U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Digital maps of compositionally classified lithologies derived from 1:500,000 scale geologic maps for the Pacific Northwest: a contribution to the Interior Columbia River Basin Ecosystem Management Project

by

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Acknowledgments

Our products would not exist without the work of generations of geologists whose maps have previously been compiled to make the state geologic maps. We had the far simpler task of assigning compositional classifications to each mapped unit. We acknowledge the work of these geologists and the agencies that supported these compilations. 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.

We particularly acknowledge Patrick Geehan, the Deputy Project Leader for the Interior Columbia River Basin Ecosystem Management Project. Pat had the foresight to recognize that geology could contribute in many ways to interpreting ecosystem patterns and processes and supplied the funds to digitize the Washington, Idaho, and Montana geologic maps. 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.

Introduction

This report is one in a series of digital maps, data files, and reports generated by the U.S. Geological Survey to provide geologic process and mineral resource information to the Interior Columbia Basin Ecosystem Management Project (ICBEMP), a U.S. Forest Service and Bureau of Land Management interagency project, . The various digital maps and data files are being used in a geographic information system (GIS)-based ecosystem assessment including an analysis of diverse questions relating to 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 July of 1993, President Clinton directed the Forest Service (USFS) to “develop a scientifically sound and ecosystem-based strategy for management of eastside forests.” (SIT, 1994) What was first called the Eastside Ecosystem Management Project was chartered in January, 1994, by the Chief of the Forest Service and Director of the Bureau of Land Management (BLM) in response to the President's directive and charged 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.” (SIT, 1994) The driving force behind the project was the need to develop a strategy for dealing with anadromous fish habitat and watershed conservation and to develop overall land management policy in eastern Oregon and Washington. When it subsequently 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).

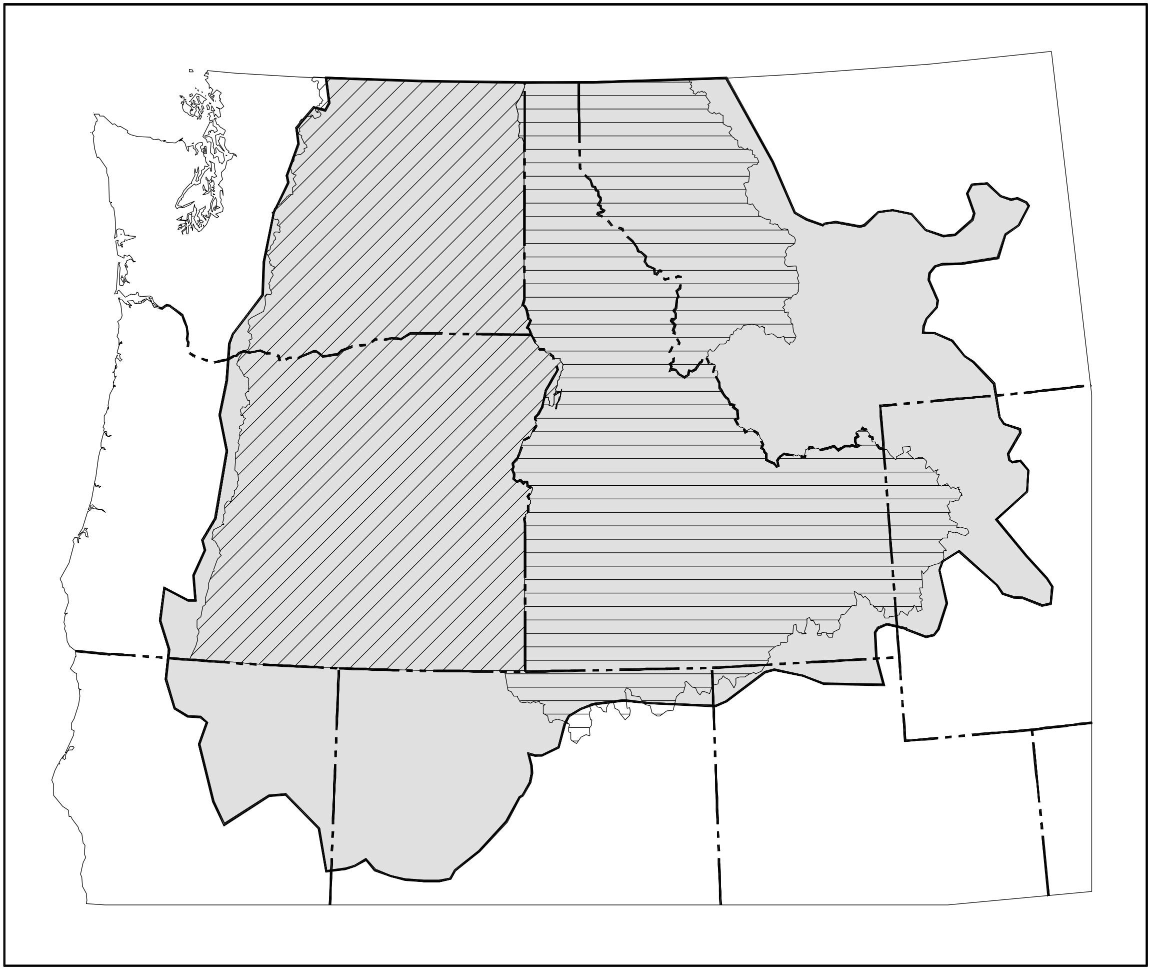

Figure 1. Index map showing the geographic extent of the Interior Columbia Basin Ecosystem Management Project. Shown on the map are the Landscape Characterization Area (grey shading) which is the study area used by most Science Integration Team staff areas, the Eastside EIS area (diagonal hatching),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

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 as well as 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 the scientific assessment is being conducted for the entire basin, the management decisions that will result from the assessments will be for public lands (USFS and BLM) only.

The goal of the ICBEMP management strategy is to provide management tools to sustain or restore ecosystem integrity and produce desired conditions, uses, products, values, and services over the long term. The intent of the project is to understand the ramifications of management practices or disturbances both in the area subject to the practice or disturbance as well as effects which may be removed, in time and space, from the area.

The project objectives are to:

- Conduct a broad integrated scientific assessment of the resources within the interior Columbia River basin to characterize and assess landscape, ecosystem, social, and economic processes and functions and describe probable outcomes of various management practices and trends.
- Develop an ecosystem management framework that includes principles and processes which may be used in a National Environmental Protection Act (NEPA) process to develop management direction for federal agencies at all levels with the basin.
- Write an Eastside Environmental Impact Statement (EIS) proposing a broad array of management alternatives for an area that encompasses ten national forests and portions of four BLM districts in eastern Washington and Oregon (fig. 1).
- Write an Upper Columbia River Basin EIS with a similar array of management alternatives 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).
- 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 assessment and planning activity used to develop a set of regional implementation management alternatives. These alternatives, derived from basin-wide analyses of regional (1:500,000 and 1:1,000,000 scales) and locally more detailed (1:100,000 scale) data, will form a framework for implementation decisions at the local level. This framework will then be adapted as better data and understanding of the basin are developed. The project will provide a basin-wide, digital data framework that 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:

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

or from:

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 depending on the objective. The broad scientific assessment considers all lands, not just those that are federally managed. It is focused on the Columbia River Basin but is not strictly limited to the actual drainage basin boundaries. Some scientific assessment staff areas have extended their work beyond the formal project area because factors such as wildfires and wildlife migration are not limited to drainage divides or political boundaries. Most staff areas use the Landscape Characterization boundary developed by the Landscape Ecology group (fig. 1). The broad assessment uses information suitable for compilation at a scale of 1:1,000,000.

U.S. Geological Survey involvement

In May, 1994, the USGS approached ICBEMP staff about providing estimates of undiscovered mineral resources to the economic, landscape ecology, and aquatic-riparian assessment staff. In discussions with members of various staff areas, it became apparent that the USGS could also provide geoscientific background information relevant to the assessment of historic, current, and future ecological, economic, and social systems. 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, compositional classifications of lithology, potential animal habitat, stream sediment geochemistry, volcanic and earthquake hazards, and mineral resources. The bedrock lithology information is summarized in Johnson and Raines (1995). The potential animal habitat information is summarized in Frost, Raines, Almquist, and Johnson (1995). The stream sediment geochemistry is summarized in Raines and Smith (1995). The digital hazards information was derived from Algermissen, et al (1990) and Hoblitt, Miller, and Scott (1987). The mineral resources information is summarized in Box and others (1995); Bookstrom, Zientek, and others (1995); Zientek and others (1995); and Bookstrom, Raines, and Johnson (1995). The compositionally classified lithology information is reported here. The bedrock lithology, compositionally classified lithology, and potential animal habitat maps were all derived from interpretation of state geologic maps at scales of 1:500,000 to 1:750,000. Johnson and Raines (1995) summarizes the strategy that was used for the rapid analysis of geologic map data using GIS techniques. 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.

Data Sources, Processing, and Accuracy

The sources of geologic information for the compositionally classified lithology maps were the geologic maps of California (Jennings, 1977), Idaho (Bond and Wood, 1978), Montana (Ross, Andres and Witkind, 1955), Nevada (Stewart and Carlson, 1978), Oregon (Walker and MacLeod, 1991), Utah (Hintze, 1980), Washington (Hunting and others, 1961), and Wyoming (Love and Christiansen, 1985). The individual state geologic maps were combined to produce a composite geologic map of the Pacific Northwest with over 800 rock units, as described in Johnson and Raines (1995). As reported in Johnson and Raines (1995), the state geologic maps were processed digitally, as follows: the source material was scanned, the scanned image was vectorized and topologically structured, the lines and polygons were edited and proofed, attributes were added and proofed, the map was transformed from scanner units to geographic coordinates, and finally, map distortions were removed by rubber-sheeting. With the state geology available as a composite digital map, new interpretations and re-classifications of the bedrock geology were readily derived. Geology shown on maps presented in this report were derived from the composite geologic map.

Compositionally Classified Lithologic Maps

The rocks of the earth are the ultimate source of all components of living organisms. These components are ultimately chemical elements. Certain chemical elements are required by living organisms, while many of these same elements can also poison living organisms. Some elements, such as calcium, are essential to some organisms and can modulate the hazards of other elements, such as heavy metals or acid water. The understanding and application of these processes is complex and not discussed here. The reader is referred to Meehan (1991a and 1991b), Murphy and Meehan (1991), Nelson and others (1991), Wetzel (1975), and Whitton (1975) for useful reviews.

Many of the elements of interest (Al, Ca, Fe, Mg, K) are major constituents of the principle rock forming minerals. The base metals Cu and Zn are preferentially enriched in mafic rocks; whereas the base metals Mo and Pb are preferentially enriched in felsic rocks. Mafic rocks are dark igneous rocks made up of ferromagnesium minerals, and felsic rocks are light-colored igneous rocks. Thus knowing the general lithology and, consequently, the typical mineralogy and the weathering processes as summarized in Rose and others (1979), it is possible to rank the lithologies into general classes of elemental abundance available in the environment, such as high, medium, and low concentrations. Medium is used to define the typical or normal value. Low or high would indicate deviations from the more typical values. This is a qualitative ranking.

Five interpretive maps were prepared from the individual state maps to help describe critical chemical elements for fish and plant habitats. Three of these maps, available calcium carbonate, available base metals, and available iron-aluminum-magnesium, were prepared to describe chemical elements relevant to fish health and nutrient supplies. The other two maps, available potassium and available phosphate, were prepared to describe the distribution of chemical elements relevant to plant health and nutrient supplies.

Classification Strategy

The classification strategy for each map is summarized on the explanation figures (figs. 2, 4, 6, 8, and 10) for each map. Pagesize illustrations of these maps are shown in figs. 3, 5, 7, 9, and 11. An example of the classification is given in Table 1. The classification strategy starts from an understanding of the typical chemical composition of lithologies (summarized in Tables 2 and 3) and an understanding of the weathering processes affecting these lithologies. The typical lithologies are assumed to be relavent for the scale and extent of these maps. The bioavailable elements are obtained from the weathered products of the lithologies. The amount of an element in the weathered products is related to the abundance in the lithology. The absolute amount that is bioavailable is affected by the resistance to weathering of the lithology and its associated minerals, the amount of water present, and the relative solubility of the element.

The data summarized in Tables 2 and 3 were used to rank the lithologic units in the map and group them into categories that have similar compositions. The relative rankings between igneous, sedimentary, and metamorphic rocks and sediments reflects the relative abundance of the elements and the consideration of the expected resistance to weathering. Thus for a first approximation, the amount of an element that is bioavailable is assumed to be proportional to the concentration of that element in the underlying lithology. As an example, limestone is essentially calcium carbonate; so calcium carbonate is highly available over limestones. Sandstones typically have low calcium carbonate; so there is low availability of calcium carbonate over sandstone. Basalts contain a moderate amount of calcium, which is rapidly weathered. This weathered calcium in the semi-arid environment of the Columbia River Basin results in formation of calcium carbonate precipitates forming hard pans or caliche in the soils over basalts. So the basalt units are ranked as moderate bioavailability for calcium carbonate. In a similar fashion, the various lithologies have been ranked for bioavailable elements.

Table 1: Example of classification tables. This example is taken from the Nevada geologic map. A table is created which lists the lithologies associated with each map unit, from most common to least common. This lithologic information is derived from the published map explanation. Then, the various derivative attributes are interpreted from this lithologic table. For geochemical interpretations, the major consideration was the most common lithology. See Appendix A for the definition of the terms and symbols used below.

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1. Description of a map unit from the published map explanation.

QUARTZITE AND MINOR AMOUNTS OF CONGLOMERATE, PHYLLITIC SILTSTONE, LIMESTONE, AND DOLOMITE - Includes Prospect Mountain Quartzite, Osgood Mountain Quartzite, and Gold Hill Formation in northern Nevada and Stirling Quartzite, Wood Canyon Formation, and Zabriskie Quartzite in southern Nevada.

2. Tabularized description of map unit. LITH## is a variable name where 01 is the most common lithology and 05 is the least common lithology. These values are ordered from most abundant to minor lithologies. See text below and Johnson and Raines (1995) for a full discussion of this aspect of the tables.

LITH01 = quartzite
LITH02 = conglomerate
LITH03 = phyllitic siltstone
LITH04 = limestone
LITH05 = dolomite

3. Interpreted bedrock geochemistry values. A blank or 0 indicates not present. See Appendix A for an explanation of these terms.

carbonate = L
base metal = L
fe-al-mg = 9
potassium = L
phosphate =

Table 2: Typical ranges of iron, aluminum, mangesium, calcium, and potassium oxide content of various rock types. The units are weight percent. The data are summarized from Barker (1983), Mason (1966), McBirney (1984), and Pettijohn (1975) and were used to help determine classifications of lithologies. The H (high), M (medium), ML (medium low), and L (low), L? (probably low) indicate how we subjectively grouped these measurements in the process of classification for the maps.

	igneous rocks	Serpentive/ ultramatic rocks	Siltstones and graywackes	Shale	Intermed. igneous rocks	Felsic igneous rocks	Ss. - argillite	Dol.	Ls.	Qzt.	Loess	Ne-normative syenite	Leucite-bearing rocks
Fe oxide FeO_t	12-14 H	10-12 H	2-12 H	3-8 M	2-8 M	2-3 L	1-2 L	<1 L	<1 L	<1 L	3-8 M	5 M	5-12 H
Al oxide Al_2O_3	14-18 H	2-7 L	11-16 H	7-24 H	13-17 H	13-14 H	9 (arkose) M	0.x-2 L	0.x-2 L	0.x-2 L	8-12 M	20 H	10 H
Mg oxide MgO	5-11 M	16-45 H	1-3 L	0.x-5 L	0.5-4 M	0.x-1 L	L	15-20 H	0.x-8 L	0.x L	1-5 L	0.7 L	6-8 H
Ca oxide CaO	8-12 M	1-5 for olivine rich Up to 14 for pyroxenite L?	0.x-2 L	0.x-8 L	3-10 ML	1-2 L	0.x-6 L	27-45 H	42-55 H	2 L	2-10 M?	1-10 M?	3-14 M
K oxide K_2O	0.x-1.5 L	0.x-1 L	1.5-2.5 M	2-9 M?	1.5-4 M	0.x-4 H	1-3 M	<1 L	<1 L	0.2 L	1-6 L?	1-5 L?	4-12 H

Table 3: Reported trace element concentrations for various lithologies listed in Krauskopf (1961)[1] and Mason (1966)[2]. The units are parts per million. Information for black shales is from Vine and Tourtelout (1970)[3] and Desbourough and Poole (1983)[4].

	crust[1,2]	granite[1]	basalt[1]	shale[1]	grainte[2] (G-1)	diabase[2] (W-1)	black shale (Phosphoria)[3]	black shale (Heath and Tyler)[3]	Meade Peak Phosphoria mean[4]	Meade Peak Phosphoria >105 C, mean[4]	Meade Peak Phosphoria >15% P_2O_5 mean[4]
Ag	0.07	0.04	0.1	0.1	-	-	10	-	8.3	11	10
Cu	55	10	100	57	13	110	70	3	-	-	-
Mo	1.5	2	1	2	7	0.05	50	5	102	244	38
Ni	75	0.5	150	95	2	78	150	70	223	567	175
Pb	12.5	20	5	20	-	-	10	20	-	-	-
Zn	70	40	100	80	-	-	1500	<300	1670	2850	1780
Se	0.05-0.5	0.5	0.5	0.6	-	-	-	-	77	144	54
As	1.8	1.5	2	6	0.8	2.2	-	-	-	-	-

Each individual map unit in each state was classified independently. These classifications were made from data tables summarizing the lithologic information from the state map legends (see Appendix A of this report; Johnson and Raines, 1995). The classification of each map unit was based primarily on the most abundant lithology (item lith01 in Table 1); consideration was also given, however, to other lithologies included in the map unit and the degree of mixing of lithologies. In classifying each unit, it was assumed initially that the first lithology listed in the map legend was the most abundant lithology. Due to differing concepts between state maps of how to compile regional geologic maps and describe units, this assumption is mostly correct. Where this assumption was recognized to be incorrect, appropriate selections were made.

Several approaches were used to test this assumption and make corrections. First, differences were evaluated at state lines. Where a difference was observed between the interpretations at state boundaries, the descriptions were checked for consistency, more detailed mapping was considered, and the interpretations were adjusted to be consistent between the states. This is a reasonably comprehensive test because of the long borders of these states, most map units are somewhere next to a state-line boundary. Based on this testing, most of the differences associated with state boundaries were resolved. The maps were checked for consistency by regional geology experts and then for consistency with the available geochemical data (Raines and Smith, 1995).

The categories, high, medium-high, medium, etc., are best thought of as a relative, nonlinear grouping of lithologies. When considering a specific question, for example toxicity effects of aluminum, high and low do not suggest a hazard and lack of a hazard. High means areas where aluminum is expected to be higher than in an area classified as medium. Thus, when considering aluminum toxicity, the highs for aluminum should be considered to have more potential of elevated aluminum, which may be a consideration in the best management of that area. Also, because high, medium, low, etc. are non-linear groupings, this does not imply that every lithology classed in one category has the same absolute amount. Each of these categories represents an interval of absolute amounts. This usage is necessary because we lack the absolute amount measurements. For example, because of grain-size differences the amount of calcium bioavailable from a limestone and a marble could be different. As defined here, the amount of calcium bioavailable from either of these lithologies is considered sufficiently greater than the medium high category that limestone and marble are both grouped together. The following sections briefly summarizes the application and considerations in classification for the individual maps of the Pacific Northwest.

Calcium Carbonate Map

The calcium carbonate map (figs. 2 and 3) was prepared to show the distribution of this important chemical element for fish and their environment. Calcium appears to be important in may ways in the growth and population dynamics of fresh water flora and fauna (Wetzel, 1975); Jim Sedell, USFS, oral communication, 1994). A second application of this map is for consideration of potential for buffering acid waters. Calcium carbonate is a primary natural buffering agent for acid drainage from mineralized areas. The major concentrations of calcium carbonate are in areas of limestone, which are precipitates of calcium carbonate. An additional significant regional source of bioavailable calcium carbonate comes from weathering of calcium-rich glass, pyroxene and feldspar in the common basalt of the Columbia River Plateau. Basalt in semi-arid environments is characterized by thick accumulations of caliche (calcium carbonate) in the deeper soil horizons. Calcium carbonate is an important factor in the environment, and, as shown in figure 3, is available in varying amounts from many types of rocks.

Base Metal Map

The base metal map (figs. 4 and 5) was prepared to describe the regional variation in background or lithologically controlled abundance of copper, lead, zinc, molybdenum, and associated elements such as cadmium. High base metal abundances can be toxic to fish and other aquatic organisms; while lower, but still elevated base metal abundances can create unhealthy aquatic environments (Meehan, 1991a). Typically, the high base metal areas shown in this map are not toxic; however, these areas might be less favorable aquatic habitats. Similarly the lows might also be less favorable fish habitats because of element deficiencies. The differences shown on this map are simply a matter of degree, not a measure of toxicity. The map is useful as a factor in ranking aquatic habitat. The sources of base metals in the lithologies are dominantly the dark minerals such as the pyroxenes and amphiboles of igneous rocks and the rocks that form in deep-water marine settings such as black shale.

Iron-Aluminum-Magnesium Map

Similarly, the iron-aluminum-magnesium map (figs. 6 and 7) was prepared as another factor in classifying aquatic habitat. These three elements can have inhibiting effects of the health of fish at elevated values (Meehan, 1991a). Aluminum, for example, can coat the gills of fish and make their breathing less efficient. Existence of these elements is not, however, always bad. Magnesium, for example, is a required element in chlorophyll, and iron is a required nutritional element for all animals. These three elements are grouped because they vary systematically as a function of lithology. The dark minerals in the mafic rocks are a major sources of iron and magnesium, some iron and magnesium is also derived from carbonate sedimentary rocks, and the aluminum comes mainly from feldspars, feldspathoids, and clays.

Potassium Map

The potassium map (figs. 8 and 9) was prepared to show the variation of this important plant nutrient. Potassium derives mainly from potassium feldspar minerals. The map is primarily based on the distribution of potassium feldspar.

Phosphate Map

The phosphate map (figs. 10 and 11) shows those rock units that contain phosphatic minerals, primarily the Phosphoria Formation of Idaho, Wyoming, and Montana, and the dolomitic phosphatic rocks of Utah and Wyoming. The phosphate in dolomitic phosphatic rocks is generally not as available as the phosphate in non-dolomitic rocks. The map was prepared as a measure of background phosphate levels available to plants. Phosphate generally is not a limiting factor in plant growth in any portion of the basin.

Obtaining Digital Data and Paper Maps

The digital files which were used to make the bedrock geochemistry maps 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 <u>one</u> of the following:

1. Download the digital files from the USGS public access World Wide Web site on the Internet.

URL=http://pubs.usgs.gov/of/1995/of95-685/

The World Wide Web site contains the coverages described in this report in ARC/INFO Export file format as well as associated data files and ARC/INFO macro programs which are used to plot the map at 1:2,000,000 scale. 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.

2. Obtain the digital files from the ICBEMP project office. Contact information is given in the section, U.S. Geological Survey involvement, above.

Paper copies of the bedrock geochemistry maps are not available from the USGS at this time. However, if you have access to the Internet and access to a large-format color plotter, you can make 1:2,000,000-scale paper copies of the maps, as follows:

1. Download the digital versions of the complete maps from the USGS public access World Wide Web site on the Internet.

URL=http://pubs.usgs.gov/of/1995/of95-685/

The World Wide Web site contains the following five files in the HPGL2 graphics language: **ca2m.hp** (calcium carbonate map), **base2m.hp** (base metals map), **fam2m.hp** (iron-aluminum-magnesium map), **k2m.hp** (potassium map), and **phos2m.hp** (phosphate map). These files can be plotted by any large-format graphics plotter which can interpret the HPGL2 language.

Paper copies of the map can also be created by obtaining one of the versions of the digital files as described above, and then creating a plot file in the GIS.

Concluding Remarks

Derivative maps produced from state map scale geology are an appropriate first step to providing a regional framework for land management decisions. The applications these maps are intended to address are very general, and they should be considered only one component for evaluation of habitat. The scale of the data is appropriate to regional applications concerning the entire Columbia River Basin. Although some of the state geologic maps are as old as the mid 1950's, 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 most abundant lithology characteristic of the rock units is well represented in the state geologic maps and the maps are appropriate to regional applications. Similar maps made from more detailed or more up to date geologic information can be prepared at larger scale for watershed analyses projects.

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 improvements in the quality of the geologic data base.

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CALCIUM CARBONATE

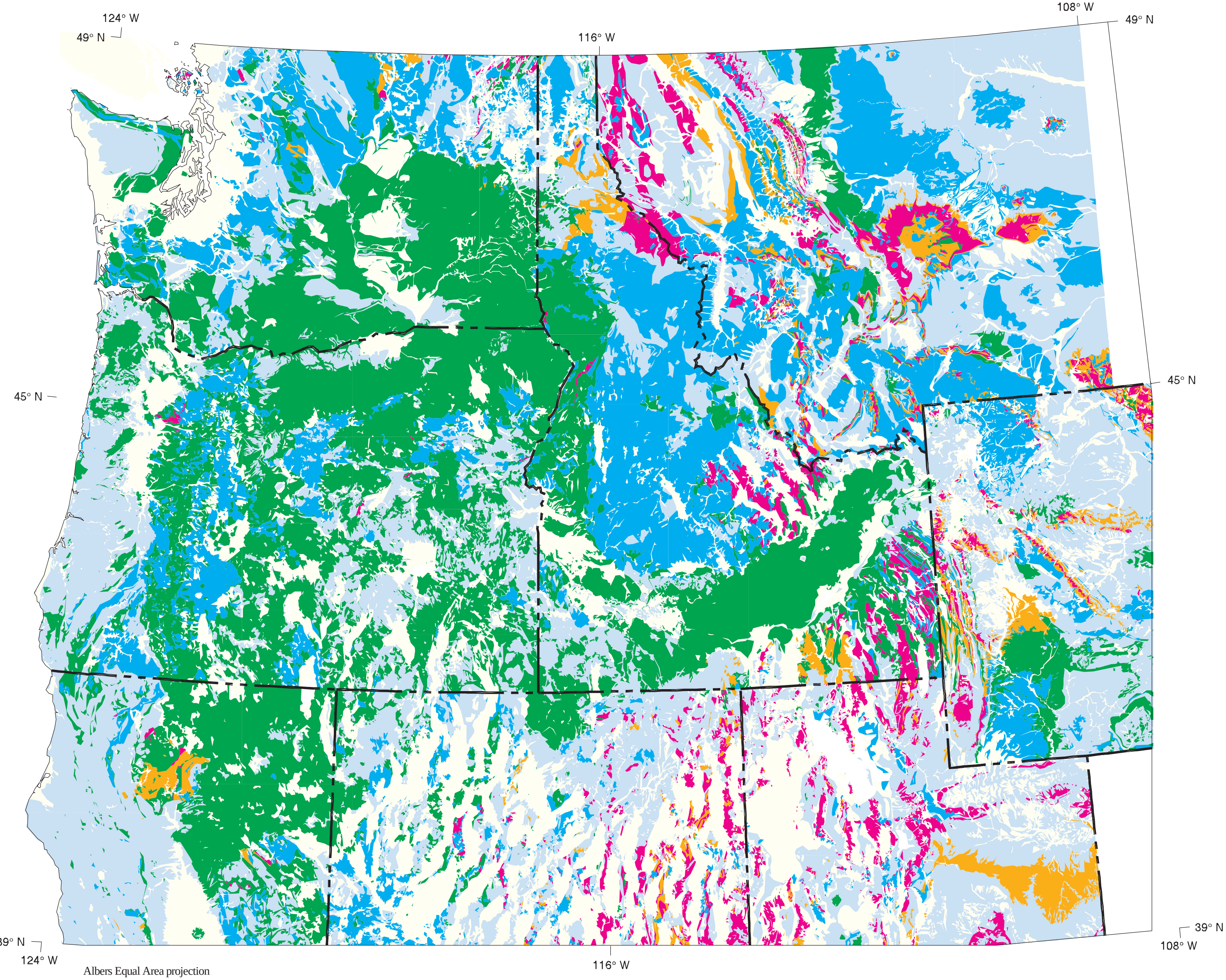
	Igneous Rocks	Sedimentary Rocks	Metamorphic Rocks	Sediments
High		Carbonate	Marble	
Medium High				
Medium	Mafic			Loess
Medium Low	Intermediate		Calc-silicates	
Low	Felsic	Quartzite Siltstone Shale	All others	
Unclassifed				Unconsolidated

Lithologies listed are representative end-members only; many additional lithologies fall between those listed.

Available Calcium Carbonate Content - Explanation

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Open-File Report 95-685
Figure 3



Available Calcium Carbonate Content

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

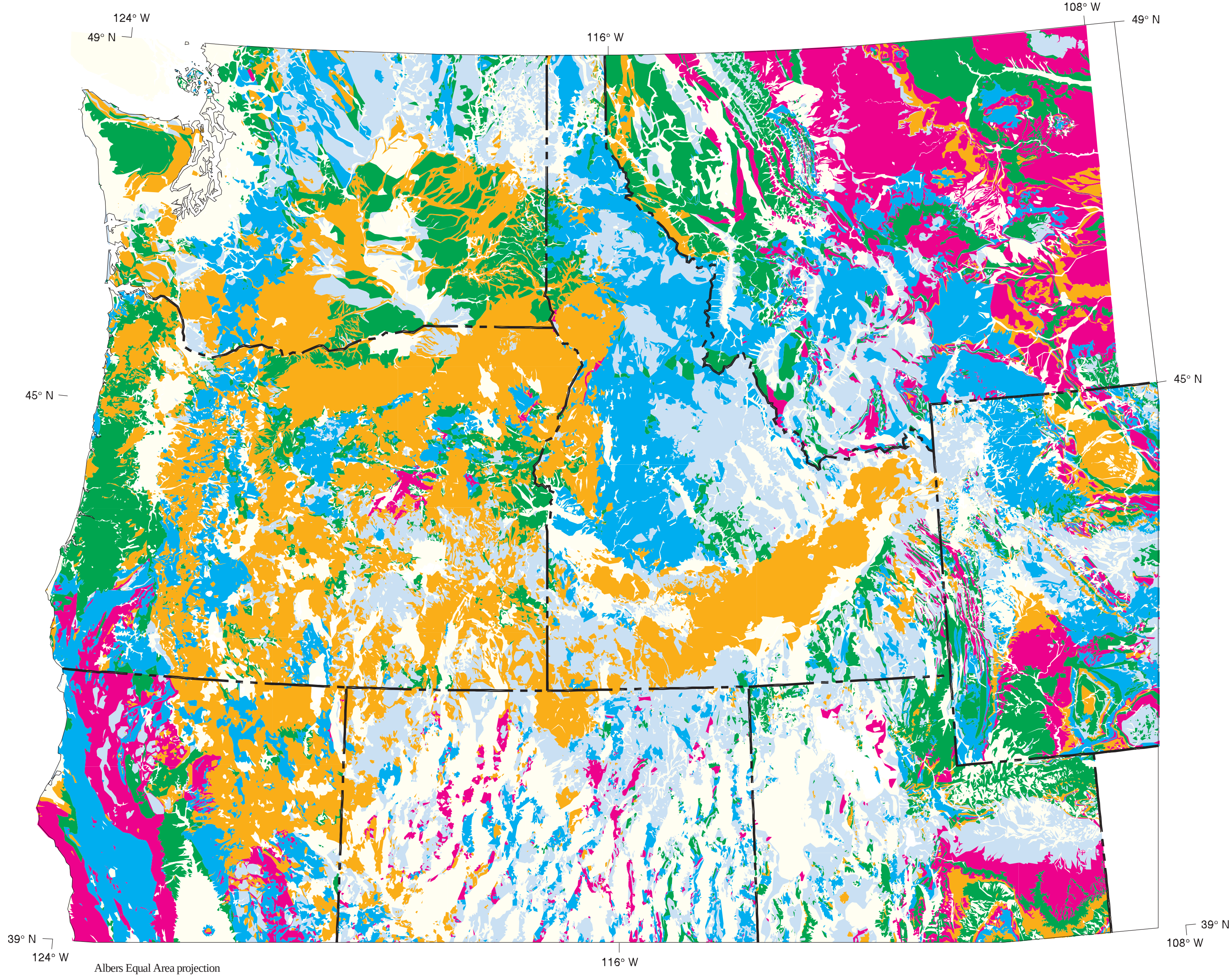
Open-File Report 95-685
Figure 4

BASE METALS

	Igneous Rocks	Sedimentary Rocks	Metamorphic Rocks	Sediments
High	Ultramafic	Shale Slates	Ultramafic	
Medium High	Mafic		Mafic	
Medium		Siltstone		
Medium Low	Intermediate		Intermediate	
Low	Felsic	Quartzite	Felsic	
Unclassifed				Unconsolidated

Lithologies listed are representative end-members only;
many additional lithologies fall between those listed.

Available Base-metal Content - Explanation



Available Base-metal Content

IRON, ALUMINUM, AND MAGNESIUM

Group	Fe Red	Al Green	Mg Blue	Lithologies (Color coding)
1	H	H	M	Mafic igneous rocks
3	H	L	H	Serpentine and ultramafic rocks
2	H	H	L	Siltstone, graywackes, and
4	M	H	M	Intermediate igneous rocks
5	M	H	L	Shale
6	L	M	L	Sandstones, argillites, and felsic igneous rocks
9	L	M	M	Sandstone plus shale plus dolomite or dolomitic limestone
7	L	L	H	Predominately dolomite
8	L	L	L	Orthoquartzite and limestone
Unclassified				Unconsolidated materials

Available Iron-Aluminum-Magnesium Content - Explanation

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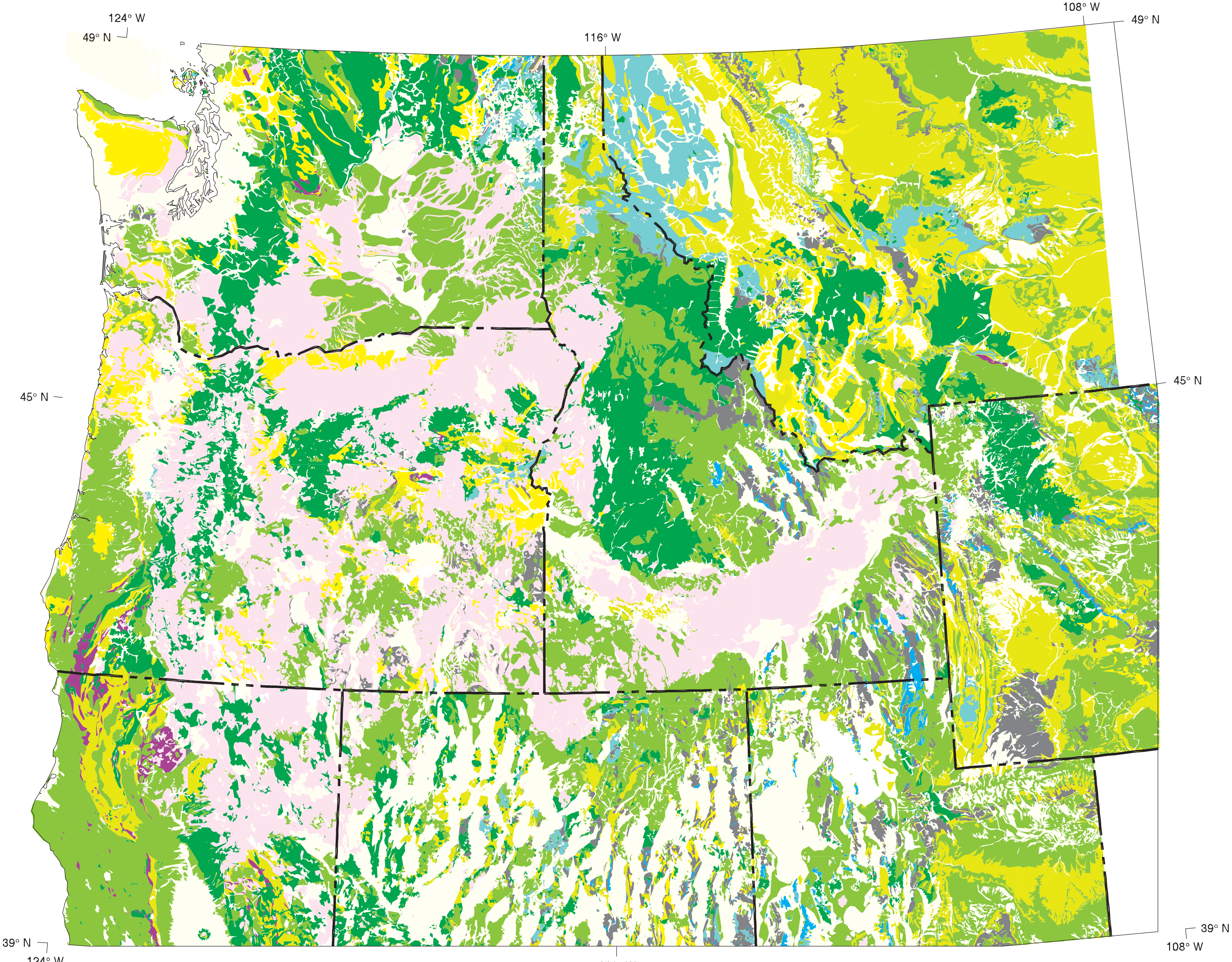
Open-File Report 95-685
Figure 7



Albers Equal Area projection

Available Iron-Aluminum-Magnesium Content

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Open-File Report 95-685
Figure 8

POTASSIUM

	Igneous Rocks	Sedimentary Rocks	Metamorphic Rocks	Sediments
High	Felsic		Felsic	
Medium High				
Medium	Intermediate	Sandstone Shale Siltstone Conglomerate	Intermediate	
Medium Low				
Low	Mafic Ultramafic	Quartzite Carbonate	Marble Mafic	
Unclassifed				Unconsolidated

Lithologies listed are representative end-members only; many additional lithologies fall between those listed.

Available Potassium Content - Explanation

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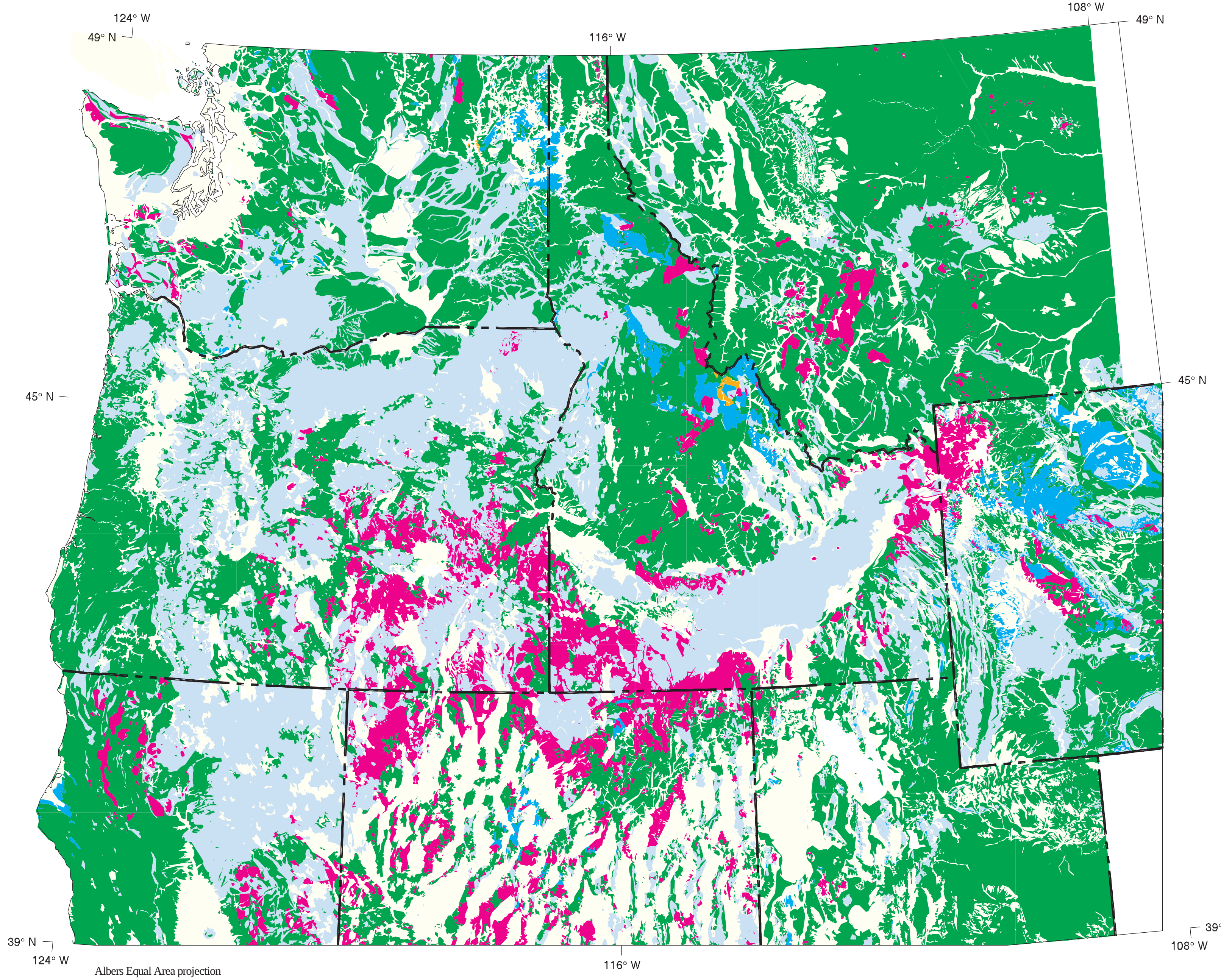
Open-File Report 95-685
Figure 9



Available Potassium Content

PHOSPHATE

(magenta)	High	Phosphate bearing rocks (Phosphoria Formation)
(green)	Medium	Phosphatic dolomite
(white)	Low	All low except adjacent to phosphate areas.

Available Phosphate Content - Explanation

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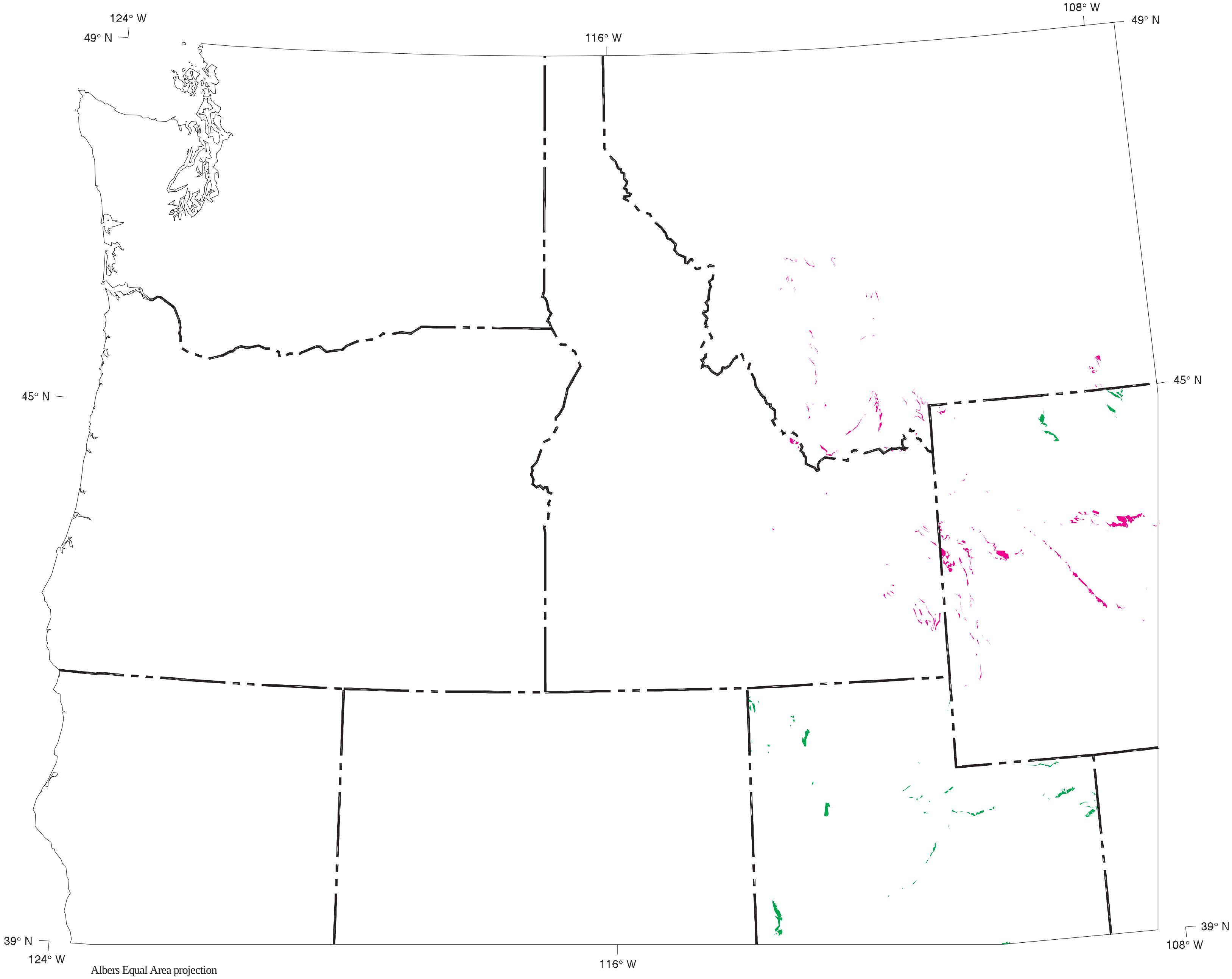
Open-File Report 95-685
Figure 11



Available Phosphate Content

Appendix A: State Geologic Map Tables.

The following are example listings of the ARC/INFO attribute tables for each state geologic map. The strategy for classification of lithologies is explained in the section, Classification Strategy, above, and discussed in more detail in Johnson and Raines (1995). The attributes (database fields) used are as follows:

Attributes compiled from the map explanations:

FORMATION: The map unit symbol used on the published state geological map. This is the attribute that is related to the map coverage.

UNIT_NAME: The map unit name from the map explanation..

ROCK_TYPE: The general rock category from the map explanation. Generally this is something like sedimentary, igneous, or metamorphic.

ERA, SYSTEM, SERIES: Age information from the map explanation.

LITH1, LITH2, etc.: Lithology from the map explanation. LITH1 is the first described lithology, LITH2 is the next, etc, which is assumed to be the order of abundance. See Johnson and Raines (1995) for more information.

Attributes interpreted from the lithology information in LITH1, LITH2, etc.:

CARB	The interpreted bioavailable calcium carbonate concentration.
BASE	The interpreted background base metal concentration.
FAM	The interpreted group for the iron, aluminum, and magnesium concentrations.
K	The interpreted bioavailable potassium concentration.
PHOS	The interpreted bioavailable phosphate concentration.

The attributes CARB, BASE, K, and PHOS can have the following values:

H	High concentration
MH	Medium-high concentration
M	Medium concentration
ML	Medium-low concentration
L	Low concentration
blank	Not classified, normally because the unit is a Quaternary alluvial unit that is derived from the surrounding rocks. Therefore these need to be individually classified in spatial context.

The classification for calcium carbonate (CARB), base-metals (BASE), potassium (K), and phosphate (PHOS) are explained in the map explanation, figs. 2, 4, 6, 8, and 10, respectively. The categories for iron, aluminum, and magnesium, FAM, are named 1 thru 9 and unclassified for groupings of these elements as explained in the map explanation, fig. 6.

Example of complete data for one stratigraphic unit from one state map

Description from map explanation:

Marine Sedimentary and Metasedimentary Rocks

Cambrian - Sandstone, shale, limestone, dolomite, chert, quartzite, and phyllite; includes some rocks that are possibly Precambrian.

GIS attributes derived from map explanation:

Attribute Name	Contents
FORMATION	C (ASCII symbol used for Cambrian C̶)
ROCK_TYPE	Marine sedimentary and metasedimentary rocks
ERA	Paleozoic
SYSTEM	Cambrian
SERIES	
LITH1	sandstone
LITH2	shale
LITH3	limestone
LITH4	dolomite
LITH5	chert
LITH6	quartzite
LITH7	phyllite
COMMENTS	includes some possible Precambrian rocks
CARB	MH
BASE	M
FAM	6
K	M
PHOS	