has wide distribution throughout the loess area of eastern Washington. The development of these soils and their subsequent burial make it possible to delimit and correlate members within the main body of the loess and may aid in finally assigning relative ages to the several units.

Ness, A. O., 1960, Soil survey of Mason County, Washington: U.S. Dept. Agri., Soil Conserv. Serv., 76 p., incl. soils maps 1:31,680.

Newcomb, R. C., 1938, Cause of the asymmetrical profiles of the typical Palouse hill: Northwest Sci., v. 12, no. 4, p. 96.

1. Palouse region, southeastern Washington.
2. Palouse loess and topography.
3. Field investigations.
4. See title.
5. ---
6. Dune action, coupled with unlike vegetation cover and resistance to seasonal erosion is dominant factor in typical, asymmetrical profile, <u>not</u> snowdrift erosion as proposed by W. A. Rockie.

______, 1961, Age of the Palouse Formation in the Walla Walla and Umatilla River Basins, Oregon and Washington: Northwest Sci., v. 35, p. 122-127.

1. Walla Walla and Umatilla River Basins, Oregon and Washington.
2. Palouse Formation.
3. ---

4. Data on the age of the Palouse Formation, description of Palouse soils; stratigraphic relationships to other sedimentary units.
5. Index map of Walla Walla and Umatilla River basins.
6. Typical Palouse Formation of Walla Walla valley is middle to late Pleistocene.

   Greatest deposition closely followed or accompanied deposition of Ringold formation and preceded Wisconsin Glacial Stage.

   If younger eolian deposits (termed Palouse soil) are to be included in Palouse Formation, age would be middle Pleistocene to Recent. Whereas Palouse soil problem would be clarified by restriction of term "Palouse" to the pre-Wisconsin loess.

Peterson, F. F., 1961, Solodized Solonetz soils occurring on the uplands of the Palouse loess: Washington State Univ. Ph.D. thesis, 280 p.

1. Southeastern Washington.
2. Palouse soil.
3. & 4. See title.
5. Chemical tables.
6. Within the former grasslands of eastern Washington and adjacent portions of Idaho and Oregon, Solodized Solonetz soils occur on the gently sloping to rolling uplands of the Palouse loess as small spots amidst the zonal soils of the chernozemic suborder, and as the dominant soils of some of these areas. Field and laboratory studies in 1950 established the morphological and chemical characteristics of these soils and their relationship to "slick spots," or areas of deflocculation and crusting in cultivated fields. Deflocculation appears to follow mixing of poorly aggregated material from lower horizons with the plow layer. The number and area of slick spots--already a serious problem in southeastern Washington--will continue to increase unless the Solodized Solonetz are recognized where they occur, and methods of cultivation are used which will not bring about mixing of horizons.

   These soils have been overlooked, or their morphology misinterpreted, in some past soil surveys of the area. The position in the landscape which they occupy does not fit the traditional theory of Solodized Solonetz formation, and the soil surveyor is left with little understanding of their patterns of occurence. This study reports the morphology, chemical characteristics, and patterns

of occurrence of these soils, and proposes theories concerning their genesis.

Peterson, P. P., 1922, Rate and mode of soil deposition in the Palouse area of Washington and Idaho: Science, new ser., v. 55, p. 102-103.

1. Southeast Washington and adjacent Idaho.
2. Palouse soil.
3. & 4. Field investigation of accumulation rate.
5. ---
6. Discusses origin of loess in general, and the Palouse Hills, in particular. Believes they formed by eolian action: wind picking up silt from an arid region (to the west) and depositing it in a more humid region where moisture and vegetation keep the silt from being moved further. Presents data from series of field experiments showing that an average of 7,500 pounds of dust is deposited around Moscow, Idaho per year. Extrapolates this to show that 4 inches of material deposited per century (with no erosion), and that it took 25,000 years to deposit the 75 feet of soil covering the lava beds in this area. States that this accumulation rate is 4 times that calculated by Free.

Phang, M. K. S.; Gilkeson, R., 1964. Soils of Clark County, State of Washington Engineering Soils Manual: Wash. State Univ., Pullman, 148 p., plus soils maps.

Rasmussen, J. J.; and others, 1971, Soil survey of Benton County area, Washington: U.S. Dept. of Agri. Soil Conservation Service in cooperation with Washington Agricultural Experiment Station, 72 p. plus 114 sheets.

Rasmussen, J. J.; Bayer, J. T.; Gale, P. S.; Raver, M. L., 1976, Soil survey of Yakima Indian Reservation irrigated area, Washington, part of Yakima County: U.S. Dept. Agri., Soil Conserv. Serv., 51 p. (incl. soils maps 1:20,000), Washington D. C.

Richmond, G. M.; Fryxell, R.; Weis, P. L.; Neff, G. E.; Trimble, D. E., 1965, Glacial Lake Missoula, its catastrophic flood..., and the loesses and soils of the Columbia Plateau, Part F. In Guidebook for Field Conference E., Northern and Middle Rocky Mountains - Internat. Assoc. Quaternary Research, 7th Cong,. USA, 1965: Nebraska Acad. Sci., Lincoln, Nebr., p. 68-89, illus.

(Annotated under Catastrophic Flood Features Section)

Rieger, S., 1950, Origin of the Palouse Formation: Washington State College Class paper, 12 p.

1. Southeast Washington.
2. Palouse loess.
3. & 4. Chemical analyses of loess, recapitulation of literature on subject, and field observations.

5. --
6. Wind erosion of the newly-deposited Ringold sediments, and deposition over the Columbia basalt. Coarsest materials were deposited closest to the source, and fineness of the material increased with distance from the source.

   Erosion of the Palouse material into a maturely developed drainage pattern with the surface of the basalt serving as temporary base level for the drainage.

   Advance of the Spokane ice sheet over the northernmost part of the Palouse Formation. Glacial meltwaters, either gradually throughout the period of glaciation, or suddenly as great masses of water, were released during the retreat of the glacier, washed away much of the western portion of the formation, leaving the present-day scablands surrounding islands of loess.

   Deposition of a layer of volcanic ash over the Palouse and surrounding country, and subsequent movement of this ash through normal erosion.

   Erosion of channels in the basalt by major drainageways in the region, with consequent accelerated erosion by intermittent tributary streams. High winter precipitation coupled with accumulation of snow on north and east slopes in the eastern part of the region causes this erosion to proceed so that the drainage pattern, as far as tributaries are concerned, is not dendritic, as one would expect under more common climatic conditions.

   Loess depositions from the front of the retreating Wisconsin glaciation resulting in a veneer of loess over much of the till plain to the north of the Palouse formation.

Rieger, S.; Smith, H. W., 1955, Soils of the Palouse Loess, Part II, Development of the A_2 horizon: Soil Sci., v. 79, p. 301-319.

1. Southeast Washington and adjacent Oregon and Idaho.
2. Palouse soil.
3. Field sampling; physical, chemical and mineralogical determinations.
4. Investigation to determine factors responsible for position of A_2 soil horizon in Palouse loess.
5. ---
6. Several soils of eastern Washington and northwestern Idaho were studied to determine the factors responsible for the development of A_2 horizons at unusually great depths in their profiles. Geographically associated soils without A_2 horizons were also studied.

   Bulk density, reaction, and textural variations among horizons in the profiles with A_2 horizons are comparable to those in planosols of the Middle West. Organic matter, under both forest and grass cover, usually decreases steadily with depth.

   Counts of heavy and light mineral grains from the very fine sand fraction of selected horizons indicate that the soils have developed from two mineralogically distinct parent materials; one, when present, always overlies the other. The upper parts of most of the profiles contain an admixture of volcanic ash. In many profiles, the A_2 occurs immediately above the boundary between the portion of the profile modified by volcanic ash and the portion containing no ash.

   The planosolic nature of the profiles with A_2 horizons is believed to be the result of the same process of whole fine clay translocation that operated in the formation of planosols of the Middle West. The location of the A_2 horizon, however, is believed to have been determined by an abrupt change in compaction and permeability occurring at the lower boundary of volcanic ash admixture in the parent material. The absence of this boundary within reach of percolating waters in several geographically associated soils is believed to have been responsible for the failure of A_2 horizons to develop in those profiles.

   It is expected that continued movement of fine clay would cause the A_2 horizon to migrate downward into the zone of parent material not affected by volcanic ash deposition. Several profiles illustrate soil development at this stage.

Sibley, E. A.; Krashevski, S. H., 1957, Soils of Kittitas County, State of Washington Engineering Soils Manual: Wash. State College, Pullman, Washington, 156 p.

Smith, H. W.; Moodie, C. D., 1947, Collection and preservation of soil profiles: Soil Sci., v. 64, p. 61-69.

Smith, H. W.; McCreery, R. A.; Moodie, C. D., 1952, Collection and preservation of soil profiles: Part II: Soil Sci., v. 73, no. 3, p. 243.

Smith, H. W.; Okazaki, R.; Aarstad, J., 1968, Recent volcanic ash in soils of northeastern Washington and northern Idaho: Northwest Sci., v. 42, no. 4, p. 150-160.

1. Northeastern Washington and northern Idaho.
2. Volcanic ash, soils.
3. Lab soil studies, field studies.
4. Properties, genesis and distribution of A_2 soil horizon.
5. ---
6. Considers the properties, genesis, and geographic distribution of an A_2 soil horizon in the West Blacktail clearcut area (27-T62N-R3WBM, Idaho) in the Kaniksu National Forest.

Smith, L. H., 1945, Soil survey of Kittitas County, Washington: U.S. Dept. Agri., 69 p., incl. soils maps.

______, 1958, Soil survey of Yakima County, Washington: U.S. Dept. Agri., 143 p., accompanied by set of 10 soil survey map sheets, 1:31,680, by the Washington Agri. Exp. Station.

Starr, W. A., 1953, Soil distribution in the Columbia Basin (Washington): Pacific Northwest Fertilizer Conf., 4th Ann., Pullman, Washington, 1953, Proc., p. 117-125.

Strahorn, A. T.; Carpenter, E. J.; Weir, W. W.; Ewing, S.; Krusekopf, H. H., 1929, Soil survey (reconnaissance) of the Columbia Basin area, Washington: U.S. Dept. Agri., 55 p., incl. soil map.

Thompson, J. P., 1936, Some relationships between the soil canyons of certain southeastern Washington valleys and summer fallow cultivation: Northwest Sci., v. 10, no. 1, p. 8-11.

Treasher, R. C., 1925, Origin of the loess of the Palouse region, Washington: Science, new ser., v. 61, p. 469.

1. Palouse region, southeastern Washington.
2. Palouse loess.
3. Field observations.
4. See title.
5. ---
6. Throughout east-central Washington, especially that region known as the Palouse wheat country, is a large area underlain by basalt, which is a part of the Columbia lava plateau. Above this basalt is a covering of very fine sand, which has a thickness as great as 250 feet and more.

   This fine sand has the characteristics of loess. When exposed in highway and railroad cuts, it stands with a vertical face, and in drying it shows vertical cleavage. It is composed of fine quartz sand, whose grains average 0.05 mm in diameter. The sand grains are sub-angular. The formation is iron stained and contains small concretions and tubelets of iron oxide. This loessial formation has two phases: one phase is massive, the other laminated; that is, stratified in thin, well-defined layers. These two phases are identical in composition, but differ in structure.

   From a study of the field conditions, the writer has reached the following conclusions in regard to the origin and occurrence of the Palouse loess: (1) That the loess was derived from the retreat of the continental ice sheet of pre-Spokane age, possibly Iowan or Illinoian. (2) That the loess was deposited in shallow, sluggish, ephemeral sheets of glacial water to a depth of about 250 feet on the surface of the flat-lying basalt before the period of Pleistocene deformation. (3) That a mature type of topography was developed on the surface of the loess. (4) That a period of deformation followed, during which the region was elevated. (5) That, following the uplift of the region, rejuvenation of the major streams came into evidence, developing deep canyons which were cut, first through the loess and then through the hard, underlying basalt. (6) That later, recent action of the wind shifted the water-laid loess, modifying its laminated structure to the massive type, and causing surface features to be developed characteristic of aeolian deposition. (7) That mud flows have subsequently developed on plowed hillsides during the rainy seasons of the year, modifying much of the surface covering so that the underlying laminated material has been largely lost to view.

Owing to the modification of the original loessial deposit by the surface action of wind and water, the underlying laminated phase is exposed only in widely separated localities, where deep roadcuts have recently been made. This laminated phase is considered by the writer to be the original loessial deposit.

The writer proposes the name Palouse Formation to these sedimentary beds. The fertile soil of the Palouse region is largely a residual modification of the Palouse formation and has locally been redeposited by wind and surface wash.

______, R. C., 1926, Stratigraphic aspects of loess of Palouse region: Pan-American Geologist, v. 46, no. 4, p. 305-314, 2 plates. C-24

1. Southeast Washington.
2. Palouse loess.
3. & 4. Field and laboratory analyses. Stratigraphic and petrologic aspects of loess.
5. Map showing extent of loess.
6. The writer previously suggested in Science a hypothesis for the origin and history of the Palouse loess. This summary is modified as follows:

(1) The Palouse Hills consist of loess, of which there are two phases, an original laminated phase which in composition is identical with the massive phase, but differs in structure and in being derived from the laminated phase.

(2) The Palouse Formation is not residual from the basalt as the formation is composed chiefly of quartz-grains, while the underlying basalt is practically quartz-free, and it does not appear to have been imported into the region as a dust deposit, but it was deposited by aqueous agents. It has many of the characteristics of glacial rock-flour, and from associated data, the most reasonable explanation of its origin at the present time, is that this loess was laid down on the retreat of the continental ice-sheet, pre-Spokane in age, probably Illinoian or Iowan age, as has been suggested by Bretz.

(3) The relationship between the loess and the Snake River canyon indicate that it was deposited before the present uplift of the region. It is suggested that deposition was effected as a flood-plain type of deposit, caused by the ephemeral flooding of the then existing drainage channels on the low-lying basalt which seems to be related to the Methow peneplain.

(4) A mature type of topography developed on the flat-lying Palouse formation.

(5) A period of deformation followed, the Palouse region being elevated and the Snake River thus rejuvenated.

Udine, G., 1956, HAPO soil information: Hanford Atomic Products Operation unclassified report HW-50239.

1. Pasco Basin, Washington.
2. Soils in Pasco Basin.
3. Compilation of existing soil data.
4. Soil information in Pasco Basin.
5. Tables.
6. Article discusses geologic features and formations in the area of Hanford Atomic Works, Richland, then sets up a guide and index showing location of existing soil data. Includes copies of test hole logs, soil bearing data, and miscellaneous soil information.

Van Duyne, C.; Agee, J. H.; Ashton, F. W., 1917, Soil survey of Franklin County, Washington: U.S. Dept. Agri., Bur. Soils, 101 p., plus soils maps.

Van Duyne, C.; Mortlock, H. C.; Hack, A. F.; Alvord, E. C., 1921, Soil survey of Spokane County, Washington: U.S. Dept. Agri., Bur. Soils, Field Operation 1917.

Vlasoff, P. I.; Wheeting, L. C., 1937, Characteristics of certain soil profiles of southeastern Washington: Soil Sci., v. 44, p. 71-72.

Waitt, R. B., Jr., 1977, Guidebook to Quaternary geology of the Columbia, Wenatchee, Peshastin, and upper Yakima Valleys, west-central Washington: U.S. Geol. Survey Open-File Report 77-753, prepared for GSA 1977 Annual Mtg. (Seattle), Field Trip No. 13, Nov. 1977, 25 p.

1. See title.
2. Surficial Quaternary deposits in eastern Cascade valleys.

3. Field study.
4. Interpretation of Quaternary glacial history.
5. Maps of glacial features near Cle Elum and Ellensburg; table of stratigraphy.
6. Eastern Cascades south of Chelan Valley record alternating periods of episodic alpine glaciation and weathering and soil formation. Best exposures found in upper Yakima Valley, Wenatchee Valley near Leavenworth and in Peshastin and Entiat Valleys. Yakima Valley shows three periods of alpine glaciation interspersed with long periods of soil formation. Wenatchee Valley also records three glaciations from morainal material.

   But nature of its terraces beyond drift limit is very different from those in Yakima Valley. Indicates different processes influenced late Quaternary development in the two valleys. Postulates is due to nearness of Wenatchee Valley to Columbia River versus Yakima Valley, and much lower altitude of Wenatchee Valley than Yakima Valley. Catastrophic late Wisconsin events influenced and obliterated most of the pro-glacial record in the Wenatchee Valley.

Wooldridge, D. D, 1964, Effects of parent material and vegetation on properties related to soil erosion in central Washington: Soil Sci. Soc. Proceedings 1964, v. 28, no. 3, 1964.

1. Central Washington.
2. Soils
3. Studies of soil's physical properties.
4. See title.
5. ---
6. In a preliminary study of physical properties of wild land soils, three soil parent materials were sampled by horizons under forest and adjacent grass cover. Soil properties analyzed were mean water-stable aggregate, bulk density, organic matter pH, total porosity, and percent clay, silt, and sand. Several of the measured soil properties were related significantly to parent material and horizon depth. Effects of vegetative cover were not reflected in overall averages of soil property values. However, these values broken down by parent materials and horizons, indicated that forest and grass covers were associated with soil property differences, although the relation of these differences to changes in parent materials and horizons is not consistent. Over 40% of the variation in soil erosion hazard (as measured by mean size of water-stable aggregates) is accounted for by multiple variation in soil organic matter content, pH, total porosity, and bulk density.

PHYSIOGRAPHIC FEATURES

Baldwin, E. M., 1950, Summary of the structure and geomorphology of the Columbia River basalt: Northwest Sci., v. 24, no. 2, p. 59-64.

1. Columbia Basin, Washington.
2. Geomorphologic features of basalt region.
3. Field observations.
4. See title.
5. ---
6. Basalt forms dominant topographic features of region. Streams flow through deep canyons at margins of broad basins before emerging onto basin floor. Others flow through water gaps. Some have been superimposed onto the basalt by vast accumulations of glacial sediments in valleys as is the case for Columbia River in certain areas. Some streams are antecedant to rise of a ridge, as parts of Columbia River were antecedant to rise of Cascades. Many rapids and ungraded portions of streams may be due to recent uplift or faulting. Question is posed about recent and ongoing deformation in region.

   Paper deals with other topics concerning Columbia River basalt - only geomorphological section is annotated.

Chappell, W. M., 1936, The effect of Miocene lavas on the course of Columbia River in central Washington: Jour. Geology, v. 44, p. 379-386.

1. Central Washington.
2. Columbia River basalt.
3. Field observations and literature review.
4. See title.
5. ---
6. Discussion of the alteration of the course of the Columbia River by projection of existing tributary drainage out onto the Columbia Plateau. Discusses the sharp easterly bend south of Wenatchee as further proof of a steep drop in the pre-lava flows topography. Discusses how the flow-interrupted drainage would lead to development of lava-

impounded lakes around margin of plateau. Sedimentary lake deposits have been described in these locations as interludes between basalt flows. Discusses Ginkgo fossil forest as further evidence and palagonite occurrences. Evidence suggests as I. C. Russell said, "that, in eastern Washington at least, the lava sheets flowed toward the mountains, and on congealing dammed the drainage streams." Discusses evidence for Miocene basalt flows from the west, also affecting the course of the Columbia River.

Denman, C. E., 1923, Topography and water supply of a Columbia River terrace: Washington State College B.S. thesis, 31 p.

1. North of Spokane, Washington.
2. River terrace.
3. Topographic field mapping.
4. Mapping topographic features and determination of water supply in area.
5. Topographic map of G. L. Denman place, Columbia River terrace.
6. Topographic mapping of terrace to determine water supply of area.

Easterbrook, D. J.; Rahm, D. A., 1970, Landforms of Washington - The geologic environment: Western Washington State College, Department of Geology, Bellingham, Washington, 156 p.

1. Includes Columbia Basin, eastern Washington.
2. All units in basin.
3., & 4. --
5. Several photographs of landforms.
6. Description of origin and nature of Columbia Basin landforms by presentation of geologic history of area.

Easterbrook, D. J.; Baker, V. R.; Waitt, R., 1977, Glaciation and catastrophic flooding of the Columbia Plateau, Washington (Field Trip No. 13). In Geological excursions in the Pacific Northwest: Geological Society of America 1977 Annual Meeting, Seattle, Washington, p. 390-414.

(Annotated under Catastrophic Flood Features section).

Fenneman, N. M., 1931, Physiography of western United States: McGraw-Hill Book Co., New York, 534 p.

1. Western U.S.

2. Physiographic features.
3. ---
4. ---
5. ---
6. Contains section on the Columbia Plateau including: province as whole; Snake River Plain; Payette section; Blue Mountains; Walla Walla; Eastern margin; Coulee district; Yakima district; Harney section; north-central Oregon.

Flint, R. F., 1934, Geomorphic features of the Okanogan region (abs.): Geol. Soc. America Proc. 1933, p. 81.

1. Okanogan region, Washington.
2. Geomorphic features.
3. --
4. Geomorphologic data including uplift, downwarp and stream changes.
5. --
6. The Okanogan region in northern Washington and southern British Columbia exhibits an undulating past-mature highland surface developed in resistant rocks, uplifted, and dissected by deep valleys. Before the uplift, the surface appears to have been deformed into a downwarp flanked by upwarps, with north-south axes. The long, south-flowing Similkameen appears to be older, antecedent to the upwarp west of the Okanogan. Smaller streams are controlled by minor structures.

   The southern part of the warped surface has been covered by the basalt of the Columbia Plateau. Although initially localized by the basalt margin in a roundabout route, the Columbia River now follows a shorter route through a deep gorge that cuts off a large salient of basalt. This and other stream courses in various parts of the region are attributed to glacial derangement of drainage.

   The inferred warping in the Okanogan region is related to the movements that brought the Cascade region into prominence.

Freeman, O. W., 1933, Stagnation of the Okanogan lobe of the Cordilleran ice sheet and the resulting physiographic effects: Northwest Sci., v. 7, no. 3, p. 61-66.

1. North central Washington.
2. Glacial erosional and depositional features.
3. Field investigations.

4. See title.
5. --
6. Article describes extent of Okanogan lobe of the Cordilleran Ice Sheet and glacial landforms it left behind. Proposes, in concurrence with R. F. Flint, that the ice lobe stagnated and slowly dissipated itself in situ and that it did not retreat. Presents geologic evidence in support of proposal.

______, 1936, Geologic and geographic interrelations of Washington: Pan-Am. Geologist, v. 66, no. 5, p. 157-158.

1. Washington State, including Columbia Basin.
2. Physiographic features.
3., & 4. Presentation of the interrelationships of Washington geology and geography through a series of maps.
5. Maps: physical regions; hypsometry of Washington; generalized geologic map; soils map; rainfall distribution; vegetation map; type of farming; principal mining centers; distribution of population.
6. Article demonstrates the influence of geology and geographic factors in the state. Boundaries of physical regions coincide largely with geologic changes. Geology has exerted a major influence on mineral deposits. The relief features have resulted mainly from geological forces and form a major determinant of the climate. As a result of climatic differences, we get vegetation and soil provinces, and as a result of climate and soil, we get diverse types of farm utilization of land.

   Maps therefore drawn to show variation in distribution of population, industries, transportaton routes, etc., in Washington, exhibit such a marked relationship to environmental factors that obviously they have been chiefly determined by the natural factors of geology, relief, soils, minerals and rainfall.

______, 1940, Glacial drainage changes north of the Columbia Plateau (abs.): Geol. Soc, Am. Bull., v. 51, no. 12, pt. 2, p. 2021-2022.

1. North central Washington.
2. Glacial erosional and depositional features.
3. Field investigations.
4. See title.
5. Map showing location of glacial drainage channels.
6. The Okanogan Highlands and other ranges of northeastern Washington were covered by glacial ice

that moved southward from the intermontane plateau of Canada. The southward extension of the ice sheet has been mapped by Bretz and Flint, who have also given their interpretations for the origin of the scablands that were eroded by glacial meltwaters. North of the area they describe are dozens of glacial drainage channels and other features such as marginal lakes and associated spillways that were developed during the melting and wasting of the ice sheet. Since the glaciers were thickest in the major valleys, the drainage channels generally form a braided sort of pattern on both sides of such north-south-trending trenches. The character of deposits made by the meltwater during the glacial period is briefly mentioned. A map showing the location of the glacial drainage channels of Washington accompanies the paper.

______, 1940, Physiographic divisions of the Columbia Plateau: Assoc. Pacific Coast Geog. Yearbook, v. 6, p. 12-20, illus. incl. index map.

1. Columbia Plateau.
2. Columbia River Basalt Group, Palouse Formation, Ellensburg Formation, Ringold Formation, etc.
3. Field observations.
4. See title.
5. ---
6. On the basis of differences in physiographic relief it has been found desirable to divide the Columbia Plateau into 12 main divisions: 1. Waterville Plateau; 2. Palouse Hills; 3. Channeled Scablands; 4. Central plains; 5. Yakima marginal folds; 6. Blue-Wallowa-Seven Devils Mountains, and connecting Snake River High Plateau; 7. Tri-State Slopes; 8. Deschutes-Columbia Plateau; 9. Payette Section; 10. Snake River plain; 11. Owyhee Section; 12. Harney Basin.

   These divisions are described in terms of geologic history and geomorphological form.

Freeman, O. W.; Forrester, J. D.; Lupher, R. L., 1945, Physiographic divisions of the Columbia Intermontane Province: Assoc. Amer. Geographers Annals, v. 35, p. 53-75.

Fryxell, R., 1966, Origin and age of Palouse Hills topography eastern Columbia Plateau: Geol. Soc. America Abs. with Prog.

1. Southeastern Washington.

2. Palouse hills.
3. Field observations.
4. See title.
5. ---
6. The Palouse Hills of eastern Washington and adjacent Idaho comprise a loessial landscape of unusual complexity. Hundreds of construction cuts, examined since 1956, show that the loess mantle rests primarily on Miocene basalt into which asymmetric valleys are incised several hundred feet. Loess sheets of Pleistocene age, separated by paleosols, overlap bedrock topography in northeasterly progression. Locally, the cumulative loess thickness exceeds 150 feet. Each loess sheet generally is thicker on northeasterly slopes of the landscape it buried; as a result, drainage divides shifted northeasterly also. Major streams such as the Palouse River and its forks maintained their preloessial valleys, into which early loess sheets and paleosols may be traced. On interfluve areas, however, control by bedrock topography diminishes where loess accumulations are thickest. Hence modern first- and second-order drainageways usually are cut in loess only, independent of bedrock configuration. Although their courses reflect frequent ponding during loess deposition, these ephemeral headwater streams scallop the thick interfluve loess blankets into groups of individual hills which generally lack bedrock cores. Cores of older loess are exposed instead, often exhumed on lower slopes and protected by resistant paleosol caps, to form knoblike or benchlike outliers. Because all but the two youngest loesses and their associated soil profiles (assigned to Pinedale [Wisconsin] and Recent ages through radiocarbon dating) consistently are truncated by present surfaces, the landscape now existing was established by Pinedale time (ca. 25,000 B.P.) Subsequently, relief was sharpened by nivation under snow drifts concentrated on northeasterly slopes, and solifluction deposits accumulated in valley bottoms.

______, 1972, Relationship of late Quaternary volcanic ash layers to geomorphic history of the Columbia Basin, Washington (abs.): Abs. with Programs, Geol. Soc. Am. Cordilleran Sec.

Gentry, H. R., 1974, Geomorphology of some selected soil-landscapes in Whitman County, Washington: Washington State University M.S. thesis, 130 p., soils maps.

1. Whitman County, southeast Washington.
2. Palouse loess.
3. & 4. Study to relate soil properties to age of parent material and positions on landscapes.
5. General soils map of Whitman County; profiles of several soils.
6. A study was conducted to relate soil properties (diagnostic horizons) to age of loess (parent material), and positions on landscapes. Whitman County, the primary area of this study, is in the southeastern part of Washington.

   The soil forming materials are derived from several sources including loess, volcanic ash, stream alluvium, glacial outwash, colluvium and residuum from basalt and metasediments. Soil forming materials were identified by age, described, and characterized.

   Past climates in this area, especially during Pleistocene, have not been constant for any great length of time. Past climatic changes were inferred from paleofeatures in soils which are correlated and included in a table on the chronology of loesses and events. Past and present climatic influences on soil formation were considered. The relationship of modern and relict landscapes to present distribution of soils was explored. Nearly all of these soils are of polygenetic origin and these differences are related to geomorphic history.

   Soils and soil associations of Whitman County were described and characterized. The proportion and patterns of individual soils on certain types of topography were described for each soil association. Major soils in each soil association were related to certain types of topography which are illustrated by computer-assisted block diagrams.

Judson, S.; Ritter, D. F., 1964, Rates of regional denudation in the United States: Jour. Geophys. Research, v. 69, no. 16, p. 3395-3401.

1. Includes Columbia basin.
2. Surface sediments.
3. Mathematic models of stream loads and surface denudation.
4. Measurements of stream sediment loads to calculate regional rates of land denudation.
5. Tables showing suspended sediment loads by individual stream basins including Columbia; estimates

of annual chemical denudations; rates of regional denudation; comparison between regional denudation rates reported in this study and others; relation by regions between detrital load and dissolved load.
6. Data, in large part collected since World War II, allow a recalculation of the rates of regional erosion in the United States as a whole of 2.4 in./1000 years, or about twice that of older estimates. The most rapid rate, 6.5 in./1000 years, is recorded from the Colorado drainage. The slowest rate, 1.5 in./1000 years, is found in the Columbia basin. Other drainage areas and their rates are the Pacific slopes, California, 3.6 in./1000 years; the western Gulf of Mexico, 2.1 in./1000 years; the Mississippi River watershed, 2.0 in./1000 years; the South Atlantic and the eastern Gulf of Mexico, 1.6 in./1000 years, and the North Atlantic, 1.9 in./1000 years.

Kaiser, V. G.; Starr, W. A.; Johnson, S. B., 1951, Types of topography as related to land use in Whitman County, Washington: Northwest Sci., v. 25, p. 69-75.

1. Whitman County, southeast Washington.
2. Palouse soil.
3., & 4. Description of different topographic units as it relates to proper land use.
5. Map showing distribution of different land forms in Whitman County.
6. The topography of the Palouse area in Whitman County is not homogeneous. Twelve different types of land forms have been recognized. Each land form imposes certain limitations and requirements on the soil and water conservation program planned for it.

King, P. B., 1958, Evolution of modern surface features of western North America. In Hubbs, C. L., ed., Zoogeography: Am. Assoc. Advancement Science Pub. 51.

1. Western North America. (Including Columbia Basin, Washington.)
2. All formations in subject area.
3., & 4. Field observations and literature review.
5. Maps of western U.S. showing generalized conditions during present, Pennsylvanian and Permian, Triassic and Early Jurassic time, Late Jurassic and Early to middle Cretaceous time, latest Cretaceous and Paleocene times; map of northwestern volcanic province.
6. Western North America is the region of the Cordilleran system of mountain ranges, which extend

inland from the Pacific Coast 400 to 1,000 miles to the Great Plains of the continental interior. The landscape of the region has been shaped by surface processes of erosion, sedimentation, and volcanism, but ultimate cause of the features is deeper in the crust, in processes that have deformed the rocks, brought about emplacement of magmas, and raised or lowered large sections of the surface. These processes, though spasmodic, are persistent through history. In considering the growth of a mountain system such as the Cordillera, they may be generalized into a geosynclinal phase, as orogenic phase, and a post-orogenic phase.

The geosynclinal phase was a time of sedimentation and rather mild crustal activity. In the Cordilleran region it persisted through Paleozoic time and through the first half of Mesozoic time.

The orogenic phase began earliest in the western part of the Cordillera, broadly in mid-Mesozoic time--in places in the Jurassic, elsewhere somewhat later. Rocks formed in this part of the geosyncline were deformed, metamorphosed, and invaded by large bodies of magma. The deformed rocks were raised into a land surface, from which detritus was shed westward into the Pacific Ocean basin, and eastward as a broad sheet into the interior of the continent, across the remainder of the geosyncline.

During Cretaceous time, deformation progressed eastward from the initial disturbed belt, folding and faulting the rocks of the Great Basin area, more lightly affecting those on the site of the Colorado Plateau, and more heavily affecting those in the Rocky Mountains beyond. In the southern part of the Rocky Mountains, zones of weakness had already been created by mountain-making during Paleozoic time. By the close of the orogenic phase, in Late Cretaceous and Paleocene times, deformation had reached the edge of the present Great Plains, but it progressed no farther inland.

The folding and faulting of the orogenic phase did not produce the modern topography. While the surface was raised and lowered by it, leveling processes of erosion and sedimentation were active and prevented development of strong relief; moreover, regional altitudes remained low.

Modern surface features evolved by a multitude of crustal processes during the post-orogenic phase, in Tertiary and Quarternary times. Intermontane basins subsided (as in Wyoming and Colorado), large areas were broken up by block faulting (as in the Great Basin), other large areas were overspread by lava (as in the Columbia Plateau), and mountains were formed by the building of chains of volcanoes (as in the Cascade Range). Besides, extensive regions were uplifted relative to their surroundings, with little internal deformation. The largest uplifted region centered in the Rocky Mountains and extended into the Great Plains and Colorado Plateau; it was raised mainly before later Tertiary time, but with diminishing uplifts into the Pleistocene. Smaller, more complex uplifts took place somewhat later in the Sierra Nevada and Cascade Range; in the Sierra Nevada, uplift was accompanied by marked faulting along the eastern side.

The post-orogenic (Tertiary and Quaternary) movements raised the Cordilleran region to its present generally high altitude. Streams, quickened by the uplift and by increased rainfall during the Pleistocene, etched out the mountains and canyons; mountain barriers prevented free circulation of moisture-laden winds from the Pacific and heightened the climatic contrasts. Since mid-Tertiary time, regional relief, local relief, and climatic contrasts have been greater in the Cordillera than at any earlier period.

Throughout geologic time, the Cordilleran system has been bordered on the west by the deep Pacific Ocean basin, floored by crustal material different from that of the continent. It is unlikely that any additional lands ever existed offshore that have since foundered to oceanic depths. More likely, continental area has been added at the expense of ocean basin by various accretionary processes. On the other hand, land connections persisted intermittently along the strike of the Cordilleran system, between North America, Asia, and South America, as the coastal areas of all three are part of a circum-Pacific belt of mountain structures whose origin, like the North American Cordillera, extends far back into the geologic past.

Kirkham, V. R. D.; Johnson, M. M.; Holm, D., 1931, Origin of Palouse hills topography: Science, new ser., v. 73, p. 207-209.

1. Whitman County, Washington.
2. Palouse Formation and topography.
3. Discussion and field observations.
4. Descriptions of measurements of amphitheaters at heads of small tributary streams in study area.
5. ---
6. 90 percent of minor valleys (intermittent tributary streams that drain into regular stream channels) are of the cirque-like amphitheater type at their head. The predominant process of dissection of the loess-covered Columbia Plateau is by the formation and enlargement of amphitheaters. All of the valleys and depressions, regardless of age, present the characteristic curves of maturity with the upper part convex and the lower part concave.

Large, T. , 1924, Drainage changes in northeastern Washington and northern Idaho since extravasation of Columbia basalts: Pan American Geologist, v. 41, no, 4, p. 259-270, 4 plates.

1. Eastern foothills of Cascade Range to Purcell Trench.
2. Stream sediments and Columbia River basalts as they record changes in stream patterns.
3., & 4. Evidence to support stream drainage changes.
5. Map of ancient and modern eastern Washington lakes.
6. Article deals with recent changes in the course of Columbia River and tributaries between eastern Cascades and Purcell Trench. Mainly discusses prehistoric Lake Clark and its drainage and reasons to account for disappearance of the lake.

Lewis, P. F., 1960, Linear topography in the southwestern Palouse, Washington-Oregon: Assoc. Am. Geographers Annals, v. 50, no. 2, p. 98-111, incl. sketch maps, diagrams, and illus.

1. Washington-Oregon Palouse region.
2. Topographic landforms and Palouse loess.
3. Field and lab work, interpretation of aerial photographs.
4. Explanation of linear topography and extent.
5. Map of aligned topography in southwest Palouse and vicinity; drainage maps for southwest Palouse and of Palouse loess from southwest to northeast; wind velocity and direction diagrams.
6. Area of aligned topography is 2000 square miles (half of Palouse) and boundaries are indistinct. Lineation is dominant feature of landscape with a constant northeast direction. Ridges are quite

uniform in dimensions. The alignment and essential form of linear topography has resulted from deposition of loessial material by the wind, more rapidly in some places than others. This is the "wind shadow" hypothesis. If wind is carrying loessial material in suspension, deposition will occur where wind velocity is reduced. The obstacles to wind were provided by obstacles in the eroded pre-loess basalt surface. Evidence for this theory: small streams are aligned with linear topography; the ridges, similar in shape, taper to the northeast, but end abruptly to southeast; silt-bearing winds blew from south-southwest with great consistency.

Mackin, J. H.; Cary, A. S., 1965, Origin of Cascade landscapes: Washington, Div. Mines and Geology, Inf. Circ. No. 41, 35 p.

1. Includes Columbia Basin, Washington.
2. All formations in the area.
3. Observatins and literature review.
4. See title.
5. --
6. Includes description and origin of landscapes including Columbia Gorge, basalt floods, the Columbia River, and the effects of glaciation and catastrophic flooding.

Meyer, B. E., 1971, Grit and grass; a historical geography of Adams County, Washington: Northwest Sci., v. 45, no. 1, p. 48-71.

1. Adams County, Washington.
2. Topography, soils.
3. Historical account.
4. See title.
5. Topographic diagram, Adams County; land use capability classes in Adams County; historical agricultural tables.
6. Geologic history of county and description of topography; description of climate, soils, ecological changes; historical account of natives and settlers, land acquisitions, ranching problems, early roads and settlements.

Miller, E. E., no date, Geography of Grant County, Washington: Washington Univ. (Seattle) M.A. thesis.

Molenaar, D., 1976, Pictorial landform map of the State of Washington and adjacent parts of Oregon, Idaho, and

British Columbia: (Published by the author) Burley, Washington, 1 sheet, multicolor. Scale approximately 1:750,000.

Newcomb, R. C., 1938, Cause of the asymmetrical profiles of the typical Palouse hill: Northwest Sci., v. 12, no. 4, p. 96.

(Annotated under Soils section.)

Ozier, R., 1971, Pre-Miocene geomorphology and the Tertiary-pre-Tertiary unconformity, Grand Canyon of the Snake River, Oregon and Washington (abs.): Geol. Soc. America Abs. with Programs, v. 3, no. 4, p. 273-274.

1. Grand Canyon of Snake River, Oregon and Washington.
2. Basalt flows, pre-Tertiary bedrock, post-basalt sediments.
3. Field observations.
4. See title.
5. --
6. Down-cutting of the Snake River in recent time has exposed the Tertiary-pre-Tertiary unconformity for a distance of more than 185 miles along the eastern borders of Oregon and Washington.

   The pre-Tertiary rocks exhibit an extremely complex geology, with considerable faulting, folding, shearing and metamorphism. These units have been described by Morrison 1961, Vallier 1967, Brooks and Vallier 1967 and 1970, and White 1968. Near the end of pre-Tertiary time the entire area was subjected to a considerable period of erosion. In early Miocene time and later the area was inundated by massive basalt flows which concealed the pre-Tertiary topography.

   During the summer of 1970 the author mapped in detail the Tertiary-pre-Tertiary unconformity. Air photo interpretation, field reconnaissance and petrographic studies were made. As a result, the relief and character of the pre-Tertiary surface can be partially reconstructed and the pre-Miocene geomorphology inferred.

   The pre-Tertiary surface can be characterized as having developed to the early mature stage, with adjustment of streams to lithological variations, sharp divides between streams and minimum area of interstream uplands. Relief attained a maximum of no more than 1500 feet. Isopach maps indicate the earliest basalt flows filled in existing stream valleys, disrupted drainage and created small lakes. Many of these lakes subsequently became receptacles for deposits of volcanic ash concentrations . In some instances soils developed between successive flows causing an interfingered appearance in the Tertiary-pre-Tertiary unconformity.

Rahm, D. A., 1961, Terracettes - an index of erosional environment of slopes (abs.): Northwest Sci., v. 35, no. 4, p. 164.

1. Columbia Plateau, Washington.
2. Soil and mantle rock on face of slopes.
3. Measurements and cross-sections through slope faces.
4. See title.
5. ---
6. Terracettes, also known as "sheeptracks," "cat steps," etc., are a common feature on slopes of the Columbia Plateau. Contrary to lingering tradition, they are not the result of impact by the hooves of animals. Cross sections of terracettes, exposed near Pullman, Washington, show that they are slump blocks produced by small-scale gravity faulting of unconsolidated surficial materials.

   Terracettes form where the surface materials of a slope are placed under tension and pull apart. This comes about where the covermass can slump toward a "free face" or steep basal segment of the slope. Active lateral erosion against the base of a slope or simply downcutting by a stream at its base can serve to undermine the soil and mantle rock and bring about the tensile condition. Terracettes form best on steep slopes, straight or convex in profile, which are undergoing active basal erosion. They are relatively poorly developed on concave slopes where basal erosion is characteristically at a minimum. Thus the terracettes can be used to "read" the erosional environment of a slope.

Ringe, L. D., 1968, Geomorphology of the Palouse Hills, southeastern Washington: Washington State Univ. Ph.D. thesis, 73 p.

1. Southeastern Washington.
2. Palouse loess, Columbia River basalt.
3. Field observations, measurements and distribution of loess deposits, resistivity measurements, drainage basin analysis study of basalt outcrops.
4. Study of basalt surface under Palouse loess to

determine topography and its effect on topography of loess.

5. Resistivity profile, Roundtop well, Howard Brown well, Whitman Company; topographic landform variations, Whitman Company; principal drainage map in southern Palouse, upper portion Penewa Creek drainage; topography of basalt surface in study area.
6. Studies have recently been made on basalt surface beneath loess of Palouse Hills region of southeastern Washington to determine topography of this surface and effect on unique topography of the Palouse. Detailed and random resistivity measurements indicate the loess was deposited on gently undulating basalt surface which presently dips to southwest at less than one degree but becomes steeper to west. Loessial soils on basalt locally attain thickness over 250 feet in southwestern Palouse but thin to less than 100 feet to northeast. Palouse hills of high relief have a thick loess mantle and more steeply dipping basalt, while hills of low relief characterize regions of thin loess and an almost flat basalt surface. Some of the large, intermittent stream valleys have thicker loess deposits on western or southwestern side, indicating wind-shadow effect during accumulation. Resistivity measurements in underfit valleys indicate channels in basalt up to 60 feet deep and filled with silt and clay. Drainage basin analysis reveals that average slope differs sharply between areas of different topography. Outcrops studied give no indication of thickness of basalt that may have been eroded away prior to deposition of the loess.

______, 1970, Sub-loess basalt topography in the Palouse Hills, southeastern Washington: Geol. Soc. America Bull., v. 81, no. 10, p. 3049-3060.

1. Southeastern Washington.
2. Basalt topography.
3. Study of outcrops, well-data and resistivity measurement reports.
4. See title.
5. Topography of basalt surface over study area, including well locations and resistivity stations; Garfield area, blown-up topographic map and cross section and topography profile; same for Pullman, St. John, Wilcox areas.
6. The Palouse loess of southeastern Washington was deposited on a gently undulating surface of Columbia River basalt. Resistivity measurements

indicate that the loess attains thicknesses in excess of 250 feet in the southwestern Palouse, but thins to less than 100 feet in the northeast. The low, rolling hills of the northeastern Palouse are formed in the areas of thin loess deposited on an almost horizontal basalt surface. The high, steep hills that typify the western and southwestern Palouse are associated with 200 feet or more of loess deposited on a more steeply inclined basalt surface.

Rockie, W. A., 1934, Snowdrifts and the Palouse topography: Geogr. Rev., v. 24, no. 3, p. 380-385; (abs.) Revue de Geologie et des Sciences Connexes, v. 15, no. 5, p. 254-255.

1. Palouse region, southeastern Washington.
2. Palouse Formation.
3. Field observation.
4. Cause of Palouse topography, especially the effect of snow drifting.
5. ---
6. Prevailing southwest winds cause the snow to form deep drifts on the northeast leeward slopes where they are protected from the low sun. The snow may contain considerable wind blown soil. Wash from the drift is effective in eroding and steepening the northeast slopes. The combination of heavy snowfalls, comparatively low incidence of the sun, prevailing southwest winds, sudden thaws, complete absence of trees or brush, and high relief all appear to contribute to the peculiar Palouse topography which resembles ocean waves with a strong southwest wind. The Palouse region may not have always been covered with a heavy mantle of grass as at present, and after the dendritic drainage had intrenched itself but before an ample vegetative cover had developed, the processes described may have helped to produce the characteristic topography.

Russell, I. C., 1898, The Great Terrace of the Columbia and other topographic features in the neighborhood of Lake Chelan, Washington: American Geologist, v. 22, p. 362-369.

1. Lake Chelan region, Washington.
2. Great Terrace of Columbia River.
3. Field observations, aneroid measurements.
4. Discussion of and dispute over another author's (W. L. Dawson) interpretation of geologic history of region and elevation of the great terrace.

5. ---
6. The Great Terrace of the Columbia is a stream terrace. Paper is the answer to a challenge by another author (W. L. Dawson) on the height of this terrace. The height of the terrace above the river at the mouth of the Methow River is 550 feet. The terrace only occurs upstream of the Columbia where its canyon is narrow. It was developed where the Columbia discharged into ancient Lake Lewis, building up a delta of coarse material and as a result, the upstream river channel became filled with gravel. After Lake Lewis disappeared, the Columbia excavated its present inner channel through the gravel. Author found evidence of glacial ice from the source of the Methow River to Winthrop. The Methow Glacier didn't reach within 50 miles of the Columbia and therefore had no connection with the origin of the coulee opposite the mouth of the Methow. Also states Antwine's Coulee was never occupied by ice, nor was Knapps Coulee.

Shedd, S., 1923, Topography and geology of the Okanogan Highlands and Columbia Plateau of Washington (abs.): Geol. Soc. America Bull., v. 34, p. 75.

1. Eastern Washington.
2. All formations of subject area.
3., & 4. Field observations.
5. --
6. A general discussion of the surface features and geology of the eastern part of Washington. The Okanogan Highlands constitute a large area of metamorphic rocks, part of which was probably originally sedimentary and part igneous. The Columbia Plateau, as used in this paper, refers to that part of the great lava field, in the northwestern part of the United States, which lies within the State of Washington. The surface features of parts of this area are very interesting and are a result, partly at least, of the action of the wind.

Smith, G. O., 1903, Geology and physiography of central Washington: U.S. Geol. Survey Prof. Paper 19, p. 9-39. D-3-87, E-1-107

Thompson, J. P., 1935, Palouse topography and its relation to stream history: Northwest Sci., v. 9, no. 8, p. 16-17.

Waitt, R. B., Jr., 1972, Geomorphology and glacial geology of the Methow drainage basin, eastern North Cascade

Range, Washington: Univ. of Washington Ph.D. thesis, 154 p.

1. See title.
2. See title
3. Field observations, mapping and measurements.
4. Evidence for revised mapping and interpretation of historical geologic processes that have occurred in study area.
5. Index map of streams; map of bedrock geology; chart of stratigraphic relations in Cascade Range and surrounding areas; comparative cross-profiles of Chelan, Yosemite and Methow troughs; time-distance diagram of latest advance of Cordilleran Ice Sheet; maximum extent of glaciers during alpine phase; summary of ice flow directional data; topographic and striation map of Methow trough; topography map of Eight Mile Creek area; maximum extent and surface contours of Cordilleran Ice Sheet; drainage derangement map of mouth of Methow Valley; major kame terraces along Methow Valley.
6. The Methow Valley, excavated in upturned Mesozoic sedimentary and volcanic rocks downfaulted between crystalline blocks, is ideally positioned to have originated as a consequent stream on floor of early Tertiary graben. Boundary scarps vary from resequent to obsequent, however, depending on erosional resistance of rocks juxtaposed across the faults. The Methow-Pasayten lowland is therefore of erosional origin - a rift-block valley, not a graben. Cirques, aretes, and U-shaped hanging troughs characteristic of alpine glaciation dominate the northern Methow landscape. Surface drift is of northern provenance and mantles high ridge-crests as well valley floors.

   Ice-sheet glaciation post-dated most recent alpine advance. Because alpine drift and depositional landforms are absent in Methow region, having been eroded by the ice sheet, the maximum extent of alpine glaciers must be inferred wholly from such erosional evidence as cirque morphology and limits of U-shaped cross-valley profiles. Alpine glaciers ranged from small, steep, independent glaciers in tributary valleys to long, gently inclined trunk glaciers in main valleys. Beveled-off cols and ridges, striations, drift, and hummocky topography at high altitudes are primary modifications of Methow upland by ice sheet. Last glaciation correlated with Fraser Glaciation of western Washington and British Columbia. Ice sheet in

Methow valley was sector of Cordilleran Ice Sheet. Cordilleran ice entered Methow drainage basin not only through Harts Pass area, but over cols at heads of all major tributaries. Ice sheet innundated Chelan trough as well. Ice sheet over the northern areas was almost continuous, broken only by few scattered nunataks. Methow Mountains were continous nunatak which separated Methow and Chelan sectors of ice sheet. Deglaciation did not produce end moraines; instead, kame terraces, associated ice-marginal channels kettles, eskers, and other ice-contact landforms indicate that mountainous terrain deglaciated largely by downwasting and regional stagnation. Alpine glaciers were not significantly regenerated after Cordilleran Ice Sheet melted. A late-glacial alpine phase was lacking. Glaciers fluctuated to changes of climate rather than to glacier dynamics.

Warren, C. R., 1941, Course of the Columbia River in southern central Washington: Am. Jour. Sci., v. 239, p. 209-232.

1. South-central Washington.
2. Ancient Columbia River.
3., & 4. Field observations of Hood River conglomerate in support of inference that Columbia River once followed course marked by belt of this conglomerate.
5. Map of distribution of Hood River conglomerate.
6. The Columbia River probably once followed a course now marked by the belt of outcrop of the Hood River conglomerate, southwest from Sentinel Gap in the Saddle Mountains past Sunnyside and Goldendale, Washington, to Hood River, Oregon. This inference is based on the lithology of pebbles, on supposed windgaps in the crests of the two highest ridges along the inferred former course, and on the change from antecedence to structural control of the Columbia and Yakima Rivers at points directly related to the inferred former course. This course it occupied at the end of the period of accumulation of the Yakima Basalt. The present course from Sentinel Gap to Hood River, crossing the Horse Heaven Hills uplift at a structural low point 80 miles east of the former crossing at Satus Pass, is structurally controlled and must have originated after the beginning of deformation of the basalt. Diversion was probably the result of defeat of the river by the rise of the anticlinal ridge across its course, probably in late Pliocene or early Pleistocene time.

Waters, A. C., 1933, Terraces and coulees along the Columbia River near Lake Chelan: Geol. Soc. Am. Bull., vol. 44, p. 783-820.

(Annotated under Sedimentary Units section.)

______, 1955, Geomorphology of south-central Washington, illustrated by the Yakima east quadrangle: Geol. Soc. America Bull., v. 66, no. 6, p. 663-684, 1 Plate, scale 1:62,500. E-2-120, 0-16

1. South-central Washington.
2. Landforms, Ellensburg Formation, Pleistocene and recent sediments, basalt flows in Ellensburg Formation, Yakima Basalt.
3. & 4. Geologic mapping, review of literature.
5. Geologic map and cross-section of Yakima East quadrangle, erosion surfaces discordant to structure; map showing anticlinal mountain ridges of south-central Washington; profiles of dissected pediments; spur east of Kelley Hollow.
6. Geologic mapping of the Yakima district has been neglected since publication of the Ellensburg and Mount Stuart folios (G. O. Smith, 1903a; 1904; see also Calkins, 1905). Reports on other parts of the Columbia River plateau, however, pose new problems and call for revision of some interpretations. This paper presents the results of extending Smith's mapping eastward into the adjacent Yakima East quadrangle, and of considerable reconnaissance work in adjoining areas. The new mapping shows that to the east and south the lower part of the Ellensburg Formation interfingers with the Yakima Basalt. It also indicates that local diastrophism and volcanism continuously modified and interrupted deposition of the Ellensburg Formation.

   Smith's conclusions that the great topographic ridges are growing anticlines, not fault blocks, and that the major rivers are antecedent to these folds, are confirmed. The anticlines appear to have grown in a single epoch of deformation instead of in two orogenic episodes separated by a period of peneplanation. The "Cascade lowland" is a local pediment formed on the flanks of a growing anticline, not a remnant of a widespread peneplain.

   The new data do not support Warren's hypothesis of defeat and diversion of Columbia River by rise of the Horse Heaven uplift, nor Flint's hypothesis of the cutting of Wallula Gap by a river thus diverted.

Willis, B., 1887, Changes in river courses in Washington Territory due to glaciation: U.S. Geol. Survey Bull. 40, 10 p.

1. See title.
2. Geomorphologic studies.
3. Field observations.
4. See title.
5. Map of eastern Washington Territory, showing distribution of rocks along lines of observation; pre-glacial channel of the Similkameen River; lower valley of the Okinakane River to the Columbia River; Columbia River from the Okinakane (sic) River to Lake Chelan.
6. General slope of area is south. Wenatchee, Methow, Okinakane and San Puel Rivers are members of consequent and unmodified system, carved on older surface of granite and crystalline sediment rocks, with broader valleys than Columbia's. Course of Columbia River determined in part by southward, northward and westward basalt flows. Channels, new without great rivers, lead into the basin where they once converged with the ancient Columbia River before it was diverted. The valleys of the Colville, Vermilion and Pack Rivers belonged to the old system, their lower valleys filled with basalt. Their abandonment by great rivers result of later causes of glacial period when valleys were filled with drift and the rivers forced to divert across lowest gap in watershed.

   Account is given of the glaciation of the region about Lake Pend d'Oreille, how glacial sediments filled old river valleys, forcing abandonment, and showing former existence of glaciers in river valleys of extreme northern part of territory, either as portions of a general ice sheet or as tongues pushed forward from disconnected ice rivers descending from the north.

Winters, H. A.; Stradling, D. F., 1967, The Yakima folds - Some relationships between topography and structures (abs.): Assoc. Am. Geographers Annals, v. 57, no. 1, p. 194-195.

1. Central and south central Washington.
2. Columbia River basalt.
3., & 4. Topographic and tectonic interpretation of origin of Yakima folds.
5. ---
6. The topographic expression of the Yakima folds, located in central and southcentral Washington,

has been described as anticlinal ridges separated by synclinal valleys. Studies in certain areas of several of the ridges in the south-central part of the state indicate considerable variation in structure. Major structures range from simple anticlines to complex positive forms, including strongly asymmetrical folds that may in some places have been overturned and/or thrust-faulted to the north. Where the fold is relatively simple, the descriptive term "anticlinal ridge" may be satisfactory. However, where the structure is strongly asymmetrical or faulted, steep escarpment often exists in the direction of inclination of the axial plane of the fold, or in the direction of thrusting. Such escarpments appear to be largely the result of erosion of the crest of the fold and may reflect crustal fractures and gradational agents more than an anticlinal structure. In these areas the topography is more complex than the term "anticlinal ridge" implies.

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APPENDIX A

COMPILATION OF GEOLOGIC MAPPING IN THE COLUMBIA BASIN, AND SURROUNDING AREAS OF WASHINGTON

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
A	1	Okanogan	Houghland, E., date unknown, Geology of part of the Okanogan quadrangle: Washington Div. Geology and Earth Resources unpublished map, 1:125,000.
A	2	Okanogan	Jones, F. O., 1961, Landslides along the Columbia River valley, northeastern Washington: U.S. Geol. Survey Prof. Paper 367, 98 p. Plate 1, 1:9,600; Plate 3, 1:31,680; Plate 5, 1:31,680; Plate 6, 1:31,680.
A	3	Okanogan	Hanson, L. G., 1970, The origin and development of Moses Coulee and other scabland features of the Waterville Plateau, Washington: Univ. of Washington Ph.D. thesis, 140 p. Map, 1:633,600.
A	4	Okanogan	Pardee, J. T., 1918, Geology and mineral deposits of the Colville Indian Reservation, Washington: U.S. Geol. Survey Bull. 677, 186 p. Plate 7, 1:62,500.
A	5	Okanogan	Pardee, J. T., 1918, Geology and mineral deposits of the Colville Indian Reservation, Washington: U.S. Geol. Survey Bull. 677, 186 p. Plate 9, 1:62,500.
A	6	Okanogan	Pardee, J. T., 1918, Geology and mineral deposits of the Colville Indian Reservation, Washington: U.S. Geol. Survey Bull. 677, 186 p. Plate 10, 1:62,500.
A	7	Okanogan	Campbell, I.; Loofbourow, J. S., Jr., 1962, Geology of the magnesite belt of Stevens County, Washington: U.S. Geol. Survey Bull. 1142-F, 53 p. Plate 1, 1:36,000.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
A	8	Okanogan	Campbell, A. B.; Raup, O. B., 1964, Preliminary geologic map of the Hunters quadrangle, Stevens and Ferry Counties, Washington: U.S. Geol. Survey Mineral Investigations Field Studies Map FM-276, 1:48,000.
A	9	Okanogan	Becraft, G. E., 1966, Geologic map of the Wilmont Creek quadrangle, Ferry and Stevens Counties, Washington: U.S. Geol. Survey Geologic Quadrangle Map GQ-538, 1:62,500.
A	10	Okanogan	Waitt, R. B., 1972, Geomorphology and glacial geology of the Methow drainage basin, eastern North Cascade Range, Washington: Univ. of Washington Ph.D. thesis, 154 p., 1:633,600.
B	11	Ritzville	Hopson, C. A., 1955, Petrology and structure of the Chelan batholith near Chelan, Washington: Johns Hopkins Univ. Ph.D. thesis, 176 p. Plate 2, 1:23,760.
B	12	Ritzville	Waters, A. C., 1933, Terraces and coulees along the Columbia River near Lake Chelan: Geol. Soc. America Bull. 44, p. 783-820. Map, 1:380,160.
B	13	Ritzville	Bretz, J H., 1932, Channeled scabland: 16th Internat. Geol. Cong. Guidebook 22. Plate 2, 1:348,000.
B	14	Ritzville	Bennett, W. A. G., 1944, Dolomite resources of Washington: Washington Div. Mines and Geology, Rept. Investigations 13, 35 p. Plates 8 and 9, 1:2,400.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
B	15	Ritzville	Tengesdal, J. L.; Bagleby, D. N.; Lockhart, A. C.; Burk, J. D., 1976, Preconstruction geologic report: Main Canal, Bacon Siphon & Tunnel No. 2, v. I and II: U.S. Bureau of Reclamation, Boise, Idaho, Geologic map, 2 sheets, 1:600.
B	16	Ritzville	Becraft, G. E.; Weis, P. L., 1963, Geology and mineral deposits of the Turtle Lake quadrangle, Washington: U.S. Geol. Survey Bull. 1131, 73 p. Plate 1, 1:62,500.
B	17	Ritzville	Grolier, M. J.; Bingham, J. W., 1971, Geologic map and sections of parts of Grant, Adams and Franklin Counties, Washington: U.S. Geol. Survey Miscellaneous Geologic Investigations Map I-589. 6 sheets, 1:62,500.
B	18	Ritzville	Grolier, M. J.; Bingham, J. W., 1965, Geologic map and sections of the Columbia Basin Project area, Washington: U.S. Geol. Survey Open-File maps, 1:62,500.
B	19	Ritzville	Mundorff, M. J.; Reiss, D. J.; Strand, J. R., 1952, Progress report on the ground water in the Columbia Basin Project, Washington: U.S. Geol. Survey Open-File Report, 229 p. Plate 1, 1:79,180.
B	20	Ritzville	Taylor, G. C., Jr., 1948, Ground water in the Quincy Basin, Wahluke Slope and Pasco Slope subareas of the Columbia Basin Project, Washington: U.S. Geol. Survey Open-File Report, 182 p. Plate 1, 1:190,080.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
B	21	Ritzville	Grolier, M. J.; Foxworthy, B. L., 1961, Geology of the Moses Lake North quadrangle, Washington: U.S. Geol. Survey Miscellaneous Geologic Investigations Map I-330, 1:24,000.
C	22	Spokane	Walters, K. L.; Glancy, P. A., 1969, Reconnaisannce of geology and of ground water occurrence and development in Whitman County, Washington: Washington Dept. Water Resources Water-Supply Bull. 26, 169 p. Map, 1:47,520.
C	23	Spokane	Barnes, V. E., 1927, Geology of the Oakesdale quadrangle, Washington: Washington State College M.S. thesis, 51 p. Plate 2, 1:316,800.
C	24	Spokane	Treasher, R. C., 1926, Stratigraphic aspects of loess of Palouse region: Pan-American Geologist, v. 46, no. 4, p. 305-314. Plate 17, 1:312,500.
C	25	Spokane	Campbell, N. P.; Sorem, R. K., 1969, Sketch map showing geology and mineral deposits in Stevens County, Washington: Washington Div. Geology and Earth Resources Open-File Report OF 69-1, 1:250,000.
C	26	Spokane	Olson, T. M., 1975, The geology and ground water resources of part of the Hangman and Marshall Creek drainage basins, Spokane County, Washington: Eastern Washington State College M.S. thesis, 70 p., Plate 1, 1:63,360; and others, 1975, Geology, ground water quality

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
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C	27	Spokane	Weissenborn, H. F., 1955, Study of the Columbia River basalts at Spokane, Washington, with a comparison of the "Rimrock and Valley" flows: Smith College M.A. thesis, 64 p. Plate 2, 1:250,000.
C	28	Spokane	Huff, L. C., date unknown, Medical Lake, Clayton and Deerpark quadrangles: U.S. Geol. Survey Ground Water Branch, Tacoma, Washington, unpublished maps, 1:62,500.
C	29	Spokane	Washington Division of Geology and Earth Resources, date unknown, Geology of parts of the Spokane quadrangle: unpublished map, 1:125,000.
C	30	Spokane	Anderson, A. L., 1923, Geology and ore deposits of the Silver Hill district, Spokane County, Washington: Univ. of Idaho M.S. thesis, 100 p. Plate 1, 1:12,000.
C	31	Spokane	Scheid, V. E., 1946, Excelsior high-alumina clay deposit, Spokane County: U.S. Geol. Survey Open-File Report. Plate 1, 1:6,000.
C	32	Spokane	Hosterman, J. W., 1969, Clay deposits of Spokane County, Washington: U.S. Geol. Survey Bull. 1270, 96 p. Map, 1:24,000.

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C	33	Spokane	Weis, P. L., 1968, Geologic map of the Greenacres quadrangle, Washington and Idaho: U.S. Geol. Survey Geologic Quadrangle Map GQ-734, 1 sheet accompanied by 4 pages of text, 1:62,500.
C	34	Spokane	Cline, D. R., 1969, Ground water resources and related geology of north-central Spokane and south-eastern Stevens Counties, Washington: Washington Dept. Water Resources Water-Supply Bull. 27, 195 p. Plate 2, 1:126,720.
C	35	Spokane	Griggs, A. B., 1973, Geologic map of the Spokane quadrangle, Washington, Idaho and Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-768, 1:250,000.
C	36	Spokane	Weissenborn, A. E.; Weis, P. L., 1976, Geologic map of the Mount Spokane quadrangle, Spokane County, Washington, and Kootenai and Bonner Counties, Idaho: U.S. Geol. Survey Quadrangle Map GQ-1336, map and text on one sheet, 1:62,500.
C	37	Spokane	Flint, R. F., 1936, Stratified drift and deglaciation of eastern Washington: Geol. Soc. America Bull., v. 47, no. 12, p. 1849-1884. Figure 2, 1:84,480.
C	38	Spokane	Foxworthy, B. L.; Washburn, R. L., 1957, Reconnaissance investigation of ground water in the Wellpinit area, Stevens County, Washington: U.S. Geol. Survey Open-File report, 14 p. Plate 1, 1:11,400.

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C	39	Spokane	Hosterman, J. W.; Scheid, V. E.; Allen, V. T; Sohn, I. G., 1960, Investigations of some clay deposits in Washington and Idaho: U.S. Geol. Survey Bull. 1091, 147 p. Plate 3, 1:12,000.
C	40	Spokane	Griggs, A. B., 1976, The Columbia River Basalt Group in the Spokane quadrangle, Washington, Idaho, Montana, with a section on petrology by D. A. Swanson: U.S. Geol. Survey Bull. 1413, 39 p. Map, 1:250,000.
D-1	41	Wenatchee	Porter, S. C., 1976, Pleistocene glaciation in the southern part of the north Cascade Range, Washington: Geol. Soc. America Bull., v. 87, no. 1, p. 61-75. Map, 1:380,160.
D-1	42	Wenatchee	Smith, G. O.; Calkins, F. C., 1906, Description of the Snoqualmie quadrangle (Washington): U.S. Geol. Survey Geol. Atlas, Folio 139. Map, 1:125,000.
D-1	43	Wenatchee	Warren, W. C., 1941, Relation of the Yakima Basalt to the Keechelus andesitic series: Jour. Geology, v. 49, no. 8, p. 795-814. Figure 2, 1:500,000.
D-1	44	Wenatchee	Clayton, D. N., 1975, Volcanic history of the Teanaway Basalt, east-central Cascade Mountains, Washington: Univ. of Washington M.S. thesis, 55 p. Map, 1:62,500.
D-1	45	Wenatchee	Russell, I. C.; Smith, G. O.; Curtis, G. C.; and others, 1914, Coal fields of Kittitas County: Washington Geol. Survey Bull. 9. Plate 1, 1:125,000.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
D-1	46	Wenatchee	Campbell, N. P., 1975, A geologic road log over Chinook, White Pass and Ellensburg to Yakima highways: Washington Div. Geology and Earth Resources Inf. Circ. 54, 82 p. Map, 1:250,000.
D-1	47	Wenatchee	Broughton, W. A., 1944, Economic aspects of the Blewett-Cle Elum iron-ore zone, Chelan and Kittitas Counties: Washington Div. Geology Rept. Investigations 12. Plate 1, 1:84,480.
D-1	48	Wenatchee	Lupher, R. L., 1944, Stratigraphic aspects of the Blewett-Cle Elum iron-ore zone, Chelan and Kittitas Counties: Washington Div. Geology Rept. Investigations 2. Plate 2, 1:3,200.
D-1	49	Wenatchee	Smith, G. O., 1904, Mount Stuart folio: U.S. Geol. Survey Geol. Atlas, Folio 106. Map, 1:125,000.
D-1	50	Wenatchee	Laval, W. N., 1948, An investigation of the Ellensburg Formation: Univ. of Washington M.S. thesis, 52 p. Map 1:125,000.
D-1	51	Wenatchee	Hopkins, K. D., 1966, Glaciation of Ingalls Creek valley, east-central Cascade Range, Washington: Univ. of Washington M.S. thesis, 79 p. Map, 1:63,360.
D-1	52	Wenatchee	Weaver, C. E.; Fettke, C. R., 1911, Geology and ore deposits of the Blewett ining district: Washington Geol. Survey Bull. 6, 104 p. Plate 1, 1:21,120.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
D-1	53	Wenatchee	Tabor, R.; Waitt, R. B., Jr.; Frizzell, V. A., Jr.; Swanson, D. A.; Byerly, G. R., 1977, Preliminary geologic map of the Wenatchee 1:100,000 quadrangle, Washington: U.S. Geol. Survey Open-File Report 77-531, 24 p. 1 plate, 4 figures, Map 1:100,000.
D-1	54	Wenatchee	Washington Division of Geology and Earth Resources, date unknown, Geology and structure of Colockum Pass unpublished map, 1:125,000.
D-1	55	Wenatchee	Porter, S. C., 1976, Stratigraphy and distribution of tephra from Glacier Peak (of 12,000 years ago) in the northern Cascade Range, Washington: U.S. Geol. Survey Open-File Report 76-186, map and text on one sheet, 1:5,280.
D-1	56	Wenatchee	Houghland, E., date unknown, Geologic and structure maps of the Wenatchee quadrangle: Washington Div. Geology and Earth Resources unpublished map, 1:62,500.
D-1	57	Wenatchee	Huntting, M. T., 1947, Geologic map of the Wenatchee area: Washington Div. Geology and Earth Resources unpublished map, 1:31,680.
D-1	58	Wenatchee	Gresens, R. L., 1975, Geologic mapping of the Wenatchee area: Washington Div. Geology and Earth Resources Open-File Report OF 75-6, 1:1,000.
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Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
D-1	60	Wenatchee	Cashman, S. M., 1974, Geology of the Peshastin Creek area, Washington: Univ. of Washington M.S. thesis, 29 p. Map, 1:15,840.
D-1	61	Wenatchee	Waters, A. C., 1932, A petrologic and structural study of the Swakane Gneiss, Entiat Mountains, Washington: Jour. Geology, v. 40, p. 604-634. Figure 3, 1:250,000.
D-1	62	Wenatchee	Waters, A. C., 1939, Resurrected erosion surface in central Washington: Geol. Soc. America Bull., v. 50, p. 635-660. Map 1:126,720.
D-1	63	Wenatchee	Hopson, C. A., 1959, Geologic mapping in area south of Lake Chelan: Washington Div. Geology and Earth Resources unpublished map, 1:250,000.
D-1	64	Wenatchee	Willis, C. L., 1953, The Chiwaukum graben, a major structure of central Washington: Am. Jour. Sci., v. 251, no. 11, p. 789-797. Figure 1, map, 1:126,720.
D-1	65	Wenatchee	Barker, P. A., 1968, Glaciation of the Chelan Trough; Washington State Univ. M.S. thesis, 52 p. Map, 1:39,600.
D-1	66	Wenatchee	Lupe, R. D., 1971, Stratigraphy and petrology of the Swauk Formation in the Wenatchee Lake area, Washington: Univ. of Washington M.S. thesis, 27 p. Map, 1:126,720.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
D-1	67	Wenatchee	Laravie, J. A., 1976, Geologic field studies along the eastern border of the Chiwaukum graben, central Washington: Univ. of Washington M.S. thesis, 56 p. Map, 1:31,680.
D-1	68	Wenatchee	Houghland, E., 1933-1934, Geology and structure of Chiwaukum quadrangle, Washington Div. Geology and Earth Resources unpublished map, 1:125,000.
D-1	69	Wenatchee	Russell, I. C.; Smith, G. O.; Curtis, G. C.; and others, 1914, Coal fields of Kittitas County: Washington Geol. Survey Bull. 9. Plate 23, 1:8,400.
D-2	70	Wenatchee	Foster, R. J., 1958, The Teanaway dike swarm of central Washington: Am. Jour. Science, v. 256, no. 9, p. 644-653. Figure 2, 1:405,504.
D-2	71	Wenatchee	Foster, R. J., 1960, Tertiary geology of a portion of the central Cascade Mountains, Washington: Geol. Soc. America Bull., v. 71, no. 2, p. 99-125. Plate 1, 1:126,720.
D-2	72	Wenatchee	Southwick, D. L., 1966, Petrography, chemistry, and possible correlations of the Camas Land Sill and Teanaway dike swarm, central Washington: Northwest Science, v. 40, no. 1, p. 1-16. Figure 1, 1:443,520.
D-2	73	Wenatchee	Broughton, W. A., 1944, Economic aspects of the Blewett-Cle Elum iron-ore zone, Chelan and Kittitas Counties: Washington Div. Geology Rept. Investigations 12. Plates 2-7 and Figures 2-14, 1:2,400.

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D-2	74	Wenatchee	Lamey, C. A.; Hotz, P. E., 1946, Cle Elum River iron-nickel ore deposits, Kittitas County: U.S. Geol. Survey Open-File Report 116 p. Plate 1, 1:4,800, Plates 2-A, 2-B, 2-C, 2-D, 1:1,200.
D-2	75	Wenatchee	Lamey, C. A., 1950, The Blewett iron-nickel deposit, Chelan County, Washington: U.S. Geol. Survey Bull. 969-D, p. 87-103. Plate 17, 1:1,200.
D-2	76	Wenatchee	Pratt, R. M., 1958, Geology of the Mount Stuart area, Washington: Univ. of Washington Ph.D. thesis, 228 p. Plate 7, 1:62,500.
D-2	77	Wenatchee	Rosenmaier, F. J., 1968, Stratigraphy and structure of the Table Mountain-Mission Peak area in the Wenatchee Mountains, central Washington: Univ. of Washington M.S. thesis, 44 p. Plate 1, 1:24,000.
D-2	78	Wenatchee	Huntting, M. T., 1949, Perlite and other volcanic glass occurrences in Washington: Washington Div. Mines and Geology Rept. Inv. 17, 77 p. Figure 5, 1:63,360.
D-2	79	Wenatchee	Page, B. M., 1939, Multiple alpine glaciation in the Leavenworth area: Jour. Geology, v. 47, p. 78, 815. Figure 2, 1:125,000.
D-2	80	Wenatchee	Page, B. M., 1939, Geology of a part of the Chiwaukum quadrangle, Washington: Stanford Univ. Ph.D. thesis, 203 p. Figure 3, 1:62,500.

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D-2	81	Wenatchee	Parrott, G., 1932, Study of the fresh water sediments north of Leavenworth: Washington State College B.S. thesis, 21 p. Map, 1:25,000.
D-2	82	Wenatchee	Willis, C. L., 1950, Geology of the northeastern quarter of the Chiwaukum quadrangle, Washington: Washington Ph.D. thesis, 158 p. Plate, 1:62,500.
D-2	83	Wenatchee	Page, B. M., 1939, Multiple alpine glaciation in the Leavenworth area, Washington: Jour. Geology, v. 47, p. 658-815. Figure 9, 1:72,000.
D-3	84	Wenatchee	Stout, M. L., 1964, Geology of a part of the south-central Cascade Mountains, Washington: Geol. Soc. America Bull., v. 75, no. 4, p. 317-334. Plate 1, 1:62,500.
D-3	85	Wenatchee	Stout, M. L., 1957, Geology of the southwestern portion of the Mount Stuart quadrangle, Washington: Univ. of Washington M.S. thesis, 115 p. Plate, 1:63,360.
D-3	86	Wenatchee	Bressler, C. T., 1951, Petrology of the Roslyn arkose, central Washington: Pennyslvania State College Ph.D. thesis, 147 p. Plate 1, 1:125,000.
D-3	87	Wenatchee	Smith, G. O.,, 1903, Geology and physiography of central Washington: U.S. Geol. Survey Prof. Paper 19, p. 9-39. Plate 3, 1:125,000.
D-3	88	Wenatchee	Chappell, W. M., 1931, Endogenetic alteration of the Camas Land irruptive, Chelan County, Washington: Univ. of Washington M.S. thesis, 37 p. Figure 1:63,360

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D-3	89	Wenatchee	Southwick, D. L., 1962, Mafic and ultramafic rocks of the Ingalls-Peshastin area, Washington, and their geologic setting: Johns Hopkins Univ. Ph.D. thesis, 287 p. Plate 1, 1:62,500.
D-3	90	Wenatchee	Rector, R. J., 1962, Geology of the east half of the Swauk Creek mining district: Univ. of Washington M.S. thesis, 73 p. Plate 2, 1:24,000
D-3	91	Wenatchee	Alexander, Frank, 1956, Stratigraphy and structural geology of the Blewett-Swauk area, Washington: Univ. of Washington M.S. thesis, 62 p. Plate 3, 1:71,280.
D-3	92	Wenatchee	Waters, A. C., 1930, Geology of the southern half of the Chelan quadrangle, Washington: Yale Univ. Ph.D. thesis, 256 p. Plate 1, 1:72,410.
D-3	93	Wenatchee	Chappell, W. M., 1936, Geology of the Wenatchee quadrangle, Washington: Univ. of Washington Ph.D. thesis, 249 p. Plate 1, 1:62,500.
D-3	94	Wenatchee	Bayley, E. P., Jr., 1965, Bedrock geology of the Twin Peaks area, an intrusive complex near Wenatchee, Washington: Univ. of Washington M.S. thesis, 47 p. Plate 1, 1:15,840.
D-3	95	Wenatchee	Patton, T. C., 1967, Economic geology of the L-D mine, Wenatchee, Washington: Univ. of Washington M.S. thesis, 29 p. Plate 1, 1:56,740.

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D-3	96	Wenatchee	Gualtieri, J. L.; Simmons, G. C.; Thurber, H. K.; Miller, M. S., 1973, Mineral resources of the Alpine Lakes study area, Chelan, King, and Kittitas Counties, Washington, with a section on aeromagnetic interpretation by W. E. Davis: U.S. Geol. Survey Open-File Report. Plate 1, 1:62,500.
D-3	97	Wenatchee	Van Diver, B. B., 1964, Petrology of the metamorphic rocks, Wenatchee Ridge area, central northern Cascades, Washington: Univ. of Washington Ph.D. thesis, 140 p. Plate 2, 1:46,080.
D-3	98	Wenatchee	Oles, K. F., 1956, Geology and petrology of the crystalline rocks of the Beckler River-Nason Ridge area, Washington: Univ. of Washington Ph.D. thesis, 192 p. Plate B, 1:76,000.
D-3	99	Wenatchee	Pratt, R. M., 1954, Geology of the Deception Pass area, Chelan, King, and Kittitas Counties, Washington: Univ. of Washington M.S. thesis, 58 p. Map, 1:31,680.
D-3	100	Wenatchee	Merrill, D. E., 1966, Glacial geology of the Chiwaukum Creek drainage basin and vicinity: Univ. of Washington M.S. thesis, 36 p. Figure 2, 1:125,000.
D-3	101	Wenatchee	McKague, H. L., 1960, Petrology of the Hatchery Creek serpentinite, Chelan County, Washington: Washington State Univ. M.S. thesis, 42 p. Plate, 1:250,000.

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D-3	102	Wenatchee	Young, R. E., 1963, Geology of the Swauk Formation in the Leavenworth, Washington, area: Univ. of Washington B.S. thesis, 49 p. Map, 1:63,360.
E-1	103	Yakima	Abbott, A. T., 1953, Geology of the northwest portion of the Mount Aix quadrangle, Washington: Univ. of Washington Ph.D. thesis, 256 p. Fig. 4, 1:125,000.
E-1	104	Yakima	Simmons, G. C.; Van Noy, R. M.; Zilka, N. T., 1974, Mineral resources of the Cougar Lakes-Mount Aix study area, Yakima and Lewis Counties, Washington, with a section on interpretation of aeromagnetic data by W. E. Davis: U.S. Geol. Survey Open-File Report 74-243, 80 p. Plate 1, 1:62,500.
E-1	105	Yakima	Warren, W. C., 1939, Geology of the southeast Mount Aix quadrangle: Washington Div. Geology and Earth Resources unpublished map 1:125,000.
E-1	106	Yakima	Warren, W. C., 1933, Age of certain andesites in the Mount Aix quadrangle, Washington: Washington State College M.S. thesis, 24 p. Plate 2, 1:125,000.
E-1	107	Yakima	Smith, G. O., 1903, Geology and physiography of central Washington: U.S. Geol. Survey Prof. Paper 19, p. 9-39. Plate 4, 1:125,000.
E-2	108	Yakima	Smith, G. O., 1903, Geologic folio of the Ellensburg quadrangle, Washington: U.S. Geol. Survey Geol. Folio 86, 7 p. Map, 1:125,000.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
E-1	109	Yakima	Diery, H. D., 1967, Stratigraphy and structure of Yakima Canyon between Roza Gap and Kittitas Valley, central Washington: Univ. of Washington Ph.D. thesis, 116 p. Plate 1, 1:24,000.
E-2	110	Yakima	Diery, H. D.; McKee, Bates, 1969, Stratigraphy of the Yakima Basalt in the type area: Northwest Sci., v. 43, no. 2, p. 47-64. Map, 1:126,720.
E-1	111	Yakima	Holmgren, D. A., 1969, Columbia River Basalt patterns from central Washington to northern Oregon: Univ. of Washington Ph.D. thesis, 55 p. Map, 1:31,680.
E-1	112	Yakima	Alto, B. R., 1955, Geology of a part of the Boylston quadrangle and adjacent areas in central Washington: Univ. of Washington M.S. thesis, 38 p. Plate 5, 1:44,352.
E-2	113	Yakima	Campbell, N. P., 1977, Geology of the Selah area, Yakima County, Washington: Washington Div. Geology and Earth Resources Open-File Report OF 77-7. Geologic map, 1:24,000; Flood Hazards Map, 1:24,000; Slope Stability Map, 1:24,000.
E-1	114	Yakima	Holmgren, D. A., 1967, The Yakima-Ellensburg unconformity, central Washington: Univ. of Washington M.S. thesis, 69 p. Plate 1, 1:142,560.
E-1	115	Yakima	Campbell, N. P., 1976, Preliminary geologic map of Yakima area: Washington Div. Geology and Earth Resources Open-File Report OF 76-11, 1:24,000.

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E-1	116	Yakima	Campbell, N. P., 1976, Relative slope stability of the Yakima core area and surrounding slopes, Yakima County, Washington: Washington Div. Geology and Earth Resources Open-File Report OF 77-2, 1:24,000 (Modified by Artim, E. R., 1977).
E-2	117	Yakima	Hammond, P. E., 1975, Preliminary geologic map and cross-sections with emphasis on Quaternary volcanic rocks, southern Cascade Mountains, Washington: Washington Div. Geol. and Earth Resources Open-File Report OF 75-13, 1:24,000.
E-2	118	Yakima	Kienle, C. F., Jr.; Bentley, R. D.; Anderson J. L., 1977, Geologic reconnaissance of the Cle Elum-Wallula lineament and related structures: Shannon and Wilson, Geotechnical Consultants, 33 p., (a) 1:63,360; (b) 1:24,000; (c) 1:24,000; (d) 1:24,000; (e) 1:24,000.
E-1	119	Yakima	Smith, G. O., 1901, Geology and water resources of a portion of Yakima County, Washington: U.S. Geol. Survey Water-Supply Paper 55, 68 p. Plate, 1:250,000.
E-2	120	Yakima	Waters, A. C., 1955, Geomorphology of south-central Washington, illustrated by the Yakima east quadrangle: Geol. Soc. America Bull., v. 66, no. 6, p. 663-685. Plate 1, 1:62,500.
E-1	121	Yakima	Robinson, C. G., 1966, Stratigraphy and structural geology of Ahtanum Ridge, Yakima, Washington: Univ. of Washington M.S. thesis, 35 p. Plate 1, 1:72,412.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
E-2	122	Yakima	Foxworthy, B. L., 1962, Geology and ground water resources of the Ahtanum Valley, Yakima County, Washington: U.S. Geol. Survey Water-Supply Paper, 1598, 100 p. Plate 1, 1:62,500.
E-1	123	Yakima	Becraft, G. E., 1950, Definition of the Tieton Andesite on lithology and structure: Washington State College M.S. thesis, 26 p. Plate 1, 1:125,000; Plate 2, 1:125,000.
E-2	124	Yakima	Simmons, G. C., 1950, Russell Ranch Formation: Washington State College M.S. thesis, 26 p. Plate 1, 1:125,000.
E-1	125	Yakima	Swanson, D. A., 1966, Tieton volcano, a Miocene eruptive center in the southern Cascade Mountains, Washington: Geol. Soc. America Bull., v. 77, no. 11, p. 1293-1314. Plate 1, 1:55,440.
E-2	126	Yakima	Swanson, D. A., 1964, The middle and late Cenozoic volcanic rocks of the Tieton River area, south-central Washington: Johns Hopkins Univ. Ph.D. thesis, 329 p. Plate 1, 1:50,688.
E-2	127	Yakima	Swanson, D. A., 1967, Yakima Basalt of the Tieton River area, south-central Washington: Geol. Soc. America Bull., v. 78, no. 9, p. 1077-1109. Figure 2, 1:190,080.
E-1	128	Yakima	Simmons, G. C., 1950, Geologic map of the southern half of the Mount Aix 30' quadrangle: Washington Div. Geology and Earth Resources unpublished map, 1:125,000.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
E-1	129	Yakima	Hammond, P. E., 1973, Preliminary geologic map of the southern Cascade Range of Washington: Washington Div. Geology and Earth Resources Open-File Report OF 73-3, 1:792,000.
E-1	130	Yakima	Waters, A. C., 1958, Part of the Columbia River Gorge: U.S. Geol. Survey unpublished map, 1:125,000 (based in part on independent work by A. C. Waters).
E-2	131	Yakima	Sheppard, R. A., 1967, Geology of the Simcoe Mountain volcanic area, Washington: Washington Div. Mines and Geology Geologic Map GM-3, 1:125,000.
E-2	132	Yakima	Milne, S.; Cross, R., 1974, Sand and gravel deposits of Klickitat County, Washington: Washington Div. Geology and Earth Resources Open-File Map 74-2, 1:125,000.
E-2	133	Yakima	Sheppard, R. A., 1960, Petrology of Simcoe Mountains area, Washington: Johns Hopkins Univ. Ph.D. thesis, 153 p. Plate 1, 1:250,000.
E-1	134	Yakima	Livingston, V. E., Jr., 1958, Geologic mapping in the southwest portion of the White Swan quadrangle, Washington Div. Geology and Earth Resources unpublished map, 1:96,000.
E-1	135	Yakima	Laval, W. N., 1956, Stratigraphy and structural geology of portions of south-central Washington: Univ. of Washington Ph.D. thesis, 223 p. Plate 21, 1:62,500; Plate 23, 1:126,720; Plate 24, 1:62,500; Plate 27, 1:62,500; Plate 28, 1:62,500;

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
			Plate 29, 1:62,500; Plate 30, 1:62,500; Plate 31, 1:62,500.
E-2	136	Yakima	Campbell, N. P., 1977, Geology of the Snipes Mountain area, Yakima County, Washington: Washington Div. Geology and Earth Resources Open-File Report OF 77-8. Slope stability and flood hazards maps, 1:24,000.
E-1	137	Yakima	Yeager and others, 1932, Geologic and structure map of the Zillah quadrangle: Washington Div. Geology and Earth Resources unpublished map, 1:125,000
E-1	138	Yakima	Yeaton, W. J., 1923, Geology of the Zillah quadrangle, Washington: Univ. of Chicago M.S. thesis, 88 p. Map, 1:125,000.
E-1	139	Yakima	Shannon and Wilson, Inc., 1973, Geologic studies of Columbia River basalt and age of deformation, the Dalles-Umatilla region, Washington and Oregon, Boardman Nuclear Project: Report to Portland General Electric Co., 55 p. Figure 3, 1:63,360.
E-1	140	Yakima	Shannon and Wilson, Inc., 1973, Geologic studies of Columbia River basalt and age of deformation, The Dalles-Umatilla region, Washington and Oregon, Boardman Nuclear Project: Report to Portland General Electric Co., 55 p. Figure 6, 1:253,440.
F-1	141	Walla Walla	Walters, K. L.; Grolier, M. J., 1960, Geology and ground water resources of the Columbia Basin

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
			Project area, Washington, volume 1: Washington Div. Water Resources Water-Supply Bull. 8, 542 p. Plate 3, 1:205,670.
F-2	142	Walla Walla	Washington Division of Geology and Earth Resources, date unknown, Geologic map of part of the Othello quadrangle: unpublished map, 1:62,500.
F-1	143	Walla Walla	Twiss, S. N., 1933, Stratigraphy of the Saddle Mountains, Washington: Washington State College M.S. thesis, 74 p. Plate 1, 1:125,000.
F-1	144	Walla Walla	Mason, G. W., 1953, Interbasalt sediments of south-central Washington: Washington State College M.S. thesis, 116 p. Figure 6, 1:62,500; Figure 7, 1:62,500; Figure 8, 1:62,500.
F-1	145	Walla Walla	Twiss, S. N., 1933, Geologic map of the Saddle Mountains region: Washington Div. Geology and Earth Resources unpublished map, 1:62,500.
F-1	146	Walla Walla	Kienle, C. F., Jr.; Bentley, R. D.; Anderson, J. L., 1977, Geologic reconnaissance of the Cle Elum-Wallula lineament and related structures: Shannon and Wilson, Geotechnical Consultants, 33 p. Map, 1:63,360.
F-2	147	Walla Walla	Bingham, J. W.; Londquist, C. J.; Baltz, E. H., 1970, Geologic investigation of faulting in the Hanford region, Washington: U.S. Geol. Survey Open-File Report, 103 p. Map, 1:31,680.
F-2	148	Walla Walla	Houghland, E., date unknown, structure and geology map of Red Rock quadrangle (Smyrna): Washington

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
			Div. Geology and Earth Resources unpublished map, 1:62,500.
F-1	149	Walla Walla	Lillie, J. T.; Tallman, A. M.; Caggiano, J. A., 1978, Preliminary geologic map of the late Cenozoic sediments of the western half of the Pasco Basin: Rockwell Hanford Operations, RHO-BWI-LD-8, 16 p.
F-1	150	Walla Walla	Jones, M. G.; Landon, R. D., 1978, Geology of the Nine Canyon map area: Rockwell Hanford Operations, RHO-BWI-LD-6, Richland, Washington, 54 p. 5 Plates, 1:24,000.
F-1	151	Walla Walla	U.S. Army Corps of Engineers, 1947, Priest Rapids Dam project: Washington Div. Geology and Earth Resources unpublished map, 10 sheets, scale varies.
F-2	152	Walla Walla	Washington Division of Geology and Earth Resources, date unknown, Structure map of Gable Mountain and geologic map along the Columbia River in the Hanford quadrangle: unpublished map, 1:125,000.
F-2	153	Walla Walla	Newcomb, R. C., 1958, Ringold Formation of Pleistocene age in type locality, the White Bluffs, Washington: Am. Jour. Science, v. 256, no. 5, p. 328-340; Washington Div. Mines and Geology Reprint 1, p. 328-340. Figure 1, 1:1,013,760.
F-2	154	Walla Walla	Brown, R. E.; Brown, D. J., 1961, The Ringold Formation and its relationships to other formations:

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
			Hanford Atomic Products Operations Report HW-SA-2319, 17 p. Map, 1:316,800.
F-2	155	Walla Walla	Washington Division of Geology and Earth Resources, date unknown, Structure map of Coyote Rapids quadrangle: unpublished map, 1:125,000.
F-1	156	Walla Walla	Fecht, K. R., 1978, Geology of Gable Mountain - Gable Butte area: Rockwell Hanford Operations, Richland, Washington, RHO-BWI-LD-5, 59 p. 4 Plates, 1:24,000.
F-1	157	Walla Walla	Reidel, S. P., 1978, Geology of the Saddle Mountains between Sentinel Gap and 119° and 30° longitude: Rockwell Hanford Operations, Richland, Washington, RHO-BWI-LD-4, 75 p. Maps, 1:24,000.
F-2	158	Walla Walla	Brooks, W. E., 1974, Stratigraphy and structure of the Columbia River basalt in the vicinity of Gable Mountain, Benton County, Washington: University of Washington M.S. thesis, 39 p. Map, 1:21,120.
F-2	159	Walla Walla	Bennett, W. A. G., date unknown, Geologic map of the Prosser quadrangle: Washington Div. Geology and Earth Resources unpublished map, 1:125,000.
F-2	160	Walla Walla	Newcomb, R. C.; Strand, J. R.; Frank, F. J., 1972, Geology and ground water characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington: U.S. Geol. Survey Prof. Paper 717, 78 p. Map, 1:62,500.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
F-2	161	Walla Walla	Washington Division of Geology and Earth Resources, date unknown, Geologic map of the Pasco quadrangle: unpublished map, 1:125,000.
F-2	162	Walla Walla	Shannon and Wilson, Inc., 1973, Geologic studies of Columbia River basalt and age of deformation, The Dalles-Umatilla region, Washington and Oregon; Boardman Nuclear Project: Report to Portland General Electric Co., 55 p. Figure 7, 1:63,360.
F-1	163	Walla Walla	Warren, W. C., date unknown, Structure map of Badger Mountain in the Pasco quadrangle: Washington Div. Geology and Earth Resources unpublished map, 1:125,000.
F-2	164	Walla Walla	Livingston, V. E.; Bennett, W. A. G., Geologic mapping and structure map of Wallula quadrangle: Washington Div. Geology and Earth Resources unpublished map, 1:125,000.
F-2	165	Walla Walla	Newcomb, R. C., 1965, Geology and ground water resources of the Walla Walla River Basin, Washington-Oregon: Washington Div. Water Resources Water Supply Bull. 31, 151 p. Plate 1, 1:95,040.
F-1	166	Walla Walla	Molenaar, D., 1968, A geohydrologic reconnaissance of northwestern Walla Walla County, Washington: Washington Dept. Water Resources Monograph 1, map and text on 1 sheet, 1:126,720.
F-2	167	Walla Walla	Gard, L. M., Jr., date unknown, Geology of Washtucna quadrangle: U.S. Geol. Survey unpublished map, 1:62,500.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
F-2	168	Walla Walla	Livingston, V. E., Jr., 1957, Reconnaissance map of the Clyde-Alto area, Columbia and Walla Walla Counties: Washington Div. Mines and Geology unpublished map, 1:125,000.
F-2	169	Walla Walla	Shannon and Wilson, Inc., 1973, Geologic studies of Columbia River basalt and age of deformation, The Dalles-Umatilla region, Washington and Oregon; Boardman Nuclear Project: Report to Portland General Electric Company, 55 p. Figure 8, 1:316,800.
F-1 & F-2	170	Walla Walla	Flint, R. F., 1938, Origin of the Cheney-Palouse scabland tract, Washington: Geol. Soc. America Bull., v. 49, no. 3, p. 461-563. Figure 3, 1:31,680; Figure 9, 1:62,500.
F-1	171	Walla Walla	Pardee, J. T., 1928, Geology of reservoir sites near Washtucna and Kahlotus, Washington: U.S. Geol. Survey Open-File Report, 15 p. Figure 4, 1:125,000.
F-2	172	Walla Walla	Gard, L. M., Jr., date unknown, Geology of the Benge quadrangle: U.S. Geol. Survey unpublished map, 1:62,500.
F-2	173	Walla Walla	Trimble, D. E., 1954, Geology of the Haas quadrangle, Washington: U.S. Geol. Survey Geologic Quadrangle Map GQ-43, 1:62,500.
F-1	174	Walla Walla	Bretz, J H., 1928, Bars of channeled scabland: Geol. Soc. America Bull., v. 39, p. 643-701. Figures 2 and 3, 1:187,500; Figure 6, 1:95,040.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
F-2	175	Walla Walla	Gard, L. M., Jr.; Waldron, H. H., 1954, Geology of the Starbuck quadrangle, Washington: U.S. Geol. Survey Geologic Quadrangle Map GQ-38, 1:62,500.
F-2	176	Walla Walla	Waldron, H. H.; Gard, L. M., Jr., 1951, Preliminary report on the geology of part of the Lower Snake River Canyon, Washington: U.S. Geol. Survey Open-File Report, 66 p. Plate 1, 1:24,000.
F-2	177	Walla Walla	Washington Division Geology and Earth Resources, date unknown, Structure and geologic map of the Beverly quadrangle: unpublished map, 1:62,500.
F-2	178	Walla Walla	Washington Division Geology and Earth Resources, date unknown, Structure and geologic map of the Corfu quadrangle: unpublished map, 1:62,500.
F-1	179	Walla Walla	Taylor, T. L., 1976, The basalt stratigraphy and structure of the Saddle Mountains of south-central Washington: Washington State Univ. M.S. thesis, 116 p. Map, 1:21,120.
F-1	180	Walla Walla	Warren, W. C., date unknown, Structure map of the southern half of the Priest Rapids quadrangle: Washington Div. Geology and Earth Resources, unpublished map, 1:62,500.
G	181	Pullman	Gard, L. M., Jr., date unknown, Geology of the La Crosse quadrangle: U.S. Geol. Survey unpublished map, 1:62,500.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
G	182	Pullman	Gard, L. M., Jr., date unknown, Geology of the Endicott quadrangle: U.S. Geol. Survey unpublished map, 1:62,500.
G	183	Pullman	Waldron, H. H.; Gard, L. M., Jr., 1955, Geology of the Penawawa quadrangle, Washington: U.S. Geol. Survey Geologic Quadrangle Map GQ-56, 1:62,500.
G	184	Pullman	Treasher, R. C., 1925, Geology of the Pullman quadrangle, Washington: Washington State College M.S. thesis, 74 p. Plate 1, 1:125,000.
G	185	Pullman	Foley, L. L., 1976, Slack water sediments in the Alpowa Creek drainage, Washington: Washington State University M.A. thesis, 55 p. Plate 1, 1:24,000.
G	186	Pullman	Foxworthy, B. L.; Washburn, R. L., 1963, Ground water in the Pullman area, Whitman County, Washington: U.S. Geol. Survey Water-Supply Paper 1655, 71 p. Plate 1, 1:63,360.
G	187	Pullman	Hubbard, P. S., 1968, Geology of the Saddle Butte quadrangle, southeastern Washington: Univ. Hawaii M.S. thesis, 75 p. Map, 1:62,500.
G	188	Pullman	Russell, I. C., 1901, Geology and water resources of Nez Perce County, Idaho: U.S. Geol. Survey Water-Supply Papers 53 and 54, pts. I and II, 141 p. Plate 2, 1:937,500.

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
G	189	Pullman	Hoffman, M. G., 1932, The geology of Bald Butte Ridge, Washington: Jour. Geology, v. XL, p. 634-51. Figure 3, 1:160,000.
G	190	Pullman	Lupher, R. L.; Warren, W. C., 1942, The Asotin stage of the Snake River Canyon near Lewiston, Idaho: Jour. Geology, v. 50, p. 866-881. Figure 1, 1:187,500.
G	191	Pullman	Lupher, R. L.; Warren, W. C., 1945, Clarkston stage of the northwest Pleistocene: Jour. Geology, v. 53, no. 5, p. 337-338. Figure 1, 1:168,960.
G	192	Pullman	Camp, V. E., 1976, Petrochemical stratigraphy and structure of the Columbia River basalt, Lewiston Basin area, Idaho-Washington: Washington State University Ph.D. thesis, 201 p. Map, 1:63,360.
G	193	Pullman	Shumway, R. D., 1960, Geology of the Lime Hill area, Asotin County, Washington: Washington State Univ. M.S. thesis, 54 p. Figure 11, 1:15,600.
G	194	Pullman	Huntting, M. T., 1942, Geology of the middle Tucannon area: Washington State College M.S. thesis, 33 p. Figure 4, 1:96,000.
G	195	Pullman	Waldron, H. H.; Gard, L. M., 1954, Geology of the Hay quadrangle, Washington: U.S. Geol. Survey Geol. Quad. Map GQ-48, 1:62,500.
G	196	Pullman	Scheid, V. E.; Sohn, I. G.; Hosterman, J. W., 1945, Deary high alumina clay deposits, Latah

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
			County, Idaho: U.S. Geol. Survey Open-File Report, 28 p. Plate 1, 1:250,000.
H	197	Pendleton	Bennett, W. A. G., date unknown, Geology of Umatilla quadrangle (Washington): Washington Div. Geology and Earth Resources unpublished map, 1:125,000.
H	198	Pendleton	Bretz, J H., 1928, Bars of channeled scabland: Geol. Soc. America Bull., v. 39, p. 643-701. Figure 12, 1:221,760.
H	199	Pendleton	Newcomb, R. C., 1971, Geologic map of the proposed Paterson Ridge pumped-storage reservoir, south-central Washington: U.S. Geol. Survey Misc. Geol. Inv. Map, no. I-653, 1:31,680, sections, explanatory text.
H	200	Pendleton	Twiss, S. N., date unknown, Geology of Blalock Island: Washington Div. Geology and Earth Resources unpublished map, 1:125,000.
H	201	Pendleton	Hodge, E. T., 1931, Exceptional morainelike deposits in Oregon: Geol. Soc. Bull., v. 42, p. 985-1010. Figure 2, 1:422,400.
I	202	The Dalles	Allen, J. E., 1932, Contributions to the structure, stratigraphy, and petrography of the Lower Columbia River Gorge: University of Oregon M.S. thesis, 96 p. Map, 1:125,000.
I	203	The Dalles	Waters, A. C., 1973, The Columbia River Gorge-basalt stratigraphy, ancient lava dams, and landslide

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
			dams. *In* Beaulieu, J. D., Chairman, Geologic field trips in northern Oregon and southern Washington: Oregon Dept. of Geology and Mineral Ind. Bull. 77, p. 133-162. Map, 1:62,500.
I	204	The Dalles	Williams, I. A., 1916, The Columbia Gorge: Its geologic history interpreted from the Columbia River Highway: Min. Res. Oregon, Oregon Bur. Mines and Geology, v. 2, no. 3, 130 p. Map, 1:1,200.
I	205	The Dalles	Barnes, F. F.; Butler, J. W., 1930, Structure and stratigraphy of the Columbia River Gorge and Cascade Mountains in the vicinity of Mount Hood: Univ. of Oregon M.A. thesis, 136 p. Map 1, 1:125,000.
I	206	The Dalles	Hodge, E. T., 1932, Geological map of north-central Oregon: Univ. of Oregon Publication, Supplement to Geology series v. 1, no. 5, 7 p., 1:250,000.
I	207	The Dalles	Sheppard, R. A., 1964, Geologic map of the Husum quadrangle, Washington: U.S. Geol. Survey Mineral Investigations Field Studies Map MF-2, 1:62,500.
I	208	The Dalles	Newcomb, R. C., 1962, White Salmon quadrangle: U.S. Geol. Survey Research Section, Ground Water Branch, publication, 1:62,500.
I	209	The Dalles	Holmgren, D. A., 1969, Columbia River Basalt patterns from central Washington to northern

Sheet No.	Geologic Map No.	AMS 1° x 2° Base Map	Reference and Map Scale
			Oregon: Univ. of Washington Ph.D. thesis, 55 p. Map, 1:55,440.
I	210	The Dalles	Piper, A. M., 1932, Geology and ground water resources of The Dalles region, Oregon: U.S. Geol. Survey Water-Supply Paper 659B, p. 107-189. Plate 1, 1:62,500.
I	211	The Dalles	U.S. Army Corps of Engineers, 1945, Reconnaissance map of The Dalles Reservoir site: U.S. Army Corps of Engineers, 13 sheets, 1:7,200.
I	212	The Dalles	Newcomb, R. C., 1969, Effect of tectonic structure on the occurrence of ground water in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington: U.S. Geol. Survey Prof. Paper 383-C, 33 p., 19 illustrations. Map, 1:62,500.
I	213	The Dalles	Bennett, W. A. G.; Twiss, S. N.; Cram, R., 1933, Geologic mapping of the Arlington, Oregon-Washington quadrangle: Washington Div. Geology and Earth Resources unpublished map, 1:125,000.
I	214	The Dalles	Portland General Electric Company, 1974, Pebble Springs Nuclear Plant Units 1 and 2, License Application PSAR, section 2.5 - Geology and Seismology, section 2.6 - References. Figure 2.5.11, 1:506,880.

APPENDIX B

COMPILATION OF GEOPHYSICAL SURVEYS IN THE COLUMBIA BASIN AND SURROUNDING AREAS OF WASHINGTON

Sheet No.	Geologic Map No.	References
J	1	Brown, J. C., 1976, Well correlation and stratigraphic information: Pullman test and observation well, Pullman, Washington: Washington State Univ., Coll. of Engrng. Res. Div. Rept. 76/15-6, 35 p.
J	2	Brown, R. E.; Raymond, J. R., 1963, Geophysical seismic evaluation study at the Hanford Works, Washington: Hanford Atomic Products Operation Unclassified Report HW-SA-3280, 17 p.
J	3	Brown, R. E.; Raymond, J. R., 1964, A geophysical seismic evaluation study at Hanford: Battelle Northwest Report BNWL-47, 22 p.
J	4	Bush, J. H., Jr.; Anderson, J. V.; Crosby, J. W., III; Siems, B. A., 1972, Test observation well near Mansfield, Washington: description, stratigraphic relationships and preliminary results: Washington State Univ. Coll. of Engrng. Res. Div. Rept. 72/11-128, 45 p.
J	5	Bush, J. H., Jr.; Morton, J. A., 1973, Test-observation well near Walla Walla, Washington: Description, stratigraphic relationships and preliminary results: Washington State Univ., Coll. of Engrng. Res. Div. Rept. 73/15-66, 38 p.
J	6	Cady, J. W., 1976, Regional gravity and aeromagnetic studies applied to uranium exploration in northeastern Washington and Wyoming: U.S. Geol. Survey Open-File Rept. 76-317, 21 p.
J	7	Cady, J. W.; Meyer, R. F., 1976, Principal facts for gravity stations in the Okanogan, Sandpoint, Ritzville and Spokane 1° by 2° quadrangles, northeastern Washington and northern Idaho: U.S. Geol. Survey Open-File Rept. 76-290, 57 p.

Sheet No.	Geologic Map No.	References
J	8	Cady, J. W.; Meyer, R. F., 1976, Bouguer gravity map of Okanogan, Sandpoint, Ritzville and Spokane 1° by 2° quadrangles, northeastern Washington and northern Idaho: U.S. Geol. Survey, Geophys. Invest. Map GP-914, Grav. Surv. Map, 1:250,000.
J	9	Campbell, D. L; Flanigan, V., 1976, Ground magnetic and VLF studies at Midnite uranium mine, Stevens County, Washington: U.S. Geol. Survey Open-File Rept. 76-230, 17 p.
J	10	Crosby, J. W., III; Cavin, R. E., 1960, Geologic investigation of the Moscow ground water basin employing geophysical studies: Washington State Univ., Geo-Hydrologic Res. Group Bull. 250, 23 p.
J	11	Danes, Z. F., 1964, Preliminary gravity data, central Cascade Mountains, Washington: Univ. of Puget Sound, Res. Inst. Rept., UPS RIP-GP-64-1, 13 p.
J	12	Donaldson, J. A., 1963, Seismic survey - Hanford Atomic Products Operation, Richland, Benton County, Washington: Geophysical Service, Inc. Rept. (Dallas, Texas) submitted to General Electric Co., 32 p.
J	13	Gregory, D. I.; Jackson, D. B., 1976, Bouguer gravity map of Moscow, Idaho-Pullman, Washington area: U.S. Geol. Survey Open-File Rept. 76-280, one sheet, 1:62,500.
J	14	Gualtieri, J. L.; Simmons, G. C.; Thurber, H. K.; Miller, M. S., 1973, Mineral resources of the Alpine Lakes study area, Chelan, King and Kittitas counties, Washington, with a section on aeromagnetic interpretation, by W. E. David: U.S. Geol. Survey Open-File Rept., 132 p.

Sheet No.	Geologic Map No.	References
J	15	Hunting Geophysical Services, 1960, Geological interpretation of airborne magnetometer and scintillometer survey, Mt. Bonaparte, Bodie Mountain, Curlew, Aeneas and Republic quadrangles, Okanogan and Ferry Counties, Washington: Washington Div. Geol. and Earth Resources, Rept. Invest. 20, 1:62,500.
J	16	Jackson, D. B., 1975, Schlumberger soundings in the Moscow, Idaho-Pullman, Washington, area: U.S. Geol. Survey Open-File Rept. 75-584, 28 p.
J	17	Jackson, D. B., 1975, Description of the geoelectric section, Rattlesnake Hills Unit 1 well, Washington: Jour. Res., U.S. Geol Survey, v. 3, no. 6, p. 665-669.
J	18	Jaske, R T., 1964, Large-scale quarry blasting on the Hanford Reservation: Hanford Atomic Products Operation, Rept. HW-79614, 63 p.
J	19	Konicek, D., 1975, Geophysical survey in south-central Washington: Northwest Sci., v. 49, no. 2, p. 106-117; (abs.) EOS (Amer. Geophys. Union Trans.), v. 53, no. 11, p. 966; Univ. of Puget Sound M.S. thesis, 1974.
J.	20	Myers, D. A., 1972, Test-observation well near Davenport, Washington: description and preliminary results: U.S. Geol. Survey Open-File Rept., Tacoma, Washington, 20 p.
J	21	Peterson, D. E., 1968, Bouguer gravity anomalies on the Hanford Reservation: Battelle Memorial Institute, Pacific Northwest Laboratory Report. BNWL-481-3, p. 10-14.
J	22	Priestley, K. F., 1971, Earth strains observed at the Cascade Geophysical Site using a long base laser interferometer strain meter: Univ. of Washington M.S. thesis, 84 p.

Sheet No.	Geologic Map No.	References
J	23	Raymond, J. R.; Ratcliffe, C. A., 1959, A test of the refraction seismic method of the Hanford Project: Hanford Atomic Products Operation Rept. HW-78924, 21 p.
J	24	Raymond, J. R.; McGhan, V. L., 1963, Results of an airborne magnetometer survey of the Hanford project: Hanford Atomic Products Operation Rept. HW78924, 15 p.
J	25	Raymond, J. R. ; Tillison, D. D., 1968, Evaluation of a thick basalt sequence in south central Washington, geophysical and hydrological exploration of the Rattlesnake Hills deep stratigraphic test well: Battelle Pacific Northwest Lab. Rept. 776, 120 p.
J	26	Robbins, S. L.; Burt , F. J.; Gregg, D. P., 1975, Gravity and aeromagnetic study of part of the Yakima River basin, Washington: U.S. Geol. Survey Prof. Paper 726-E, 7 p.
J	27	Siems, B. A., 1973, Surface to subsurface correlation of Columbia River basalt using geophysical data, in parts of Adams and Franklin Counties, Washington: Washington State Univ. M.S. thesis; Washington State Univ., Coll. of Engrng. Res. Div. Bull. 331, 65 p., 1973.
J	28	Simmons, G. C.,; Van Noy, R. M.; Zilka, N. T., 1974, Mineral resources of the Cougar Lakes-Mount Aix study area, Yakima and Lewis Counties, Washington, with a section on interpretation of aeromagnetic data, by W. E. Davis: U.S. Geol. Survey Open-File Rept. 74-243, 80 p., plus 3 map sheets.
J	29	Swanberg, C. A., 1968, A gravity survey over the central part of the Okanogan Range, Washington: Southern Methodist Univ. M.S. thesis, 51 p.

Sheet No.	Geologic Map No.	References
J	30	Swanson, D. A., Wright, T. L.; Zietz I., 1976, Geologic interpretation of an aeromagnetic map of the west-central Columbia Plateau, Washington and Oregon: U.S. Geol. Survey Open-File Rept. 76-51, 28 p., 1 plate, 3 figures.
J	31	U.S. Geological Survey, 1973, Aeromagnetic map of parts of Okanogan and Sandpoint 1° by 2° quadrangles, Washington, Idaho, Montana: U.S. Geol. Survey Open-File map, 1 sheet, scale 1:250,000.
J	32	U.S. Geological Survey, 1974, Aeromagnetic map of parts of Okanogan, Sandpoint, Ritzville, and Spokane 1° by 2° quadrangles, northeastern Washington: U.S. Geol. Survey Open-File map, scale 1:250,000, 1 sheet. Also 23 sheets, scale 1:62,500 of the same area.
J	33	U.S. Geological Survey, 1976, Aeromagnetic map for part of southwestern Washington: U.S. Geol. Survey Open-File Rept. 75-648, 4 sheets, scale 1:62,500.
J	34	U.S. Geological Survey, 1976, Aeromagnetic map of the Horseshoe Basin quadrangle, Okanogan County, Washington: U.S. Geol. Survey map, 1:62,500.
J	35	U.S. Geological Survey, 1977, Aeromagnetic map of part of northern Washington: U.S. Geol. Survey Open-File Rept. 77-254, 2 plates, scale 1:62,500.
J	36	Walters, K. L.; Cline, D. R.; Luzier, J. E., 1972, Test-observation well near Odessa, Washington: description and preliminary results: U.S. Geol. Survey Open-File Rept., Tacoma, Washington, 25 p.

Sheet No.	Geologic Map No.	References
J	37	Walters, K. L., 1973, Test-observation well near Almira, Washington: description and preliminary results: U.S. Geol. Survey Open-File Rept., Tacoma, Washington, 20 p.
J	38	Woollard, G. P., 1958, Results for a gravity control network at airports in the United States: Geophysics, v. 23, no. 3, p. 520-535, 7 figures.
J	39	Yost, C. R., 1976, Gravity survey of the Cheney quadrangle, Washington: Eastern Washington State College M.S. thesis, 37 p.
J	40	Zietz, I.; others, 1971, Interpretation of an aeromagnetic strip across the northwestern United States: Geol. Soc. Am. Bull., v. 82, no. 12, p. 3347-3372. Figure 1 includes an aeromagnetic map at scale 1:2,500,000.

APPENDIX C

COMPILATION OF COLUMNAR, CROSS AND TYPE SECTIONS IN THE COLUMBIA BASIN AND SURROUNDING AREAS OF WASHINGTON

CROSS SECTIONS

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
K	Okanogan	1	Campbell, I,; Loofbourow, J. S., Jr., 1957, Preliminary geologic map and sections of the magnesite belt, Stevens County, Washington: U.S. Geol. Survey Mineral Investigations Field Studies Map MF-117, 1:36,000.
L	Ritzville	1a-c	Becraft, G. E., 1959, Geology of the southern part of the Turtle Lake quadrangle, northeastern Washington: Univ. of Washington Ph.D. thesis, 95 p. Plate 1, 1:48,274; Plate 2, 1:2,400.
L	Ritzville	2	Becraft, G. E.; Weis, P. L., 1963, Geology and mineral deposits of the Turtle Lake quadrangle, Washington: U.S. Geol. Survey Bulletin 1131, 73 p. Plate 1, 1:62,500.
L	Ritzville	3	Campbell, I.; Loofbourow, J. S., Jr., 1957, Preliminary geologic map and sections of the magnesite belt, Stevens County, Washington: U.S. Geol. Survey Mineral Investigations Field Studies Map MF-117, 1:36,000.
L	Ritzville	4a-b	Grolier, M. J.; Foxworthy, B. L., 1961, Geology of the Moses Lake North quadrangle, Washington: U.S. Geol. Survey Miscellaneous Geological Investigations Map 1-330, 1:24,000.
L	Ritzville	5a-d	Mundorff, M. J.; Reis, D. J.; Strand, J. R., 1952, Progress report on the ground water in the Columbia Basin Project, Washington: U.S. Geol. Survey Open-File Report, 229 p. Plate 3, 1:316,800

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
M	Spokane (See reference for exact location of cross sections)	1a-c	Griggs, A. B., 1976, The Columbia River Basalt Group in the Spokane quadrangle, Washington, Idaho, Montana, with a section on petrography by D. A. Swanson: U.S. Geol. Survey Bulletin 1413, 39 p. Figure 6, 1:266,780.
M	Spokane	2a-u	Hosterman, J. W.; Scheid, V. E.; Allen, V. T.; Sohn, I. G., 1960, Investigations of some clay deposits in Washington and Idaho: U.S. Geol. Survey Bulletin 1091, 147 p. Plate 3, 1:12,000.
			Scheid, V. E.; Hosterman, J. W.; Sohn, I. G., 1954, Excelsior high-alumina clay deposits, Spokane County: U.S. Geol. Survey Open-File Report, 73 p. Plate 1, 1:6,000.
M	Spokane	3	Hosterman, J. W., 1969, Clay deposits of Spokane County, Washington: U.S. Geol. Survey Bulletin 1270, 96 p. Plate 1, 1:24,000.
M	Spokane	4a-d	Olson, T. M., 1975, The geology and groundwater resources of part of the Hangman and Marshall Creek drainage basins, Spokane County, Washington: Eastern Washington State College M.S. thesis, 70 p. Plate 1, 1:63,360;
M	Spokane	4a-d	Olson, T. M. and others, 1957, Geology, ground water quality of part of southern Spokane County, Washington: Office of Water Research and Technology Project Completion Report, Eastern Washington State College, 139 p., Plate 1, 1:50,688.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
M	Spokane	5	Walters, K. L.; Glancy, P. A., 1969, Reconnaissance of geology and of ground water occurrence and development in Whitman County, Washington: Washington Department Water Resources Water-Supply Bulletin 26, 169 p. Plate 3, 1:84,480.
M	Spokane	6a-b	Weis, P. L., 1968, Geologic map of Greenacres quadrangle, Washington and Idaho: U.S. Geol. Survey Geologic Quadrangle Map GQ-734, 1:62,500.
M	Spokane	7a-b	Weissenborn, H. F., 1955, Study of the Columbia River Basalts at Spokane, Washington, with a comparision of the "Rimrock and Valley" flows: Smith College M.A. thesis, 64 p. Plate 2, 1:250,000.
M	Spokane	8a-c	Weissenborn, A. E., Weis, P. L., 1976, Geologic map of the Mount Spokane quadrangle, Spokane County, Washington, and Kootenai and Bonner Counties, Idaho: U.S. Geol. Survey Geologic Quadrangle Map GQ-1336, 1:62,500.
M	Spokane	9a-c	Conners, J. A., 1976, Quaternary history of northern Idaho and adjacent areas: Univ. of Idaho Ph.D. thesis, 504 p. Figure 34.
N	Wenatchee	1a-b	Alexander, Frank, 1956, Stratigraphic and structural geology of the Blewett-Swauk area, Washington: Univ. of Washington M.S. thesis, 64 p. Plate 3, 1:72,411.
N	Wenatchee	2	Bayley, E. P., Jr., 1965, Bedrock geology of the Twin Peaks area, an intrusive complex near Wenatchee, Washington: Univ. of Washington M.S. thesis, 47 p. Plate 1, 1:15,840.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
N	Wenatchee	3a-b	Foster, R. J., 1960, Tertiary geology of a portion of the central Cascade Mountains, Washington: Geol. Society of America Bulletin, v. 71, no. 2, p. 99-125. Plate 1, 1:126-720.
N	Wenatchee	4	Houghland, E., 1932, The structure of the Natapoc Formation north of Leavenworth, Washington: Washington State College Report, 24 p., 1:125,000.
N	Wenatchee (See reference for exact location of cross sections.)	5	Lamey, C. A., 1945, The Blewett iron-nickel deposit, Chelan County, Washington: U.S. Geol. Survey Open-File Report, 47 p. Plate 1, 1:1,200.
N	Wenatchee	6a-e	Lamey, C. A.; Hotz, P. E., 1952, The Cle Elum River nickeliferous iron deposits, Kittitas County, Washington: U.S. Geol. Survey Bulletin 978-B, p. 27-65. Plate 9, 1:4,800.
N	Wenatchee	7a-c	Laval, W. N., 1948, An investigation of the Ellensburg Formation: Univ. of Washington M.S. thesis, 52 p. Appendix A, 1:125,000.
N	Wenatchee	8	Page, B. M., 1939, Geology of a part of the Chiwaukum quadrangle, Washington: Stanford Univ. Ph.D. thesis, 203 p. Figure 3, 1:62,500.
N	Wenatchee	9a-f	Pratt, R. M., 1958, Geology of the Mount Stuart area, Washington: Univ. of Washington Ph.D. thesis, 228 p. Plate 7, 1:62,500.
N	Wenatchee	10a-d	Rector, R. J., 1962, Geology of the east half of the Swauk Creek mining district: Univ. of Washington M.S. thesis, 73 p. Plate 11, 1:24,000.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
N	Wenatchee	11	Rosenmaier, F. J., 1968, Stratigraphy and structure of the Table Mountain-Mission Peak area in the Wenatchee Mountains, central Washington: Univ. of Washington M.S. thesis, 44 p. Plate 1, 1:24,000.
N	Wenatchee	12a-b	Russell, I. C.; Smith, G. O.; Curtis, C. G.; Mendenhall, W. C., 1904, Mount Stuart quadrangle: U.S. Geol. Survey Geologic Folio 106. Map 1, 1:125,000
N	Wenatchee	13a-g	Saunders, E. J., 1914, The coal fields of Kittitas County: Washington Geol. Survey Bull. no. 9, 191 p. Plate 1, 1:126,720; Plate 2, 1:15,840.
N	Wenatchee	14a-c	Stout, M. L., 1959, Geology of a part of the south-central Cascade Mountains of Washington: Univ. of Washington Ph.D. thesis, 183 p. Plate 2, 1:63,360.
N	Wenatchee	15	Tabor, R. W.; and others, 1977, Preliminary geologic map of the Wenatchee 1:100,000 quadrangle, Washington: U.S. Geol. Survey Open-File Report 77-531, 24 p.
N	Wenatchee	16	Van Diver, B. B., 1964, Petrology of the metamorphic rocks, Wenatchee Ridge area, central North Cascades: Univ. of Washington Ph.D. thesis, 140 p. Plate 11, 1:146,080.
N	Wenatchee	17a-c	Washington Public Power Supply System, Inc., 1977, Preliminary safety analysis report (Amendment 23): WPPSS Nuclear Project No. 1, Richland, Washington, 13 sub-appendices in 2 volumes, pagination varies. Figure 2RD.6-3, 1:68,571; Figure 2RD.8-2, 1:68,571.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
N	Wenatchee	18a-c	Waters, A. C., 1930, Geology of the southern half of the Chelan quadrangle, Washington: Yale Univ. Ph.D. thesis, 256 p. Plate 1, 1:72,410.
N	Wenatchee	19a-c	Weaver, C. E., 1911, Geology and ore deposits of the Blewett Mining District: Washington Geol. Survey Bull. no. 6, 104 p. Plate 1, 1:21,120.
N	Wenatchee	20	Willis, C. L., 1950, Geology of the northeastern quarter of the Chiwaukum quadrangle, Washington: Univ. of Washington Ph.D thesis, 158 p. Plate 46, 1:63,360.
N	Wenatchee	21a-b	Young, R. E., 1963, Geology of the Swauk Formation in the Leavenworth area, Washington: Univ. of Washington B.S. thesis, 49 p. Map, 1:63,360.
O	Yakima	1a-b	Alto, B. R., 1955, Geology of a part of the Boylston quadrangle and adjacent areas in central Washington: Univ. of Washington M.S. thesis, 38 p. Plate 5, 1:44,352.
O	Yakima	2a-b	Becraft, G. E., 1950, Definition of the Tieton andesite on lithology and structure: Washington State College M.S. thesis, 26 p. Plate 1, 1:125,000.
O	Yakima	3a-b	Diery, H. D., 1967, Stratigraphy and structure of Yakima canyon between Roza Gap and Kittitas Valley, central Washington: Univ. of Washington Ph.D. thesis, 116 p. Plate 1, 1:24,000.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
0	Yakima	4a-e	Foxworthy, B. L., 1962, Geology and ground water resources of the Ahtanum Valley, Yakima County, Washington: U.S. Geological Survey Water-Supply Paper 1958. Plate 1, 1:62,500.
0	Yakima	5a-c	Holmgren, D. A., 1967, The Yakima-Ellensburg unconformity, central Washington: Univ. of Washington M.S. thesis, 69 p. Plate 1, 1:126,720.
0	Yakima	6	Holmgren, D. A., 1969, Columbia River Basalt patterns from central Washington to northern Oregon: Univ. of Washington Ph.D. thesis, 55 p. Plate 1, 1:31,680.
0	Yakima	7a-e	Laval, W. N., 1948, An investigation of the Ellensburg Formation: Univ. of Washington M.S. thesis, 52 p. Appendix A, 1:125,000.
0	Yakima	8a-q	Laval, W. N., 1956, Stratigraphy and structural geology of portions of south central Washington: Univ. of Washington Ph.D. thesis, 223 p. Plates 21, 24, 27, 29 and 31, 1:62,500.
0	Yakima	9	Mason, G. W., 1953, Interbasalt sediments of south-central Washington: Washington State College M.S. thesis, 116 p. Figure 3.
0	Yakima	10a-e	Robinson, C. F., 1966, Stratigraphy and structural geology of Ahtanum Ridge, Yakima, Washington: Univ. of Washington M.S. thesis, 35 p.
0	Yakima	11a-b	Sheppard, R. A., 1960, Petrology of the Simcoe Mountains area, Washington: Johns Hopkins Univ. Ph.D. thesis, 153 p. Plate 1, 1:126,720.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
0	Yakima	12a-b	Simmons, G. C., 1950, Russell Ranch Formation: Washington State College M.S. thesis, 26 p. Plate 1, 1:125,000.
0	Yakima	13a-d	Swanson, D. A., 1964, The middle and late Cenozoic volcanic rocks of the Tieton River area, south-central Washington: The Johns Hopkins Univ. Ph.D. thesis, 329 p. Plate 1 and 2, 1:50,688.
0	Yakima	14a-b	Swanson, D. A., 1966, Tieton volcano, a Miocene eruptive center in the southern Cascade Mountains, Washington: Geol. Society of America Bull., v. 77, no. 11, p. 1293-1415. Plate 1, 1:50,688.
0	Yakima	15a-b	Washington Public Power Supply System, Inc., 1977, Preliminary safety analysis report (Amendment 23): WPPSS Nuclear Project No. 1, Richland, Washington, 13 sub-appendices in 2 volumes, pagination varies. Figure 2RD.6-3, 1:68,571.
0	Yakima	16	Waters, A. C., 1955, Geomorphology of south-central Washington, illustrated by the Yakima East quadrangle: Geol. Society of America Bull., v. 66, no. 6, p. 663-684. Plate 1, 1:62,500.
0	Yakima	17a-d	Yeaton, W. J., 1923, Geology of the Zillah quadrangle, Washington: Univ. of Chicago M.S. thesis, 88 p. Plate 1, 1:125,000.
P	Walla Walla	1	Alto, B. R., 1955, Geology of a part of the Boylston quadrangle and adjacent areas in central Washington: Univ. of Washington M.S. thesis, 38 p. Plate 5, 1:44,352.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
P	Walla Walla	2a-f	Bingham, J. W.; Londquist, C. J.; Baltz, E. H., 1970, Geologic investigation of faulting in the Hanford region, Washington: U.S. Geol. Survey Open-File Report, 103 p. Figure 6, 1:24,137; Figure 13, 1:24,137.
P	Walla Walla	3	Brooks, W. E., 1974, Stratigraphy and structure of the Columbia River basalt in the vicinity of Gable Mountain, Benton County, Washington: Univ. of Washington M.S. thesis, 39 p. Figure 3, 1:19,495.
P	Walla Walla	4a-e	Brown, D. J., 1959, Subsurface geology of the Hanford separation areas: Hanford Laboratories Operation Report HW 61780, 21 p. Figure 2, 1:63,360.
P	Walla Walla	5a-f	Brown, D. J., 1962, Geology underlying Hanford reactor areas: Hanford Atomic Products Operation Report HW69471, 20 p. Figure 2, 1:158,400.
P	Walla Walla	6	Brown, R. E.; McConiga, M. W., 1960, Some contributions to the stratigraphy and indicated deformation of the Ringold Formation: Northwest Sci., v. 34, no. 2, p. 43-54. Figure 1, 1:442,618.
P	Walla Walla	7a-k	Laval, W. N., 1956, Stratigraphy and structural geology of portions of south-central Washington: Univ. of Washington Ph.D. thesis, 223 p. Plates 21, 24, 27, 29, and 31, 1:62,500.
P	Walla Walla	8a-b	Mason, G. W., 1953, Interbasalt sediments of south-central Washington: Washington State College M.S. thesis, 116 p. Figure 3, 1:100,000.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
P	Walla Walla	9a-d	Mundorff, M. J.; Reis, D. J.; Strand, J. R., 1952, Progress report of the ground water in the Columbia Basin Project, Washington: U.S. Geol. Survey Open-File Report, 229 p. Plate 3, 1:316,800.
P	Walla Walla	10a-b	Newcomb, R. C., 1965, Geology and ground-water resources of the Walla Walla Basin, Washington-Oregon: Washington Division Water Resources Water Supply Bull. 21, 151 p. Plate 1, 1:92,160.
P	Walla Walla	11a-b	Newcomb, R. C., Strand, J. R.; Frank F. J., 1972, Geology and ground water characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington: U.S. Geol. Survey Professional Paper 717, 78 p. Plate 1, 1:62,500.
P	Walla Walla	12	Pardee, J. T., 1928, Geology of reservoir sites near Washtucna and Kahlotus, Washington: U.S. Geol. Survey Open-File Report, 15 p. Figure 4, 1:125,000.
P	Walla Walla	13a-b	Swanson, D. A.; and others, 1977, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, southeast Washington and adjacent Idaho: U.S. Geol. Survey Open-File Report 77-100, 11 p. Sheet 1, 1:250,000.
P	Walla Walla	14a-c	Taylor, T. L., 1976, The basalt stratigraphy and structure of the Saddle Mountains of south-central Washington: Washington State University M.S. thesis, 116 p. Map, 1:18,103.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
P	Walla Walla	15a-e	Jones, M. G.; Landon, R. D., 1978, Geology of the Nine Canyon map area: Rockwell Hanford Operations, RHO-BWI-LD-6, Richland, Washington, 54 p., Plate 6.
P	Walla Walla	16a-b	Brown, R. E.; Brown, D. J., 1959, The surface of the basalt series in the Pasco Basin, Washington: Hanford Laboratories Operation, Richland, 13 p. Figures 3 and 3a.
Q	Pullman	1a-g	Foxworthy, B. L.; Washburn, R. L., 1963, Ground water in the Pullman area, Whitman County, Washington: U.S. Geol. Survey Water-Supply Paper 1655, 71 p. Plate 1, 1:63,360; Plate 2, 1:24,000.
Q	Pullman	2a-d	Graham, C. E., 1949, Structure of the western portion of the Lewiston downwarp in southeastern Washington: Washington State College M.S. thesis, 36 p. Figure 4, 1:63,360.
Q	Pullman	3a-b	Swanson, D. A.; and others, 1977, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, southeast Washington and adjacent Idaho: U.S. Geol. Survey Open-File Report 77-100, 11 p. Sheet 1, 1:250,000.
Q	Pullman	4a-c	Treasher, R. C., 1925, Geology of the Pullman quadrangle, Washington: Washington State College M.S. thesis, 74 p. Plate 1, 1:125,000.
Q	Pullman	5	Walters, K. L.; Glancy, P. A., 1969, Reconnaissance of geology and of ground water occurrence and development in Whitman County, Washington:

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
			Washington Department Water Resources Water-Supply Bull. 26, 169 p. Plate 3, 1:84,480.
Q	Pullman	6	Shumway, R. D., 1960, Geology of the Lime Hill area, Asotin County, Washington: Washington State Univ. M.S. thesis, 54 p. Figure 11, 1:15,600.
Q	Pullman	7a-c	Hubbard, P. S., 1968, Geology of the Saddle Butte quadrangle, southeastern Washington: Univ. of Hawaii M.S. thesis, 75 p.
Q	Pullman	8	Ross, M. E., 1978, Stratigraphy, structure and petrology of Columbia River basalt in a portion of the Grande Ronde River-Blue Mountains area of Oregon and Washington: Rockwell Hanford Operations, Richland, Washington, RHO-SA-58, 460 p.
R	The Dalles	1a-b	Newcomb, R. C., 1969, Effect of tectonic structure on occurence of ground water in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington: U.S. Geol. Survey Professional Paper 383-C, 33 p. Plate 1, 1:62,500.
R	The Dalles	2	Sheppard, R. A., 1960, Petrology of the Simcoe Mountains area, Washington: Johns Hopkins Univ. Ph.D. thesis, 153 p. Plate 1, 1:126,720.
R	The Dalles	3	Sheppard, R. A., 1964, Geologic map of the Husum quadrangle, Washington: U.S. Geol. Survey Mineral Investigations Field Studies Map MF-280, 1:62,500.

Sheet No.	AMS 1° x 2° Base Map	Cross-Section No.	Reference, Plate Number and Scale
S	Pendleton	1a-b	Newcomb, R. C., 1965, Geology and ground water resources of the Walla Walla Basin, Washington-Oregon: Washington Division Water Resources Water Supply Bull. 21, 151 p. Plate 1, 1:92,160.
S	Pendleton	2a-d	Newcomb, R. C., 1969, Geologic map of the proposed Paterson Ridge pumped-storage reservoir, south-central Washington: U.S. Geol. Survey Open-File Report, 8 p., 1:31,680

COLUMNAR SECTIONS

Sheet No.	AMS 1° x 2° Base Map	Columnar Section No.	Reference, Plate Number and Scale
L	Ritzville	1a-z,aa-ee	Lefebvre, R. H., 1966, Variations of flood basalts of the Columbia River plateau, central Washington: Northwestern Univ. Ph.D. thesis, 211 p.
L	Ritzville	2	Mason, G. W., 1953, Interbasalt sediments of south-central Washington: Washington State College M.S. thesis, 116 p.
L	Ritzville	3a-b	Stevenson, R. E., 1942, Petrology of the Ringold in the Palouse area: Washington State College M.S. thesis, 43 p.
L	Ritzville	4a-b	Patton, P. C.; Baker, V. R., 1978, New evidence for pre-Wisconsin flooding in the channeled scab-land of eastern Washington: Geology, v. 6, no. 9, p. 567-571.
M	Spokane	1a-c	Barnes, V. E., 1927, The geology of the Oakesdale quadrangle, Washington: Washington State College M.S. thesis, 43 p.
M	Spokane	2a-c	Stevenson, R. E., 1942, Petrology of the Ringold in the Palouse area: Washington State College M.S. thesis, 43 p.
M	Spokane	3a, 4a	Conners, J. A., 1976, Quaternary history of northern Idaho and adjacent areas: Univ. of Idaho Ph.D. thesis, 504 p., Figure 24.
N	Wenatchee	1	Holmgren, D. A., 1969, Columbia River basalt patterns from central Washington to northern Oregon: Univ. of Washington Ph.D. thesis, 55 p.
O	Yakima	1a-h	Diery, H. D.; McKee, B., 1969, Stratigraphy of the

Sheet No.	AMS 1° x 2° Base Map	Columnar Section No.	Reference, Plate Number and Scale
			Yakima basalt in the type area: Northwest Sci., v. 43, no. 2, p. 47-64.
0	Yakima	2a-c	Holmgren, D. A., 1969, Columbia River basalt patterns from central Washington to northern Oregon, Univ. of Washington Ph.D. thesis.
0	Yakima	3a-i	Laval, W. N., 1956, Stratigraphy and structural geology of portions of south-central Washington: Univ. of Washington Ph.D. thesis, 223 p.
0	Yakima	4a-n	Mason, G. W., 1953, Interbasalt sediments of south-central Washington: Washington State College M.S. thesis, 116 p.
0	Yakima	5a-e	Swanson, D. A., 1964, The middle and late Cenozoic volcanic rocks of the Tieton River area, south-central Washington: The Johns Hopkins Univ. Ph.D. thesis, 329 p.
0	Yakima	6a-g	Cochran, B. D., 1978, Late Quaternary stratigraphy and chronology in Johnson Canyon, central Washington: Washington State Univ. M.A. thesis, 81 p. Figure 2.
P	Walla Walla	1a-k	Laval, W. N., 1956, Stratigraphy and structural geology of portions of south-central Washington: Univ. of Washington Ph.D. thesis, 223 p.
P	Walla Walla	2a-b	Lefebvre, R. H., 1966, Variations of flood basalts of the Columbia River Plateau, central

Sheet No.	AMS 1° x 2° Base Map	Columnar Section No.	Reference, Plate Number and Scale
			Washington: Northwestern Univ. Ph.D. thesis, 211 p.
P	Walla Walla	3a-w	Mason, G. W., 1953, Interbasalt sediments of south-central Washington: Washington State College M.S. thesis, 116 p.
P	Walla Walla	4a-d	Newcomb, R. C., 1958, Ringold Formation of Pleistocene age in type locality, the White Bluffs, Washington: Am. Jour. Sci., v. 256, Reprint 1, p. 328-340.
P	Walla Walla	5a-c	Pardee, J. T., 1928, Geology of reservoir sites near Washtucna and Kahlotus, Washington: U.S. Geol. Survey Open-File Report, 15 p.
P	Walla Walla	6a-c	Stevenson, R. E., 1942, Petrology of the Ringold in the Palouse area, Washington State College M.S. thesis, 43 p.
P	Walla Walla	7a-c	Taylor, T. L., 1976, The basalt stratigraphy and structure of the Saddle mountains of south-central Washington: Washington State Univ. M.S. thesis, 116 p.
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