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Mineral-resource and Environmental Geochemistry of the Coconino National Forest, Coconino, Gila, and Yavapai Counties, Arizona

by

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EXECUTIVE SUMMARY

This report describes geochemical studies conducted by the United States Geological Survey in the Coconino National Forest, Coconino, Gila, and Yavapai Counties, northern Arizona. This report is based on analyses of rock and stream-sediment samples that were analyzed for 41 different elements. The distributions and abundances of these elements provide information that is useful (1) for understanding geologic environments in the forest area that are known to contain, or may contain, mineral deposits, and (2) for determining the mineral resource potential of the forest. In addition, the analytical information identifies areas with possible chemically-related environmental problems. The information contained in this report should thus be useful for decision-making purposes regarding land use in the forest.

Many anomalies were identified in a variety of lithologic environments. However, most of these anomalies are weak and deemed to be only the upper parts of the ranges of background values for the elements and environments in question.

Significant anomalies in surficial materials include the following:

1. Those related to past mining for manganese in the Long Valley area, near Clints Well, where samples are anomalous for as many as 16 elements (Ag, As, Au, Ba, Be, Cd, Co, Cu, Mo, Ni, Pb, Sb, Sr, V, W, and(or) Zn);

2. Those related to past mining and smelting, as well as to natural concentrations, in the Verde River Valley, where samples are anomalous for as many as 12 elements (Ag, As, Au, Cd, Cu, Mo, Pb, Sb, Sn, U (and by association, Rn), and(or) Zn); and

3. Those related to scattered, minor exposures in the Supai Formation in the Fossil Creek area (and possibly to exposures of this unit elsewhere) that are anomalous for as many as 10 elements (Ag, As, Au, Cd, Cu, Mo, Pb, U (and by association, Rn), and(or) Zn).

Other areas with possibly significant anomalies are described in the report; however, their relation to as-yet undefined mineral resources, and(or) their impact on the environment, is not clear.

Although surface and ground waters were not studied for this report, it is important to note that both surface and (particularly) ground waters may be contaminated by many of the elements listed above. Of particular concern is the potential for anomalous radon in soils and well waters in the Verde Valley. Although not as yet known to be a problem, another potential concern for ground water contamination may exist in areas where silicified or cherty lenses in the Kaibab Formation have been penetrated in a given well. Samples from these zones were found to contain anomalies of as many as 10 elements (Ag, As, Cd, Cu, Mo, Pb, Sb, U (and by association, Rn), and(or) Zn).

INTRODUCTION

This report describes geochemical studies conducted by the United States Geological Survey in the Coconino National Forest (the study area), Coconino, Gila, and Yavapai Counties, northern Arizona (Fig. 1). The distributions and abundances of elements provide essential information that is useful for determining favorable geologic environments for mineral deposits in the study area and therefore for identifying its mineral resource potential. In addition, the analytical information can be used to identify possible chemically-related environmental problems.

This report is based on analyses for 291 samples of rock and 449 samples of stream sediment collected in 1993 and 1994 by the United States Geological Survey (USGS) and 662 samples of stream sediment collected in the 1970's for the United States Department of Energy-sponsored National Uranium Resource Evaluation (NURE) program and re-analyzed for this report. Oil and gas resources have not been identified or evaluated for this report; only metallic mineral resources, and environments related to metallic resources, are discussed here. A separate report covering non-metallic resources has been published by the USGS (Bliss, 1997).

The climate in the Coconino National Forest has an important relationship to the physical and chemical mobility and dispersion of elements. Topographic relief in the forest is more than 10,000 feet. The highest point is Humphrey's Peak (elev. 12,633 ft.), just north of Flagstaff. The lowest point (elev. about 2550 ft.) is at the junction of Fossil Creek and the Verde River, on the extreme southern tip of the forest. Major vegetation life zones range from the Lower Sonoran Desert Zone to the Arctic-Alpine Zone, with most of the forest found in the Upper Sonoran and Transition Zones.

Because of the extreme range in elevations in the forest, precipitation and temperatures vary widely. Data in Sellers (1960) for weather stations in the forest show a yearly mean precipitation of 22.56 inches at the highest station (Fort Valley, 7 miles northwest of Flagstaff, at an elevation of 7347 ft.) and a yearly mean of 17.27 inches at the lowest station (Childs, near the extreme southern tip of the forest, at an elevation of 2650 ft.). Yearly mean maximum and minimum temperatures are 59.2°F and 26.3°F for the Fort Valley station and 80.9°F and 47.3°F for the station at Childs (Sellers, 1960). No data were presented for more extreme elevations in the San Francisco Peaks area, but a contoured map of yearly precipitation in Sellers (1960) shows amounts in excess of 25 inches in the high parts of that area, just to the north of the Fort Valley Station. Evaporation tends to be much higher in areas of the forest at lower elevations because of higher year-round temperatures.

GEOLOGIC SUMMARY

The Coconino National Forest lies mostly within the Colorado Plateau Physiographic Province. Smaller parts on the southern edge of the forest are in the Transition Zone between the Colorado Plateau and Basin and Range Provinces. The Mogollon Rim, a distinct topographic feature occurring where the relatively flat surface of the Colorado Plateau is terminated regionally southward by steep cliffs, is generally considered to represent the southern boundary of the Colorado Plateau Physiographic Province.

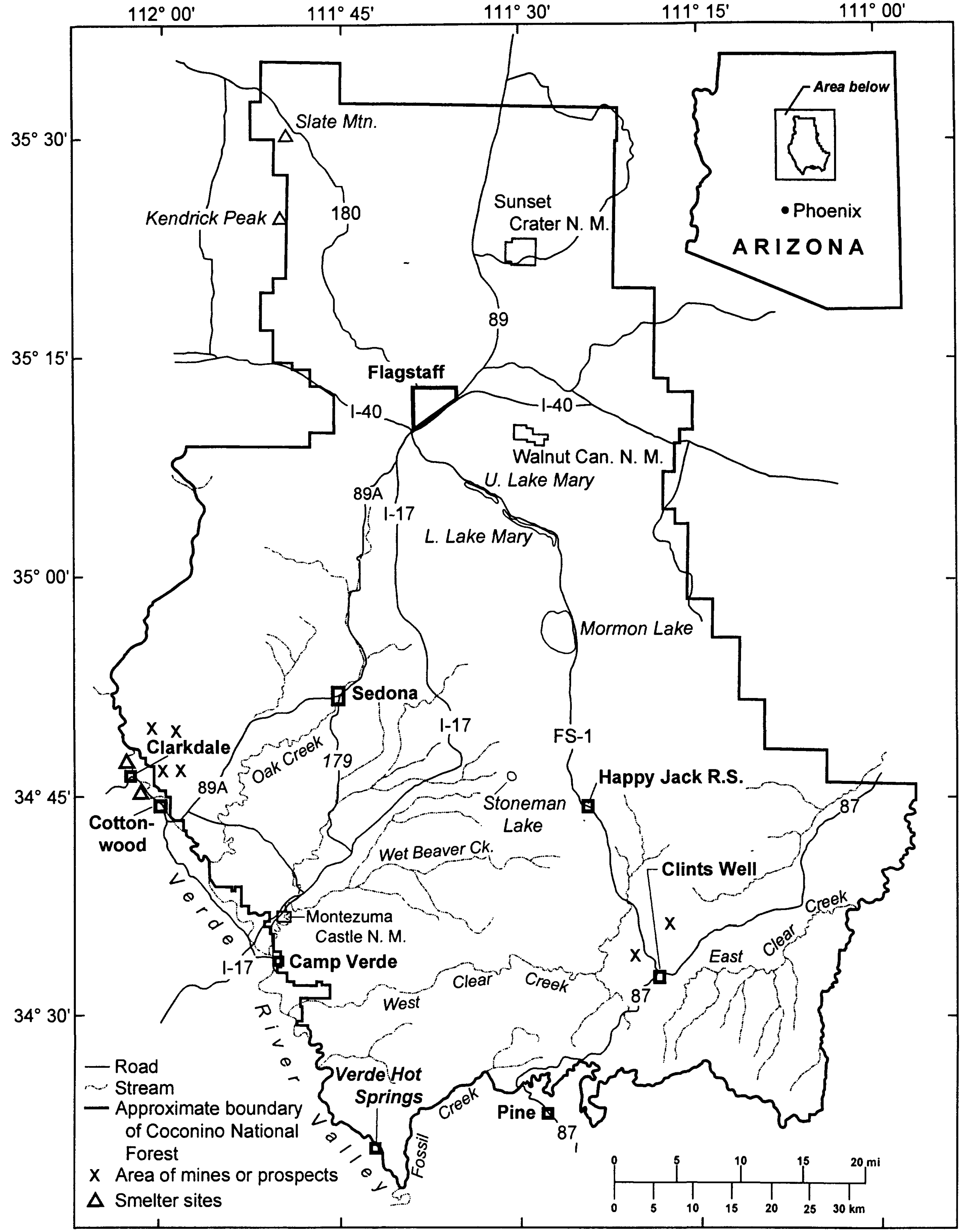

Figure 1.--Maps showing location of Coconino National Forest and geographic features in and near the forest.

North of the Mogollon Rim, rock exposures in the study area consist of a nearly flat-lying sequence of upper Paleozoic sedimentary rocks, including the Coconino Sandstone, Toroweap Formation, and Kaibab Formation, all of Permian age (see, for example, Billingsley and others, 1988; Ulrich and others, 1984; Weir and others, 1989). Locally, this sequence is overlain by beds of the Triassic Moenkopi and Chinle Formations. Extensive areas of Tertiary and Quaternary volcanic flows and volcaniclastic rocks, varying from felsic to mafic compositions, cover the Paleozoic sedimentary sequence. The San Francisco Peaks region north of Flagstaff includes the majority of the Quaternary volcanic rocks; the Tertiary volcanic rocks are generally west and south of Flagstaff (Ulrich and others, 1984). In the area just north of the Mogollon Rim, Tertiary conglomerates representing channel deposits are locally present (Weir and others, 1989; 1994).

South of the Mogollon Rim, cliffs contain exposures of generally flat-lying sedimentary rocks that range in age from Pennsylvanian to Permian (Karlstrom and others, 1983; Weir and others, 1989). In the Verde Valley and adjacent hills, on the west border of the forest (Fig. 1), carbonate-dominant to clastic-dominant lake-bed and alluvial deposits of the Tertiary Verde Formation are widespread. Locally, these rocks are interbedded with, or overlain by, volcanic flows of predominantly basaltic composition (Karlstrom and others, 1983; Weir and others, 1989). Tertiary volcanic rocks of intermediate composition and a small area containing Precambrian schist and Paleozoic sedimentary rocks are present locally in the extreme southwestern part of the forest (G.B. Haxel, written communication, 1997).

Unconsolidated sediments of Quaternary age are also found in most stream channels in the forest.

MINERAL OCCURRENCES

Several types of mineral deposits have been recognized in the Coconino National Forest. The two most important of these are manganese and uranium deposits. Secondary manganese oxide ores have been mined in the past from several localities in the Long Valley manganese district, in the southern part of the study area, just north of the Mogollon Rim (Farnham and Stewart, 1958; Lane, 1992; Weir and others, 1994). The most significant of these deposits is at the site of the Last Chance mine, northwest of Clints Well (Fig. 1). Most of these deposits occur as irregular bodies in the Kaibab Formation; however, similar mineralization also occurs locally in Tertiary gravels and in the Moenkopi Formation (Weir and others, 1994). The origin of these deposits is not completely understood. In many localities in the forest, small (about 1-mm diameter) manganese oxide nodules are present in abundance in washes and low swales on the surface of basalt flows, indicating that manganese oxides are forming as part of the weathering of these basalts. Weir and others (1994) suggest that the manganese deposits have formed on Tertiary erosional surfaces. We speculate that manganese and other metals have been carried in solution in ground waters through relatively permeable, near-surface horizons in the Tertiary gravels, and in the Kaibab and Moenkopi Formations, and deposited locally in these rocks to form the manganese oxide deposits. All known manganese deposits occur within about 60 feet of the surface (Farnham and Stewart, 1958); thus, the maximum potential depth of these deposits is not known. No deposits of this type are currently being mined.

Secondary uranium minerals, locally accompanied by arsenic and(or) molybdenum, occur in scattered localities in the Verde Formation, a sequence of Tertiary lake-bed deposits found in the Verde Valley, in the southwestern part of the study area (Duncan and Spencer, 1993; Lane, 1992) (Fig. 1). Numerous prospects are present within the forest; however, no significant deposits have been found and no mining of uranium has occurred. The source(s) of these three elements is not known. They were probably leached from uranium-rich rocks, such as some of the Tertiary volcanic rocks or strata within the Supai Formation, carried in solution in ground waters, and then redeposited in various localities in the lake beds of the Verde Formation.

To the north, east, and west of the Coconino National Forest, chiefly in the Kaibab National Forest and the Navajo Indian Reservation, uranium- and copper-rich collapse breccia pipes have been recognized in many localities along the south side of the Grand Canyon (Sutphin and Wenrich, 1989). No deposits of this type are known to exist in the Coconino National Forest. However, such deposits might be present but covered by younger volcanic flows.

Uranium is also known to occur widely in the Colorado Plateau in fluvial deposits in the Shinarump Member of the Chinle Formation. One small exposure of this unit crops out in the extreme northwest boundary of the forest and contains weakly to moderately anomalous arsenic, gold, molybdenum, lead, and(or) uranium. No mining has occurred in this locality.

Karlstrom and others (1983) describe unusual silver anomalies in the Coconino Sandstone "about 20 mi south of the Rattlesnake Roadless Area" (no location given). Silver concentrations have been found in this unit and in the Kaibab Formation in the West Clear Creek Roadless Area (Ulrich and Bielski, 1983). However, details of these occurrences were not given. These anomalous samples may be from the locality referred to by Karlstrom and others (1983). Anomalous silver has been identified during the present study in stream-sediment samples from several localities in the southeastern part of the Coconino National Forest containing outcrop of Coconino Sandstone. The source(s) of the silver (and locally As, Au, Cd, U, and Zn) is not known but may have originally been the Precambrian highlands thought to have existed to the south of the forest (Ulrich and Bielski, 1983). Although Karlstrom and others (1983) report silver concentrations of 6 to 9 ppm, the concentration levels of this element determined for this present study of the Coconino National Forest are all much lower, and thus not economic, making such occurrences of academic interest only.

Secondary copper and uranium occurrences have been reported in several horizons in the Supai Formation in the Fossil Springs Roadless Area (Peirce and others, 1977; Weir and others, 1983). Other anomalous elements have been reported in coal beds from this area and include Ag, As, B, Ba, Bi, Cd, Co, Mo, Nd, Ni, and Y (C. W. Holmes, written communication, 1993). The source(s) of these elements is not known. No mining has been done there and the occurrences are deemed to be subeconomic.

Hydrothermally altered Tertiary volcanic rocks were recognized during this study in the vicinity of the Childs power plant, near Verde Hot Springs, in the extreme southern part of the study area (Fig. 1); however, no mining has been done in this area, either. In the extreme northwestern part of the forest, near Slate Mountain (Fig. 1), a contact zone between a small

Tertiary rhyolite intrusion and Paleozoic carbonate sedimentary rocks has been reported to contain skarn-type base-metal occurrences (Lockrem, 1983; quoted in Bliss, 1997).

Gold has been reported to occur in scattered localities in areas of volcanic cinders in the San Francisco Volcanic Field, north of Flagstaff (Lane, 1992). The nature of these occurrences has not been described. Analyses of samples of cinders from many localities in the forest failed to identify any meaningful gold resources (Lane, 1992).

SAMPLE COLLECTION AND PREPARATION

Rock Samples

Two types of rock samples were collected. The first type included samples of material deemed to be representative of the general area of a given sample site. These samples were not obviously altered and were collected in order to provide baseline chemical information about various rock types and localities in the study area. All rock samples of this type consisted of composited chips collected from several outcrops. Before crushing, the rock chips were trimmed to remove any obviously weathered surface material.

The second type of rock sample consisted of untrimmed grab samples from mine dumps or prospect pits or of trimmed, composited outcrop samples of visibly altered (usually silicified and iron-stained) material. These samples were collected to provide information on the elements associated with known manganese or uranium mineral deposits in the study area.

The rock data set consists of 291 samples, all collected by the USGS. The data set includes 132 new samples collected from 125 sites plus 159 previously collected samples that were re-analyzed for the present study. These older samples were originally collected for the Arnold Mesa (Wolfe, 1983), Fossil Springs (Beard and Weir, 1984; Weir and others, 1983), Strawberry Crater (Wolfe and Hahn, 1982), West Clear Creek (Ulrich, 1983), and Rattlesnake and Wet Beaver (Gerstel and others, 1983) Roadless Area studies conducted for the U.S. Forest Service. These samples may have been single grab samples or samples composited from several different outcrops. We could not verify the details of collection for these older samples. All sites for rock samples are shown on figure 2.

Stream-sediment Samples

Stream-sediment samples consist of unconsolidated material deemed to represent a composite of all rock material cropping out in the basin upstream from each sample site. The chemistry of these samples represents a sum of (1) a mixture of the chemistries of all types of rock eroded from outcrops throughout the drainage basin, including rocks that have been enriched naturally as a result of the formation of mineral deposits, and (2) the chemistries of materials introduced to a given drainage as a result of human activities, such as mining, timbering, road building, and recreation.

Within a given drainage basin, the specific source or sources for the concentrations of any given element in a stream-sediment sample may or may not be known. In contrast, the source of the rock sample taken from an outcrop is obviously known but its chemistry is normally only representative of a very small area.

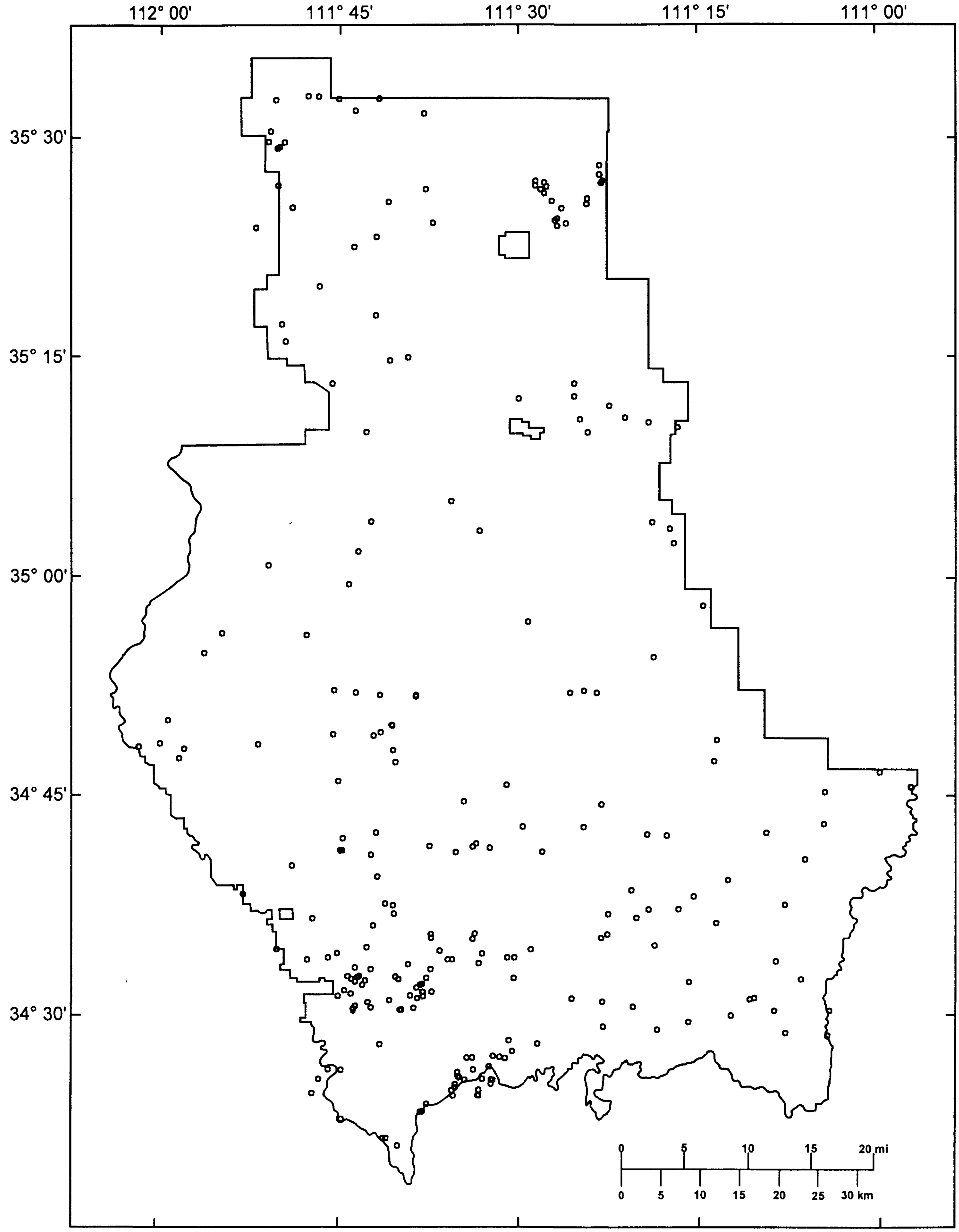

Figure 2. Site locality map for 291 USGS rock samples, Coconino National Forest, Arizona. Open circles locate sample sites.

It is important to note that the chemistry of stream-sediment samples largely reflects the chemistry of materials at or near the present erosion surface. Thus, a mineral deposit not exposed at the surface will not normally be detected by the geochemical sampling procedure used for this study. Samples that are found to be strongly anomalous for one or more of the elements considered to be related to mineral deposits in the study area probably reflect near-surface mineralization. In contrast, samples that are found to be weakly anomalous for mineral deposit-related elements may reflect (1) material eroded from near-surface, mineralized rock that has been diluted by barren sediment, (2) the upper, weak manifestations of a deep-seated mineral deposit that is not truly exposed at the surface, or (3) normal but relatively high background concentrations in one lithology as compared to another.

USGS Stream-sediment Samples

Two stream-sediment data sets have been evaluated for this report. The first set of stream-sediment samples, collected by the USGS, consisted of bulk sediment from 449 sites representing first-order (unbranched) and second-order (below the junction of two first-order) streams as defined on 1:24,000-scale topographic maps (Fig. 3). The bulk stream sediment for each sample was composited from material collected from several locations within a 30-meter radius of each site plotted on figure 3. The bulk sample was sieved and a <0.17-mm (minus-80-mesh) fraction was saved for analysis.

NURE Stream-sediment Samples

The second stream-sediment data set includes new analyses for 662 samples of <0.15-mm (minus-100-mesh) stream sediment collected during the 1970's from the Flagstaff, Holbrook, and Prescott 1° x 2° quadrangles for the NURE program (Clark, 1979; Cook and Fay, 1982; Thayer and Cook, 1980). Our examination of the locations of sites for these samples on topographic bases, as well as our study of photographs of the sites taken by the sample collectors, indicate that many of these samples, particularly those collected in the Flagstaff quadrangle, are from the upper reaches of stream channels. As a result, these samples represent drainage basins that are very limited in size. The rest of the samples represent larger basins and are therefore more typical of the type of stream-sediment samples collected by the USGS. The sites for the NURE samples are shown on figure 4.

CHEMICAL ANALYSIS

All samples were analyzed by several different methods for a total of 53 elements. These 53 include 41 different elements plus other repeated elements. The samples were analyzed for 40 elements (Ag, Al, As, Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cu, Eu, Fe, Ga, Ho, K, La, Li, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Sc, Sn, Sr, Ta, Th, Ti, U, V, Y, Yb, and Zn) by a hot-acid extraction followed by inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Briggs, 1990) and for 10 elements (Ag, As, Au, Bi, Cd, Cu, Mo, Pb, Sb, and Zn) using a partial-extraction ICP-AES method (ICP-P) (Motooka, 1990). The samples were also analyzed for uranium and thorium by instrumental neutron activation

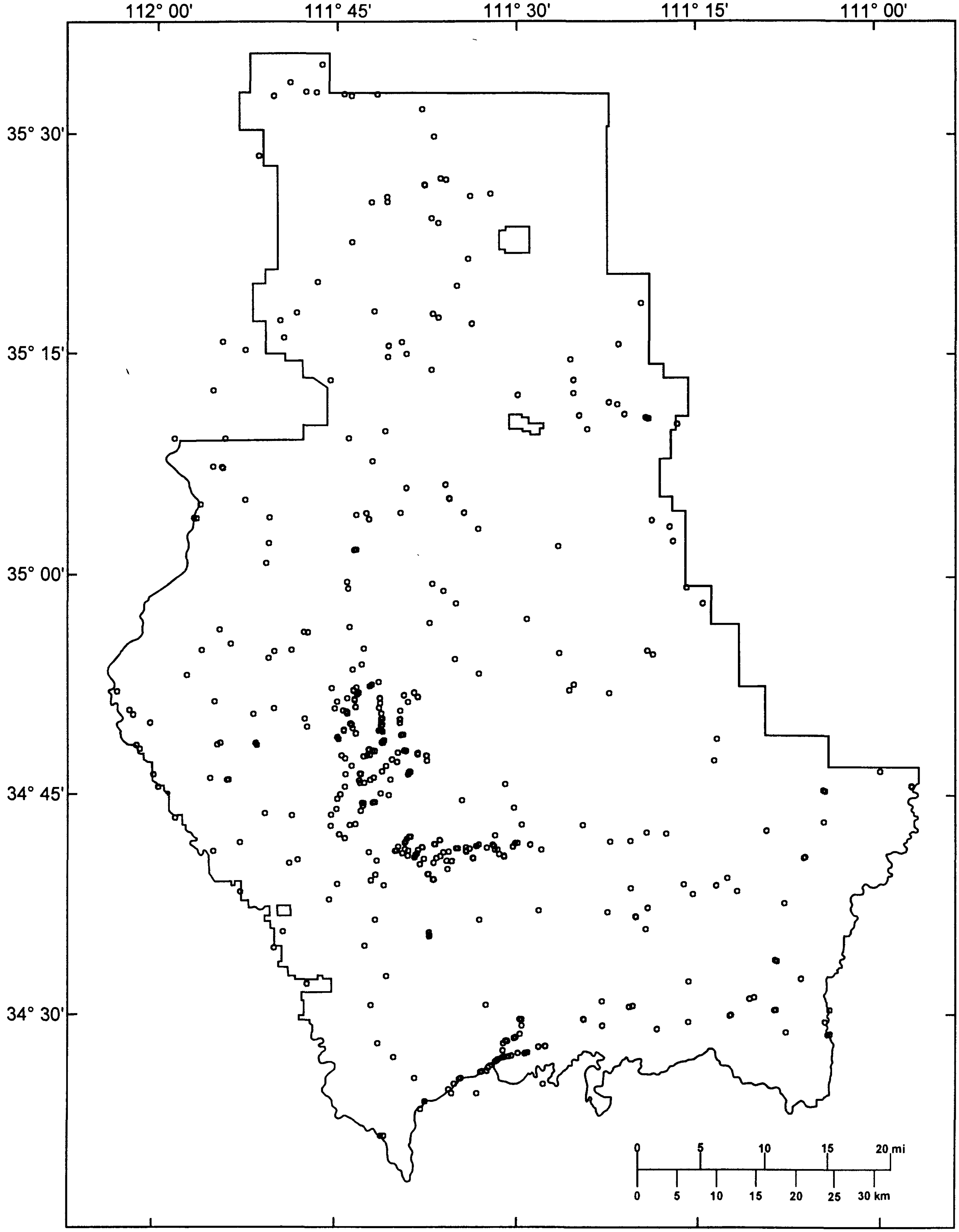

Figure 3. Site locality map for 449 USGS stream-sediment samples, Coconino National Forest, Arizona. Open circles locate sample sites.

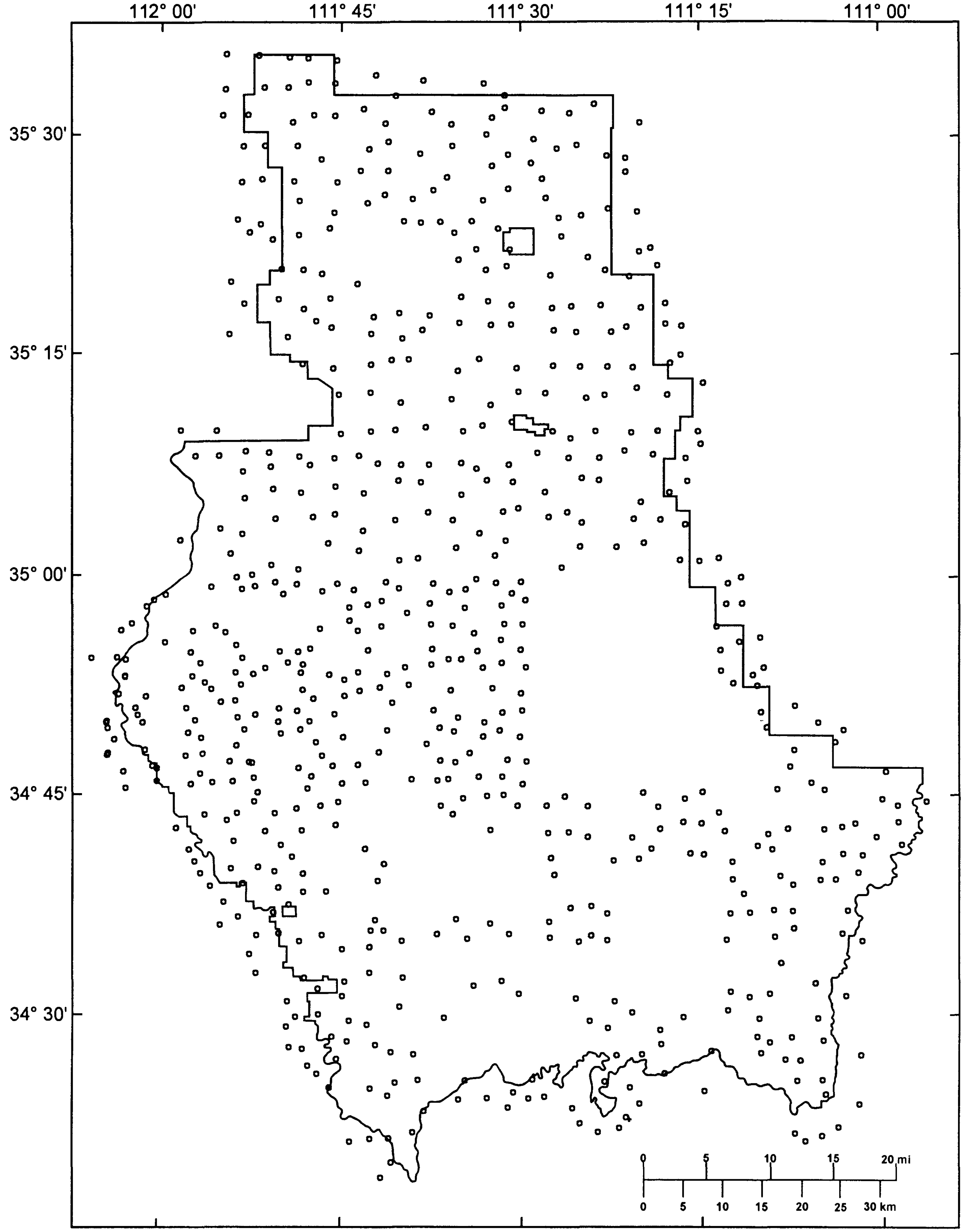

Figure 4. Site locality map for 662 NURE stream-sediment samples, Coconino National Forest, Arizona. Open circles locate sample sites.

analysis (INAA) (McKown and Knight, 1990), and for gold by graphite-furnace atomic-absorption spectrophotometry (AA) (O'Leary and Meier, 1990). Further details of the sample preparation and analysis for these samples, as well as a complete listing of the analyses for the samples, have been published elsewhere (Chaffee and others, 1996). Additionally, sample locations in that report allow the interested reader to locate sites in more detail than is possible on the maps in this report.

EVALUATION OF THE DATA SETS

Of the original 53 elements determined by the various analytical methods, 11 determined by ICP-AES (Ag, As, Au, Bi, Cd, Ho, Mo, Sn, Ta, Th, and U) and five elements determined by ICP-P (Au, Bi, Cu, Pb, and Zn) were deleted from the rock and USGS stream-sediment data sets either (1) because a given element had two or fewer reported values above its lower limit of determination (an unqualified value) for the method used, or (2) because a given element was determined by more than one method and the alternate method contained fewer censored values (a value below the lower limit of determination). With fewer censored values, the ranges of values were commonly greater for the analytical technique chosen for most of these elements, making selection of a threshold value easier. For similar reasons, analyses for 10 elements determined by ICP-AES (Ag, As, Au, Bi, Cd, Mo, Ho, Ta, Th, and U) and four determined by ICP-P (Au, Cu, Pb, and Zn) in the NURE stream-sediment data set were not considered further. Information on the remaining elements for each sample type is summarized in tables 1-3.

Threshold values are shown on each geochemical map. The values were not statistically calculated but were instead determined after first examining histograms showing the distributions of the ranges of reported values for each element and sample medium and then evaluating locations of sites for anomalous samples with reference to the local geology. Threshold values were then adjusted where necessary to better fit the known geology.

GEOCHEMICAL MAPS

Rock Samples

A diverse group of lithologies are present in the Coconino National Forest, and the normal expected ranges of concentrations of many elements vary with rock type. For example, one finds relatively higher background concentrations of the elements associated with dark minerals (such as Co, Cr, Fe, Mg, Mn, Ni, and V) commonly found in andesites and basalts as compared to dark-mineral-poor carbonate rocks and felsic volcanic rocks. Concentrations of calcium and magnesium are usually much higher in carbonate-rich rocks, such as those in the Kaibab Formation, than in the igneous rocks found in the forest area. Lithologies that are dominantly sandstone, such as the Tapeats Formation and the Coconino Sandstone, are chiefly composed of silicon and normally contain very low concentrations of most other major elements, as well as low concentrations of most trace elements.

Because of these chemically different lithologies, the anomalous range of concentrations, based on one population for all samples, typically represent the high end of a background range rather than additions of elements as a result of mineralization.

TABLE 1. SUMMARY STATISTICS FOR ANALYSES OF 37 ELEMENTS IN 291 SAMPLES OF ROCK, COCONINO NATIONAL FOREST, ARIZONA

[All values in ppm unless % shown after element symbol. N=not detected at the lower limit of determination shown in parentheses. L=detected but in a concentration less that the lower limit of determination shown in parentheses. Mean values based on unqualified values only. "P" following element symbol=ICP partial analysis; "NA"=neutron-activation analysis; "AA"=atomic-absorption analysis; no letters, ICP-AES analysis]

Element	Range of values		Geometric mean	Number unqualified	Percent unqualified
	Minimum	Maximum			
Ag-P[1,2]	N(0.067)	1.90	0.32	25	9
Al (%)	0.07	9.90	3.18	291	100
As-P[1,2]	N(1.0)	2200	5.9	87	30
Au-AA[1,3]	L(0.002)	0.034	0.004	30	10
Ba	8	17,000	320	291	100
Be	L(1.)	35	1.5	168	58
Ca (%)	0.01	39	3.54	291	100
Cd-P[1,2]	N(0.050)	40	0.18	119	41
Ce	L(4.)	250	35	268	92
Co	L(1.)	920	13	260	89
Cr	L(1.)	2700	35	278	96
Cu	L(1.)	186,000	20	282	97
Eu	L(2.)	4	2.6	28	10
Fe (%)	0.05	39	1.7	291	100
Ga	L(4.)	25	15	202	69
K (%)	0.03	5.0	0.74	291	100
La	L(2.)	150	20	278	96
Li	L(2.)	370	11	290	99
Mg (%)	0.02	12	1.4	285	98
Mn	6	328,000	410	291	100
Mo-P[1,2]	N(0.10)	1100	0.54	260	90
Na (%)	L(0.005)	4.1	0.44	284	98
Nb	L(4.)	110	25	188	65
Nd	L(4.)	110	22	232	80
Ni	L(2.)	810	24	267	92
P (%)	L(0.005)	0.71	0.076	283	97
Pb	L(4.)	1900	11	157	54
Sb-P[1,2]	N(1.0)	17	4.0	10	3
Sc	L(2.)	83	12	207	71
Sr	10	2100	250	291	100
Th-NA[1]	L(1.00)	49.9	6.6	188	65
Ti (%)	L(0.005)	1.90	0.17	286	98
U-NA[1]	L(0.14)	158	1.78	281	97
V	L(2.)	1000	52	286	98
Y	L(2.)	64	13	250	86
Yb	L(1.)	6	1.7	187	64
Zn	L(2.)	2800	39	287	99

[1]Lower limits vary. Lowest reported value shown.
[2]Only 288 samples analyzed for Ag, As, Cd, Mo, and Sb.
[3]Only 290 samples analyzed for Au.

TABLE 2. SUMMARY STATISTICS FOR ANALYSES OF 37 ELEMENTS IN 449 SAMPLES OF USGS STREAM SEDIMENT, COCONINO NATIONAL FOREST, ARIZONA

[All values in ppm unless % shown after element symbol. N=not detected at the lower limit of determination shown in parentheses. L=detected but in a concentration less that the lower limit of determination shown in parentheses. Mean values based on unqualified values only. "P" following element symbol=ICP partial analysis; "NA"=neutron-activation analysis; "AA"=atomic-absorption analysis; no letters, ICP-AES analysis]

	Range of values		Geometric	Number	Percent
Element	Minimum	Maximum	mean	unqualified	unqualified
Ag-P[1]	N(0.045)	0.52	0.15	13	3
Al (%)	0.47	9.10	3.39	449	100
As-P[1]	N(1.0)	46	3.4	230	51
Au-AA[2]	L(0.002)	0.046	0.003	62	14
Ba	39	1900	370	449	100
Be	L(1.)	6	1.5	232	52
Ca (%)	0.04	18	1.52	449	100
Cd-P[1]	N(0.050)	2.20	0.20	324	72
Ce	6	400	41	449	100
Co	L(1.)	270	15	448	99
Cr	6	1400	94	449	100
Cu	2	160	20	449	100
Eu	L(2.)	2	2	6	1
Fe (%)	0.23	12	2.4	449	100
Ga	L(4.)	32	10	372	83
K (%)	L(0.10)	2.3	0.88	448	99
La	4	120	22	449	100
Li	3	220	15	449	100
Mg (%)	0.06	6.10	1.01	449	100
Mn	38	11,000	530	449	100
Mo-P[1]	N(0.10)	6.6	0.51	408	91
Na (%)	0.01	3.3	0.33	449	100
Nb	L(4.)	88	16	286	64
Nd	L(4.)	68	18	441	98
Ni	3	400	41	449	100
P (%)	0.005	0.31	0.052	449	100
Pb	L(4.)	59	11	441	98
Sb-P[1]	N(0.60)	1.4	1.2	6	1
Sc	L(2.)	120	9	398	89
Sr	19	1700	140	449	100
Th-NA[1,2]	L(0.97)	31.2	5.5	403	92
Ti (%)	0.03	2.10	0.27	449	100
U-NA[2]	0.39	7.59	1.64	440	100
V	7	370	63	449	100
Y	2	30	11	449	100
Yb	L(1.)	3	1.5	272	61
Zn	6	200	45	449	100

[1]Lower limits vary. Lowest reported value shown.

[2]Only 440 samples analyzed for Au, Th, and U.

TABLE 3. SUMMARY STATISTICS FOR ANALYSES OF 39 ELEMENTS IN 662 SAMPLES OF NURE STREAM SEDIMENT, COCONINO NATIONAL FOREST, ARIZONA

[All values in ppm unless % shown after element symbol. N=not detected at the lower limit of determination shown in parentheses. L=detected but in a concentration less that the lower limit of determination shown in parentheses. G=detected but in a concentration greater than the upper limit of determination shown in parentheses. Mean values based on unqualified values only. "P" following element symbol=ICP partial analysis; "NA"=neutron-activation analysis; "AA"=atomic-absorption analysis; no letters, ICP-AES analysis]

	Range of values		Geometric	Number	Percent
Element	Minimum	Maximum	mean	unqualified	unqualified
Ag-P[1]	N(0.067)	0.68	0.13	39	6
Al (%)	1.10	9.50	4.66	662	100
As-P[1]	N(1.0)	110	3.0	535	81
Au-AA[1]	L(0.002)	0.04	0.004	48	7
Ba	73	2700	310	662	100
Be	L(1.)	9	1.3	496	75
Bi-P[1]	L(1.)	4.1	2.5	3	0.5
Ca (%)	0.07	16	1.64	662	100
Cd-P[1]	N(0.050)	13	0.22	611	92
Ce	10	870	50	662	100
Co	1	67	16	662	100
Cr	7	990	95	662	100
Cu	1	1000	26	662	100
Eu	L(2.)	2	2	4	0.6
Fe (%)	0.29	17	3.0	662	100
Ga	L(4.)	27	12	630	95
K (%)	0.29	3.2	1.3	662	100
La	6	470	29	662	100
Li	4	110	20	662	100
Mg (%)	0.09	G(5.00)	0.95	661	99
Mn	50	3000	605	662	100
Mo-P[1]	N(0.10)	20	0.51	648	98
Na (%)	0.03	3.0	0.54	662	100
Nb	L(4.)	70	15	607	92
Nd	5	360	24	662	100
Ni	2	300	36	662	100
P (%)	0.008	0.37	0.064	662	100
Pb	L(4.)	300	16	660	99
Sb-P[1]	N(1.0)	25	1.8	16	2
Sc	L(2.)	43	9.4	648	98
Sn	L(5.)	21	8.3	13	2
Sr	24	2200	190	662	100
Th-NA[1, 3]	L(1.40)	270	7.6	625	98
Ti (%)	0.04	1.70	0.39	662	100
U-NA[3]	L(0.086)	14.6	2.45	638	99
V	9	510	77	662	100
Y	3	130	15	662	100
Yb	L(1.)	19	1.6	593	90
Zn	11	520	59	662	100

[1]Lower limits vary. Lowest reported value shown.

[2]Only 661 samples analyzed for Au.

[3]Only 639 samples analyzed for Th, and U.

The distributions of anomalous concentrations of 10 elements (Ag, As, Au, Cd, Cu, Mo, Pb, Sb, U, and Zn) in rock samples are shown on figures 5 to 14, at the back of this report. Small open circles on each map show the approximate locations of samples with concentrations less than the threshold value shown on the map. Larger, filled circles show the approximate locations of samples with concentrations greater than or equal to the threshold value shown. The letters A to H on each map refer to sites or clusters of sites for each of the selected lithologic environments described below under ENVIRONMENTS A to I. For each site or cluster of sites, all of the described elements are not necessarily anomalous for all samples. Readers are referred to the data report (Chaffee and others, 1996) for more specific information for each site.

ENVIRONMENT A. Sites labeled "A" on the maps represent samples collected from two outcrops of the Shinarump Member of the Chinle Formation, a known favorable host for uranium deposits in many areas of the Colorado Plateau. The only outcrops of this unit in the study area are found at the extreme northern boundary of the forest. Anomalous elements (with single anomalous values or ranges of anomalous values in parentheses) include As (6.9-65 ppm) (Fig. 6), Au (0.034 ppm) (Fig. 7), Mo (3.1-4.0 ppm) (Fig. 10), Pb (32 ppm) (Fig. 11), and U (7.50 ppm) (Fig. 13). With the possible exception of gold, all of these elements are known to be associated with uranium deposits found elsewhere in this lithologic environment (Rose, Hawkes and Webb, 1979). As compared to rocks of similar lithology elsewhere in the forest, the concentration ranges for arsenic and molybdenum at this location are moderately anomalous; those for the other elements are only weakly anomalous. The gold value is low and is not deemed to represent a potential gold resource.

ENVIRONMENT B. Sites labeled "B" on the maps include samples from outcrops of felsic to intermediate volcanic rocks that range in composition from rhyolite to dacite. These sites are found in the northwestern and southwestern parts of the forest. Samples from a few sites in these areas exhibit hydrothermally altered rocks; however, the highest concentrations of the selected elements are not necessarily in the most obviously altered rocks, mainly because weathering processes have caused some elements in altered samples to be leached at the surface. Anomalous elements include Ag (0.11-0.91 ppm) (Fig. 5), As (5.2-17 ppm) (Fig. 6), Au (0.01 ppm) (Fig. 7), Cu (100-330 ppm) (Fig. 9), Mo (2.2-4.5 ppm) (Fig. 10), Pb (25-27 ppm) (Fig. 11), Sb (2.2 ppm) (Fig. 12), U (5.27-9.45 ppm) (Fig. 13), and Zn (100-240 ppm) (Fig. 14). The ranges for most of these elements (except for lead and possibly uranium) are at least moderately anomalous as compared to normally expected background ranges for lithologies of these compositions. The associations, if any, of these anomalies with possible metallic mineral deposits is not known.

ENVIRONMENT C. Sites labeled "C'" on the maps include samples of the Verde Formation. This unit crops out along both sides of the Verde Valley. This formation locally contains anomalous concentrations of As (7.3-66 ppm) (Fig. 6), Mo (3.3 ppm) (Fig. 10), and U (5.52-63 ppm) (Fig. 13). When compared to concentration ranges in rocks of similar composition found elsewhere, these ranges indicate that these three elements are moderately enriched in the Verde Formation, at least locally. Rock samples analyzed by Lane (1992) also contain anomalous arsenic and uranium, plus antimony, but not molybdenum. As noted above, enrichment of these elements in the Verde Formation is thought to have resulted from their deposition from metal-rich ground waters.

ENVIRONMENT D. Sites labeled "D" on the maps include samples that are most commonly from silicified and(or) cherty limestone or dolomitic limestone beds of the Kaibab Formation. Several sites are for samples that were chiefly composed of sandstone. Exposures of this formation are scattered throughout the forest. Samples from these sites contain anomalous concentrations of one or more of the elements Ag (0.34-1.1 ppm) (Fig. 5), As (4.7-93 ppm) (Fig. 6), Au (0.008 ppm) (Fig. 7), Cd (0.42-5.2 ppm) (Fig. 8), Mo (2.4-7.3 ppm) (Fig. 10), Pb (28-1900 ppm) (Fig. 11), Sb (3-17 ppm) (Fig. 12), U (5.16-6.62 ppm) (Fig. 13), and Zn (120-220 ppm) (Fig. 14). Most of these elements were found to be most highly concentrated in the siliceous zones or in chert nodules and not in the carbonate-rich layers. As compared to the typical abundances of these elements in limestone or dolomite layers in the Kaibab Formation, the levels listed above are moderately to strongly anomalous for all of the elements except gold and uranium, which are only weakly anomalous. The reason for these unusual concentrations is not understood. They may represent contributions of elements from volcanism occurring in the region at the time of deposition of the carbonate rocks or might represent deposition from circulating ground waters at a later time.

ENVIRONMENT E. Sites labeled "E" on the maps consist of three samples of manganese oxide "ore" collected from abandoned mines or prospects located north of Clints Well (Fig. 1). Elements associated with these samples include Ag (0.39-1.9 ppm) (Fig. 5), As (120-2200 ppm) (Fig. 6), Au (0.012 ppm) (Fig. 7), Cd (0.47-2.5 ppm) (Fig. 8), Cu (97-480 ppm) (Fig. 9), Mo (3.5-1100 ppm) (Fig. 10), Pb (61 ppm) (Fig. 11), Sb (2.5-3.6 ppm) (Fig. 12), and Zn (550-750 ppm) (Fig. 14). Many of these element ranges are clearly strongly anomalous. It is probable that these elements were carried in metal-rich ground waters and adsorbed onto manganese (and possibly iron) oxides as they were deposited in a natural process commonly called manganese scavenging (Chao and Theobald, 1976; Rose and others, 1979). Many elements are known to be naturally enriched by this process. Other elements enriched in the manganese deposits in the study area (but not discussed here) include Ba, Be, Bi, Co, Fe, Hg, Ni, Sr, Tl, V, and W (Chaffee and others, 1996; Lane, 1992; Ulrich and Bielski, 1983). If there were deposits of manganese in the forest that could be mined economically (not presently the case), then it might be worth recovering at least some of these associated elements as by-products.

ENVIRONMENT F. The sites labeled "F" on the maps include samples from shale, limestone, or calcareous sandstone beds in the Supai Formation, found mainly in the southwestern part of the forest. Some of these samples were collected to determine elements associated with local zones of outcropping, visible secondary copper minerals and(or) anomalous radioactivity in the Fossil Springs Roadless Area (Peirce and others, 1977; Weir and others, 1983). The samples contained anomalous concentrations of one or more of the elements Ag (1.2 ppm) (Fig. 5), As (9.2 ppm) (Fig. 6), Cd (40 ppm) (Fig. 8), Cu (170-190,000 ppm) (Fig. 9), Mo (3.7-8.7 ppm) (Fig. 10), Pb (32-47 ppm) (Fig. 11), U (5.0-158 ppm) (Fig. 13), and Zn (120-2800 ppm) (Fig. 14). With the possible exception of lead, these elements are moderately to strongly enriched locally in the zones containing visible copper minerals and(or) anomalous radioactivity. As previously noted, the source(s) of the anomalous elements is not known.

ENVIRONMENT G. Samples from sites labeled "G" on the maps are from massive sandstone exposures of the Toroweap Formation or the Coconino Sandstone that crop out in scattered sites in this lithologic environment, most of which are in the southern part of the forest. Samples from these sites contain anomalous concentrations of one or more of the elements Ag (0.22-1.4 ppm) (Fig. 5), As (5.1-580 ppm) (Fig. 6), Au (0.022 ppm) (Fig. 7), Cd (0.42 ppm) (Fig. 8), U (5.01-5.72 ppm) (Fig. 13), and Zn (170 ppm) (Fig. 14). These concentration levels are deemed to be weakly to moderately anomalous for a rock lithology that normally contains very low levels of these selected elements. As noted previously, weakly anomalous silver has been identified elsewhere in this lithologic environment (Karlstrom and others, 1983; Ulrich and Bielski, 1983). These new analyses suggest that the anomalous silver may be accompanied locally by anomalous concentrations of other elements. The source(s) of these elements is not known. Ulrich and Bielski (1983) suggest that the silver (and thus, by analogy, the other elements listed above) may have come from the Precambrian highlands that are thought to have existed to the south of the forest.

ENVIRONMENT H. Sites labeled with the letter "H" on the maps identify samples from outcrops of mafic volcanic rocks, mainly basalt flows. A few samples are of cinders or tuffs of similar chemical composition. These sites are mostly in the southern part of the forest. Anomalous elements include Ag (0.11-1.2 ppm) (Fig. 5), As (6.9-31 ppm) (Fig. 6), Cu (81-110 ppm) (Fig. 9), Mo (3.0 ppm) (Fig. 10), U (5.1 ppm) (Fig. 13), and Zn (130-140 ppm) (Fig. 14). These ranges of values are thought to only represent the high end of the background ranges for the respective elements, with the highest concentrations generally associated with high levels of iron and(or) manganese. Two samples of weathered material from a cinder quarry (site labeled "HQ" on figures 11 (Pb) and 12 (Sb)) yielded very strongly anomalous concentrations of Pb (1700 ppm) and Sb (2.6-13 ppm). No other mafic volcanic rock samples contained anomalous concentrations of these two (and only these two) elements. Because this locality has been used extensively for a target range, it seems likely that the concentrations of these two metals are the result of contamination.

ENVIRONMENT I. Samples labeled "I" on the maps were all collected from outcrops of Tertiary gravels. These samples include: (1) one containing anomalous As (5.2 ppm) (Fig. 6) and Sb (1.6 ppm) (Fig. 12) in Precambrian clasts in gravels collected from the Fossil Springs Roadless Area, in the southern part of the forest (site labeled "I1") ; (2) one containing anomalous Sb (2.5 ppm) (Fig. 12) in a granite clast in conglomerate collected from the West Clear Creek Roadless Area (site labeled "I2"); and (3) one containing anomalous As (8.2 ppm) (Fig. 6) and Cd (0.45 ppm) (Fig. 8) in a sample of gravel collected northeast of Clints Well (site labeled "I3"). All of these anomalies are considered to be weak. The sources of the elements in these samples of transported material is not known but may have been the Precambrian highlands that are thought to have existed to the south of the forest (Ulrich and Bielski, 1983).

USGS Stream-sediment Samples

The distributions of anomalies for 10 elements in USGS stream-sediment samples are shown on figures 15 to 24, in the back of this report. These anomalies are also classified into sites or clusters of sites with common lithologic environments, which are listed below as ENVIRONMENTS A to I.

ENVIRONMENT A. Sites labeled "A" on the maps identify anomalous sediment samples whose dominant source material is mafic volcanic rocks, chiefly basalt flows. Minor amounts of sediment derived from the Kaibab Formation, Coconino Sandstone, Tapeats Formation, and(or) the Supai Formation may also be present. These anomalies are scattered throughout the study area. Most of these samples are only anomalous for one or two of the elements in the suite. These elements include (with single anomalous value or range of anomalous values in parentheses) Ag (0.088-0.3 ppm) (Fig. 15), As (4.2-30 ppm) (Fig. 16), Au (0.008 ppm) (Fig. 17), Cd (0.40-2.0 ppm) (Fig. 18), Cu (71-160 ppm) (Fig. 19), Mo (6.6 ppm) (Fig. 20), Pb (25-42 ppm) (Fig. 21), Sb (0.9-7.5 ppm) (Fig. 22), U (5.75 ppm) (Fig. 23), and Zn (120-200 ppm) (Fig. 24). All of these anomalies are considered to represent simply the upper part of the normal background ranges for weathered mafic rocks, with some enhancement of concentrations caused by the iron- and(or) manganese-scavenging process.

ENVIRONMENT B. Sites labeled "B" on the maps identify samples from stream channels with sediment that is predominantly composed of felsic volcanic rocks. These sites are scattered throughout the study area. Anomalous elements found in this environment include As (9.7-11 ppm) (Fig. 16), Cd (0.55 ppm) (Fig. 18), Mo (2.4-2.8 ppm) (Fig. 20), Pb (59 ppm) (Fig. 21), Sb (1.4 ppm) (Fig. 22), U (4.09-7.59 ppm) (Fig. 23), and Zn (120-190 ppm) (Fig. 24). All of these anomalies are relatively weak and are thought to represent only the high end of the normal background ranges for the respective elements.

ENVIRONMENT C. Sites labeled "C" on the maps identify samples with anomalous concentrations from stream channels in which the sediment is mostly composed of material from the Kaibab Formation. This material mostly includes carbonate-rich fragments commonly accompanied by silicified and(or) cherty fragments that may include iron and(or) manganese oxides. These sites are found near Flagstaff and in the southern part of the forest.

Anomalous elements in this environment include As (4.3-19 ppm) (Fig. 16), Cd (0.66-2.2 ppm) (Fig. 18), Mo (2.5-4.0 ppm) (Fig. 20), U (4.16-4.67 ppm) (Fig. 23), and Zn (130 ppm) (Fig. 24). All of these anomalies are deemed to represent relatively high but normal concentrations for the lithologies present. As was noted for the rock samples from this lithologic environment, anomalies for these elements in sediment seem to be associated with material from silicified and(or) cherty horizons. The origins for these unusual concentrations is not understood. They may represent contributions of elements from volcanism occurring in the region at the time of deposition of the carbonate rocks or might represent deposition from ground waters.

ENVIRONMENT D. Sites labeled "D" on the maps identify localities where the sample material is composed of an approximately equal mixture of mafic volcanic rocks (mostly basalts) and the carbonate-rich Kaibab Formation, two chemically contrasting lithologies. These sites are mostly in the central third of the forest. Anomalous elements include Ag (0.52 ppm) (Fig. 15), As (6.0-46 ppm) (Fig. 16), Au (0.012 ppm) (Fig. 17), Cd

(0.44-0.87 ppm) (Fig. 18), Cu (79 ppm) (Fig. 19), Mo (2.5-3.7 ppm) (Fig. 20), and U (4.06 ppm) (Fig. 23). None of the samples in this lithologic environment is anomalous for more than two of these elements. All of the anomalies are deemed to be related to high but normal concentration levels for the lithologies present.

ENVIRONMENT E. Four samples of sediment derived chiefly from Coconino Sandstone and collected in the extreme southeastern part of the study area, comprise lithologic environment E. These samples contain weakly anomalous Ag (0.087-0.18 ppm) (Fig. 15) but are not anomalous for any of the other elements studied. As noted previously, the presence of anomalous silver has been reported for this lithologic environment elsewhere in the region (Karlstrom and others, 1983; Ulrich and Bielski, 1983). This weakly anomalous silver does not indicate a significant mineral resource and is thus only of academic interest. Weakly anomalous arsenic (5.9 ppm) was identified in one sample that was collected during evaluation of the Wet Beaver Roadless Area (Ulrich and others, 1983) in a side canyon draining outcrops of Coconino Sandstone, in the upper part of Wet Beaver Creek (Fig. 16). This arsenic anomaly is not accompanied by anomalous concentrations of any of the other elements studied, and is thus thought to represent only a high background concentration.

ENVIRONMENT F. One sample originally collected for the Fossil Springs Roadless Area (sample number FC61S; Chaffee and others, 1996) was from a drainage basin characterized as containing mostly Paleozoic sedimentary rocks, chiefly the Supai Formation (Weir and others, 1983). This sample contained 140 ppm copper (Fig. 19). As noted previously, locally high copper contents were measured in rock samples from the Supai Formation in this general area. Anomalies for copper were previously determined by Weir and others (1983) in rock, stream-sediment, and panned heavy-mineral-concentrate samples from the area. The source of the copper has not been identified.

ENVIRONMENT G. Sites labeled "G" on the maps are found along the Verde River Valley and identify anomalies that are composed predominantly of material from the Verde Formation, which consists mostly of clastic- and carbonate-rich lake-bed sediments. Rock samples collected from this lithologic environment were found to be locally anomalous in arsenic, molybdenum, and(or) uranium. Stream sediments derived from this unit also contain anomalous arsenic (6.2-17 ppm) (Fig. 16) and uranium (4.93 ppm) (Fig. 23). Several samples collected along the Verde Valley also exhibit weak anomalies for either gold (0.008 ppm) (Fig. 17) or cadmium (0.41-0.59 ppm) (Fig. 18). These weakly anomalous concentrations of gold and cadmium are thought to result from contamination from past prospecting, mining, and(or) smelting in the upper Verde River Valley (Fig. 1) and not from metal-enriched deposits in the Verde Formation.

ENVIRONMENT H. Samples with anomalies labeled "H" are from the extreme northwestern part of the study area and are located on the maps for lead (25 ppm) (Fig. 21) and uranium (5.45 ppm) (Fig. 23). These samples are of sediment derived chiefly from the Shinarump Member of the Chinle Formation, a known source of uranium deposits in other parts of the Colorado Plateau region. The relatively low concentrations in the samples from this area, along with the similar low concentrations of these elements in rock samples from the same area, suggest that any exposed concentrations of uranium in the area are not significant.

ENVIRONMENT I. Several sites just north of Clints Well, in the southeastern part of the forest (Fig. 1), identify samples collected downstream from inactive manganese mines or prospects. These samples are in drainage basins containing outcrops of the Kaibab Formation. Anomalies for Ag (0.17 ppm) (Fig. 15), As (8.6-46 ppm) (Fig.16), Cd (0.65-1.1 ppm) (Fig 18), and Mo (3.2-5.9 ppm) (Fig. 20) were detected. As noted under rock samples, manganese "ores" from this area often contain anomalous concentrations of other elements. All of these anomalies are deemed to be the direct result of elements enriched by the iron-and(or) manganese-scavenging process and therefore do not identify hydrothermal mineral deposits.

NURE Stream-sediment Samples

As noted earlier, most of the samples collected from drainage channels in the forest for the NURE program are from the upper reaches of drainage basins. As such, these samples represent material that has not been transported for very long distances and may thus more closely approximate soil samples than true stream-sediment samples.

The anomalous distributions of 11 elements (Ag, As, Au, Cd, Cu, Mo, Pb, Sb, Sn, U, and Zn) in NURE stream-sediment samples are shown on figures 25 to 35, in the back of this report. The anomalies shown on these figures are classified into areas of common lithologic environments that are listed below as ENVIRONMENTS A to G.

ENVIRONMENT A. Sites labeled "A" on the maps identify anomalous sediment samples whose dominant source material is mafic volcanic rocks, chiefly basalt flows. These areas are scattered throughout the forest. Anomalous elements (with single anomalous values or ranges of anomalous values in parentheses) include Ag (0.10-0.11 ppm) (Fig. 25), As (5.0-6.1 ppm) (Fig. 26), Au (0.008-0.04 ppm) (Fig. 27), Cd (0.50-3.90 ppm) (Fig. 28), Cu (70-87 ppm) (Fig. 29), Mo (1.6 ppm) (Fig. 30), Pb (32-51 ppm) (Fig. 31), Sn (5 ppm) (Fig. 33), U (4.49-5.43 ppm) (Fig. 34), and Zn (120-190 ppm) (Fig. 35). With the possible exception of tin, all of these concentrations are deemed to represent the upper part of the normal background ranges for each of these elements in this lithologic environment. Some of the high values for elements such as cadmium, molybdenum, and zinc may be the result of the enriching effects of manganese and(or) iron scavenging. The anomalous tin value is in a sample collected in basaltic cinder deposits in the vicinity of Kendrick Peak (Fig. 1), an area of Quaternary rhyolites (Ulrich and others, 1984). Thus, the tin value may indicate a contribution to this chiefly basaltic sediment sample of material from these rhyolites. The tin is therefore considered to be within its normal background range.

ENVIRONMENT B. The sites labeled "B" on the maps indicate localities where the sediment is composed mostly of felsic to intermediate volcanic rocks chiefly related to dacite flows in the San Francisco Peaks region just north of Flagstaff or to rhyolite flows near Kendrick Peak, near the western boundary of the forest. Elements identified as anomalous in this lithologic environment include Cd (0.54-1.91 ppm) (Fig. 28), Mo (1.3-2.2 ppm) (Fig. 30), Pb (32-39 ppm) (Fig. 31), Sn (6-10 ppm) (Fig 33), and U (4.40-11.3 ppm) (Fig. 34). All of these values are deemed to represent normal values at the upper end of background ranges for the respective elements in this lithologic environment.

ENVIRONMENT C. The sites labeled "C" on the maps identify localities where the sediment is composed mostly of carbonate-rich fragments in the Kaibab Formation that may include silicified and(or) cherty fragments. Manganese-oxide coatings have been observed locally on sediment grains in the vicinity of these localities. For NURE samples, these anomalies are found mostly in the southeastern part of the forest but are also present in scattered localities east of Flagstaff and along the eastern and western boundaries of the forest. Anomalies identified include Ag (0.11-0.14 ppm) (Fig. 25), As (5.4-82 ppm) (Fig. 26), Cd (0.53-3.2 ppm) (Fig. 28), Mo (1.3-8.5 ppm) (Fig. 30), Pb (30 ppm) (Fig. 31), U (4.41-6.35 ppm) (Fig. 34), and Zn (140 ppm) (Fig. 35). All of these anomalies are deemed to represent relatively high but normal background concentrations. As noted previously, the reasons for some of these relatively high concentrations, especially for arsenic, cadmium, molybdenum, lead, and uranium, is not understood but may represent contributions of these elements from volcanism occurring in the region at the time of deposition of the carbonate rocks or contributions caused by deposition of the elements from circulating ground waters.

ENVIRONMENT D. Sites labeled "D" on the maps identify localities where the sample materials are thought to be composed of an approximately equal mixture of mafic volcanic rocks (chiefly basalts) and the carbonate-rich Kaibab Formation, two chemically contrasting lithologies. These areas are mostly located in the west-central part of the forest, south and west of Flagstaff but are also present in other localities scattered throughout the forest. Anomalous elements include Ag (0.11-0.68 ppm) (Fig. 25), As (5.8-7.6 ppm) (Fig. 26), Cd (0.51-2.40 ppm) (Fig. 28), Cu (73-160 ppm) (Fig. 29), Mo (3.0 ppm) (Fig. 30), Pb (40-54 ppm) (Fig. 31), and Zn (180 ppm) (Fig. 35). All of these anomalies are thought to represent the normal, upper range of background values for the lithologies present.

ENVIRONMENT E. Two samples of sediment derived chiefly from Coconino Sandstone were collected in the extreme southeastern part of the forest. As was the case for some of the USGS stream-sediment samples collected in this same environment (Fig. 15), these two samples contained weakly anomalous silver (0.11-0.17 ppm) (Fig. 25). In addition, one of the two samples also contained weakly anomalous molybdenum (1.5 ppm) (Fig. 30). As noted previously, the source(s) of these elements in this usually metal-barren sandstone is not known but may be the Precambrian highlands thought to have existed to the south of the forest (Ulrich and Bielski, 1983). The concentrations are of academic interest only and do not represent hydrothermal mineralization processes.

ENVIRONMENT F. Sites labeled "F" are from localities containing mixed clastic and carbonate Paleozoic sediments, with the Supai Formation (mostly sandstones and siltstones) being the dominant unit. These few areas are found in the west central part of the study area. Anomalous elements include As (6.3 ppm) (Fig. 26), Au (0.009 ppm) (Fig. 27), and Pb (31-37 ppm) (Fig. 31). All of these concentrations are deemed to be in the upper parts of the ranges of background concentrations for the respective elements.

ENVIRONMENT G. Sites labeled "G" on the maps are found in the Verde River Valley and identify anomalous samples composed of material derived from the Verde Formation, which has been previously described, and also derived from a variety of rock types exposed to the west of the Verde River (and outside of the forest), that are not present within the forest and are not further discussed here. The chemistry for samples collected outside of

Coconino National Forest was added to the data set to provide context to the zone bounding the forest. The element concentrations for most of the samples labeled "G" are based on the cumulative effects of natural concentrations added to those caused by mining and smelter contamination in the general area of the Verde River Valley (Fig. 1). Anomalous elements identified in samples from areas labeled "G" include Ag (0.11-0.62 ppm) (Fig. 25), As (5.2-110 ppm) (Fig. 26), Au (0.008-0.016 ppm) (Fig. 27), Cd (0.59-8.0 ppm) (Fig. 28), Cu (87-580 ppm) (Fig. 29), Mo (1.3-20 ppm) (Fig. 30), Pb (30-300 ppm) (Fig. 31), Sb (1.6 ppm-8.2 ppm), (Fig. 32), Sn (5-11 ppm) (Fig. 33), U (4.40-14.8 ppm) (Fig. 34), and Zn (120-520 ppm) (Fig. 35).

ENVIRONMENTAL GEOCHEMISTRY

The geochemical data for both rock and stream-sediment samples provide some guidance as to possible environmental concerns related to dispersion of potentially toxic elements in the Coconino National Forest. Potential environmental problems are discussed below for two environments: the surficial environment and the subsurface environment.

Surficial Environmental Geochemistry

Based on the chemistry of surficial materials, four areas in or near the Coconino National Forest are potentially of environmental concern. In the Long Valley area, near Clints Well, in the southern part of the forest (Fig. 1), manganese oxide ores have been mined in the past. Other prospects for manganese are known in the same general area (Farnham and Stewart, 1958). Analyses of samples of ores, described earlier, indicate that strongly anomalous concentrations of as many as nine elements (Ag, As, Au, Cd, Cu, Mo, Pb, Sb, and Zn) are present, as well as 11 other elements not discussed here (Ba, Be, Bi, Co, Fe, Hg, Ni, Sr, Tl, V, and W). Samples of stream sediment collected about two miles or less downstream from the abandoned mines are also enriched in many of the elements analyzed for this report. Sample data from the West Clear Creek Roadless Area study (Ulrich, 1983) indicate that chemical anomalies related to the manganese mining drop to background ranges at a distance downstream from the old workings of between two and nine miles, suggesting that the effects of dispersion of ore-related elements downstream from the mines are limited.

Other manganese prospects examined for this study were found to be limited in exposure. In addition, most are not located in or near any major drainage channel, so that potential mechanical or chemical dispersion from these prospects is limited. Consequently, these minor areas of manganese deposits are probably not an environmental concern.

It is also important to note that these secondary manganese deposits do not contain any sulfide minerals; consequently, any water draining such deposits will not be acidic.

The second area of environmental concern related to surficial materials is along the western boundary of the forest, where beds of the Verde Formation crop out. As previously noted, localized areas in the Verde Formation are known to contain weakly to moderately anomalous concentrations of arsenic, molybdenum, and(or) uranium. Radon, a daughter product of uranium, was not measured for this report; however, significant concentrations of this gas have been found in the Camp Verde-Middle Verde area (Duncan and Spencer, 1993) and might be present elsewhere in the rocks and soils in and near the Verde Valley. Thus, caution is advised regarding constructing any enclosed structures on outcrops or shallowly covered areas of the Verde Formation that may present a potential radon hazard. Again, sulfide minerals have not been identified in the Verde Formation, so surface waters draining this formation will not be acidic.

As noted earlier, many of the NURE stream-sediment samples were collected from channels representing very small watersheds. Samples from such areas often tend to have more characteristics of residual-soil samples, which are composed of very local material, than of stream-sediment samples, which are commonly composed of actively migrating material. Although we have not conducted any soil surveys for this report, the high concentrations of many of the selected elements in the NURE samples suggest a widespread, smelter-related soil contamination problem--one that probably exists both on private lands and on forest lands. Our observation is corroborated by Nash and others (1996), who suggested that soil contamination related to smelters in the Verde River area (Fig. 1) is probably widespread in the Verde River Valley north and east of Clarkdale.

The third area of concern is in the Fossil Springs Roadless Area, where minor amounts of sulfide minerals have been reported to occur locally in outcrops of the Supai Formation in association with secondary copper minerals, as well as with various other minerals containing the suite of elements determined for this study (Peirce and others, 1977; Ulrich and Bielski, 1983). Waters leaching these sulfide-rich areas may become acidic. However, it seems unlikely that these waters would remain acidic for any significant distance below the sulfide-rich outcrops because of (1) strongly oxidizing conditions and (2) the presence of carbonate-rich material that would rapidly neutralize any acid present.

The last area of possible concern is in the vicinity of Slate Mountain, in the northwestern part of the forest (Fig. 1). Oxidized base-metal minerals, which probably have unoxidized, sulfide-phase analogs at depth, have been reported from this area (Lockrem, 1983; quoted in Bliss, 1997). The locality was not further examined for this study. Low topographic relief in the area, together with relatively low precipitation, have created only a very poorly integrated stream network. As a result, any downstream movement of base-metal sulfides that may exist would be minimal. Thus, the production of acidic waters in the immediate area is not deemed to be a significant environmental concern.

Subsurface Environmental Geochemistry

Under the right combination of physical and chemical conditions, many elements can migrate in solution in ground water. As a result, the siting of wells in some areas of the forest, whether for domestic or agricultural purposes, must be evaluated carefully, and the chemistry of well waters should be monitored.

Within the Coconino National Forest, an area of primary concern for ground water is that underlain by the Verde Formation, west of Sedona and extending along the Verde Valley. No water analyses were determined for this study, but the potential exists for toxic levels of elements such as arsenic, molybdenum, and(or) uranium (as well as radon) in waters from wells drilled in the Verde Formation.

Although no uranium-rich collapse-type breccia-pipe deposits (which contain significant volumes of sulfide minerals) have been identified in the forest (Sutphin and

Wenrich, 1989), this type of mineral deposit might still be present at shallow depths under a veneer of volcanic rocks or alluvium, particularly in the northern part of the forest. Deep wells penetrating such a deposit could produce acidic water containing significant levels of potentially toxic elements such as As, Cd, Cu, Mo, Pb, Rn, U, and Zn.

Another potential groundwater-related environmental problem could occur over major parts of the forest. Samples of both rock and stream sediment containing silicified and(or) cherty material in the Kaibab Formation have been found to contain anomalous concentrations of as many as nine of the elements determined for this report (Ag, As, Cd, Cu, Mo, Pb, Sb, U, and Zn). The origin and extent of these zones is not known but may be widespread in areas where the Kaibab Formation is present, either at the surface or in the subsurface. No sulfide minerals are known to be associated with these mineralized zones. The mobility, if any, of these elements in the Kaibab aquifers has also not been established but is not thought to be significant. Nevertheless, a slight potential exists for the presence of toxic levels of these elements in waters from wells drilled anywhere the Kaibab Formation occurs.

CONCLUSIONS AND RECOMMENDATIONS

Only a few localities in Coconino National Forest contain significant anomalies for one or more of the selected elements discussed for this report. As a consequence, only limited areas in the forest can be identified as having: (1) any potential for metallic mineral deposits or (2) potential environmental problems.

The most significant area, for both mineral resources and environmental concerns, is the region along the Verde River Valley. Although uranium anomalies are widespread, past studies indicate that the potential resources for uranium in this region are small. In this area, relatively high concentrations of a number of elements in surficial materials identify contamination related to past mining and smelting, which occurred on the west side of the Verde River, outside of the forest (Fig. 1). In addition, uranium prospects are present in a few localities in the Verde Formation, both along, and just east of, the Verde River Valley. Rock samples analyzed for the present study indicate that relatively low but anomalous levels of arsenic and(or) molybdenum may accompany the uranium. Although concentrations of radon were not measured for this study, a potential exists for the presence of this element in areas enriched in uranium. Wells drawing ground water from this region may also contain potentially hazardous concentrations of uranium, radon, and(or) other elements. We are not aware of any study of such well waters and recommend that well waters be analyzed, especially if used for domestic purposes.

As noted above, soils in the area from the Verde River Valley eastward for an unknown distance have been contaminated with a number of potentially toxic elements deposited from smelter effluent. The extent of this contamination was not determined for this study. Detailed soil surveys for this purpose are recommended.

We also caution that, although no problem is now known to exist, a potential environmental problem may exist in well waters coming from some aquifers in the Kaibab Formation, as anomalous concentrations of a number of potentially toxic elements were found in silicified zones in that formation. The locations and extents of these silicified zones are not known. No sulfide minerals were identified in the samples of rock collected from these zones for this study; thus, the mobility of the elements of concern is probably limited. Again, analyses of well waters were not done for this study but would seem to be a prudent recommendation if a given well is expected to penetrate any silica-rich zones in the Kaibab Formation.

Samples of manganese from deposits in the Long Valley area, near Clints Well in the southern part of the forest, were found to contain significant concentrations of as many as 13 of the elements determined for this study. However, downstream dispersion of these elements probably does not extend more than a few miles below old mine workings. The lack of any sulfide minerals in these deposits indicates that no acid is generated upon weathering of these deposits. Past studies suggest that the potential resources for manganese are small.

The minor exposures of sulfide minerals in Fossil Creek Canyon do not constitute a significant acid-generating source. Based on our evaluation of the data gathered for this report, other potential sources of concentrations of metallic minerals are not thought to be significant enough in terms of grade, tonnage, or sulfide content, to identify significant mineral resources or to produce potential environmental problems.

A concern has been registered in the past by Forest Service officials that claims are being filed for gold in the forest in localities where geologic conditions suggest that gold deposits are not likely to occur. We note that very few gold values above the lower limit of determination (0.002 ppm) were found in the samples analyzed for this report. Our observations are corroborated by the regional sampling and analysis for gold described by Lane (1992). The lack of any meaningful gold concentrations in the samples collected within the forest suggests that this element is probably not enriched to the level of a potential resource anywhere in the forest and, in any case--with the exception of several NURE samples included in the NURE data set but collected from outside the forest in the Verde River Valley--is not associated with any known type of mineral deposit or alteration phase sampled in the study area.

ACKNOWLEDGMENTS

Many people have assisted us in this project. Help provided by the Coconino National Forest personnel, Flagstaff, Arizona, is appreciated. We thank P.M. Theodorakos, USGS, Denver, Colorado, for assistance in preparing the samples for analysis and G.B. Haxel and J.D. Hendricks of the USGS office in Flagstaff, Arizona, for guidance in the field.

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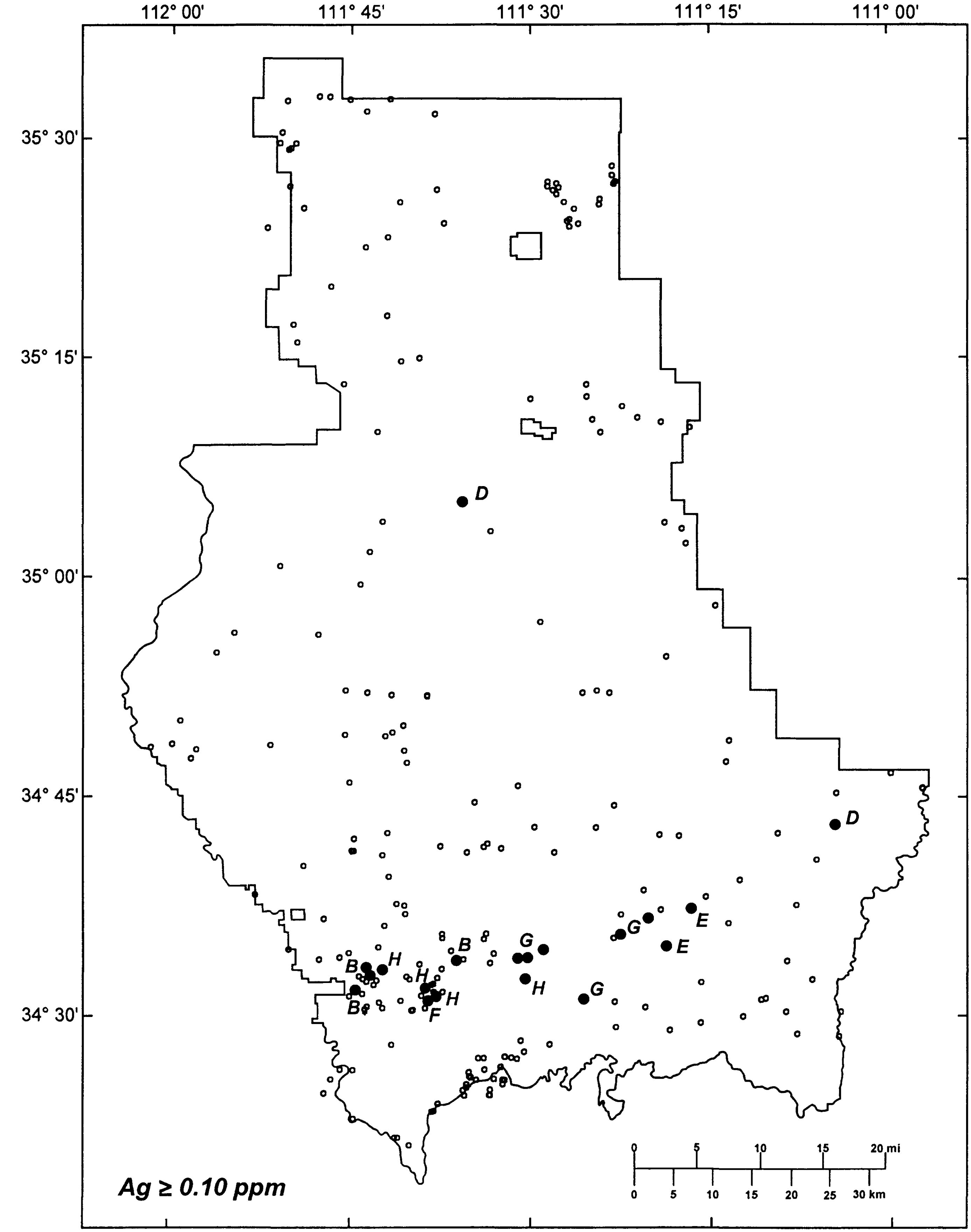

Figure 5. Distribution of anomalous silver in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

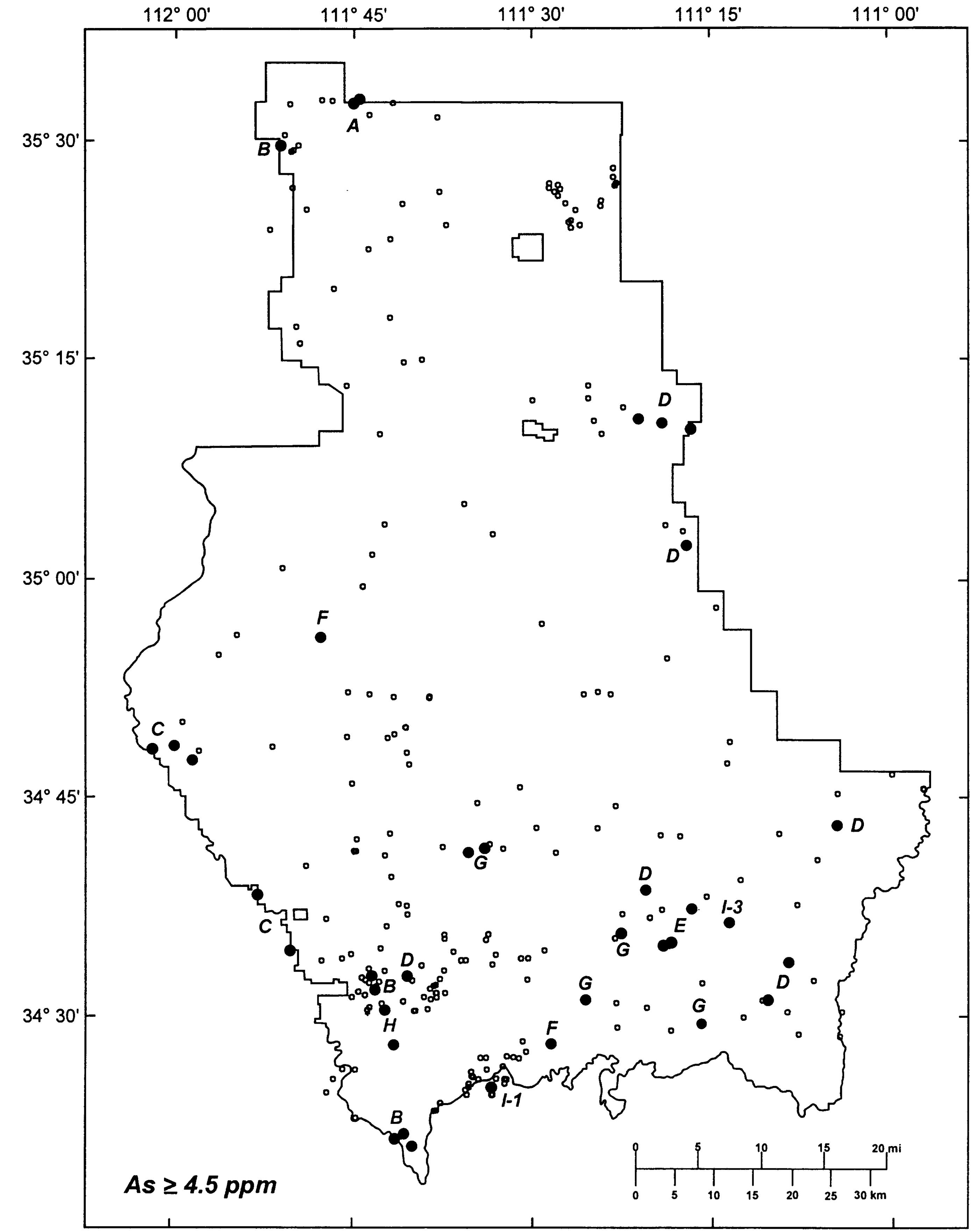

Figure 6. Distribution of anomalous arsenic in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

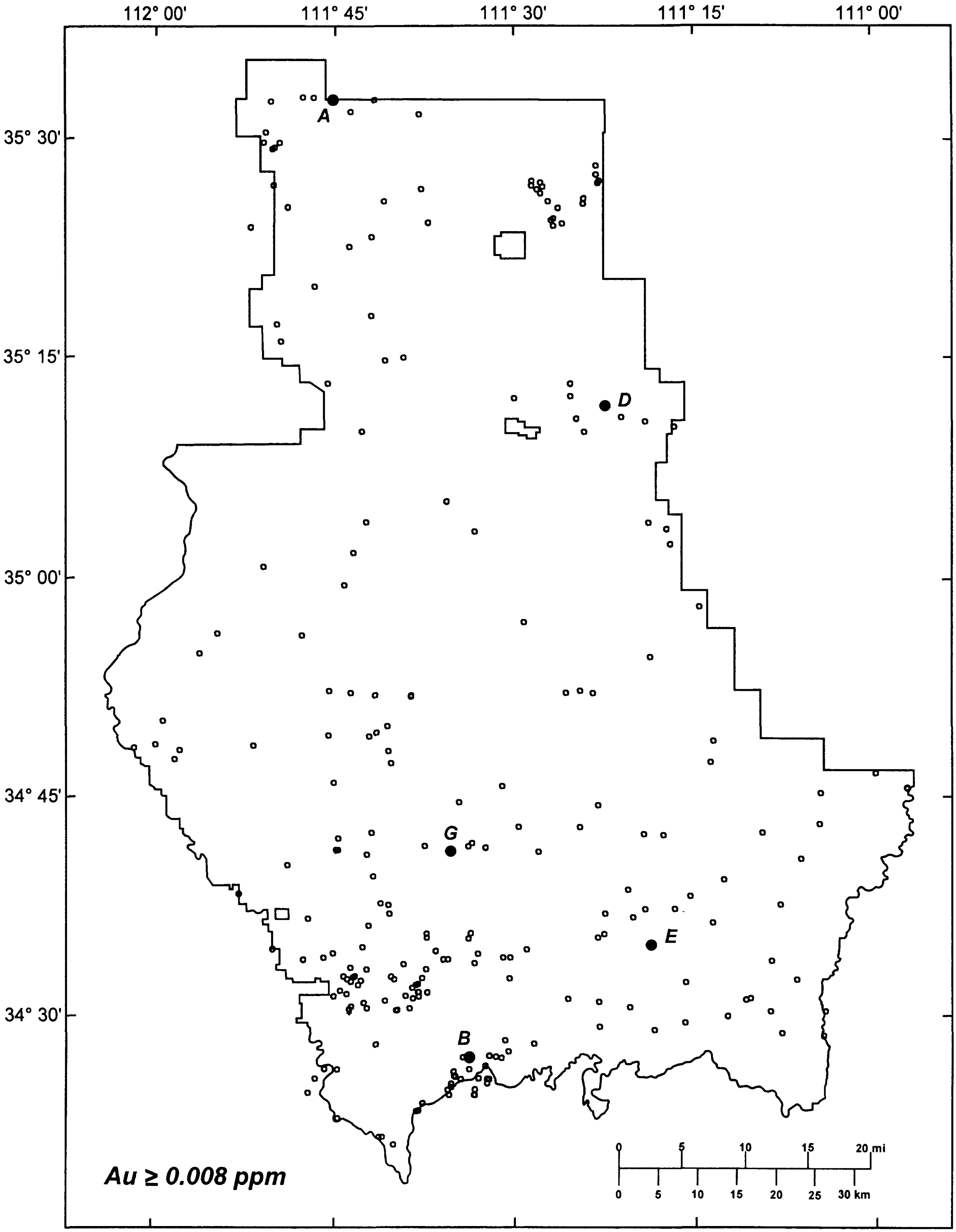

Figure 7. Distribution of anomalous gold in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

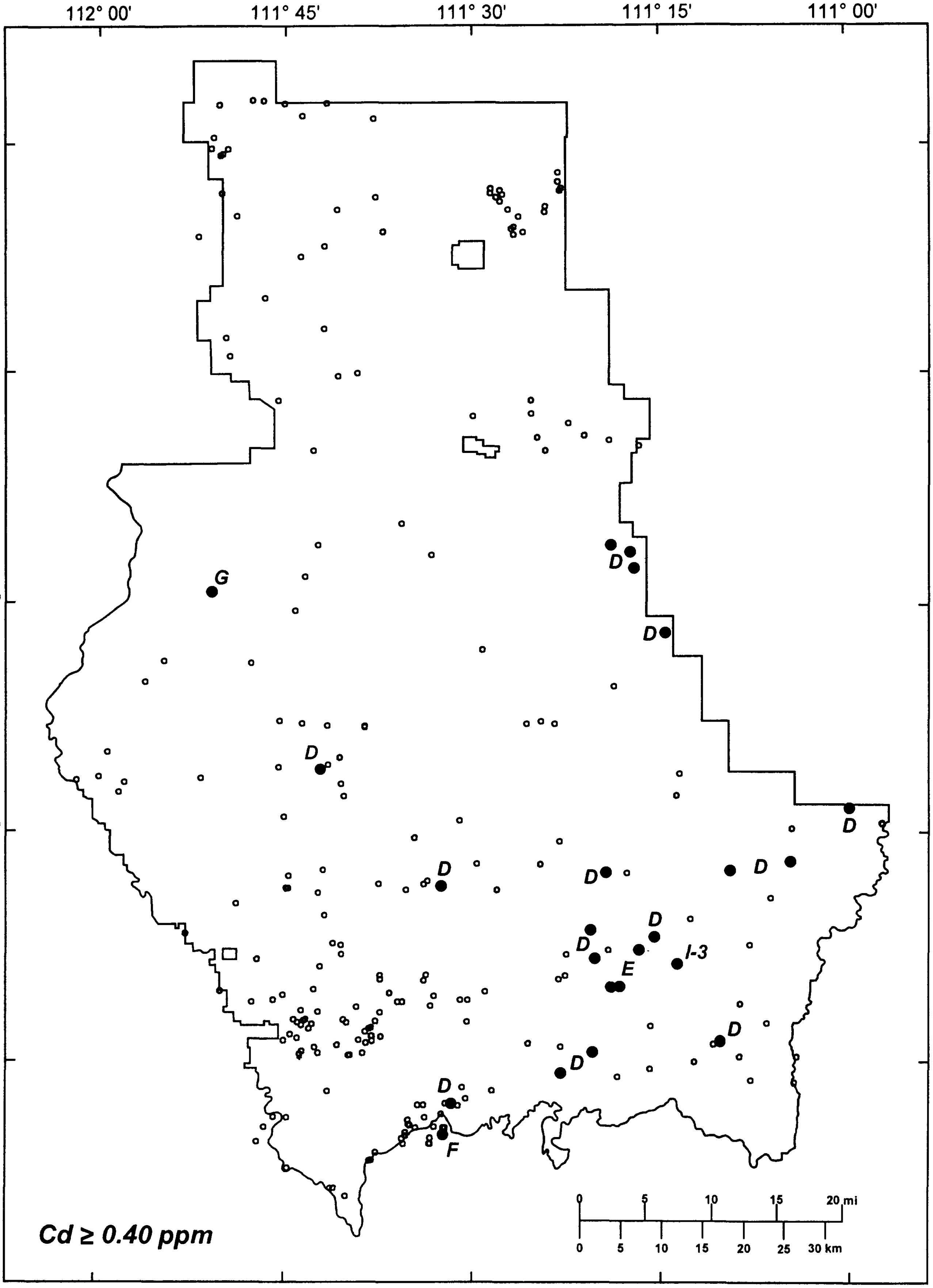

Figure 8. Distribution of anomalous cadmium in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

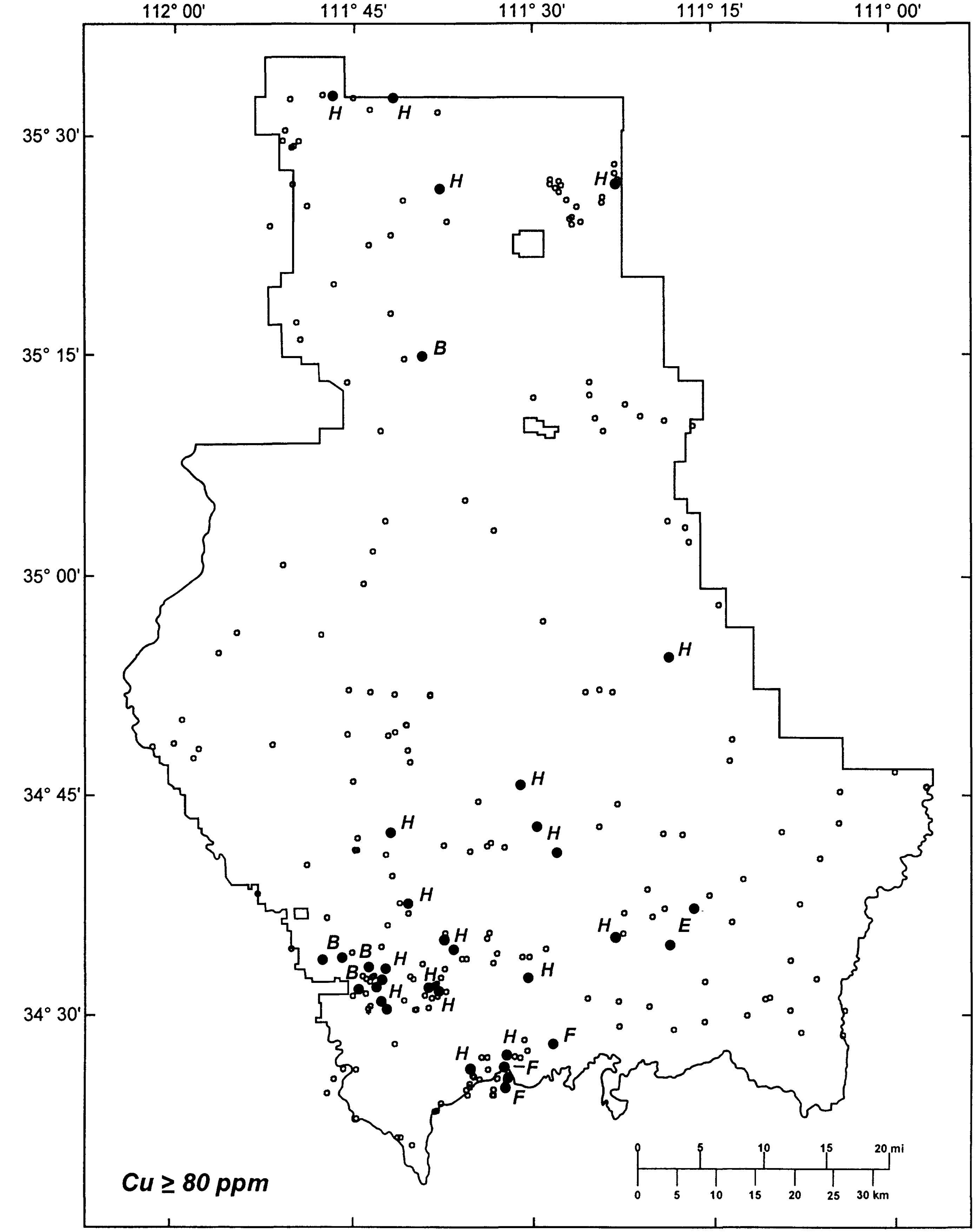

Figure 9. Distribution of anomalous copper in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

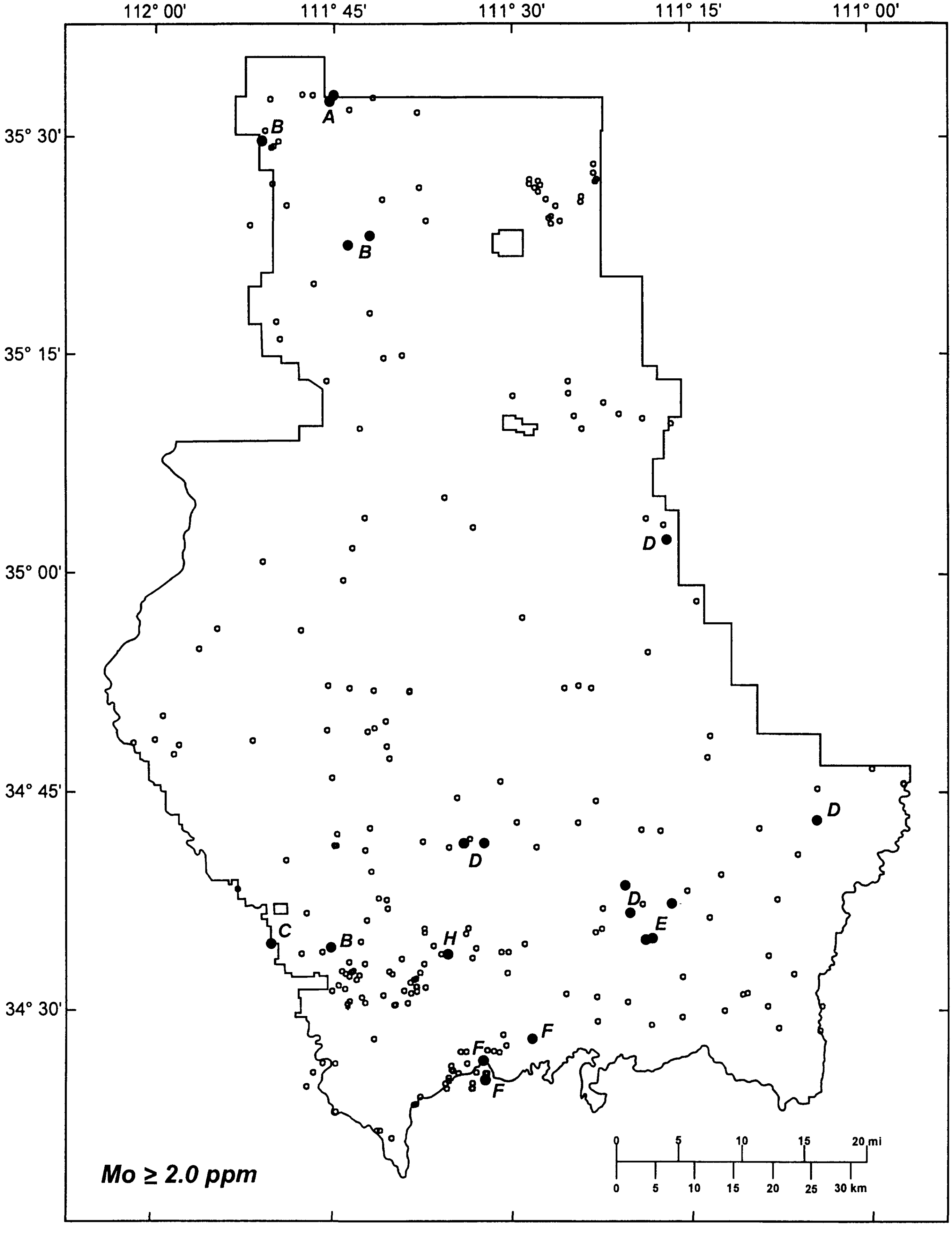

Figure 10. Distribution of anomalous molybdenum in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

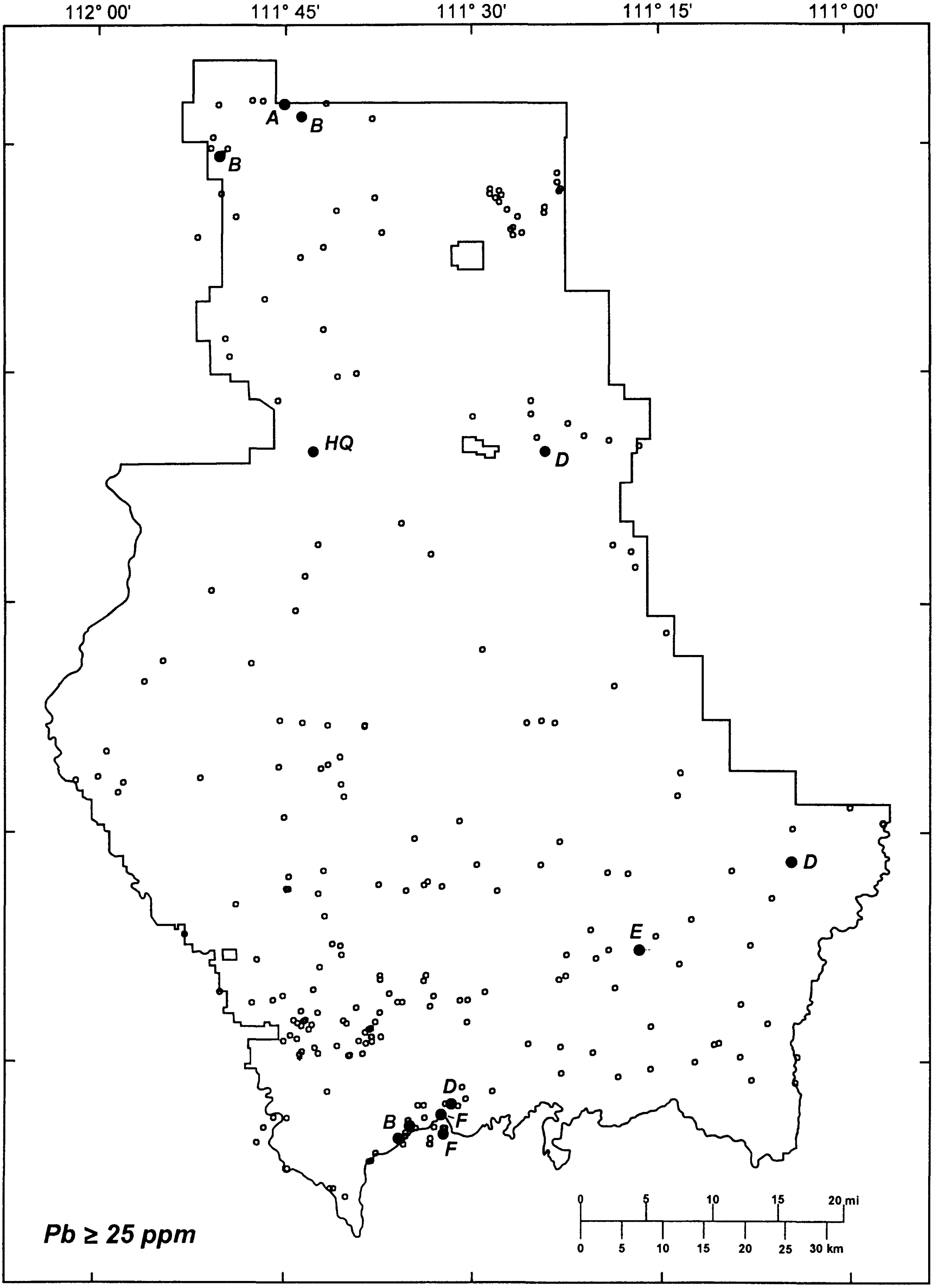

Figure 11. Distribution of anomalous lead in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

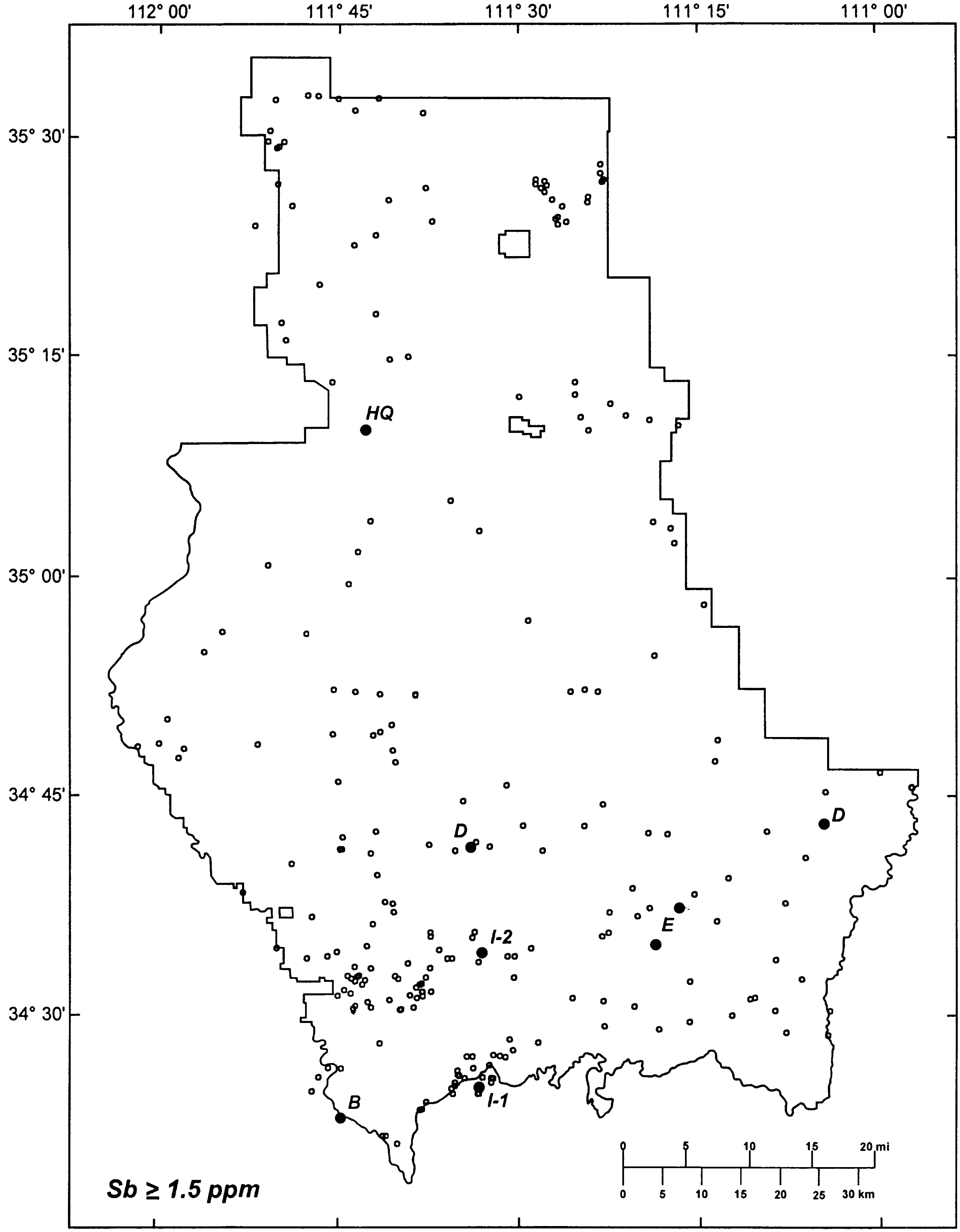

Figure 12. Distribution of anomalous antimony in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

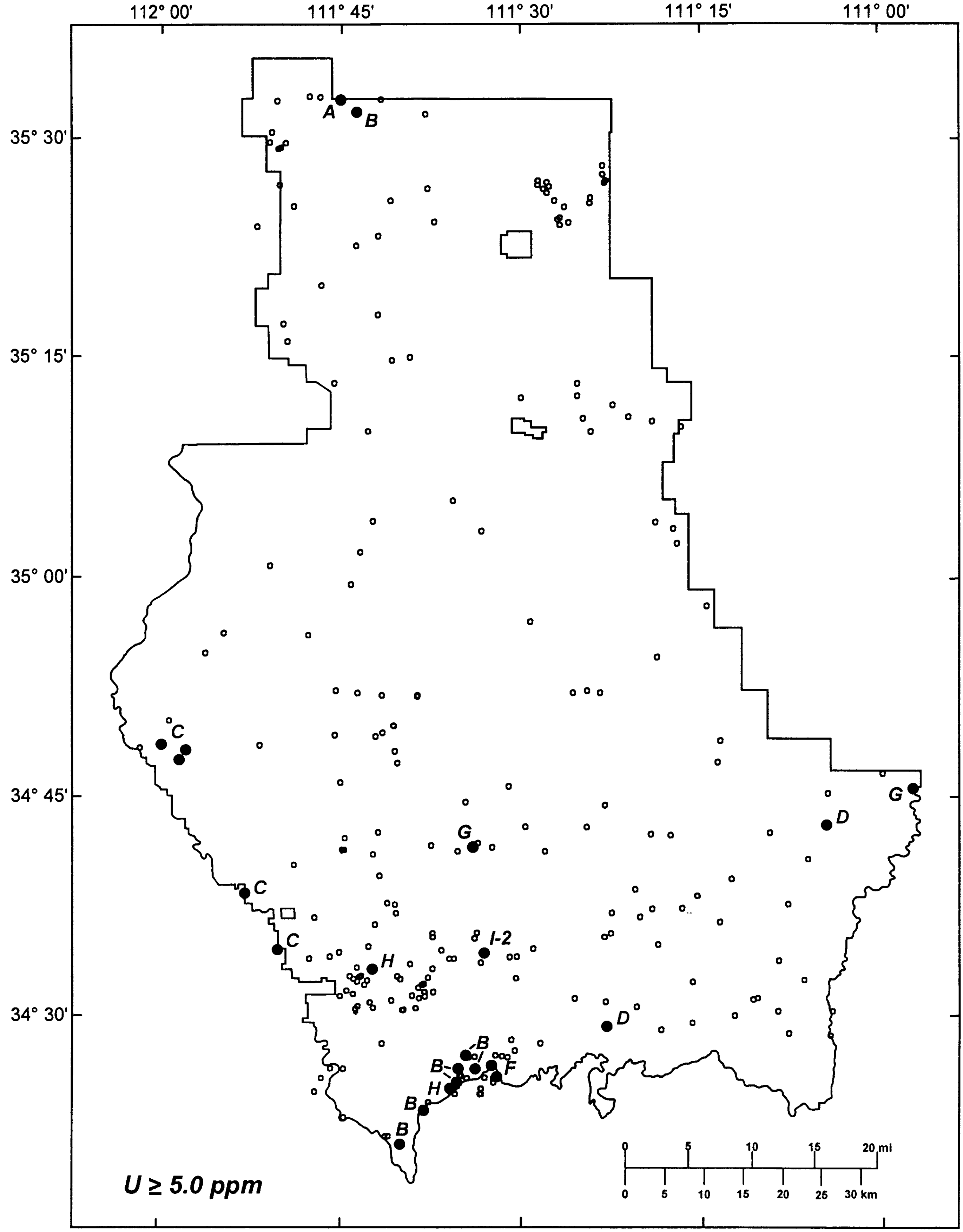

Figure 13. Distribution of anomalous uranium in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

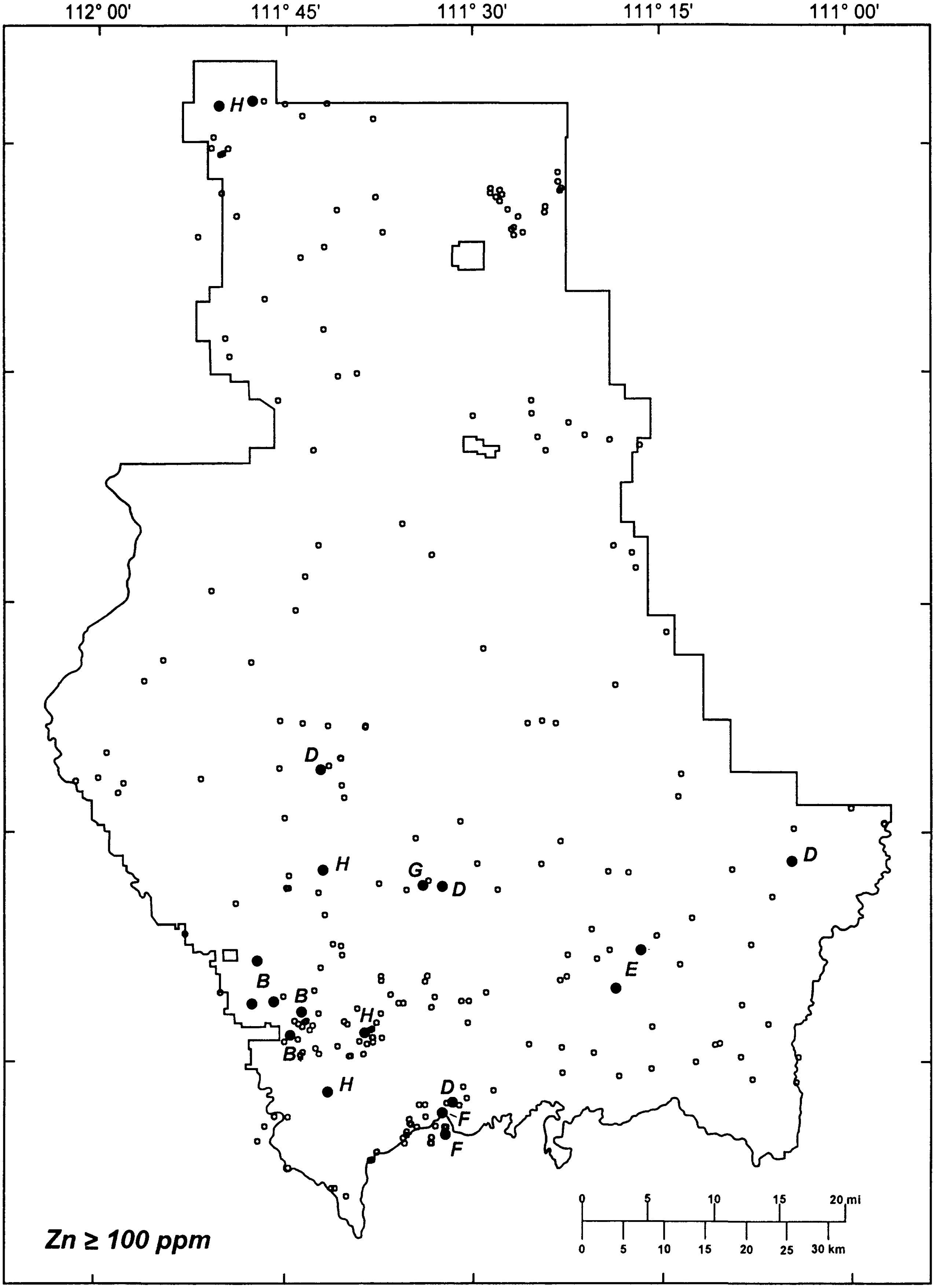

Figure 14. Distribution of anomalous zinc in rock samples, Coconino National Forest, Arizona. See text for explanation of symbols.

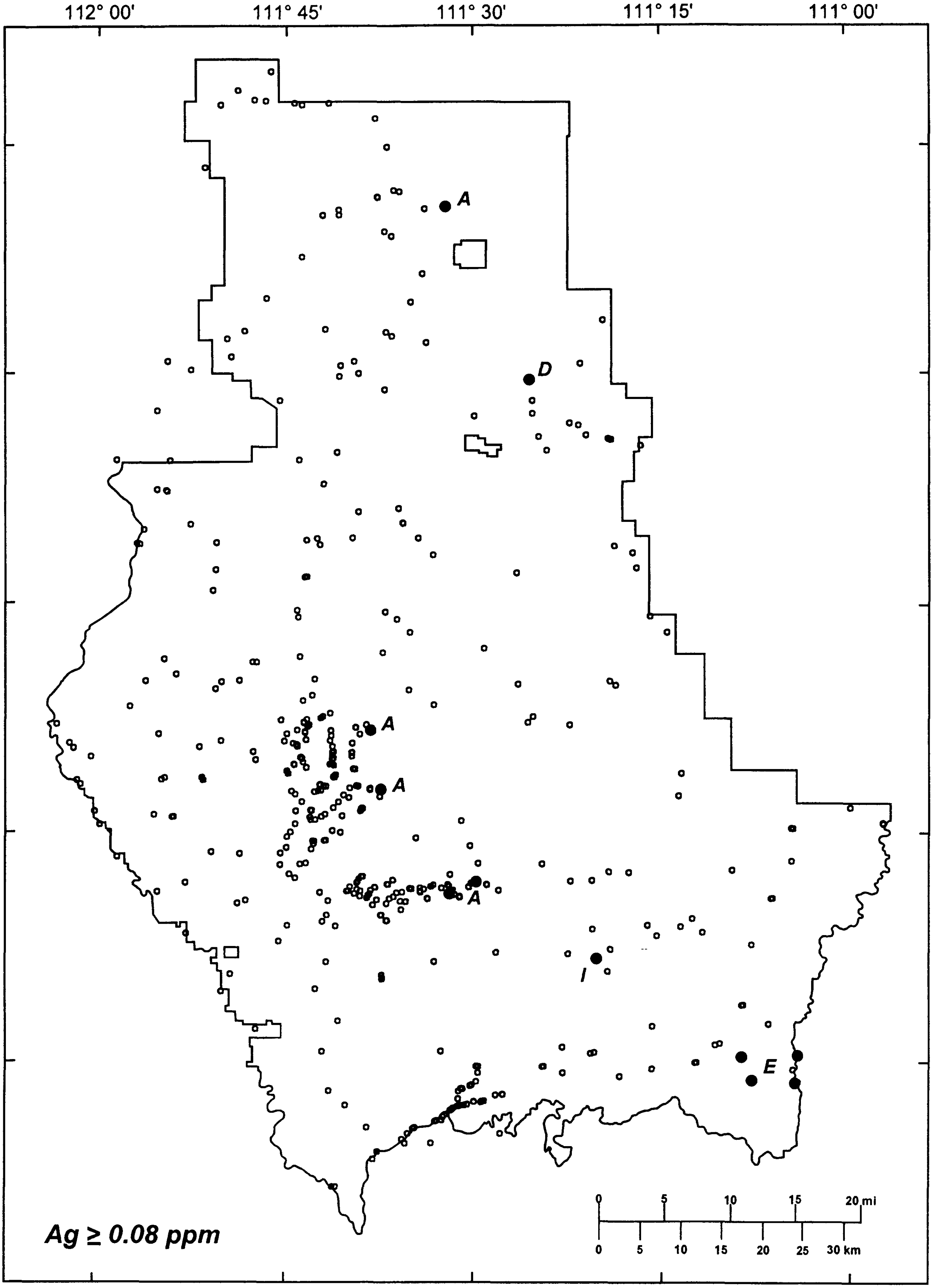

Figure 15. Distribution of anomalous silver in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

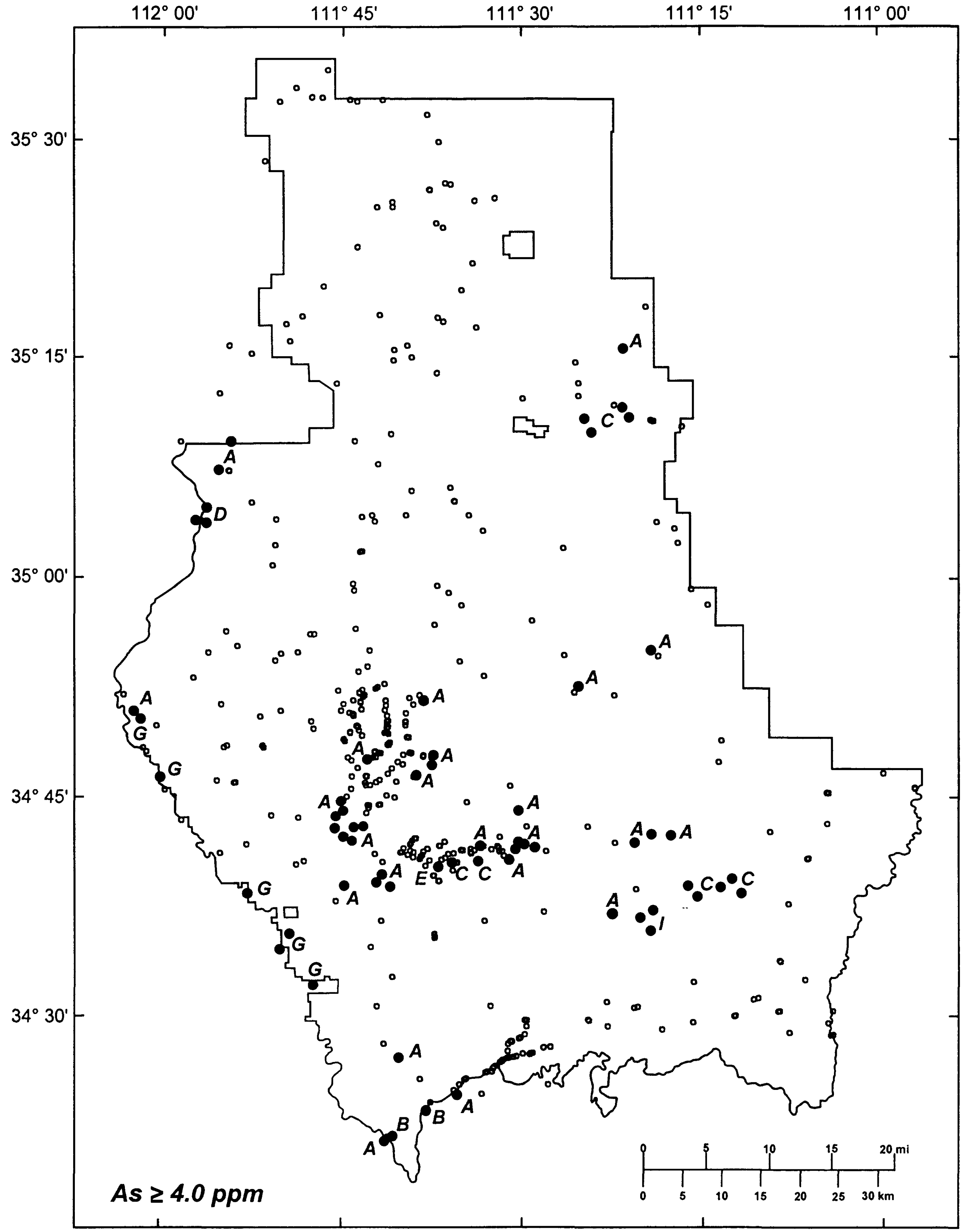

Figure 16. Distribution of anomalous arsenic in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

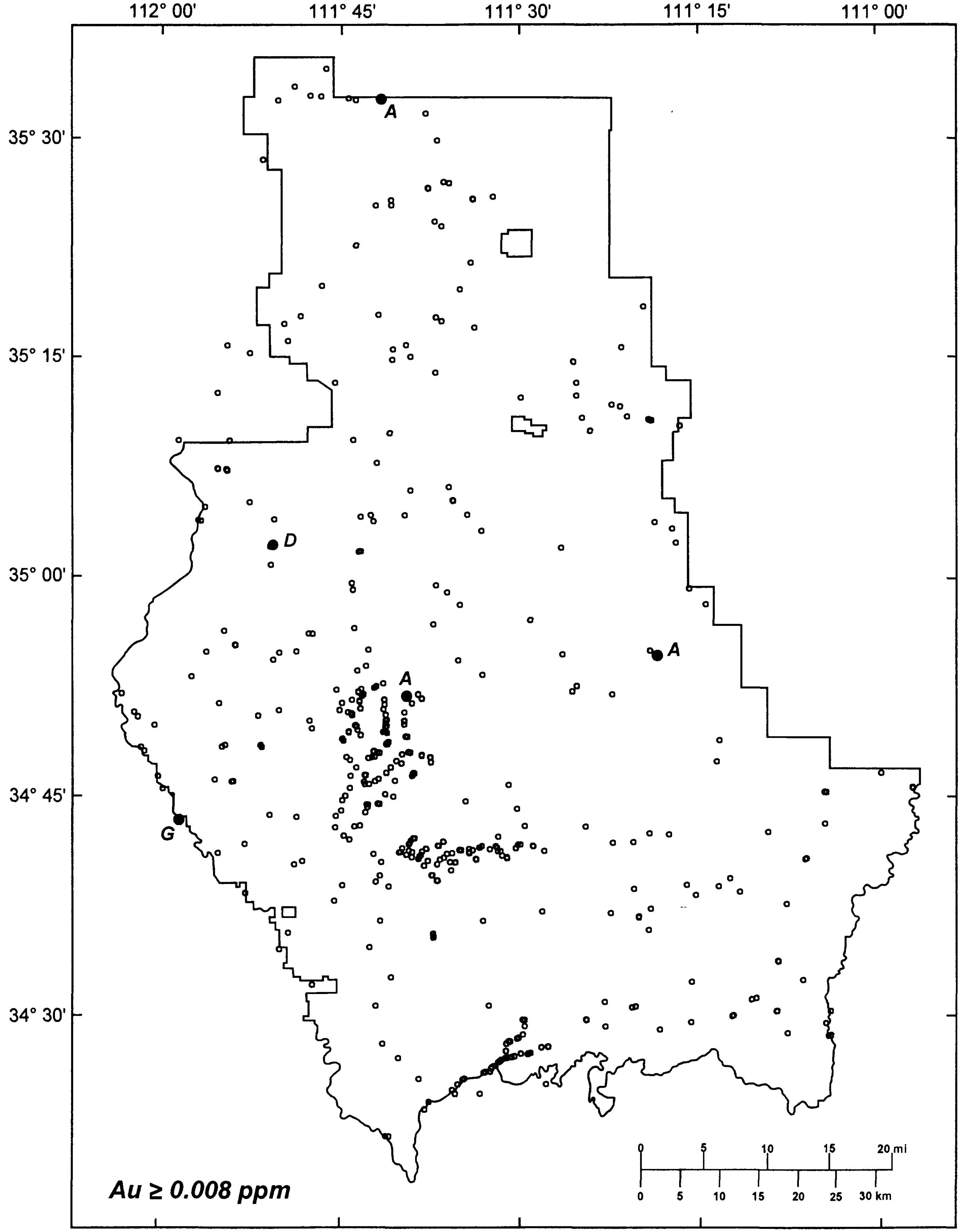

Figure 17. Distribution of anomalous gold in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

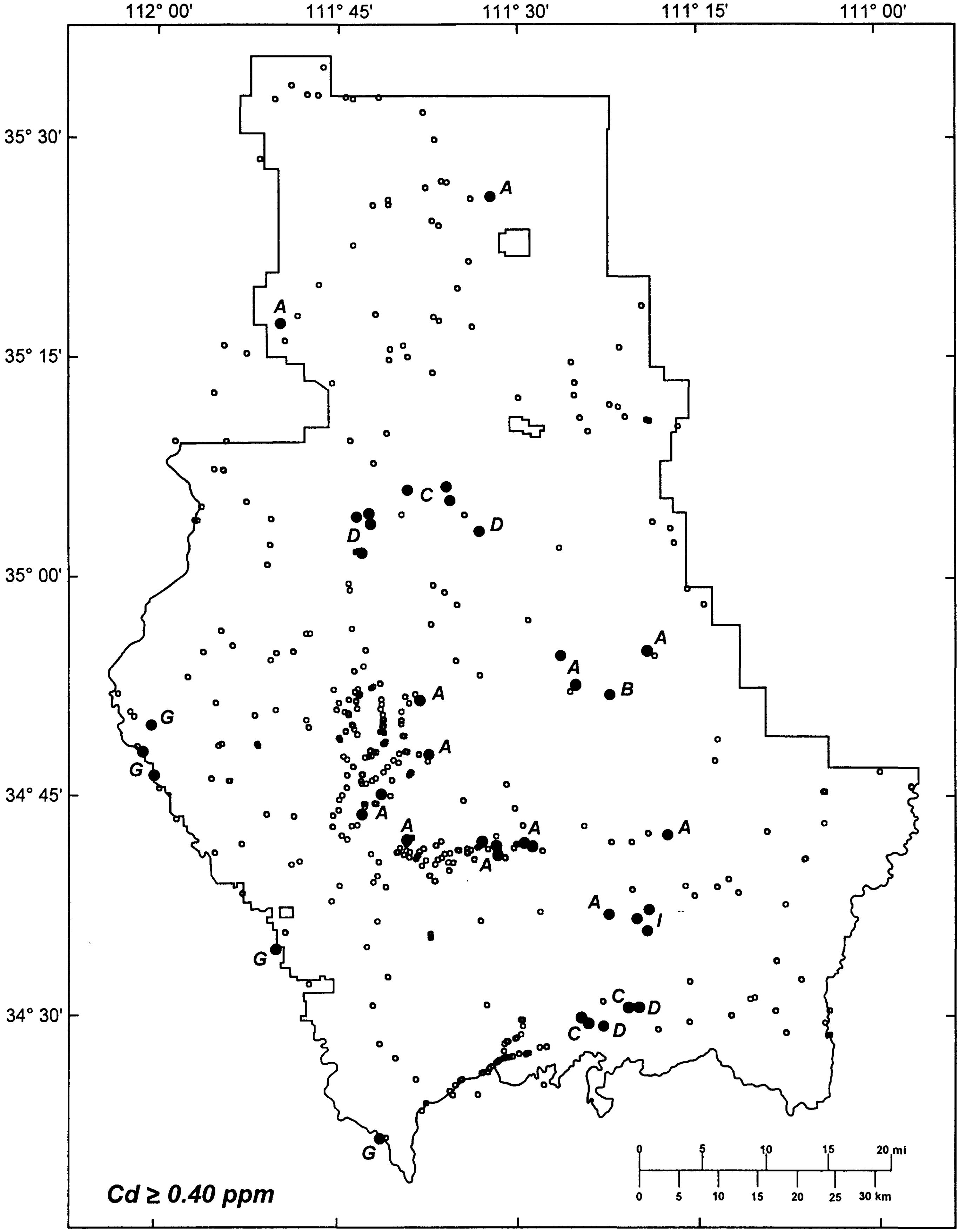

Figure 18. Distribution of anomalous cadmium in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

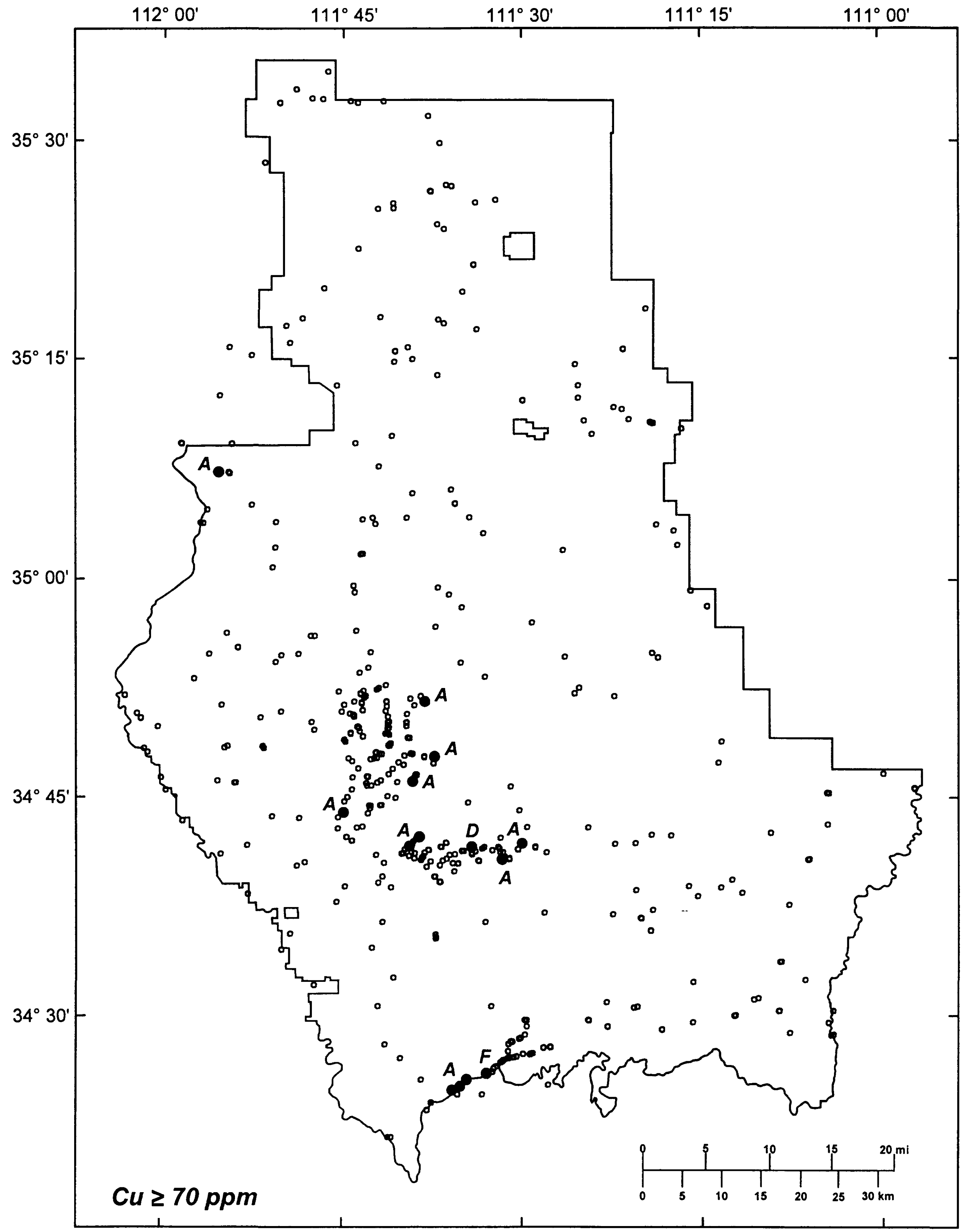

Figure 19. Distribution of anomalous copper in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

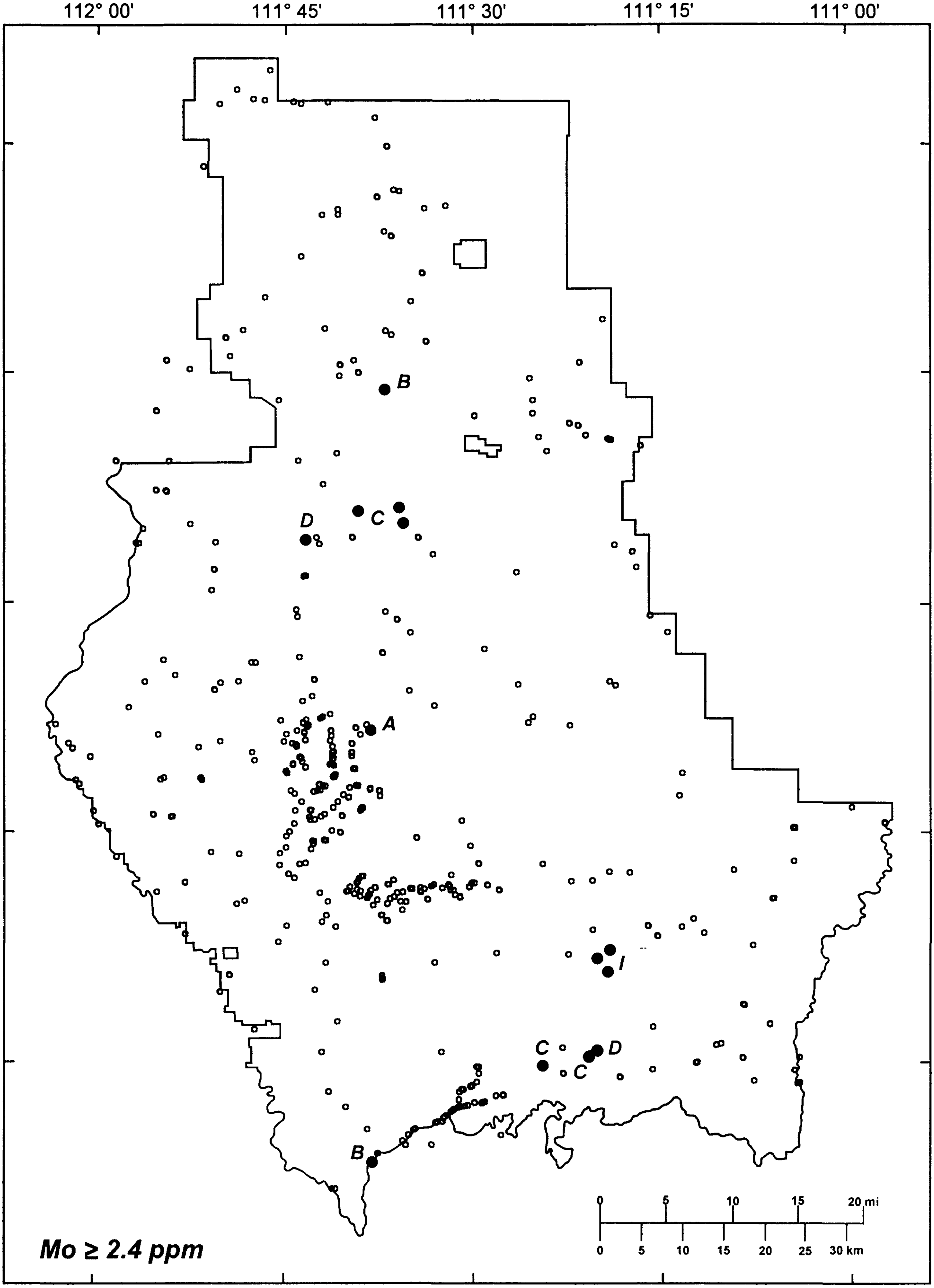

Figure 20. Distribution of anomalous molybdenum in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

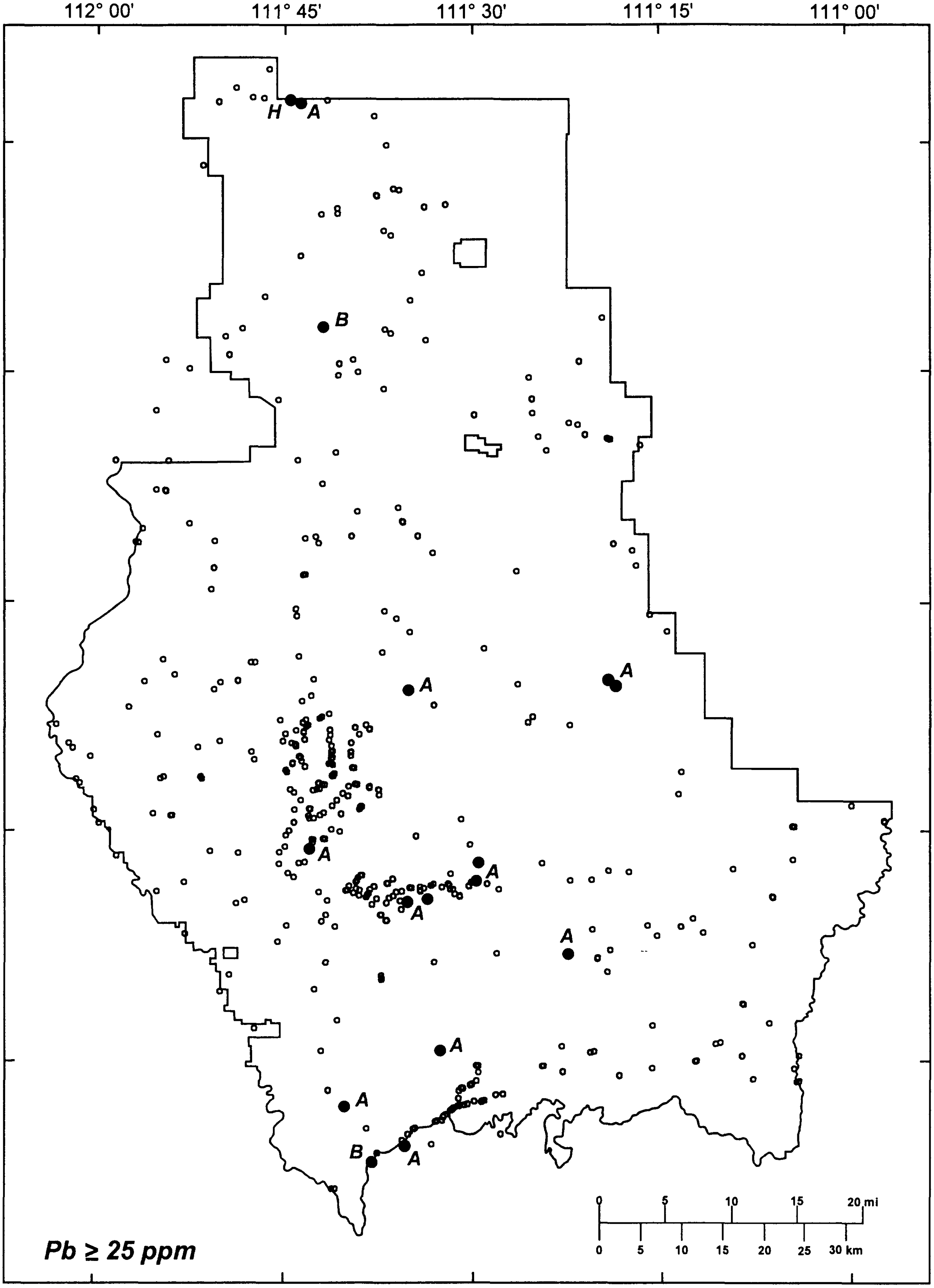

Figure 21. Distribution of anomalous lead in USGS stream sediment-samples, Coconino National Forest, Arizona. See text for explanation of symbols.

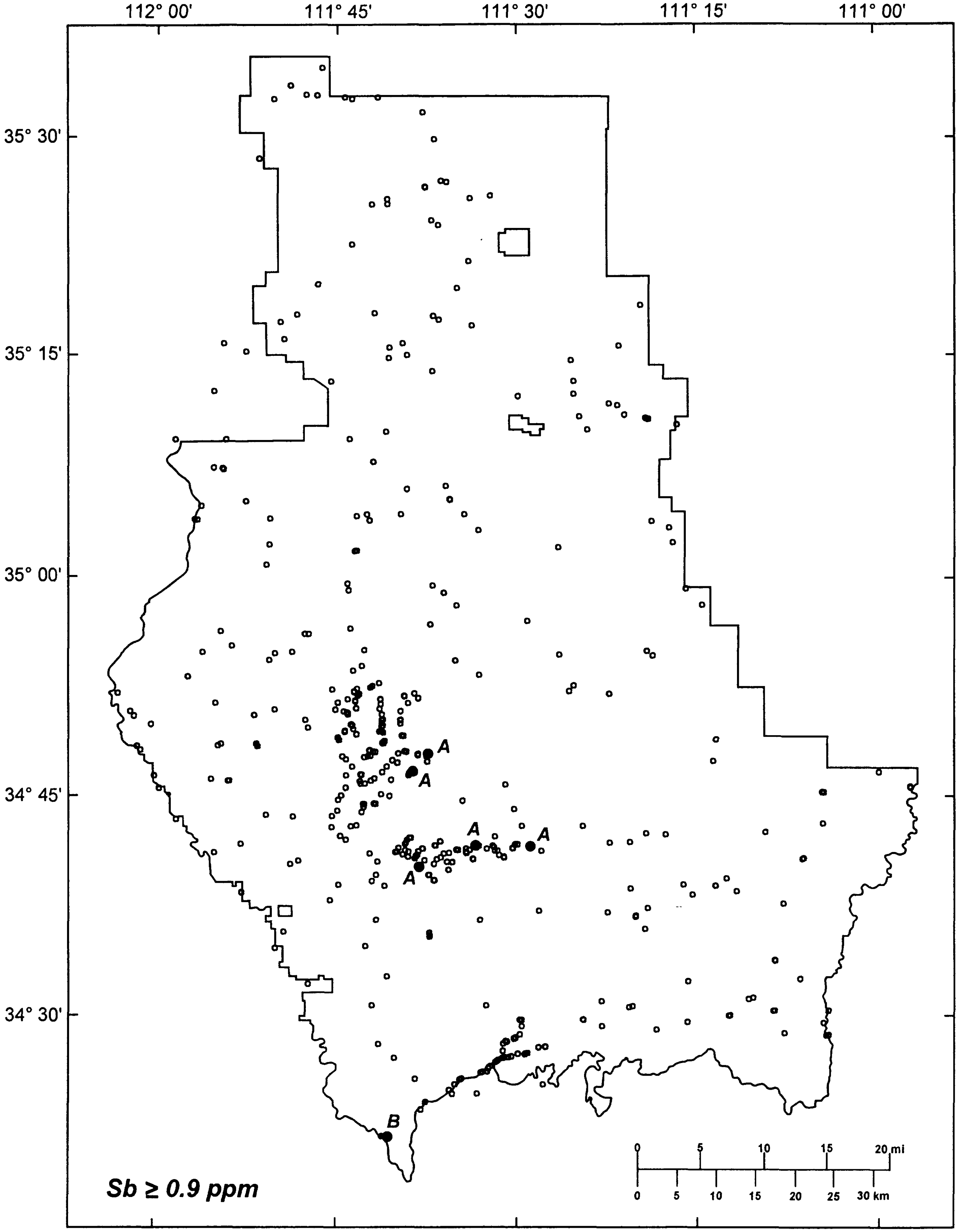

Figure 22. Distribution of anomalous antimony in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

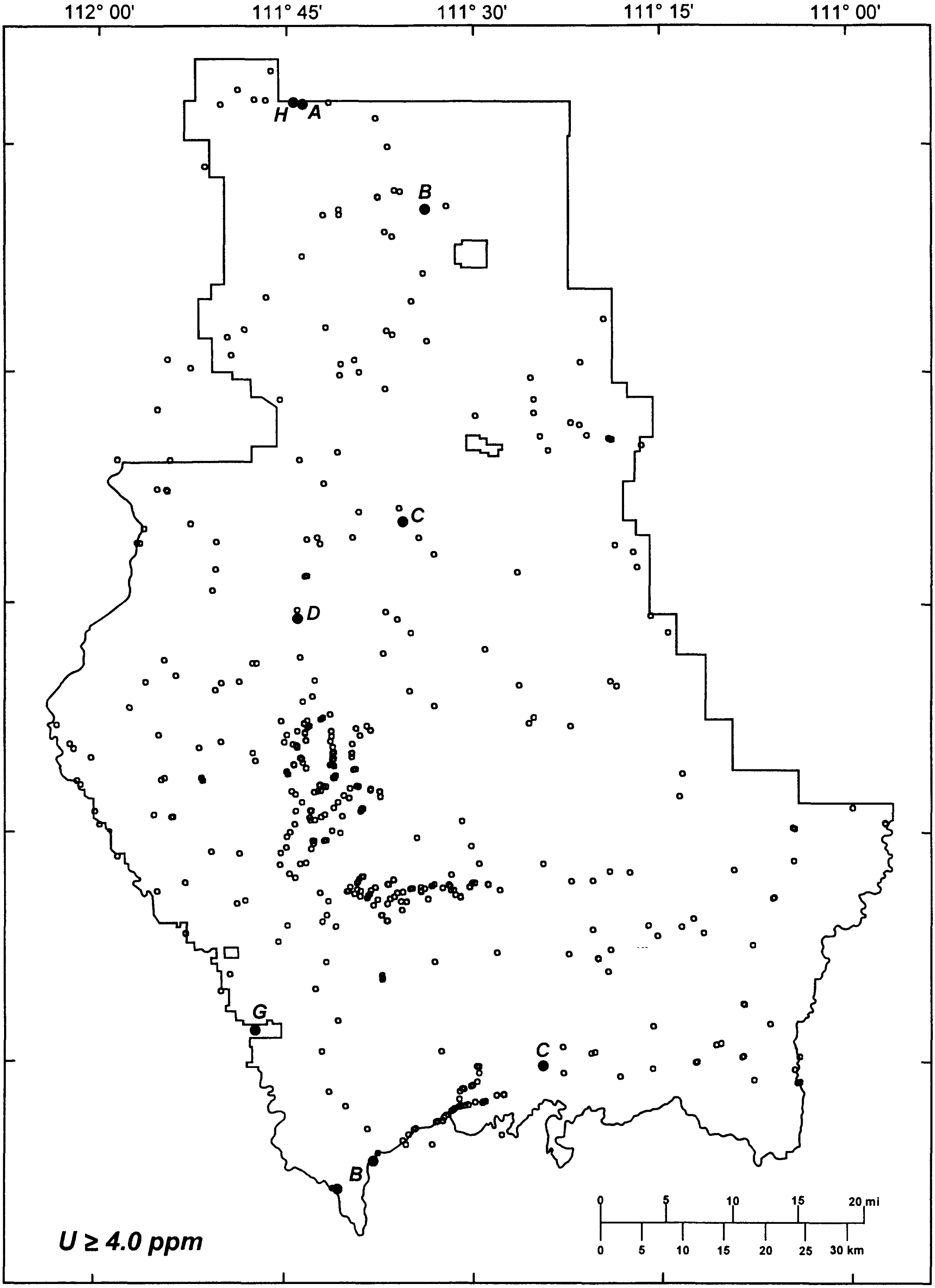

Figure 23. Distribution of anomalous uranium in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

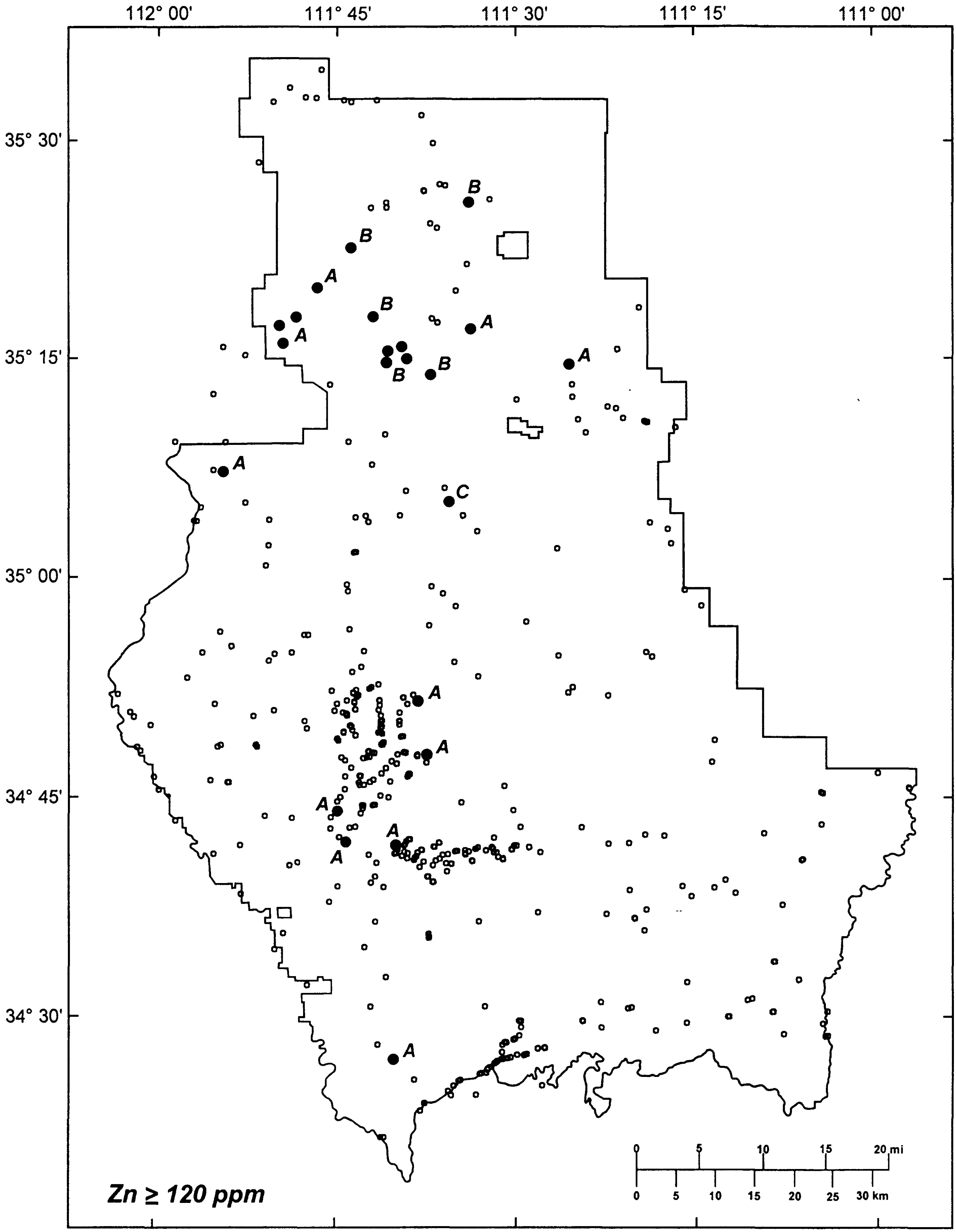

Figure 24. Distribution of anomalous zinc in USGS stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

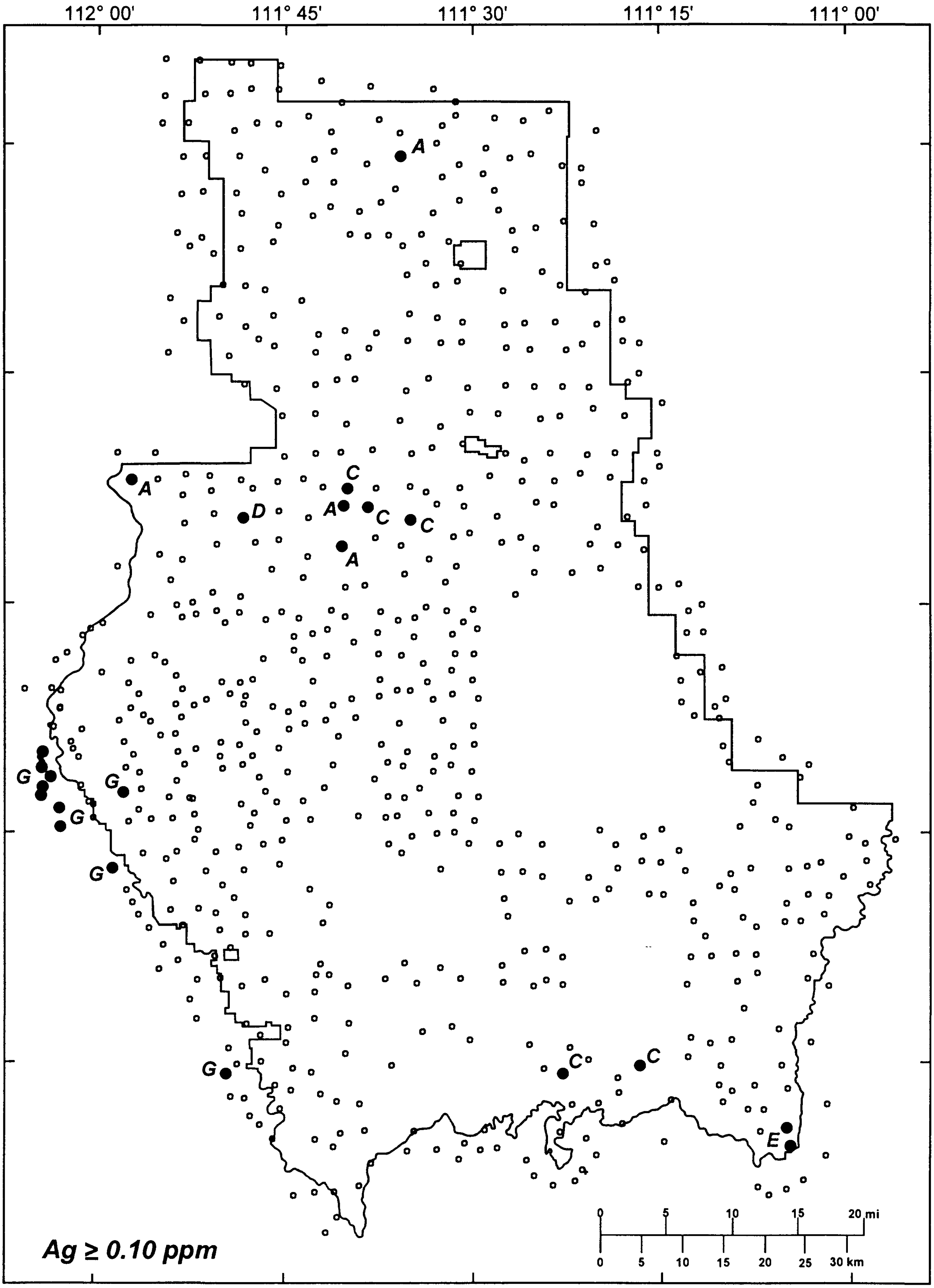

Figure 25. Distribution of anomalous silver in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

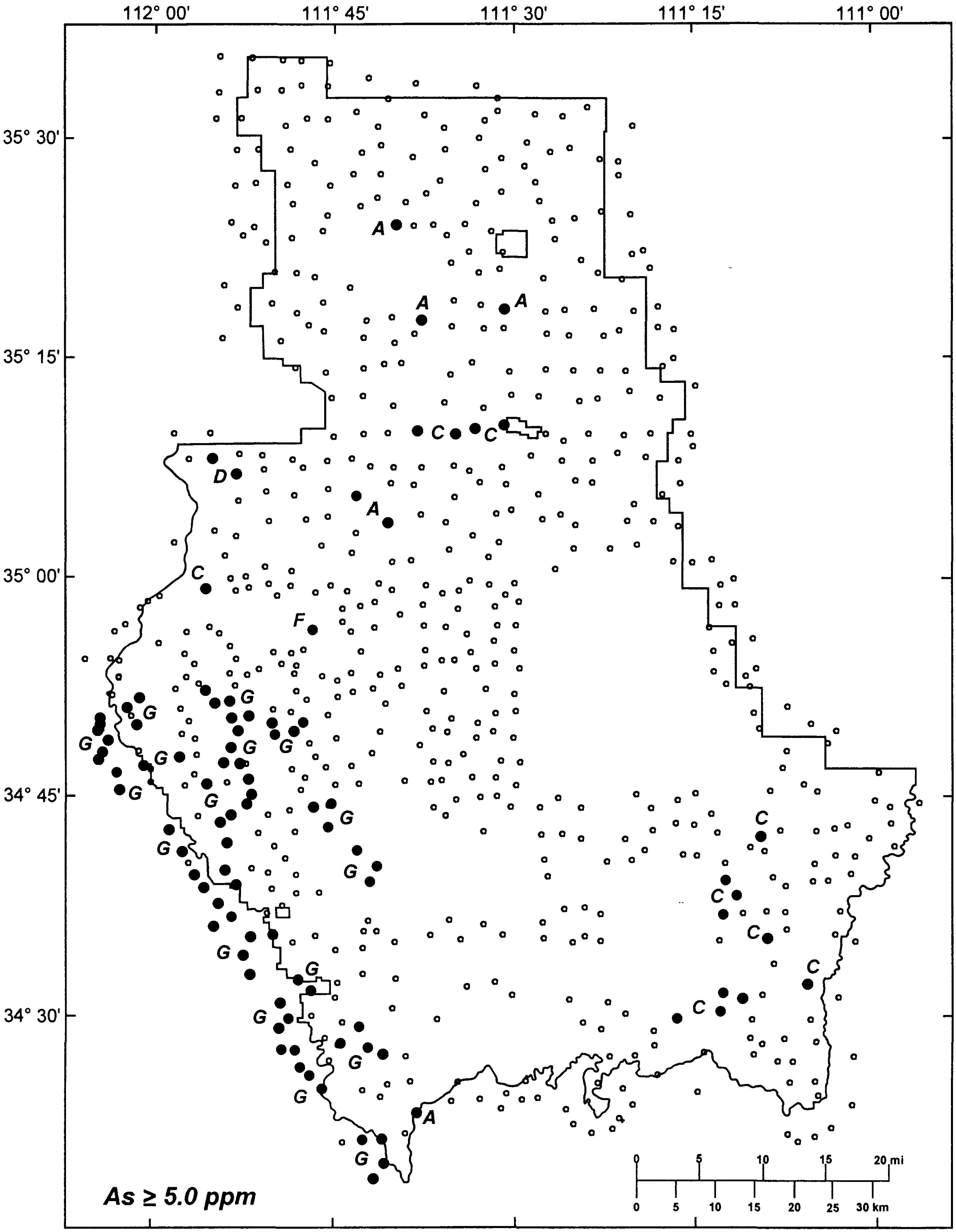

Figure 26. Distribution of anomalous arsenic in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

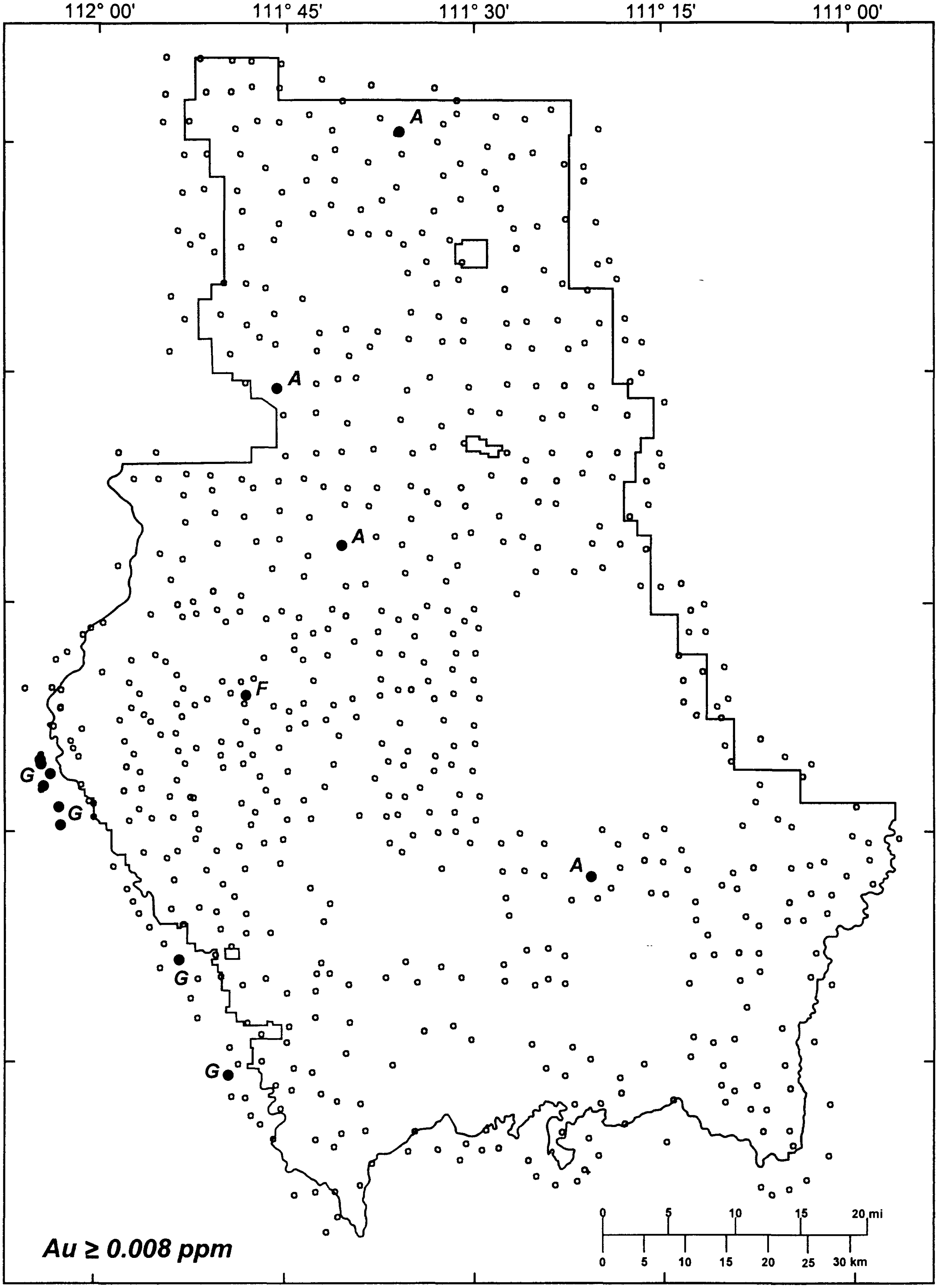

Figure 27. Distribution of anomalous gold in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

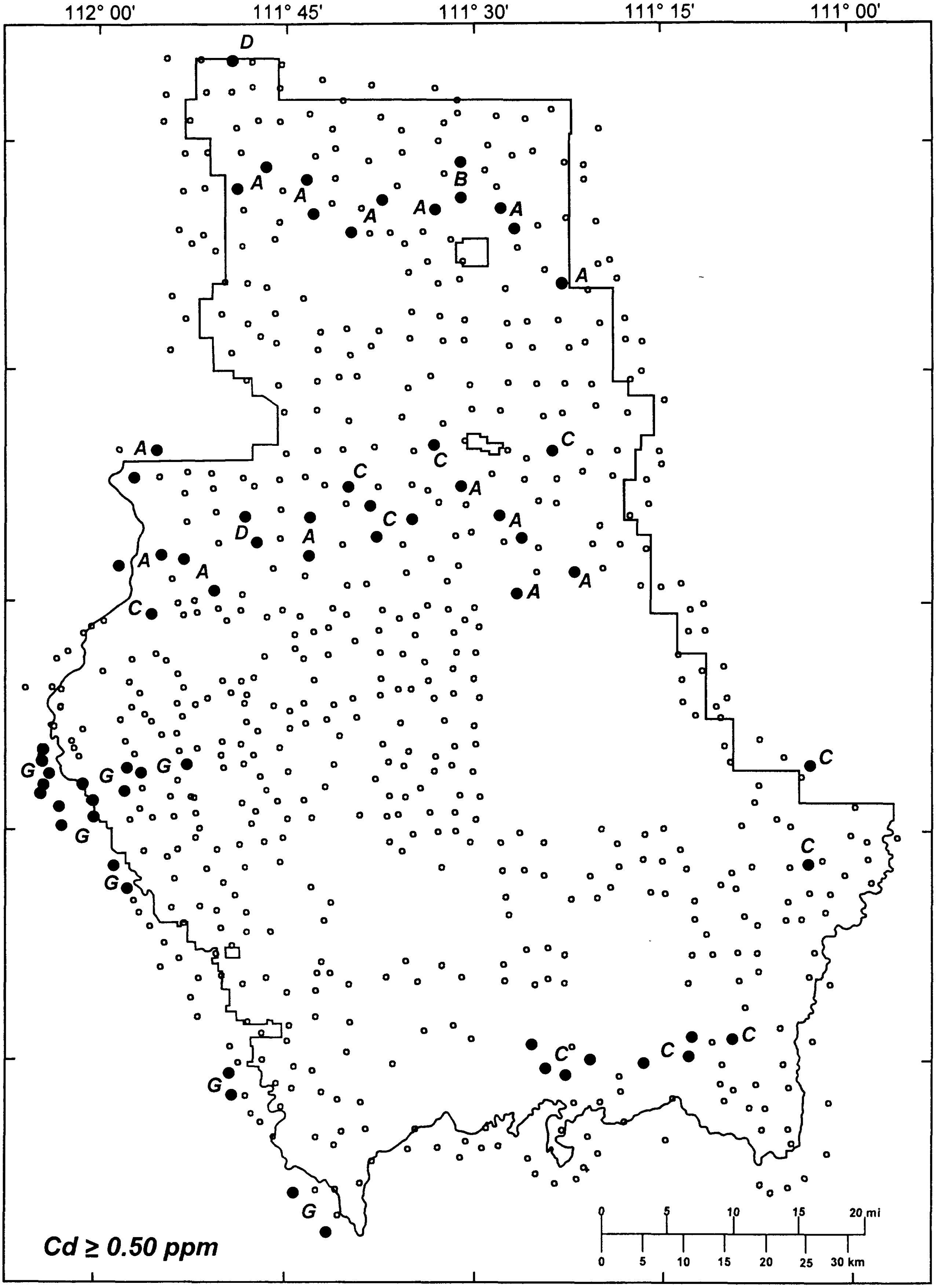

Figure 28. Distribution of anomalous cadmium in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

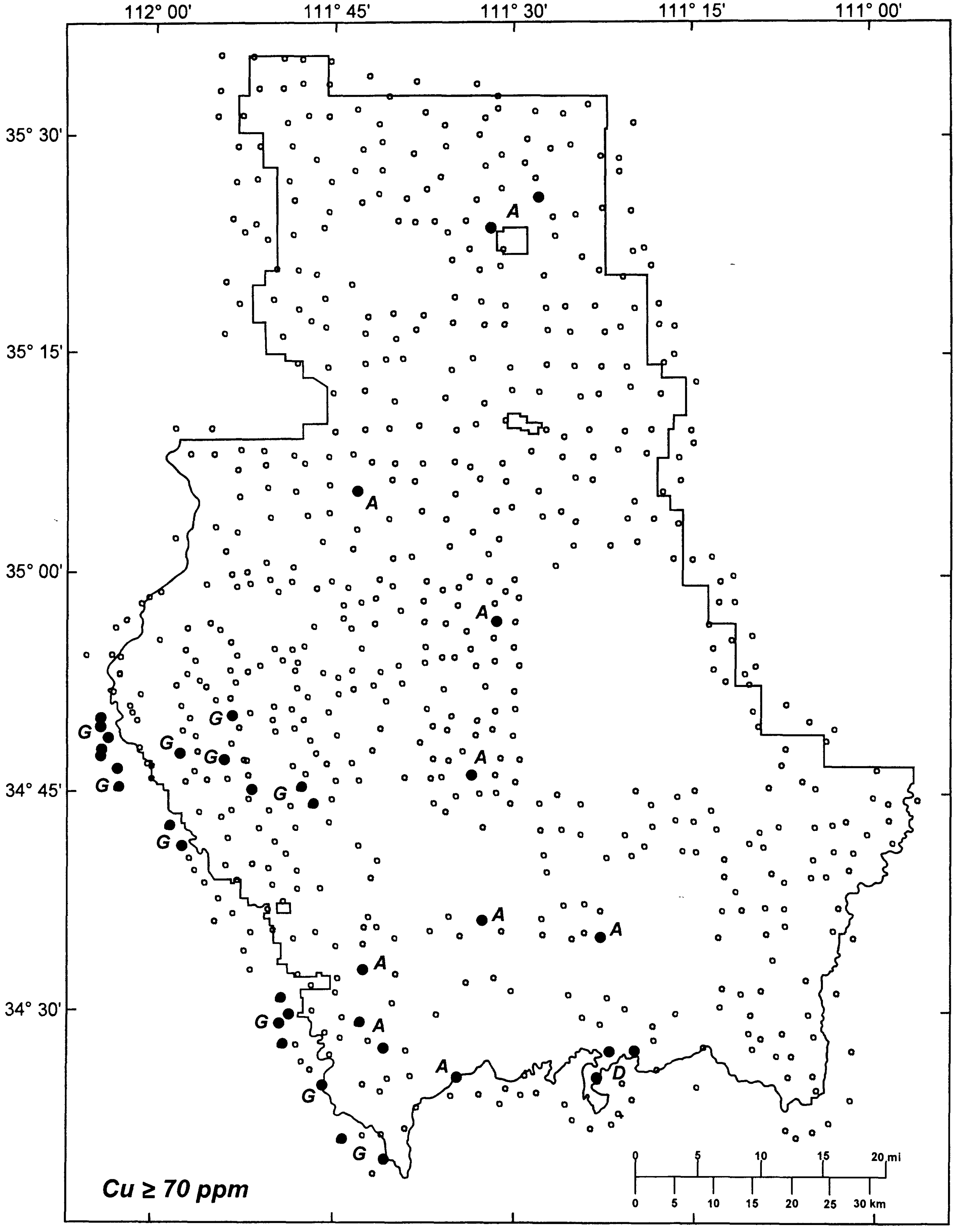

Figure 29. Distribution of anomalous copper in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

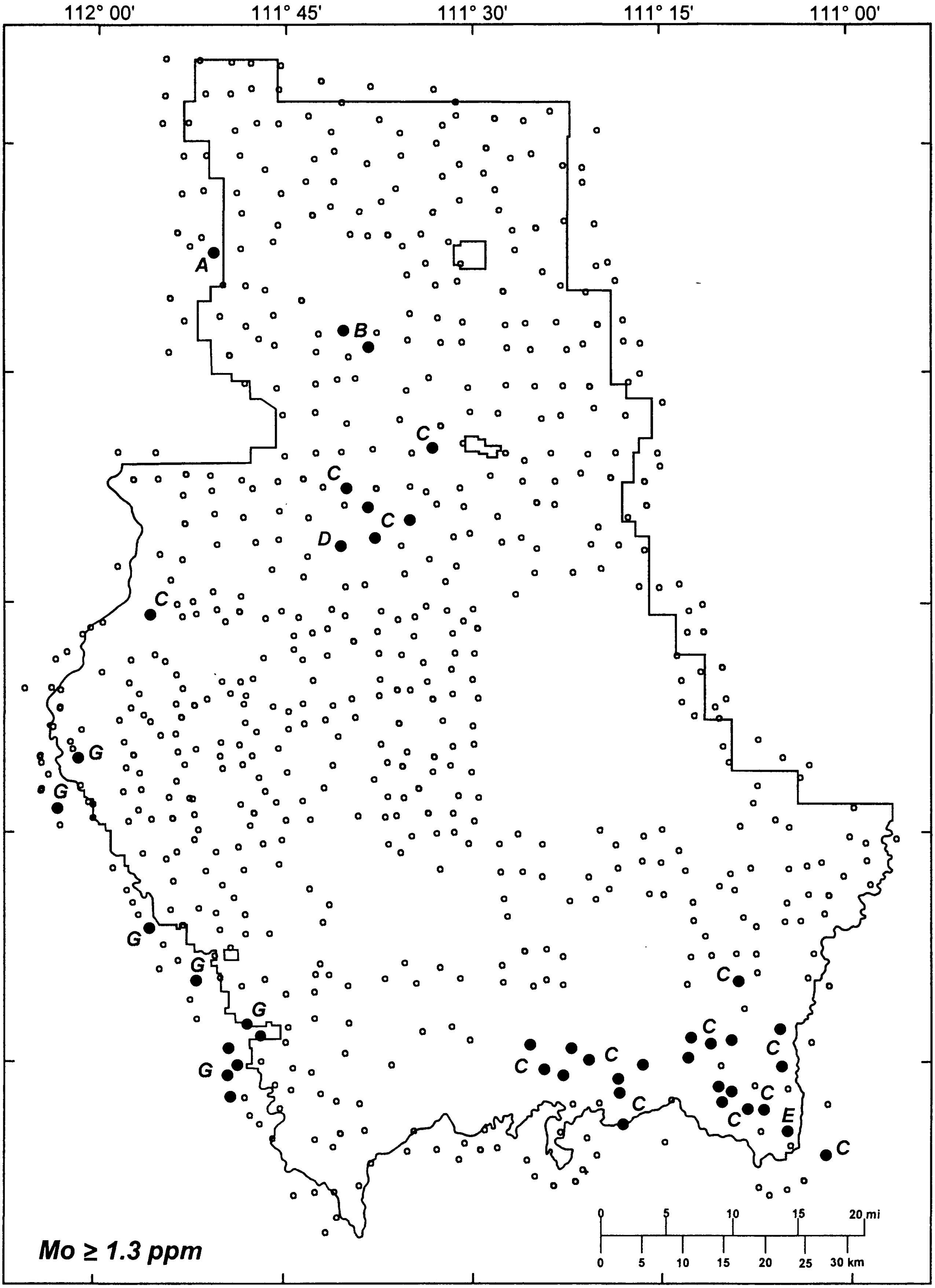

Figure 30. Distribution of anomalous molybdenum in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

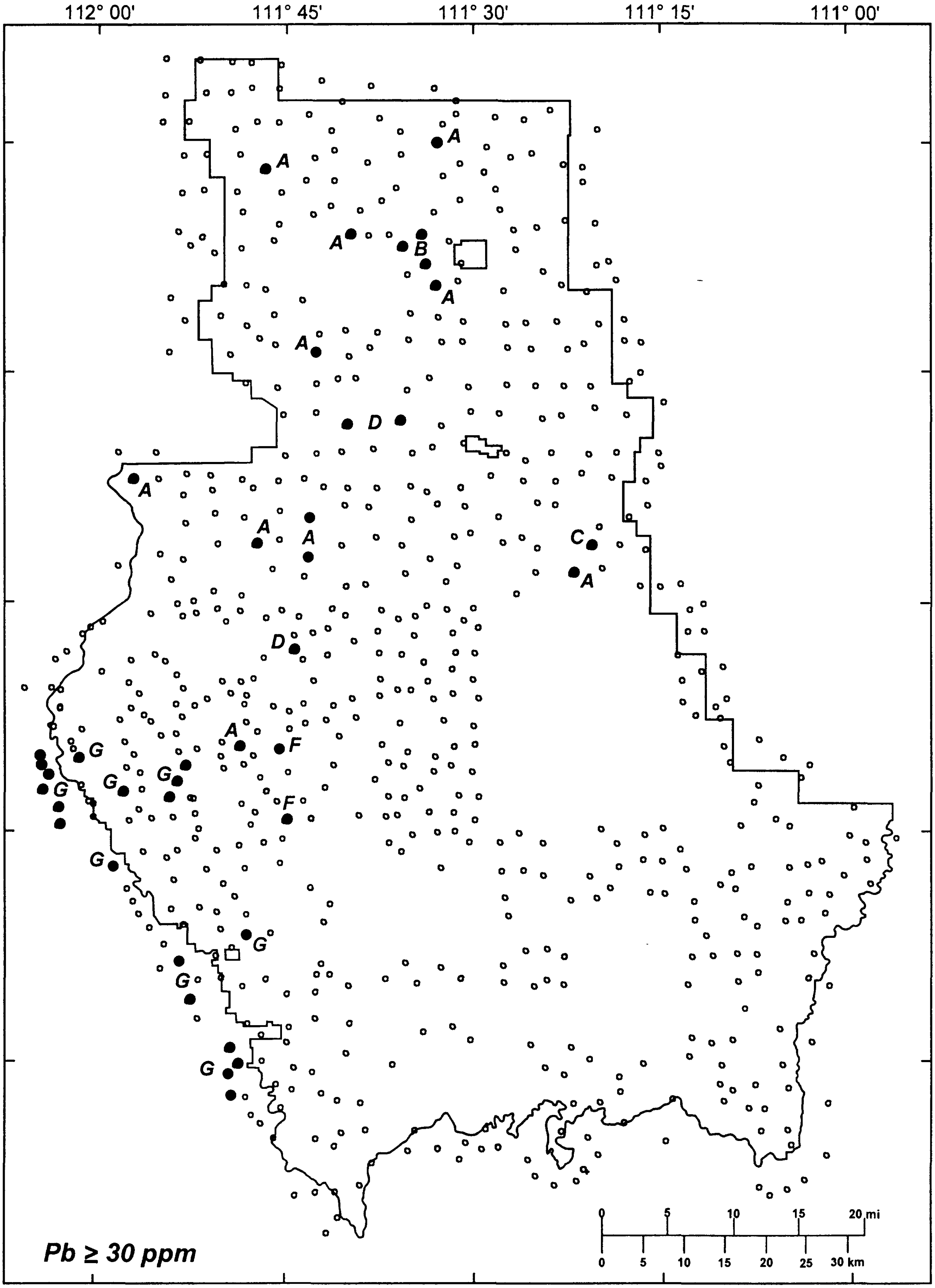

Figure 31. Distribution of anomalous lead in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

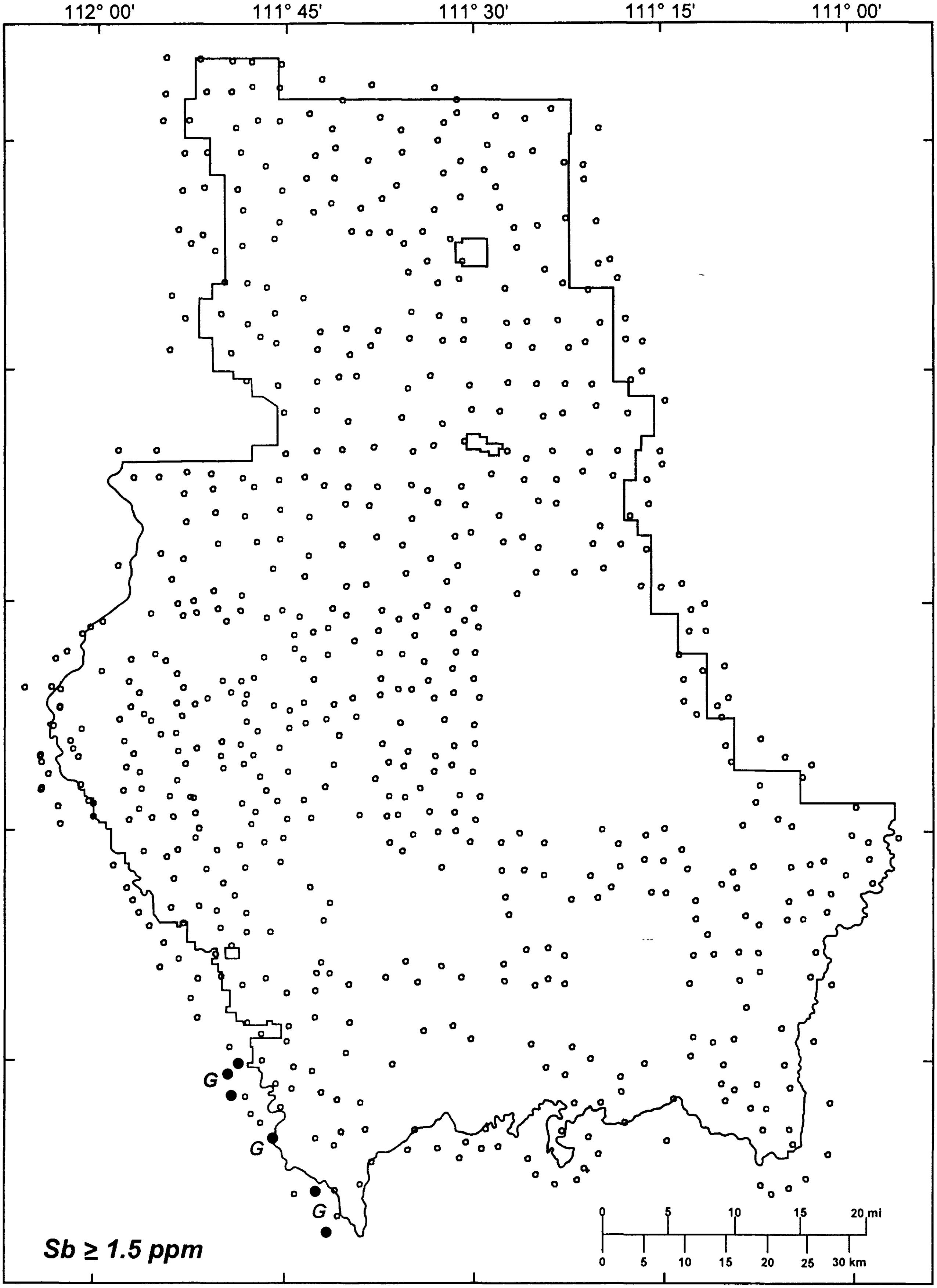

Figure 32. Distribution of anomalous antimony in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

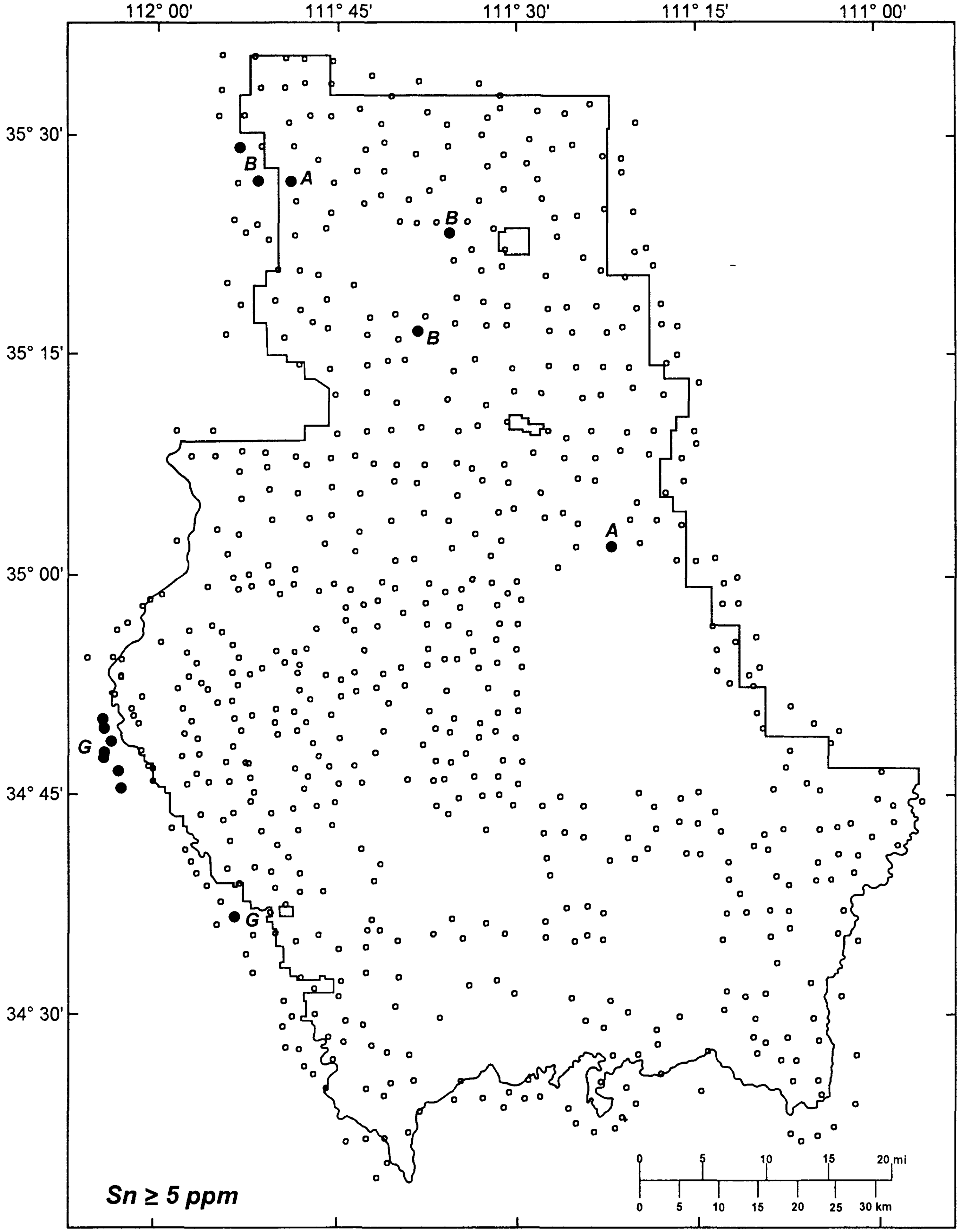

Figure 33. Distribution of anomalous tin in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

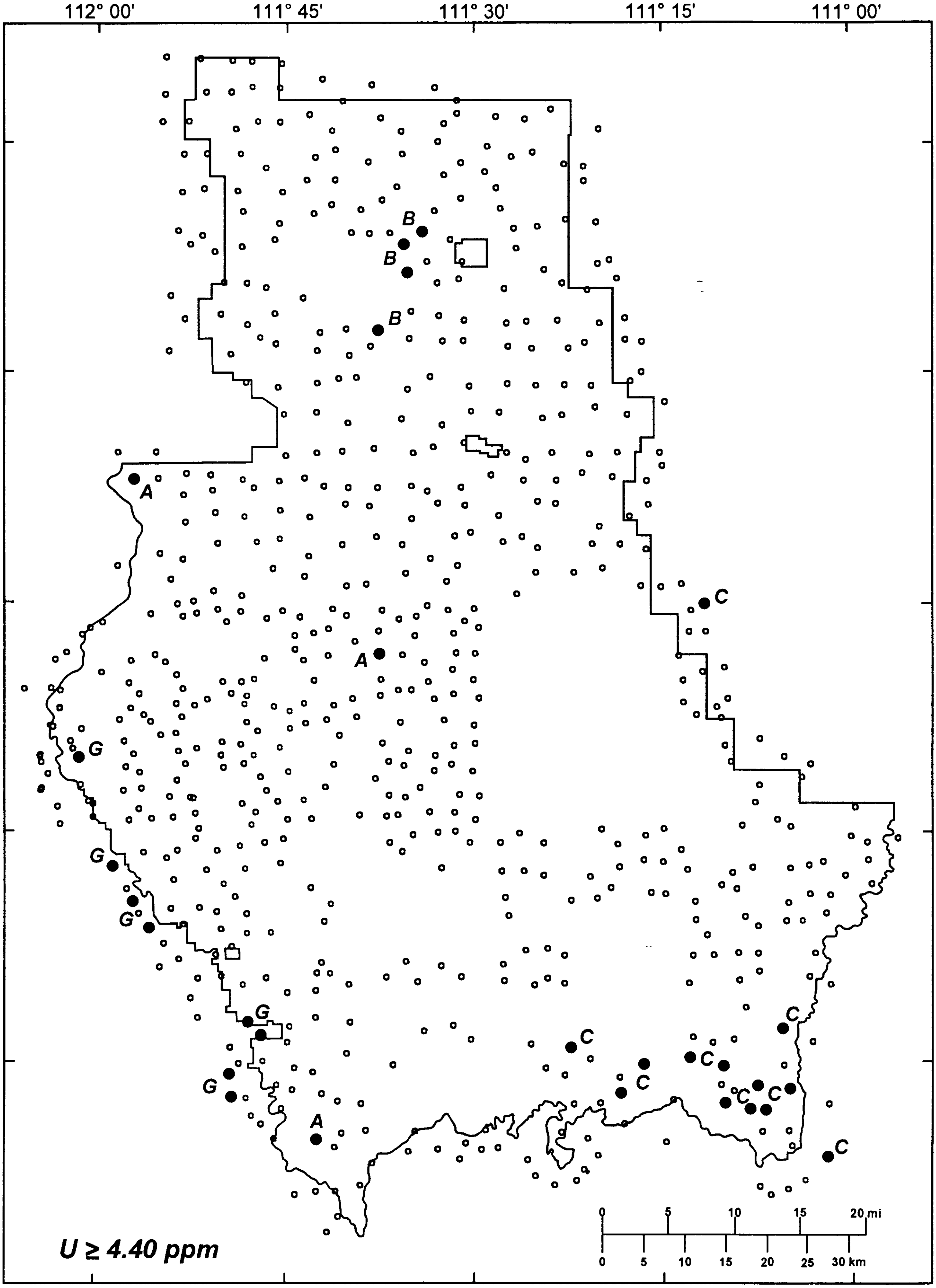

Figure 34. Distribution of anomalous uranium in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.

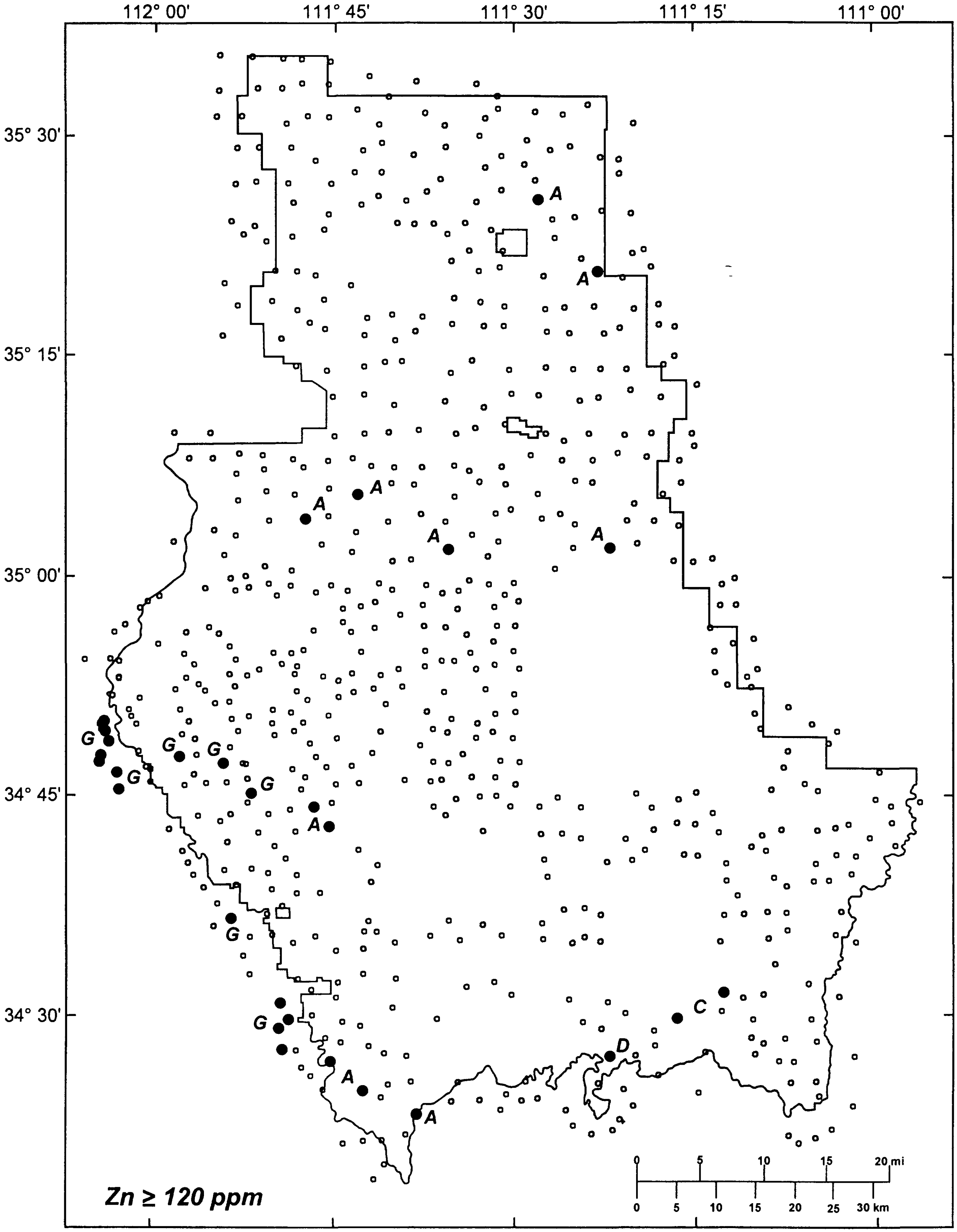

Figure 35. Distribution of anomalous zinc in NURE stream-sediment samples, Coconino National Forest, Arizona. See text for explanation of symbols.