MAP OF MAJOR BEDROCK LITHOLOGIC UNITS FOR THE PACIFIC NORTHWEST: A CONTRIBUTION TO THE INTERIOR COLUMBIA BASIN ECOSYSTEM MANAGEMENT PROJECT

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INTRODUCTION

This report is one in a series of digital maps, data files, and reports generated by the U.S. Geological Survey (USGS) to provide geologic process and mineral resource information for the Interior Columbia Basin Ecosystem Management Project, a U.S. Forest Service and Bureau of Land Management interagency project. The various digital maps and data files that were provided by the USGS are being used in a geographic information system (GIS)-based ecosystem assessment that includes a comprehensive analysis of past, present, and future ecosystem conditions within the general area of the Columbia River Basin east of the Cascade Mountains.

THE INTERIOR COLUMBIA BASIN ECOSYSTEM MANAGEMENT PROJECT

In January of 1994, the Chief of the U.S. Forest Service (USFS) and the Director of the Bureau of Land Management (BLM) initiated what was then called the Eastside Ecosystem Management Project to "develop a scientifically sound and ecosystem-based strategy for management of eastside forests." The project was further directed to "develop an ecosystem management framework and assessment for land administered by the Forest Service and the Bureau of Land Management on those lands east of the Cascade crest in Washington and Oregon and within the interior Columbia River Basin." The driving force behind the project was the need to develop a strategy for dealing with anadromous fish habitat and watershed conservation in eastern Oregon and Washington. Subsequently, when it became clear that similar strategies were needed for anadromous fish in the remainder of the Columbia River Basin (particularly in Idaho and Montana), the project was extended to include all of the Columbia River drainage basin in the United States east of the Cascade Mountain divide plus the remainder of southeastern Oregon, which is not within the drainage basin (fig. 1). At that time, the project was renamed the Interior Columbia Basin Ecosystem Management Project (ICBEMP).

The ICBEMP is producing scientific assessments of current and historic landscape conditions; aquatic and terrestrial habitat, species distributions, and populations; and economic and social conditions. The project is also producing scientific assessments of the potential future conditions and possible tradeoffs likely to result from a range of possible disturbances and management practices on public lands in the basin. Although scientific assessments are being conducted for the entire basin, management decisions that are based on the assessments will apply to public lands (USFS and BLM) only.

The goal of the ICBEMP management strategy is to provide management tools that can be used to sustain or restore ecosystem integrity and to promote products and services desired by society over the long term. The management strategy is intended to provide tools to balance ecosystem conditions, resource uses, and competing values of ecosystem users. The intent of the project is to understand the ramifications of past, present, and future management practices and man-made or natural disturbances both in the area subject to the management prac-

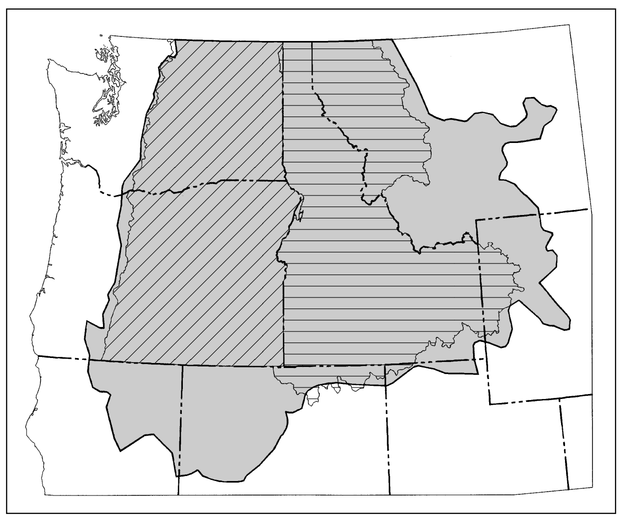

Figure 1. Map showing the geographic extent of the Interior Columbia Basin Ecosystem Management Project: the Landscape Characterization Area (gray shading), which is the study area used by most Science Integration Team staff areas; the Eastside EIS area (diagonal hatching); and the Upper Columbia EIS area (horizontal hatching).

tice or disturbance and in areas that may be remote, in time and (or) space.

The project is organized around two teams, the Science Integration Team and the Environmental Impact Statement Team. Both teams are further sub-divided into subteams of subject experts: (1) landscape ecology, (2) aquatic/riparian, (3) terrestrial, (4) forest policy and economics, and (5) social sciences. Many staff scientists work on both the Science Integration Team and the Environmental Impact Statement Team.

Specific objectives of the project are:

•To conduct a broad scientific assessment of the resources within the interior Columbia River basin to characterize and assess landscape, ecosystem, social, and economic processes and functions and to describe probable outcomes of various management practices and trends.

•To develop an ecosystem management framework that includes principles and processes that may be used in a National Environmental Protection Act (NEPA) process to develop management direction for federal agencies at all levels within the basin.

•To write an Eastside Environmental Impact Statement (EIS) proposing a broad array of alternative strategies for an area that encompasses ten national forests and portions of four BLM districts in eastern Washington and Oregon (fig. 1).

•To write an Upper Columbia River Basin EIS with a similar array of alternative strategies for an area that encompasses lands administered by the BLM and USFS in Idaho, western Montana, Wyoming, Utah, and Nevada within the Columbia River Basin (fig. 1).

•To conduct a scientific evaluation of issues and alternatives identified through the NEPA scoping process for the Eastside EIS.

The ICBEMP is an intense, short-term project designed to develop several regionally-consistent, land-management alternatives. These alternatives, derived from basin-wide analyses of highly generalized data, will form a framework for land-management decisions at the local level. This framework will be modified as better data and understanding of the basin are developed. Within the scope of the project, a flexible, basin-wide, digital database will be developed and will evolve and improve as higher resolution data become available. All data are being collected in a GIS-compatible format for digital display, analysis, and distribution. Information on the availability of all digital data sets, paper maps, and other reports generated by the ICBEMP can be obtained from either of the following:

Interior Columbia Basin Ecosystem Management Project
ATTN: Cindy Dean
112 E. Poplar Street
Walla Walla, WA 99362
(509) 522–4030

Bureau of Land Management
ATTN: Becky Gravenmeier, OR99.2
Oregon–Washington State Office
P.O. Box 2965
Portland, OR 97208
(503) 952–6273

PROJECT EXTENT AND SCALE

The scope and extent of the project area varies as a function of the objective. The scientific assessment, for example, includes all lands, not just those that are federally managed. This objective is focused on the Columbia River Basin but is not strictly limited to the actual drainage basin boundaries. Moreover, some scientific assessment subject sub-teams, by necessity, have extended their work beyond the limits of the formal project because factors such as wildfires and wildlife migration are not limited by drainage divides or political boundaries. Most subject sub-team project areas are restricted to the Landscape Characterization boundary developed by the Landscape Ecology group (fig. 1). The scientific assessment is primarily based on information suitable for compilation at a scale of 1:1,000,000. This published map is presented at a scale of 1:1,500,000.

U.S. GEOLOGICAL SURVEY INVOLVEMENT

In June, 1994, the USGS was asked to provide estimates on the value of undiscovered mineral resources for the Columbia River Basin. In the course of discussions with members of various sub-teams from both project teams, it became apparent that additional earth science information was also highly relevant to the assessment of historic, current, and future ecological, economic, and social systems, and that the USGS could provide this information in a digital format. Within the ICBEMP's tight schedule (7 months from the USGS start date until the information had to be available to the rest of the Science Integration Team), the USGS was able to provide basin-wide, integrated, digital information about bedrock lithology, rock chemistry, potential animal habitat, stream sediment geochemistry, volcanic and earthquake hazards, geothermal resources, and mineral resources. The bedrock chemistry information is summarized in Raines and others (1996). Potential animal habitat information is summarized in Frost and others (1996), and stream sediment geochemistry is summarized in Raines and Smith (1995). Digital information on hazards was derived from Algermissen and others (1990) and Hoblitt and others (1987). Geothermal resources information is summarized in Derkey and Johnson (1995). Mineral resources information is summarized in Bookstrom and others (1995); Bookstrom and others (1996); Box and others (1996); and Zientek and others (1996).

Information on the bedrock lithology portion of the study is covered by this report and by Johnson and

Raines, 1995. This report also summarizes the strategy that was used for rapid analyses of regional geologic map data using GIS techniques to produce the bedrock lithology, rock chemistry, and potential animal habitat maps, which were all derived from the state geologic maps. Considerably more information was identified as potentially useful to the ICBEMP, but integrated digital products could not be provided for the entire study area within the time frame of the assessment.

ACKNOWLEDGMENTS

Digital compilation products such as this map would not exist without the geologic mapping of generations of geologists whose work contributed to the small-scale state geologic maps that have been published by most states. Our task of constructing a digital compilation of the geology of the Interior Columbia Basin Ecosystem Management Project area was far simpler because of the existence of these state geologic maps, and we gratefully acknowledge the work of the geologists and agencies that supported compilation of the maps. Those agencies include the U.S. Geological Survey, the California Division of Mines and Geology, the Idaho Bureau of Mines and Geology, the Montana Bureau of Mines and Geology, the Nevada Bureau of Mines and Geology, the Oregon Department of Geology and Mineral Industries, the Utah Geological and Mineral Survey, the Washington State Department of Natural Resources, and the Geological Survey of Wyoming.

USGS geologists, Thor Kiilsgaard and Fred Miller, provided useful advice about regional geology and the identification of unlabeled features on the published state geologic maps. Art Bookstrom, Steve Box, Jim Evans, Tom Frost, and Michael Zientek, USGS geologists, contributed to the development of the major lithology classification scheme and to the classification of individual bedrock units for the map.

We particularly wish to acknowledge Patrick Geehan, the Bureau of Land Management Project coordinator for the Interior Columbia River Basin Ecosystem Management Project, for recognizing the importance of geology to ecosystem management and for supplying funds to digitize the Washington, Idaho, and Montana state geologic maps.

DATA SOURCES, PROCESSING, AND ACCURACY

The starting points for the major bedrock lithologic map and other derivative maps were the state geologic maps: California, scale 1:750,000 (Jennings, 1977); Idaho, scale 1:500,000 (Bond and Wood, 1978); Montana, scale 1:500,000 (Ross and others, 1955); Nevada, scale 1:500,000 (Stewart and Carlson, 1978); Oregon, scale 1:500,000 (Walker and MacLeod, 1991); Utah, scale 1:500,000 (Hintze, 1980); Washington, scale 1:500,000 (Hunting and others, 1961); and Wyoming, scale 1:500,000 (Love and Christiansen, 1985). Characteristics of the source materials for each of these maps are summarized in Table 1. All of the maps were processed using the GIS package, ARC/INFO, and based on the results presented in Table 1 are considered accurate geographic representations of the original maps for the purposes of regional assessments.

State geologic maps were selected as the basis for the major lithology map because their scale provides an appropriate level of information to satisfy project objectives, and because they cover large areas, thereby reducing errors inherent in resolving correlation differences between maps. In addition, several state maps were available in digital form, and the others could be quickly digi-

Table 1. *Source of materials and registration errors for the digital, state geologic maps*

[The registration root-mean-square (RMS) errors are obtained while transforming from scanner units of inches (input in table) to real world coordinates of meters (output in table). These errors are the RMS difference between the scanned latitude and longitude location points from the source material and the calculated locations of these points. Where the registration error is queried (?) the data are not available; however, these maps were all digitized by scanning mylar copies of original publication material. These normally have an input RMS error of approximately 0.003, much smaller than the errors obtained from the paper sources used here. The Oregon geologic map was created using digital techniques so no additional (N.A.) processing was required. The large transform error for the western Montana sheet was caused by distortion in the southeastern corner of the paper map sheet.]

State	Date	Scale	Source Material	Registration Error (RMS) input (inches), output (meters)
California	1977	1:750,000	Mylar	?
Idaho	1978	1:500,000	Paper	0.011, 145.720
Montana	1955	1:500,000	Paper	Western Montana: 0.076, 965.561 Eastern Montana: 0.011, 133.434
Nevada	1978	1:500,000	Mylar	?
Oregon	1991	1:500,000	Digital	N.A.
Utah	1980	1:500,000	Mylar	?
Washington	1961	1:500,000	Mylar	0.015, 189.092
Wyoming	1985	1:500,000	Mylar	?

tized. The state maps provide considerably more detail and, in some areas, more current interpretations of the geology than the 1:2,000,000-scale geologic map of the United States (King and Beikman, 1974), even though some of the state maps are relatively old and, in places, do not represent the most current geologic understanding.

Digital processing of the state geologic maps was initialized by scanning the source materials. The scanned images were then vectorized and topologically structured, the lines and polygons were edited and proofed, attributes were added and proofed, the maps were transformed from scanner units to geographic coordinates, and finally, map distortions were removed by rubber-sheeting. The initial objective was to obtain a digital representation that, when plotted, would overlay the source materials within a line width. Each of the digital state maps meets this test.

In each of the state geologic maps, approximately 100 to 200 extremely small polygons were found that were either ambiguously attributed or un-attributed. These polygons were assigned map-unit attributes by consultation with regional experts and inspection of more detailed maps.

Geometric accuracy of the digitized source materials was determined by comparing the calculated locations of 15–25 points with known latitudes and longitudes with the locations of the same points on the source materials. Table 1 contains the results of this comparison as the registration root-mean-square error. Except for the western Montana sheet, these errors range from much less than to slightly larger than the national standard for 1:500,000-scale topographic base maps, which is ±140 m horizontally. The Montana maps (2 sheets) were scanned from old paper versions of the published map, because the map is out of print and original materials are no longer available. The large transform error for the western Montana sheet was caused by distortion in the southeastern corner of the paper map sheet. To correct for the geographic distortion of the source maps, the digital maps were rubber-sheeted to move the scanned latitude and longitude points to the correct calculated locations. This rubber-sheet correction provides the most accurate representation of the individual state geologic maps.

Digital versions of individual state geologic maps are available as follows:

California	California Division of Mines and Geology 1416 Ninth Street, Room 1341 Sacramento, CA 95814
Idaho	Descriptive report, Johnson and Raines (1996); digital files can be downloaded from the USGS public access World Wide Web site on the Internet: **URL=http://wrgis.wr.usgs.gov/docs/geologic/id/idaho.html**
Montana	Descriptive report, Raines and Johnson (1996a); digital files can be downloaded from the USGS public access World Wide Web site on the Internet: **URL=http://greenwood.cr.usgs.gov/pub/open-file-reports/ofr-95-0691**
Nevada	CD-ROM, Turner and Bawiec (1991)
Oregon	Data files can be downloaded from the USGS public access World Wide Web site on the Internet: **URL=http://greenwood.cr.usgs.gov/pub/oregon**
Utah	Data files can be downloaded from the USGS public access World Wide Web site on the Internet: **URL=http://greenwood.cr.usgs.gov/pub/utah**
Washington	Descriptive report, Raines and Johnson (1996b); digital files can be downloaded from the USGS public access World Wide Web site on the Internet: **URL=http://wrgis.wr.usgs.gov/docs/geologic/wa/washington.html**
Wyoming	Descriptive report, Green and Drouillard (1994); digital files can be downloaded from the USGS public access World Wide Web site on the Internet: **URL=http://greenwood.cr.usgs.gov/pub/open-file-reports/ofr-94-0425**

As a final step, the individual state maps were edge-matched by rubber-sheeting along their boundaries to fit the adjacent state maps. Because of the differences in how the digital maps had been prepared, there are differences in geometric accuracy from state to state. The Oregon state map was originally prepared digitally, so the published and digital version are identical. The Wyoming map was digitized from original source materials, and the California, Nevada, and Utah maps were prepared from base-stable copies of original source materials. These four maps have a root-mean-square error of registration near 0.003 inches. Because these maps have higher geometric accuracy than the Idaho, Montana, and Washington maps, the latter three maps were rubber-sheeted to fit the more accurate California, Oregon, Nevada, Utah, and Wyoming maps along their common boundaries. The maximum translation needed to match boundaries was approximately 400 meters; in most areas 200 meters or less were needed. The remaining borders were then rubber-sheeted to a compromise boundary to make a composite of all of the states. Because the Idaho-Montana border is very irregular and the two state maps used different base materials, many adjustments were required. Consequently this is the area of largest residual geometric error. Because of the differences in geologic representation between the state maps, the state boundaries were maintained in the bedrock lithology digital composite and were only eliminated in derivative maps.

As a partial test of the digitizing and attributing of the individual state maps, all derivative maps were checked for differences at the state boundaries. A few incorrectly labeled map units and areas where the map units were defined differently across state boundaries were identified. Examples include a rock unit mapped as granitic gneiss in one state and granite in the adjacent state, and several sedimentary facies changes that occur in the vicinity of state boundaries. To evaluate these problems and refine some of the interpretive maps, newer, larger-scale, geologic maps were examined and regional geology experts were consulted. National Uranium Resource Evaluation stream sediment geochemistry was also used where available to test the geochemical interpretations of the lithologic information (Raines and Smith, 1995).

MAJOR BEDROCK LITHOLOGY MAP

The composite digital map of the entire study area, which was generated from the state geologic maps, facilitates interpretation and reclassification of the bedrock geology for specific tasks such as those required by the ICBEMP. The following section describes a major bedrock lithology map that was derived from the composite state geology for the ICBEMP's Columbia River Basin analyses.

There are a number of possible approaches to creating a lithologic map of a large region, each emphasizing different features of the rocks and each appropriate for particular applications. Regional ecosystem management analyses of the Columbia River Basin required a means of integrating bedrock lithology into the Landscape Characterization process, which was the method by which the basin was divided into a small number of subsections, each with its own unique character. Each subsection, or landscape type, in the basin is relatively consistent in terms of geomorphology, bedrock geology, climate, and vegetation. The characterization process required a geologic map having a limited number of lithologies that could be consistently applied throughout the basin. We are confident that the digital map presented here defines the dominant lithologic character of the Pacific Northwest in 38 units; we consider this the minimum number of lithologic units needed to adequately represent the region.

Map units from the state geologic maps are regrouped here solely on the basis of rock type (lithology); criteria such as age, tectonic province, or other characteristics that may have been used to distinguish map units on state maps are not considered. Table 2 shows mapped bedrock units from each state geologic map that are included in each major lithologic category. The grouping of map units into lithologic categories used for this map is only one of many ways the lithologic information could be represented; starting from tables describing the map units of each state map, other groupings of lithologies could easily be devised that would serve different purposes.

Because many geologic map units (1) are a mixture of lithologic types, (2) have misleading names, or (3) have unit names that give insufficient information regarding lithology, individual map units on each state map were evaluated to assure that each was assigned to the most representative lithologic unit on our map. These assignments were made using data tables summarizing the lithologic information from the state map legends. The assignment of each state geologic map unit to one of our lithologic units was based primarily on the dominant lithology; consideration was also given, however, to other lithologies and the degree of mixing of lithologies. In classifying each unit, it was assumed that the first lithology listed in the map legend was the dominant lithology. Due to differing concepts between state maps of how to compile regional geologic maps and describe units, this assumption is only partially valid. Several approaches were used to test this assumption and make corrections. On our initial compilation, lithologic differences at state lines pointed out obvious problems. Where lithologic differences were observed at state boundaries, the descriptions of the state map units were checked for consistency, in some cases more detailed maps were consulted, and lithologic assignments were adjusted to be consistent between the states. This test proved reasonably comprehensive because the borders of these states are so extensive that most map units are found somewhere next to a state-line boundary. Based on this testing, most of the differences associated with state boundaries were resolved. To further avoid inconsistencies in unit assignment, maps were checked in some detail by regional geology experts.

OBTAINING DIGITAL DATA

The digital files that were used to make the major lithology map are available as GIS coverages and associated data files. All data files and map images are maintained in the projection used for all ICBEMP products:

Projection:	Albers Equal Area
1st Standard Parallel:	43° N
2nd Standard Parallel:	48° N
Central Meridian:	117° W
Origin of Projection:	41° N
Y-offset (digital files):	700,000 m

To obtain copies of the digital data, do one of the following:

1. Download the digital files from the USGS public access World Wide Web site on the Internet:
   URL=http://wrgis.wr.usgs.gov/docs/

geologic/northwest_region/ofr95-680.html

or Anonymous FTP from:

ftp://wrgis.wr.usgs.gov

directory:**pub/geologic/northwest_region/geology/ofr95-680**

These Internet sites contain the major lithology GIS coverage in ARC/INFO Export file format as well as the associated data files and ARC/INFO macro programs that are used to plot the map at 1:1,000,000 and 1:2,000,000 scales. Use of this data requires a GIS that is capable of reading ARC/INFO Export formatted files and a computer capable of reading UNIX ASCII files. To use these files on a DOS computer, they must be put through a unix-to-dos filter.

2. Or obtain the digital files from the ICBEMP project office. Contact information is given above in the section called U.S. Geological Survey Involvement.

CONCLUDING REMARKS

The major lithology map presented here was derived from digital versions of existing state geologic maps. Descriptions of the 800+ individual map units on the state geologic maps were tabularized for rapid interpretation. The complex geologic vocabulary used in the map legends was then systematically classified into a small number of categories based strictly on lithology. By this methodology, the state geologic maps could be rapidly combined into a new, derivative map representing a particular, restricted feature of the original map units. This and other new maps constructed by this method are derivative maps that can be used to answer focused questions.

Derivative maps produced from state map scale geology are an appropriate first step to providing a regional context for land management decisions. The applications these maps are intended to address are very general. The 1:500,000 scale of the data is appropriate to regional applications concerning the entire Columbia River Basin. Although some of the state geologic maps are old, much of the evolution of geologic knowledge since the 1970's has been concerned with the temporal correlation of rock units, with details of the compositions of the individual units, and with how the existing arrangement of rock units came to exist. These types of information have little bearing on the derivative maps presented here. Thus, the dominant lithologic character of the rock units is well represented in the state geologic maps, which are appropriate to regional applications.

Fundamental geologic information is a critical portion of any ecosystem study and should be part of the basis for land management decisions. Future ecosystem monitoring and adaptive management planning within the Columbia River Basin should include studies to improve the quality of the geologic data base.

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Table 2. *Major Bedrock Lithology Classification*

Formations	Lithology
California	
Q	Alluvium
Qs	Dune sand
Qls	Landslide
Qg	Glacial drift
E, J, TR, Pm, C	Shale and mudstone
QPc, P, M, Mc, ø, øc, €, Ec, Ep, Tc, TK, K, Kl, Ku, KJf, SO	Sandstone
p€	Conglomerate
D, ls	Carbonate
sch	Phyllite and schist
KJfm, KJfs, Pz, m	Interlayered meta-sediment
Qrv, Qrv^{p}, Qv^{p}, Tv^{p}, Mzv	Calc-alkaline volcanic rocks
mv	Calc-alkaline meta-volcanics
Qv, Tv	Mafic volcanic flows
Pzv	Greenstone
Ti, gr, gr^{Cz}, gr^{Mz}, $gr^{p€}$, gr^{Pz}	Calc-alkaline intrusive rocks
gb	Mafic intrusive rocks
um	Ultramafic rocks
p€, gr-m	Mixed granitic gneiss
Idaho	
Q_a, Q_d, Q_g, Qp_a, Qp_g, Qpl_g, Qpm_g, Qpu_g, Q_s, QT_g, QT_s	Alluvium
Qr_w	Dune sand
Qp_w, Q_w	Loess
Qp_d, Qpm_d	Lake sediments
Qp_c, Qp_t	Glacial drift
Kl, TRu, TRuw, DSc, €mn	Shale and mudstone
Jwm, Y1N, Y1Nm, Y4N, Y4Nm	Argillite and slate
Ted	Tuff
Tmd, SOc	Siltstone
Y2N, Y2Nm	Meta-siltstone
Tpd, Ju, €c, Y1s, Y3s, Y4s, Z2s	Sandstone
Y2s	Quartzite
TKg	Conglomerate
Ku, Jl, TRl, C, M, Ms, MD, D, DS, S, SO, O, Ol, Ou, O€c, €un, Pz	Carbonate
Td, Ps, PℙPc, ℙPs, Mc, Dc, €, Pzu	Mixed miogeosynclinal rocks
Jw, PℙPN	Mixed eugeosynclinal rocks
O€m, Pzm, p€1, p€2, p€3, Ys	Interlayered meta-sediment
J, TR, P, PℙPs, DO, O€, Zs	Carbonate and shale
Y3N, Y3Nm	Meta-carbonate and shale
Qpl_f, $Qpm1_f$, $Qpm2_f$, $Qpm3_f$, Qpm_f, Qpu_f, $Qpu1_f$, $Qpu2_f$, $Qpu3_f$, Tev, Tpv, Tpf	Felsic Pyroclastics
QT_f, Tmf, Tov	Felsic volcanic flows
Z1s	Calc-alkaline volcanic rocks
TRPv	Calc-alkaline meta-volcanics
Qpm_b, $Qpu1_b$, $Qpu2_b$, $Qpu3_b$, $Qpu4_b$, Qpu_b, Qr_b, QT_b, Tm1b, Tm2b, Tm3b, Tmb, Tpb, Pv, ZN	Mafic volcanic flows
TRv	Greenstone
Tei	Granite
Ti, Ki, Kif, Kii, KJi, JTRi, pKi, p€i	Calc-alkaline intrusive rocks
Tmi, Kib, Zi, Zib	Mafic intrusive rocks
Kim, Km, pKim, p€im, X, mig	Mixed granitic gneiss
p€	Mafic gneiss
Montana	
Qal, QTt, Tf	Alluvium
Qgl	Lake sediments
Qg	Glacial drift

Table 2. *Major Bedrock Lithology Classification — continued*

Formations	Lithology
Tfu, Twc, Twr, Kb, Kbf, Kc, Kcb, Kce, Kcl, Kf, Kg, Kmo, Kn, Kp, Ksm, Kt, Ktc, Ktm, Ku, JꞦ, Ju, Du	Shale and mudstone
p€ap, p€c, p€e, p€g, p€ga, p€p, p€s	Argillite and slate
p€m, p€nb, p€r	Meta-siltstone
Ta, Tw, Keu, Kfh, Kh, Khc, Kjr, Kk, Kl, Km, Kvi, PAL, Pu, ℙu	Sandstone
p€ne	Quartzite
Ꞧu	Conglomerate
Ou, p€w, p€a, p€h, p€n, p€si	Carbonate
Ts, €u	Mixed miogeosynclinal rocks
Mu	Carbonate and shale
p€pi, p€w	Meta-carbonate and shale
Tv, TKl, Kv	Calc-alkaline volcanic rocks
Tg	Granite
Tga	Alkalic bodies
Td, TKb, Ki, p€gr	Calc-alkaline intrusive rocks
Kdg, p€d, p€b	Mafic intrusive rocks
p€sc	Ultramafic rocks
Kib, p€gs	Mixed granitic gneiss
Nevada	
Qa, QToa	Alluvium
Qp, QTs	Lake sediments
Qls	Landslide
Qm	Glacial drift
JꞦs, JꞦsv, Ꞧch, MDs, Ds, Ss, Ot, €t	Shale and mudstone
Ts3, €Zs, Ks, Ꞧmt, Psc	Siltstone
Jv, JꞦa, Se, €h, €ss	Sandstone
€Zq, Zqs	Quartzite
Jd, ꞦPd, Pℙa, MDmc	Conglomerate
Ꞧc, ꞦPs, Pc, PℙPc, Pℙcd, PMc, ℙc, ℙcd, Mc, Ml, Dc, Dt, D€c, Sc, St, SOc, Oc, O€c,€c	Carbonate
TKs, TKsu	Mixed miogeosynclinal rocks
Ths, Ts1, Ts2, PMh, Dsl, D€sv, Os, Osv, €sc	Mixed eugeosynclinal rocks
O€t, Zw	Interlayered meta-sediment
Trt, Tt1, Tt2, Tt3	Felsic Pyroclastics
QTr, Tr1, Tr2, Tr3	Felsic volcanic flows
QTa, Ta1, Ta2, Ta3, Tts, Tbr, Ꞧk, ꞦPvs, JPu	Calc-alkaline volcanic rocks
QTb, Tb, Tba, Tbg, Tob, Msv	Mafic volcanic flows
Tri, KJim, Ꞧlgr, Ygr	Granite
Tgr, TJgr, Kgr, Jgr, Ꞧgr, Mzgr	Calc-alkaline intrusive rocks
Ti, Tmi, KJd, Jgb	Mafic intrusive rocks
Ᵽzsp	Ultramafic rocks
Xm	Mixed granitic gneiss
Oregon	
Qal, Qf, Qgf, Qgs, Qpl, Qt, QTg	Alluvium
Qd	Dune sand
Ql	Loess
Qs	Lake sediments
Qls	Landslide
Qg	Glacial drift
QTs, Tct, Tss, Js, Jss, JꞦs, Ꞧs	Shale and mudstone
Ꞧᵽzs	Argillite and slate
Tts, QTst	Tuff
Ta, Tcss, Tms, Tmsc, Tsd, Ty	Siltstone
Tco, Tfe, Tm, Tmsm, Tmss, Tmst, Ts, Tsm, Tt, Tyq, Kc, Ks, KJds, Jop	Sandstone
Tn, KJm	Conglomerate

Table 2. *Major Bedrock Lithology Classification — continued*

Formations	Lithology
₸Ᵽzsn, Ᵽzs	Carbonate
Tfee, Tsfj, Jm, J₸sv, Ᵽzsv	Mixed eugeosynclinal rocks
cm, cs	Phyllite and schist
₸sv, ₸Psv, ₸Ᵽzm, Psv, mr	Interlayered meta-sediment
Qmp, Qma, Tat, Tlf, Trh, Tsf, Twt, Tvs	Felsic Pyroclastics
Qrd, QTvs, Tr, Tsv	Felsic volcanic flows
Qa, Qba, Tas, Tbaa, Tbas, Tca, Tfc, Tut, Tu, Tus, Jv	Calc-alkaline volcanic rocks
₸Pv	Calc-alkaline meta-volcanics
QTmv, QTp, QTps, QTvm, Tp, Tps, Ttvm	Mafic Pyroclastics
Qb, Qlb, Qyb, QTa, QTb, QTba, QTib, Tb, Tba, Tc, Tcg, Tci, Tcp, Tcs, Tcw, Tfeb, Tig, Tob, Tpb, Trb, Tsff, Tsr, Tstv, Ttv, Tub, Tvm, KJdv, Jub	Mafic volcanic flows
₸v	Greenstone
Tia	Alkalic bodies
KJg, KJi, J₸gd	Calc-alkaline intrusive rocks
Thi, Ti, Tib, Tmv, Tvi, Tim, KJgu, Jc, ₸Ᵽzg	Mafic intrusive rocks
Ju, ₸Ᵽzu	Ultramafic rocks
bc, mc	Mafic gneiss
Utah	
Qa, Qao, QT	Alluvium
Qe	Dune sand
Ql, Qm, Qs	Lake sediments
Qls	Landslide
Qg	Glacial drift
T2, TK, ₸2, J2, M3	Shale and mudstone
T4	Siltstone
T1, T3, K1, K2, J₸, P1	Sandstone
€1	Quartzite
T5, K3	Conglomerate
J1, ₸1, P2, PIP, IP, M1, M2, D, O, S, €2, €3	Carbonate
P€s	Interlayered meta-sediment
Qr, Tpr	Felsic volcanic flows
Tmr, Tov, Tma, Tmv, Tvu	Calc-alkaline volcanic rocks
Qb, Tmb, Tpb	Mafic volcanic flows
Ti, Ji, P€i	Calc-alkaline intrusive rocks
P€m	Mixed granitic gneiss
Washington	
Qa, Qc, Qg, Qt	Alluvium
Qe	Dune sand
Qce	Loess
Qcl, Qgl	Lake sediments
Qs	Landslide
Qg$_1$, Qg$_1$o, Qg$_1$t, Qg$_2$	Glacial drift
E$_2$, pE$_2$, Ku, J, CPM, SD	Siltstone
O	Meta-siltstone
M, MP, MPc, ø, øM, E$_1$, Ec, TKc, Tc, Ts, Kc, Kl, JK, JKs, Mc, D, €q	Sandstone
MzT, pT, pJ, pJs, CPMS, IPu	Meta-sandstone
P, Pc, øc, K, ₸J, PM	Conglomerate
p€c	Meta-conglomerate
₸, €ls, p€d	Carbonate
C	Mixed eugeosynclinal rocks
pJph, €ph, p€, p€ph	Phyllite and schist
pTm, pJsc, IPl	Interlayered meta-sediment
Ev$_1$r	Felsic volcanic flows
PQv, øMv, øv, Eøv, Ev, Ev$_1$, Ev$_1$a, Tv,	Calc-alkaline volcanic rocks

Table 2. *Major Bedrock Lithology Classification — continued*

Formations	Lithology
lTv, uTv, TKv, pTv, Jv, CPMv, Mzv	
JKv	Calc-alkaline meta-volcanics
Qv, MPv, Mv, Ev$_1$b, Ev$_2$, MzTv	Mafic volcanic flows
pJv	Greenstone
Tas, Mzag, Mzas, p€i	Alkalic bodies
Ti, Tg, Tkg, Mzg, pCg	Calc-alkaline intrusive rocks
TKbi, pTbi, bi	Mafic intrusive rocks
Td, pTb, pTd	Ultramafic rocks
pJgn	Mixed granitic gneiss
pJgs, p€v	Mafic schist and greenstone
pCm	Mafic gneiss
Wyoming	
Qa, Qt, Qu, QTg	Alluvium
Qs	Loess
Ql	Lake sediments
Qls	Landslide
Qg	Glacial drift
QTb, Ta, Teml, Tfl, Tflt, Tgl, Tglu, Tgrw, Tgt, Tim, Tmu, Tsi, Tta, Tte, Tw, Twb, Twc, Twdr, Twg, Twl, Twlc, Twr, Twrb, Twrc, Ka, Kba, Kbr, Kc, Kcf, Kcl, Kg, Kh, Kle, Kmr, Kmt, Kp, Ks, Ksn, Kws, Jsg, JTRad, TRc, TRPs, Pp, DO	Shale and mudstone
Tsl	Tuff
TKe, Jst, TRc, TRcd, TRPcg, DO	Siltstone
Tb, Tbw, Tco, Tdb, Tf, Tft, Tftl, Tftr, Tfu, Tgw, Tgwt, Th, Tha, Tm, Tml, Tmo, Tmu, Tu, Tw, Twa, Twd, Twdr, Twim, Twm, Twn, Twru, TKf, TKu, Kal, Kav, Kb, Kbb, Kbl, Kcf, Ke, Ket, Kf, Kfb, Kfh, Kfl, Kft, Kl, Klc, Klm, Km, Kmb, Kml, Kmv, Kns, Kr, Ksb, Kso, Kss, KJ, KJg, KJk, KJs, KTR, Js, JTR, JTRgc, JTRgn, JTRn, TRPg, TRPjs, Pp, PIPc, PIPcf, PIPh, PIPm, PIPM, PM, MzPz	Sandstone
Xdl	Quartzite
QTc, Tbi, Tbs, Tcd, Tcg, Tcr, Tcs, Tep, Tgc, Thl, Thp, Tip, Tp, Tr, Tt, Tv, Twi, Twk, Twmo, TKp, Kha	Conglomerate
Kgb, Kgbm, Kn, Knc, Knt, TRcd, Pfs, Pmo, Pzr, PIPM, PIPMa, Mm, MD, MDe, MDg, MDO, MO, Ob, OC, Sl, €r	Carbonate
JTRnd	Mixed miogeosynclinal rocks
JTRnd	Mixed eugeosynclinal rocks
Xlc	Phyllite and schist
Ws	Interlayered meta-sediment
PIPMa	Carbonate and shale
Tcc, Thr, Ts	Felsic Pyroclastics
Qr	Felsic volcanic flows
Toe, Tcv, Ttp, Taw, Tc, Ttl, Tts, Twp	Calc-alkaline volcanic rocks
Qb, Tbf	Mafic volcanic flows
Wg, Ys	Granite
Qi, Tai	Alkalic bodies
Ti, Tid, Tie, Tii, Ki, Yla, Yls, Yd, Xgo, Xgy, Xqd, Wgd, Wqm, WVg, Ug	Calc-alkaline intrusive rocks
YX, Xm, Pw	Mafic intrusive rocks
Wp	Ultramafic rocks
Xsv, Wgn, Ugn, shear	Mixed granitic gneiss
WVsv, Wmu	Mafic gneiss