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

ASSESSMENT OF UNDISCOVERED PORPHYRY COPPER DEPOSITS WITHIN THE RANGE OF THE NORTHERN SPOTTED OWL, NORTHWESTERN CALIFORNIA, WESTERN OREGON, AND WESTERN WASHINGTON

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EXECUTIVE SUMMARY

By Michael F. Diggles

The range of the northern spotted owl in the Cascade geologic province (fig. 1) was assessed for tracts that are permissive for undiscovered porphyry copper deposits. These deposits are valuable for copper, molybdenum, gold, and silver. This quantitative resource assessment was performed by the U.S. Geological Survey to estimate the metal endowment contained in porphyry copper deposits. The assessment of the metal endowment of the Cascades geologic province entails three basic steps: (1) delineation of tracts permissive for types of mineral deposits, (2) providing appropriate grade and tonnage models for undiscovered deposits, and (3) estimating the number of undiscovered deposits. The delineation consists of three tracts: (A) the northern part of the Cascade Range in Washington, (B) the remaining southern part of the Cascade Range in Washington and approximately the northern two-thirds of Oregon, and (C) the remaining southern part of Oregon and northern part of California (fig. 2). An estimate of the total area of permissive tracts was made using the areas of the inferred plutons delineated (Blakely and Plouff, this report). These estimates, however, are minimum areas because porphyry copper prospects occur outside the boundaries of plutons in both tracts A and B, and because the magnetic signature of overlying volcanic rocks masks the weaker magnetic signature of buried plutons. We have increased the areas of known plutons by 15 percent in tract A and by 30 percent in tract B to account for the areas of plutons assumed to be present because of their required association with porphyry copper deposits. These plutons are concealed and thus their areal extent is unknown. Some of these concealed plutons would certainly lie within the proposed Critical Habitat Area. The U.S. Fish and Wildlife Service has delineated 18,125 mi^2 of Critical Habitat Area for northern spotted owls. Of the delineated Critical Habitat Area, 2,250 mi^2 are in Tract A, 10,390 mi^2 are in Tract B and its extensions to the Pacific coast, and 4,985 mi^2 are in tract C when extended to the Pacific coast. At least 2,850 mi^2 of area permissive for the occurrence of porphyry copper deposits are present in Tract A as both inferred and concealed plutons, about 500 mi^2 of which lie within the proposed Critical Habitat Area. In Tract B, there is at least 4,000 mi^2 of area permissive for the occurrence of porphyry copper deposits, about 1,050 mi^2 of which lie within the proposed Critical Habitat Area. Within Tract C, there are at least 1,300 mi^2 of inferred and concealed plutons, at least 400 mi^2 of which lie within the proposed Critical Habitat Area.

Estimates of metal endowment is in addition to the resources contained in the seven known porphyry copper deposits in the Cascade geologic province. Eight million metric tons of copper are present in the six known porphyry copper deposits in Tract A and 1.9 million tons are present in the one known deposit in Tract B (table 1). By combining the number of deposits estimated with the grade and tonnage frequencies through computer simulation, Tract A is estimated to have a metal endowment in undiscovered porphyry copper deposits of at least 8.3 million tons of copper metal, 100,000 tons of molybdenum, 48 tons of gold, and 780 tons of silver with a probability of 0.9. Tract B is estimated to have a metal endowment of at least 250,000 metric tons of copper metal with a probability of 0.9. The geologic environment in Tract C is not favorable for the occurrence of undiscovered porphyry copper deposits within the upper 1 km limit of this study. At a 0.5 probability level, the metal endowment is estimated to be: Tract A; 34 million metric tons of copper, 720,000 tons of molybdenum, 300 tons of gold, and 6,400 tons of silver; Tract B; 6.5 million metric tons of copper, 100,000 tons of molybdenum, 50 tons of gold, and 880 tons of silver. At the 0.1 probability level, the metal endowment is estimated to be: Tract A; 91 million metric tons of copper, 3.4 million tons of molybdenum, 980 tons of gold, and 19,000 tons of silver; Tract B; 34 million metric tons of copper, 1 million tons of molybdenum, 360 tons of gold, and 7,900 tons of silver. Short-term copper futures were trading at $2,234/metric ton on August 26, 1991.

The number of undiscovered deposits likely to be present in Tract A is 7 at the 0.9 probability level, 14 at the 0.5 probability level and 23 at the 0.1 probability level. For Tract B, the number of undiscovered deposits likely to be present is 1 at the 0.9 probability level, 3 at the 0.5 probability level and 10 at the 0.1 probability level. Porphyry copper mines in the United States, including tailings and support structures, range in size of disturbed area from 2 mi^2 to 12 mi^2 with a median size of 4 mi^2.

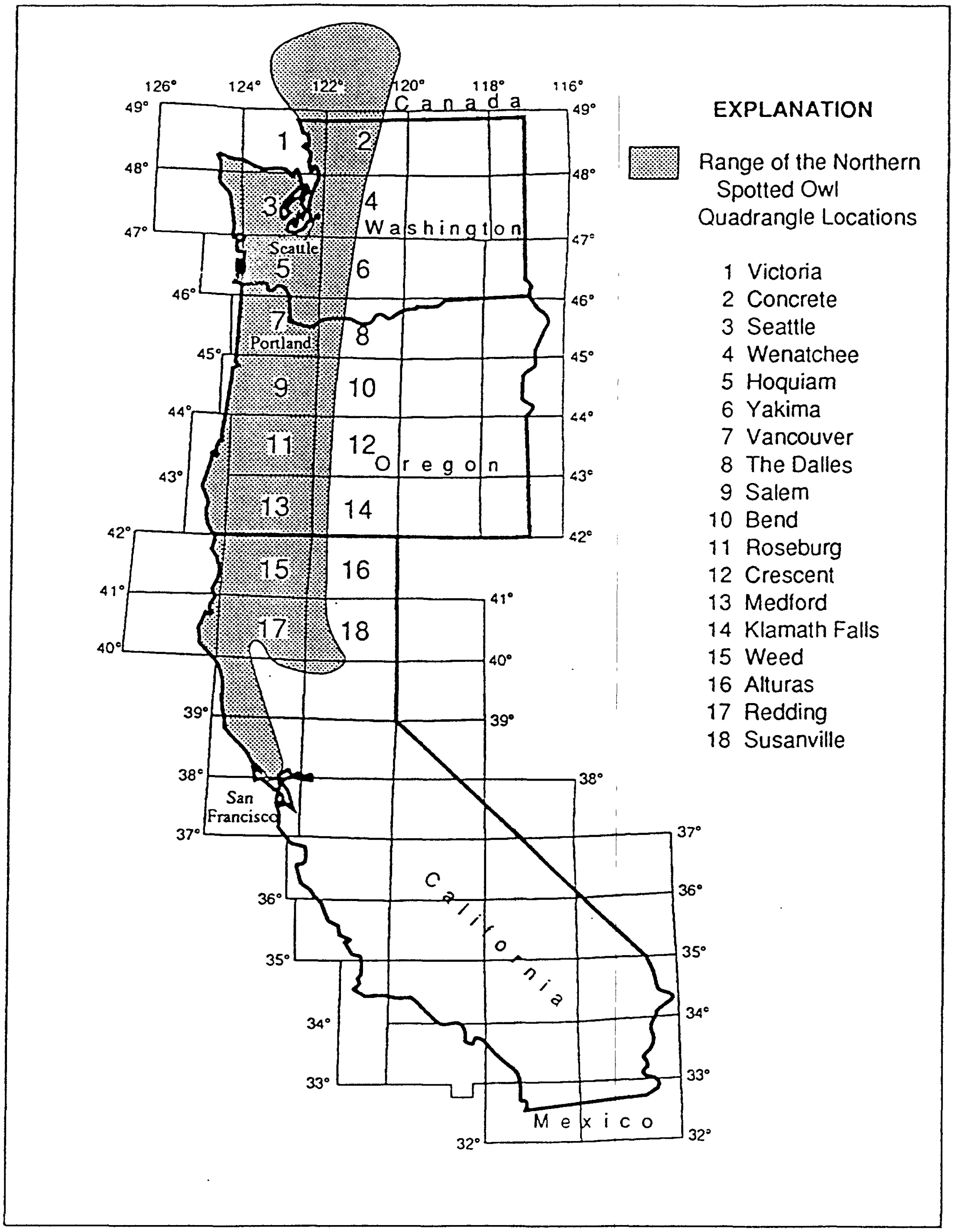

Figure 1.--Index map showing the range of the northern spotted owl. 1° by 2° quadrangles in the study area are outlined.

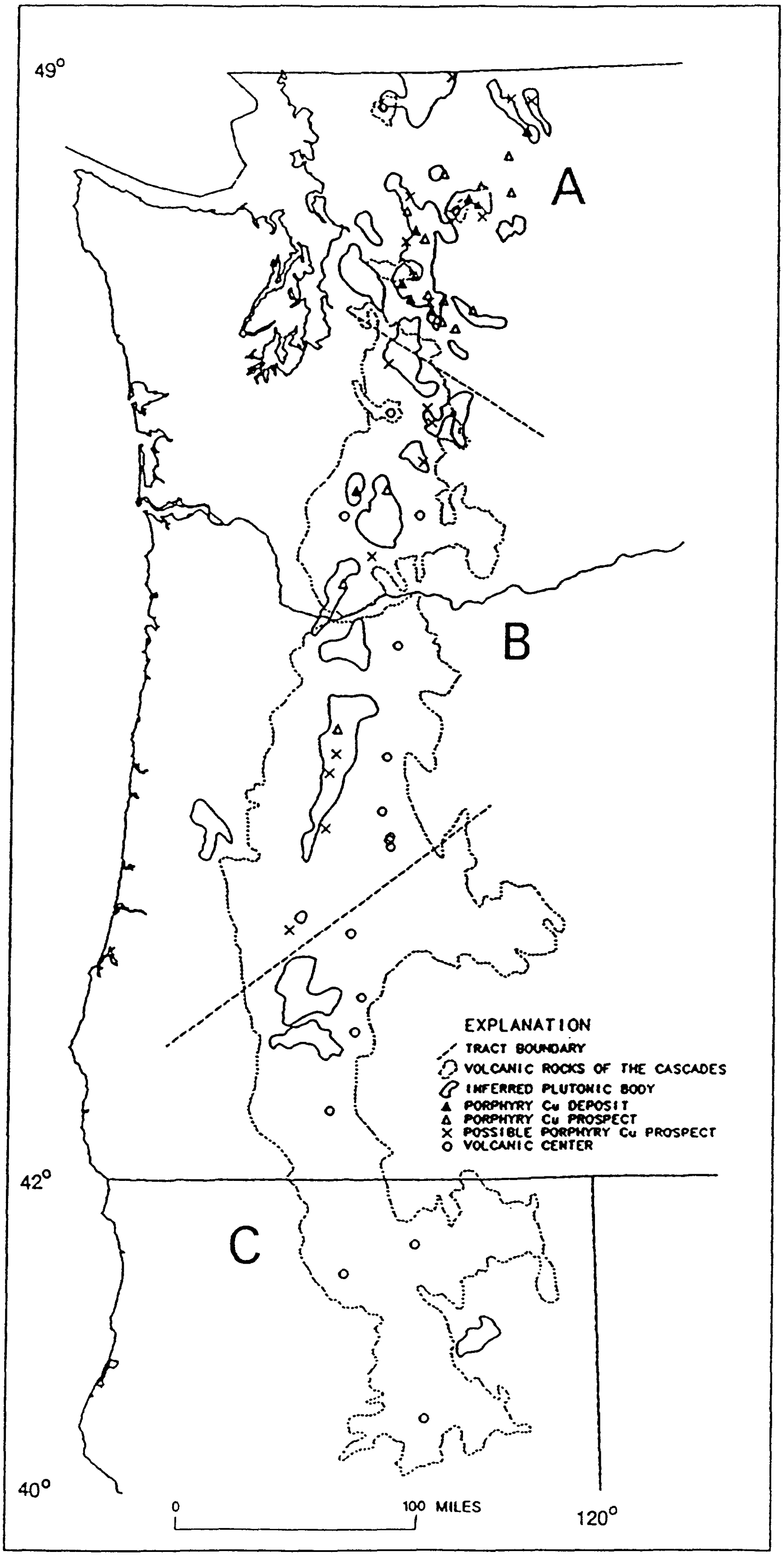

Figure 2.--Map of the Cascade Range showing tract permissive for the presence of undiscovered deposits of porphyry copper.

Table 1. Known and possible porphyry copper deposits within the Cascade Range showing alternative names, reserve estimates for known deposits, latitude and longitude, and references
[▲ , porphyry copper deposit; △ , porphyry copper prospect; × , possible porphyry copper prospect]

Map number		Name	Alternate names	Tonnages and grades	Latitude	Longitude	Reference
1	×	Monument Peak	–	–	48-49-05N	120-32-12W	Hollister, 1979 Staatz and others, 1971
2	×	Mount Beaver	Billy Goat	–	48-48-00N	120-20-26W	Derkey and others, 1990 Grant, 1976
3	▲	Mazama	Goat Creek, Lesley	136 million metric tons at 0.37% Cu	48-36-19N	120-23-11W	Derkey and others, 1990 Hollister, 1979
4	△	Crescent Mountain	–	–	48-27-30N	120-34-37W	Grant, 1976 Hollister, 1979
5	△	Round Mountain	Meadow Creek	–	48-13-40N	120-33-30W	Grant, 1969, 1976 Hollister, 1979
6	×	Silver Creek	Davis, Ross	–	48-57-33N	121-07-40W	Grant, 1969 Hollister, 1979
7	△	Buckindy	–	–	48-21-08N	121-13-00W	Church and others, 1984 Grant, 1969, 1982 Hollister, 1979 Stotelmeyer and others, 1982
8	×	Gold Mountain	Darrington	–	48-12-57N	121-33-25W	Grant, 1976 Hollister, 1979
9	△	Helena Peak	N. Squire Cr., Big Four, Clear Cr.	–	48-07-26N	121-34-47W	Grant, 1976 Church and others, 1986
10	△	Goericke	–	–	48-16-20N	120-51-20W	Church and others, 1984 Grant, 1969, 1982 Stotelmeyer and others, 1982
11	▲	Glacier Peak	Miners Ridge, Calumet	1,710 million metric tons at 0.33% Cu, 0.0188% Mo	48-11-52N	120-58-45W	Church and others, 1984 Grant, 1969, 1982 Hollister, 1979 Stotelmeyer and others, 1982
12	△	Esmeralda	–	–	48-09-30N	120-53-07W	Church and others, 1984 Grant, 1969, 1982 Stotelmeyer and others, 1982
13	×	Trinity	Red Mountain	–	48-04-44N	120-50-56W	Grant, 1976
14	▲	Sunrise	Vesper Peak, Bren Mac	63.9 million metric tons at 0.35% Cu, 0.026% Mo, 0.0227 g/mt Au	48-00-06N	121-30-00W	Derkey and others, 1990 Hollister, 1979
15	×	Kromona	Scriber, Jones	–	47-55-58N	121-35-34W	Derkey and others, 1990 Hollister, 1979 Grant, 1976
16	△	Seacrest	Silver Creek, New York	–	47-57-09N	121-24-54W	Church and others, 1983c Grant, 1969 Hollister, 1979 Johnson and others, 1983a
17	△	Index	–	–	47-43-07N	121-30-38W	Grant, 1969, 1976
18	▲	North Fork Snoqualmie	–	44 million metric tons at 0.5% Cu	47-40-08N	121-38-11W	Grant, 1976
19	△	Green Lakes Ridge	–	–	47-35-56N	121-23-31W	Grant, 1976
20	×	Upper Myrtle Lake	–	–	47-33-05N	121-22-48W	Grant, 1976
21	▲	Quartz Creek	–	13.5 million metric tons at 0.5% Cu	47-34-14N	121-33-16W	Derkey and others, 1990 Grant, 1969 Hollister, 1979

22	△	Dutch Miller	–	–	47-33-33N	121-14-19W	Derkey and others, 1990 Gualtiere and others, 1975 Hollister, 1979
23	▲	Middle Fork Snoqualmie	Condor-Hemlock, Clipper, Three Brothers	180 million metric tons at 0.7% Cu, 0.02% Mo	47-29-48N	121-21-37W	Derkey and others, 1990 Grant, 1969, 1976 Gualtiere and others, 1973 Gualtiere and others, 1975 Hollister, 1979
24	△	Mineral Creek	Durrwachter, Liberty Lode	–	47-25-30N	121-15-16W	Derkey and others, 1990 Grant, 1969, 1976 Hollister, 1979
25	△	Gold Creek	–	–	47-26-44N	121-18-22W	Grant, 1969
26	△	Red Mountain	–	–	47-22-47N	121-07-30W	Grant, 1976 Hollister, 1979
27	×	Enumclaw	–	–	47-09-40N	121-46-00W	Grant, 1976 Hollister, 1979
28	×	Fortune Creek	Van Epps, Pickwick Mine	–	47-29-40N	120-57-19W	Gualtiere and others, 1973 Gualtiere and others, 1975 Hollister, 1979 Grant, 1976
29	×	Mesatchee Creek	Morse-Union, American River	–	46-52-21N	121-24-28W	Grant, 1969, 1976 Gualtiere and others, 1973 Gualtiere and others, 1975 Hollister, 1979
30	×	Bumping Lake	Copper Mining Co.	–	46-47-01N	121-21-55W	Simmons and others, 1983
31	×	Goat Rocks	Glacier	–	46-32-00N	121-27-00W	Grant, 1976 Church and others, 1983a
32	△	Camp Creek	McCoy Creek, McCoy Peak	–	46-21-40N	121-47-21W	Grant, 1976 Hollister, 1979
33	▲	Margaret	Earl Group, Ryan Lake	521 million metric tons at 0.36% Cu, 0.011% Mo, 0.24 g/mt Au, 1.6 g/mt Ag	46-21-23N	122-04-51W	Derkey and others, 1990 Hollister, 1979
34	×	Wind River	–	–	45-56-31N	121-56-22W	Church and others, 1986
35	△	Black Jack	Miners Queen	–	45-46-20N	122-11-59W	Derkey and others, 1990
36	△	North Santiam Copper	Black Eagle	–	44-51-20N	122-14-30W	Callaghan and Buddington, 1938 Cummings and others, 1990 Power and Field, 1981
37	×	Detroit Reservoir Prospect	–	–	44-41-45N	122-15-30W	Power and Field, 1981
38	×	Quartzville mining district	–	–	44-34-30N	122-19-00W	Callaghan and Buddington, 1938
39	×	Blue River mining district	–	–	44-13-30N	122-21-00W	Callaghan and Buddington, 1938
40	×	Bohemia mining district	–	–	43-35-00N	122-40-00W	Callaghan and Buddington, 1938

INTRODUCTION

By Michael F. Diggles

The listing of the northern spotted owl as a threatened species has been the topic of much discussion and debate in the Pacific northwest recently. The Endangered Species Act of 1973 provides two levels of listing, endangered and threatened (species likely to be endangered in the foreseeable future). Petitions for additions may be made by anyone presenting adequate evidence of the status of a species. The decision to list may be based only on biological evidence and may not consider economic factors. In 1978, the Act was amended to require each species listing to be accompanied by a listing of critical habitat; habitat listing requires consideration of economic factors.

The listing of the northern spotted owl by the U.S. Fish and Wildlife Service was petitioned by Green World. The listing took place on June 26, 1990 as a result of a ruling in the 9th U.S. Circuit Court of Appeals in San Francisco (Dale Robertson, et al. vs. Seattle Audubon Society, et al., 90-1596). In May, 1990, habitat conservation areas were delineated by an interagency scientific committee (Thomas and others, 1990). In November, 1990, the U.S. Geological Survey prepared a preliminary report at the same scale as the Thomas report (1:500,000) describing the potential for undiscovered mineral resources within the range of the northern spotted owl (Diggles and others, 1990). On February 26, 1991, Judge William Dwyer, U.S. District Court, Seattle, directed the listing of Critical Habitat Area. The U.S. Fish and Wildlife Service proposed critical habitat delineations that were published in the Federal Register the week of May 6. A 30-day public-comment period (the second of two) has an early-August, 1991, start date. Legislation proposed to address the issues of ancient forests, timber production, and the northern spotted owl include H.R. 842 (Jontz), Ancient Forest Protection Act of 1991, H.R. 1309 (Smith), Community Stability Act of 1991, H.R. 1590 (Vento), Ancient Forest Act of 1991, H.R. 2463 (Huckaby), Forests and Families Protection Act of 1991, S 1536 (Adams), Pacific Northwest Community Recovery and Ecosystem Conservation Act, and S. 1156 (Packwood), Federal Lands and Families Protection Act of 1991. This mineral assessment provides information on economic factors that can be considered in designating critical habitat and other land-use decisions in the Cascade Range.

In this mineral study, the range of the northern spotted owl (fig. 1; Peterson, 1990) is assessed for tracts that are permissive for the occurrence of undiscovered porphyry copper deposits. Within the owl's range, porphyry copper deposits are most likely to be present in the Cascade Range, which extends from the Canadian border into northern California. Among the numerous types of prospects, mineral occurrences, and deposits known in the region, the largest and most well defined are the porphyry copper deposits. Mineralized areas in the Cascade Range are present as disseminations and stockworks, in breccia pipes, and in polymetallic veins that appear to form haloes around the porphyry copper deposits. Numerous smaller mineral deposits of several other types have been found and have produced in the Cascade Range. These other mineral-deposit types also constitute undiscovered mineral resources, but lack of time and data throughout the region currently preclude an evaluation of the total metal endowment of the Cascade Range. Further systematic scientific studies are required to achieve this objective.

GEOLOGIC SETTING

By Stanley E. Church

The Cascade geologic province is commonly divided into two regions: the Western Cascades and the High Cascades. The High Cascades is a narrow band of late Tertiary and Quaternary volcanic rocks on the east side of the Cascade Range. The Western Cascades lie adjacent to and west of the High Cascades; it is an elongate belt underlain by a thick sequence of locally gently folded and faulted Tertiary volcanic rocks that overlie or interfinger with Tertiary marine rocks to the west. The Western Cascades contain all the known porphyry copper mineral resources of the Cascade Range. In the High Cascades, Tertiary plutons are buried beneath a thick Quaternary volcanic cover; they extend from Mount Adams south with Mount St. Helens and Mount Rainier forming piles that locally cover Western Cascades rocks. Ore deposits buried deeper than 1 km, such as any likely to be present in the High Cascades, have not been considered for this study. Deeper erosion in the Western Cascades exposed some of the plutons and their associated porphyry copper deposits. We divided the Cascade geologic province into three tracts (fig. 2): Tract A where numerous plutons are exposed, Tract B where some plutons are exposed but where there is considerable volcanic cover, and Tract C where all Cascade rocks are volcanic cover. The boundary between Tracts A and B is the Olympic-Wallowa lineament. Tracts B and C are separated by the Klamath Mountains-Blue Mountains lineament (Riddihough and others, 1986; Blakely and Jachens, 1990).

The following description is from Church and others (1986). The Cascade Range consists, in part, of a young volcanic arc that began to form as early as Eocene time. The arc rocks overlie belts of pre-Cenozoic rocks, both in northern Washington and southern Oregon. The North Cascades of Washington are underlain mostly by a metamorphic-plutonic terrane, fault-bounded on the east and west sides against dominantly pre-Tertiary marine and continental rocks. According to Misch (1966), the core rocks consist of pre-Middle Devonian crystalline rocks, pre-Cascade intrusive rocks, crystalline rocks produced during the Cascade metamorphic cycle, and Late Cretaceous and Tertiary intrusive rocks. Mattinson (1972) reported radiometric dates for crystallization of the parent pre-Middle Devonian crystalline rocks that range from 1,452 million years (Ma) to as old as 2,000 Ma. These rocks underwent intense regional metamorphism about 415 Ma (Mattinson, 1972). The metamorphic complex was uplifted, eroded, and buried again by middle Paleozoic time and younger supracrustal rocks were, in part, derived from this older terrane. Composite plutons were intruded into the older crystalline and supracrustal rocks at about 220 Ma. Regional metamorphism (Cascade cycle of Misch, 1966) accompanied by synkinematic igneous activity occurred between 90-60 Ma (Mattinson, 1972; Engels and others, 1976; Armstrong and others, 1977). Concurrent with the Cascade metamorphic cycle was the beginning of an extended period of plutonism resulting in the emplacement of the Late Cretaceous and Tertiary intrusive rocks.

The rocks exposed in the southern Washington and northern and central Oregon Cascade Range are mostly middle to upper Tertiary volcanic rocks intruded in some areas by composite calc-alkaline plutons. In the central Washington Cascade Range the northern crystalline rocks are buried by a pile of volcanic rocks that thickens to the south. In southern Oregon, the dominantly Tertiary-volcanic terrane of the central Oregon Cascade Range overlies lower Mesozoic flysch, volcaniclastic, metavolcanic, and ophiolitic rocks of the Klamath Mountains. The latter rocks are found in several large thrust sheets that have been locally intruded by Cretaceous igneous rocks ranging in composition from gabbro to granite (Peck, 1961). Similar sequences of oceanic flysch and volcanic rocks are present in the Blue Mountains in eastern Oregon (Armstrong and others, 1977). Two $^{87}Sr/^{86}Sr$ isopleths east of the present study area (Church and others, 1986, fig. 2) are believed to represent the boundaries of the buried Precambrian craton (0.706) and the accreted Paleozoic and Mesozoic terranes (0.704).

Between blocks of predominantly pre-Tertiary crust, the Columbia embayment (Carey, 1958) is filled by Tertiary volcanic rocks, some of which are calc-alkaline and presumably related to subduction. White and McBirney (1978), in a study of the temporal variations in rock composition, showed that the volcanoes of the central High Cascades (central and northern

Oregon) are more basaltic and contain lower abundances of incompatible trace elements than volcanic rocks in northern California that were intruded through Paleozoic and Mesozoic crust. They stated that the relatively lower concentrations of incompatible trace elements reflected a thin, young crust in the central Cascade Range. Their data support the suggestion made by previous workers (for example Hamilton and Myers, 1966) that volcanic rocks of central and northern Oregon have filled the embayment between blocks of Mesozoic and older rocks.

ORE DEPOSIT MODEL FOR PORPHYRY COPPER

By Dennis P. Cox and Donald A. Singer

The following section contains a model for porphyry copper deposits (after Cox, 1986a, and Singer and others, 1986b, Model 17).

Descriptive Model of Porphyry Copper

Geologic Environment

This generalized model (Titley, 1982) includes various subtypes, all of which contain chalcopyrite in stockwork veinlets in hydrothermally altered porphry and adjacent country rock (see fig. 3). Mineralization was generally associated with intrusive rocks of tonalite to monzogranite or syenitic porphyry that intrude pre-existing intrusive, volcanic, calcareous sedimentary, and other rocks. The predominate texture is that of a porphyry that has closely spaced phenocrysts and microaplitic quartz-feldspar groundmass. Most deposits are associated with Mesozoic and Cenozoic porphyries, but they may be any age. Deposits form in or near high-level intrusive stocks or cupolas of batholiths. Abundant contemporaneous dikes, breccia pipes, and faults are found in the mineralized area. Porphyry copper deposits are present in rift zones that form contemporaneously with Andean or island-arc volcanism along convergent plate boundaries. Uplift and erosion are essential to expose subvolcanic rocks where the deposits are located. Base-metal skarn, epithermal veins, polymetallic replacement, and volcanic hosted massive replacement are commonly associated mineral-deposit types.

Description of Porphyry Copper Deposits

The associated metallic mineral assemblages consist of chalcopyrite and pyrite, which may be accompanied by molybdenite; alternatively, they consist of chalcopyrite and magnetite that may be accompanied by bornite and (or) gold. The assemblages may be superposed. Associated nonmetallic mineral suites consist of quartz, potassium-feldspar, and biotite that may be accompanied by anhydrite; alternatively, they consist of quartz and sericite that may be accompanied by clay minerals. Late veins of enargite, tetrahedrite, galena, sphalerite, and barite may be present in some deposits. The mineralized zones consist of stockwork veinlets and disseminated sulfide grains. The alteration, from the bottom, innermost zones outward progresses from sodic-calcic, potassic, phyllic, and argillic, to propylitic. High-alumina alteration is present in upper parts of some deposits (table 2). Propylitic or phyllic alteration may overprint an early potassic assemblage. The ore tends to form in stockwork veins in porphyry, along porphyry contacts, and in favorable country rocks such as carbonate rocks, mafic igneous rocks, and older granitic plutons. Weathering appears as green and blue copper carbonates and silicates in weathered outcrop, or, where leaching is intense, barren outcrops after copper is leached, transported downward, and deposited as secondary sulfides at the water table or paleowater table. Fractures in leached outcrops are coated with hematitic limonite having bright red streaks. Deposits of secondary sulfides contain chalcocite as well as other copper-sulfide minerals replacing pyrite and chalcopyrite. Residual soils

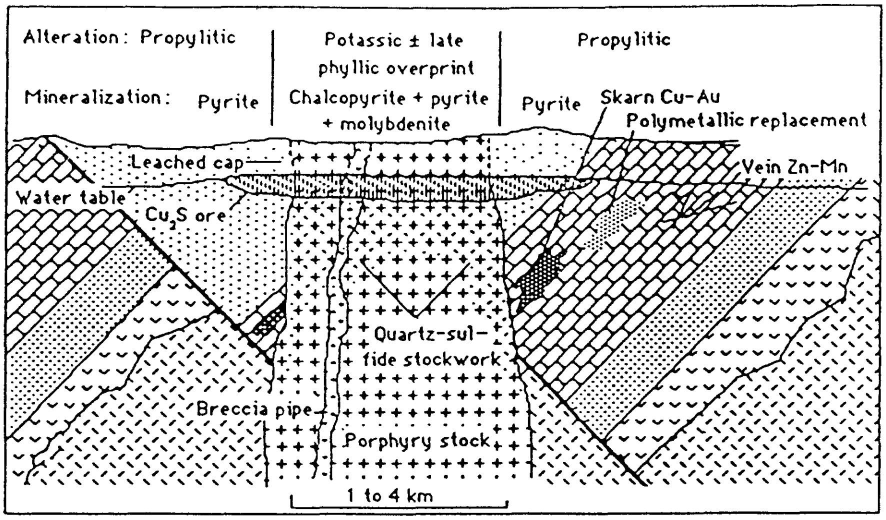

Figure 3.--Cartoon cross section illustrating generalized model for porphyry Cu deposits showing relation of ore minerals, alteration zoning, supergene enrichment, and associated skarn, replacement, and vein deposits (source, Cox, 1986a).

Table 2.--Types of hydrothermal alteration characteristic of porphyry copper and other deposit models

Type of alteration and synonyms	Original mineral	replaced by	Appearance
Potassic alteration (K-silicate)	plagioclase------- hornblende--------	K-feldspar fine-grained biotite + rutile + pyrite or magnetite. Anhydrite	Rocks look fresh but may have pinkish K-feldspar veinlets. and black biotite veinlets and clusters of fine biotite after mafic phenocrysts.
Sodic-calcic alteration (albitic)	K-feldspar-------- biotite-----------	oligoclase or albite actinolite + sphene	Rocks are hard and dull white. Biotite is absent. Veinlets of actinolite, epidote, and hematite have hard, white alteration haloes.
Phyllic alteration (quartz-sericite)	plagioclase------- hornblende and biotite-----------	sericite sericite + chlorite + rutile + pyrite	Rocks are soft and dull to lustrous white. Pyrite veinlets have distinct, soft translucent gray, sericite haloes. Tourmaline rosettes may be present.
Propylitic alteration	plagioclase------- hornblende and biotite-------	albite or oligoclase + epidote or calcite chlorite + rutile + magnetite or pyrite	Rocks are hard and dull greenish gray. Veinlets of pyrite or chlorite and epidote lack prominent alteration haloes.
Argillic alteration	plagioclase------- mafic minerals----	clay + sericite clay + sericite + chlorite + pyrite	Rocks are soft and white. Tongue will stick to clay-altered minerals.
High alumina (alsic, advanced argillic)	All original and earlier hydrothermal minerals converted to pyrophyllite, alunite, andalusite, corundum, and diaspore with variable amounts of clay and sericite.		Rocks are light colored and moderately soft.

overlying deposits may contain anomalous amounts of rutile. The geochemical signature of these deposits is copper with or without molybdenum, gold, silver, tungsten, boron, and (or) strontium in the center. It is lead, zinc, gold, arsenic, antimony, selenium, tellurium, manganese, cobalt, barium, and (or) rubidium in the outer parts. Locally, bismuth and tin form the most distal anomalies. High silica is present all zones. Some deposits have weak uranium anomalies.

Examples of porphyry copper deposits are Bingham, Utah (Lanier and others, 1978), San Manuel, Arizona (Lowell and Guilbert, 1970), and El Salvador, Chile (Gustafson and Hunt, 1975).

Grade and Tonnage Model of Porphyry Copper

All porphyry copper deposits with available grades and tonnages were included in these plots to provide a model for cases where it is not possible to use the gold-rich or molybdenum-rich models. Parts of the porphyry copper deposits which could be considered skarn were included in these data. Gold grade is correlated with tonnage ($r = -0.49$, $n = 81$) and with molybdenum grade ($r = -0.45$, $n = 55$) See figures 4-6.

Deposits for which Grades and Tonnages are Known

Name	Location	Name	Location	Name	Location
Afton	CNBC	Cash	CNYT	Fish Lake	CNBC
Ajax	CNBC	Casino	CNYT	Florence	USAZ
Ajo	USAZ	Castle Dome	USAZ	Frieda River	PPNG
Am	CNBC	Catface	CNBC	Galaxy	CNBC
Amacan	PLPN	Catheart	USMN	Galore Creek	CNBC
Andacolla	CILE	Cerro Blanco	CILE	Gambier Island	CNBC
Ann	CNBC	Cerro Colorado	CILE	Gaspe	CNQU
Ann Mason	USNV	Cerro Colorado	PANA	Gibraltar	CNBC
Arie	PPNG	Cerro Verde	PERU	Glacier Peak	USWA
Atlas Carmen	PLPN	Chaucha	ECDR	Granisle	CNBC
Atlas Frank	PLPN	Chuquicamata	CILE	Hale-Mayabo	PLPN
Atlas Lutopan	PLPN	Coalstoun	AUQL	Heddleston	USMT
Axe	CNBC	Copper Basin	USAZ	Helvetia	USAZ
Aya Aya	PLPN	Copper Cities	USAZ	Highmont	CNBC
Bagdad	USAZ	Copper Creek	USAZ	Hinobaan	PLPN
Basay	PLPN	Copper Flat	USNM	Huckleberry	CNBC
Bear	USNV	Copper Mountain	CNBC	Ingerbelle	CNBC
Bell Copper	CNBC	Cordon	PLPN	Inguaran	MXCO
Berg	CNBC	Cuajone	PERU	Ino-Capaya	PLPN
Bethlehem	CNBC	Cubuagan	PLPN	Inspiration	USAZ
Big Onion	CNBC	Dexing	CINA	Iron Mask	CNBC
Bingham	USUT	Dizon	PLPN	Island Copper	CNBC
Bisbee	USAZ	Dorothy	CNBC	Ithaca Peak	USAZ
Bluebird	USAZ	Dos Pobres	USAZ	June	CNBC
Bond Creek	USAK	Eagle	CNBC	Kadzharan	URAM
Boneng Lobo	PLPN	El Abra	CILE	Kalamaton	PLPN
Bozshchaku	URRS	El Arco	MXCO	Kalamazoo-San Manuel	USAZ
Brenda	CNBC	El Pachon	AGTN	Kalmakyr	URUZ
Brenmac	USWA	El Salvador	CILE	Kennon	PLPN
Buulad	PLPN	El Soldado	CILE	King-King	PLPN
Butte	USMT	El Teniente	CILE	Kirwin	USWY
Campanamah	AGTN	Elatsite	BULG	Kounrad	URKZ
Cananea	MXCO	Ely	USNV	Krain	CNBC
Canariaco	PERU	Escondida	CILE	Kwanika	CNBC
Cariboo Bell	CNBC	Esperanza	CILE	La Alumbrera	AGTN
Carpenter	USAZ	Exotica	CILE	La Caridad	MXCO

La Florida	MXCO	Namosi East	FIJI	San Juan	USAZ
La Verde	MXCO	Namosi West	FIJI	San Xavier	USAZ
Lakeshore	USAZ	North Fork	USWA	Sanchez	USAZ
Lights Creek	USCA	Ok	CNBC	Santa Rita	USNM
Lornex	CNBC	Ok Tedi	PPNG	Santo Nino	PLPN
Lorraine	CNBC	Orange Hill	USAK	Santo Tomas	MXCO
Los Bronces	CILE	Pampa Norte	CILE	Santo Tomas	PLPN
Los Pelambres	CILE	Panguna	PPNG	Sar Cheshmeh	IRAN
Los Pilares	MXCO	Paramillos	AGTN	Schaft Creek	CNBC
Lumbay	PLPN	Parks	AUNS	Sierra Gorda	CILE
Luna-Bash	PLPN	Pashpap	PERU	Silver Bell	USAZ
MacArthur	USNV	Petaquilla	PANA	Sipalay	PLPN
Maggie	CNBC	Philippine	PLPN	Star Mt.-Fubilan	PPNG
Majdanpek	YUGO	Pima-Mission	USAZ	Star Mt.-Futik	PPNG
Mamut	MDGS	Plurhinaler	THLD	Star Mt.-Nong River	PPNG
Mantos Blancos	CILE	Poison Mountain	CNBC	Star Mt.-Olgal	PPNG
Mapula	PLPN	Potrerillos	CILE	Sugarloaf Hill	CNBC
Marcopper	PLPN	Primer	CNBC	Tagpura	PLPN
Margaret	USWA	Quebrada Blanca	CILE	Tanama	PTRC
Marian	PLPN	Quelleveco	PERU	Tawi-Tawi	PLPN
Mazama	USWA	Ray	USAZ	Taysan	PLPN
Metcalf	USAZ	Recsk	HUNG	Toledo	PLPN
Michiquillay	PERU	Red Chris	CNBC	Toquepala	PERU
Middle Fork	USWA	Red Mountain	USAZ	Trojan	CNBC
Mineral Butte	USAZ	Rio Blanco	CILE	Twin Buttes	USAZ
Misty	CNBC	Rio Vivi	PTRC	Tyrone	USNM
Mocha	CILE	Sacaton (E-W)	USAZ	Valley Copper	CNBC
Mocoa	CLBA	Safford (KCC)	USAZ	Vekol	USAZ
Moniwa	BRMA	Saindak East	PKTN	Washington	MXCO
Morenci	USAZ	Saindak North	PKTN	Yandera	PPNG
Morococha	PERU	Saindak South	PKTN	Yeoval	AUNS
Morrison	CNBC	Samar	PLPN	Yerington	USNV
Mountain Mines	PLPN	San Antonio	PLPN		
Mount Canninda	AUQL	San Fabian	PLPN		

KNOWN COPPER DEPOSITS

By Jocelyn A. Peterson

Mineral Resource Data System

The Mineral Resource Data System (MRDS) of the U.S. Geological Survey is a computerized database containing nearly 85,000 records of mines, prospects, and occurrences throughout the world (MRDS, 1990). About 4,600 records exist on sites within northern California, Oregon, and Washington. Records can contain detailed information on the name(s), location, commodities, exploration and development, deposit description, geology, references, production, and reserves and resources. Most of the data have been collected from published literature and unpublished files maintained by geologists of the U.S. Geological Survey. Additionally, some data have come from field observations by geologists of the U.S. Geological Survey and, to a lesser degree, contributions from other federal agencies (such as the U.S. Bureau of Mines, U.S. Forest Service, U.S. Bureau of Land Management, U.S. Department of State), state geological surveys, mining companies, and private consultants. Geologists with the Oregon Department of Geology and Mineral Industries substantially improved records for that state. The MRDS data have not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. We make no claims as to the completeness of the file for the area under consideration. The summary of porphyry copper deposits in table 1 includes all data from public sources.

We have used our working version of the publicly available MRDS file, which

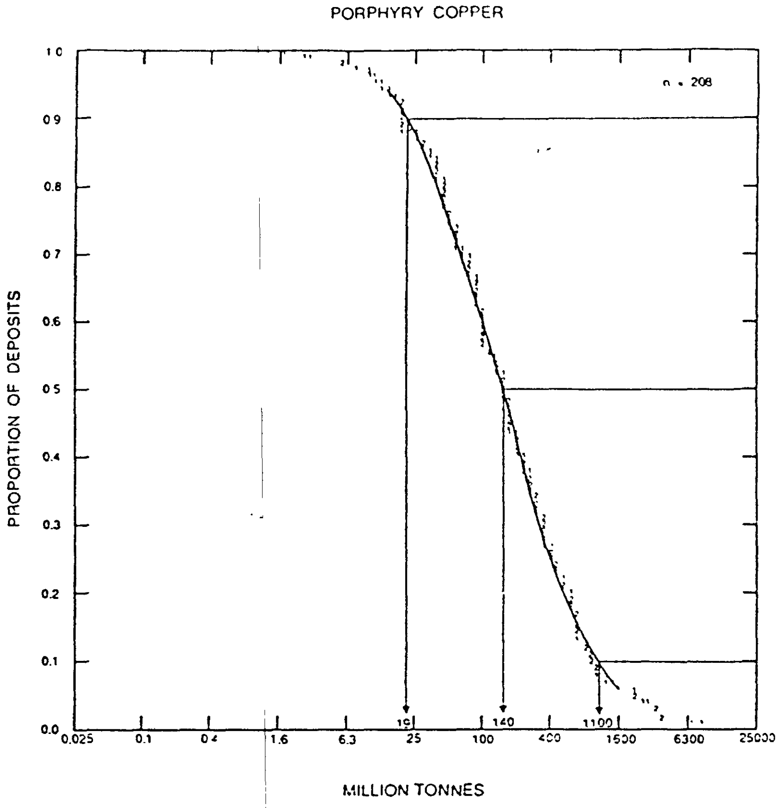

Figure 4.--Tonnages of porphyry Cu deposits. Individual digits represent number of deposits (source, Singer and others, 1986b).

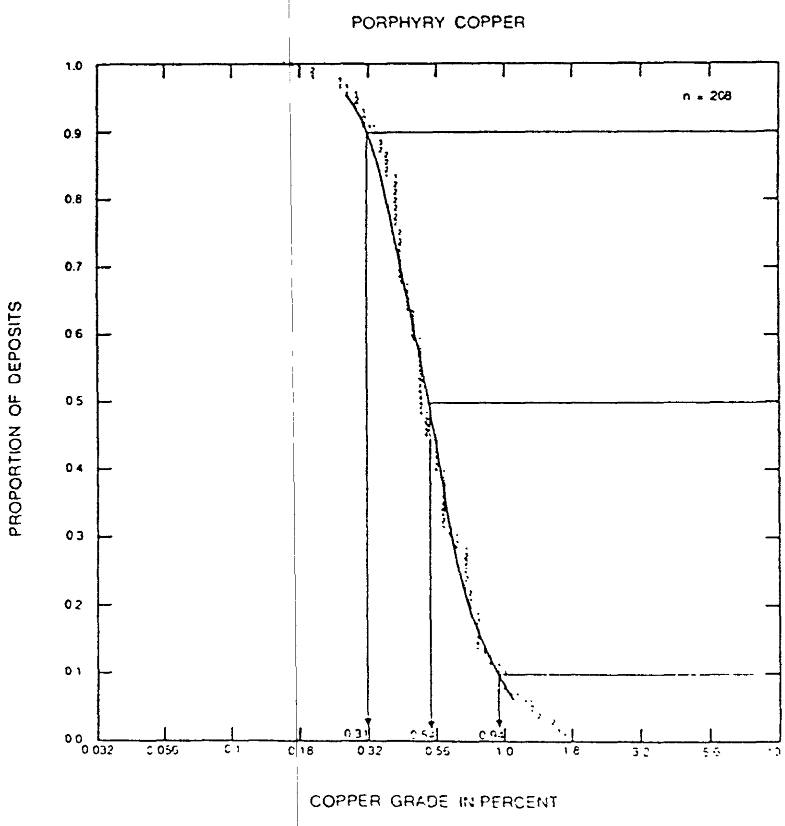

Figure 5.--Copper grades of porphyry Cu deposits. Individual digits represent number of deposits (source, Singer and others, 1986b).

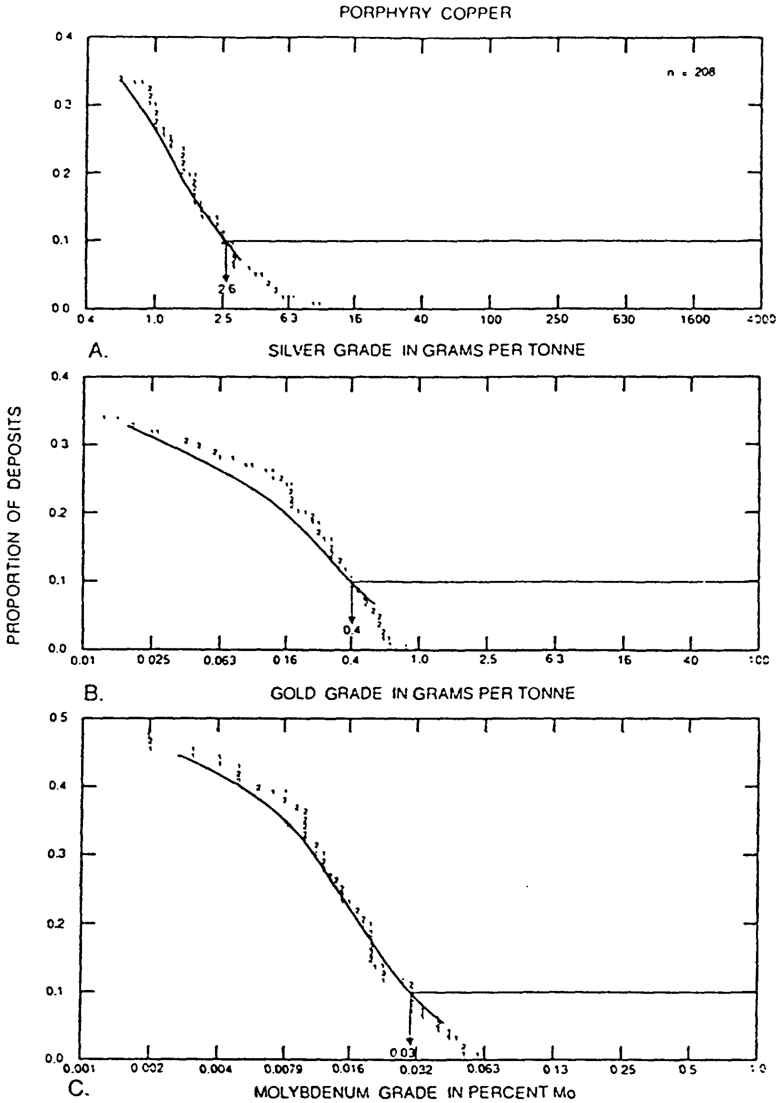

Figure 6.--Byproduct grades of porphyry Cu deposits. A, silver; B, gold; C, molybdenum. Individual digits represent number of deposits (source, Singer and others, 1986b).

is being updated for entry into the public file. This modified file is being used because it contains information not yet in the public file that is relevant to deposit-type classification. Also, modifications to this file have eliminated some duplicate records.

For parts of states being examined here, there are 308, 263, and 246 sites for Washington, Oregon, and California, respectively, for which copper is a reported commodity. This includes records for mines, prospects, and occurrences, which are depicted as "+" on plates 2, 3, and 4. Records that were initially identified as possible porphyry copper deposits are shown on these plates as circles. The plates also show generalized county boundaries and grid tics corresponding to 1° intervals.

Known Mineral Occurrences

Several types of copper-bearing deposits are present in the Cascade geologic province. Some are porphyry copper or probable porphyry copper deposits; others are related to porphyry deposits. Some deposits, however, bear no relation to porphyry copper deposits and are incidental to this study. Mineral deposits are located mostly within the Western Cascades and older rocks (see geology section above); the High Cascades are not significantly mineralized.

Porphyry Copper Deposits

Initially 34 sites within the Cascade Range were identified as having characteristics that confirm or strongly suggest porphyry copper mineralization. Subsequent to the meeting of the assessment team, several properties were added to this list to designate 40 areas of interest. The additions are not shown on plates 2-4 but are listed in table 1 and shown on figure 2 and plates 1, 26, and 27. None of these properties have produced copper from porphyry copper deposits by bulk-mining methods. However, high-grade parts of some were mined early in the history of the districts by underground mining methods.

Most of the known and probable porphyry copper localities are located in Washington. The North Santiam and Detroit Reservoir localities are in the North Santiam mining district of Oregon (see Cummings and others, 1990), and the Quartzville, Blue River, and Bohemia mining districts farther south have characteristics suggestive of concealed porphyry copper mineralization. No porphyry copper occurrences are known to lie within the Cascade Range in California. Table 1 shows the known and probable porphyry copper properties in the area of interest. Several sources were used to identify porphyry copper localities including Grant (1969, 1976), Hollister (1978, 1979), Derkey and others (1990), and many wilderness study area assessment reports summarized by Marsh and others (1984). There were, however, problems in identifying porphyry copper localities in Washington. (1) In some cases, different names were used to refer to the same deposit. Because some reports contain only small-scale maps, it was difficult to accurately locate some deposits. (2) It was difficult to assign a degree of certainty to the classification of a locality as a porphyry copper. All porphyry copper deposits listed by Grant (1969, 1976), Hollister (1978, 1979), or Derkey and others (1990) were included. Mineral deposits listed in the various wilderness reports as having high potential for porphyry copper mineralization also were included. Some areas were assigned moderate or low potential for porphyry copper deposits (Church and others, 1983a; Evarts and others, 1983; Simmons and others, 1983); of these, only Goat Rocks (Church and others, 1983a) has been included in our compilation as a probable porphyry copper deposit. Some mineral deposits with records in the MRDS file and others included in Derkey and others (1990) have descriptive information that suggests the deposits are probably porphyry copper deposits. Although they have not been identified as such previously, some of these were included as probable deposits. (3) Porphyry copper systems are difficult to distinguish from breccia-pipe systems, for which the suite of metals is essentially the same. Some of those from

Derkey and others (1990) are included as porphyry copper localities here.

Reserve estimates have been made for some of these deposits and are included in table 1. A visual comparison of the estimates of grades and tonnages in table 1 with those for porphyry copper deposits described by Singer and others (1986b, model 17; see section on Ore Deposit Model For Porphyry Copper above) shows that most of the deposits for which we have data have tonnages near and below the median tonnage, copper grades comparable to those in the published model, and molybdenum grades generally near or above the median value (see section on Quantitative Resource Assessment below).

Polymetallic Vein Deposits

Most copper-bearing mineral deposits in the Cascade Range of California, Oregon, and Washington are polymetallic vein deposits. In Washington, polymetallic veins are the primary kind of deposit associated with the porphyry copper deposits and were the deposits historically mined in most of the porphyry copper districts. Significant mining districts containing polymetallic veins are also situated in the Western Cascades of Oregon, including North Santiam, Quartzville, Blue River, Fall Creek, and Bohemia, from north to south. Because of the known association of porphyry copper deposits and polymetallic veins and the presence of porphyry copper mineralization in the North Santiam district (Power and Field, 1981), it has been proposed that other major districts in Oregon may be underlain by porphyry copper deposits (Power and Field, 1981; Power, 1984).

Epithermal Vein Deposits

Two epithermal-vein deposits without economic concentrations of copper, are located in southern Oregon, the Al Serena (Buzzard) and Barron, along with smaller deposits. These tend to be small isolated deposits outside large mining districts. Cummings and others (1990) noted, however, that the North Santiam district has undergone two episodes of mineralization: the porphyry copper-polymetallic vein mineralization and a younger epithermal-vein mineralization. Similar epithermal mineralization may have occurred in other districts in Oregon and possibly also in Washington. The High Grade district in northern California, on the east boundary of our map, contains epithermal veins. Although it does not lie within the Cascade Range, mineralization may be genetically related to Cascade magmatism.

Other Deposit Types

Not all deposits shown on our maps are related to plutonism and volcanism of the Cascade Range. Most of these unrelated deposits are massive sulfide deposits within the Klamath Mountains of California and Oregon. A few massive sulfide deposits are also found in northern Washington. Low-sulfide gold-quartz veins, some of which contain minor quantities of copper are also present in the Klamath Mountains. A few deposits containing nickel and copper in mafic or ultramafic rocks in the Klamath Mountains and in northern Washington probably formed from magmatic segregations within plutons intruded during pre-Tertiary orogenic episodes. These massive sulfide, low-sulfide gold-quartz, and copper-nickel deposits are not related to the Cascade Range or to porphyry copper mineralization and are incidental to this study. Some copper-bearing deposits are also included that we were unable to classify using currently established deposit models (Cox and Singer, 1986). Most of these lie outside the Cascade Range and their genetic relationship with Cascade Range magmatism is unknown.

GEOPHYSICAL INTERPRETATIONS

By Richard J. Blakely and Donald Plouff

Introduction

This chapter summarizes a compilation and preliminary interpretation of gravity and magnetic data from the Cascade geologic province of Washington, Oregon, and California. The interpretation focuses on anomalies that may indicate intrusive rocks associated with porphyry copper deposits and was designed to provide information to assist assessment of porphyry copper resources in the Cascade geologic province.

Magnetic anomalies generally indicate concentrations of magnetite in upper-crustal rocks. In some cases, magnetic anomalies may directly reflect porphyry copper deposits if, for example, the deposition was accompanied by alteration of magnetite (Griscom, 1975). Flightline spacing and survey altitude of the data used in this study, however, are usually too great relative to the volume of porphyry copper deposits to directly indicate the presence of specific deposits. Interpretations of magnetic anomalies usually are used to constrain the geologic framework associated with the deposits, particularly the presence of intrusive rocks associated with mineralization. Other geophysical techniques, such as the induced-polarization method (Pelton and Smith, 1976), are more appropriate for direct exploration for porphyry copper deposits.

Gravity anomalies are less sensitive than magnetic anomalies to the presence of buried intrusive rocks because the range of densities is relatively small compared to the range of magnetization. Gravity anomalies are instrumental in defining geologic and tectonic frameworks, thickness of sedimentary cover, location of faults, and other information valuable for regional assessment of mineralization.

Although magnetic anomalies are useful in locating intrusive rocks related to porphyry copper systems, the signature of magnetic anomalies varies considerably in different geologic settings. The Laramide and Tertiary monzonitic-type intrusive rocks of Arizona are generally only weakly magnetic, possibly due to alteration; these intrusions cause negative magnetic anomalies when surrounded by more magnetic rocks, such as older granitic and metamorphic rocks (Brant, 1966). Intrusive rocks in Nevada and western Utah, on the other hand, are magnetic compared to surrounding rocks (Brant, 1966) and consequently cause positive magnetic anomalies. The quartz monzonite intrusion associated with the Ruth porphyry copper deposit near Ely, Nev., for example, is significantly magnetic relative to surrounding sedimentary rock (Carlson and Mabey, 1963).

Data Description

Magnetic data were extracted from a gridded compilation of aeromagnetic surveys from the entire conterminous U.S. (Godson and Scheibe, 1982; Godson, 1986b). The U.S. compilation was originally gridded at 2-km intervals using an Albers equal-area projection. We extracted a subset for the Cascade geologic province from this U.S. grid and then regridded the subset to a Lambert conformal projection to be consistent with state topographic maps published at 1:500,000 scale.

Aeromagnetic surveys used in the U.S. compilation have widely different survey specifications and data quality (Godson, 1986a). Over the Cascade geologic province in Oregon and northern California, the grid is based primarily on aeromagnetic surveys conducted by Oregon State University under contract to the U.S. Geological Survey (McLain, 1981; Connard and others, 1983; Foote, 1985). These data are of high quality. Aeromagnetic surveys from the Washington Cascade Range are of variable quality, in some cases with flightlines separated by 8 km. Therefore, these data provide only a regional representation of the magnetic field; our interpretation of these data should be evaluated accordingly.

The gravity maps in this report are based on Bouguer gravity anomalies described by Williams and others (1988) and Finn and others (1986). Bouguer gravity anomalies include long wavelength components caused by mass distributions that isostatically support topographic loads.

The effects of these regional anomalies were minimized by subtracting an isostatic correction described by Simpson and others (1983, 1986). The resulting isostatic residual gravity maps predominantly reflect density variations in the middle and upper crust and have proved useful in previous studies of the regional geologic and tectonic setting of the Cascade geologic province (Blakely and Jachens, 1990).

The aeromagnetic and isostatic residual gravity data were contoured at 1:500,000 scale to be compatible with geologic maps of the Cascade Range (Smith, 1989; Sherrod and Smith, 1989; Jennings, 1977). The geophysical maps are included with this report as plates 5-10.

Strategy

The magnetic and gravity data available for this study are suitable only for interpretations at regional scales (Blakely and others, 1985). Moreover, the short time frame of the assessment precluded a detailed, quantitative interpretation. Therefore, a technique was required to rapidly interpret regional-scale gravity and magnetic data for the presence of buried intrusive rocks associated with porphyry copper mineralization.

Forty known and identified possible porphyry copper deposits are located within the U.S. Cascade geologic province, and 35 of these are located in Washington (table 1). Most of these deposits are associated with exposed Tertiary intrusive rocks. Magnetic data collected over these intrusive rocks were examined for characteristic anomaly shapes and amplitudes. Magnetic data from the entire U.S. Cascade Range were then searched for the presence of similar magnetic anomalies.

We used a numerical technique to assist our interpretation of the lateral extent of buried intrusive rocks. This technique (Blakely and Simpson, 1986) automatically calculates from magnetic-intensity data the location of abrupt changes in crustal magnetization, commonly indicative of lithologic boundaries. This calculation is subject to several simplifying assumptions. The method assumes that magnetization boundaries are vertical; although this is an obvious oversimplification of real geologic situations, it does not cause significant errors at the scale of our interpretation. Figures 7-9 show the magnetic boundaries determined by automatic analysis of magnetic-intensity data. The magnetic boundaries also were plotted at a scale of 1:500,000 to compare with the gravity and magnetic maps.

The search for magnetic anomalies associated with intrusive rocks in the Cascade Range was not straightforward. The relatively young, unmetamorphosed volcanic terrane of the Cascade Range generally have high magnetizations and, therefore, produce high-amplitude, short-wavelength anomalies, some of which are negative in sign due to reversed remnant magnetization. These volcanic anomalies commonly mask anomalies caused by underlying intrusive rocks. Consequently, special attention was given to areas where intrusive rocks of Tertiary age crop out, as shown by the geologic maps of Smith (1989), Sherrod and Smith (1989), and Jennings (1977). Exposures of Tertiary intrusive rocks are rare in the Cascade geologic province of southern Oregon and northern California; our interpretations are more speculative in this part of the study area.

Gravity data were compared with the magnetic anomalies. In some cases, gravity anomalies permitted an interpretation of rock type. A negative correlation between gravity and magnetic anomalies, for example, indicates the presence of a magnetic, relatively low-density rocks, such as granodiorite plutons.

Geophysical Expression of Tract Boundaries

To aid their assessment of porphyry copper resources in the Cascade Range, Spanski and others (this report) divided the study area into three tracts, labeled A, B,

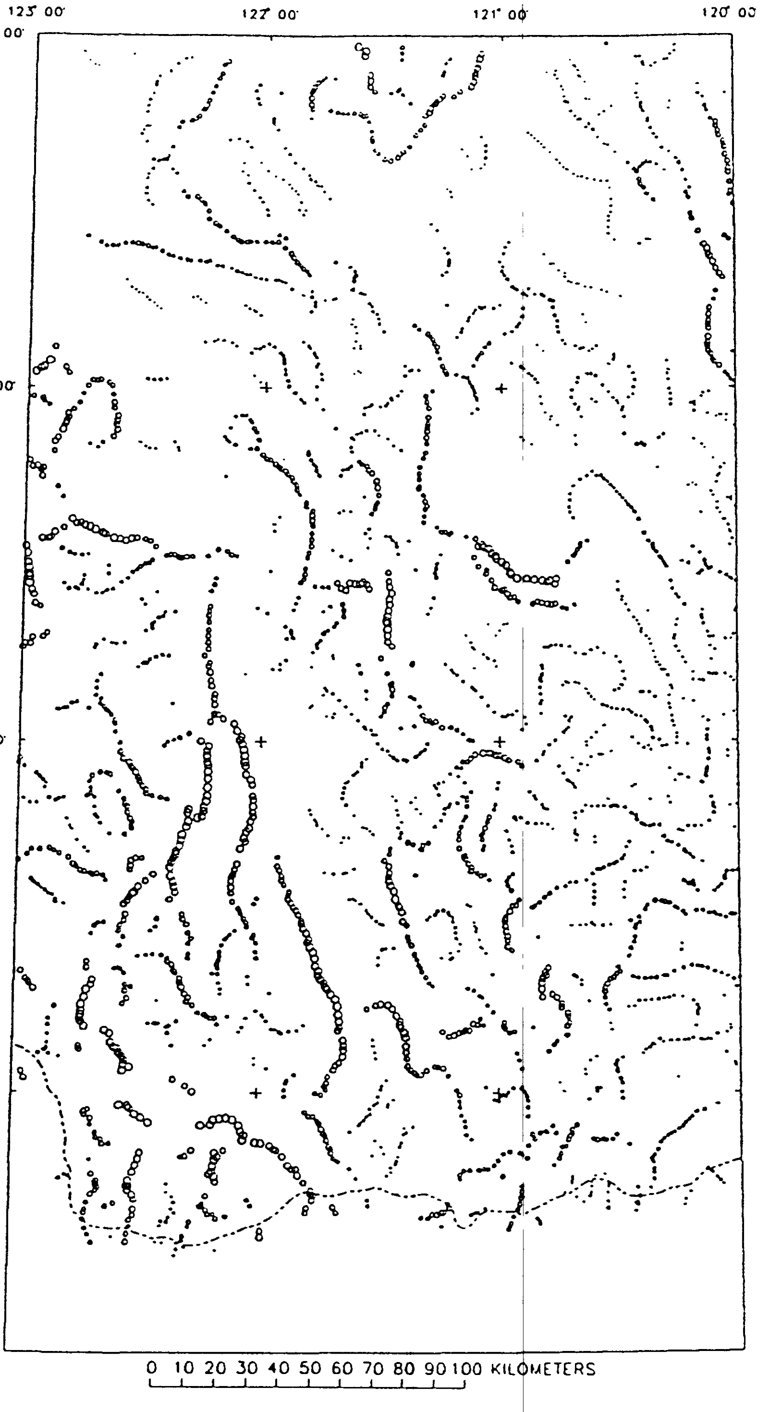

Figure 7.--Numerically determined magnetic boundaries, Washington. Size of dot represents steepness of horizontal gradient.

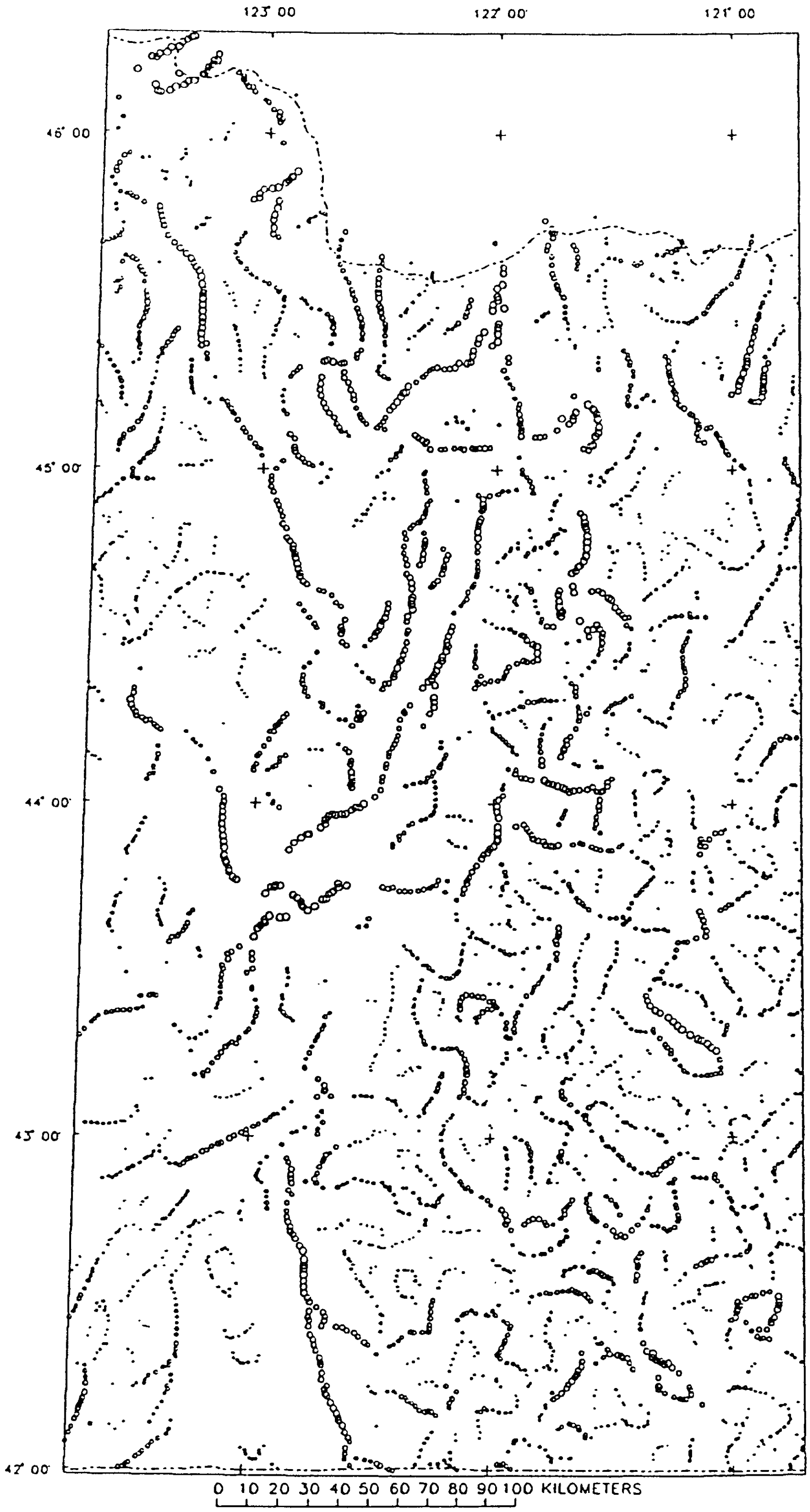

Figure 8.--Numerically determined magnetic boundaries, Oregon. Size of dot represents steepness of horizontal gradient.

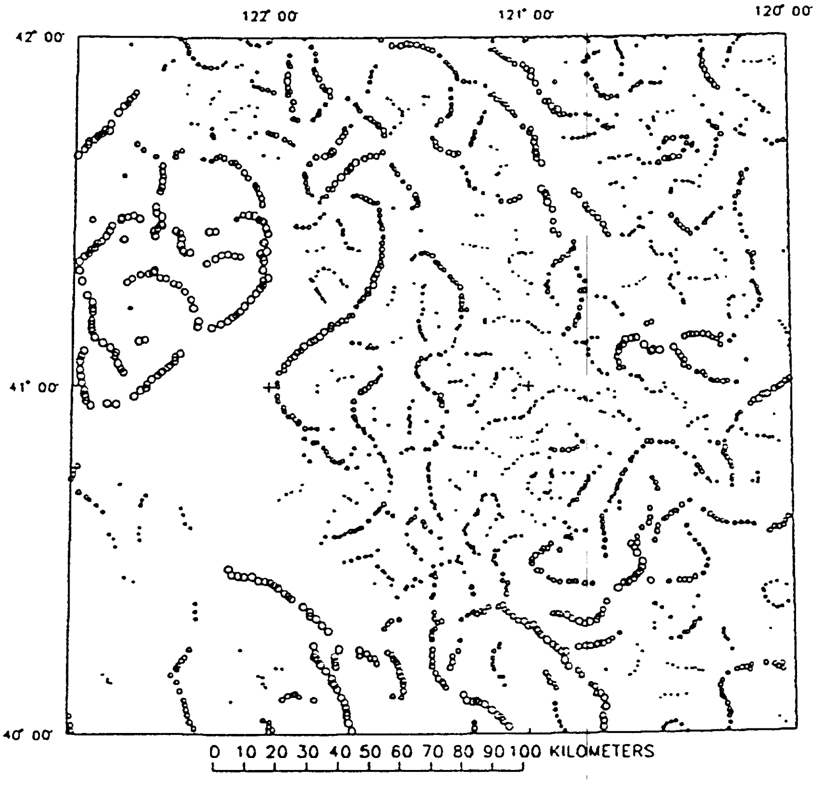

Figure 9.--Numerically determined magnetic boundaries, California Size of dot represents steepness of horizontal gradient.

and C on figure 2 and plates 1, 26, and 27. All permissive areas within a given tract are expected to have the same probability of porphyry copper occurrences. The boundaries between the three tracts are based on regional geologic and tectonic features: Tracts A and B are separated by the Olympic-Wallowa lineament; Tracts B and C are separated by the Klamath Mountains-Blue Mountains lineament.

Olympic-Wallowa Lineament

Plate 11 shows the location of the Olympic-Wallowa lineament as interpreted from gravity and magnetic anomalies. The lineament is represented by the truncation and offset of individual gravity and magnetic anomalies and can be traced in geophysical data from Puget Sound to the Blue Mountains in Oregon. Within the study area, the lineament lies along a broad, northwest-trending gravity low.

The northwest-trending gravity low truncates another gravity low that extends northeast to the Canadian border and that encompasses many of the known porphyry copper deposits of Washington. The northeast-trending gravity low may reflect an underlying plutonic terrane of Mesozoic and Cenozoic age.

Klamath Mountains-Blue Mountains Lineament

Riddihough and others (1986) described the gravitational expression of the Klamath Mountains-Blue Mountains lineament (pl. 12) and proposed that the lineament represents a pre-Tertiary continental margin. The lineament is well defined by gravity anomalies in both the Klamath Mountains and the Blue Mountains, but volcanic cover of the Cascade Range obscures the gravitational expression of the lineament within the study area.

In the Klamath Mountains, the gravitational expression is associated with the suture between the western Jurassic plate of the Klamath Mountains and Mesozoic rocks of the Oregon Coast Range (Irwin, 1981). In northeastern Oregon, the lineament marks the northwestern extent of exposed pre-Tertiary rocks of the Blue Mountains. Blakely and Jachens (1990) suggested that the Klamath Mountains-Blue Mountains lineament is one of several northeast-trending, pre-Cenozoic structures beneath the Cascade arc that are reflected by gravity anomalies in the Pacific Northwest.

Concealed Plutons

Plate 11 shows a preliminary interpretation for the state of Washington based largely on aeromagnetic data (pl. 5), locations of porphyry copper deposits, and mapped geology (Smith, 1989; Sherrod and Smith, 1989; Jennings, 1977). The interpretive map shows the lateral extent of magnetic sources presumed to be the magnetic parts of Tertiary intrusive rocks, either exposed or buried at depth. In Washington, many of these intrusive outcrops reflect underlying plutons and batholiths. The intrusive boundaries shown on plate 11 were determined in part by the analysis of magnetization boundaries shown in figure 7.

The U.S. Cascade Range has 40 known and identified possible porphyry copper deposits (table 1). Thirty-five of these lie in Washington; five are located in northern Oregon. Table 3 shows the relation between the location of these deposits and the interpreted location of buried Tertiary intrusive rocks. Of the 40 known and identified possible deposits, 31 are located within 4 km of the edge of positive magnetic anomalies assumed to be caused by buried intrusions. Therefore, most Tertiary intrusive rocks associated with porphyry copper deposits apparently have moderate to high magnetization and cause magnetic anomalies detectable in regional aeromagnetic data. We have applied this hypothesis to other parts of the Cascade Range to locate concealed plutons with which porphyry copper deposits might be found. It is difficult, however, to distinguish magnetic anomalies caused by intrusive

Table 3.--Location of known and identified possible porphyry copper deposits with respect to interpreted buried Tertiary intrusions

[Number refers to map number in table 1]

Within 4 km of anomaly edge	Inside anomaly, away from edge	Outside Anomaly, away from edge
01 Monument Peak	11 Glacier Peak	04 Crescent Mountain
02 Mount Beaver	16 Seacrest	05 Round Mountain
03 Mazama	18 North Fork Snoqualmie	26 Red Mountain
06 Silver Creek	19 Green Lakes Ridge	34 Wind River
07 Buckindy	36 North Santiam Copper	39 Blue River district
08 Gold Mountain	37 Detroit Reservoir	40 Bohemia district
09 Helena Peak	38 Quartzville district	
10 Goericke		
12 Esmeralda		
13 Trinity		
14 Sunrise		
15 Kromona		
17 Index		
20 Upper Myrtle Lake		
21 Quartz Creek		
22 Dutch Miller		
23 Middle Fork Snoqualmie		
24 Mineral Creek		
25 Gold Creek		
27 Enumclaw		
28 Fortune Creek		
29 Mesatchee Creek		
30 Bumping Lake		
31 Goat Rocks		
32 Camp Creek		
33 Margaret		
35 Black Jack		

rocks from anomalies caused by other lithologies, particularly young volcanic rocks. Therefore, our interpretation focuses on areas where anomalies appear to be related to exposures of Tertiary intrusive rocks. The following sections describe the interpretation.

Washington

Many Tertiary plutons crop out in the Cascade Range of Washington (Smith, 1989), and many of these produce distinctive magnetic anomalies (Finn, 1990). The Squire Creek, Snoqualmie, Grotto, and Index batholiths and the Chilliwack, Duncan Hill, and Spirit Lake plutons all cause magnetic anomalies. Our interpretation (pl. 11) indicates the possible lateral extent of these granitoid rocks at relatively shallow depth. Not all plutonic rocks in Washington have significant magnetizations. The Tatoosh Pluton in the Mount Rainier area, for example, is relatively nonmagnetic. These less magnetic granitoids are not associated with known or probable porphyry copper deposits. Other magnetic anomalies appear to be caused by similar granitoids, although no intrusive rocks are mapped in the area. Two of these anomalies were discussed by Finn (1990) and are labeled W1 and W2 on plate 11.

Oregon

Most of the high-amplitude, short-wavelength anomalies in the Oregon Cascade Range are caused by Tertiary and Quaternary volcanic rocks of the Cascade volcanic arc (pls. 1, 26, 27). Anomalies caused by underlying plutonic rocks are difficult to detect among these intense volcanic anomalies, and our interpretations should be weighed accordingly. Tertiary intrusive rocks are exposed along a discontinuous north-trending belt within the Western Cascade Range (Taylor, 1971), and magnetic anomalies appear associated with some of these outcrops. Plate 12 shows our interpretation of possible underlying plutons.

Several of the highest amplitude anomalies in North America are located beneath the Willamette Valley and the Western Cascades (O1 and O2, pl. 12). These anomalies are most likely caused by Eocene oceanic crust subsequently accreted to North America (Couch and Riddihough, 1989). Finn (1991) suggested that these anomalies are caused by plutons of the Cascade arc, but if so, their magnetizations are higher than expected for granitoid rocks. Blakely (1986) suggested that anomaly O3 (pl. 12) is caused by an ophiolite complex buried by younger Cascade volcanic rocks. This interpretation is consistent with that indicated by the lead-isotope data of Church and others (1986).

California

The Cascade Range of northern California has typical high-amplitude, short-wavelength magnetic anomalies caused by Tertiary and Quaternary volcanic rocks. Many of these anomalies, both positive and negative, are caused by volcanoes and other topographic features.

Exposures of Tertiary intrusive rocks related to the Cascade arc are rare in this part of the study area. Intrusive rocks crop out in a limited area north-northwest of Mount Shasta, but they apparently are insufficiently magnetic or volumetrically too small to produce magnetic anomalies. A Tertiary intrusive outcrop at Hayden Hill apparently causes a positive anomaly that may indicate an underlying pluton at shallow depth (pl. 13).

The large anomaly along the west edge of the study area is caused by the Trinity Ophiolite Complex. As shown on plate 13, the ophiolite complex extends both north and south from its mapped extent at relatively shallow depth (Griscom, 1973; 1977). The boundary of the ophiolite complex shown on plate 13 indicates only the lateral extent of the shallow part of the complex, but similar rocks probably extend eastward beneath Mount Shasta and surrounding volcanic terrane (Blakely and others, 1985).

Acknowledgments

We are grateful to Carol Finn for providing her gravity compilation in digital form and to R.W. Simpson for assistance in calculating isostatic residual gravity anomalies.

GAMMA-RAY RADIOACTIVITY

By James A. Pitkin

Data Coverage

Aerial gamma-ray spectrometry data for this study include National Uranium Resource Evaluation (NURE) surveys of the 18 1° by 2° quadrangles that comprise the study area (fig. 1). The study area is partly within regional radioelement maps (Duval and others, 1989b) and wholly within national radioelement maps (Duval and others, 1989a; 1990), all compiled from NURE quadrangle surveys for the conterminous United States.

The NURE surveys for the study area consist of 5-km spaced east-west flightlines (Bend, Medford, Klamath Falls quadrangles) and 10-km spaced east-west flightlines (all other quadrangles) and north-south flightlines spaced 19-km apart (all quadrangles). All NURE aerial data were acquired at about 122 m above ground level where gamma-ray systems detect natural radioactivity from a swath about 244 m wide along flightlines. The measured radioactivity is from near-surface distributions of natural radioelements uranium (U), potassium (K), and thorium (Th). Quantitative calibration of NURE aerial systems at sites of known radioelement concentrations at Grand Junction, Colo., (Ward, 1978) and Lake Meade, Ariz., (Geodata International, Inc., 1977) permits conversion of aerial measurements to concentration values reported in parts per million (ppm) for uranium and thorium and percent for potassium. Use of this conversion assumes equilibrium in the uranium (as uranium-238) and thorium (as thorium-232) decay series.

Preparation of Maps

NURE data for the study area were compiled at a scale of 1:500,000 (pls. 14-22). The study area was divided into three subareas, one for Washington, Oregon, and California. For each state, three maps -- uranium, potassium, and thorium black-and-white contour maps -- were prepared from 3.089 km grids (pls. 14-22). All maps include areas of no data as indicated by missing contours. These blank areas result either from lack of data (Canada, Seattle, National Parks) or because further processing excluded data where the survey aircraft or helicopter was higher than 180 m above ground level.

Bodies of water normally have no measurable gamma-ray sources and, therefore, should appear as lows on maps derived from aerial gamma-ray data. Exceptions can occur, however, because of the limitation of the aerial systems and because of relatively coarse flightline spacing.

The part of the study area in Washington includes the Concrete, The Dalles (part), Hoquiam, Seattle, Vancouver (part), Victoria, Wenatchee, and Yakima 1° by 2° quadrangles. NURE references for these quadrangles were published by High Life Helicopters, Inc., and QEB, Inc., (1981a; c; d).

The part of the study area in Oregon includes the Bend, Crescent, The Dalles (part), Klamath Falls, Medford, Roseberg, Salem, and Vancouver (part) quadrangles. NURE references for these quadrangles were published by Aero Service Corp. (1981b; d) and High Life Helicopters, Inc., and QEB, Inc., (1981b; c).

The part of the study area in California includes the Alturas, Redding, Susanville, and Weed quadrangles. NURE references for these quadrangles were published by Aero Service Corp. (1981a; c; e; f)

Interpretation of radioelement maps

The radioelement maps (pls. 14-22) portray the near-surface distributions of the natural radioelements. Because these distributions are controlled by geologic processes, radioelement measurements aid geologic mapping and mineral exploration, and contribute to understanding geologic processes. Geologic and other features that have surface and near surface expression can be identified and categorized by radioelement measurements. Radioelement data can directly locate anomalous concentrations of radioactive minerals and can indirectly locate anomalous concentrations of non-radioactive minerals by detecting associated minor concentrations of radioactive minerals.

Examples of the use of radioelement measurements in mineral exploration include discovery of uranium deposits (Charbonneau and Ford, 1979; Guillemont, 1987; Killeen, 1979), carbonatite bodies (Ford and others, 1988), tin deposits (Yeates and others, 1982; Frick, 1986), and zinc deposits (Gnojek and Prichystal, 1985). The radioelement distributions of some porphyry copper deposits have been examined and the common potassium association was found to be distinctive (Davis and Guilbert, 1973). The use of radioelement data in gold exploration has been compiled by Hoover and Pierce (1990) who documented extensive application in the Soviet Union. Recent gold exploration in western Australia routinely used aerial gamma-ray measurements to define ground targets (Richard Lane, CRA Exploration, oral commun., 1989).

GEOCHEMISTRY

By Stanley E. Church

Three geochemical databases, RASS and PLUTO, maintained by the U.S. Geological Survey, and the NURE database, were examined for analytical results from stream-sediment samples. The area of the data search (fig. 1) covered northern California (north of 40°) and all of western Oregon and Washington (west of 120°). The NURE and RASS databases are designed primarily for evaluating mineral endowment whereas the PLUTO database is primarily intended for studies of geologic provenance. Data for the Klamath Falls 1° by 2° quadrangle were available from the NURE database, but no other quadrangles in the Cascade geologic province were sampled during the NURE program. Data from two quadrangles, Medford and Redding, have been collected by the U.S. Geological Survey during CUSMAP studies of these two quadrangles. The remaining data in the RASS database are from U.S. Forest Service Wilderness and Roadless area studies (Marsh and others, 1984). Geochemical data from stream-sediment samples are summarized by state in figures 10-12.

To summarize the geochemical data at 1:500,000 scale, the data from individual sample localities within the study area were grouped and the results plotted at the center of a grid 2.5 km (1.55 mi) on a side. The effect of this procedure can be readily seen by comparing the plot of all the data (fig. 10A) with the grid cells (fig. 10B). The high values for all samples within the grid for each variable were selected and the data were plotted using a star diagram on the accompanying geochemical maps (pls. 23-25). Thus, the data within a given cell may represent as few as one sample or as many as ten or more depending on the density of the sampling for the initial geochemical study.

Numerous analytical data are available for the state of Washington (figs. 10A and 10B), mostly from the U.S. Forest Service Wilderness studies (Marsh and others, 1984). Analyses from a total of 4,682 samples from Washington were present in the RASS and PLUTO databases. In addition, minimal geochemical data were determined in stream-sediment samples collected in two large studies of the Pasayten Wilderness (Staatz and others, 1971) and the North Cascades National Park (Staatz and others, 1972). Data from these samples are not included in this summary. Porphyry copper prospects and deposits are

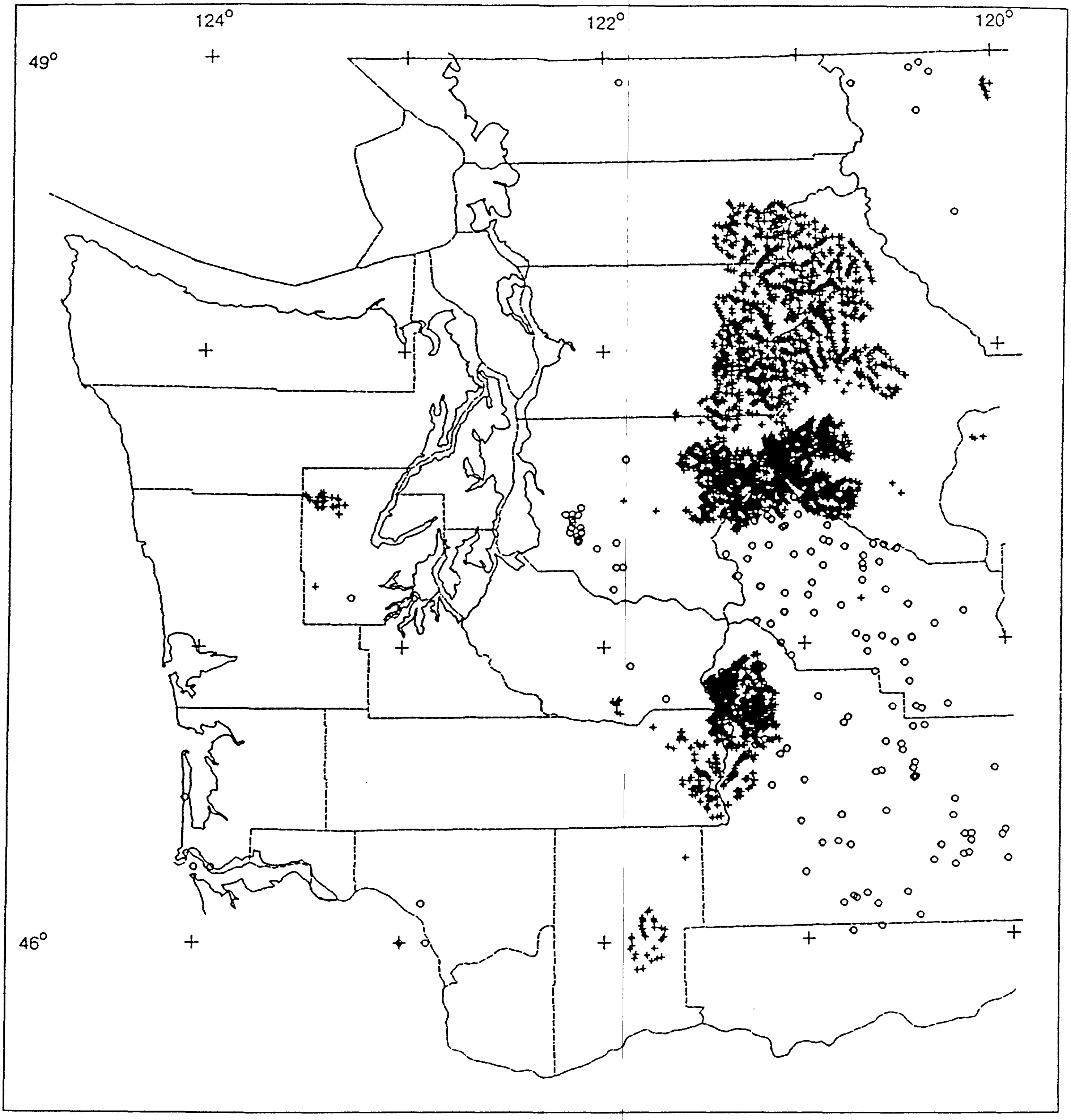

Figure 10A. Localities of stream sediment samples from Washington (+, samples from the RASS database; o, samples from the PLUTO database). County lines are also shown for reference.

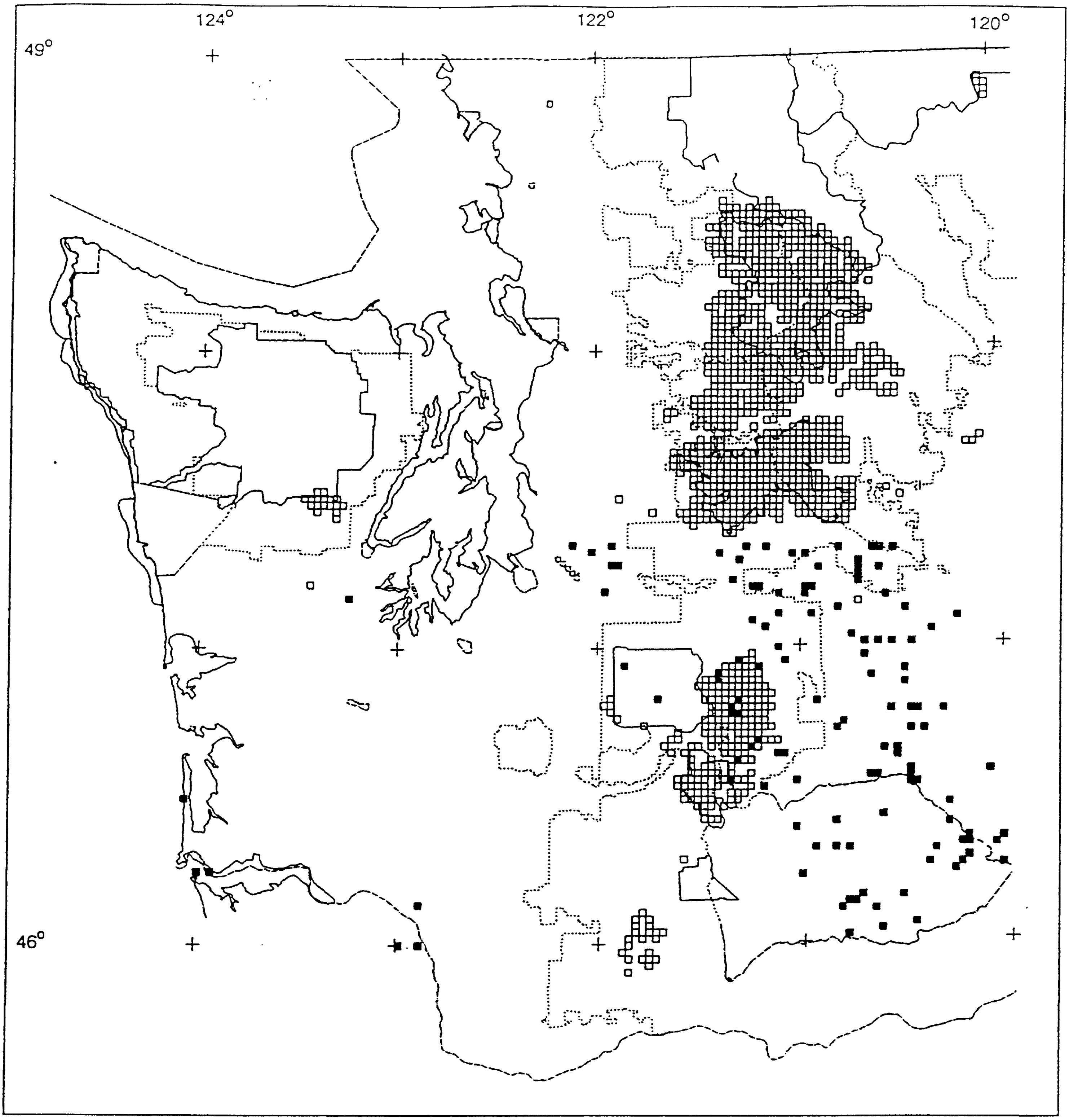

Figure 10B. Localities of gridded data from Washington (□, RASS database; and ■, PLUTO database). Boundaries of National Parks, Monuments, and some U.S. Forest Service Wilderness areas are shown as solid lines. Boundaries of Indian Reservation lands are shown as dashed lines. Boundaries of the U.S. Forest Service lands are shown as dotted lines (some boundaries are incomplete where they intersect other Federal lands not shown on this figure).

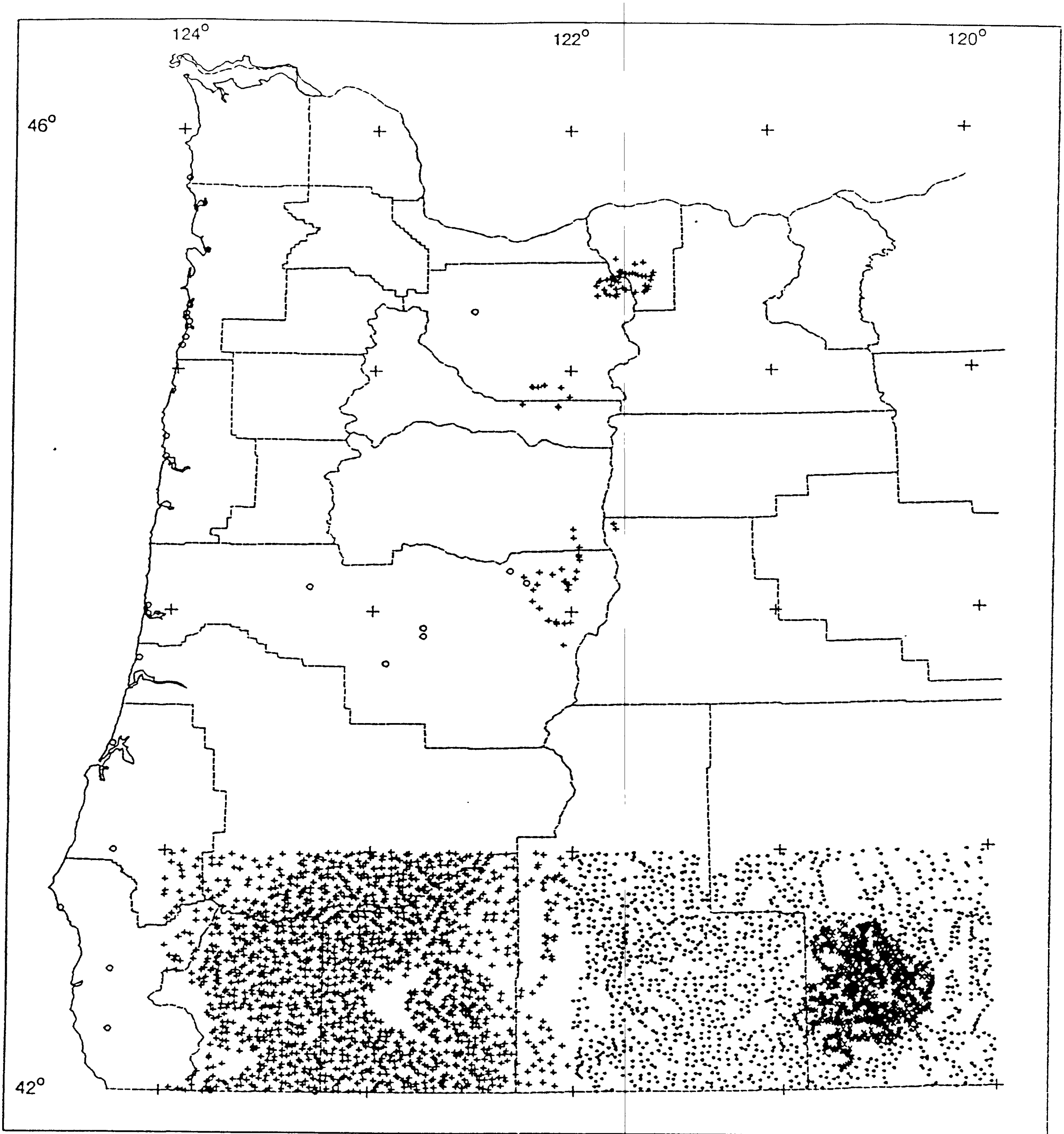

Figure 11A. Localities of stream sediment samples from Oregon (+, samples from the RASS database; o, samples from the PLUTO database; ·, INAA data from NURE database; and ×, ICP-AES data from the NURE database). County lines are also shown for reference.

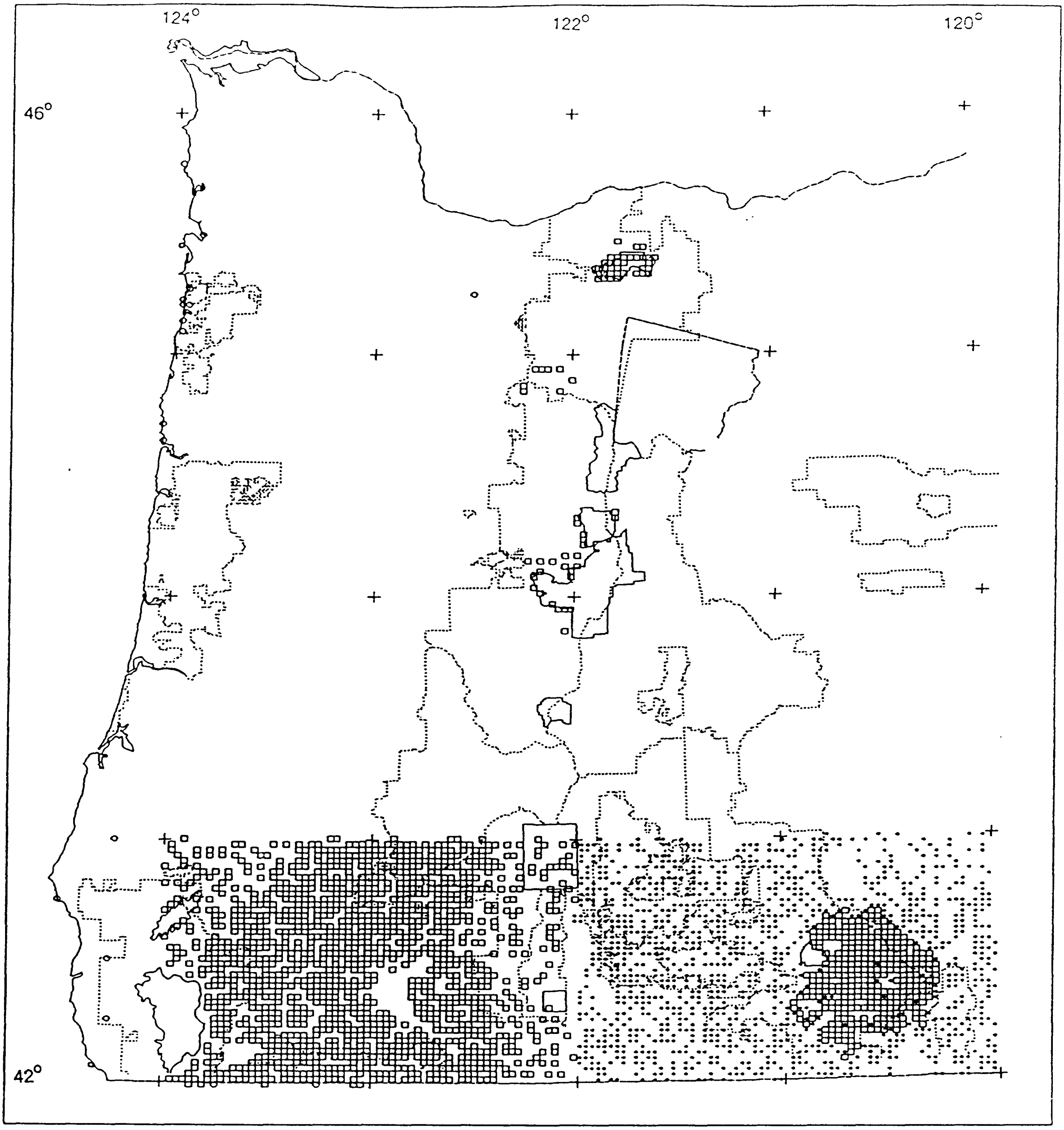

Figure 11B. Localities of gridded data from Oregon (□, samples from the RASS database and ICP-AES data from the NURE database; •, INAA data from the NURE database; and ○, samples from the PLUTO database). Boundaries of National Parks, Monuments, and some U.S. Forest Service Wilderness areas are shown as solid lines. Boundaries of Indian Reservation lands are shown as dashed lines. Boundaries of the U.S. Forest Service lands are shown as dotted lines (some boundaries are incomplete where they intersect other Federal lands not shown on this figure).

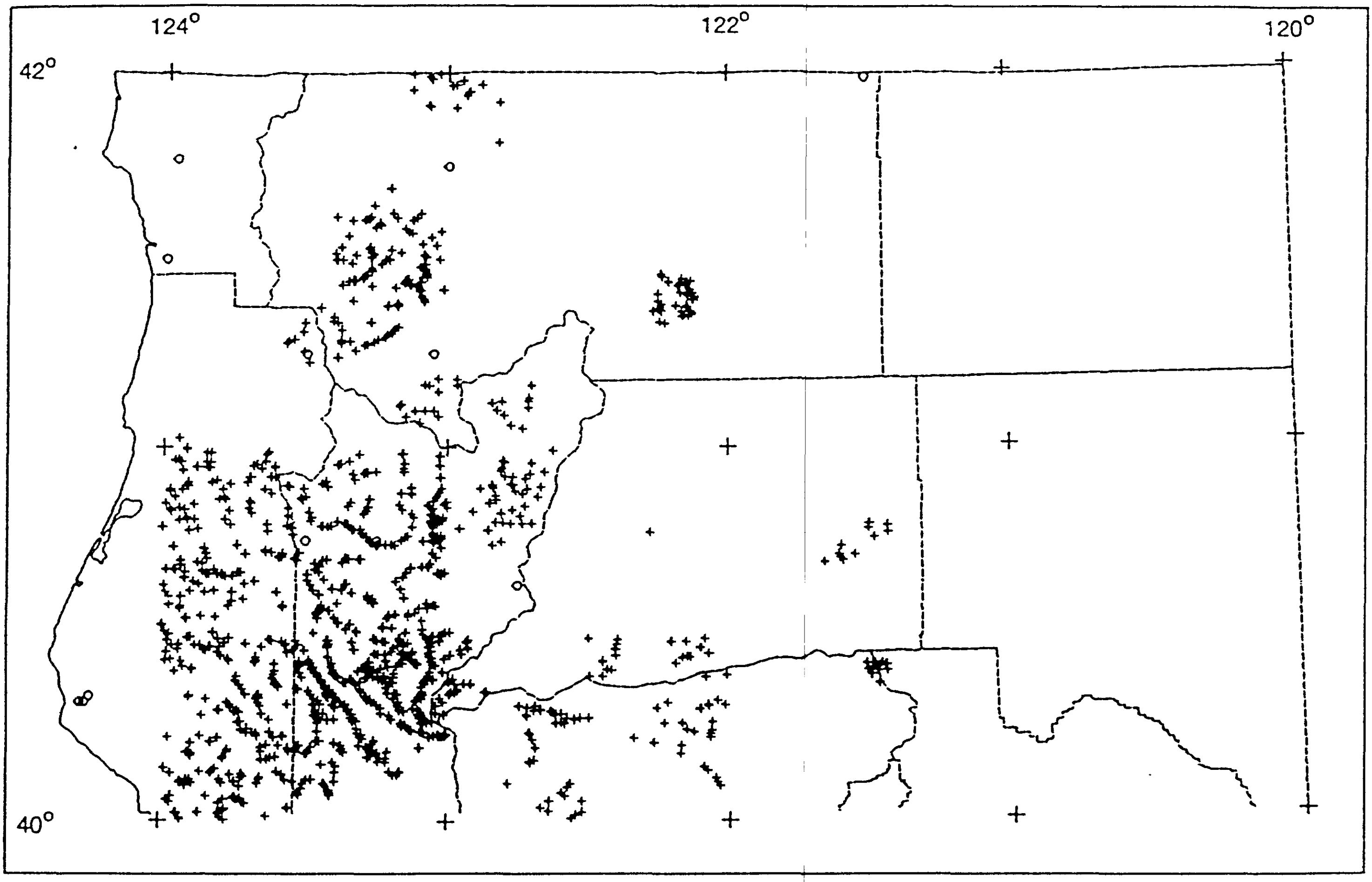

Figure 12A. Localities of stream sediment samples from northern California (+, samples from the RASS database; o, samples from the PLUTO database). County lines are also shown for reference.

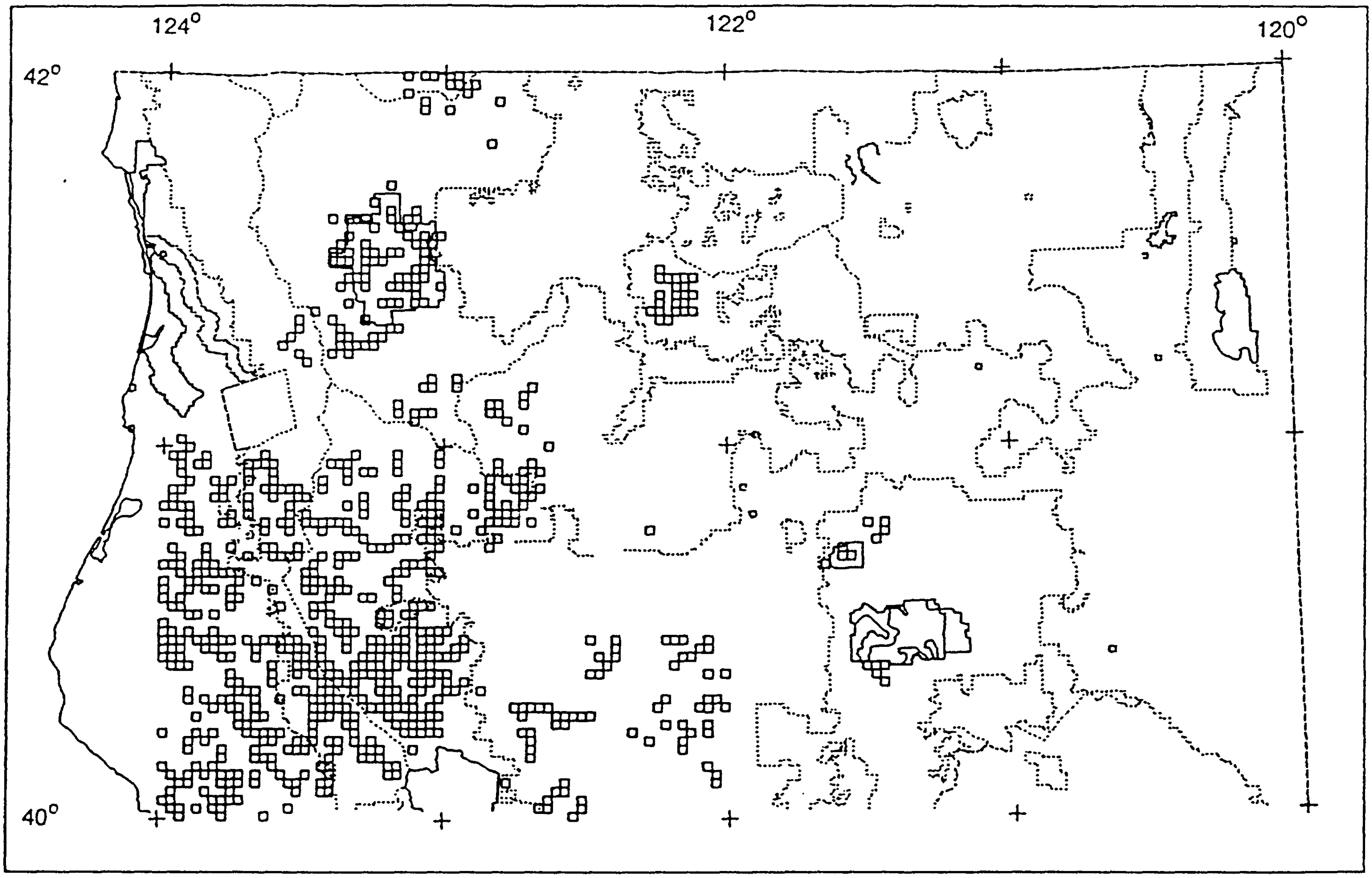

Figure 12B. Localities of gridded data from northern California (□, RASS database). Boundaries of National Parks, Monuments, and some U.S. Forest Service Wilderness areas are shown as solid lines. Boundaries of the U.S. Forest Service lands are shown as dotted lines (some boundaries are incomplete where they intersect other Federal lands not shown on this figure).

present in these areas (pl. 1 and table 1; Church and others, 1986). Analytical data from stream-sediment samples from Washington are summarized in table 4.

Analytical results from Oregon include geochemical data from 1,516 stream-sediment samples present in the RASS and PLUTO databases. NURE data from the Klamath Falls quadrangle have been determined using two different analytical methods, instrumental neutron activation analysis (INAA) and inductively coupled plasma-atomic emission spectrometry (ICP-AES). Supplemental analyses for gold were also made using atomic-absorption (AA) analysis on 62 samples (Butz and others, 1980). Only the ICP-AES and the supplemental AA gold analyses are useful in evaluating the area for porphyry copper resources because the INAA method, which was used for most of the geochemical data produced during the NURE program, does not provide analytical results for the metals found in or characteristic of the porphyry copper and associated mineral-deposit types. Because the ICP-AES data from the Lakeview study in the Klamath Falls quadrangle generally lie east of the boundary of this study, the NURE data were of little use. The distribution of analyzed stream-sediment samples from Oregon is shown in figures 11A and B and a statistical summary is given in table 5.

Analytical results for stream-sediment samples from northern California are mostly confined to samples from the western part of the state north of 40°. Many of the stream-sediment analyses in the PLUTO database are from the Pacific coast; they are outside the area of interest and have not been included in this report (fig. 12A and B). A total of 1,409 stream-sediment samples from California were present in the RASS database. A statistical summary of the geochemical data is given in table 6.

The analytical method used for most of the stream-sediment samples used in this study, other than those mentioned above, was d.c.-arc emission spectrography (OES; Grimes and Marranzino, 1968) with supplemental analyses for arsenic, antimony, and gold by atomic absorption (AA) and for mercury by a separate instrumental method (O'Leary and Meier, 1986). Not all samples included in this study were analyzed for these elements using the supplemental techniques.

Elemental suites and thresholds determined in stream-sediment samples during the U.S. Forest Wilderness studies of the north Cascade Range were adopted for use throughout this study. For the most part, a consistent suite of threshold values were used for all the geochemical maps (tables 4-6 and pls. 23-25). Threshold values derived from stream-sediment samples collected in Washington using data from the PLUTO database were evaluated, and somewhat higher thresholds were adopted; these thresholds are listed separately in table 4. For each of the data sets (tables 4-6) two threshold levels have been designated for the purpose of plotting and analyzing geochemical data. The higher thresholds are indicated by the longer of the two vectors shown on plates 23-25. By plotting two levels of geochemical anomalies for multiple elements on a single plot, geochemical associations are displayed which aid in interpreting the source of the geochemical anomaly.

One of the most critical geochemical distinctions between occurrences of porphyry copper and occurrences of polymetallic veins or massive sulfides is the presence of a tungsten anomaly. Of the elements plotted on the accompanying geochemical maps (pls. 23-25), four elements (As, Sb, Au, and W) were not detected at crustal abundance levels by the OES analytical method. Either supplemental sampling procedures (collection and analysis of panned-concentrate samples) or supplemental analytical methods (ICP-AES or AA) are necessary to refine the data set before definitive interpretations can be made. Since neither of these approaches has been uniformly applied throughout the study area and the time frame for the completion of the study was short, evaluation of geochemical anomalies within individual study areas

Table 4.--Statistical summary of geochemical data from stream-sediment samples from Washington

[two threshold levels are for purpose of plotting and analysis; higher thresholds indicated by longer of two vectors shown on plate 23]

Database Element Method	No. of samples analyzed	No. of quantitative determinations	Percentiles				Threshold values used
			90th	95th	98th	99th	
RASS							
Cu	4327	4315	70	100	200	700	150, 200
Mo	4327	413	--	5	10	20	5, 7
W	4327	55	--	--	--	50	--, 50
Zn	4327	184	--	--	200	300	200, 300
Zn AA	1747	1747	100	150	200	300	150, 200
Pb	4327	3641	30	50	100	150	70, 100
Ag	4329	242	--	0.5	1.0	3.0	0.5, 1.0
Au	4327	3	--	--	--	--	--, 10
Au AA	916	62	--	0.05	0.15	0.3	0.05, 0.1
As	4327	68	--	--	--	300	--, 200
Sb	4327	2	--	--	--	--	--, 200
PLUTO							
Cu	355	355	50	70	100	150	100, 150
Mo	355	30	--	0.7	1.5	3.0	5, 7
W	251	0	--	--	--	--	--, --
Zn	336	280	700	>700	>700	>700	200, 300
Pb	355	316	20	50	100	200	70, 100
Ag	355	82	0.7	1.0	2.0	5.0	1.5, 2.5
Au	64	0	--	--	--	--	--, --
As AA	353	121	20	20	50	150	20, 50
Sb AA	164	43	--	--	0.7	1.0	1.0, 2.0

Table 5.--Statistical summary of geochemical data from stream-sediment samples from Oregon

[two threshold levels are for purpose of plotting and analysis; higher thresholds indicated by longer of two vectors shown on plate 24]

Database Element Method	No. of samples analyzed	No. of quantitative determinations	Percentiles 90th	95th	98th	99th	Threshold values used
RASS							
Cu	1516	1516	70	100	100	150	150, 200
Mo	1516	34	--	--	--	5	5, 7
W	1516	0	--	--	--	--	--, --
Zn	1516	89	--	--	200	300	200, 300
Zn AA	1516	21	--	--	--	50	100, 200
Pb	1516	371	--	20	30	50	70, 100
Ag	1516	128	--	0.5	0.7	1.0	0.5, 1.0
Au	1516	0	--	--	--	--	--, 10
Au AA	1516	3	--	--	--	--	0.05, 0.1
As	1516	2	--	--	--	--	--, 200
As AA	1516	4	--	--	--	--	--, 20
Sb	1516	0	--	--	--	--	--, --
Sb AA	1516	0	--	--	--	--	--, --
NURE							
Cu ICP-AES	878	840	52	67	80	88	100, 150
Mo ICP-AES	878	103	--	--	8	10	10, 20
Zn ICP-AES	2	827	97	115	144	158	100, 150
Pb ICP-AES	99	99	--	--	9	12	50, 70
Ag ICP-AES	8	3	--	--	--	--	--, 5
Au AA	62	62	--	--	0.05	0.11	0.05, 0.1
INAA	1458	No useable data					

Table 6.--Statistical summary of geochemical data from stream-sediment samples from California

[two threshold levels are for purpose of plotting and analysis; higher thresholds indicated by longer of two vectors shown on plate 25]

Database Element Method	No. of samples analyzed	No. of quantitative determinations	Percentiles				Threshold values used
			90th	95th	98th	99th	
RASS							
Cu	1409	1408	70	100	100	150	150, 200
Mo	1409	43	--	--	--	5	5, 7
W	1409	1	--	--	--	--	--, --
Zn	1409	65	--	--	--	200	200, 300
Zn AA	1147	1146	70	100	100	150	150, 200
Pb	1409	944	20	20	30	50	50, 70
Ag	1409	25	--	--	--	0.5	0.5, 1.0
Au	1409	0	--	--	--	--	--, --
Au AA	1093	64	--	--	0.1	0.5	0.05, 0.1
As	1409	0	--	--	--	--	--, --
As AA	1070	133	2	2	10	20	--, 20
Sb	1409	0	--	--	--	--	--, --
Sb AA	1109	34	--	--	--	2	--, 2
Hg	1161	1100	0.1	0.15	0.2	0.3	0.2, 0.5

were made by reference to the original work. Thus, anomalous concentrations of these four elements, as indicated on the accompanying geochemical maps, probably under represent the true geochemical anomaly pattern. As a consequence, exposed porphyry copper prospects and deposits will probably be represented by anomalous suites of metals on the accompanying geochemical maps. However, concealed deposits and prospects within the Cascade geologic province will tend to be poorly represented, if at all, because of analytical or sampling limitations, or both. A single vector or element anomaly within a grid cell may or may not be significant. Most important however, are the elemental and spatial associations of metals that can be readily discerned by the presentation used in the accompanying geochemical maps. The following elements are represented on plates 23-25 by vectors surrounding the gridded sample localities: Cu, Mo, W, Zn, Pb, As, Ag, Au, Sb, and Hg. Porphyry copper deposits occur in the Glacier Peak Wilderness and the Glacier Peak Roadless area (table 1; figs. 2 and 10B). The second largest copper mine in the state of Washington, a polymetallic vein deposit exploited at the Sunset Mine, was situated immediately west of the Eagle Rocks Roadless area (Church and others, 1983b).

The geochemical data presented in plates 23-25 had limited use in this assessment. Whereas the geochemical data clearly delineated porphyry copper deposits in permissive areas within the tracts assessed, too little of the area within the Cascade geologic province has been adequately sampled at a sufficient density to be of regional use. The geochemical data presented show the potential value of their use in mineral resource assessments, but further geochemical work is needed to assess completely the three tracts for all mineral deposit types. Had the area been completely sampled, the uncertainty associated with estimating the area of concealed plutons using only the presence of porphyry copper prospects would have been greatly reduced and the mineral resource assessment presented here would be more thorough.

QUANTITATIVE RESOURCE ASSESSMENT

By Gregory T. Spanski, Donald A. Singer, Stanley E. Church, Dennis P. Cox, Roger P. Ashley, William C. Bagby, Michael F. Diggles, Lawrence J. Drew, and David D. Menzie, II

This quantitative resource assessment was performed by the U.S. Geological Survey using a three-part form of assessment developed over the last 16 years (Singer and Cox, 1988). The three parts include (1) identifying tracts containing permissive geology for a given mineral-deposit type (2) estimating the numbers of undiscovered deposits of a given mineral-deposit type that may be present in each tract, and (3) selecting appropriate grade and tonnage models for each mineral-deposit type. Computer simulation is used to combine probabilistic estimates of the metal endowment that could be present in each tract for each mineral-deposit type. The procedure requires subjective analysis and, therefore, is best performed by personnel familiar with the geology and mineralization in the area, knowledgeable about the mineral-deposit types being estimated, and experienced in making the necessary informed judgments.

In the Cascades geologic province, an evaluation for the potential occurrence of porphyry copper type deposits was conducted. Porphyry copper deposits are found in the plutonic part of the Cascades in northern Washington and in the volcanic rocks of the Western Cascades (fig. 2, pl. 26). Using information gathered on the geology and regional tectonics (Church, this report), mineral occurrences, production, and exploration history (Peterson, this report), geophysics (Blakely and Plouff, this report; Pitkin, this report), and geochemistry (Church, this report) from published sources and non-proprietary company reports, estimates of the copper, gold, silver, and molybdenum endowment expected to occur in undiscovered porphyry copper deposits have been made. These estimates consider only undiscovered deposits in the uppermost 1 km of the crust.

Tract Delineation

In general, tracts, as defined for mineral assessments, are geographic areas within which all ground designated as permissive for a specific mineral-deposit type are presumed to possess the same degree of favorability. Criteria for recognizing ground permissive for porphyry copper type deposits are those described by Cox (1986a) as tonalite to monzogranite or syenite-porphyry intrusions emplaced at depths of 1 to 5 km, commonly associated with contemporaneous dikes, breccia pipes, and faults. Chalcopyrite, pyrite, and molybdenite characteristically are found in stockwork veinlets and as disseminated grains within a potassic alteration zone. This zone of sulfide mineralization is surrounded by pronounced zones of propylitic and phyllic alteration. Porphyry systems develop where Andean-style and island-arc volcanism occur along convergent plate boundaries. Plutons are exposed where the sub-volcanic part of the systems have been exposed by uplift and erosion.

The Cascade geologic province was divided into three tracts that have varying degrees of favorability. Tract A is bounded on the north by the Canadian border and on the south by the northwest-trending Olympic-Wallowa lineament. Within Tract A, the crust has been uplifted and erosion has stripped much of the Tertiary volcanic cover, exposing dioritic to granitic plutons ranging from 85 to 6 Ma. Locations of six porphyry copper deposits and other mineral properties in Tract A that may be related to porphyry copper systems are shown in figure 2 and plates 1, 26, and 27. Nearly every deposit is spatially associated with a Tertiary pluton. The six deposits have been extensively explored and are considered to be discovered and are termed "known deposits." The remaining prospects (21) are categorized as "undiscovered," either because grade and tonnage data are incomplete or because it is uncertain whether the mineralization is truly related to a porphyry system.

Interpretation of magnetic and gravity data (Blakely and Plouff, this report) suggests that the plutons, with which most porphyry copper mineralization is correlated, are anomalously magnetic and have broad, shallow lateral extensions, which are shown in figure 2 and plates 1, 26, and 27. There are also interpreted plutons that lack surface expression. These plutonic areas constitute the primary permissive terrane for the occurrence of undiscovered porphyry copper deposits. There are three porphyry copper prospects known in areas where there is no geologic or geophysical evidence for the occurrence of plutonic rocks. These prospects and occurrences are possibly related to subsurface plutons that were undetected in the geophysical surveys either because they lacked an anomalous magnetic signature or were masked by overlying volcanic rocks. It follows that all remaining lands in the tracts lying within the trend of the Cascade Range are also permissive for hosting porphyry copper deposits. The assessment of these remaining lands are approximated by examining the ratio between known mineral deposit and occurrence localities associated with known plutons (24) and deposit and occurrence localities not associated with plutons (3). This examination suggests that there may be additional land underlain by concealed plutons equal in area to about 15 percent of the area underlain by known plutons shown on plates 11 and 12 (Blakely and Plouff, this report). However, the location of this additional permissive terrane remains unknown.

Tract B lies immediately south of Tract A and extends into Oregon to the Klamath Mountains-Blue Mountains lineament (Riddihough and others, 1986; Blakely and Jachens, 1990) south of the Bohemia mining district (Church and others, 1986) (pl. 27). The crust in Tract B has not been subjected to as much uplift and erosion as occurred in Tract A and, therefore, much of the Tertiary volcanic cover remains intact. Interpretation of geophysical data (Blakely and Plouff, this report) indicates the presence of magnetically anomalous plutons in the subsurface; however, they are fewer in number and their areal extent is less well defined because of the abundance of volcanic cover. Surface expression of porphyry copper mineralization is limited to one known porphyry copper deposit and twelve "undiscovered" prospects. The thicker volcanic cover and lower incidence of known localities indicates Tract B has a lower probability for undiscovered porphyry copper deposits at crustal depths of less than 1 km compared to Tract A. Within Tract B about 70 percent (9 of 13) of the known mineral deposits and occurrences are located within the boundaries of interpreted plutons shown on plate 11 (Blakely and Plouff, this report). We assumed that this distribution of localities can be used to approximate the area of additional terrane that may be underlain by concealed plutons.

Tract C includes the remainder of the area south of the Klamath Mountains-Blue Mountains lineament which includes the older Klamath Mountains. Although arc-related plutonic rocks are present at or near the surface, no known deposits or "undiscovered" mineral prospects that suggest the presence of porphyry copper systems are within 1 km of the surface in this tract. Available evidence suggests that Tract C is not permissive for porphyry copper deposits. Tract boundaries are shown in figure 2 and plates 1, 26, and 27.

Estimation of Numbers of Undiscovered Deposits

Estimates of numbers of undiscovered deposits of a specific deposit type typically required a subjective analysis in this study. In arriving at this estimate, several considerations had to be addressed. The first consideration is whether the grade and tonnage curves for the deposit model (Cox and Singer, 1986) properly represent the mineralization in the assessment area. The grade and tonnage model for porphyry copper deposits (Singer and others, 1986b) has been accepted in this assessment. Acceptance is based on a comparison of the grades and tonnages of the seven well-explored copper porphyry deposits in the Cascade geologic province with the global model deposit distributions. The distributions of tonnage and copper and molybdenum grades were not found to differ significantly at the five percent level (using a "t" test), and the global porphyry copper model was accepted. A second consideration is that half the estimates of the number of deposits must be thought of as having grades or tonnages that are as large or larger than the median values on the model curves. The median values for the accepted model are 140 million metric tons of ore and a copper grade of 0.54 percent.

In addition to the above, criteria, the quantifiers had to consider other factors that influence their judgments about the number of porphyry copper deposits. In the Cascade geologic province these factors include:

- (1) area of concealed plutonic rock as interpreted from geophysical data
- (2) area of concealed plutonic rock as interpreted from locality ratios
- (3) areal density of known porphyry copper deposits, prospects, and occurrences
- (4) thoroughness of surface exploration and drilling for mineral deposits
- (5) results of geochemical and geophysical surveys and their extent
- (6) geometry of existing ore bodies where defined by drilling
- (7) alteration zones and geologic features (breccia pipes for example) that are inferred to be related to porphyry copper deposits

Taking all of the above factors into consideration, a nine-member panel reached a consensus on the estimates of numbers of undiscovered porphyry copper deposits that may be present in Tracts A and B. Results are shown in table 7. Estimates were made at three levels of probability to facilitate the later development of a frequency distribution for deposit occurrence in each of the two tracts.

Larger percentage differences between the estimates associated with the 0.9 and the 0.1 probability levels reflect greater uncertainty. The estimates for Tract A reflect its greater favorability for hosting undiscovered porphyry copper deposits, whereas the lower favorability of Tract B is shown by lower values. The larger relative difference in the estimates associated with the 0.9 and the 0.1 probability levels for Tract B reflects the greater uncertainty attached to these values by the quantifiers. In the case of Tract C, the geology is not generally permissive for porphyry copper deposits. No estimates of the number of undiscovered deposits were made and there is less than 0.01 probability that a concealed porphyry copper deposit exists in Tract C.

Metal Endowment

The metal endowment for Tracts A and B in the Cascades geologic province was estimated using the U.S. Geological Survey Mark3 Simulator (David Root, written commun., 1991). The simulation program employs a Monte Carlo technique to combine the probabilistic estimates of the number of undiscovered deposits, and the grade and tonnage deposit model frequencies to create estimates of the metal endowment. For each of the tracts in the Cascade geologic province, the program first generates a theoretical deposit frequency distribution curve (DFDC) based on the 3-level estimates of the number of undiscovered deposits (table 7). It then enters a simulation cycle in which it repetitively models areas that are hypothetically identical in their mineral character to those of the tract being considered. For each cycle, a number for deposits present is selected from the DFDC and then tonnage and grade values for each deposit are selected from the copper porphyry deposit model curves (figs. 4-6). Endowment estimates for each cycle are calculated by multiplying the grade and tonnages for each deposit and summing the totals. The endowment total for each cycle is stored until 4,999 cycles are completed for the tract. The endowment values from the 4,999 cycles are then sorted for each metal present and total deposit tonnage in order of ascending values. From these sorts, information can be derived concerning the tonnage of ore and metal endowment occurrence probability that is directly applicable to the tract being modeled. For example, the metal endowment total for the 500th cycle in an ascending sort, represents a 0.9 probability that the endowment in the tract will equal or exceed that value. A summary of the results of the endowment

Table 7.--Estimates of numbers of undiscovered porphyry copper deposits in the Cascade geologic province.

Tract	Estimates of Number of Undiscovered Deposits		
	0.9 probability of at least the following number of deposits	0.5 probability of at least the following number of deposits	0.1 probability of at least the following number of deposits
A	7	14	23
B	1	3	10

simulations for Tracts A and B follow; a more complete presentation of the results of the Mark3 runs is given in the Appendix.

Table 8 reports the estimates of metal endowment in Tract A for the 0.9, 0.5, and 0.1 probability levels and the mean for copper, gold, silver, and molybdenum. Gold, silver, and molybdenum are byproducts of mining of many porphyry copper deposits and are present in the known deposits in the Cascade geologic province. The copper endowment estimated to be present in "undiscovered" porphyry copper deposits in Tract A exceeds 8.3 million metric tons with a probability of 0.9. At this high level of certainty, the endowment is slightly greater than the 7.9 million metric tons confirmed to be present in the six known porphyry copper deposits in Tract A. At the 0.5 probability level, the copper endowment could exceed 34 million metric tons or over 4 times the known resources. There is also a high probability (0.9) that the gold endowment could exceed 48 metric tons, silver 780 metric tons, and molybdenum 100,000 metric tons. The undiscovered deposits containing this endowment are expected to occur mainly within the boundaries of inferred plutons; however, it is also probable that one or more might be present in areas where geophysical and geologic indications of buried plutons have been masked from detection by overlying volcanic rocks.

The estimates of metal endowment for Tract B are shown in table 9. The much lower estimates of endowment at the 0.9 probability level clearly demonstrate the quantifiers' lower estimates of the number of porphyry copper deposits in Tract B. The endowment of at least 250,000 metric tons of copper present in undiscovered deposits at the 0.9 probability level is less than a sixth of the 1.88 million metric tons known in the one discovered porphyry copper deposit in the tract. The steep increase in the estimated endowment at the 0.5 and 0.1 probability levels further demonstrate the uncertainty of the high-end potential in Tract B, and the 34 million metric tons falls well short of the comparable 91 million-metric-ton figure for Tract A demonstrating the overall lower potential of Tract B. The higher degree of uncertainty in the numbers can be attributed to the lack of relevant data about the area, whereas the lower overall totals reflect the expectation that the porphyry copper deposits are buried beneath a thicker cover of volcanic rock and, therefore, many would fall below the 1 km depth limitation applied in the study.

Table 8.--Estimates of metal endowment in undiscovered porphyry copper deposits in Tract A (in thousand metric tons of metal).

Metal	Endowment			
	0.9 probability of at least the following amount of metal	0.5 probability of at least the following amount of metal	0.1 probability of at least the following amount of metal	Mean
Cu	8,300	34,000	91,000	44,000
Mo	100	720	3,400	1,300
Au	.048	.30	.89	.41
Ag	.78	6.4	19	8.6

Table 9.--Estimates of metal endowment in undiscovered porphyry copper deposits in Tract B (in thousand metric tons of metal).

Metal	Endowment			
	0.9 probability of at least the following amount of metal	0.5 probability of at least the following amount of metal	0.1 probability of at least the following amount of metal	Mean
Cu	250	6,500	34,000	14,000
Mo	0	100	1,000	390
Au	0	.05	.36	.13
Ag	0	.88	7.9	2.7

Plates 26 (Washington) and 27 (Oregon) show the tracts permissive for undiscovered porphyry copper resources at a scale of 1:500,000, the same scale as the maps of Critical Habitat Areas available from the U.S. Fish and Wildlife Service.

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APPENDIX

RESULTS OF MARK3 ENDOWMENT SIMULATIONS

The estimates of ore tonnage and metal endowment for porphyry copper deposits in the Cascade geologic province were computed in two runs of the U.S. Geological Survey Mark3 simulator. Run 1 contains results for the estimation of endowment and deposit tonnage for undiscovered porphyry copper deposits in Tract A, and Run 2 presents the same data for Tract B. For each metal and ore tonnage, values are reported for each tenth percentile for the new cumulative totals, and mean values are given. The output also provides a tabulation of the actual and theoretical deposit frequency distribution that approximates the "number of undiscovered deposits" estimates made by the quantifiers. The outputs shown are standards for the Mark3.

Run 1.--Undiscovered porphyry copper deposits in Tract A, number of deposits per simulation

Number	Frequency	Theoretical Frequency
0	66	0.0133
1	62	0.0133
2	62	0.0133
3	72	0.0133
4	65	0.0133
5	68	0.0133
6	59	0.0133
7	157	0.0352
8	279	0.0571
9	318	0.0571
10	268	0.0571
11	299	0.0571
12	271	0.0571
13	317	0.0571
14	259	0.0508
15	224	0.0444
16	238	0.0444
17	210	0.0444
18	196	0.0444
19	217	0.0444
20	224	0.0444
21	230	0.0444
22	213	0.0444
23	625	0.1222
	Mean number of deposits	14.258

Sorted simulation results for copper, order of occurrence

Rank	Metric tons Cu
1	0.00000E-01
500	8.32979E+06
1000	1.47863E+07
1500	2.07486E+07
2000	2.69717E+07
2500	3.36632E+07
3000	4.16303E+07
3500	5.18854E+07
4000	6.60525E+07
4500	9.08880E+07
4999	2.91408E+08

Expected mean copper metal tonnage = 4.37700E+07

Sorted simulation results for molybdenum, order of occurrence

Rank	Metric tons Mo
1	0.00000E-01
500	1.01249E+05
1000	2.37289E+05
1500	3.73313E+05
2000	5.26644E+05
2500	7.20858E+05
3000	9.76974E+05
3500	1.37469E+06
4000	2.03694E+06
4500	3.39163E+06
4999	1.32040E+07

Expected mean molybdenum metal tonnage = 1.29444E+06

Sorted simulation results for gold, order of occurrence

Rank	Metric tons Au
1	0.00000E-01
500	4.83289E+01
1000	1.09251E+02
1500	1.65678E+02
2000	2.31221E+02
2500	2.96966E+02
3000	3.76919E+02
3500	4.82020E+02
4000	6.35059E+02
4500	8.91162E+02
4999	5.22593E+03

Expected mean gold metal tonnage = 4.12770E+02

Sorted simulation results for silver, order of occurrence

Rank	Metric tons Ag
1	0.00000E-01
500	7.80392E+02
1000	1.97466E+03
1500	3.33142E+03
2000	4.84052E+03
2500	6.43874E+03
3000	8.24976E+03
3500	1.04618E+04
4000	1.37104E+04
4500	1.94181E+04
4999	6.33290E+04

Expected mean silver metal tonnage = 8.56190E+03

Sorted simulation results for metric tons, order of occurrence

Rank	Metric tons ore
1	0.00000E-01
500	1.53273E+09
1000	2.64318E+09
1500	3.59095E+09
2000	4.65685E+09
2500	5.79852E+09
3000	7.09403E+09
3500	8.67685E+09
4000	1.07046E+10
4500	1.39435E+10
4999	3.35798E+10

Expected mean ore tonnage = 6.89346E+09

Run 2.--Undiscovered porphyry copper deposits in Tract B, number of deposits per simulation

Number	Frequency	Theoretical Frequency
0	303	0.0667
1	697	0.1333
2	962	0.2000
3	649	0.1286
4	294	0.0571
5	309	0.0571
6	290	0.0571
7	278	0.0571
8	292	0.0571
9	280	0.0571
10	645	0.1286
	Mean number of deposits	4.457

Sorted simulation results for copper, order of occurrence

Rank	Metric tons Cu
1	0.00000E-01
500	2.53448E+05
1000	1.05095E+06
1500	2.29961E+06
2000	4.13473E+06
2500	6.49450E+06
3000	9.64799E+06
3500	1.40091E+07
4000	2.10907E+07
4500	3.44893E+07
4999	2.30788E+08

Expected mean copper metal tonnage = 1.37490E+07

Sorted simulation results for molybdenum, order of occurrence

Rank	Metric tons Mo
1	0.00000E-01
500	0.00000E-01
1000	4.16022E+03
1500	2.13962E+04
2000	5.22171E+04
2500	1.00684E+05
3000	1.76345E+05
3500	2.91810E+05
4000	5.22576E+05
4500	1.01390E+06
4999	9.95446E+06

Expected mean molybdenum metal tonnage = 3.93418E+05

Sorted simulation results for gold, order of occurrence

Rank	Metric tons Au
1	0.00000E-01
500	0.00000E-01
1000	0.00000E-01
1500	7.12524E+00
2000	2.53169E+01
2500	4.84821E+01
3000	8.13588E+01
3500	1.30104E+02
4000	2.08072E+02
4500	3.56234E+02
4999	3.10607E+03

Expected mean gold metal tonnage = 1.32750E+02

Sorted simulation results for silver, order of occurrence

Rank	Metric tons Ag
1	0.00000E-01
500	0.00000E-01
1000	0.00000E-01
1500	1.15980E+02
2000	4.00242E+02
2500	8.78447E+02
3000	1.57949E+03
3500	2.67725E+03
4000	4.48679E+03
4500	7.86426E+03
4999	5.26711E+04

Expected mean silver metal tonnage = 2.72179E+03

Sorted simulation results for metric tons, order of occurrence

Rank	Metric tons ore
1	0.00000E-01
500	5.82611E+07
1000	2.13878E+08
1500	4.38605E+08
2000	7.55900E+08
2500	1.20451E+09
3000	1.68859E+09
3500	2.44423E+09
4000	3.61678E+09
4500	5.82092E+09
4999	2.19711E+10

Expected mean ore tonnage = 2.16059E+09