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U.S. GEOLOGICAL SURVEY

Digital mineral resource maps of phosphate and natural aggregate for the Pacific Northwest: a contribution to the Interior Columbia River Basin Ecosystem Management Project

by

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Acknowledgements

Our products would not exist without the contributions of generations of geologists whose work was essential to making both state geologic maps and mineral resources databases. We had the comparatively simple task of digitizing these maps, and using them to identify areas considered permissive to favorable for deposits of phosphate and sand and gravel. This effort would not be possible without those past products and others from the following agencies: 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 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 geologic maps. We also acknowledge James D. Bliss for his helpful review of this report.

Introduction

Interior Columbia Basin Ecosystem Management Project (ICBEMP)

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 forests 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 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. 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. At that time, the project was renamed the Interior Columbia Basin Ecosystem Management Project (ICBEMP).

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 (ICBEMP), a U.S. Forest Service and Bureau of Land Management interagency project. The various digital maps and data files which were provided by the USGS, and which are available in this and other reports, are being used in a geographic information system (GIS)-based ecosystem assessment which 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 ICBEMP is producing scientific assessments of current and historic landscape conditions; of aquatic and terrestrial habitat, species distributions, and populations; and of economic and social conditions. The project is also producing scientific assessments of the potential future conditions and possible trade-offs 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 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 staff is divided in two teams—the Scientific Integration Team and the Environmental Impact Statement Team. Each is further sub-divided by topic, as follows: landscape ecology, aquatic/riparian habitat, terrestrial habitat, forest policy and economics, and social sciences. Many staff scientists work on both the Scientific Integration Team and the Environmental Impact Statement Team.

The project objectives are to:

- Conduct a <u>broad scientific assessment of the resources</u> 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 <u>ecosystem management framework</u> 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 <u>Eastside Environmental Impact Statement</u> (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).
- Write an <u>Upper Columbia River Basin EIS</u> 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).
- Conduct a <u>scientific evaluation of issues and alternatives</u> identified through the NEPA scoping process for the Eastside EIS.

The ICBEMP is an intense, short term project to plan and develop a set of 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. Under the project, a flexible, basin-wide, digital database will be developed 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:

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ATTN: Cindy Dean
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(509) 522-4030

or from:

Bureau of Land Management
ATTN: Becky Gravenmeier, OR99.2
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Project extent and scale

The ICBEMP study area is regional in extent. It includes The Eastside EIS area, which covers eastern Washington and Oregon (east of the crest of the Cascades), and the Upper Columbia EIS area, which covers most of Idaho and northwestern Montana, and extends into western Wyoming, northern Utah, and northern Nevada (fig. 1). The scientific assessment includes all lands, not just those that are federally managed, and since phenomena such as wildfires and wildlife migration are not limited by the drainage divides or political boundaries that define the ICBEMP, some scientific assessment sub-teams have extended their work beyond the limits of the formal ICBEMP area. For example, the Landscape Characterization area (fig. 1) extends across northeastern California, northern Nevada, northwestern Wyoming, and western Montana. Much of the data included in the scientific assessment was derived from source maps at scales of 1:500,000 or larger, but because of the regional extent of the ICBEMP, and the limited time allowed for its completion, the information has been compiled at a scale of 1:1,000,000.

For purposes of ecosystem analysis, and reporting, the ICBEMP study area is divided into Ecological Reporting Units (ERUs). ERU areas and boundaries fig. 2) are based on combinations of Ecoregions, as defined and described by Bailey (1976, 1978), and hydrologic drainage areas.

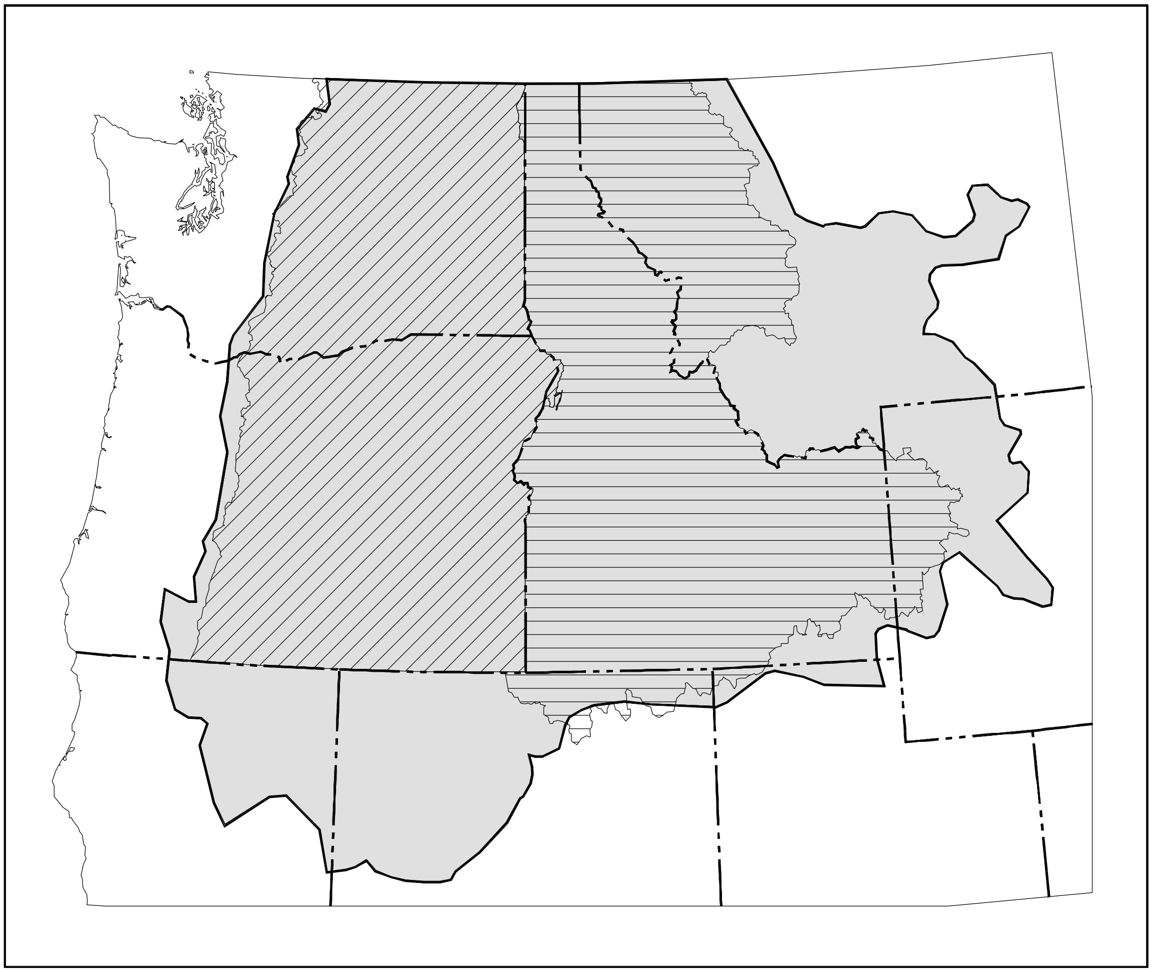

Figure 1. Index map showing the geographic extent of the Interior Columbia Basin Ecosystem Management Project. Shown on the map are the Landscape Characterization Area (grey shading) which is the study area used by most Science Integration Team staff areas, the Eastside EIS area (diagonal hatching),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

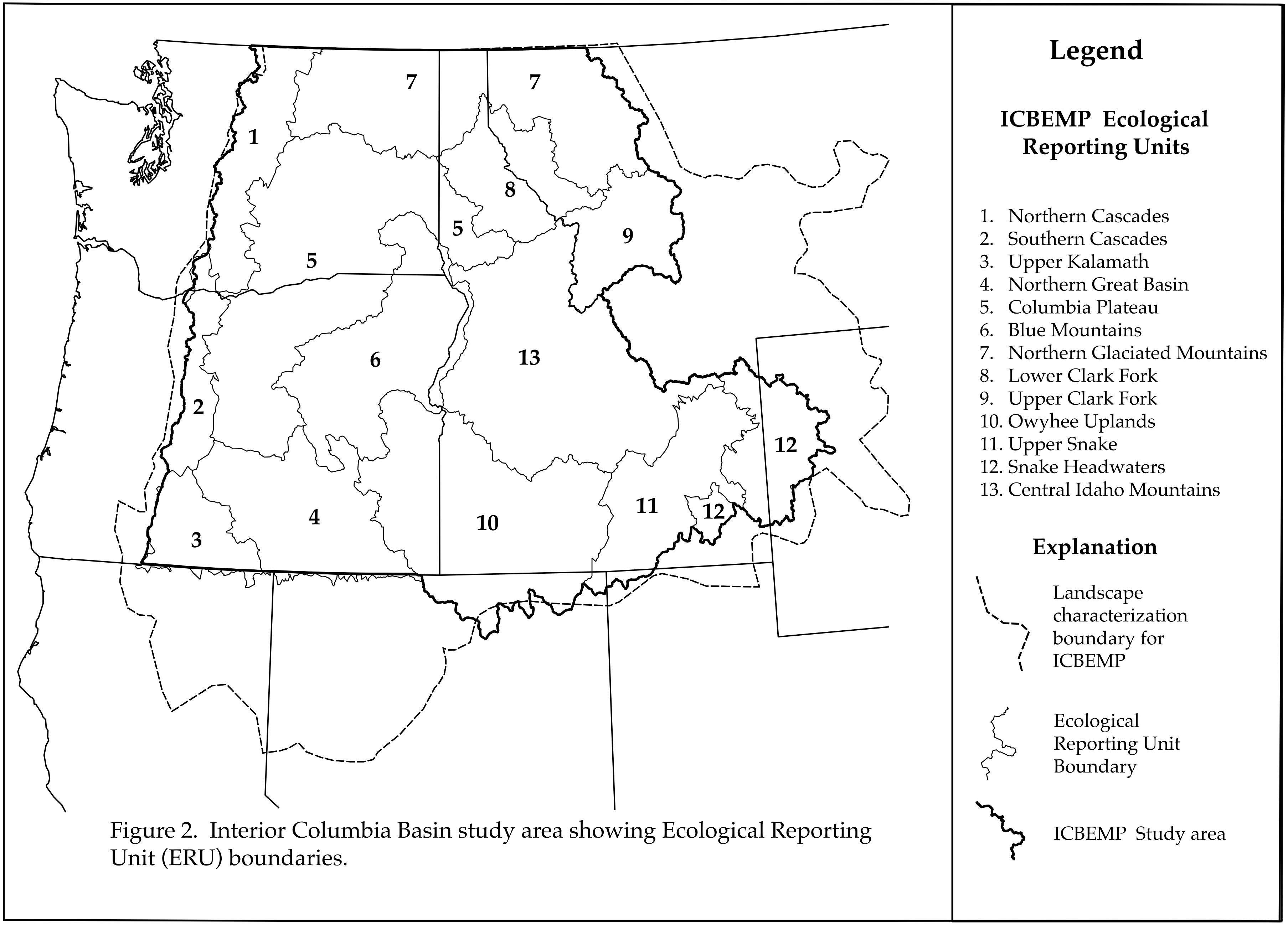

Figure 2. Interior Columbia Basin study area showing Ecological Reporting Unit (ERU) boundaries.

U.S. Geological Survey involvement in ICBEMP

In June, 1994, the USGS was asked to provide estimates on the value of undiscovered mineral resources for the Columbia 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, and mineral resources. The bedrock lithology information is summarized in Johnson and Raines (1995). 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 hazards information was derived from Algermissen and others (1990), and Hoblitt and others (1987). Mineral resources information is summarized in Box and others (1996); Bookstrom and others (1996); Zientek, Bookstrom, Box, and Johnson (1996); and in this report. The reports on bedrock lithology, rock chemistry, potential animal habitat, and portions of this report were derived from interpretation of state geologic maps at scales of 1:500,000 to 1:750,000. Johnson and Raines (1995) summarize 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 phosphate and natural aggregate 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). 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 easily derived. Geology shown on maps presented in this report was derived from the composite geologic map.

Locations of phosphate mines and prospects were extracted from digital data files of the U.S. Geological Survey Mineral Resource Documentation System (MRDS).

Swanson, McKelvey, and Sheldon (1953) also provided information on western phosphate deposits. Locations of rivers and perennial streams used on the Sand and Gravel Map were obtained from USGS 1:2,000,000 scale Digital Line Graphs (U.S. Geological Survey, 1990). Locations of cities and towns used on the Sand and Gravel Map were obtained from a GIS coverage supplied by the ICBEMP. The following sections describe the phosphate and sand and gravel maps of the Pacific Northwest.

Definition of Permissive and Favorable Tracts

Permissive tracts are areas where the geology permits the existence of mineral deposits of a specific type (Singer, 1993). Geologic criteria for permissive tracts are derived from descriptive mineral deposit models that are based on studies of known deposits. Geologic maps, mineral-occurrence maps, geochemical and geophysical maps, and mineral-exploration literature and files are searched for features that include or exclude the permissive geologic criteria, and permissive tracts are outlined accordingly. The possibility of the occurrence of the specified deposit type outside the permissive tract should be negligible. However, because of the small scale and generality of the geologic maps used as the basis of this preliminary regional study, it is likely that some deposits of the specified types to occur outside the permissive tracts outlined here.

Favorable tracts are indicated where known deposits are clustered, as on the Phosphate Map (plate 2), or where geologic maps indicate materials that are favorable for deposits of good-quality material, as on the Sand and Gravel Map (plate 4).

Phosphate Mineral Resources

The Phosphate Mineral Resource Map for the ICBEMP Study Area (plates 1 and 2) shows locations of surface expressions of potential supplies of phosphatic rock (from state geologic maps), and locations of known phosphate mines and prospects (from MRDS).

Phosphate ore deposits

Phosphate ore deposits consist of phosphatic rock that can be economically mined to produce phosphate concentrate (called phosphate rock). Ninety-three percent of domestic phosphate rock is used in the manufacture of fertilizers, and the rest is used to produce chemicals from elemental phosphorus (U. S. Bureau of Mines, 1993a). Fluosilicic acid, vanadium, uranium, and rare-earth elements are possible byproducts. Within the northwest United States, phosphate ore occurs within marine sedimentary strata of the Permian Phosphoria Formation and its lateral equivalents, over an area of about 130,000 sq mi, centered in southeastern Idaho and extending into western Montana, western Wyoming, and northern Utah (plate 2). The deposits within these strata have previously been classified as "upwelling-type" (Mosier, 1986a), in contrast to Tertiary deposits of Florida, for example, which have been classified as "warm-current-type" deposits. Both types of phosphate deposits probably formed under conditions of upwelling seawater, which brings nitrate and phosphate (essential and limiting nutrients of marine plants) into the photic zone. The Florida phosphate deposits accumulated quickly, under conditions of high biological productivity, on an open-ocean continental shelf. By contrast, phosphate the Phosphoria deposits accumulated slowly, on the floor of a shallow inland sea, under conditions of moderate biological productivity, and bottom-water oxygen depletion (D.Z. Piper, written communication, 1995).

Mosier (1986b) compiled a grade-tonnage model for districts of "upwelling-type" deposits. However, this model cannot be used to estimate probable resources of individual undiscovered deposits, because the model is based on examples that represent entire districts, not individual deposits. The distribution of phosphatic rocks in the ICBEMP study area that it is unlikely that undiscovered phosphate districts exist there. However, it is likely that there are individual phosphate deposits that have not been sufficiently characterized in terms of size and grade to be considered as known (or discovered) resources.

Phosphate Permissive and Favorable Tracts

Permissive and favorable tracts for the presence of phosphate mineral resources are defined by outcrop patterns of phosphate-bearing sedimentary rocks, and by the distribution of known phosphate mines and prospects. State geologic maps do not provide sufficient detail to separate favorable from permissive tracts. Some phosphate mines and prospects are located on bodies of phosphatic rock too small to be depicted at 1:500,000 scale. Therefore, some mines and prospects lie outside the areas of phosphate-bearing sedimentary rock units that are shown on 1:500,000-scale state geologic maps. Nevertheless, most of these mines and prospects are near to and(or) on-trend with outcrop patterns of phosphatic rock shown on the state geologic maps, and the areas containing such mines and prospects are considered permissive and favorable for the presence of phosphate mineral resources. Listed by state, permissive and favorable tracts for the presence of phosphate mineral resources generally coincide with the following phosphate-bearing sedimentary rock units:

Washington — None identified (Hunting and others, 1961)

Oregon — None identified (Walker and MacLeod, 1991)

Idaho — Permissive and Favorable unit from the geologic map of Idaho (Bond and Wood, 1978): P — Permian phosphatic sandstone, mudstone and chert of southeastern Idaho (where phosphate mines and prospects are abundant, and phosphate mining is an important industry)

Montana — Favorable unit from the geologic map of Montana (Ross, Andres, and others, 1955): Pu — Permian undivided, mainly Phosphoria Formation (chert, sandstone, limestone, quartzite, and shale, with rock phosphate mostly at the base)

Wyoming — Favorable unit in western Wyoming, from the geologic map of Wyoming (Love and Christiansen, 1985): Pp — Permian Phosphoria Formation and related rocks of the Shedhorn Sandstone and the Park City Formation)

Utah — Favorable unit in northern Utah, from the geologic map of Utah (Hintze, 1980): P2 — Phosphoria and Park City Formations

Nevada — None identified (Stewart and Carlson, 1978)

California — None identified (Jennings, 1977)

Southeast Idaho Phosphate

Although phosphate resources of the Interior Columbia Basin are vast, tonnages that can be economically mined are limited. Phosphate deposits that can by mined by open-pit methods are concentrated in southeast Idaho, where the thickest part of the phosphate section occurs, and the phosphate beds are repeatedly exposed on the steeply dipping limbs of tight folds. Weathering residually enriches near-surface phosphate, and renders it more amenable to extraction. Closely spaced faults and fractures locally serve to enhance the degree and depth of residual enrichment by weathering.

The phosphate mines of southeast Idaho produce about 4 percent of global phosphate and 12 percent of United States phosphate (U.S. Bureau of Mines 1993a,b). Most of the phosphate deposits of southeast Idaho are located Caribou County, in ERU 12 (Snake Headwaters), and in adjacent parts of ERU 11 (Upper Snake). Seven major active open-pit mines in the southeast Idaho phosphate district are the Conda, Henry, Maybe Canyon, Wooley Valley, Enoch Valley, Mountain Fuel, and Smokey Canyon mines (Randol, 1994; Kraus, Henning, and Schmidt, 1984). The open-pit Gay mine, in Bingham County, Idaho was recently depleted, and is being reclaimed.

Montana Phosphate

Montana is a relatively minor producer of phosphate rock from underground mines, located in west-central Montana (ERU 9, Upper Clark Fork), and on the Idaho-Montana border (ERU 11, Upper Snake).

Phosphate Treatment Plants

Three major phosphate treatment plants are located at Soda Springs, Idaho; two others are located at Pocatello, Idaho. A vanadium-recovery plant is also located at Soda Springs (Bennett and Gillerman, 1994). Five parts of gypsum result from the production of every part of phosphate, and efforts to use significant amounts of byproduct gypsum have been unsuccessful (Bartels and Gurr, 1994). Large quantities of gypsum waste that accumulate near phosphate processing plants may have a local detrimental environmental impact.

Future Phosphate Production

Large-scale, open-pit mining and processing of phosphate ore probably will continue for the foreseeable future in ERUs 12 and 11 (Snake Headwaters and Upper Snake). Smaller-scale, underground mining of phosphate ore will probably also continue in ERU 9 (Upper Clark Fork). Krauss, Henning, and Schmidt (1984) estimated resources of economically exploitable phosphate ore as 1 billion metric tonnes in the Southeast Idaho, and 600 million metric tonnes in Montana, at average grades of about 24 wt percent P_2O_5.

Recent total annual production from southeast Idaho has averaged about 5 million metric tonnes per yr (U.S. Bureau of Mines, 1993b). Assuming continued production at similar rates and economic conditions, the known mineable resource may be sustainable for about 200 years. Another 15 billion metric tonnes of subeconomic phosphate-bearing rock probably lies within the southeast Idaho phosphate district, according to Kraus, Henning, and Schmidt (1984). Over time, mining probably will shift toward lower-grade and(or) deeper ores, as warranted by changing technologies, economic conditions, and competitor activities.

Natural Aggregate Resources

Natural aggregate consists of rock fragments that are used in their natural state, or are used after mechanical processing such as crushing, washing, and sizing (Langer and Glanzman, 1993). Crushed stone, and sand and gravel are the two primary sources of natural aggregate. Suitable aggregate consists of clean, uncoated particles of proper size range, shape, physical soundness, hardness and strength, and chemical properties (Langer and Glanzman, 1993). Crushed stone can substitute for sand and gravel in most applications. Angular particles of crushed stone are desirable in asphaltic mixes, because intergranular contact between the angular particles provides strength. However, the rounded particles of sand and gravel are preferable in cement concrete, because rounded particles improve the workability of the wet concrete (Langer and Glanzman, 1993).

Aggregate Uses, Demand, and Value

Natural aggregate is used primarily in construction and repair of physical-societal infrastructure (buildings, roads, bridges, runways, railways, dams, canals, and sewer systems, for example). Urban areas and highways are major consumers of natural aggregate. Sources are needed near markets, because the product is bulky, low in unit value, and expensive to transport.

Urban areas of high demand for natural aggregate are shown on Plate 4. Areas of high urban demand for natural aggregate are shown as zones within 15 kilometers of cities or towns within the Columbia River Basin with 20,000 or more residents (as identified in the populated places data base from the ICBEMP). There are also higher demand areas along major transportation routes but these are not shown on Plate 4.

According to the U.S. Bureau of Mines (written communication, 1995), the 1980-92 cumulative value of natural aggregate produced in the Interior Columbia River Basin was $1.3 billion, or 10 percent of the value of the total mineral production of the region.

Crushed Stone

Competent, homogeneous, fine-grained rocks that are not too abrasive and have not been decomposed by weathering generally are preferred as sources of crushed stone for aggregate. For example, limestone, dolomite, and trap rock (basalt or diabase) are good sources of crushed-stone for aggregate. Where these are not locally available, other competent igneous and metamorphic rocks are used. However some volcanic and volcano-sedimentary rocks are soft and friable, and some silicic volcanic rocks tend to react deleteriously when used as aggregate in cement concrete.

Potential sources for good-quality crushed stone generally are available within acceptable haulage distances throughout the Interior Columbia Basin region. Bedrock in the entire region is therefore considered permissive for crushed-stone aggregate. Locations of mining sites for crushed-stone aggregate are distributed in suitable rocks located near areas of high demand, many of which correspond to urban centers and transportation corridors. No quantitative estimates were made for undiscovered resources of rocks suitable for crushed-stone aggregate, because the required tonnage and grade models have not been compiled, and the potential supply is limited less by geology than by land-use patterns.

Sand and Gravel

"Sand and gravel deposits consist of rock or mineral fragments in loose, non-cohesive bodies" that result from "sedimentary processes, including fluvial, lacustrine, marine, eolian and glacial" (Bliss, 1993, p. 4). "Sand and gravel aggregate is a mixture (aggregation) of sand and gravel in which gravel constitutes about 25 percent or more of the mixture" (Langer and Glanzman, 1993, p. 5). Gravel typically occurs in layers or lenses with sand. "Sand and gravel deposits are best when they contain little silt" (Bliss, 1993, p. 5). Minor replenishment of sand and gravel deposits may occur, especially during flooding.

Bliss (1993) developed a general volume model for sand and gravel deposits, based on data for 275 deposits of various genetic types, located in California and the United Kingdom. He also developed a model for sand and gravel deposits in alluvial fans, which tend to be relatively thick, based on data from 18 deposits of that type, located in California. The median volume for the general model is 5.4 million cubic meters, whereas the median volume for sand and gravel deposits in alluvial fans is 35 million cubic meters (Bliss, 1993; Bliss and Page, 1994). Although these models are available, no quantitative estimates were made for undiscovered resources of sand and gravel in the Interior Columbia Basin, because insufficient time was available to compile the locations and sizes of known resources, and to make well-informed estimates of the undiscovered resources. However, permissive and favorable tracts for sand and gravel were delineated, and urban areas of potential high demand for sand and gravel were identified, as shown on the Sand and Gravel Map for the Columbia River Basin Ecosystem Study (plate 4).

State geologic maps provide a general source of information about the distribution of sand and gravel deposits. Quaternary sedimentary map units shown on each state map were classified for their potential sand and gravel content. Surficial sedimentary units that contain sand and gravel as significant components, and are unweathered and unconsolidated, were classified as favorable for the presence of fair- to good-quality sand and gravel deposits. Surficial sedimentary units that contain sand and gravel, but are predominantly finer grained, strongly weathered, or partly consolidated, were classified as permissive for the presence of poor- to fair-quality sand and gravel deposits.

Listed by state, the surficial sedimentary units classified as favorable for the presence of deposits of fair- to good-quality sand and gravel, or permissive for the presence of poor to fair sand and gravel deposits are as follows.

Washington—Favorable units from the geologic map of Washington (Hunting and others, 1961) are: Qa—alluvium (silt, sand, and gravel); and Qg—glacial and glacio-fluvial sand, gravel, and till (includes Qg1, Qg1t, and Qg1o). Permissive units from the geologic map of Washington are: Qt—terrace deposits (unconsolidated to partly consolidated sand and gravel, with minor silt and clay); Qg_2 -- older glacial drift (weathered pre-Wisconsin till, outwash, sorted and unsorted gravel, sand, silt, and clay); and Qgl—glacio-lacustrine deposits (silt with some sand and gravel)

Oregon—Favorable units from the geologic map of Oregon (Walker and others, 1991) are: Qal—alluvium; Qt—terrace gravels; Qgf, and Qgs—glacio-fluvial deposits. Permissive units from the geologic map of Oregon are: Qg—glacial deposits (unsorted); Qf—fanglomerate; QTg—older terrace gravels; and Qs—lacustrine and fluvial sedimentary rocks (unconsolidated to semi-consolidated clay, silt, sand, and gravel)

Idaho—Favorable units from the geologic map of Idaho (Bond and Wood, 1978) are: Qa—alluvium; QPa—Pleistocene waterlaid detritus; and QPg—Pleistocene glacial outwash (includes QPug, QPmg, and QPlg). Permissive units from the geologic map of Idaho are: Qg—colluvium (fanglomerate, talus, and unsorted glacial debris); QPc -- Pleistocene upland deposits; QPt—Pleistocene till; and QPd—basin-fill deposits

Montana—Favorable units from the geologic map of Montana (Ross, Andres, and Witkind, 1955) are: Qal—alluvium (includes valley-fill and terrace deposits); and Qg—glacial drift (Qg). Permissive units from the geologic map of Montana are: Qgl—glacial lake deposits; QTt—terrace remnants (gravel, sand, and silt of Quaternary and Tertiary alluvial terrace remnants); and Tf—Flaxville gravel (Miocene gravel, sand, and silt, with marl and volcanic ash, locally)

Wyoming—Favorable units in western Wyoming, from the geologic map of Wyoming (Love and Christiansen, 1985) are: Qa—alluvium and colluvium; Qg—glacial till and outwash; and Qu—Quaternary units, undivided. Permissive units of western Wyoming, from the geologic map of Wyoming, are: QTg—terrace gravel (partly consolidated), and QTb—Bug Formation (lake deposits)

Utah—Favorable units in northern Utah, from the geologic map of Utah (Hintze, 1980) are: Qa—alluvium and colluvium; and Qg—glacial deposits. Permissive units of northern Utah, from the geologic map of Utah, are: Qao—older alluvial deposits (weathered).

Nevada—No favorable units were identified in northern Nevada on the basis of unit descriptions on the explanation of the geologic map of Nevada. Permissive units of northern Nevada, from the geologic map of Nevada (Stewart and Carlson, 1978) are: Qa—alluvial deposits (poorly sorted); QTa—older alluvial deposits (poorly sorted, semi-consolidated); Qls—landslide deposits (very poorly sorted), and morainal deposits (small, poorly sorted)

California—No favorable units were identified in northern California on the basis of unit descriptions on the explanation of the geologic map of California. Permissive units of northern California, from the geologic map of California (Jennings, 1977) are: Q—alluvium (alluvial and lacustrine deposits, playa, and terrace deposits—unconsolidated to semi-consolidated); Qg—glacial till and moraines (poorly sorted); and QPc—Plio-Pleistocene clastic sediments (loosely consolidated sand, shale, and gravel).

In addition to the surficial geologic units listed above, the sediments of modern streams and rivers (shown in blue on plate 4) and their valley bottoms are considered to be permissive for the presence of sand and gravel deposits. Sand and gravel deposits tend to occur along the channels, banks, braidplains, and terraces of such rivers and streams. We used the rivers data from the 1:2,000,000 scale DLG CDROM (U.S. Geological Survey, 1990), because it was available in digital form. Only major drainages are represented at this scale, but deposits of sand and gravel also occur along minor drainages, which are not shown at this scale. Therefore, more-detailed future studies should use larger-scale maps of streams and rivers.

Sand and gravel are not evenly distributed along the gradients of streams and rivers, which flatten toward their baselines. Segments of streams and rivers with high gradients and rapid flow tend to have bouldery to gravely channels and margins. Sand and gravel tend to be deposited abundantly where gradients flatten, and streams and rivers have braided channels. Grain size generally decreases downstream and(or) down-gradient. Segments of streams and rivers with low gradients and slow, laminar flow tend to have sandy to silty bed deposits. More-detailed future studies should combine stream locations with gradients and peak flow rates to identify segments of streams and rivers that are favorable for the presence of sand and gravel deposits.

Eolian Sand

Deposits of eolian (wind-deposited) sand are shown on Plate 4 as possible sources of sand. Locations of these deposits were compiled from state geologic maps, where they are depicted as follows.

Washington—Qe—Eolian deposits (Hunting and others, 1961)

Oregon—Qd—Dune sand (Walker and others, 1991)

Idaho—Qrw—Dune sand (Bond and Wood, 1978)

Wyoming—Qs—Dune sand and loess (Love and Christiansen, 1985)

Utah—Qe—Eolian deposits (Hintze, 1980)

California—Qs—Sand only (Jennings, 1977)

Eolian sands of the Interior Columbia Basin have not been mined significantly. Most construction sand comes from alluvial sand and gravel deposits, and most eolian sands are not the high-purity quartz sands required for most industrial uses. Although impure sands can be upgraded, it generally is more economical to find high-purity quartz sands, sandstones or quartzites, which have been naturally upgraded by undergoing several cycles of erosion and deposition.

Silica Sand

Silica sand is used in making glass, ceramics, and ground silica. It also is used as foundry sand, filtration sand, blasting sand, and hydraulic fracturing sand. Currently, the Ordovician Addy Quartzite is being mined for silica sand at a location in northeastern Washington (Zdunczyk and Linkous, 1994). Other silica sand resources of Interior Columbia Basin are present in the Eocene Puget Group of western Washington, and the Miocene Payette Formation of southwestern Idaho (Zdunczyk and Linkous, 1994, fig. 3, p. 883).

Natural Aggregate Regions of the Interior Columbia Basin

Langer and Glanzman (1993, p. 14) have characterized the natural aggregate resources of United States by region. The Interior Columbia River Basin contains parts of three Natural Aggregate Regions—the Western Mountain Ranges, the Columbia Plateau, and the Basin and Range (fig. 3). The Northern Glaciated Mountains are here considered a distinctive Natural Aggregate Subregion (of the Western Mountain Ranges Region), and are characterized separately below.

The Northern Glaciated Mountains Natural Aggregate Subregion (fig. 3) coincides with ERU 7 (Northern Glaciated Mountains), and is located along the southern margin of Pleistocene continental glaciation. Regionally glaciated mountains and valleys are underlain by igneous and metamorphic rocks (including some metamorphosed limestones and dolomites), which provide potential sources of good-quality crushed stone. Mountains are drained by streams that flow into large rivers and lakes, located in broad valleys, containing abundant deposits of sand and gravel, and(or) deposits of sand, silt, and clay. Stream-channel and stream-terrace deposits of sand and gravel are common. The giant sand and gravel deposits of the Spokane-Rathdrum Valley were deposited by a series of catastrophic floods, caused by rapid and repeated draining of glacial Lake Missoula.

The Western Mountain Ranges Natural Aggregate Region (fig. 3) includes ERU 1 (Northern Cascades), ERU 2 (Southern Cascades), ERU 3 (Upper Klamath), the eastern part of ERU 6 (Blue Mountains), ERU 8 (Lower Clark Fork), ERU 9 (Upper Clark Fork), ERU 12 (Snake Headwaters), and ERU 13 (Central Idaho Mountains). This region is characterized by tall mountains alternating with relatively narrow, steep-sided valleys. Mountain ranges are underlain by igneous and metamorphic rocks, flanked by sedimentary rocks (including some limestones) which provide

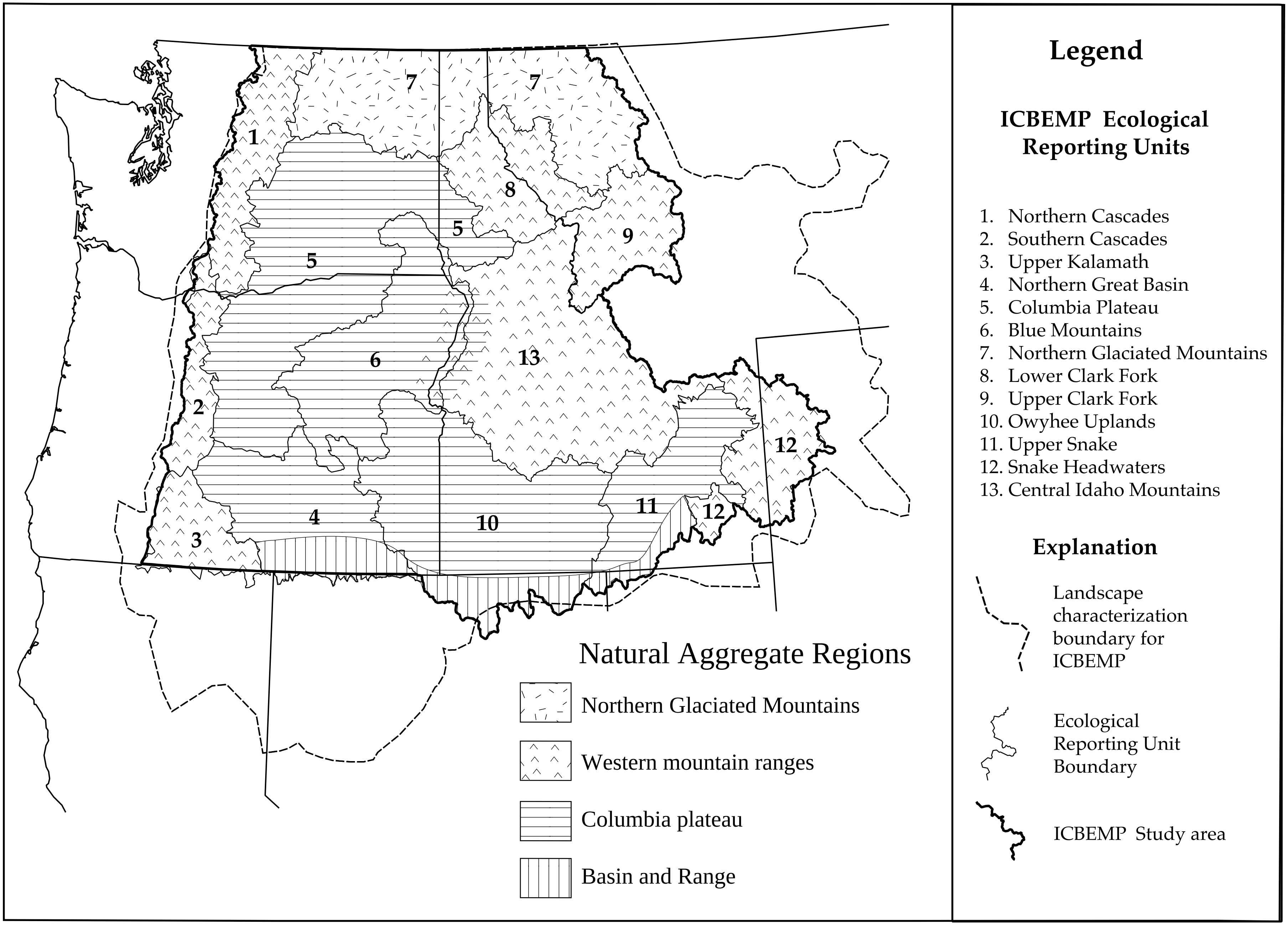

Figure. 3 Interior Columbia Basin study area showing natural aggregate regions.

potential sources of good-quality crushed stone. Most sand and gravel resources are located in stream-channel deposits, but larger valleys may have higher terraces of sand and gravel. Some broad, flat-bottomed valleys are fault-bounded, and such valleys may contain alluvial fans, and thick valley-fill deposits of poorly sorted sand and gravel.

The Columbia Plateau Natural Aggregate Region (fig. 3) includes ERU 5 (Columbia Plateau), the eastern part of ERU 6 (Blue Mountains), ERU 10 (Owyhee Uplands), the northern part of ERU 4 (Northern Great Basin), the northern part of ERU 11 (Upper Snake River), and the western margin of ERU 13 (Central Idaho Mountains). This region is characterized by gently sloping plateaus, underlain by a thick sequence of extensive lava flows, separated by soil zones and interbedded sediments. The northern part of this region is underlain by basalt, a potentially suitable source of crushed stone. The southern part is underlain by basalt and siliceous volcanic rocks. Some volcanic and volcano-sedimentary rocks are soft and friable; and silicic volcanic rocks of the southern part of the region tend to react deleteriously when used as aggregate in cement concrete. Sand and gravel deposits are well distributed throughout the northern parts of the region. In the rest of the region, limited sand and gravel are restricted to river and terrace deposits, which commonly contain clasts of silicic volcanic rocks that may be reactive in cement concrete.

The Basin and Range Natural Aggregate Region (fig. 3) includes the southern part of ERU 4 (Northern Great Basin) and the southern part of ERU 11 (Snake Headwaters). This region is characterized by alternating basins (broad, elongate valleys), flanked by fault-bounded mountain ranges. Mountain ranges of the Basin and Range Natural Aggregate Region commonly are underlain by igneous, metamorphic, and consolidated sedimentary rocks, some of which are potential sources of good quality crushed stone. Large alluvial basins commonly contain marginal alluvial fans and thick, extensive deposits of poorly sorted sand and gravel, which are coarser-grained near basin margins and finer-grained toward basin centers. Poorly sorted basin-fill deposits may be reworked, cleaned of fines and weathering products, and re-sorted in modern stream channels. Some basins contained Pleistocene lakes, in which deposits of sand and gravel accumulated locally at inlet deltas, and along shorelines. Other areas are deficient in sand and gravel. Quality problems tend to be localized.

Future Production of Natural Aggregate

The U.S. Bureau of Mines (written communication, 1995) estimates that about 11 tons of natural aggregate are produced per person per year in the Interior Columbia River Basin (from a total of 449 operations). If this continues, and population increases as predicted, "total production could rise from 46.4 million tons in 1992...to over 100 million tons per year" (U.S. Bureau of Mines, written communication, 1995). Areas of likely urban demand for natural aggregate in the Interior Columbia River Basin are indicated by circular zones that extend 15 km outward from symbols that represent cities or towns with populations of at least 20,000 people (plate 4). Narrow linear zones of high-demand for natural aggregate also occur along transportation routes, which are not shown.

Deposits of sand and gravel are, for practical purposes, a nonrenewable resource and are being depleted in urban areas. To ensure continuing and uninterrupted supplies of sand and gravel to high-demand areas, nearby resources should be identified, evaluated, and protected from being overbuilt or otherwise made unavailable (Langer and Glanzman, 1993). Protection of sites on ten-mile spacings in areas of high demand would minimize future hauling costs and conserve energy. Nevertheless, in the long term, sand and gravel probably will be progressively depleted and(or) built-over in urban market areas, and aggregate production will shift toward crushed rock, as it has in heavily populated eastern and mid-western states.

Environmental Impacts of Natural Aggregate Production

Increased airborne particulates, increased sediment load to streams, and increased noise are short-term environmental impacts of aggregate production. Mine-induced changes to landscapes are long-term environmental impacts. If gravel pits extend below the water table, groundwater can become exposed to direct contamination and evaporation. Reclamation to return the land to beneficial use should be planned before extraction, so that equipment can be used for both mining and reclamation, and mined-out areas can be reclaimed concurrent with extraction in other parts of the operation (Langer and Glanzman, 1993).

Obtaining Digital Data

Plates 1 to 4 are reduced versions of 1:2,000,000 scale digital plates. The digital files that were used to make the phosphate and sand and gravel 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 meters

To obtain copies of the digital data, Download the digital files from

http://pubs.usgs.gov/of/1995/of95-681/

This Internet sites contain the phosphate and sand and gravel GIS coverages in Arc/Info Export file format as well as the associated data files and Arc/Info macro programs which are used to plot the maps at a scale of 1:2,000,000. 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. Or,

Obtaining Paper Maps

Paper copies of the phosphate and sand and gravel maps are not available from the USGS at this time. However, with access to the Internet and access to a large-format color plotter, a 1:2,000,000-scale paper copy of the map can be made, as follows:

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

http://pubs.usgs.gov/of/1995/of95-681/maps.tar.Z

This Internet site contains two files, **phos2m.hp** (phosphate map), and **sg2m.hp** (sand and gravel map), which are in HPGL2 language.

2. These files can be plotted by any large-format graphics plotter which can interpret HPGL2 language. The finished plots are 27 by 38 inches.

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.

PDFs of the HPGL2 on this site were made with an evaluation copy of a conversion app.

Concluding Remarks

Composite maps were produced using state geologic maps. These derivative maps, at 1:500,000 scale, help in land management decisions and are appropriate to regional issues for the entire Columbia River Basin. Although some of the state geologic maps are old, geologic knowledge since the 1970's has been primarily concerned with temporal correlation of rock units, with details of the compositions of the individual rock units, and with how the present arrangement of rock units came to exist. Thus, the dominant character of rock units is well represented in the state geologic maps and the maps are useful for regional applications.

Geologic information is a critical portion of any ecosystem study and for making 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 and resource databases, particularly for industrial minerals, including sand and gravel.

A more complete and rigorous estimation of phosphate resources would require a compilation of production and remaining resources of known deposits, and a thorough study of the phosphate contents, mineability, and recoverability of phosphate-bearing strata of the ICBEMP region. Furthermore, if quantitative estimates are to be made for individual phosphate deposits, a new tonnage-grade model will have to be made for deposits of the western United States.

Quantitative estimation of sand and gravel resources would require the following: 1) compilation of locations, past production and remaining resources of significant deposits of sand and gravel; 2) compilation of the geology of sand and gravel deposits, as noted on relatively large-scale geologic maps that emphasize surficial deposits; 3) classification of known and potential deposits of sand and gravel, using the geologic and fragment-size classification schemes of Bliss and Page (1994); 4) estimation of the size and quality of undiscovered resources of sand and gravel, using the methods and models of Bliss and Page (1994) where appropriate. Analysis of gradients and flow rates of rivers and streams might help identify reaches of modern rivers and streams that are favorable for sand and gravel deposits. Analysis of present and future patterns of demand for sand and gravel would help identify areas of likely future development of sand and gravel resources.

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APPENDIX A: GIS Documentation

Polygon attribute descriptions for **MRPHOS.PAT** are as follows:

ITEM NAME	START COLUMN	ITEM LENGTH	ATTRIBUTE DESCRIPTIONS
phos	17	3	**H** - includes *'Permian phosphatic sandstone, mudstone, and chert of southeastern Idaho'* (Phosphoria, Shedhorn, and Park City formations) in Idaho; *'Permian undivided, mainly Phosphoria Formation'* in Montana; and *'Permian Phosphoria Formation and related rocks of the Shedhorn Sandstone and the Park City Formation'* in Wyoming. **M** - includes *'Park City Formation'* and *'Goose Egg Formation'* (which contains phosphate according to USGS Circular 297) in Wyoming; and *'Phosphoria and Park City formations'* in Utah.
permis	20	3	**P** - permissive for the presence of phosphate mineral resources
favor	23	3	**F** - favorable for the presence of phosphate mineral resources

There are no point attribute descriptions for **SITE_PHOS.PAT**

Polygon attribute descriptions for **SG.PAT** are as follows:

ITEM NAME	START COLUMN	ITEM LENGTH	ATTRIBUTE DESCRIPTIONS
sg	17	3	**W** - open water **fg** - fair to good favorable area - Gravel, sand, and silt; relatively well sorted, unweathered, and unconsolidated. **fp** - fair to poor permissive area - Silt, sand, and gravel; poorly sorted, weathered, and/or partly consolidated. **san** - permissive area - sand only; dune or wind blown sand. *blank* or *state abbreviation* (**wa**, **id**, **mt**, **wy**, **ut**, **nv**, **ca**, **or**) - No potential for significant sand or gravel
stream	20	3	**in** - within 250 meters of stream mapped at 1:2,000,000 *blank* - More than 250 meters from stream
city	23	3	**in** - within a town or city site within the Interior Columbia River Basin. Populated area; no significant sand or gravel development is likely. **buf** - areas of high demand within Interior Columbia River Basin. Area outside, but within 15 km of city or town with population greater than 20,000. *blank* - More than 15 km from city or town with population greater than 20,000.
sum	17	9	redefined item that links 'sg stream city' to *SG.LU1* lookup table

Attribute descriptions for lookup table for **SG.LU1** are as follows:

ITEM NAME	START COLUMN	ITEM LENGTH	ATTRIBUTE DESCRIPTIONS
sg	1	3	**W** - open water **fg** - fair to good favorable area - Gravel, sand, and silt; relatively well sorted, unweathered, and unconsolidated. **fp** - fair to poor permissive area - Silt, sand, and gravel; poorly sorted, weathered, and/or partly consolidated. **san** - permissive area - sand only; dune or wind blown sand. *blank* or *state abbreviation* (**wa**, **id**, **mt**, **wy**, **ut**, **nv**, **ca**, **or**) - No potential for significant sand or gravel
stream	3	3	**in** - within 250 meters of stream mapped at 1:2,000,000 *blank* - more than 250 meters from stream
city	7	3	**in** - within a town or city site within the Interior Columbia River Basin. Populated area; no significant sand or gravel development is likely. **buf** - areas of high demand within Interior Columbia River Basin. Area outside, but within 15 km of city or town with population greater than 20,000. *blank* - more than 15 km from city or town with population greater than 20,000.
symbol	10	5	calcomp1 shadeset symbol number
sum	17	9	redefined item that links ‘sg stream city’ to *SG.PAT* polygon attribute table. There are 63 unique combinations of sg, stream, and city.

The unique combinations of SG, STREAM, and CITY are as follows:

$recno	**sg**	**stream**	**city**	**symbol**
1				0
2		in		688
3	W			424
4	W		buf	156
5	W		in	1
6	W	in		688
7	W	in	buf	688
8	W	in	in	1
9	ca			0
10	ca	in		688
11	fg			7
12	fg		buf	170
13	fg		in	1
14	fg	in		688
15	fg	in	buf	688
16	fg	in	in	1
17	fp			97
18	fp		buf	304
19	fp		in	1
20	fp	in		688
21	fp	in	buf	688
22	fp	in	in	1
23	id			0
24	id		buf	156
25	id		in	1
26	id	in		688
27	id	in	buf	688
28	id	in	in	1

$recno	sg	stream	city	symbol
29	mt			0
30	mt		buf	156
31	mt		in	1
32	mt	in		688
33	mt	in	buf	688
34	mt	in	in	1
35	nv			0
36	nv		in	1
37	nv	in		688
38	nv	in	in	1
39	or			0
40	or		buf	156
41	or		in	1
42	or	in		688
43	or	in	buf	688
44	or	in	in	1
45	san			36
46	san		buf	156
47	san		in	1
48	san	in		688
49	san	in	buf	688
50	ut			0
51	ut		in	1
52	ut	in		688
53	ut	in	in	1
54	wa			0
55	wa		buf	156
56	wa		in	1
57	wa	in		688

$recno	sg	stream	city	symbol
58	wa	in	buf	688
59	wa	in	in	1
60	wy			0
61	wy		in	1
62	wy	in		688
63	wy	in	in	1

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Open-File Report 95-681
Plate 1 of 4

Mineral Deposit Terranes

Nonpermissive

Favorable

▲ Phosphate mine or prospect from MRDS

Note: Many outcrops of phosphate-bearing rocks are too small to be shown at this scale

Phosphate Mineral Resources - Explanation

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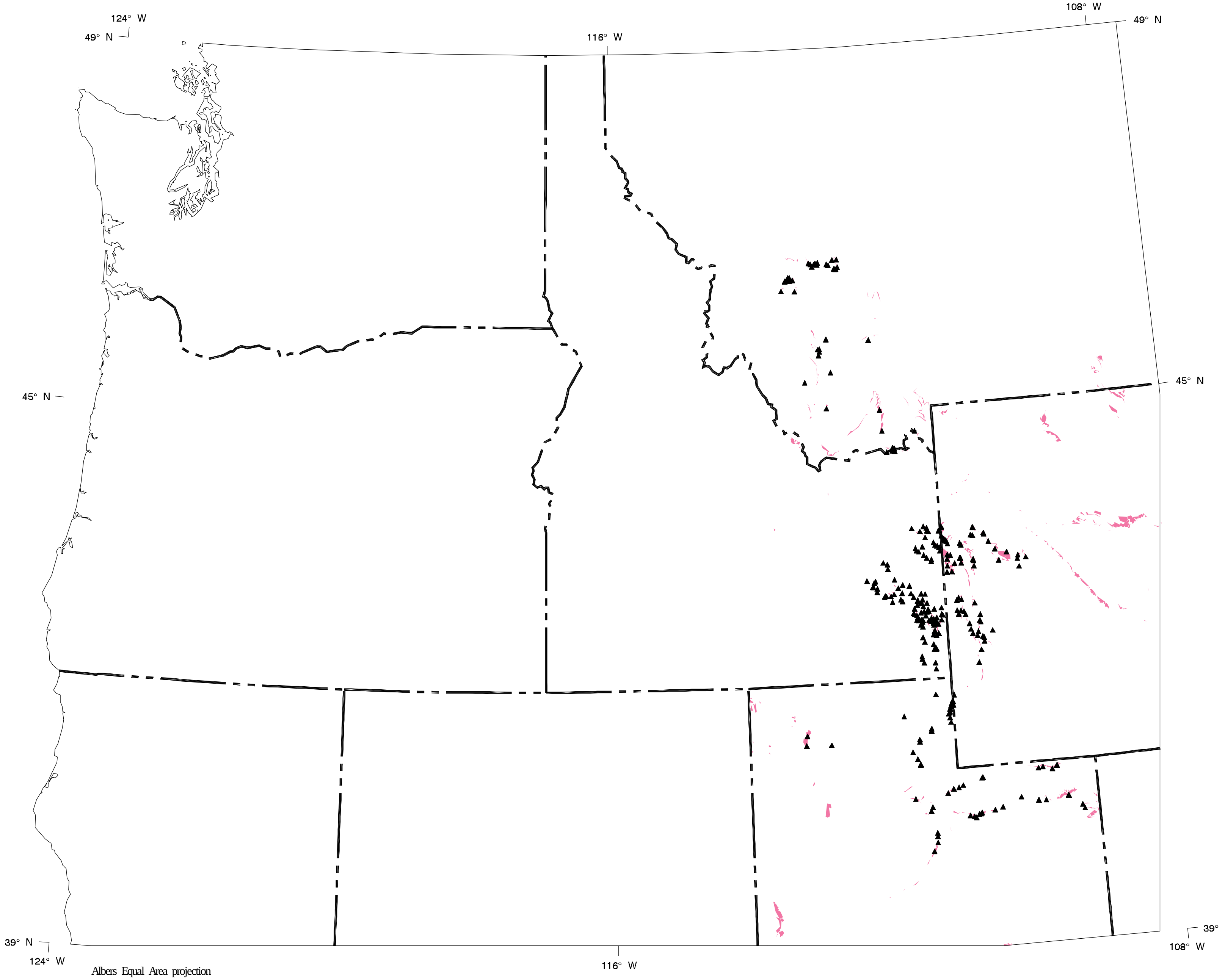
Open-File Report 95-681
Plate 2 of 4



Phosphate Mineral Resources

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

Open-File Report 95-681
Plate 3 of 4

Sand and Gravel Potential

No potential for significant sand and gravel.

Favorable
Fair to Good - Gravel, sand, and silt; relatively well sorted, unweathered, and unconsolidated.

Permissive
Fair to Poor - Silt, sand, gravel; poorly sorted, weathered, and/or partly consolidated.

Permissive
Streams - From 1:2M source

Permissive
Sand Only - Dune or wind blown sand.

Town site within interior Columbia River basin. Area is proportional to population.

Areas of high demand within interior Columbia River basin. Near towns of greater than 20,000 residents. Area is proportional to population.

Sand and Gravel Resources - Explanation

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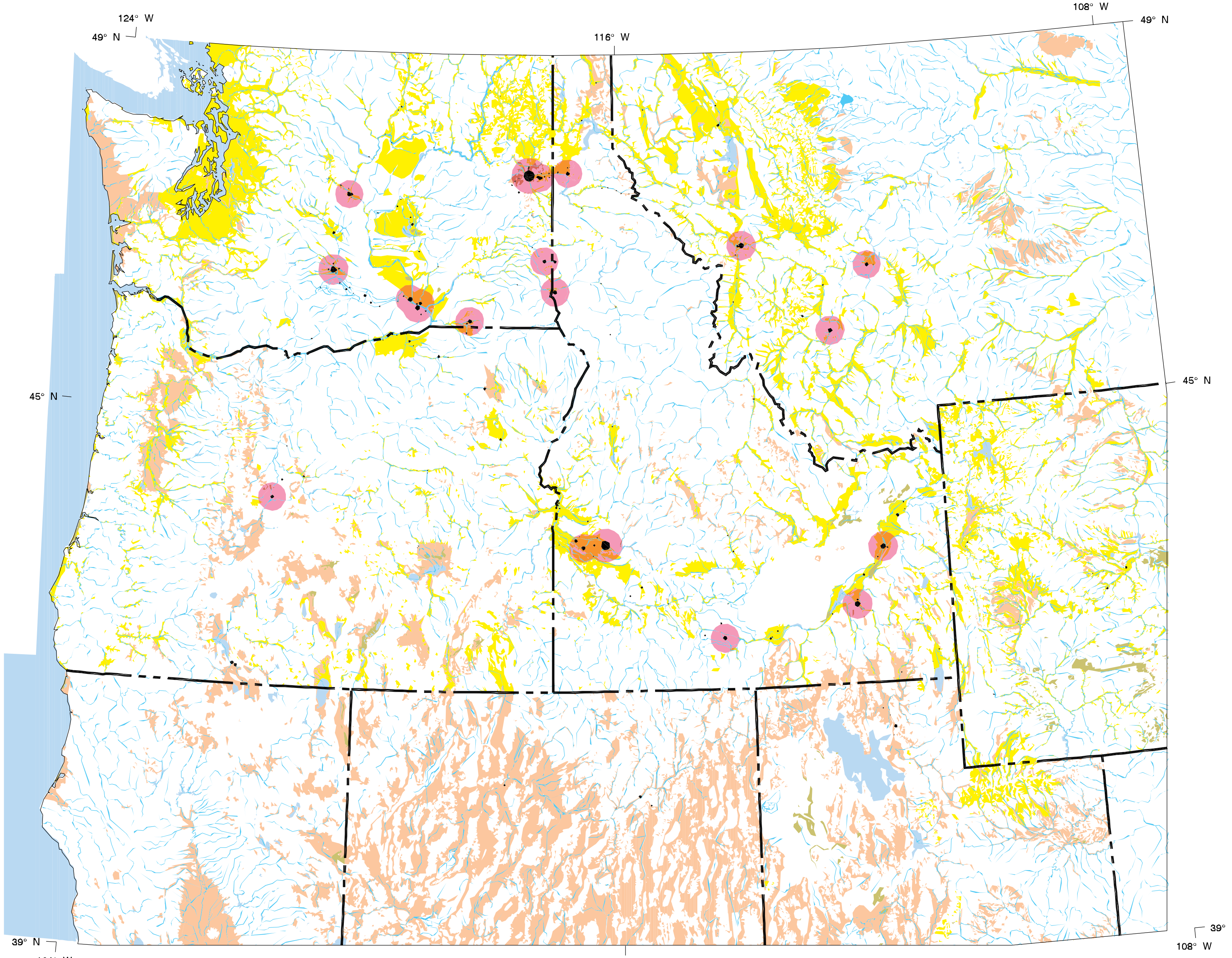
U.S. GEOLOGICAL SURVEY

Open-File Report 95-681



Albers Equal Area projection

Sand and Gravel Resources