Equivalent Uranium and Selected Minor Elements in Magnetic Concentrates from the Candle Quadrangle, Solomon Quadrangle, and Elsewhere in Alaska

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EQUIVALENT URANIUM AND SELECTED MINOR ELEMENTS IN MAGNETIC CONCENTRATES FROM THE CANDLE QUADRANGLE, SOLOMON QUADRANGLE, AND ELSEWHERE IN ALASKA

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ABSTRACT

Equivalent uranium and 11 minor elements in the magnetic fractions of 347 panned concentrates from the Candle and Solomon quadrangles, Alaska, and elsewhere in the State, were determined in the first investigation by the U.S. Geological Survey of the utility of magnetic concentrates as a geochemical sample medium for subarctic and arctic regions. The magnetic concentrates were obtained from the Survey's Alaskan placer concentrate file. Magnetic separation from the nonmagnetic parts of the panned concentrates was done in randomized order, as were radiometric and atomic absorption analyses. The elements determined by atomic absorption are silver, bismuth, cadmium, cobalt, copper, nickel, lead, zinc, gold, indium, and thallium. Replicate analyses of standard samples were made as a check on the analytical results. Sixty-seven of the magnetic concentrates were examined by microscope and by X-ray diffraction to determine their mineralogical composition and to determine what parts of the concentrates were taken into solution during analysis.

Most of the magnetic concentrates contain more than 50 percent magnetite, and in 60 percent of the samples the magnetic concentrates consist of 90–99 percent magnetite. Many of the samples, especially the few that contain less than 50 percent magnetite, are diluted by ilmenite, rutile, sulfide minerals, gold, quartz, hematitic coatings, silicate minerals, metallic spherules, and tramp iron. Because of intergrowths between minerals, coatings, and the mechanical trapping of nonmagnetic grains in clusters of magnetic grains, no effective method is available for obtaining monomineralic detrital magnetite as a geochemical sample medium.

Metallic spherules are present in seven samples, five of which also contain slivers of tramp iron. Both the spherules and the tramp iron adhere to grains of detrital magnetite by ferromagnetic attraction, or are cemented to the magnetite by hematite or limonite, or are present as loose intergranular particles. The tramp iron is derived from machinery used in placer mining, and the metallic spherules may originate as welding spatter or fly ash from mining activities. However, the metallic spherules may have formed in several natural ways: they may be fusion products from volcanic activity, lightning, or forest fires; or they may in part be extraterrestrial material such as meteoric dust or ablation products from iron meteorites. This last possibility adds immensely to the scientific interest generated by the metallic spherules.

Chemical digestion of the magnetic concentrates in preparation for analysis by atomic absorption was not complete. Magnetite was largely but not entirely digested. Ilmenite and rutile were slightly leached on the surface. Hematitic coatings, sulfide minerals, and gold were completely dissolved. No effect was noticed on quartz and the common silicate minerals except that they attained a high gloss indicative of the removal of surface coatings. The metallic spherules and tramp iron were taken into solution. Thus, the part of the magnetic concentrate that went into solution was magnetite, hematite and other coatings, sulfide minerals, native gold, metallic spherules, and tramp iron.

The minor elements contained in the magnetic concentrates are present in substitution for major elements in magnetite, sorbed on the surface of magnetite, in trace minerals included in the magnetite, and in accessory minerals trapped among grains of magnetite. The most probable sources of anomalous amounts of minor elements in these concentrates are: (1) silver, copper, lead, zinc, cobalt, and nickel substituted for iron in the magnetite structure; (2) equivalent uranium, copper, lead, and zinc held in surface sorption on magnetite; (3) copper, cadmium, indium, and thallium in trace minerals; and (4) equivalent uranium, silver, bismuth, cadmium, copper, gold, indium, and thallium in accessory minerals. Virtually all measured equivalent uranium comes from hematitic coatings that constitute an accessory mineral in the concentrates. High values for the elements that substitute for iron in the magnetite structure are increased by accessory particles of sulfide minerals, native gold, metallic spherules, and tramp iron. Native gold is the source of much of the anomalous gold and silver. The least understood aspect of minor elements in magnetite is the role of surface sorption of the elements.

The enrichment of trace elements in detrital magnetite or in magnetic concentrates does not necessarily mean that the source rocks have a superior economic potential. However, anomalously high contents of minor elements are guides to areas deserving further exploration. For example, magnetites with radioactive hematitic coatings clearly identified areas of alkalic intrusive rocks containing abnormal amounts of thorium and uranium. Of 36 previously known copper deposits or occurrences, 24 yielded magnetic concentrates containing anomalous amounts of copper, and the other 12 provided magnetic concentrates with various anomalous lead, zinc, silver, cobalt, or nickel contents. Nineteen previously known lead-bearing deposits or occurrences were the sources for eight magnetic concentrates with anomalous lead content, and all 19 of these deposits were reflected by various combinations of anomalous amounts of base metals, silver, or gold. Ten of the thirteen areas previously known to have zinc mineralization were the sources of magnetic concentrates with anomalous zinc content, and the others had anomalous amounts of other metals. Magnetic concentrates from polymetallic deposits seldom failed to have anomalous trace-

element contents. Therefore, magnetic concentrates may be used satisfactorily as a geochemical sample medium in subarctic and arctic environments.

Anomalous amounts of copper and zinc in magnetic concentrates indicate sulfide mineralization. Where anomalous amounts of copper and zinc are combined with anomalous amounts of silver, bismuth, and lead in magnetic concentrates, polymetallic sulfide deposits are indicated. Anomalous silver content usually indicates silver and gold deposits, mainly gold. Anomalous cobalt and nickel content indicates the presence of chromite and, locally, sulfide deposits associated with mafic and ultramafic rocks. Anomalous lead and gold content usually indicates lead sulfide deposits and gold, but not all lead and gold deposits have corresponding anomalous values for lead and gold in the magnetic concentrates. The abundances of these two elements are more affected by chance in collecting and in preparing the sample than are the previously cited elements. However, lead and gold deposits can be detected from anomalous amounts of copper, zinc, and silver in magnetic concentrates.

Of interest is the number of tungsten deposits or occurrences that yield magnetic concentrates containing anomalous amounts of copper. This geochemical association is one that requires appropriate follow-up investigations to determine if skarn-type tungsten-copper deposits or porphyry-type deposits may be related to the presence of copper in magnetic concentrates.

Several prominent regional geochemical highs are indicated by the varied distribution of the anomalous amounts of elements in magnetic concentrates from Alaska. Large copper and silver anomalies are present in the Ketchikan quadrangle in southeastern Alaska. In southern Alaska, high values are found for copper, zinc, and gold in the McCarthy quadrangle. Copper and silver concentrations are anomalous in the Valdez quadrangle, and anomalous zinc content is found in magnetic concentrates from the Anchorage, Talkeetna, and Talkeetna Mountains quadrangles. Cobalt and nickel attain high values in the Mount Hayes quadrangle. Magnetic concentrates from the Bethel and Iliamna quadrangles in southwestern Alaska contain anomalous amounts of base metals. In west-central Alaska, anomalous equivalent uranium is associated with magnetic concentrates from the Bendeleben, Candle, and Solomon quadrangles. Extremely high values for lead, cobalt, bismuth, and other metals are found in samples from the Ruby quadrangle. Multielement highs, indicating various combinations of silver, bismuth, copper, nickel, and zinc, are obtained from magnetic concentrates from the Iditarod and Teller quadrangles, and anomalous amounts of cobalt and nickel are found in the Bendeleben quadrangle. West-central Alaska appears to be a bismuth province. In east-central Alaska, high values for silver and gold are common in magnetic concentrates from the Circle, Eagle, Livengood, and Tanana quadrangles. Nickel and zinc are enriched in samples from the Livengood quadrangle, and bismuth attains a high value in one concentrate from the Circle quadrangle.

INTRODUCTION

PURPOSE OF INVESTIGATION

The use of magnetic fractions of panned concentrates—called here the magnetic concentrate—for a geochemical sample medium has been tested by the U.S. Geological Survey in the humid temperate zone (Theobald and Thompson, 1959; Theobald and others, 1967) and the arid tropics (P. K. Theobald, Jr., oral commun., 1971). The magnetic fraction of coarse-grained alluvium has been similarly used for geochemical exploration in humid, tropical, central Ecuador (de Grys, 1970), as well as in the subarctic glaciated region around Churchill Falls, Labrador (J. E. Callahan, written commun., 1973; 1974). The trace-element distribution in accessory magnetites from quartz monzonite stocks in the Basin and Range Province of Utah and Nevada has been studied for its relation to sulfide mineralization (Hamil and Nackowski, 1971).

An unusual opportunity to test the possible value of the magnetic concentrate as a geochemical sample medium in the subarctic and arctic environments was afforded by an investigation initiated in 1970 by C. L. Sainsbury, U.S. Geological Survey. His interest was the minor elements in the nonmagnetic fractions of heavy minerals from the Alaskan placer concentrate file. Nonmagnetic fractions were prepared in 1971 by W. R. Marsh from 1,072 of the 5,000 concentrates in the file. A byproduct of 682 magnetic fractions resulted, which W. C. Overstreet thought should be analyzed both to continue the Survey's research on minor elements in magnetite, and to provide a comparison with the results of the spectrographic analyses of the nonmagnetic concentrates (Hamilton and others, 1974).

Two avenues for the analysis of these magnetic concentrates were available: (1) a standard semiquantitative spectrographic procedure for 30 elements, and (2) an analytical method developed in the U.S. Geological Survey by H. M. Nakagawa (1975) to determine the abundances of silver, bismuth, cadmium, copper, cobalt, nickel, lead, and zinc by atomic absorption techniques on single solutions of iron-rich materials. The spectrographic procedure requires only 10–20 mg of sample; thus, all 682 magnetic concentrates could be so analyzed (Rosenblum and others, 1974). One gram is needed for the method employing atomic absorption. Many of the Alaskan concentrates were lean in magnetite, so only 347 magnetic fractions were large enough for study by atomic absorption. However, several other tests could be carried out on the large samples of magnetic concentrates: (1) equivalent uranium by radiometric counting; (2) gold by atomic absorption; and (3) mineralogical examination. Therefore, the atomic absorption analytical method was selected. An analytical procedure developed in the Survey (Hubert and Lakin, 1973) made possible the analyses for indium and thallium on part of the set of magnetic concentrates.

The present report is an account of the results of these various analyses on the 347 magnetic concentrates from Alaska to which 30 replicate subsamples of one sample were added for internal control. The report

shows the relation of variations in minor elements to the source and mineralogy of the magnetic concentrate, and illustrates the use of this material as a geochemical sample medium in the subarctic and arctic environment.

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MAGNETIC FRACTIONS OF CONCENTRATES

SOURCE AND PREPARATION

The magnetic fractions of the concentrates described in this report are contained in the U.S. Geological Survey's Alaskan placer concentrate file. This file of concentrates was largely acquired by Survey geologists during the period 1895–1953. It numbers about 5,000 concentrates from gold placer districts, mineralized regions, and other areas in Alaska, and each concentrate has its own file number. Most of the material consists of concentrates panned from alluvium, but a small percentage is sluice-box concentrates donated to the Survey by prospectors and miners, and a few concentrates are from crushed rock, drill core, or beach placers.

A split of the raw concentrate finer than 20 mesh was separated into magnetic and nonmagnetic fractions with a hand-held permanent magnet. The magnetic fraction from the first separation was further separated magnetically twice to insure that, as far as practical in the context of a feasible exploration technique, the magnetic fraction was reasonably free of nonmagnetic minerals. In general, the magnetic fractions were found to consist of more than 90 percent magnetite. A full discussion of the actual mineral composition of the magnetic fraction is given in the section called "Distribution of the elements." Inasmuch as the final magnetic product was not entirely magnetite, the material analyzed is referred to here as the magnetic concentrate.

LOCATION AND DISTRIBUTION

The file number and location of each magnetic concentrate is given in table 1, where the description follows that given in the record of the Alaskan placer concentrate file. The codes in table 1 show the source material for the magnetic concentrate. In several instances more than one concentrate came from the same locality, reflecting the fact that certain gold placers were sampled intermittently through their productive life by various geologists with the U.S. Geological Survey. Some of the older locality descriptions, made before Alaska was systematically covered by topographic quadrangle maps, give the general source only. Quadrangles represented by the magnetic concentrates are shown on plate 1.

RANDOMIZATION

The original group of 1,072 concentrates from which these magnetic fractions were taken was randomized using tables of random permutations (Moses and Oakford, 1963), and the concentrates were processed in random sequence to prepare them for analysis. Throughout all following treatment the magnetic fractions were handled in this random sequence.

ANALYTICAL PROCEDURES AND RELIABILITY OF THE CHEMICAL DATA

CONTROL SAMPLES

Three samples of magnetic concentrates were used for control in connection with the analyses made in this investigation. Two of the control samples came from outside of Alaska: one from Nevada and one from North Carolina. These two control samples were analyzed in replicate by atomic absorption to test the reliability of the analytical procedure for silver, bismuth, cadmium, copper, cobalt, nickel, lead, and zinc before it was adopted for this investigation. The third control sample came from the Alaskan placer concentrate file. Thirty replicate subsamples of the third control sample were intercalated into the randomly arranged set of 682 magnetic fractions obtained

TABLE 1.—*Locations and results of analyses of 347 magnetic concentrates from Alaska, related to known mineral deposits*

[Unless otherwise noted, samples are derived from panned stream (or beach) concentrates and have a density greater than 2.87. All samples are finer than 20 mesh. All samples were analyzed for all elements listed except Au, In, and Tl; the number of samples in each quadrangle tested for these three elements is given next to the quadrangle name (regional total is 132). Values considered anomalous are underlined. Leader, —, indicates no data available. N, element was looked for but not detected. L, element was detected, but in amounts less than the lower limit of determination. Number in parentheses beneath each element symbol is the lower limit of determination for that element. Known mineral deposits are from Berg and Cobb, 1967, and Cobb, 1973]

File Number	North Latitude ° ' "	West Longitude ° ' "	Description of Location[1]	Element concentrations (parts per million) eU (30)	Ag (0.2)	Bi (5)	Cd (0.2)	Co (1)	Cu (1)	Ni (1)	Pb (5)	Zn (1)	Au (0.2)	In (0.2)	Tl (0.2)	Known mineral deposits nearby[2]
Anchorage quadrangle (11 concentrates; 4 analyzed for Au, In, and Tl)																
2163	61 51 15	147 23 15	Glenn Hwy mile 117----------	N	0.4	5	0.4	40	40	25	40	1,000	---	---	---	Ld:Cu.
2178	61 43 15	148 51 0	Glenn Hwy Granite Cr----------	N	.2	5	L	40	35	35	15	60	---	---	---	None.
2187	61 47 0	149 17 30	Fishhook Cr----------	N	L	10	L	45	45	40	10	45	L	L	L	Ld:Au,Cu,Ag,Zn,Hg,Pb,Mo,W.
2190	61 45 30	149 35 45	Willow Cr----------	N	.2	10	.4	60	15	260	15	110	L	L	L	Ld:Au; Pd:Au.
2191	61 46 15	149 11 30	Little Susitna R----------	N	.4	10	.2	45	55	70	10	65	---	---	---	Pd:Au,Cu,W.
2192	61 48 15	149 11 0	Archangel Cr----------	N	1	10	.4	50	35	35	15	55	L	L	L	Ld:Au; Pd:Au.
2194	61 35 30	149 0 15	Lf trib of Matanuska R--------	N	.4	5	.2	40	55	55	25	110	---	---	---	Pd:Hg,W.
2198	61 40 0	149 19 30	Little Susitna R----------	N	.2	5	.2	50	30	45	10	55	L	L	L	None.
2199	61 24 45	149 28 0	Peters Cr----------	N	.2	L	.4	100	55	130	15	330	---	---	---	Ld:Cu,Pb,Zn.
2202	61 26 15	149 48 0	Fish Cr----------	N	.4	5	L	50	35	100	35	130	---	---	---	None.
2203	61 39 0	149 1 0	Glenn Hwy Wolverine Cr--------	N	.6	10	.2	90	60	480	15	130	---	---	---	Ld:Cu,Ag,Zn.
Bendeleben quadrangle (20 concentrates; 4 analyzed for Au, In, and Tl)																
400	65 21 30	164 42 30	Dahl Cr placers----------	N	0.2	10	L	170	10	2,200	35	30	1	L	L	Pd:Au.
2027	65 53 30	164 25 45	Humboldt Cr ----------	60	.2	15	.6	15	L	10	25	55	---	---	---	None.
3041	65 1 45	162 8 0	Tubutulik R 1st lf trib below Admiral Cr.	N	L	10	.4	120	10	1,700	15	210	---	---	---	Pd:Au.
3042	65 2 30	162 9 0	Tubutulik R just below Admiral Cr.	100	.4	35	.4	45	15	40	50	100	---	---	---	Pd:Au.
3044	65 1 45	162 11 30	275 m up from mouth of Rock Cr, Quartz Cr area.	180	.2	10	.4	30	10	15	25	85	L	.2	.3	Pd:Au.
3045	65 1 45	162 11 30	Rock Cr 2 km ustr of mouth----	150	.2	10	.4	35	15	20	35	95	---	---	---	Pd:Au.
3046	65 1 45	162 11 30	Old streambed 2 km above mouth Rock Cr.	120	L	10	L	35	10	20	30	65	---	---	---	Pd:Au.
3047	65 1 45	162 11 30	Tubutulik R area 275 m up Rock Cr.	80	.6	45	.4	35	20	25	45	95	---	---	---	None.
3054	65 1 45	162 11 30	Tubutulik R opposite mouth of Rock Cr.	160	.2	30	L	40	10	25	35	85	---	---	---	Pd:Au.
3056	65 1 45	162 11 30	Tubutulik R 275 m above mouth of Rock Cr.	130	.4	15	.4	45	5	30	100	100	---	---	---	Pd:Au.
3066	65 3 15	162 12 30	35 m above mouth lf fk of rt br Grouse Cr.	70	.2	10	.4	25	5	15	15	50	L	L	L	Pd:Au.
3068	65 3 15	162 12 30	Tubutulik R 400 m above Grouse Cr.	150	.4	10	.4	40	5	25	35	100	---	---	---	Pd:Au.
3069	65 1 30	162 15 30	Old streambed dstr of 1st rt trib Rock Cr.	180	L	15	L	35	10	20	35	70	L	.2	L	Pd:Au.
3070	65 1 30	162 15 30	Tubutulik R below 1st rt trib above Rock Cr.	190	0.4	20	0.6	40	10	30	60	95	---	---	---	Pd:Au.
3072	65 1 45	162 12 0	1st rt trib to Tubutulik R above Rock Cr.	280	.4	10	.4	30	5	20	50	75	---	---	---	None.
3074	65 2 0	162 17 30	Big Cr 32 m above mouth-------	130	.2	10	1	35	10	25	55	65	---	---	---	Pd:Au.
3075	65 1 30	162 19 30	Big Cr, Tubutulik R area------	220	.2	5	.4	55	L	15	60	65	---	---	---	Pd:Au.
3076	65 2 0	162 17 30	Tubutulik R 55 m above Big Cr	120	.2	20	.4	35	10	25	50	55	---	---	---	Pd:Au.
3077	65 2 0	162 17 30	1st lf trib to Tubutulik R above Grouse Cr.	150	.2	10	.4	30	L	15	30	80	---	---	---	Pd:Au.
3078	65 3 0	162 18 0	2nd lf trib to Tubutulik R above Grouse Cr.	110	.4	10	.4	30	L	20	45	120	---	---	---	Pd:Au.

Bethel quadrangle (6 concentrates; 2 analyzed for Au, In, and Tl)																				
240	60	46	30	161	23	0	Riglugalik R, Bethel area-----	N	0.2	10	L	30	20	35	10	230	---	---	---	None.
918	60	16	30	160	12	30	Canyon Cr halfway btw Nyac and Goodnews.	N	.4	10	.4	70	15	110	50	230	4.5	.2	L	None.
928	60	54	15	159	37	30	Marvel Cr----------	N	.4	10	.4	65	190	280	35	700	4.9	.5	L	Pd:Au.
929	60	53	45	159	37	15	Marvel Cr----------	N	68	20	.6	75	70	350	50	1,300	---	---	---	Pd:Au.
2120	60	42	0	159	32	30	Cripple Cr, Mt Hamilton area[3]	N	20	5	.2	50	160	160	15	250	---	---	---	Pd:Au.
2121	60	55	0	159	38	0	Marvel Cr[3]----------	N	33	10	.6	45	220	100	45	180	---	---	---	Pd:Au.
Bradfield Canal quadrangle (1 concentrate; not analyzed for Au, In, and Tl)																				
3338	56	1	0	130	4	0	1st str N of Riverside mine	N	0.8	10	0.4	35	70	80	95	290	---	---	---	Ld:Cu,Pb,Zn,Au,Ag,Mo,W.
Candle quadrangle[4] (85 concentrates; 25 analyzed for Au, In, and Tl)																				
262	65	35	15	161	2	45	Sheridan Cr, trib of Bear Cr--	N	L	20	L	55	15	30	55	35	0.7	L	L	Pd:Au.
276	65	37	15	161	9	0	Bear Cr----------	N	.2	10	.4	50	15	45	55	30	L	L	L	None.
444	65	8	45	161	8	30	Dime Cr above Discovery claim	40	.4	10	.4	150	50	85	50	630	---	---	---	None.
1060	65	19	0	161	13	30	Lower Sweepstakes Cr----------	N	.4	10	.2	70	15	100	20	270	---	---	---	Pd:FM,Au,Pt.
2464	65	27	0	161	7	0	1st lf trib to Peace R--------	N	L	15	L	55	25	95	50	75	L	L	L	Ld:Cu; Pd:Bi,Cr,Cu,FM, Au,Pb,Mo,Ag.
2468	65	27	0	161	7	0	1st lf trib to Peace R--------	N	.2	15	.6	55	25	70	120	90	---	---	---	Ld:Cu; Pd:Bi,Cr,Cu,FM, Au,Pb,Mo,Ag.
2469	65	27	0	161	7	0	Peace R, 1st rt trib to 1st lf trib.	N	.8	20	L	55	25	75	50	100	---	---	---	Ld:Cu; Pd:Bi,Cr,Cu,FM, Au,Pb,Mo,Ag.
2473	65	27	0	161	7	0	Peace R, 1st rt trib----------	N	.8	10	.2	75	30	130	65	100	---	---	---	Ld:Cu; Pd:Bi,Cr,Cu,FM, Au,Pb,Mo,Ag.
2485	65	32	45	160	48	30	Bear Cr 45 m below 1st lf trib.	N	.6	10	L	65	50	65	35	120	---	---	---	Pd:FM.
2487	65	32	45	160	48	45	Bear Cr 70 m below 1st rt trib	N	0.4	15	0.6	60	40	65	30	95	---	---	---	Pd:FM.
2488	65	32	15	160	51	30	Bear Cr 30 m below mouth of Cub Cr.	N	.6	10	.2	75	35	85	35	150	---	---	---	None.
2489	65	31	45	160	58	30	Bear Cr 90 m below 3rd rt trib	N	.4	10	.4	60	45	75	30	110	L	L	.3	Pd:FM,Au,Pt.
2491	65	31	45	160	58	30	Bear Cr 1st rt trib dstr from Bob Cr.	N	.6	15	.4	50	55	440	30	95	---	---	---	Pd:FM,Au,Pt.
2492	65	31	45	160	58	30	Bear Cr area, Bob Cr 45 m below mouth.	N	1	15	L	75	50	85	45	50	---	---	---	Pd:FM,Au,Pt.
2494	65	31	45	160	58	30	Bear Cr area, Bob Cr----------	N	.4	15	.4	75	55	95	55	100	---	---	---	Pd:FM,Au,Pt.
2496	65	33	0	161	3	0	Bear Cr, Wallace Porters sluice box[3].	N	.4	10	L	65	30	70	25	55	L	L	L	Ld:Au,Cu; Pd:Au,Pt.
2501	65	32	0	161	1	0	Bear Cr, 1st rt trib below Bob Cr.	N	.4	10	.4	65	70	85	110	100	---	---	---	Ld:Au,Cu; Pd:Au,Pt.
2502	65	33	0	161	3	0	Bear Cr 30 m below mouth of Split Cr.	N	.2	15	.4	50	65	40	15	120	L	L	L	Ld:Au,Cu; Pd:Au,Pt.
2503	65	32	45	161	2	45	Bear Cr area, Split Cr--------	N	.6	10	.4	55	55	60	35	85	---	---	---	Ld:Au,Cu; Pd:Au,Pt.
2504	65	32	45	161	6	0	Bear Cr area, Discovery Gulch of Split Cr.	N	.4	10	.4	55	40	40	20	110	---	---	---	Ld:Au,Cu; Pd:Au,Pt.
2509	65	35	30	161	8	0	Bear Cr area, Eagle Cr--------	N	.6	10	.4	40	15	25	30	65	1.5	L	L	Pd:Au,Pt.
2515	65	31	15	160	54	0	Cub Cr 35 m above mouth-------	N	.8	10	.2	60	30	65	55	280	---	---	---	Ld:Au.
2517	65	31	15	160	54	0	Cub Cr 1.6 km above mouth-----	N	.6	10	.2	55	25	60	50	270	---	---	---	Ld:Au.
2528	65	28	45	161	11	0	Cub Cr area, 1st lf trib to lf hw fk.	N	.8	20	.8	75	60	45	35	55	---	---	---	Pd:FM.
2538	65	28	45	161	11	0	Cub Cr area, mid hw br--------	120	.4	10	.8	70	30	100	55	120	---	---	---	Pd:FM.
2543	65	28	45	161	11	0	Cub Cr area, mid hw br--------	N	L	10	L	75	15	100	40	120	---	---	---	Pd:FM.
2549	65	28	45	161	11	0	Rt hw br of Cub Cr----------	50	L	20	L	60	20	100	45	100	L	L	.3	Pd:FM.
2556	65	26	45	161	11	15	2nd lf trib to rt hw br of Cub Cr.	40	L	10	.4	65	10	100	25	150	---	---	---	None.
2557	65	26	45	161	11	15	Cub Cr, 2nd rt trib to rt hw fk.	N	.2	5	.2	65	5	85	30	180	.2	L	L	None.
2558	65	26	45	161	11	15	Cub Cr area, rt hw br--------	N	.2	10	.4	60	L	70	35	130	L	L	L	None.
2559	65	26	45	161	11	15	Cub Cr area, 3rd lf trib to rt hw br.	N	L	10	.8	75	10	85	35	160	L	L	L	None.

TABLE 1.—*Locations and results of analyses of 347 magnetic concentrates from Alaska, related to known mineral deposits*—Continued

File Number	North Latitude ° ' "	West Longitude ° ' "	Description of Location[1]	Element concentrations (parts per million) eU (30)	Ag (0.2)	Bi (5)	Cd (0.2)	Co (1)	Cu (1)	Ni (1)	Pb (5)	Zn (1)	Au (0.2)	In (0.2)	Tl (0.2)	Known mineral deposits nearby[2]
Candle quadrangle[4] (85 concentrates; 25 analyzed for Au, In, and Tl)--Continued																
2560	65 26 45	161 11 15	Cub Cr, 4th lf trib to rt hw fork.	40	L	10	.2	70	5	100	30	180	---	---	---	None.
2561	65 26 45	161 11 15	Rt hw br of Cub Cr	N	.2	5	.4	65	10	100	25	160	L	L	L	None.
2562	65 26 45	161 11 15	Str on Granite Mt above Spring Cr.	N	L	10	.4	65	5	80	40	180	---	---	---	None.
2564	65 26 45	161 11 15	Str on Granite Mt above Kiwalik R.	N	L	5	.4	60	20	180	60	130	.3	L	L	None.
2567	65 28 30	161 11 15	Str on Granite Mt above Kiwalik R.	N	0.2	10	0.4	65	15	160	60	160	---	---	---	Pd:FM.
2568	65 28 45	161 11 0	Granite Mt above rt hw fk of rt br Kiwalik R.	N	.2	10	L	75	5	100	15	110	---	---	---	Pd:FM.
2570	65 28 45	161 11 0	Above rt hw fk of rt br of Kiwalik R.	100	.2	10	.4	65	L	120	35	190	L	L	L	Pd:FM.
2571	65 28 45	161 11 0	Granite Mt above rt hw fk of rt br of Kiwalik R.	70	.4	L	L	75	L	85	60	170	L	L	L	Pd:FM.
2575	65 28 45	161 11 0	Granite Mt above Syenite Gulch, Quartz Cr area.	N	.2	5	L	70	5	85	45	160	---	---	---	Pd:FM.
2587	65 28 45	161 11 0	Rt hw fk of mid fk of Quartz Cr.	N	.2	10	.2	45	90	65	30	80	---	---	---	Pd:FM.
2636	65 42 30	161 35 30	1st lf trib to Linda Cr, Hunter Cr area.	N	L	10	.6	30	10	65	35	35	L	L	L	None.
2637	65 42 30	161 35 30	1st lf trib to Linda Cr, Hunter Cr area.	N	.2	10	.4	30	5	45	25	30	L	L	L	None.
2639	65 43 15	161 34 0	1st lf trib to Linda Cr, Hunter Cr area.	N	L	10	L	55	10	50	15	85	---	---	---	None.
2640	65 43 0	161 34 0	Linda Cr in Hunter Cr area	70	.2	5	.4	50	10	60	50	90	---	---	---	None.
2657	65 44 30	161 21 30	Rt fk of Hunter Cr	N	.4	L	.2	35	5	55	15	45	---	---	---	None.
2661	65 44 30	161 21 45	3rd rt trib to rt fk of Hunter Cr.	N	.2	10	L	25	5	40	5	35	---	---	---	None.
2663	65 44 30	161 21 30	4th lf trib to rt fk of Hunter Cr.	N	.2	5	.2	25	10	45	20	55	---	---	---	None.
2665	65 44 15	161 18 0	Lf hw fk of rt fk of Hunter Cr.	80	.6	5	.4	30	5	40	15	35	---	---	---	None.
2667	65 44 15	161 18 0	Hunter Cr area, rt hw fk of rt fk Hunter Cr.	60	.4	10	L	35	10	50	15	30	L	L	.2	None.
2668	65 44 15	161 18 0	1st rt trib to rt hw fk of rt fk of Hunter Cr.	50	.2	10	.6	30	5	45	10	75	---	---	---	None.
2669	65 44 15	161 18 15	2nd rt trib to rt hw fk of rt fk of Hunter Cr.	100	.2	10	.4	30	5	45	15	50	L	L	L	None.
2672	65 44 30	161 18 15	Hunter Cr area, rt hw fk of rt fk of Hunter Cr.	N	L	5	L	25	20	45	15	35	---	---	---	None.
2673	65 45 0	161 27 30	Lf fk Hunter Cr above rt fk	N	.4	15	.4	65	15	60	25	85	---	---	---	None.
2678	65 42 45	161 26 0	Hare Cr 3rd lf trib to lf fk Hunter Cr.	N	L	5	L	50	L	55	10	140	---	---	---	None.
2690	65 41 0	161 23 0	Lf fk Hunter Cr btw 4th and 5th lf tribs.	N	1.5	10	.2	60	20	65	20	90	---	---	---	Pd:FM,Au(?).
2693	65 41 0	161 23 0	1st rt trib to Wasp Cr	N	.6	10	.4	40	35	75	20	100	---	---	---	Pd:FM,Au(?).
2695	65 41 0	161 23 0	1st lf trib to 1st rt trib to Wasp Cr.	N	0.2	10	0.4	35	40	50	20	75	---	---	---	Pd:FM,Au(?).
2696	65 41 0	161 23 0	2nd lf trib to 1st rt trib to Wasp Cr.	N	.4	10	.4	35	55	570	35	75	---	---	---	Pd:FM,Au(?).
2698	65 41 0	161 23 0	3rd lf trib to 1st rt trib to Wasp Cr.	N	.4	15	.4	40	65	60	20	140	---	---	---	Pd:FM,Au(?).
2712	65 41 0	161 23 0	7th lf trib to lf fk Hunter Cr[5].	N	.4	10	L	50	15	25	35	35	---	---	---	Pd:FM,Au(?).
2722	65 41 30	161 18 30	Rt hw fk of 2nd rt trib to lf fk Hunter Cr.	160	L	10	.4	20	15	35	40	30	L	L	L	None.
2726	65 57 30	161 23 30	1st lf trib to West Clem Cr S of Clem Mt.	N	.2	10	.4	55	10	100	15	30	L	L	L	Pd:FM.

Candle quadrangle (85 concentrates; 25 analyzed for Au, In, and Tl)--Continued

2727	65	57	30	161	24	0	Duck Cr area, 2nd lf trib to West Clem Cr.	N	.2	10	.6	75	10	210	15	60	---	---	---	Pd:FM.
2729	65	55	15	161	23	0	1st lf trib to 3rd rt trib to Duck Cr.	N	.2	10	L	65	10	150	15	60	L	.2	L	Pd:FM.
2730	65	55	30	161	23	0	3rd rt trib to Duck Cr above West Clem Cr.	N	L	10	.4	60	10	110	15	75	L	L	L	Pd:FM.
2732	65	55	30	161	23	0	1st rt trib to 4th rt trib to Duck Cr.	N	.2	10	.6	55	5	100	10	60	---	---	---	Pd:FM.
2733	65	54	15	161	21	30	4th rt trib to Duck Cr above West Clem Cr.	N	.4	10	L	55	10	50	15	30	---	---	---	Pd:FM.
2753	65	58	15	161	19	0	Buckland R area, East Clem Cr	N	L	15	L	70	10	180	20	85	---	---	---	Pd:FM.
2780	65	50	15	161	15	0	Fairhaven Cr area, 7th lf trib to Meinzer Cr.	N	L	10	L	30	10	45	30	50	---	---	---	Pd:FM.
2785	65	47	15	161	14	0	11th lf trib to Meinzer Cr----	50	.4	5	.4	30	15	50	40	140	---	---	---	Pd:FM.
2797	65	46	0	161	6	30	Rt hw fk to rt hw fk Fisher Cr, Fairhaven Cr area.	50	.2	15	.4	25	5	20	15	75	---	---	---	Pd:FM.
2799	65	44	0	161	12	30	Sugar Loaf Cr 35 m from mouth	40	.4	5	.4	30	5	45	30	75	---	---	---	Pd:FM.
2802	65	44	0	161	12	30	1st rt trib to 2nd lf trib of Sugar Loaf Cr.	N	.2	10	.6	25	5	30	15	75	L	L	L	Pd:FM.
2804	65	44	0	161	12	30	Below jct of hw fks of Sugar Loaf Cr.	N	.2	10	L	25	5	40	20	45	---	---	---	Pd:FM.
2805	65	44	0	161	12	30	Lf hw fk of Sugar Loaf Cr-----	N	.4	10	.4	30	5	45	15	35	---	---	---	Pd:FM.
2806	65	44	0	161	12	30	Rt hw fk to lf hw fk of Sugar Loaf Cr.	N	.2	5	L	30	5	50	15	35	---	---	---	Pd:FM.
2807	65	44	0	161	12	30	Lf hw fk to lf hw fk of Sugar Loaf Cr.	N	L	5	.4	30	5	45	15	35	---	---	---	Pd:FM.
2803	65	44	0	161	12	30	Fairhaven Cr area, rt fk of Sugar Loaf Cr.	80	L	10	L	25	10	40	30	45	L	L	L	Pd:FM.
2810	65	44	0	161	12	30	Rt hw fk of Sugar Loaf Cr, Fairhaven Cr area.	N	0.2	10	0.4	25	5	40	25	30	---	---	---	Pd:FM.
2811	65	44	0	161	7	0	18 m above Sugar Loaf Cr on Fairhaven Cr.	N	.2	10	.4	55	10	50	25	80	---	---	---	Pd:FM.
2814	65	42	30	161	10	0	2nd lf trib to Fairhaven Cr---	N	.2	10	.4	20	5	35	25	30	---	---	---	Pd:FM.
2816	65	40	45	161	10	30	Scotch Cr 45 m from mouth-----	N	.6	10	L	35	25	40	15	50	---	---	---	None.
2818	65	41	0	161	10	45	Fairhaven Cr area, lf hw fk of Scotch Cr.	N	L	10	L	40	40	45	20	40	---	---	---	None.
2820	65	40	45	161	10	45	Fairhaven Cr 45 m above mouth of Scotch Cr.	N	.6	5	L	50	10	35	40	65	---	---	---	None.

Circle quadrangle (1 concentrate; 1 tested for Au, In, and Tl)

3646	65	26	15	144	37	15	Portage Cr, H. C. Carstens mine[3].	150	18	70	0.2	80	220	300	45	150	640	0.2	L	Ld:Zn; Pd:Bi,Cu,Au, Sn,W,RE.

Eagle quadrangle (10 concentrates; 6 analyzed for Au, In, and Tl)

1	64	4	45	141	36	15	Wade Cr----------	N	0.4	5	L	40	L	15	15	30	9.6	L	L	Pd:Au,Hg,Sn,W.
27	64	5	0	141	55	30	Chicken Cr trib to Mosquito Fk of Fortymile R.	N	28	10	.4	30	5	20	25	75	---	---	---	Pd:Au,W.
79	64	10	30	141	25	45	Gilleland Cr trib of Wade Cr--	N	L	10	L	50	10	25	5	35	---	---	---	Pd:Au.
84	64	6	45	141	33	15	Wade Cr----------	N	L	10	L	40	5	10	5	20	.4	L	L	Pd:Au.
277	64	3	45	141	50	0	S fk Fortymile R, Jos. Danker no. 6.	N	L	5	L	45	25	35	15	90	.6	L	L	Pd:Au,Sn,W,FM,RE.
532	64	4	0	141	52	45	Lost Chicken Cr----------	N	L	10	L	40	35	35	15	75	---	---	---	Pd:Au,Sn,W,FM,RE.
535	64	6	0	141	55	15	Myers Fk----------	N	.6	L	L	25	L	20	10	60	5.1	L	L	Pd:Au,W.
2251	64	16	30	141	17	30	50 km above mouth on Fortymile R.	N	L	15	L	45	20	70	15	75	L	L	L	Pd:Au.
3689	64	3	15	141	47	30	Atwater Bar S Fk Fortymile R--	N	1	L	.2	35	25	25	95	60	2.7	L	L	None.
3704	64	6	45	143	16	30	My Cr SE Mt Veta----------	N	L	L	L	30	35	40	15	50	---	---	---	Ld:Pb,Sb.

TABLE 1.—*Locations and results of analyses of 347 magnetic concentrates from Alaska, related to known mineral deposits*—Continued

File Number	North Latitude ° ' "	West Longitude ° ' "	Description of Location[1]	Element concentrations (parts per million) eU (30)	Ag (0.2)	Bi (5)	Cd (0.2)	Co (1)	Cu (1)	Ni (1)	Pb (5)	Zn (1)	Au (0.2)	In (0.2)	Tl (0.2)	Known mineral deposits nearby[2]
Fairbanks quadrangle (1 concentrate; 1 analyzed for Au, In, and Tl)																
109	64 58 45	147 23 0	Gilmore Cr 1.1 km above Hill Pup, Janiksela placer.	N	L	10	0.4	65	15	150	10	55	L	L	L	Ld:W,Mo; Pd:Bi,Au,W.
Goodnews quadrangle (2 concentrates; 2 analyzed for Au, In, and Tl)																
149	59 20 15	161 13 30	Wattamuse Cr, Discovery claim	N	2	5	L	50	10	45	10	80	0.6	0.2	L	Pd:Au.
268	59 33 45	161 28 30	Arolik R----------	N	.8	10	.4	60	15	240	20	90	12	L	L	Pd:Au,Pt.
Hagemeister Island quadrangle (2 concentrates; 1 analyzed for Au, In, and Tl																
542	58 55 30	161 46 45	10 km S of Platinum----------	N	0.4	10	L	110	5	240	15	85	L	L	L	Ld:Cr.
553	58 55 30	161 43 45	Squirrel Cr----------	N	.4	20	.4	100	35	270	15	65	---	---	---	Ld:Au,Pt,Cr.
Iditarod quadrangle (7 concentrates; 1 analyzed for Au, In, and Tl)																
1804	62 19 45	157 58 45	Chicken Cr, Fritz Awe mine near mouth of Cr[3].	N	1.5	25	L	70	45	430	30	480	---	---	---	Pd:Cr,Au,Hg,W.
1815	62 22 15	157 59 30	Chicken Cr[3]----------	N	4	15	.4	55	140	300	80	700	---	---	---	Ld:Sb,Au,Ag,Hg,Cu,Pb,Zn, W; Pd:Au.
1831	62 28 15	157 53 0	Frank Salem cut on Granite Cr	N	1	20	.6	130	25	820	85	930	---	---	---	Ld:Sb,Au,Ag,Hg,Cu,Pb,Zn, W; Pd:Au.
1838	62 27 0	157 57 30	Malamute Pup, Fred Lusher mine[3].	N	.8	15	.4	45	15	280	55	730	---	---	---	Ld:Sb,Au,Ag,Hg,Cu,Pb,Zn, W; Pd:Au.
1867	62 27 15	158 1 15	Otter Cr, Riley dredge[3]-------	N	43	10	1.5	70	230	600	530	140	---	---	---	Ld:Sb,Au,Ag,Hg,Cu,Pb,Zn, W; Pd:Au.
1877	62 26 0	158 0 30	Flat Cr, upper part W limit cut near upper end.	N	L	20	.8	40	10	35	15	370	L	L	L	Ld:Sb,Au,Ag,Hg,Cu,Pb,Zn, W; Pd:Au.
1883	62 25 45	157 59 15	Flat Cr, Pat Savage mine[3]-----	N	4.5	15	.6	70	130	390	20	270	---	---	---	Ld:Co,Au; Pd:Au.
Iliamna quadrangle (5 concentrates; 2 analyzed for Au, In, and Tl)																
3775	59 24 15	155 1 0	Dennis Cr----------	N	0.2	L	0.2	55	30	50	15	470	---	---	---	None.
3776	59 40 0	154 11 15	1st str entering Pile Bay on S side.	N	.2	L	.2	75	55	70	10	220	.5	L	L	None.
3777	59 50 45	153 52 30	6 km from mouth of Pile R-----	N	.2	L	L	50	30	50	10	60	---	---	---	None.
3778	59 48 0	153 58 30	1st str in NW arm of Pile Bay.	N	L	L	L	50	30	20	10	210	.2	.2	L	None.
3779	59 47 30	154 30 0	Millets prospect near Chekok Bay.	N	12	5	.6	50	25,000	15	15	770	---	---	---	Ld:Cu,Au,Ag.
Juneau quadrangle (1 concentrate; 1 analyzed for Au, In, and Tl)																
4905	58 21 30	134 35 0	Dredgings at Juneau Airport[3]--	N	0.2	L	0.2	35	35	15	10	70	L	L	L	None.
Ketchikan quadrangle (9 concentrates; 2 analyzed for Au, In, and Tl)																
3330	55 21 0	131 37 30	Hoadley Cr 3 km N of Ketchikan.	N	0.2	L	0.2	55	15	45	15	120	L	L	L	Ld:Cu.
3332	55 21 0	131 37 30	1st str N of Sawmill Cr-------	N	.2	L	L	45	10	35	10	90	---	---	---	Ld:Cu.
3335	55 21 0	131 37 30	Cr below bridge on rd 0.8 km N of main road.	N	.2	L	L	50	10	30	10	90	---	---	---	Ld:Cu.
3339	55 58 15	130 3 30	Fish Cr above rd bridge at Fourmile.	50	.6	L	.2	40	60	25	25	75	---	---	---	Ld:Cu,Au,Pb,Ag,W,Zn.
3343	55 56 15	130 2 15	1st str N of Hyder----------	40	.2	L	L	35	50	10	15	95	L	L	L	Ld:Cu,Au,Pb,Ag,W,Zn.
3372	55 58 45	130 3 15	Adnac Cr below Mt View trail bridge.	N	2.5	10	.4	50	430	30	100	75	---	---	---	Ld:Cu,Au,Pb,Ag,W,Zn.
3373	55 58 45	130 3 15	1st big trib to Fish Cr below Adnac Cr.	N	3	5	.2	55	230	25	15	65	---	---	---	Ld:Cu,Au,Pb,Ag,W,Zn.
3375	55 58 45	130 3 15	4th trib to Fish Cr below Adnac Cr.	N	1.5	5	.4	55	190	30	15	55	---	---	---	Ld:Cu,Au,Pb,Ag,W,Zn.
3377	55 58 45	130 3 15	1st small trib to Fish Cr below Adnac Cr.	N	4	10	1.5	60	310	35	85	120	---	---	---	Ld:Cu,Au,Pb,Ag,W,Zn.

Lake Clark quadrangle (8 concentrates; 6 analyzed for Au, In, and Tl)																		
3783	60	18	15	154	14	15	180 m above mouth Kijik R-----	N	0.6	5	0.2	85	55	80	30	430	---	---	---	Ld:Cu,Pb,Ag,Zn.
3791	60	11	30	154	20	15	N br of Tanalian R----------	N	.2	5	.2	65	30	45	15	190	L	L	L	None.
3794	60	23	0	153	43	30	1st str entering S side Little Lake Clark[5].	N	.2	5	L	50	35	25	15	95	L	L	L	None.
3795	60	25	0	153	38	30	2nd str entering S side Little Lake Clark[5].	N	L	L	.2	55	20	40	10	65	L	L	L	None.
3796	60	26	30	153	36	0	180 m above mouth of Chokotonk R.	N	L	L	L	50	50	40	5	95	L	L	L	None.
3797	60	23	0	153	55	30	Hatchet Cr----------	N	.2	L	L	100	60	320	15	330	---	---	---	None.
3798	60	21	30	154	1	15	Portage Cr 45 m from mouth----	N	.2	5	L	45	55	60	15	75	L	L	L	Pd:Au.
3799	60	22	30	154	2	30	Bowmen cut----------	N	.6	5	.4	90	40	110	270	250	11.1	L	L	Pd:Au.
Livengood quadrangle (11 concentrates; 4 analyzed for Au, In, and Tl)																		
36	65	1	15	147	10	30	Fish Cr trib to Little Chena R[3].	N	6.5	55	0.2	65	55	130	190	110	---	---	---	Pd:Sb,Bi,Au,Sn,W.
74	65	29	30	148	30	30	Livengood area, Olive Cr------	N	2	10	L	60	15	560	35	160	---	---	---	Pd:Cr,Au,Hg,W.
96	65	7	0	147	30	30	Lower Cleary Cr, F. E. Co. Dredge No. 3[3].	N	.4	10	L	85	75	170	45	30	---	---	---	Pd:Au,Sn,W,Sb.
97	65	3	30	147	9	30	Fairbanks Cr just above mouth of Deep Cr[3].	N	L	10	L	45	65	400	45	35	4.8	L	L	Pd:Au.
99	65	4	30	147	25	30	Chatham Cr[3]----------	N	.4	10	.4	60	15	110	60	60	---	---	---	Pd:Au.
100	65	4	30	147	10	30	Fairbanks Cr near Meehan[3]-----	N	3.5	L	0.2	45	50	160	95	50	47	L	L	Pd:Au.
145	65	0	30	147	16	0	Fairbanks Cr, No. 12 bench 1f limit.	N	.2	10	.4	30	35	40	35	130	---	---	---	Pd:Au,Sn,W,Sb.
148	65	4	0	147	14	30	Fairbanks Cr, claim 3 above discovery.	N	.4	10	.4	55	5	100	25	45	---	---	---	Pd:Au,Sn,W,Sb.
1446	65	31	15	148	31	30	Ruth Cr[3]----------	N	.2	10	.4	45	50	400	75	120	44	L	L	Pd:Sb,Cr,Au,Hg,W,RE.
1455	65	32	15	148	26	30	Amy Cr----------	N	.8	5	.4	190	60	970	10	170	135	L	L	Pd:Sb,Cr,Au.
1457	65	33	0	148	24	30	Goodluck Cr from tailing pile	N	.4	10	.6	50	40	80	20	140	---	---	---	Pd:Cr,FM,Au,Hg,RE,Sn.
McCarthy quadrangle (4 concentrates; 2 analyzed for Au, In, and Tl)																		
2134	61	22	0	142	28	30	Rt trib of Dan Cr----------	N	0.8	10	L	45	80	120	15	170	L	0.2	L	Ld:Cu; Pd:Au.
2136	61	20	45	142	44	30	Young Cr----------	N	.2	10	.4	50	55	120	20	180	---	---	---	Pd:Cu,Au,Pb,Ag,Sb.
2148	61	22	30	142	29	0	Dan Cr[3]----------	N	1	5	.4	65	2,000	110	55	230	---	---	---	Ld:Cu.
2438	61	18	30	142	33	30	Rex Cr, Chititu mines[3]--------	N	.8	10	.2	80	1,700	100	45	630	8.2	.2	L	Ld:Cu; Pd:Cu,Au,Pb,Ag,Sb.
McGrath quadrangle (2 concentrates; both analyzed for Au, In, and Tl)																		
483	62	41	15	155	43	45	Alder Gulch, Vinasale Mt[5]-----	N	0.2	10	0.4	25	5	30	20	150	6.7	L	L	Ld:Au,Sb,Bi,W.
1917	62	53	15	155	49	0	Candle Cr[3]----------	N	.4	10	2	100	50	120	190	470	9.3	.4	L	Pd:Au,Hg,W.
Medfra quadrangle (3 concentrates; none analyzed for Au, In, and Tl)																		
296	63	5	0	155	27	30	Gulch back of Appel Mt--------	40	0.2	15	0.6	40	5	40	20	200	---	---	---	None.
900	63	15	45	154	44	45	Greer Gulch----------	N	L	15	L	60	15	85	25	110	---	---	---	Ld:Bi,Cu,FM; Au,RE,Ag,W.
902	63	12	45	154	46	0	Holmes Gulch----------	N	.4	10	.4	40	25	40	20	100	---	---	---	Ld:Bi,Au,W,Cu; Pd:Au.
Mount Hayes quadrangle (13 concentrates; 5 analyzed for Au, In, and Tl)																		
230	63	10	0	144	51	30	Open cut, M. E. W. Co., State Cr.	N	L	10	L	130	15	340	15	45	---	---	---	Ld:Cu,Ag,Au; Pd:Au,Pt.
232	63	10	45	144	50	15	Meyers and Froelich ground on bend of Slate Cr.	N	.2	10	.6	150	20	1,300	35	85	2	L	L	Ld:Cu.
238	63	9	45	144	45	0	Ruby Gulch,Chisna R----------	N	.2	10	.4	160	15	440	45	50	L	L	L	Ld:Cu,Ag; Pd:Au.
241	63	10	30	144	47	45	Slate Cr, Miller claims N of Miller Gulch.	N	.6	10	.2	130	20	400	25	50	2.5	L	L	Ld:Cu,Ag; Pd:Au.
293	63	10	30	144	47	45	Slate Cr----------	N	.4	5	.2	120	20	540	20	55	.3	L	L	Ld:Cu,Ag; Pd:Au.
1469	63	41	15	144	21	0	Berry Cr 90 m above hwy bridge	N	.2	5	.2	25	10	15	40	80	---	---	---	None.

Lake Clark quadrangle (8 concentrates; 6 analyzed for Au, In, and Tl)																		
3783	60	18	15	154	14	15	180 m above mouth Kijik R-----	N	0.6	5	0.2	85	55	80	30	430	---	---	---	Ld:Cu,Pb,Ag,Zn.
3791	60	11	30	154	20	15	N br of Tanalian R----------	N	.2	5	.2	65	30	45	15	190	L	L	L	None.
3794	60	23	0	153	43	30	1st str entering S side Little Lake Clark[5].	N	.2	5	L	50	35	25	15	95	L	L	L	None.
3795	60	25	0	153	38	30	2nd str entering S side Little Lake Clark[5].	N	L	L	.2	55	20	40	10	65	L	L	L	None.
3796	60	26	30	153	36	0	180 m above mouth of Chokotonk R.	N	L	L	L	50	50	40	5	95	L	L	L	None.
3797	60	23	0	153	55	30	Hatchet Cr----------	N	.2	L	L	100	60	320	15	330	---	---	---	None.
3798	60	21	30	154	1	15	Portage Cr 45 m from mouth----	N	.2	5	L	45	55	60	15	75	L	L	L	Pd:Au.
3799	60	22	30	154	2	30	Bowmen cut----------	N	.6	5	.4	90	40	110	270	250	11.1	L	L	Pd:Au.
Livengood quadrangle (11 concentrates; 4 analyzed for Au, In, and Tl)																		
36	65	1	15	147	10	30	Fish Cr trib to Little Chena R[3].	N	6.5	55	0.2	65	55	130	190	110	---	---	---	Pd:Sb,Bi,Au,Sn,W.
74	65	29	30	148	30	30	Livengood area, Olive Cr------	N	2	10	L	60	15	560	35	160	---	---	---	Pd:Cr,Au,Hg,W.
96	65	7	0	147	30	30	Lower Cleary Cr, F. E. Co. Dredge No. 3[3].	N	.4	10	L	85	75	170	45	30	---	---	---	Pd:Au,Sn,W,Sb.
97	65	3	30	147	9	30	Fairbanks Cr just above mouth of Deep Cr[3].	N	L	10	L	45	65	400	45	35	4.8	L	L	Pd:Au.
99	65	4	30	147	25	30	Chatham Cr[3]----------	N	.4	10	.4	60	15	110	60	60	---	---	---	Pd:Au.
100	65	4	30	147	10	30	Fairbanks Cr near Meehan[3]-----	N	3.5	L	0.2	45	50	160	95	50	47	L	L	Pd:Au.
145	65	0	30	147	16	0	Fairbanks Cr, No. 12 bench 1f limit.	N	.2	10	.4	30	35	40	35	130	---	---	---	Pd:Au,Sn,W,Sb.
148	65	4	0	147	14	30	Fairbanks Cr, claim 3 above discovery.	N	.4	10	.4	55	5	100	25	45	---	---	---	Pd:Au,Sn,W,Sb.
1446	65	31	15	148	31	30	Ruth Cr[3]----------	N	.2	10	.4	45	50	400	75	120	44	L	L	Pd:Sb,Cr,Au,Hg,W,RE.
1455	65	32	15	148	26	30	Amy Cr----------	N	.8	5	.4	190	60	970	10	170	135	L	L	Pd:Sb,Cr,Au.
1457	65	33	0	148	24	30	Goodluck Cr from tailing pile	N	.4	10	.6	50	40	80	20	140	---	---	---	Pd:Cr,FM,Au,Hg,RE,Sn.
McCarthy quadrangle (4 concentrates; 2 analyzed for Au, In, and Tl)																		
2134	61	22	0	142	28	30	Rt trib of Dan Cr----------	N	0.8	10	L	45	80	120	15	170	L	0.2	L	Ld:Cu; Pd:Au.
2136	61	20	45	142	44	30	Young Cr----------	N	.2	10	.4	50	55	120	20	180	---	---	---	Pd:Cu,Au,Pb,Ag,Sb.
2148	61	22	30	142	29	0	Dan Cr[3]----------	N	1	5	.4	65	2,000	110	55	230	---	---	---	Ld:Cu.
2438	61	18	30	142	33	30	Rex Cr, Chititu mines[3]--------	N	.8	10	.2	80	1,700	100	45	630	8.2	.2	L	Ld:Cu; Pd:Cu,Au,Pb,Ag,Sb.
McGrath quadrangle (2 concentrates; both analyzed for Au, In, and Tl)																		
483	62	41	15	155	43	45	Alder Gulch, Vinasale Mt[5]-----	N	0.2	10	0.4	25	5	30	20	150	6.7	L	L	Ld:Au,Sb,Bi,W.
1917	62	53	15	155	49	0	Candle Cr[3]----------	N	.4	10	2	100	50	120	190	470	9.3	.4	L	Pd:Au,Hg,W.
Medfra quadrangle (3 concentrates; none analyzed for Au, In, and Tl)																		
296	63	5	0	155	27	30	Gulch back of Appel Mt--------	40	0.2	15	0.6	40	5	40	20	200	---	---	---	None.
900	63	15	45	154	44	45	Greer Gulch----------	N	L	15	L	60	15	85	25	110	---	---	---	Ld:Bi,Cu,FM; Au,RE,Ag,W.
902	63	12	45	154	46	0	Holmes Gulch----------	N	.4	10	.4	40	25	40	20	100	---	---	---	Ld:Bi,Au,W,Cu; Pd:Au.
Mount Hayes quadrangle (13 concentrates; 5 analyzed for Au, In, and Tl)																		
230	63	10	0	144	51	30	Open cut, M. E. W. Co., State Cr.	N	L	10	L	130	15	340	15	45	---	---	---	Ld:Cu,Ag,Au; Pd:Au,Pt.
232	63	10	45	144	50	15	Meyers and Froelich ground on bend of Slate Cr.	N	.2	10	.6	150	20	1,300	35	85	2	L	L	Ld:Cu.
238	63	9	45	144	45	0	Ruby Gulch,Chisna R----------	N	.2	10	.4	160	15	440	45	50	L	L	L	Ld:Cu,Ag; Pd:Au.
241	63	10	30	144	47	45	Slate Cr, Miller claims N of Miller Gulch.	N	.6	10	.2	130	20	400	25	50	2.5	L	L	Ld:Cu,Ag; Pd:Au.
293	63	10	30	144	47	45	Slate Cr----------	N	.4	5	.2	120	20	540	20	55	.3	L	L	Ld:Cu,Ag; Pd:Au.
1469	63	41	15	144	21	0	Berry Cr 90 m above hwy bridge	N	.2	5	.2	25	10	15	40	80	---	---	---	None.

TABLE 1.—*Locations and results of analyses of 347 magnetic concentrates from Alaska, related to known mineral deposits*—Continued

File Number	North Latitude ° ' "	West Longitude ° ' "	Description of Location[1]	Element concentrations (parts per million) eU (30)	Ag (0.2)	Bi (5)	Cd (0.2)	Co (1)	Cu (1)	Ni (1)	Pb (5)	Zn (1)	Au (0.2)	In (0.2)	Tl (0.2)	Known mineral deposits nearby[2]
Mount Hayes quadrangle (13 concentrates; 5 analyzed for Au, In, and Tl)--Continued																
1471	63 41 30	144 27 30	Sears Cr 0.4 km above hwy bridge.	N	0.8	L	L	35	10	30	15	65	---	---	---	None.
1472	63 41 15	144 33 30	Dry Cr 75 m above hwy bridge --	40	.2	5	.4	20	10	15	35	85	---	---	---	None.
1473	63 47 0	144 48 0	Little Gerstle R 90 m above hwy bridge.	N	.8	5	.2	40	30	130	45	100	---	---	---	None.
1475	63 37 15	144 0 30	Chief Cr 23 m above hwy bridge	N	.4	L	L	25	5	30	40	60	---	---	---	None.
1510	63 16 30	145 39 15	Rt trib of Phelan Cr 7 km above mouth.	N	.4	10	.4	45	110	90	25	75	---	---	---	Ld:Cu,Ag,Pb.
1511	63 17 30	145 38 45	Rt trib of Phelan Cr 5.6 km above mouth.	N	.2	5	.4	230	20	50	20	800	L	L	L	Ld:Cu,Ag,Pb.
1513	63 19 30	145 45 0	Delta R 0.4 km below Phelan Cr	N	.4	L	.4	75	55	390	30	65	---	---	---	Ld:Cu,Ag,Pb.
Mount McKinley quadrangle (6 concentrates; 5 analyzed for Au, In, and Tl)																
196	63 47 0	150 22 30	Little Moose Cr, Toklat R, claim no. 20.	N	1.5	5	0.4	60	5	100	5	15	---	---	---	Pd:Au,Ag,W.
1019	63 35 45	150 46 30	Caribou Cr below mouth Crevice Cr.	N	.2	10	.4	40	25	100	65	25	.3	L	L	Ld:Sb,Au,Pb,Zn,Ag.
1021	63 36 30	150 45 30	Caribou Cr ----------	N	.2	10	L	40	10	130	35	30	L	L	L	Pd:Sb,Au,W.
1023	63 36 15	150 47 0	Caribou Cr ----------	N	L	5	L	40	10	610	50	30	.3	L	L	Pd:Sb,Au,W.
1026	63 34 45	150 53 0	Glacier Cr, claim no. 14 just below Fifteen Gulch.	N	L	5	L	40	5	100	15	20	.5	L	L	Pd:Au,Pb.
1028	63 36 15	150 42 45	Caribou Cr ----------	N	.2	5	.4	40	5	100	30	25	10.5	L	L	Ld:Au.
Nabesna quadrangle (4 concentrates; none analyzed for Au, In, and Tl)																
1493	62 56 15	143 30 0	Trib of Mentasta Cr 7 km E of Station Cr.	N	0.6	L	0.2	75	45	100	55	140	---	---	---	None.
1504	62 51 0	143 51 0	1st rt trib to Indian Pass Cr	N	.4	L	.4	40	75	60	25	85	---	---	---	Ld:Cu.
1507	62 49 30	143 45 0	2nd rt trib to Slana R above Porcupine Cr.	N	.6	10	.2	40	80	65	15	85	---	---	---	None.
1771	62 10 0	142 7 0	Cross Cr ----------	N	L	10	.4	40	10	85	10	30	---	---	---	None.
Nome quadrangle (5 concentrates; 2 analyzed for Au, In, and Tl)																
201	64 41 30	165 37 30	Sledge Cr ----------	N	L	5	L	75	10	75	10	50	---	---	---	Pd:Bi,Au,W.
237	64 35 30	165 28 45	Monument Cr ----------	N	.2	10	L	5	5	15	15	65	---	---	---	Pd:Au,Sn.
279	64 34 30	165 6 0	Osborn Cr, Nome ----------	N	.2	5	L	55	10	90	150	45	---	---	---	Ld:Cu,Au; Pd:Au.
332	64 45 30	165 18 45	Hobson Cr ----------	N	L	10	L	50	5	80	5	25	.3	L	L	Ld:Cu,Sb,Au.
649	64 49 30	165 14 30	Dorothy Cr trib of Nome R -----	N	.2	10	.4	30	5	20	35	50	L	L	L	Pd:Sb,Au.
Norton Bay quadrangle (4 concentrates; 2 analyzed for Au, In, and Tl)																
304	64 33 30	160 44 45	Bonanza Cr E of Ungalik-------	N	L	5	0.4	30	50	100	15	30	1.1	L	L	Pd:Sb,Au,W.
2966	64 44 45	161 52 45	Mouth of Tubutulik R----------	40	.2	10	.4	30	5	35	20	85	---	---	---	None.
2967	64 45 30	161 54 30	Tubutulik R rt bar at fish camp.	60	L	5	.4	30	5	50	15	65	L	L	L	None.
2968	64 47 15	161 56 0	Tubutulik R 4 km dstr of Camp 15.	70	L	10	.6	35	5	65	25	85	---	---	---	None.
Ruby quadrangle (4 concentrates; 2 analyzed for Au, In, and Tl)																
56	64 4 0	155 38 15	Mouth of Solomon Cr----------	N	600	15	0.4	85	120	330	75	75	---	---	---	Pd:Au,Sn.
59	64 24 15	155 21 45	Glen Gulch----------	N	340	90	2.5	1,000	470	830	4,700	220	---	---	---	Pd:Au.
128	64 44 0	155 29 30	Robinson placer ground on Ruby Cr.	N	.2	10	L	80	L	160	10	15	L	L	L	Pd:Au,Sn.
682	64 42 0	155 21 0	Shaft near Warners cabin on Glacier Cr.	N	.2	10	L	55	L	110	20	110	L	L	L	Pd:Bi,Au,Sn.

TABLE 1.—*Locations and results of analyses of 347 magnetic concentrates from Alaska, related to known mineral deposits*—Continued

File Number	North Latitude ° ' "	West Longitude ° ' "	Description of Location[1]	Element concentrations (parts per million) eU (30)	Ag (0.2)	Bi (5)	Cd (0.2)	Co (1)	Cu (1)	Ni (1)	Pb (5)	Zn (1)	Au (0.2)	In (0.2)	Tl (0.2)	Known mineral deposits nearby[2]
			Solomon quadrangle[6] (101 concentrates; 41 analyzed for Au, In, and Tl)--Continued													
2951	64 48 0	162 8 0	0.8 km below 3rd rt trib on Kwiniuk R.	50	.4	10	.4	35	5	20	20	75	---	---	---	None.
2954	64 44 0	162 19 15	Kwiniuk R above 4th rt trib below Camp 19.	80	L	10	L	35	5	15	15	50	---	---	---	Pd:Cu,RE,W.
2956	64 44 0	162 19 15	1st lf trib to Kwiniuk R below Camp 19.	100	.6	10	.6	95	10	280	40	500	---	---	---	Pd:Cu,RE,W.
2957	64 44 0	162 19 15	Kwiniuk R lf bar in front of Camp 19.	60	L	10	L	30	L	15	15	65	L	L	L	Pd:Cu,RE,W.
2958	64 44 0	162 19 15	Kwiniuk R below island above Camp 19.	110	0.2	5	0.4	35	10	20	20	70	---	---	---	Pd:Cu,RE,W.
2959	64 44 0	162 19 15	Above 1st lf trib above Camp 19 on Kwiniuk R.	110	.2	10	.4	30	5	20	15	65	L	.2	.2	Pd:Cu,RE,W.
2960	64 43 0	162 22 30	Kwiniuk R lf bar above islands above Camp 19.	60	.2	10	.6	25	5	15	55	35	.2	L	L	Pd:Cu,RE,W.
2961	64 43 0	162 22 30	3rd lf trib above Camp 19 Kwiniuk R area.	200	.4	10	.6	30	L	15	25	75	L	L	.2	Pd:Cu,RE,W.
2963	64 40 15	162 25 30	2nd rt trib to Kwiniuk R below hw fks.	50	L	10	.2	30	L	20	15	55	L	L	L	None.
2970	64 50 30	162 3 45	Tubutulik R at Camp 10--------	N	.2	10	.6	35	5	50	15	75	L	L	L	None.
2972	64 53 45	162 8 0	Tubutulik R 0.4 km below Clear Cr.	50	.4	10	.2	30	5	30	20	75	L	L	L	Pd:RE.
2973	64 53 45	162 8 0	Lf cobble bar of Clear Cr at side of Camp 11.	140	L	10	.4	25	10	15	25	65	L	L	L	Pd:RE.
2974	64 53 30	162 11 0	Clear Cr above mouth of 1st lf trib.	90	.4	5	L	30	L	15	25	65	L	.3	L	Pd:RE.
2975	64 54 15	162 13 45	2nd rt trib to 1st lf trib to Clear Cr.	110	L	15	L	35	5	15	30	45	---	---	---	None.
2976	64 54 15	162 13 45	3rd rt trib to 1st lf trib to Clear Cr.	210	.2	10	.4	25	5	10	25	45	L	L	.3	None.
2977	64 54 15	162 13 45	1st lf trib to Clear Cr-------	130	.4	10	.4	30	L	15	35	55	---	---	---	None.
2978	64 54 15	162 13 45	4th rt trib to 1st lf trib to Clear Cr.	190	L	15	5.5	30	5	15	45	50	L	L	.2	None.
2980	64 54 15	162 13 45	Tubutulik R area, 1st lf trib to Clear Cr.	60	.4	10	L	35	5	40	15	35	---	---	---	None.
2981	64 53 30	162 11 0	Tubutulik R old streambed 0.8 km above 1st trib.	90	L	10	L	30	5	15	25	55	L	L	L	Pd:RE.
2982	64 53 30	162 11 0	Clear Cr 0.8 km above 1st lf trib.	140	.2	10	.4	25	5	10	35	35	L	.2	.2	Pd:RE.
2983	64 52 45	162 14 0	2nd lf trib to Clear Cr, Tubutulik R area.	290	.4	20	.6	25	5	10	120	60	---	---	---	Pd:FM,RE,Sn,W,Cb.
2984	64 53 45	162 16 30	1st lf trib to 2nd lf trib to Clear Cr.	150	.6	5	.2	25	L	15	45	60	---	---	---	Pd:FM,RE,Sn,W,Cb.
2985	64 53 45	162 16 30	1st lf trib to 2nd lf trib to Clear Cr.	100	.4	35	.4	30	10	15	30	85	---	---	---	Pd:FM,RE,Sn,W,Cb.
2986	64 53 45	162 16 30	1st lf trib to 2nd lf trib to Clear Cr.	90	.2	10	.4	20	5	10	35	55	---	---	---	Pd:FM,RE,Sn,W,Cb.
2987	64 53 45	162 16 30	1st lf trib to 2nd lf trib to Clear Cr.	170	6.5	10	.4	25	5	15	45	65	---	---	---	Pd:FM,RE,Sn,W,Cb.
2988	64 53 15	162 16 0	2nd lf trib to 2nd lf trib to Clear Cr.	150	0.2	10	0.4	20	5	10	25	55	---	---	---	Pd:FM,RE,Sn,W,Cb.
2989	64 52 45	162 14 0	2nd lf trib to Clear Cr-------	330	.4	10	L	25	5	10	35	60	---	---	---	Pd:FM,RE,Sn,W,Cb.
2990	64 52 45	162 14 0	1st rt trib to 2nd lf trib to Clear Cr.	190	.2	15	.6	25	5	15	30	65	L	L	.3	Pd:FM,RE,Sn,W,Cb.
2992	64 53 45	162 16 30	Tubutulik R area, Clear Cr 0.8 km above 1st lf trib.	560	.2	10	.6	30	5	15	40	90	---	---	---	Pd:FM,RE,Sn,W,Cb.
2993	64 53 15	162 16 0	Tubutulik R area, 2nd lf trib to Clear Cr.	410	L	15	L	25	5	10	40	65	---	---	---	Pd:FM,RE,Sn,W.Cb.

Solomon quadrangle[6] (101 concentrates; 41 analyzed for Au, In, and Tl)--Continued

2994	64	53	15	162	16	0	4th lf trib to 2nd lf trib to Clear Cr.	310	.2	15	.6	30	10	15	35	75	---	---	---	Pd:FM,RE,Sn,W,Cb.
2995	64	53	15	162	16	0	Slope above 4th lf trib to 2nd lf trib to Clear Cr[5].	500	.4	40	.4	25	10	10	70	30	---	---	---	Pd:FM,RE,Sn,W,Cb.
2996	64	53	15	162	16	0	Lf hw br of 2nd lf trib to Clear Cr[5].	410	.2	10	.6	20	5	10	35	50	---	---	---	Pd:FM,RE,Sn,W,Cb.
2997	64	53	45	162	16	30	Rt hw br of 2nd lf trib to Clear Cr.	150	.2	20	.4	20	5	10	25	65	---	---	---	Pd:FM,RE,Sn,W,Cb.
2998	64	52	45	162	14	0	Small str at Camp 12----------	150	.2	10	.4	25	5	20	25	70	---	---	---	Pd:FM,RE,Sn,W,Cb.
3000	64	51	45	162	14	15	Island 0.8 km below 3rd lf trib to Clear Cr.	190	.4	10	.4	25	5	15	20	70	L	L	.2	None.
3001	64	51	45	162	14	15	Tubutulik R area, Clear Cr above 3rd lf trib.	170	.4	15	L	30	5	15	25	55	L	L	.2	None.
3002	64	51	45	162	14	15	3rd lf trib to Clear Cr-------	90	L	10	.4	25	5	15	25	75	---	---	---	None.
3004	64	52	0	162	17	0	Tubutulik R area, 3rd lf trib to Clear Cr.	100	.4	15	L	30	10	15	20	55	L	L	.2	None.
3005	64	52	0	162	17	0	2nd rt trib to 3rd lf trib to Clear Cr.	140	.2	15	.4	30	5	20	25	70	L	L	1	None.
3006	64	52	0	162	17	0	Lf fk of 2nd rt trib to 3rd lf trib to Clear Cr.	100	.2	15	.6	25	5	20	35	55	---	---	---	None.
3007	64	52	0	162	17	0	Btw fks of 2nd rt trib to 3rd lf trib to Clear Cr.	100	.2	10	L	25	5	10	20	50	L	L	.2	None.
3008	64	52	0	162	17	0	3rd rt trib to 3rd lf trib to Clear Cr.	120	1	10	.4	20	L	10	35	55	---	---	---	None.
3009	64	52	0	162	17	0	Below jct of hw fks of 3rd lf trib to Clear Cr.	200	.2	15	.6	20	10	10	65	60	L	L	.6	None.
3010	64	52	0	162	17	0	Lf fk of 3rd lf trib to Clear Cr.	140	L	15	L	30	10	10	35	65	L	L	.3	None.
3011	64	52	0	162	17	0	Rt hw fk of 3rd lf trib to Clear Cr.	210	.4	10	.2	25	5	15	35	80	---	---	---	None.
3012	64	51	30	162	16	15	1st rt trib above 3rd lf trib to Clear Cr.	60	.4	10	.4	35	L	15	20	95	L	L	L	None.
3013	64	51	30	162	16	15	2nd rt trib above 3rd lf trib to Clear Cr.	70	0.2	10	0.4	25	5	10	45	65	---	---	---	None.
3014	64	51	30	162	16	15	Clear Cr 135 m above 4th lf trib.	110	.4	15	.4	30	L	15	25	80	L	.2	L	None.
3015	64	51	30	162	16	15	Clear Cr 45 m below sample 3016.	50	.2	10	L	45	5	15	30	65	---	---	---	None.
3016	64	51	30	162	16	15	Clear Cr btw 4th and 5th lf tribs.	140	.4	15	.6	35	5	15	25	75	L	L	L	None.
3017	64	51	30	162	16	15	6th lf trib of Clear Cr-------	240	.4	15	.4	30	5	15	35	95	L	L	L	None.
3018	64	51	0	162	19	30	Lf hw fk to 6th lf trib of Clear Cr.	210	.4	10	.2	30	L	15	40	55	L	L	.3	Pd:RE.
3019	64	51	0	162	19	30	Rt fk to 6th lf trib of Clear Cr.	370	.8	15	L	30	5	20	25	50	L	L	.3	Pd:RE.
3020	64	51	0	162	17	30	7th lf trib to Clear Cr-------	170	.4	10	.4	30	L	10	45	60	L	L	.4	Pd:RE.
3021	64	51	0	162	17	30	Tubutulik R area, 7th lf trib of Clear Cr.	190	L	15	L	30	5	15	30	45	L	L	.4	Pd:RE.
3022	64	50	15	162	20	30	Mouth of 8th lf trib of Clear Cr.	200	.2	10	.6	25	5	15	35	45	L	L	.3	Pd:RE.
3023	64	50	15	162	20	30	Tubutulik R area, 8th lf trib of Clear Cr[5].	120	.4	15	L	35	10	15	30	45	L	L	L	Pd:RE.
3024	64	50	15	162	20	30	Clear Cr 90 m above 8th lf trib.	130	1.5	10	L	30	5	15	25	60	.2	.2	L	Pd:RE.
3025	64	53	45	162	8	0	Tubutulik R just below Clear Cr.	60	.4	10	.4	30	5	15	25	90	---	---	---	Pd:RE.

TABLE 1.—*Locations and results of analyses of 347 magnetic concentrates from Alaska, related to known mineral deposits*—Continued

File Number	North Latitude ° ' "	West Longitude ° ' "	Description of Location[1]	Element concentrations (parts per million) eU (30)	Ag (0.2)	Bi (5)	Cd (0.2)	Co (1)	Cu (1)	Ni (1)	Pb (5)	Zn (1)	Au (0.2)	In (0.2)	Tl (0.2)	Known mineral deposits nearby[2]
Solomon quadrangle[6] (101 concentrates; 41 analyzed for Au, In, and Tl)--Continued																
3026	64 55 15	162 8 30	2nd island upstr from mouth of Clear Cr.	50	L	10	L	35	5	55	25	55	---	---	---	None.
3028	64 55 15	162 8 30	275 m up Vulcan Cr, Tubutulik R area.	60	.2	5	.4	10	15	20	10	10	L	L	L	None.
3029	64 56 0	162 13 45	Vulcan Cr near head of 2nd rt trib.	120	.2	10	.6	25	5	15	30	60	---	---	---	Pd:Cb,FM,RE.
3030	64 56 30	162 7 0	Tubutulik R area, Vulcan Cr	120	L	10	L	30	10	15	25	50	---	---	---	None.
3031	64 56 30	162 11 30	Vulcan Cr just below 3rd rt trib.	220	.2	10	.6	30	5	15	45	70	---	---	---	None.
3032	64 56 0	162 13 45	3rd rt trib to Vulcan Cr Tubutulik R area.	260	.2	10	.4	25	5	15	25	100	---	---	---	Pd:Cb,FM,RE.
3033	64 56 0	162 13 45	Vulcan Cr 275 m below 3rd rt trib.	290	.4	10	.4	30	L	10	35	70	---	---	---	Pd:Cb,FM,RE.
3034	64 56 30	162 11 30	Tubutulik R area above 3rd rt trib of Vulcan Cr.	70	.4	15	.8	30	5	20	30	65	---	---	---	None.
3035	64 56 30	162 11 30	4th rt trib to Vulcan Cr------	170	.4	10	.4	25	L	10	25	85	---	---	---	None.
3036	64 55 15	162 8 30	Tubutulik R 90 m above Vulcan Cr.	100	0.2	20	0.4	35	10	40	35	90	---	---	---	None.
3037	64 56 30	162 2 30	Tubutulik R opposite lower Vulcan Pt ridge.	90	.2	10	.4	45	10	100	25	120	---	---	---	None.
3048	64 59 30	162 15 0	Rock Cr near uppermost spruce forest.	210	.4	15	.4	35	10	20	120	100	---	---	---	None.
3049	64 57 45	162 22 0	1st lf trib to Rock Cr--------	100	.2	10	.6	30	10	20	95	65	---	---	---	Pd:RE.
3050	64 57 45	162 22 0	2nd lf trib to Rock Cr, Tubutulik R area.	130	L	10	.6	30	10	15	30	60	L	L	.2	Pd:RE.
3052	64 57 45	162 22 0	Tubutulik R above mouth of rt hw br Rock Cr.	130	.4	10	.6	30	10	15	30	75	---	---	---	Pd:RE.
Talkeetna quadrangle (5 concentrates; 2 analyzed for Au, In, and Tl)																
254	62 20 30	151 22 0	Mills Cr, Cache Cr district---	N	0.4	10	0.4	65	10	75	45	250	62	L	L	Pd:Au.
482	62 36 0	150 45 30	Canyon Cr trib to Long Cr-----	N	1	10	1	75	20	45	35	930	---	---	---	Pd:Au,Sn,Pt.
1290	62 30 45	150 55 30	Cache Cr 0.6 km dstr from Nugget Cr.	N	L	5	.4	130	20	490	25	45	L	L	L	Pd:Au,Sn,Pt, W.
1304	62 28 0	151 0 30	Cheechako Gulch, Krummenachers cut.	N	L	10	L	70	10	70	10	600	---	---	---	Pd:Cu,Au,Sn,W.
1336	62 30 0	150 57 30	Cache Cr opposite Lucky Gulch[3]	N	.8	10	.2	90	20	480	80	430	---	---	---	Pd:Au.
Talkeetna Mountains quadrangle (3 concentrates; 1 analyzed for Au, In, and Tl)																
2179	62 0 15	147 15 0	Slate Cr, trib to Crooked Cr--	N	0.2	10	.6	60	30	45	75	630	---	---	---	Pd:Au.
2181	62 0 15	147 20 30	Albert Cr, trib to Crooked Cr[3].	N	.8	20	L	110	25	75	25	430	L	.2	L	Pd:Au,Pt.
2182	62 2 15	147 14 30	Crooked Cr----------	N	.2	10	.6	80	20	60	25	2,800	---	---	---	Pd:Au.

Tanacross quadrangle (3 concentrates; none analyzed for Au, In, and Tl)																						
1479	63	22	45	143	37	0	Yerrick Cr 90 m above hwy bridge.	N	L	L	0.2	40	25	35	15	65	---	---	---	None.
1499	63	7	30	143	14	30	Trib of Tok R 9 km NE of 1498	N	.2	L	.2	140	30	180	25	470	---	---	---	None.
1500	63	5	0	143	19	30	Road cut at mouth of Little Tok R.	N	.4	L	.2	50	60	90	25	100	---	---	---	None.
Tanana quadrangle (1 concentrate; not analyzed for Au, In, and Tl)																						
2418	65	9	30	150	16	0	Lower Rhode Is Cr[3]----------	N	120	10	.4	75	480[4]	340	85	20	---	---	---	Pd:Au.
Teller quadrangle (2 concentrates; 1 analyzed for Au, In, Tl)																						
494	65	34	45	167	56	0	Cape Cr, Overlook claim near North Star mines.	N	L	10	0.4	20	5	100	10	80	---	---	---	Pd:Cb,Sn.
497	65	33	30	167	57	15	Cape Cr, Tin City[5]----------	N	.4	45	.4	20	L	100	15	1,100	L	L	L	Pd:Sn.
Valdez quadrangle (3 concentrates; 1 analyzed for Au, In, and Tl)																						
2131	61	44	30	145	9	30	Rock Cr----------	N	0.2	5	L	70	40	150	15	160	---	---	---	Ld:Cu,Zn.
2156	61	37	30	145	7	30	Bernard Cr----------	N	.6	L	.2	65	55	130	35	140	---	---	---	Ld:Cr.
2162	61	59	45	146	56	0	Little Nelchina R----------	N	.2	5	.2	80	35	60	15	330	L	L	L	None.

[1] Abbreviations used to describe location: br(s), branch(es); btw, between; Co.. company; conc, concentrate; Cr(s), Creek(s); dstr, downstream; E, east; fork(s); hw(s), headwater(s); hwy, highway; is, island; jct, junction; lf, left; mid, middle; mt, mountain; N, north; no., number; pt, point; R, River; rd, road; rt, right; S, south; spgs, springs; str, stream; trib, tributary; ustr, upstream; W, west; 1st, first; 2nd, second; 3rd, third; 4th, fourth; etc.

[2] Elements with a record of production are underlined; Ld = lode deposit; Pd = placer deposit; RE = rare earth minerals; FM = fissionable materials.

[3] Derived from sluice box or dredge concentrate.

[4] Threshold values in the Candle quadrangle are different from those elsewhere (see table 10), so anomalous values will also differ.

[5] Density greater than 3.3.

[6] Threshold values in the Solomon quadrangle are different from those elsewhere (see table 10), so anomalous values will also differ.

from the original suite of 1,072 concentrates to test the repeatability of analytical results. Hence, this sample appeared 31 times in the set of magnetic concentrates weighing 1 g or more: once as a sample and 30 times as a replicate subsample.

The control sample (number 300DL) from Nevada was detrital magnetite collected in 1964 by D. E. Lee, U.S. Geological Survey. The magnetite was separated from a table concentrate of a placer in the canyon floor at the mouth of Hampton Creek at an altitude of 1,860 m on the east side of the northern Snake Range in Humboldt National Forest, Nevada. The principal source rocks for the placer concentrate were Lower Cambrian clastic sediments metamorphosed to garnet-staurolite-muscovite schist (Hose and Blake, 1970). Carbonate rocks of Cambrian age are locally present, and small areas of the basin are underlain by igneous rocks. Thus, the magnetite in the Hampton Creek control sample was probably derived from several kinds of source rocks.

The control sample (number 52-WE-819) from North Carolina was panned in 1952 by A. M. White, U.S. Geological Survey, from gravel in the bed of Lyle Creek, Catawba County. The basin of Lyle Creek is underlain by metamorphosed sedimentary rocks, mafic rocks, and intrusive quartz monzonite (Theobald and others, 1967). Separation of the magnetic fraction from the panned concentrate and division of the magnetic fraction into appropriate subsamples for replicate analyses were done in 1971 by A. L. Larson, U.S. Geological Survey.

The control sample of magnetic concentrate (number 3799) from Alaska was prepared in 1971 by A. L. Larson from a sample in the Alaskan placer concentrate file. This sample was collected in 1949 by A. E. Nelson, U.S. Geological Survey, in the Bowman Cut of the gold placer on Portage Creek at an altitude of 300 m on the north side of Lake Clark in the Lake Clark quadrangle (table 1). The placer was exploited from 1910 to 1912 and for a few years after World War II (Cobb, 1973, p. 11-12). Portage Creek drains an undivided complex of mafic lava and tuff with considerable metamorphosed sediments and some intrusive rocks locally present (Capps, 1935, pl. 2). This complex was regarded as Early Jurassic to Cretaceous in age. Doubtless the lavas were the main source of the abundant magnetite in the concentrate.

EQUIVALENT URANIUM

The radioactivity of 347 magnetic concentrates and 30 replicates was measured by K.-L. Pan to determine the equivalent uranium before the samples were dissolved for chemical analyses. To measure the equivalent uranium, about 1 g of the magnetic concentrate was placed in a lead shield 4 cm thick in which an end-window Geiger-Muller tube was mounted. Radiation was recorded in counts per second by a scaler-type instrument operated at 1,450 volts. A counting time of 256 seconds marked by automatic timer was used for the samples, and background counts were made over the longer interval of 2,560 seconds. By comparing the counts recorded for the magnetic concentrates with those recorded for a standard sample with 0.1 percent uranium obtained from the U.S. Atomic Energy Commission, and correcting for background, the radiation of each magnetic concentrate was recorded as percent equivalent uranium (eU). Because of the high random fluctuation in both intensity and direction of β-particle and γ-ray emission measured by the instrument (Wayne Mountjoy, oral commun., 1971), the cutoff value was defined as twice the standard deviation of the counts, and was determined to be 0.003 percent eU (30 ppm). The results of these analyses are listed in table 1.

Higher-than-background radioactivity was not detected in any of the 30 subsamples of the replicate magnetic concentrate (3799) from the Portage Creek placer. Thus, it is difficult to draw a conclusion about the precision of the eU determinations. However, they are thought to be reliable because of the consistent results from many repeated measurements of the 0.1 percent uranium standard and from the background counting.

EIGHT ELEMENTS BY ATOMIC ABSORPTION

The method used by K.-L. Pan to determine the abundances of silver, bismuth, cadmium, copper, cobalt, nickel, lead, and zinc in the magnetic concentrates was modified from the single-solution, atomic absorption procedure developed in the U.S. Geological Survey by H. M. Nakagawa (1975) for use with iron-rich samples. The modification, worked out with R. L. Turner, employed the following steps.

One gram of magnetic concentrate was decomposed without grinding (as a way to save time in geochemical exploration) in a test tube in 15 ml of concentrated HCl under moderate heat. After evaporation to dryness, the residue was dissolved in 4 ml of concentrated HNO_3 and brought to dryness. The residue was then dissolved again under warm heat in 1 ml of concentrated HNO_3 and 9 ml of 6*N* HCl. After filtration, the abundant iron in the sample solution, which interferes with the determination of the minor elements, was extracted by 0.5 ml of concentrated HBr and 10 ml of methyl isobutyl ketone (MIBK). This extraction was repeated several times, either until the organic layer

that was discarded was colorless or until the color ceased to change. The iron-free sample was then read on a Perkin-Elmer[1] 290 atomic absorption instrument. The concentrations were determined in parts per million (ppm) in the same single solution, with lower limits of detection as follows: silver, 0.2 ppm; bismuth, 5 ppm; cadmium, 0.2 ppm; cobalt, 1 ppm; copper, 1 ppm; nickel, 1 ppm; lead, 5 ppm; zinc, 1 ppm. About 15 samples (120 determinations) were analyzed in one man-day.

TESTS OF PROCEDURE

Three tests of the reproducibility of the results by the eight-element procedure were carried out on two of the control samples of magnetic concentrates. The purposes of these tests were to determine the suitability of the procedures for typical applications in geochemical exploration, and to consider aspects of sample preparation prior to analysis. Because the acid digestion used in the procedure takes unground magnetite into solution, the grinding of the magnetic concentrate could be eliminated to reduce time needed for the analysis, provided unacceptable bias is not introduced. Inasmuch as the samples were dissolved twice in different concentrations of acids over moderate heat, the efficiency of the digestion could have been affected by many physical and chemical factors. The only way to lessen this kind of bias was to maintain identical conditions of heating and digestion, so far as possible, for each lot of samples. An effort was made to maintain identical conditions in the three tests described below.

The first test was designed to evaluate reproducibility for each of the eight elements in unsplit and unsized samples. The control sample from the Hampton Creek placer was chosen for this test because it was large and the magnetite consisted of poorly sorted grains. Twenty-four unsplit and unsized specimens were volumetrically scooped out of the sample container, and each specimen was analyzed just as it was scooped. The results are given in table 2, which shows that the variance for all elements except silver and zinc is relatively acceptable. Silver and zinc show great variations, and several individual values approach or are greater than twice the arithmetic mean. These variations may be caused by: (1) inhomogeneity of the subsamples, constituting a sampling bias; (2) variations in the content of minor elements in the magnetite related to grain size and source; and (3) errors in analysis. The chemical variations shown in table 2 probably reflect differences in the relative amount of coarse and fine grains of magnetite in the subsamples.

[1]The use of trade names in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

TABLE 2.—*Replicate analyses of unsplit and unsized control sample of magnetic concentrates from Hampton Creek placer, Nevada, for Ag, Bi, Cd, Co, Cu, Ni, Pb, and Zn*

[Data are in parts per million]

Subsamples of 300DL	Elements							
	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
1	0.96	12	1.2	48	59	48	420	60
2	1.44	12	1.6	48	39	48	420	40
3	1.20	9	1.6	47	54	48	420	40
4	1.92	9	1.2	47	44	36	420	44
5	1.80	12	1.6	48	52	48	360	112
6	2.64	9	1.6	47	54	48	420	44
7	1.68	12	1.6	44	44	48	420	48
8	1.44	12	1.6	44	38	36	540	56
9	1.44	12	1.6	42	36	48	540	36
10	5.10	15	1.6	48	49	48	354	133
11	1.92	12	1.2	47	53	48	420	60
12	1.44	12	1.6	44	41	48	420	36
13	1.44	12	2.0	47	42	36	480	100
14	.72	12	1.6	41	45	36	420	112
15	2.70	12	1.6	48	42	48	396	119
16	.96	12	1.6	50	38	36	420	64
17	1.20	9	1.2	48	40	48	480	68
18	.72	9	1.2	42	40	36	420	64
19	.96	9	1.6	48	48	36	480	76
20	1.80	12	1.6	46	50	48	336	144
21	.96	9	1.2	42	42	36	420	56
22	1.68	12	1.2	47	60	36	420	80
23	1.44	12	1.6	47	52	48	480	92
24	1.44	12	1.2	45	49	36	480	84
Mean	1.15	11	1.5	46	46	43	433	74
Standard deviation	1.00	1.6	.22	2.4	6.9	6.0	50.4	31.9
Relative standard deviation (percent)	87.0	14.5	15.3	5.2	15.0	14.0	11.6	43.1

Detrital magnetite in replicate sample 300DL from Hampton Creek is a mixture of grains derived from several source rocks. The minor elements in a detrital mineral display a tendency to vary by grain size, and the grain size tends to vary by source (Overstreet and others, 1970). Distinctive populations of minor elements have been found to characterize magnetites from individual intrusive rocks and mineralized districts (Hamil and Nackowski, 1971). Thus, the physical and chemical properties of grains of magnetite in a detrital mixture will be irregular and inhomogeneous. Variations in grain size of the magnetite in the 24 subsamples from the Hampton Creek control sample probably caused the great variations in the results of the replicate analyses.

The second test was designed to examine possible variation in the composition of the unsplit magnetic concentrate related to particle size. For this test the Hampton Creek control sample was sieved to give four sized fractions (mesh): +42; −42+80; −80+170; and −170. One subsample, called here the original subsample, was scooped from each size fraction, which exhausted the supply of the coarsest material but left

enough of the smaller sizes to permit replicate analyses to be made (table 3). The data from this test show convincingly that the content of minor elements in the coarsest grains is substantially different from that in the finer fractions. The data in table 3 suggest that in a well-sized sample the material can be volumetrically scooped instead of split to acquire a suitable subsample for analysis. However, further study of the relations of the minor-element content, grain size, and source of detrital magnetite is evidently needed.

TABLE 3.—*Replicate analyses of unsplit but sized control sample 300DL of magnetic concentrates from Hampton Creek placer, Nevada, for Ag, Bi, Cd, Co, Cu, Ni, Pb, and Zn*

[Data are in parts per million]

Sieve fraction (mesh)	Subsample	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
+42	Original-	2.2	76	2.9	91	67	652	362	106
-42+80	Original-	.5	13	1	50	41	60	233	128
	Replicate	.5	13	1	50	40	65	233	130
	--do-----	.5	13	1	50	43	60	240	130
	--do-----	.5	13	1	50	40	60	233	142
-80+170	Original-	.5	13	1	48	39	50	300	143
	Replicate	.5	13	1	50	41	50	300	145
	--do-----	.8	13	1	50	50	60	300	150
	--do-----	.8	13	1	50	40	60	300	167
-170	Original	.5	13	1	50	50	50	400	140
	Replicate	.5	13	1	50	50	60	400	157

Sizing by screens is less convenient than sizing by grinding; therefore, grinding is indicated unless the original concentrate can be split into a representative magnetic fraction containing essentially the same distribution of particle sizes as the original concentrate. Also, sizing by screens would eliminate from analysis some extra large or extra small grains whose compositions would be needed in a geochemical survey to represent a group of rocks or ore deposits that would otherwise be missed.

The inhomogeneity of magnetic fractions should be easier to reduce than many of the other biases that lead to variance in analytical results. The standard splitting procedures used in sedimentary petrology should give subsamples of a magnetic concentrate that are of appropriate weight for analysis and contain representative parts of all grain sizes in the original sample. A split of this sort could be taken into solution without grinding.

A test was made on the control sample from Lyle Creek, North Carolina, to examine the results of replicate analyses of an unsized sample split into subsamples by the use of a CARPCO microsplitter having 3.17-mm (1/8-in.) chutes. The bulk sample of magnetic concentrate used for the test was first cleaned five times with the hand magnet, then it was split into 32 subsamples with the CARPCO microsplitter. The first 10 subsamples were further split into 20, so that the original control sample was divided into 42 subsamples. Each subsample was assigned a number and every fifth was analyzed (table 4). The data in table 4 show that the metal contents of the 1/64-split specimens (numbers 5, 10, 15, and 20) have no major differences from those of the 1/32-split specimens (numbers 25, 30, 35, 40), though some minor differences can be seen. The results of the replicate analyses of the subsamples of the carefully split but unsized control sample have acceptable standard deviations for geochemical exploration. They show that preparation by splitting, digestion of the unground subsample, and single-solution determination of the eight elements constitute an acceptably accurate method for geochemical exploration.

TABLE 4.—*Replicate analyses of split but unsized control sample of magnetic concentrates from Lyle Creek, North Carolina, for Ag, Bi, Cd, Cu, Ni, Pb, and Zn*

[Data are in parts per million]

Subsamples of 52-WE-819	Elements							
	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
5	0.9	9	1.2	46	44	48	280	136
10	0.9	9	1.2	48	47	48	280	132
15	0.9	9	1.2	46	47	48	280	132
20	0.9	9	1.2	45	45	48	280	132
25	0.6	9	1.2	48	45	48	280	136
30	0.9	12	1.2	50	47	60	280	136
35	0.9	9	1.2	46	46	48	240	136
40	0.9	9	1.2	45	44	48	280	128
Mean	0.9	9	1.2	47	46	50	275	133
Standard deviation	0.1	1.06	0	1.75	1.30	4.24	14.14	2.98
Relative standard deviation (percent)	11.1	11.8	0	3.5	2.7	8.0	4.8	2.1

INTERNAL REPLICATE ANALYSES IN THE FULL DATA SET

The results of the analyses by K.-L. Pan of the full set of samples for silver, bismuth, cadmium, cobalt, copper, nickel, lead, and zinc, are given in table 1. One of the samples (3799) in table 1 was also inserted as an additional 30 subsamples in the 347 samples of the set. The subsamples of 3799 were prepared in the same manner as the subsamples of 52-WE-819 (table 4). Thus, several subsamples are in each lot of 50 that was analyzed. The advantage of this array is that the reliability of the analytical data can be evaluated as a whole, or by the lot. Inasmuch as the replicate subsamples were hidden in the numbering system provided the analyst, any factor of operator bias during

TABLE 5.—*Replicate analyses of split but unsized subsamples of file number 3799 from the Portage Creek placer, Alaska, for Ag, Bi, Cd, Cu, Ni, Pb, and Zn*

[Data are in parts per million. L=detected but less than lower limits of determination]

Subsamples of 3799	Elements							
	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
1	0.8	15	0.2L	100	40	100	270	210
2	0.8	15	0.2L	100	50	100	270	210
3	0.4	15	0.6	100	30	100	270	210
4	0.4	10	0.4	100	30	100	270	200
5	0.4	10	0.6	110	35	100	270	210
6	0.4	15	0.6	100	35	100	280	210
7	0.2	10	0.6	90	30	100	260	190
8	0.4	10	0.4	90	30	110	270	210
9	0.4	10	0.4	85	30	100	270	190
10	0.6	15	0.4	90	30	140	240	230
11	0.6	10	0.4	100	35	100	260	220
12	0.6	10	0.4	100	35	110	270	220
13	0.4	10	0.4	85	35	100	290	220
14	0.6	10	0.4	100	35	110	260	220
15	0.4	10	0.4	90	35	100	260	210
16	0.6	10	0.4	90	35	110	270	220
17	0.6	10	0.4	90	35	110	260	210
18	0.6	10	0.4	90	35	110	270	210
19	5.5	5	0.4	90	40	100	250	250
20	0.6	10	0.4	90	35	100	250	230
21	0.6	10	0.4	90	30	110	270	230
22	0.6	10	0.4	100	40	100	270	240
23	0.6	5L	0.4	90	45	100	250	250
24	0.6	5	0.4	90	30	100	260	190
25	0.6	5	0.4	100	35	110	270	200
26	0.6	5	0.4	100	35	100	270	210
27	0.6	5	0.4	90	35	110	270	220
28	0.6	5	0.4	90	30	100	260	200
29	0.8	5	0.2	100	35	100	270	210
30	0.8	5	0.4	100	65	110	270	220
Mean	0.7	9.3	0.4	94.7	35.8	104.7	265.7	215.0
Standard deviation	0.91	3.5	0.1	6.1	7.2	8.2	9.7	15.3
Relative standard deviation (percent)	130.0	37.6	25.0	6.4	20.1	7.8	3.6	7.1

the analyses was reduced to a minimum. The results of the replicate analyses of the 30 subsamples are given in table 5.

The relative standard deviations shown in table 5 are larger than those reported in table 4 for all elements determined except lead and nickel. It is thought that these poorer results are probably due to instrumental noise and variability. For example, the amounts of silver and cadmium in the magnetic concentrates are low, with the exception of one aberrant subsample unusually rich in silver, but the smallest reading that could be made on the test instrument for these two elements was 0.2 ppm, regarded as the lower limit of detection for each. Thus, the large variance may be partially a function of size of reporting interval and concentration present. The lower values for silver and cadmium were not easy to read with certainty, because of the fluctuations of the meter (instrumental noise). Thus, the lower limit of detection for silver and cadmium probably should have been set at 1 ppm each, which would have greatly reduced the relative standard deviation for these elements. Indeed, by 1975 the lower limit of detection for silver and cadmium was raised to this level (Nakagawa, 1975). Another apparent reason for the larger standard deviations in table 5 is that the replicate subsamples in that table were digested at different times in different lots, whereas the subsamples in table 4 were digested at the same time. However, at the 99.7-percent confidence level the means are not far from the true concentrations of these eight elements.

GOLD, INDIUM, AND THALLIUM BY ATOMIC ABSORPTION

Gold, indium, and thallium contents were determined by A. E. Hubert and G. L. Crenshaw on the 140 magnetic concentrates weighing 2 g or more remaining after the eight-element analyses. Thus, the data for these three elements are for part of the set only: 131 of these samples are from the main set, including file number 3799, and 9 are replicate subsamples of 3799.

The three elements were measured by atomic absorption with a lower limit of detection of 0.2 ppm each in a single solution of 2 g of sample. The procedure was modified from the technique for gold described by Thompson, Nakagawa, and Van Sickle (1968) and the technique for indium and thallium presented by Hubert and Lakin (1973). After repeated digestions of the unground sample in hot HCl, the mixture was evaporated to dryness, and the residue was then dissolved in a Br-HBr solution. This solution was heated to eliminate excess bromine, then diluted with water, and the metals were extracted in methyl isobutyl ketone (MIBK). Indium and thallium were extracted from the MIBK layer with 1.5 *N* HBr and were determined by atomic absorption spectrophotometry. After this determination, the remaining MIBK solution was shaken with 0.1 *N* HBr to remove iron, and the gold in the MIBK solution was measured by atomic absorption. Seventy-five determinations were made per man-day. The results are given in table 1.

Owing to the small amounts of gold, indium, and thallium in these magnetic concentrates, too few replicate subsamples of sample 3799 were left in the set to permit a study of variance in the analytical results. One of the nine subsamples was found to contain 0.3 ppm gold and 0.3 ppm indium, and another subsample had 0.2 ppm indium. The amounts of gold, indium, and thallium in all other subsamples were below the limit of detection (<0.2 ppm), except that

sample 3799 itself registered 11.1 ppm gold. The great difference in the amount of gold determined for sample 3799 and for its nine subsamples is attributed to the variable presence of particulate gold, even in carefully split samples. This problem is further discussed in other sections.

DISTRIBUTION OF THE ELEMENTS

BACKGROUND REVIEW

Almost one-third of the 347 magnetic concentrates are from the Solomon quadrangle, and one-fourth are from the Candle quadrangle (table 1). The remaining samples are scattered in 31 other quadrangles (pl. 1). Owing to this lack of balance in the distribution of the samples, the discussion of the results of the analyses is given under three headings instead of by 33 quadrangles: (1) Regional results; (2) Candle quadrangle results; and (3) Solomon quadrangle results. Note that the regional results encompass data from the Candle and Solomon quadrangles.

The distribution of the elements is described by methods of analysis and by the geochemical associations of the elements in the region and in the Candle and Solomon quadrangles. Thus, equivalent uranium, which was determined by radiometric counting, is discussed separately from the 11 elements determined by atomic absorption spectrophotometry. These 11 elements are discussed in five geochemical associations: (1) copper, lead, zinc, and cadmium; (2) silver and gold; (3) bismuth; (4) cobalt and nickel; and (5) indium and thallium.

The magnetic concentrates used to determine the distribution of these minor elements are not monomineralic separates of magnetite; rarely they may contain as much as 50 percent of other minerals, including some recognizable sulfides of the base metals. Thus, some of the minor elements contained in the magnetic concentrate may be in minerals other than the dominant magnetite. Variations in the minor-metal content of the magnetic concentrates from a given district, or from several districts, may reflect in part—possibly in large part—variations in the abundance of associated minerals other than magnetite. Keeping this condition in mind, and recognizing that the discussion will return in detail farther along to the roles of the various minerals as sources for the minor elements, this introduction is concerned with the problem of minor elements in magnetite—a subject on which there is an extensive literature relevant to exploration geochemistry (table 6).

Minor elements in magnetite have been investigated in studies of the genesis of ore deposits, principally those of iron and copper, but with conflicting results. The conceptual basis for the interpretation of the analytical data is that the major elements in magnetite are generally accompanied by minor amounts of other elements. The presence and quantity of the minor elements are affected by: (1) the origin of the deposit; (2) the geologic setting; (3) the temperature of crystallization; (4) the availability of the elements to the crystallizing magnetite; (5) thermodynamic and crystal chemical factors of the structure of magnetite; (6) postdepositional metamorphism; and (7) surface sorption phenomena during hypogene and supergene processes, including events after the magnetite has been eroded from its source rocks and is being transported as detrital grains in streams (table 6).

The minor elements are contained in minerals as

TABLE 6.—*Selected references on the composition of magnetite*

Subject	Authors and date
Origin of the deposit---------	Carstens, 1943; Chakraborty and Majumdar, 1971; Chistyakov and Babanskiy, 1971; Deb and Banerji, 1967; Duncan and Taylor, 1968; Elsdon, 1972; Green, 1960; Green and Carpenter, 1961; Hamil and Nackowski, 1971; James and Dennen, 1962; Kiseleva and Matveyev, 1967; Komov, 1968, 1969; Ksenofontov and Davydov, 1971; Landergren, 1948; Lewis, 1970; Lindsley and Smith, 1971; Lipman, 1971; McKinstry and Kennedy, 1957; Marmo, 1959; Nagaytsev, 1971; Němec, 1968; Neuerburg and others, 1971; Newhouse, 1936; Oshima, 1972; Pavlov, 1969; Ramdohr, 1940, 1962; Rost, 1940; Sastry and Krishna Rao, 1970; Shangireyev, 1969; Shcherbak, 1969, 1970; Vartanova and Zav'yalova, 1970; Vassileff, 1971.
Geologic setting--	Belkovskiy and Fominykh, 1972; Bocchi and others, 1969; Borisenko and Zolotarev, 1969; Boyadzhyan and Mkrtchyan, 1969; Deb and Ray, 1971; Duchesne, 1972; Fleischer, 1965; Fominykh and Yarosh, 1970; Frietsch, 1970; Howie, 1955; Kisvarsanyi and Proctor, 1967; Lauren, 1969, Leung; 1970; Lopez M. and others, 1970; Santos and Walters, 1971; Sen and others, 1959; Sklyar, 1972; Theobald and others, 1967; Theobald and Thompson, 1962; Unan, 1971; Vergilov, 1969; Vincent and Phillips, 1954; Yamaoka, 1962.
Temperature of crystallization-	Abdullah and Atherton, 1964; Oshima, 1971; Shilin, 1970.
Availability of elements--------	Borisenko, 1968; Green and Carpenter, 1961.
Thermodynamic and crystal chemical factors---------	Dasgupta, 1967, 1970.
Postdepositional metamorphism----	Abovyan and Borisenko, 1971; Leblanc, 1969; Ogorodova, 1970; Sergeyev and Tyulyupo, 1972; Shteynberg and Chasechukhin, 1970.
Sorption of minor metals----------	Colombo and others, 1964; Fujigaki and others, 1967; Hegemann and Albrecht, 1955.

trace elements and as trace minerals (Haberlandt, 1947). In magnetic concentrates, minor elements are also contributed by accessory minerals mechanically trapped among grains of magnetite. As trace elements, the minor elements are held in isomorphous substitution for major elements, or are held by sorption or other chemical means permitted by thermodynamic and crystal chemical considerations. As trace minerals, the minor elements are present in minute inclusions, intergrowths, or overgrowths caught up in the host mineral and not cleared by subsequent geologic events affecting the host.

Several minor elements are common in magnetite. These minor elements usually occur in subordinate amounts as substitutes for other elements in the mineral. The only major cations in magnetite that are available for substitution are Fe^{+3} and Fe^{+2}, as shown by the conventional formula for magnetite, $Fe^{+3}(Fe^{+2}, Fe^{+3})O_4$.

The term diadochy has been used to describe the ability of different elements to occupy the same lattice position in a mineral. Several cations are known to substitute for ferrous and ferric iron in magnetite, but the diadochy between ferric iron and titanium is most prevalent (Dasgupta, 1967). Diadochy always refers to a given structure; thus, two elements may be diadochic in one mineral but not in another. A minor element may substitute for a major element diadochically if the difference in the size of their radii does not exceed about 15 percent (Goldschmidt, 1954). However, this rule is not always valid, but it gives a rough approximation of the magnitude of the difference tolerated.

Substitution is also affected by the ionic charge. Ions of similar radii whose charges differ by one unit may substitute readily for one another, but the substitution is only slight if the difference in the charges is greater than one. Of two ions that compete for a lattice site, the one that forms the stronger bonds with its neighbors is the one with the smaller radius or the higher charge or both.

Ionization potential also influences the substitution between elements with the same ionic charge and similar ionic radii (Ahrens, 1953; Goldschmidt, 1954). Some elements occupying identical positions in the structures of minerals, and therefore being geochemically closely related, have similar ionization potentials.

Ringwood (1955) proposed using values of electronegativity in addition to Goldschmidt's rules to predict substitution of one ion for another. The electronegativity of an element is clearly related to its ionization potential (for cations) and to its electron affinity (for anions). A bond formed between two atoms is almost purely ionic if the electronegativities are very different. Substitution of one ion for another may be very limited even where they have similar radii and charges, if there is a marked difference in electronegativities between the two ions.

Temperature affects the degree of diadochy; thus, high temperatures of formation usually favor diadochic substitution.

Ions or atoms may fit into interstices in the lattice instead of replacing another element diadochically, or the ions or atoms may occupy lattice defects where some atoms are missing and lattice positions are vacant.

The sorption of trace elements on the surfaces of minerals also accounts for the presence of minor elements. Sorption has been intensively studied in clays, for example, by soil scientists for plant nutrition, by environmental geologists for the disposal of radioactive wastes, and by geochemists for mineral exploration. The sorption of minor elements on minerals, and the possible application of this phenomenon in ore deposition, was discussed by Sullivan (1907), but his experiments did not include magnetite. Green and Carpenter (1961) identified an activity gradient decreasing from the surface to the center of magnetite grains studied for distribution of radioactivity. They interpreted the gradient as an effect produced either by exsolution during crystallization or by later surface sorption from external sources of uranium and thorium. Later work by Fujigaki and others (1967) showed how magnetite sand could remove the metal ions Mn^{+2}, Cu^{+2}, Pb^{+2}, and Zn^{+2} from industrial waters. This observation opened the possibility that detrital grains of magnetite downstream from base-metal deposits might adsorb ions of the base metals from stream water.

Half of the ferric ions in magnetite are coordinated to four oxygen ions (Bragg and others, 1965), whereas the remaining ferric ions and all the ferrous ions are surrounded by six nearest-neighbor anions. Each oxygen ion is bounded by one tetrahedrally coordinated cation and by three octahedrally coordinated cations. The physical characteristics of the 11 minor elements determined in this investigation of magnetite are listed (table 7) to give an idea of the capability for substitution of these elements for ferrous and ferric iron in magnetite.

Taking the major cations Fe^{+2} and Fe^{+3} in six-fold coordination, and accepting Goldschmidt's 15-percent tolerance in ionic radius for easy substitution, cations of radius 0.63–0.85 A might replace Fe^{+2}, and those of radius 0.54–0.74 A might replace Fe^{+3}. Among the minor elements determined here, the divalent ions Cu^{+2}, Zn^{+2}, Co^{+2}, Ni^{+2} and the trivalent ions Co^{+3} and Ni^{+3} all have radii within the limits set above. Commenting on the substitution of these ions in the magnetite lat-

TABLE 7.— *Physical properties of 11 trace elements in magnetic concentrates from Alaska, compared to the same properties of ferrous and ferric iron in magnetite*

[–means no data available]

Ion	Ionic radius for 6-coordination (A)	Observed coordination number	Electro-negativity	Ionic bond with O_2 (percent)	Ionization potential (eV)
Fe^{+2}	0.74	6	1.8	69	16.16
Fe^{+3}	0.64	6	1.9	54	30.8
Ag^{+}	1.26	8, 10	1.9	71	7.57
Bi^{+3}	0.96	6, 8	1.9	66	25.6
Bi^{+5}	0.74	--	--	--	55.7
Cd^{+2}	0.97	6, 8	1.7	66	16.84
Co^{+2}	0.72	6	1.8	65	17.3
Co^{+3}	0.63	--	--	--	33.6
Cu^{+}	0.96	6, 8	1.9	71	7.72
Cu^{+2}	0.72	6	2.0	57	20.34
Ni^{+3}	0.78	6	1.8	60	18.2
Ni^{+2}	0.62	--	--	--	35.2
Pb^{+2}	1.20	6-10	1.8	--	14.96
Pb^{+4}	0.84	--	--	72	42.4
Zn^{+2}	0.74	4, 6	1.7	63	17.89
Au^{+}	1.37	3-12	2.4	62	9.22
In^{+3}	0.81	6	1.7	62	28.1
Tl^{+3}	0.95	6, 8	1.8	58	29.9

[1]Compiled from: Mason (1966), Krauskopf (1967), Summers (1970), and Whittaker and Muntus (1970).

tice, Frietsch (1970) noted that Cu^{+2} is similar in ionic radius to Fe^{+2} but has a higher electronegativity, thus it does not readily substitute although it tends to increase in magnetites from late felsic magmatic rocks and in magnetites from hydrothermal, contact pneumatolytic, and skarn deposits. Zn^{+2} has the same ionic radius as Fe^{+2} and slightly lower electronegativity, thus it tends to substitute for ferrous iron and is camouflaged in minerals like magnetite. Zinc is particularly common in magnetites from late magmatic differentiates, where the ratio Zn^{+2}/Fe^{+2} increases (Frietsch, 1970). According to Frietsch, zinc is most abundant in magnetites from the contact pneumatolytic deposits of rare mafic late magmatic rocks. The Co^{+2} content was thought by Frietsch to be high in magnetites from early mafic magmatic rocks, as is Ni^{+2}, and the Ni/Co ratio in magnetite was thought to fall during magmatic differentiation. For some unusually cobalt-rich magnetites, the source of the cobalt was inferred to be trace minerals, probably pyrite and pyrrhotite. Thus, the presence of copper, cobalt, nickel, and zinc in diadochic substitution in magnetite is identified by theory and confirmed by the literature. However, these four elements may also be present in minor minerals or in trapped accessory minerals, both of which were discussed above. The importance of these two mineral forms, compared to diadochic substitution, will be reviewed below.

The ionic radii of lead, cadmium, silver, and gold are too large to permit them to substitute for either Fe^{+2} or Fe^{+3}. Lead tends to occur in silicate structures as the Pb^{+2} ion (Rankama and Sahama, 1950); the smaller Pb^{+4} ion is rarely found in mineral systems (Taylor, 1965). The major ions which are possibly replaced by Pb^{+2} in minerals are Ca^{+2} (0.99 A) and K^{+} (1.33 A). Calcium has commonly been reported in magnetite (Vincent and Phillips, 1954), and as much as 0.94 percent CaO has been found in magnetite (Deer and others, 1962). Thus, Pb^{+2} might replace Ca^{+2} in magnetite. The presence of lead in magnetite might also be explained by lattice defects or minor mineral inclusions, principally sulfides.

In spite of the similarity of the ionic radii of Cd^{+2} (0.97 A) and Ca^{+2} (0.99 A), cadmium appears to follow iron instead of calcium (Vincent and Bilefield, 1960). The second ionization potential of Cd^{+2} (16.84 eV) is much higher than that of Ca^{+2} (11.90 eV) but is similar to that of Fe^{+2} (16.16 eV), which may explain why cadmium follows iron. Cadmium also has a notable tendency to be concealed in zinc minerals despite the difference in ionic radii of cadmium and zinc (table 7). Cadmium may replace zinc diadochically at elevated temperatures; however, cadmium is readily separated from zinc minerals during weathering at ambient temperatures. Doubtless much of the small amount of cadmium found in the Alaskan magnetic concentrates is in minor or accessory minerals.

Silver belongs to the same subgroup in the periodic table as copper; therefore, the geochemical distribution of silver tends to resemble that of copper. However, the ionic radius of Ag^{+} is too great for silver to substitute directly for iron in magnetite. Ag^{+} (1.26 A) has a suitable radius to replace K^{+} (1.33 A) and, with increased tolerance, perhaps under conditions of high temperature, Ag^{+} might replace Ca^{+2}. Frietsch (1970) suggested that traces of silver he found in magnetite possibly resulted from diadochic substitution, but he recognized the role of silver-bearing minor minerals in the magnetite as an alternate explanation.

Gold exhibits a different geochemical behavior from silver (Rankama and Sahama, 1950). One marked difference is that the first ionization potential of gold is much greater than that of silver (table 7); therefore, gold ionizes with difficulty. Gold might be incorporated into minerals in the form of uncharged atoms (Vincent and Crocket, 1960). However, it is not likely that the gold atom could be accommodated in unoccupied structural sites (interstitial solid solution) because its radius is large (1.44 A). Nor could the Au^{+} ion substitute for the ferrous or ferric ions in magnetite. Probably much of the gold in magnetite is in the form of a minor mineral (native gold) or serves as an element

in other minor minerals such as sulfides. The presence of native gold embedded in grains of magnetite from the Innoko district, Alaska, has long been known (Eakin, 1914, p. 28).

The trivalent ions Bi^{+3} (0.96 A), In^{+3} (0.81 A), and Tl^{+3} (0.95 A) might replace Ca^{+2} (0.99 A), but not readily (Nockolds, 1966). Because it has a smaller radius than the other two trivalent elements, In^{+3} might substitute for Fe^{+2}, Zn^{+2}, or Mn^{+2} (0.80 A), where the latter two are also present in magnetite. Bismuth and thallium replace lead in lead minerals; thus, they may be incorporated as minor minerals.

Copper and zinc can substitute diadochically for bivalent iron in magnetite. Lead is usually associated with copper and zinc in sulfide deposits, and cadmium has a geochemical affiliation for zinc. Because of these relations this group of four elements is discussed together in the interpretations of the analyses from the magnetic concentrates. The precious metals silver and gold are discussed together, and bismuth is set aside for individual treatment. The ferrides cobalt and nickel are usually associated in nature with iron; thus, they are described as a group. The dispersed elements indium and thallium, which rarely form their own minerals but occur in host minerals such as sphalerite (indium) and galena (thallium), compose the last group for discussion.

REGIONAL RESULTS

AREAS DISCUSSED

The regional results of the determinations of equivalent uranium and the atomic absorption analyses for 11 elements in 347 magnetic concentrates from Alaska are given in table 1. These regional results are discussed by five geographic subareas, which are listed below, along with the 1:250,000-scale quadrangles that represent them:

1. *Southeastern Alaska:* Bradfield Canal, Juneau, Ketchikan.
2. *Southern Alaska:* Anchorage, McCarthy, Mount Hayes, Mount McKinley, Nabesna, Talkeetna, Talkeetna Mountains, Valdez.
3. *Southwestern Alaska:* Bethel, Goodnews, Hagemeister Island, Iliamna, Lake Clark, Russian Mission.
4. *West-central Alaska:* Bendeleben, Candle, Iditarod, McGrath, Medfra, Nome, Norton Bay, Ruby, Solomon, Teller.
5. *East-central Alaska:* Circle, Eagle, Fairbanks, Livengood, Tanacross, Tanana.

STATISTICAL TREATMENT

Statistical summaries of the minor elements in the magnetic concentrates are given in table 8. The table lists the regional data and data from the Candle and Solomon quadrangles. The range of abundance for each element in the magnetic concentrates is shown by its minimum, maximum, and geometric mean. Also listed are the geometric deviations and the percentage of samples having less than the limit of detection of an element. The estimates of mean and geometric deviation are based on censored data—that is, data which are qualified on table 1 with L (less than the limit of detection), N (not detected), and --- (not determined). The samples with qualified values were not used in computations of mean and standard deviation; therefore, the summaries in table 8 are not suitable for general estimates of abundance.

The frequency distributions of the abundances of equivalent uranium, silver, bismuth, cadmium, cobalt, copper, nickel, lead, zinc, and gold were studied in the form of histograms and cumulative frequency curves. Because most of the magnetic concentrates were found to have indium and thallium below the limits of detection, cumulative frequency curves for these two elements could not be satisfactorily constructed.

The concentration and cumulative frequency were plotted on log probability paper with the frequencies cumulated from the highest to the lowest concentrations (figs. 1–10) in order to use Lepeltier's method to identify threshold and anomalous values for the metals (Lepeltier, 1969). In this procedure, as it is generally applied to stream-sediment samples, the background is given by the intersection of the straight-line cumulative frequency distribution curve on the log-probability plot with the 50-percent ordinate, and the threshold is given by the intersection of the same line with the 2.5-percent ordinate.

These considerations are not applicable to the Alaskan magnetic concentrates, because the concentrates are strongly biased toward anomalous values as they were collected mostly from mineralized areas. Therefore, the percentage of anomalous magnetic concentrates is much greater than what would be expected from the usual regional program of geochemical exploration based on stream sediments. A normal distribution is completely determined by the arithmetic mean and the standard deviation. Because a normal curve is both unimodal and symmetrical, the arithmetic mean, the mode, and the median coincide. The median—the value that divides the area under the curve in half—is usually taken as the background value. For a perfectly

normal distribution, 4.54 percent of the distribution will fall outside the limits indicated by a distance equal to two standard deviations measured on the X-axis on both sides of the arithmetic mean. For a moderately skewed distribution, the percentage is often taken as approximately 5 percent, only half of which will fall on each side of the curve tails. Therefore, the 2.5-percent ordinate is drawn to give the threshold (Hawkes and Webb, 1962). Unfortunately, the cumulative frequency curves for most of these elements show polymodal lognormal distribution (figs. 1–10). Therefore, no attempt is made to draw the background and threshold based exactly on the above definitions. For some elements the threshold in the magnetic concentrates is given by the intersection of the cumulative curve with the 16-percent ordinate, a limit that seems to insure detection of strongly mineralized areas but may permit some weakly mineralized areas to be overlooked. Another reason that these statistical procedures are not satisfactory for these data is that only a few samples are represented for quadrangles other than the Candle and Solomon quadrangles.

The values selected as background and threshold for the region and for the Candle and Solomon quadrangles are listed in table 9. The arguments for these values are set out in appropriate sections that follow.

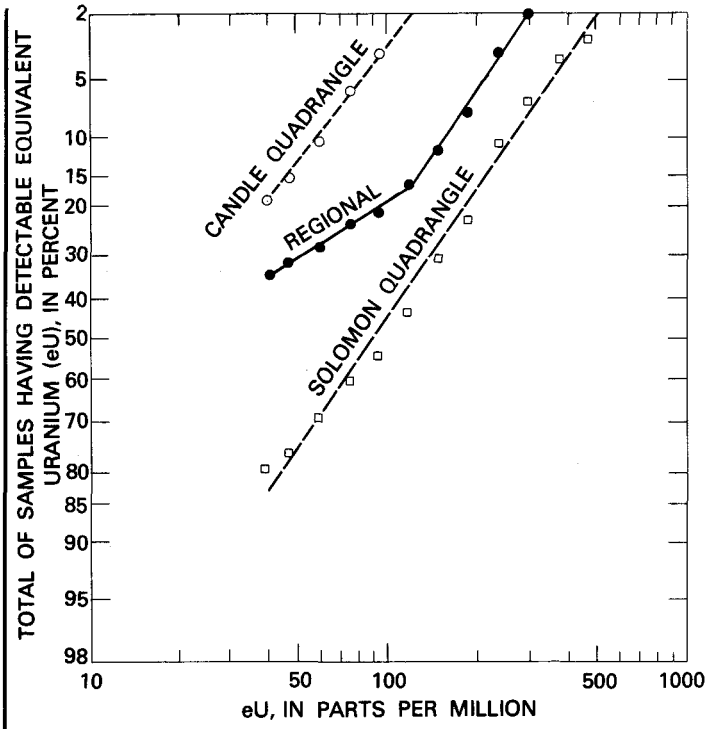


FIGURE 1.—Concentration and cumulative frequency of equivalent uranium in Alaskan magnetic concentrates.

TABLE 8.—*Statistical summaries of the regional geochemical data for 347 magnetic concentrates and of the data for the Candle and Solomon Quadrangles, Alaska*

[n.d. indicates no data available]

Statistic	eU	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn	Au	In	Tl
REGIONAL												
Minimum (ppm)	40	0.2	5	0.2	5	5	10	5	10	0.2	0.2	0.2
Maximum (ppm)	560	600	90	5.5	1,000	25,000	2,200	4,700	2,800	640	0.5	1
Geometric mean (ppm)	108	0.44	10	0.39	44	16	50	26	85	2.13	0.23	0.27
Geometric deviation	1.9	3.32	1.6	1.59	1.7	3.3	3.0	2.1	2.3	7.6	1.39	1.54
Percent of samples below detection	64	21	9	30	0	9	0	0	0	[1]69	[1]85	[1]83
CANDLE QUADRANGLE												
Minimum (ppm)	40	0.2	5	0.2	20	5	20	5	30	0.2	<0.2	0.2
Maximum (ppm)	160	1.5	20	0.8	150	90	570	120	630	1.5	0.2	0.3
Geometric mean (ppm)	65	0.34	10	0.38	48	15	66	27	79	0.5	<0.2	0.23
Geometric deviation	1.5	1.7	1.4	1.45	1.5	2.4	1.8	1.8	1.9	2.5	n.d.	1.6
Percent of samples below detection	80	24	2	32	0	5	0	0	0	[2]84	[2]96	[2]88
SOLOMON QUADRANGLE												
Minimum (ppm)	40	0.2	5	0.2	10	5	10	5	10	0.2	0.2	0.2
Maximum (ppm)	560	6.5	40	5.5	95	30	280	1,100	500	1.4	0.3	1
Geometric mean (ppm)	124	0.32	11	0.44	31	7	20	26	58	0.3	0.22	0.28
Geometric deviation	1.9	1.8	1.4	1.6	1.4	1.5	2.0	1.9	1.5	3.1	1.2	1.6
Percent of samples below detection	21	23	1	30	0	20	0	0	0	[3]93	[3]88	[3]54

[1]Percentages computed for 131 analyzed samples.
[2]Percentages computed for 25 analyzed samples.
[3]Percentages computed for 41 analyzed samples.

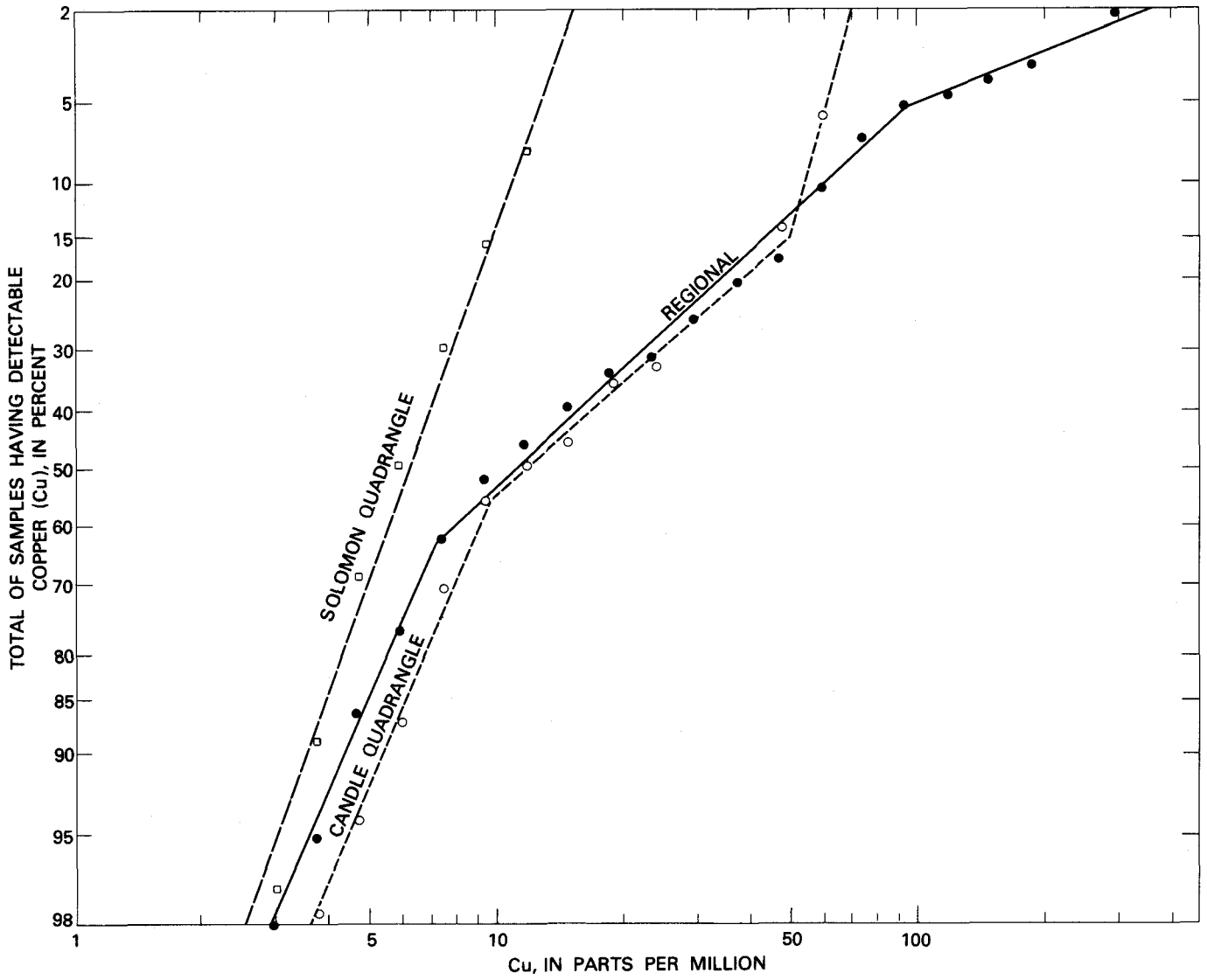


FIGURE 2.—Concentration and cumulative frequency of copper in Alaskan magnetic concentrates.

EQUIVALENT URANIUM

ABUNDANCE

Partly as a result of the number of samples analyzed, most of the radioactive magnetic concentrates are from four quadrangles: Bendeleben, Candle, Norton Bay, and Solomon (table 1). Other areas where radioactive magnetic concentrates were found are the Circle, Ketchikan, Medfra, and Mount Hayes quadrangles, where the areas yielding radioactive magnetic concentrates are few and the levels of radioactivity are low, generally near the lower limit of detection of 30 ppm eU.

The cumulative frequency curves marked "regional" on figures 1–10 encompass data from all 347 magnetic concentrates. For eU (fig. 1), this curve appears to be bimodally lognormally distributed. The low-value fraction of this distribution is contributed mainly from the Candle and Solomon quadrangles. This straight line intersects the X-axis outside the figure. Most of the magnetic concentrates have values for eU below the limit of detection. The background value for these samples (not the radiation background) is established at the point of intersection between the extended line and the 50-percent ordinate, and is less than the limit of detection (table 9). Above 120 ppm eU, the line abruptly turns toward low values (the slope of the line increases). Thus, for the regional distribution, the histogram of eU is negatively skewed (fig. 11). The high-value fraction is contributed mostly by samples from the Bendeleben and Solomon quadrangles. Interestingly, both the high values and the low values of the

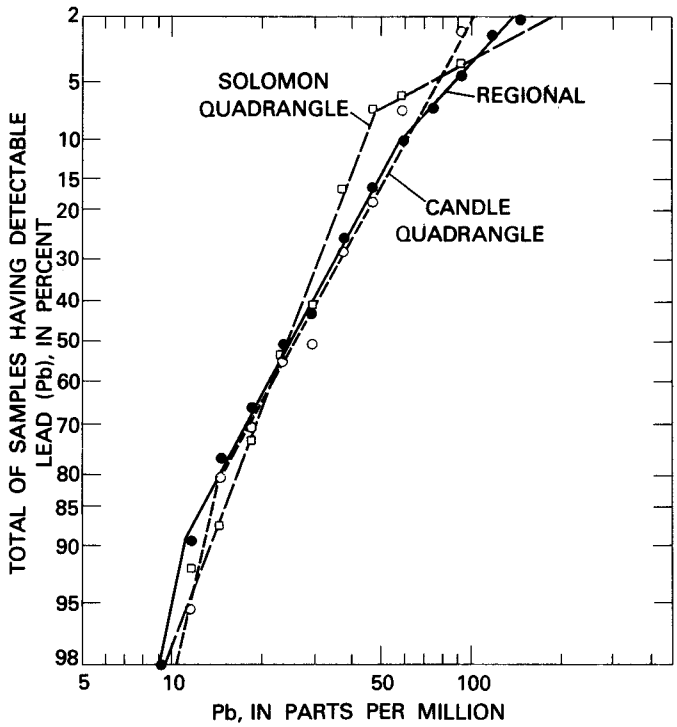


FIGURE 3.—Concentration and cumulative frequency of lead in Alaskan magnetic concentrates.

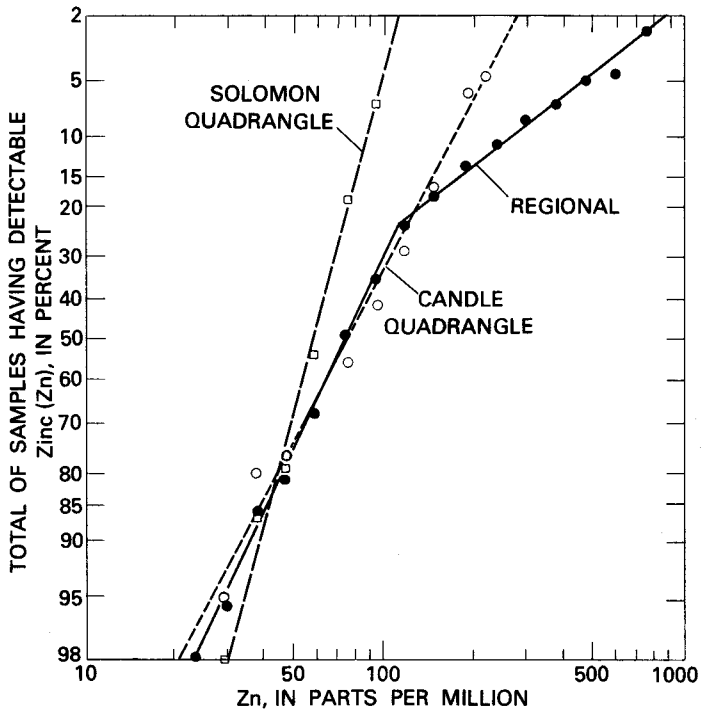


FIGURE 4.—Concentration and cumulative frequency of zinc in Alaskan magnetic concentrates.

regional bimodal distribution of eU are represented in the Solomon quadrangle, whereas the samples from the Bendeleben and Norton Bay quadrangles are typically highly radioactive and those from the Candle

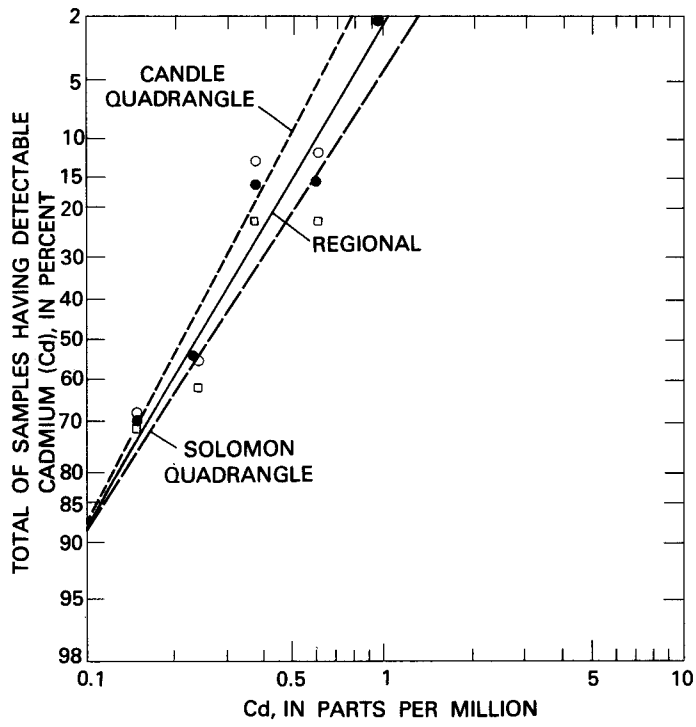


FIGURE 5.—Concentration and cumulative frequency of cadmium in Alaskan magnetic concentrates.

quadrangle tend to have the lower values. The value for the radioactivity of the breaking point on the regional cumulative curve, 120 ppm eU, is taken as the threshold between background and anomalous values. About 16 percent of the magnetic concentrates with measurable radioactivity are above this threshold.

The radioactive magnetic concentrates from the Bendeleben, Candle, Norton Bay, and Solomon quadrangles come from a single geologic area divided by the arbitrary boundaries of the quadrangles. All the radioactive magnetic concentrates from this area were obtained from streams that drain the Darby Mountains, which are underlain in part by granite, quartz monzonite, and potassium-rich alkaline intrusive rocks (Miller, 1972; Miller and others, 1971; Miller and others, 1972; Elliott and Miller, 1969; Cass, 1959). The most radioactive magnetic concentrates are derived from the alkaline rocks with ultrapotassic character in the intrusive complex of the Darby Mountains, and come mainly from the Bendeleben, Norton Bay, and Solomon quadrangles. Samples from the Candle quadrangle tend to be somewhat less radioactive than those from the other three (tables 8–9).

The relations between the radioactivity of magnetic concentrates and the source rocks for the concentrates can be most clearly detailed by a study of the 85 samples from the Candle quadrangle and the 101 samples from the Solomon quadrangle. Details of these two areas are discussed separately below. The rela-

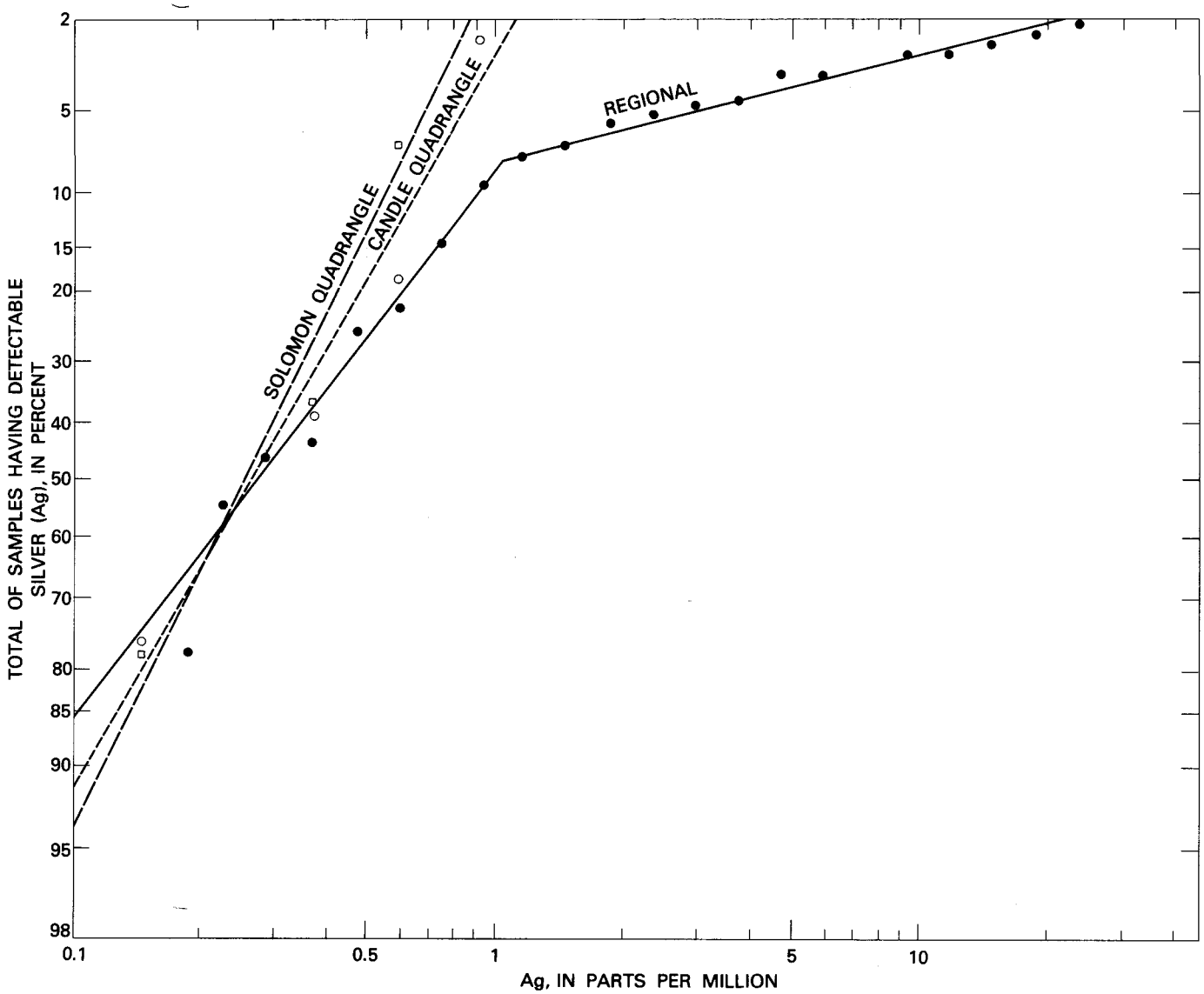


FIGURE 6.—Concentration and cumulative frequency of silver in Alaskan magnetic concentrates.

tions found in the Candle and Solomon quadrangles apply also in the Bendeleben and Norton Bay quadrangles, where only 20 and 4 samples, respectively, were measured for radioactivity.

The equivalent uranium in the magnetic concentrates from the Circle, Ketchikan, Medfra, and Mount Hayes quadrangles is compared in table 10 with the equivalent uranium cited for the original concentrate in the records of the Alaskan placer concentrate file, as determined in the late 1940's and early 1950's by John J. Matzko, U.S. Geological Survey. Generally similar equivalent uranium was found for the two materials, but a tendency exists for the magnetic concentrate to have slightly greater equivalent uranium than the whole concentrate. The reverse was found to be characteristic of concentrates from the Solomon quadrangle, described later in the report.

The magnetic concentrate from the Circle quadrangle was separated from a sluice-box concentrate from the H. C. Carstens mine on Portage Creek. Allanite, garnet, scheelite, sphene, topaz, uranothorianite, and zircon occur in this placer, and apatite, fluorite, garnet, limonite, scheelite, and zircon are in the granitic source rock for the placer (Nelson and others, 1954, table 9). Uranium is present in allanite, sphene, uranothorianite, zircon, apatite, and limonite at this locality.

The two concentrates from the Ketchikan quadrangle, listed in table 10, are from streams draining mainly the Eocene Hyder Quartz Monzonite and Upper Triassic or Lower Jurassic Texas Creek Granodiorite (West and Benson, 1955, pl. 7). No independent uranium-bearing mineral was recognized by West and Benson (1955, table 1) in concentrate 3339, but in 3343

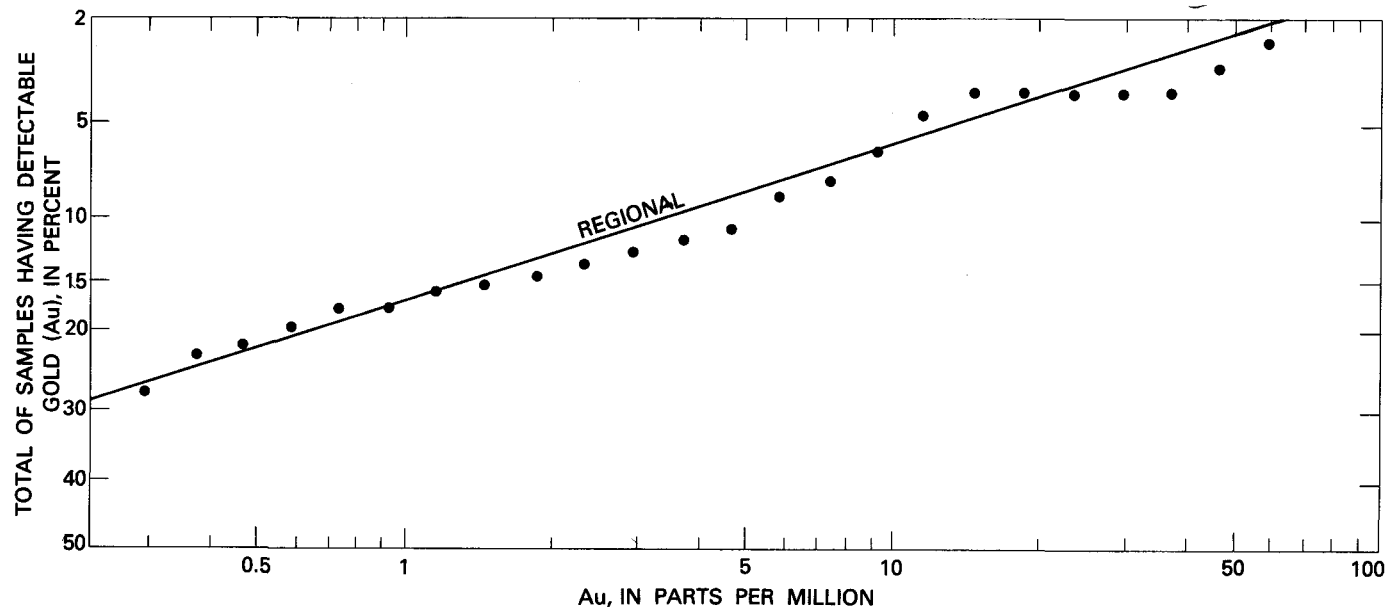


FIGURE 7.—Concentration and cumulative frequency of gold in Alaskan magnetic concentrates.

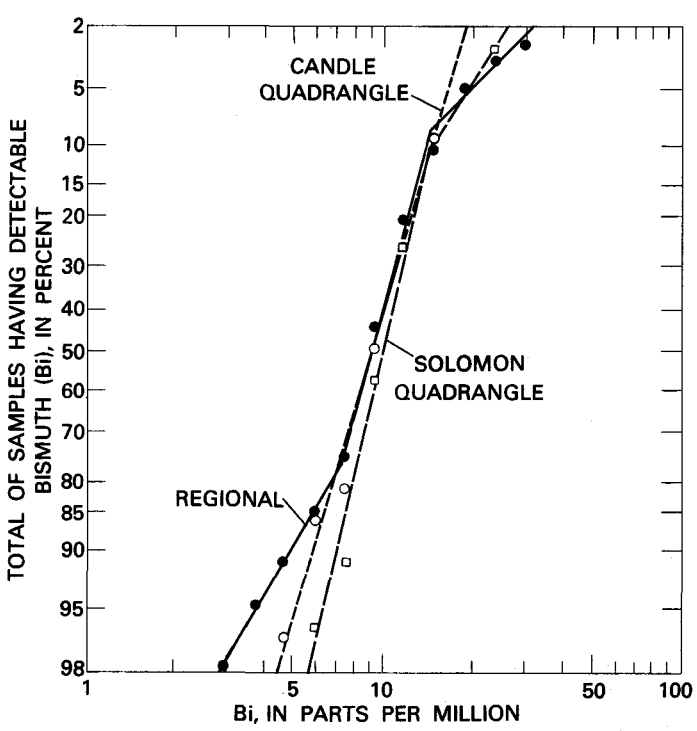


FIGURE 8.—Concentration and cumulative frequency of bismuth in Alaskan magnetic concentrates.

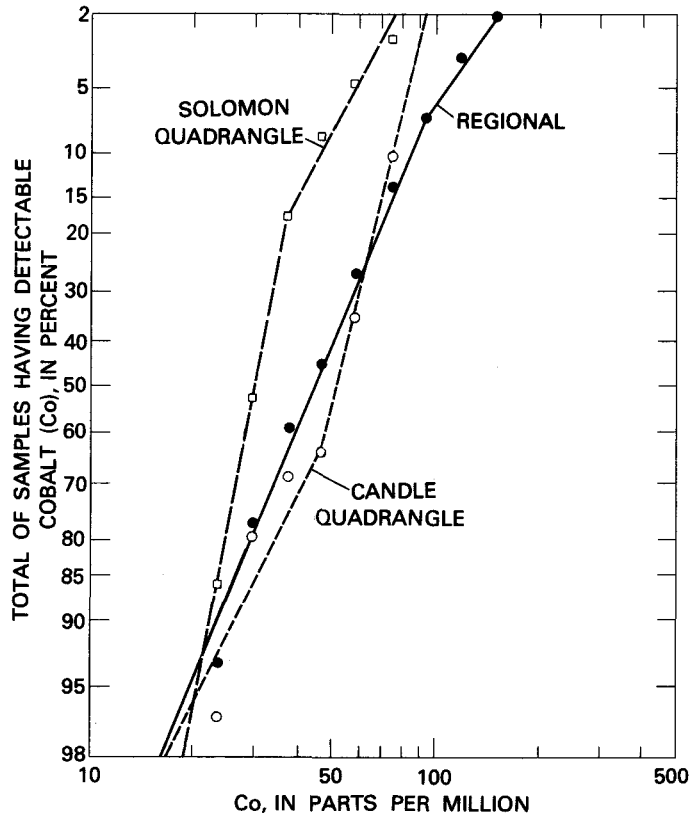


FIGURE 9.—Concentration and cumulative frequency of cobalt in Alaskan magnetic concentrates.

uranium was identified in sphene. In the same general area as the sources of these two concentrates, hematite and limonite, either as independent minerals in concentrates or as coatings on other minerals, were shown to contain uranium.

The concentrate from the Medfra quadrangle listed in table 10 comes from a gulch on the north side of Appel Mountain, but it is not described in the literature. Concentrates from the Nixon Fork mining district about 30–40 km to the northeast of Appel Mountain were discussed by White and Stevens (1953).

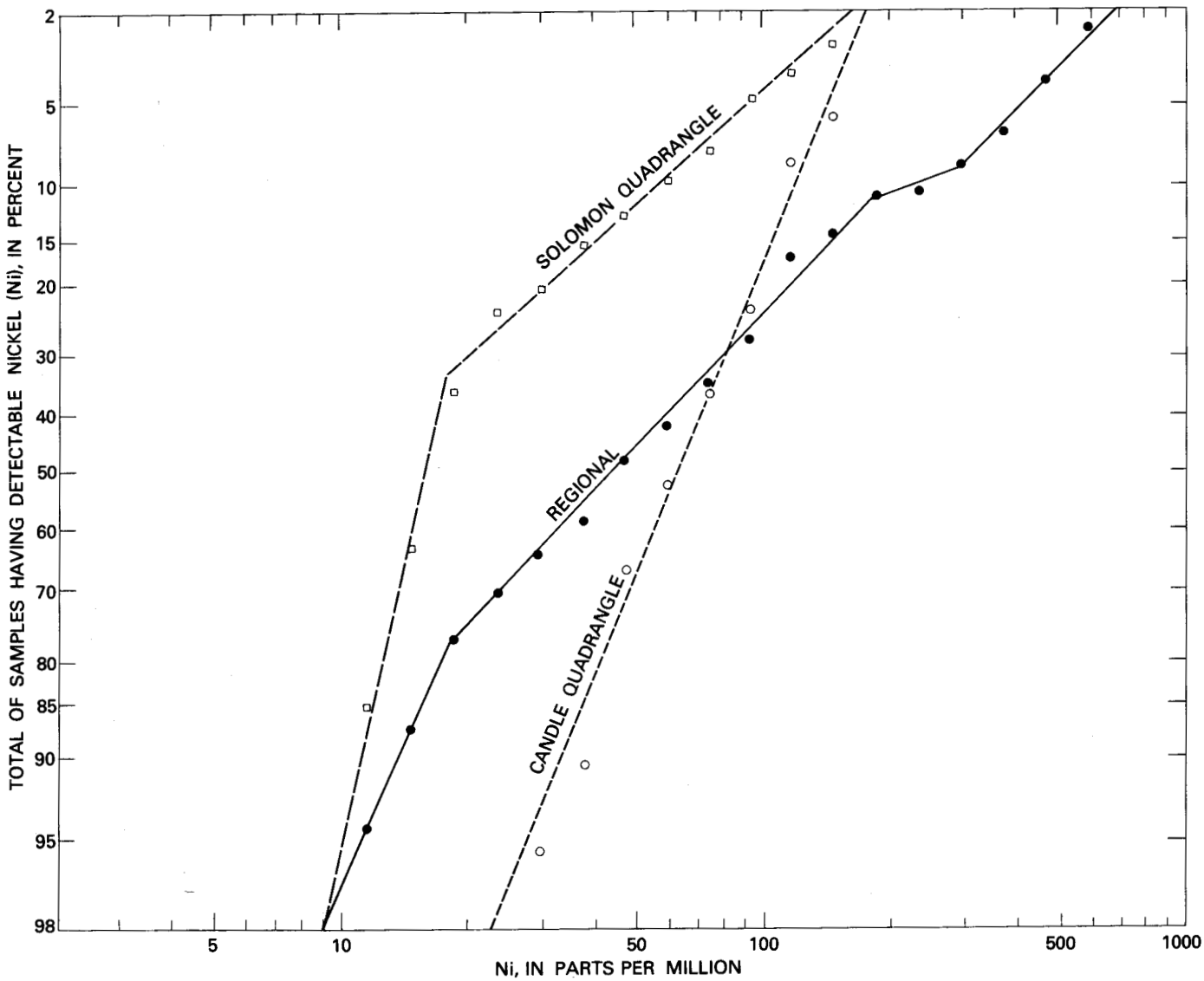


FIGURE 10.—Concentration and cumulative frequency of nickel in Alaskan magnetic concentrates.

TABLE 9.—*Background and threshold values for equivalent uranium and nine elements in magnetic concentrates from Alaska*

[Data are in parts per million]

Area	Level	eU	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn	Au
Regional	Background	<30	0.2	8	0.24	45	10	45	25	75	0.2
	Threshold	120	1	14	1	95	25	240	60	120	1
Candle quadrangle	Background	<30	0.27	9	0.25	55	10	65	25	80	n.d.
	Threshold	100	1	15	1	90	22	170	50	140	1
Solomon quadrangle	Background	90	0.27	10	0.30	30	6	15	25	60	n.d.
	Threshold	220	1	15	1	40	15	20	50	80	1

They stated that most of the radioactivity in concentrates from granite and from contacts of granite was from thorium-bearing minerals or from uranium in thorium minerals, but locally hematite was found to be uraniferous.

The radioactive magnetic concentrate from the

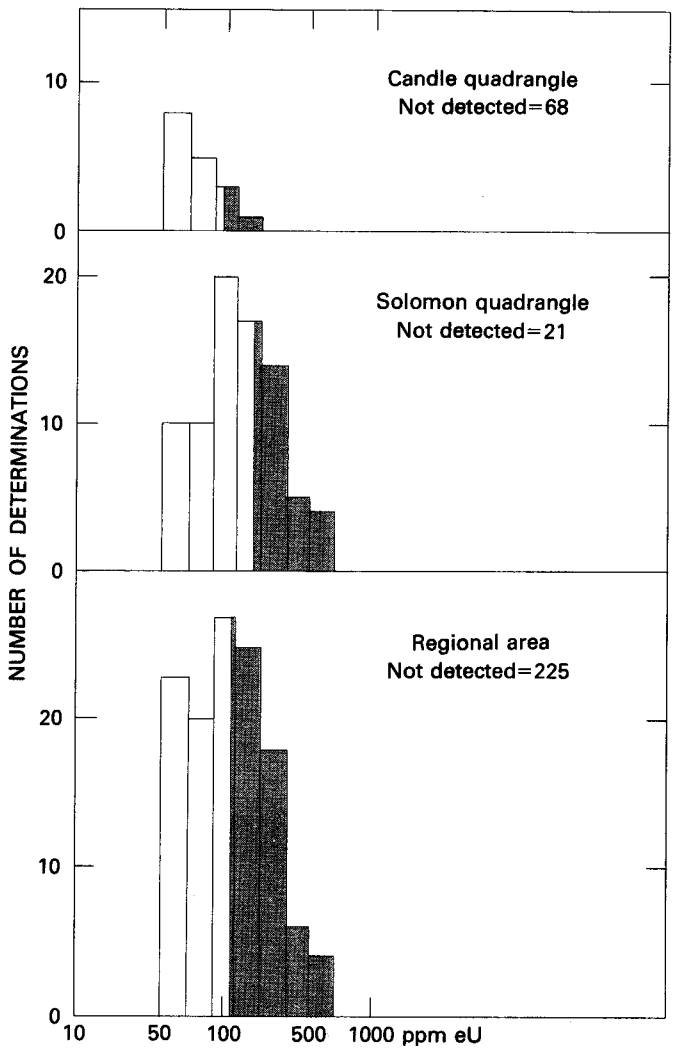


FIGURE 11.—Histograms for equivalent uranium in Alaskan magnetic concentrates; shaded areas anomalous.

Mount Hayes quadrangle was separated from a concentrate panned from 100 pounds of gravel from Dry Creek about 80 m upstream from the bridge on the Alaska Highway (Wedow and others, 1954, table 1, fig. 8). Granitic intrusive rocks were the source for gravel in Dry Creek. Tests by Wedow and others (1954, p. 16) showed that most of the radioactive minerals in concentrates similar to 1472 were in the nonmagnetic fraction; thus, removal of the magnetic fraction causes a relative enrichment in the equivalent uranium of the nonmagnetic fraction owing to the presence of zircon, the main radioactive mineral from the granite. The role of radioactive limonite or hematite in these concentrates was not assessed.

The original literature did not report whether the radioactive magnetic concentrates listed in table 10 were derived from potassium-rich intrusives like those in the Darby Mountains.

TABLE 10.—*Comparison of equivalent uranium in magnetic concentrates and original source concentrates in the Circle, Ketchikan, Medfra, and Mount Hayes quadrangles, Alaska*

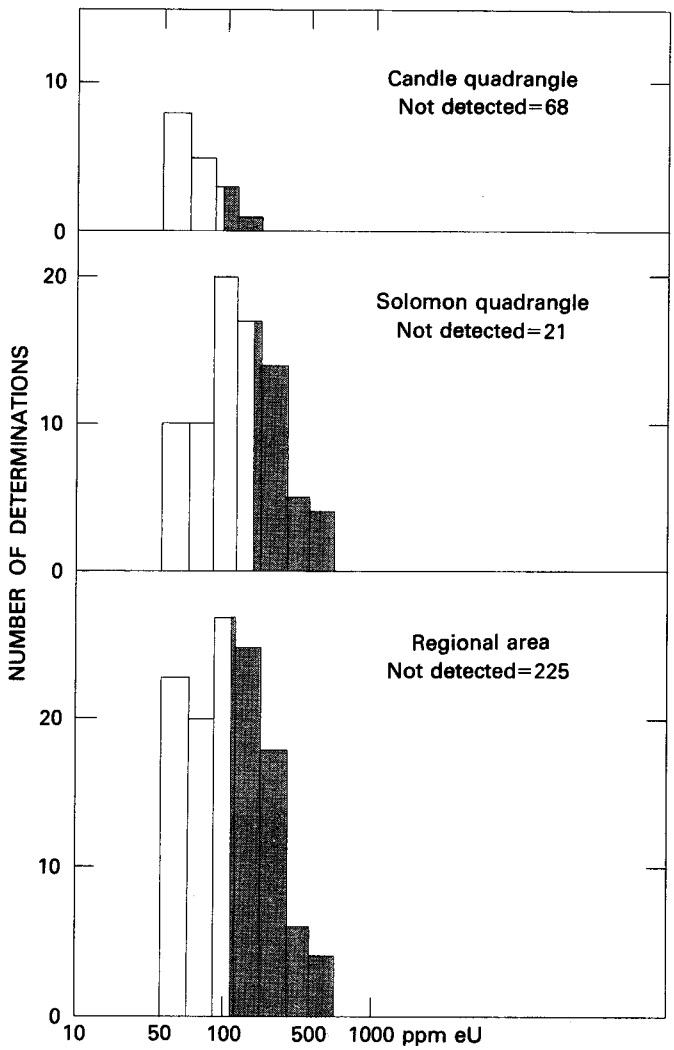
[Equivalent uranium of original concentrate determined 1949–53 by John J. Matzko, U.S. Geological Survey; equivalent uranium of magnetic concentrate determined by K.-L. Pan, 1971]

Quadrangle	File number	Equivalent uranium (ppm)	
		Original concentrate	Magnetic concentrate
Circle	3646	120	150
Ketchikan	3339	20	50
Do-------	3343	100	40
Medfra	296	10	40
Mount Hayes	1472	80	40

MINERALOGICAL SOURCES

The reports of the investigations of radioactive deposits in Alaska cited above called attention to uranium-bearing hematite and limonite as one source for radioactivity in concentrates. Radioactive uraniferous iron oxides are widely reported in the literature (Lovering, 1955; McKelvey and others, 1956; Karkhanavala, 1958; Lovering and Beroni, 1959; Green, 1960), and the intimate association of hematite with certain uranium deposits has been used as a guide in geologic prospecting (Nininger, 1956, p. 116). The surface contamination of magnetite by uranium is known (Damon and others, 1960; Green and Carpenter, 1961), and the coating of magnetite with hematite, or the alteration of magnetite to hematite, is a common phenomenon.

Many, if not most, of the radioactive magnetic concentrates are less splendent than the nonradioactive ones, and tend to be dull brown or brownish black instead of bright black. A test was made to determine if the dull brown color was attributable to a coating, and if the coating was more radioactive than the grains on which it was deposited. For this test, sample 299 from Jump Creek (65°51'15" N.; 162°01'15" W.) in the Bendeleben quadrangle was chosen, although it is not one of the magnetic concentrates otherwise analyzed here. Jump Creek is north of the Darby Mountains in the northwestern headwaters of Candle Creek where silicified intrusive breccia of Cretaceous age is reported (C. L. Sainsbury, oral commun., 1972). The magnetic concentrate was measured for radioactivity before removal of the coating. Then the coating was removed by ultrasonic cleaning and the cleaned magnetite and its coating were separately measured for radioactivity. Because the coating was thin, only enough could be obtained to make one sample



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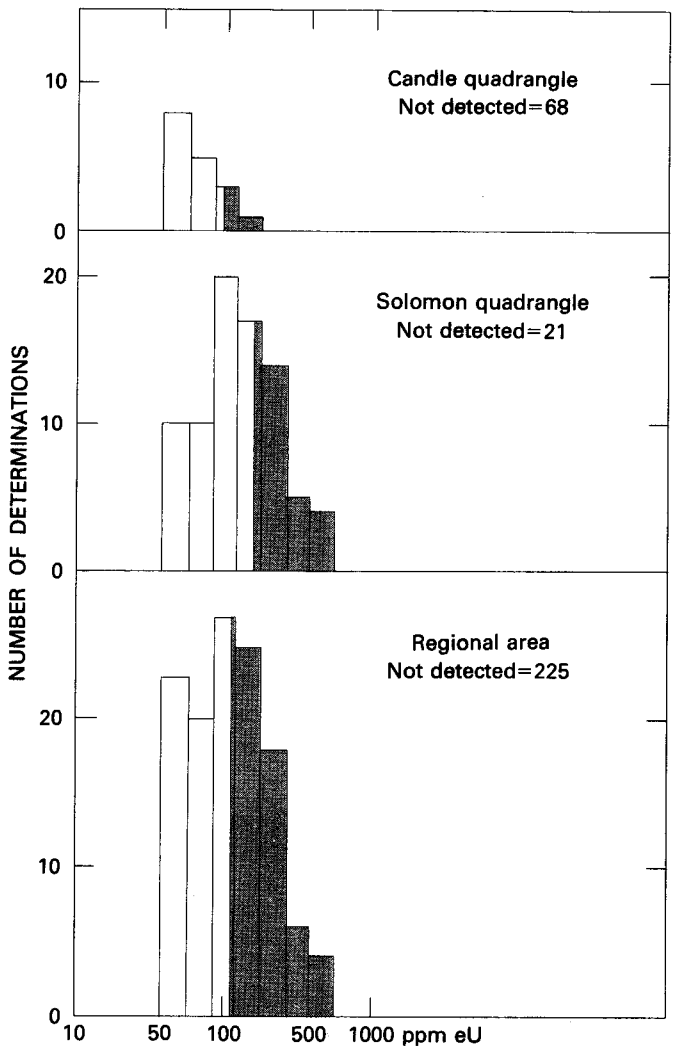

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for counting, but the cleaned magnetic residue was large enough to be divided into eight subsamples for counting. The counting followed the procedure used for the other magnetic concentrates, with the same standard for comparison. The results of these radiometric analyses are given in table 11, where it can be seen that about two-thirds of the radioactivity of the magnetic concentrate is attributable to the brown coating.

TABLE 11.—*Equivalent uranium in magnetite and in hematitic coatings on the magnetite, Jump Creek placer, Bendeleben quadrangle, Alaska*

[Measured by Wayne Mountjoy, U.S. Geological Survey, January 26, 1972]

Material analyzed	Equivalent uranium (ppm)
Magnetic concentrate before cleaning	98
Magnetic concentrate after cleaning	
Subsample 1	65
Subsample 2	57
Subsample 3	35
Subsample 4	39
Subsample 5	<30
Subsample 6	41
Subsample 7	<30
Subsample 8	30
Nonmagnetic coating removed by ultrasonic cleaning	315

X-ray diffraction studies, by Keith Robinson, of the brown coating from sample 299 showed that it is mainly hematite. A small percentage of analcime is mixed with the hematite. The grains on which the coating was deposited are magnetite.

It seems probable that much of the radioactivity of the other magnetic concentrates is in hematitic coatings on grains of magnetite. Also, the source of the radioactivity is probably mainly uranium instead of thorium.

POSSIBLE USE

Magnetic concentrates from streams draining alkalic rocks in the Seward Peninsula, Alaska, are radioactive, whereas most magnetic concentrates from other geologic provenances in Alaska are not radioactive. This distinctive association may afford a method for recognizing the presence of otherwise hidden alkalic rocks or uranium deposits in areas with a heavy cover of vegetation or with deeply weathered rocks. The relative ages of different intrusive rocks in a sequence might be distinguished by different degrees of radioactivity of the magnetic concentrates.

Much work to test these concepts is needed. One test made in connection with the present investigation failed to show radioactivity in magnetites separated from rocks associated with two alkalic complexes in Brazil. These samples, contributed by D. B. Hoover, U.S. Geological Survey, are a specimen of olivine gabbro from José Fernando about 20 km south of Ribeira, São Paulo, and a specimen of carbonatite from Jacupiranga, Paraná State. These specimens were crushed and sieved, and the magnetite was removed with a hand magnet following procedures used for making magnetic concentrates. A clean sample of magnetite (AP-5) was obtained from the olivine gabbro, and two samples of magnetite were recovered from the carbonatite, of which one was clean magnetite (JP-1) and one is magnetite with intergrown carbonate minerals (JP-1a). None of these magnetites is coated with hematite. They were analyzed for radioactivity using twice the counting time previously employed. The three magnetites have no measurable radioactivity at a lower limit of detection of < 10 ppm eU (Wayne Mountjoy, written commun., March 27, 1972).

COPPER, LEAD, ZINC, AND CADMIUM

The geometric means of copper, lead, zinc, and cadmium in the magnetic concentrates from Alaska (table 8) show that zinc (85 ppm) is the most abundant of these elements, followed by lead (26 ppm), copper (16 ppm), and cadmium (0.4 ppm).

Copper appears to have three populations in the regional samples (fig. 2). The abscissa of the inflection points on the cumulative frequency curve indicates the limit above which there is a departure from lognormal distribution. The low-value branch corresponds to the background, the central branch to the weakly mineralized population, and the high-value branch to the highly mineralized population. However, the central branch seems to be a mixture of the other two populations instead of an independent population; therefore, the threshold for anomalous copper was taken as the abscissa of the middle of the central branch at 25 ppm copper. Values for copper greater than 100 ppm, marked by the second inflection point on the curve (fig. 2), are probably indicators of strong mineralization. The histograms in figure 12 show a positive skewness for the regional distribution of copper, but many samples have low values. The gap between the two lowest value bars is caused by the 5-ppm reporting interval used for copper.

The inflection points on the regional cumulative frequency curves for lead (fig. 3) and zinc (fig. 4) are taken as threshold levels of concentration for these two elements in the Alaskan magnetic concentrates. The second inflection at 60 ppm is used for the lead threshold, and the inflection at 120 ppm is used for zinc. Both lead and zinc have positively skewed distributions in the histograms (figs. 13–14), but lead has three un-

positive anomaly (1700 ppm Cu) in sample 2438. No mineral deposit is reported in the immediate vicinity of sample 2136, but a number of base-metal and gold deposits are located upstream to the east along Young Creek and in the Mount Holmes area (MacKevett and Cobb, 1972).

A few magnetic concentrates from the Mount Hayes quadrangle have weakly anomalous copper (1473, 1510, and 1513) and zinc contents (1511), but the content of lead and cadmium is low (table 1). No mineralization is reported for the area represented by 1473, but the three other anomalous samples are from the Rainbow Mountain copper deposits (Cobb, 1972b).

The only magnetic concentrate from the Mount McKinley quadrangle with anomalous base metals is 1019, which has threshold amounts of copper and lead associated with background zinc and cadmium (table 1). The sample is from Last Chance Creek in the gold, antimony, and base metal district at Glacier Peak and Spruce Peak (Cobb, 1972c).

Three of the four magnetic concentrates (1493, 1504, and 1507) from the Nabesna quadrangle are weakly anomalous for copper and sample 1493 is weakly anomalous for zinc (table 1), but none is anomalous for lead or cadmium. None of the three comes from a recognized mineralized area (Richter and Matson, 1972).

Copper content is not anomalous in any of the five magnetic concentrates from the Talkeetna quadrangle (table 1), but four samples (254, 482, 1304, and 1336) contain zinc in greatly anomalous amounts, and the lead content in sample 1336 is weakly anomalous, as is the cadmium content in 482. The cadmium-rich sample also contains the most zinc. Samples 482, 1304, and 1336 are from the gold placer district between Peters Hills and Dutch Hills and downstream from the lode gold deposits on Dutch Hills (Clark and Cobb, 1972). Zinc deposits are unreported. Sample 254, which also contains anomalous amounts of gold, is from a locality downstream from the Big Boulder Creek, Chicago Gulch, and Twin Creek gold placers at Fairview Mountain.

The three magnetic concentrates (2179, 2181, and 2182) from the Talkeetna Mountains quadrangle also have highly anomalous zinc content and two (2179 and 2181) have weakly anomalous copper content, but none has anomalous concentrations of cadmium (table 1). One sample (2179) is weakly anomalous for lead. They come from an area that includes gold placers along Crooked Creek on the southeast side of the Horn Mountains, but base-metal deposits are unreported (Cobb, 1972d). The extremely high zinc content (2800 ppm) of sample 2182 is notable. This concentrate was collected farther downstream along Crooked Creek than the other samples, thus the greatest enrichment in zinc might be even farther downstream where magnetic concentrates have not been collected.

The three magnetic concentrates (2131, 2156, and 2162) from the Valdez quadrangle contain anomalous amounts of copper and zinc but have only background amounts of lead and cadmium (table 1). The source localities of these samples are widely separated. Only 2131 is near a known mineral deposit: it comes from a point about 2.7 km south-southeast of the Willow Mountain copper-zinc lode deposit (Berg and Cobb, 1967, p 52).

SOUTHWESTERN ALASKA

The magnetic concentrates from the Goodnews quadrangle lack anomalous copper, lead, zinc, and cadmium content (table 1). One of the two from the Hagemeister Island quadrangle is weakly anomalous for copper, and those from the Russian Mission quadrangle are weakly anomalous for copper and lead. Magnetic concentrates strongly anomalous for copper and zinc were obtained from the Bethel, Iliamna, and Lake Clark quadrangles.

In the Bethel quadrangle, magnetic concentrates (928, 929, 2120, and 2121) with strongly anomalous copper and zinc content were obtained from Marvel Creek and Cripple Creek, both tributary to the Salmon River and both exploited for placer gold (Cobb, 1972e). Samples 240 and 918, anomalous for zinc, come from localities on the Kuskokwim River and Canyon Creek where zinc deposits have not been reported.

The single magnetic concentrate (553) from the Hagemeister Island quadrangle with weakly anomalous copper content comes from the Platinum Creek placer, where platinum, gold, and chromite are reported (Cobb, 1972f). The copper may be accounted for by the great amounts of basic and ultrabasic igneous rocks near the sources of the detrital magnetite.

All five of the magnetic concentrates from the Iliamna quadrangle have anomalous copper content, and four have anomalous zinc content (table 1). The five samples were collected from the southern, eastern, and northern sides of Iliamna Lake, an area that has many lode deposits of copper (Detterman and Cobb, 1972). However, only one sample is close to a known deposit: sample 3779 is from Millets copper prospect near Chekok Bay on the north shore of the lake. This sample has 25,000 ppm copper, the largest value reported for this set of magnetic concentrates.

Copper content is anomalous in all the magnetic concentrates from the Lake Clark quadrangle, and four (3783, 3791, 3797, and 3799) contain highly anomalous amounts of zinc (table 1). These four are downstream

from gold and base-metal deposits on the north and south shores of Lake Clark (Cobb, 1972g). The other samples, containing anomalous amounts of copper but not of zinc, are from the northeastern end of Little Lake Clark, where ore deposits are unreported.

Only one (2119) of the four magnetic concentrates from the Russian Mission quadrangle contains anomalous amounts of base metals (table 1). It is from the gold placer on Bear Creek (Hoare and Cobb, 1972).

WEST-CENTRAL ALASKA

The strongest anomalies found for copper, lead, and zinc in the magnetic concentrates from west-central Alaska are in the Iditarod and Ruby quadrangles. Magnetic concentrates from west-central Alaska are more commonly anomalous for cadmium than are those from any of the other areas (table 1).

None of the magnetic concentrates from the Bendeleben quadrangle has anomalous copper content (table 1), and relatively few have anomalous amounts of lead (3056, 3070, and 3075), zinc (3041 and 3078), or cadmium (3074). All these samples are in the Darby Mountains and come from streams that drain granitic plutons (3070, 3074, 3075, and 3078) or sedimentary rocks (3041 and 3056) in the vicinity of known mineral deposits (Cobb, 1972h). Sample 3056, which contains anomalous amounts of lead, comes from the Grouse Creek gold placer. Samples 3070 and 3075 also have anomalous lead content; 3070 comes from the drainage southwest of the Grouse Creek placer, and 3075 was collected between the Grouse Creek gold placer and the Otter Creek tin placer. This latter location is also the source of the zinc-bearing sample 3078 and the sample with anomalous cadmium content (3074). Sample 3041 with anomalous zinc content was collected near the Camp Creek gold placer.

Anomalous amounts of copper and lead are less common in magnetic concentrates from the Candle quadrangle than is anomalous zinc content, and cadmium occurs only in background amounts (table 1). Most of the samples that are anomalous for copper are not anomalous for zinc. The three samples (2468, 2473, and 2501) with anomalous lead content also have anomalous amounts of copper but not of zinc. These relations are discussed in the section on the Candle quadrangle.

Magnetic concentrates from the Iditarod quadrangle that are anomalous for zinc also tend to be weakly anomalous for copper and lead. Thus, samples 1804 and 1815 from the gold placers in the Willow Creek area have anomalous zinc and copper content, and 1815 also has anomalous lead content. Gold placers in the Flat area are the source of zinc-rich samples 1831, 1838, 1867, 1877, and 1883. These samples also contain anomalous amounts of other metals: copper and lead in 1831; copper, lead, and cadmium in 1867; and copper in 1883. Most of the samples from the Flat area were taken from Otter Creek and Flat Creek, where lode deposits containing gold, silver, copper, lead, zinc, tungsten, antimony, and mercury are reported (Cobb, 1972i).

Only two magnetic concentrates come from the McGrath quadrangle (table 1). Number 483, which contains anomalous amounts of zinc, was collected at the lode deposit of antimony, bismuth, gold, and tungsten on the south side of Vinasale Mountain; and number 1917, from the Candle Creek gold placer on the northwestern flank of Roundabout Mountain (Cobb, 1972j), has anomalous copper, lead, zinc, and cadmium content.

In the Medfra quadrangle, magnetic concentrate 902, which contains anomalous amounts of copper (table 1), is from the Hidden Creek mineralized area between Greens Head and Jumbo Peak, where placers and lode deposits of bismuth, gold, tungsten, and copper are known (Cobb, 1972k). No ore deposits are reported in association with sample 296, which contains anomalous amounts of zinc.

Only one magnetic concentrate of the five analyzed from the Nome quadrangle (table 1) has any anomalous base metal content. Lead is weakly anomalous in sample 279. Gold placers together with lode deposits of copper and gold are reported in the vicinity of the sample (Cobb, 1972*l*).

Copper content is weakly anomalous in only one of the four magnetic concentrates analyzed from the Norton Bay quadrangle (table 1). The sample (304) is from the Bonanza Creek gold placer 6 km east of Ungalik (Cobb, 1972m). The placer contains anomalous amounts of antimony and tungsten.

Copper and lead contents are strongly anomalous in two magnetic concentrates (56 and 59) from the Ruby quadrangle, and sample 59 also has weakly anomalous amounts of zinc and cadmium (table 1). The 4,700 ppm lead in sample 59 is the largest value for lead found in any of the 347 magnetic concentrates. The sample is from the area of the Flint Creek placer gold and tin deposits east of Long (Cobb, 1972n). Sample 56 is from the mouth of Solomon Creek in the area of the Poorman Creek gold and tin placers.

The weakly anomalous values noted for copper, lead, zinc, and cadmium in magnetic concentrates from the Solomon quadrangle are widely scattered (table 1). Of the 101 concentrates analyzed, only 10 samples have any anomalous base-metal content at all: six for lead, two for zinc, and one each for copper and cadmium.

Of the two analyzed magnetic concentrates from the Teller quadrangle (table 1), only one (497) contains an

anomalous amount of a base metal: 1,100 ppm zinc. This value is one of the highest for zinc in the set of 347 concentrates. The sample is from Cape Creek at Tin City (Cobb and Sainsbury, 1972). The source area for the detrital magnetite seems to be upstream along Cape Creek, southeast of the Bartels tin mine (Mulligan, 1966, fig. 6). However, detailed petrographic descriptions of minerals in tin placer concentrates from this area do not mention the presence of independent zinc minerals, nor did spectrographic analyses of core from the area show a trace of zinc (Mulligan, 1966, tables 10, 14–18).

EAST-CENTRAL ALASKA

The concentrations of copper, lead, zinc, and cadmium are below threshold anomalous values in magnetic concentrates from the Fairbanks quadrangle in east-central Alaska, and cadmium does not reach anomalous abundances in any of the magnetic concentrates from east-central Alaska (table 1). The largest base-metal anomalies in these concentrates are found in the Livengood quadrangle.

The single sample (3646) of magnetic concentrate from the Circle quadrangle contains greatly anomalous amounts of copper and zinc but has little lead or cadmium (table 1). This sample comes from Portage Creek, about 2.4 km upstream from a known occurrence of zinc (Cobb, 1972o), but its copper content is more anomalous than its zinc content.

Only four of the ten magnetic concentrates (277, 532, 3689, and 3704) from the Eagle quadrangle contain anomalous amounts of copper, and one (3689) has anomalous lead content. None of the anomalous values is very large (table 1). Cadmium is not present in anomalous amounts. The first three copper-rich samples were collected along the South Fork Fortymile River in or downstream from the Chicken district, an area known to have placer deposits of gold, minor tin, and minor tungsten, and several lode deposits of lead and silver (Cobb, 1972p). Sample 3704 is from My Creek just downstream from some small prospect occurrences of antimony and lead (Cobb, 1972p).

The magnetic concentrates containing anomalous amounts of base metals in the Livengood quadrangle (table 1) come from two areas: the gold placers east and north of Cleary Summit, where tin and tungsten are also reported (Cobb, 1972q); and the placer and lode gold area at Livengood. Copper and zinc are about equally distributed in the Livengood samples, where lead is sparse, and copper is more common than lead or zinc in the material from the Cleary Summit area.

Three magnetic concentrates from the Tanacross quadrangle have weakly anomalous copper content (table 1), yet none of these represents an area of recognized mineralization (Cobb, 1972r; Foster, 1970). Lead content is below the anomalous threshold in all three samples, but one sample (1499) contains strongly anomalous amounts of zinc.

The single magnetic concentrate (2418) from the Tanana quadrangle has anomalous amounts of copper and lead (table 1). It is from Rhode Island Creek downstream from gold placers in which lead and mercury are reported (Cobb, 1972s).

SILVER AND GOLD

The distribution of silver in the magnetic concentrates from Alaska (fig. 6) is more or less similar to that of copper (fig. 2). However, silver has two distinct populations and a positive skewness. Gold, however, has a linear distribution (fig. 7). The anomalous threshold value for silver, 1 ppm (table 9), is taken from the regional cumulative curve in much the same way as was used for copper. Establishing the anomalous threshold value for gold is a problem. The cumulative frequency curve for gold (fig. 7) displays a nearly linear distribution. The slope of the line is such that if the threshold value is taken from the 2.5-percent ordinate, the minimum anomalous value would be as great as 50 ppm gold, which would lead to misinterpretation of the data. Therefore, the threshold value for gold was taken to be the same as silver, 1 ppm. This value might be rather high for gold, because silver is 200 times as abundant as gold in the average igneous rock (Hawkes and Webb, 1962, table 2–7). However, in the present work the lower limit of detection was the same (0.2 ppm) for both gold and silver; thus, similar thresholds are used for anomalous values, but it might reasonably be assumed that any value above the lower limit of detection would be anomalous for gold. The upper values for silver (600 ppm) and gold (640 ppm) in the magnetic concentrates are close (figs. 16 and 17), but the ranges in abundance vary so much that the gold must occur either as native gold particulates (trace minerals) in the magnetite or as accessory minerals in the magnetic concentrates.

Many of the magnetic concentrates were collected from sites near gold placer mines; thus, some anomalous silver and gold was found in about half of the quadrangles (table 1). The largest number of magnetic concentrates containing anomalous amounts of silver and gold are from the Bethel, Circle, Eagle, and Livengood quadrangles, where the contents of silver and gold are several times to more than 3,000 times background.

SOUTHEASTERN ALASKA

Four magnetic concentrates (3372, 3373, 3375, and 3377) from tributaries to Fish Creek in the Ketchikan

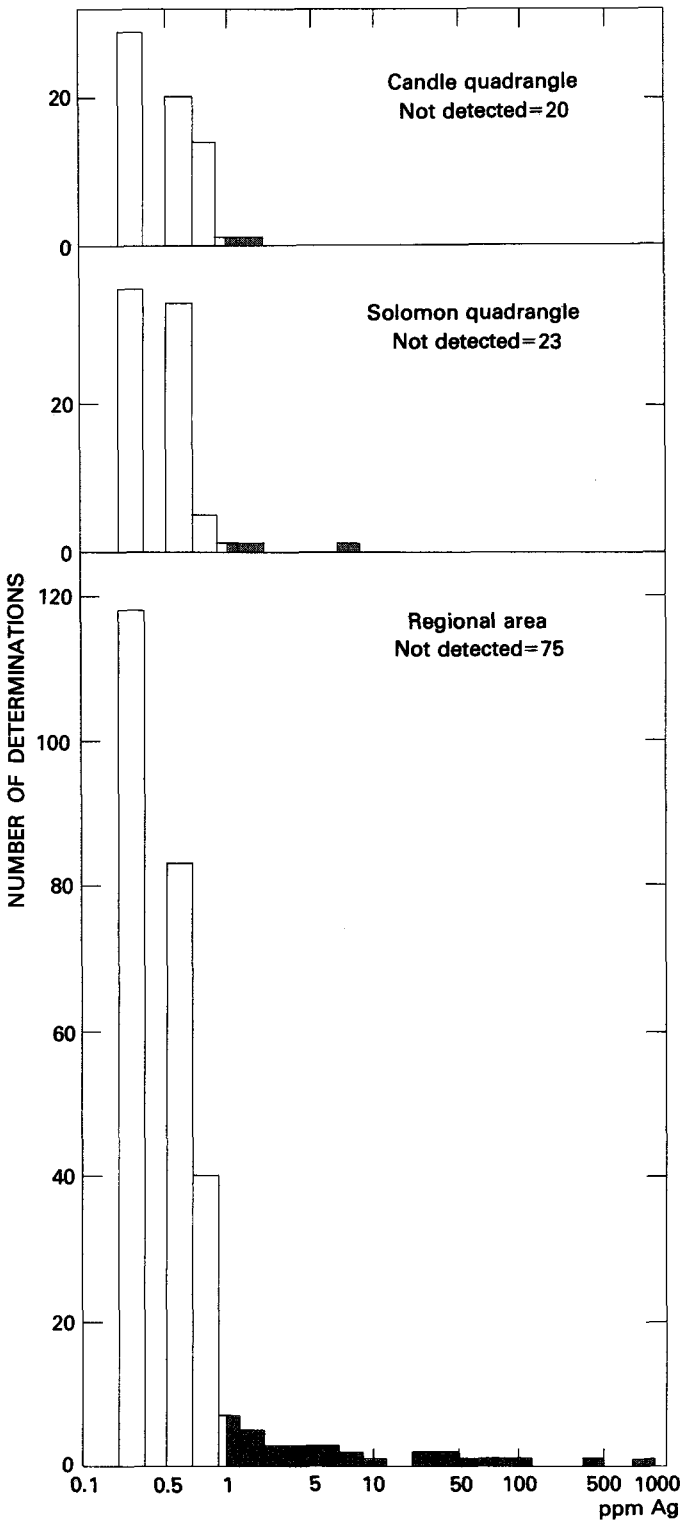


FIGURE 16.—Histograms for silver in Alaskan magnetic concentrates; shaded areas anomalous.

quadrangle, southeastern Alaska, contain anomalous amounts of silver. Insufficient material was available for analysis of gold. Therefore, it is not known if these samples also have anomalous gold content (table 1).

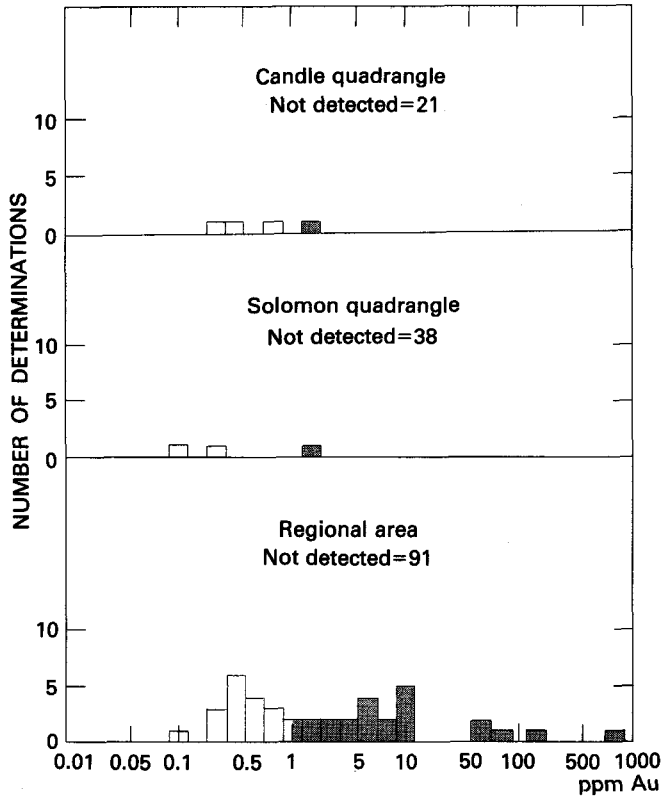


FIGURE 17.—Histograms for gold in Alaskan magnetic concentrates; shaded areas anomalous.

The area has lode deposits of copper, lead, zinc, gold, and silver (Cobb, 1972t).

SOUTHERN ALASKA

Silver and gold are absent in most of the magnetic concentrates from southern Alaska; the few samples that contain silver have weakly anomalous amounts of it, whereas gold is present in strongly anomalous amounts or not at all.

Sample 2192 from the Anchorage quadrangle, which contains threshold amounts of silver but lacks gold at the lower limit of detection (table 1), comes from Archangel Creek in the vicinity of many lode deposits of gold, some of which contain silver and lead (Cobb, 1972a). The creek is a tributary to the Little Susitna River on the south flank of the Talkeetna Mountains and is located along the southern border of a granitic batholith (Dutro and Payne, 1954; Cobb, 1972a).

In the McCarthy quadrangle, threshold silver content is determined in magnetic concentrate 2148, but insufficient material is available to permit analysis for gold (table 1). The concentrate is from Dan Creek immediately downstream from the Nikolai Butte copper deposit (MacKevett and Cobb, 1972) and from lode deposits that contain antimony, copper, gold, silver, and tungsten. The gold-rich magnetic concentrate

2438 (table 1) is from the Kennecott copper mines area. Silver is present in the magnetic concentrate, but its concentration (0.8 ppm) is just under the threshold value.

The two gold-rich magnetic concentrates (232 and 241) from the Mount Hayes quadrangle (table 1) come from gold placers in the Slate Creek area where both placer gold and lode deposits of gold, silver, and copper are known (Cobb, 1972b). Silver is present in the concentrates, but only in background amounts (table 1).

Weakly anomalous silver content is detected in magnetic concentrate 196 from a gold placer on Little Moose Creek in the Mount McKinley quadrangle (table 1), but insufficient sample is available for a determination of gold. In sample 1028 from the Caribou Creek gold placer (Cobb, 1972c) the highly anomalous value of 10.5 ppm gold is determined, but silver content is at background level (table 1).

The Talkeetna quadrangle yielded one magnetic concentrate (254) that has strongly anomalous gold content and background silver content, and one sample (482) that has threshold amounts of silver but is too small to provide material for the determination of gold (table 1). The gold-rich magnetic concentrate is from Mills Creek at a site downstream from the Big Boulder Creek and Chicago Gulch gold placers near Fairview Mountain (Clark and Cobb, 1972). The sample with threshold silver content is from Canyon Creek, a tributary to the Long Creek placer deposits of gold, platinum, and tin (Clark and Cobb, 1972).

SOUTHWESTERN ALASKA

Anomalous and nearly equal amounts of gold are detected in two magnetic concentrates (918 and 928) from the Bethel quadrangle in southwestern Alaska (table 1), and both have equal background quantities of silver. Placer gold deposits are reported about 19 km upstream from the area of sample 918, and 928 is from the Marvel Creek gold placer (Cobb, 1972e).

Of the two magnetic concentrates from the Goodnews quadrangle (table 1), sample 149 contains anomalous amounts of silver and background amounts of gold; and sample 268 has strongly anomalous gold content, but its silver content is just below threshold. Sample 149 is from the discovery claim on the Wattamuse Creek gold placer in the Slate Creek area (Cobb and Condon, 1972), and 268 is from the Snow Gulch gold-platinum placer on the Arolik River.

Magnetic concentrate 3779 is from Millets prospect near Chekok Bay in the Iliamna quadrangle where copper, gold, and silver are reported (Detterman and Cobb, 1972). The sample has 12 ppm silver (table 1), but it was of insufficient size for an analysis of gold.

The Bowmen Cut at the Portage Creek gold placer (Cobb, 1972g), in the Lake Clark quadrangle, is the source of magnetic concentrate 3799, which has background silver and anomalous gold content (table 1).

In the Russian Mission quadrangle, magnetic concentrate 2119 from the Bear Creek gold placer in the Bonanza Creek area (Hoare and Cobb, 1972) contains anomalous amounts of gold and low background amounts of silver (table 1).

WEST-CENTRAL ALASKA

Analytical results from two of the sampled quadrangles in west-central Alaska, the Candle and the Solomon quadrangles, are discussed in other parts of the text. Neither quadrangle contains a notable number of magnetic concentrates that have anomalous silver and gold content. Only two concentrates out of the 85 analyzed for silver and one of the 25 analyzed for gold in the Candle quadrangle have anomalous amounts of these metals (table 1). Of the 101 magnetic concentrates from the Solomon quadrangle analyzed for silver, three are anomalous, and of the 41 analyzed for gold, one is anomalous. High values were found for silver in two samples from the Ruby quadrangle, and strongly anomalous amounts of gold were detected in two samples from the McGrath quadrangle.

The Dahl Creek gold placer in the Bendeleben quadrangle (Cobb, 1972h) is the source locality of magnetic concentrate 400, which has threshold gold content and low background silver content (table 1).

The five magnetic concentrates from the Iditarod quadrangle that have anomalous silver content (table 1) were too small to permit analysis for gold; thus, it is not known if their gold content might also be anomalous, but the five come from gold placers (Cobb, 1972i).

Magnetic concentrates 483 and 1917 from the McGrath quadrangle have strongly anomalous gold content and low background silver content (table 1). Both are from gold placers (Cobb, 1972j).

Magnetic concentrate 304 from the Norton Bay quadrangle contains threshold amounts of gold, but its silver content is below the limit of detection (table 1). The sample comes from a gold placer 6 km east of Ungalik. This placer contains minor amounts of antimony and tungsten (Cobb, 1972m).

Two magnetic concentrates (56 and 59) from the Ruby quadrangle, which have highly anomalous silver contents (table 1), are associated with lode and placer deposits of gold and tin (Cobb, 1972n), but both samples were too small to permit the determination of gold.

EAST-CENTRAL ALASKA

East-central Alaska yields magnetic concentrates with strong anomalies in silver and gold, but relatively few samples are represented. All the concentrates from this area were collected from streams that drain granitic rocks except for samples 74, 1446, and 1455 from the Livengood quadrangle, which were collected from areas underlain by mafic, ultramafic, sedimentary, and metasedimentary rocks. Concentrates from both terranes have anomalous silver and gold contents, but the samples from the granitic areas in the Livengood quadrangle have higher values for silver and lower values for gold than samples from areas of mafic rocks.

The magnetic concentrate (3646) from the Portage Creek gold placer in the Circle quadrangle (Cobb, 1972o) has anomalous silver content and strongly anomalous gold content (table 1). The amount of gold, 640 ppm, is the largest value determined for that element in the magnetic concentrates analyzed for this study.

Four magnetic concentrates (1, 27, 535, and 3689) from the Eagle quadrangle are variously anomalous for silver and gold (table 1). All are associated with gold placers (Cobb, 1972p). Sample 1 with 9.6 ppm gold is from Wade Creek. Sample 27, from the Chicken Creek area, has 28 ppm silver but was too small for a gold analysis. The Myers Fork material (sample 535) has anomalous gold content (5.1 ppm) but only background silver content, whereas sample 3689 from the Atwater Bar of the South Fork Fortymile River has anomalous contents of both silver (1 ppm) and gold (2.7 ppm).

Three magnetic concentrates from the Livengood quadrangle contain anomalous amounts of silver (36, 74, and 100), and four (97, 100, 1446, and 1455) have anomalous to highly anomalous gold content (table 1). Samples 36 and 74 were not analyzed for gold owing to their small size, but are probably auriferous because they are from areas of gold lode and placer deposits (Cobb, 1972q).

Magnetic concentrate 2418 from Rhode Island Creek in the Tanana quadrangle has strongly anomalous silver content (table 1), but was not analyzed for gold. The source locality of the sample is downstream from speculative and unproven lode deposits of gold, lead, and tin (Cobb, 1972s).

BISMUTH

Bismuth shows three populations in its regional distribution (fig. 8). More than half of the magnetic concentrates analyzed contain 10 ppm bismuth, and the maximum concentration reaches 90 ppm (fig. 18). The histogram shows a positive skewness. From the cumulative frequency diagram (fig. 8) it appears that the regional threshold for bismuth is about 14 ppm (table 9).

A clear geographic control is seen for the regional distribution of bismuth in the magnetic concentrates (table 1). Anomalous amounts of the element are lacking in samples from southeastern Alaska. Only one quadrangle in southern Alaska—the Talkeetna Mountains quadrangle—yielded a magnetic concentrate with anomalous bismuth content, and that sample (2181) is only weakly anomalous (20 ppm). In southwestern Alaska only two samples were found to have anomalous amounts of bismuth. Both have the weakly anomalous content of 20 ppm; one (929) is from the Bethel quadrangle, and the other (553) is from the Hagemeister Island quadrangle. The quadrangles in west-central Alaska and east-central Alaska have the greatest amounts of bismuth in magnetic concentrates. Two of these, the Candle and Solomon quadrangles, are discussed in separate sections of the text and are not considered here. Elsewhere in west-

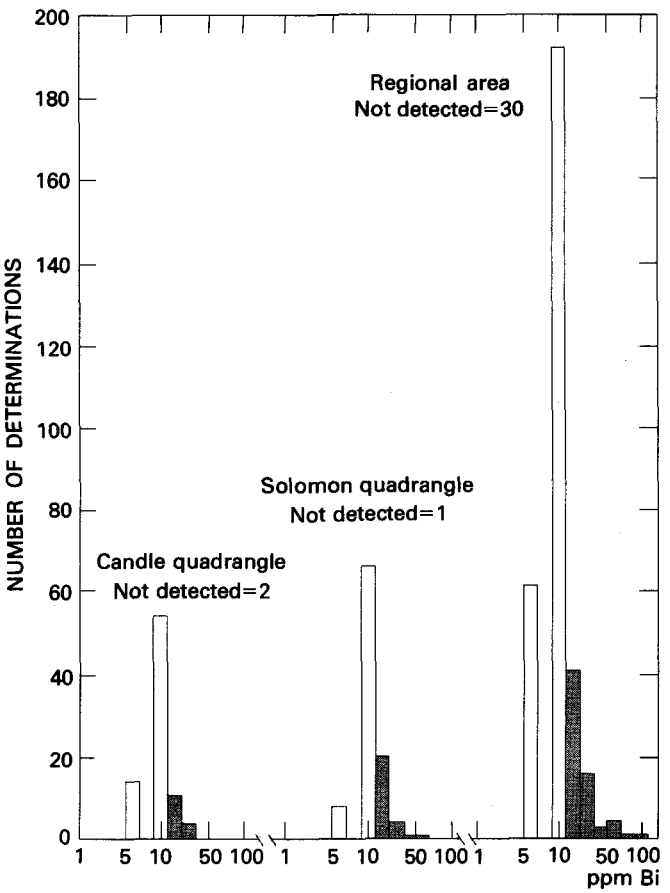


FIGURE 18.—Histograms for bismuth in Alaskan magnetic concentrates; shaded areas anomalous.

central Alaska, bismuth-rich magnetic concentrates are characteristic of the Bendeleben, Idatarod, Medfra, Ruby, and Teller quadrangles. In east-central Alaska, samples with anomalous bismuth content are found in the Circle, Eagle, and Livengood quadrangles.

WEST-CENTRAL ALASKA

Magnetic concentrates 2027, 3042, 3047, 3054, 3056, 3069, 3070, and 3076 contain bismuth in anomalous amounts ranging from 15 to 45 ppm (table 1). All except 2027 are from a tight cluster of sample sites on the east side of the Darby Mountains, where small lode gold deposits have been reported (Cobb, 1972h), and where large anomalous values for bismuth—more than 10,000 ppm—were discovered in stream sediments by Miller and Grybeck (1973, p. 4). The area was regarded by Miller and Grybeck to be highly mineralized, a conclusion also supported by the anomalous values found for many metals in these magnetic concentrates. Sample 2027, which contains anomalous amounts of bismuth, is from a site 5.5 km north of a gold and tin placer reported on Humboldt Creek (Cobb, 1972h).

Only one of the seven magnetic concentrates from the Iditarod quadrangle lacks anomalous amounts of bismuth (table 1); the rest have from 15 to 25 ppm bismuth. The samples are from the mineralized area around Flat and southward to Chicken Creek, where placer deposits of gold, silver, antimony, chromium, and tungsten and lode deposits of antimony and gold with associated cobalt are known (Cobb, 1972i).

No mineral deposits have been reported (Cobb, 1972k) for the Medfra quadrangle in the vicinity of magnetic concentrate 296, which has threshold bismuth content (table 1). The other concentrate (900) with threshold bismuth is from Greer Gulch near Jumbo Peak. Greer Gulch drains a small mass of granite that hosts several lode deposits of bismuth, copper, gold, and silver about 5 km to the southwest (Cobb, 1972k).

Two magnetic concentrates from the Ruby quadrangle contain anomalous amounts of bismuth (table 1): sample 56 has 15 ppm and sample 59 has 90 ppm, which is the largest value found for bismuth in any of the 347 magnetic concentrates. These are unusual samples in that they contain anomalous amounts of five and eight different metals, respectively. Only gold placers are reported in the vicinity of sample 56 (Cobb, 1972n), but both gold and tin placers have been mentioned in the vicinity of sample 59 (Chapman and others, 1963, p. 48).

Magnetic concentrate 497, from Cape Creek at Tin City in the Teller quadrangle, contains 45 ppm bismuth (table 1). However, bismuth is not detected in drill core from the Bartels tin mine area at the head of Cape Creek (Mulligan, 1966, table 10).

EAST-CENTRAL ALASKA

One magnetic concentrate each from the Circle (3646), Eagle (2251), and Livengood (36) quadrangles in east-central Alaska contains anomalous amounts of bismuth (table 1). The sample from the Circle quadrangle not only yields the highly anomalous value of 70 ppm bismuth, but also is anomalous for six other elements. Its source is the H. C. Carstens placer gold mine on Portage Creek, where bismuth, copper, gold, tin, and tungsten have also been reported (Cobb, 1972o). The sample from the Eagle quadrangle contains only threshold amounts of bismuth. It is from the Fortymile River about 2.4 km downstream from the nearest gold placer of a group of placers scattered upstream to the head of the river (Cobb, 1972p). Sample 36, from the Livengood quadrangle, contains 55 ppm bismuth and comes from a site on Fish Creek about 3 km downstream from placers where antimony, bismuth, gold, tin, and tungsten have been reported (Cobb, 1972q). A small gold-bismuth-quartz lode is also located in Melba Creek, a headwater tributary of Fish Creek.

COBALT AND NICKEL

The distributions of the ferride elements cobalt and nickel are the least skewed from lognormal of all the metal distributions studied in these magnetic concentrates. Although cobalt shows two populations and nickel shows four (figs. 9 and 10), the cumulative frequency curves for cobalt and nickel do not depart much from a linear distribution. An estimate of the backgrounds for these two metals is given by the intersection of the 50-percent ordinate and the cumulative frequency curves, which is at 45 ppm for both metals (figs. 9 and 10). This is close to the geometric means of 44 ppm for cobalt and 50 ppm for nickel listed in table 8. From the geometric deviations given in table 8 and the histograms in figures 19 and 20, it is seen that values for nickel have a wider dispersion than those for cobalt. However, both have a slight positive skewness. The threshold value for each element is derived by Lepeltier's (1969) method from inflections of the regional cumulative frequency curves.

On the curve for cobalt (fig. 9), concentrations above the 95-ppm threshold are considered anomalous. The high-value branch thus defined deviates to the right slightly from the lognormal distribution because of an excess of high values. From the curve for nickel (fig. 10), a threshold value of 240 ppm is taken from the midpoint of the third branch.

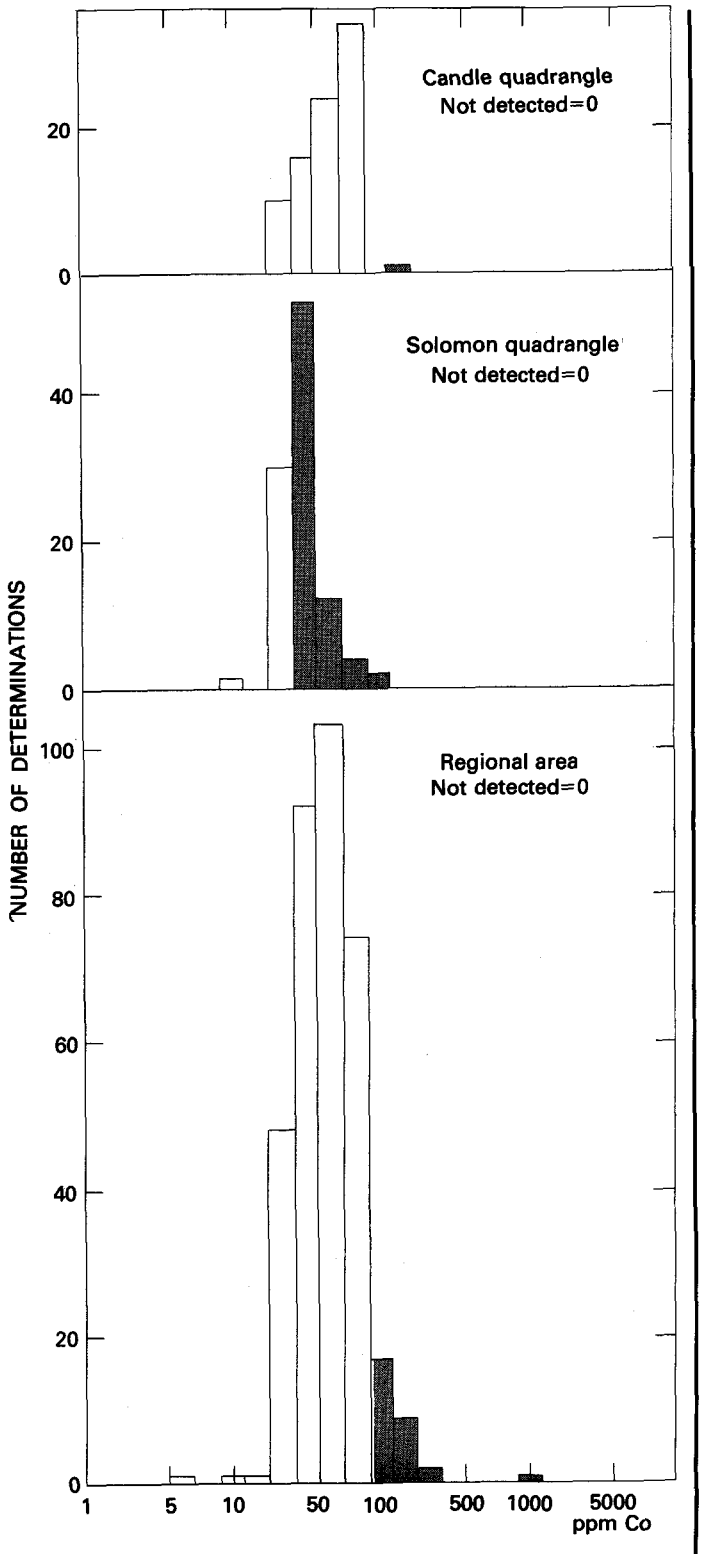


FIGURE 19.—Histograms for cobalt in Alaskan magnetic concentrates; shaded areas anomalous.

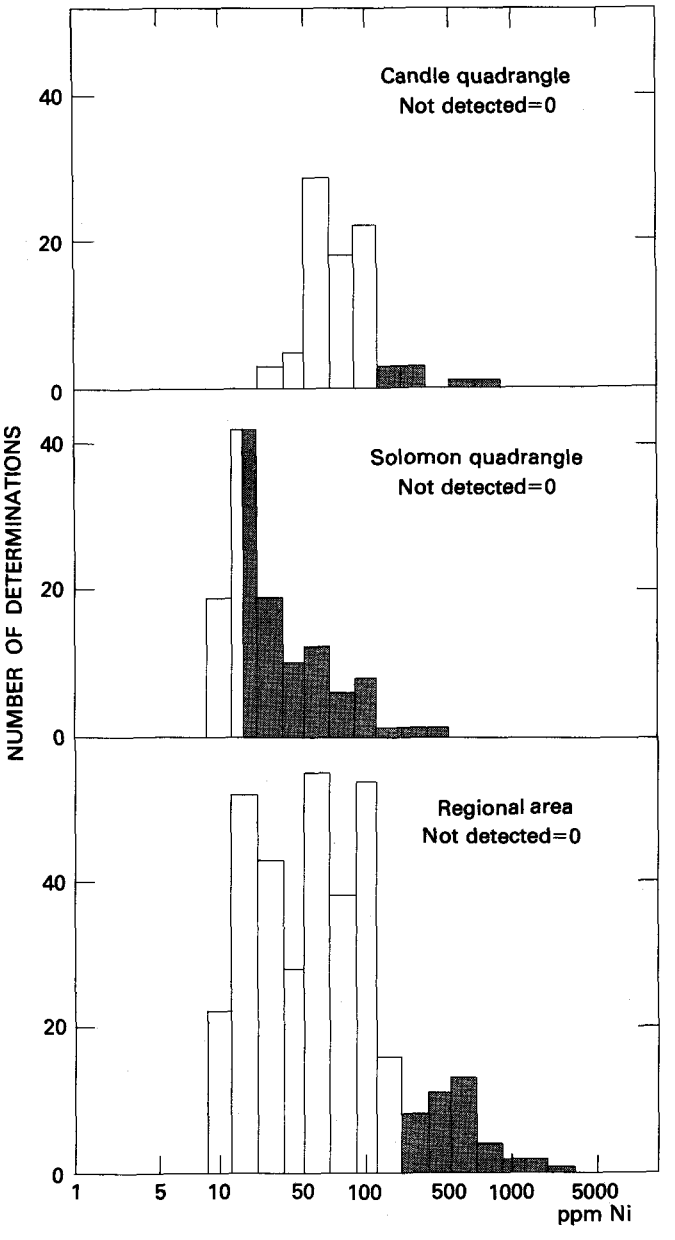


FIGURE 20.—Histograms for nickel in Alaskan magnetic concentrates; shaded areas anomalous.

The geometric mean contents of 44 ppm and 50 ppm for cobalt and nickel, respectively, in the magnetic concentrates from Alaska are not greatly different. However, in magmatic differentiation, cobalt shows only a slight early enrichment whereas nickel is strongly enriched in the early differentiates, particularly the ultramafic rocks, yielding Co/Ni ratios that increase from 0.08 for peridotites to 3.3 for granites (Rankama and Sahama, 1950, p. 681–683). Nickel is thus depleted at a faster rate than cobalt during magmatic differentiation. Owing to the substitution of these elements for iron in magnetite, the Co/Ni ratio in magnetites precipitated at different stages of differentiation has been found to increase as the stage of fractionation of the magma becomes more advanced (Wager and Mitchell, 1951; Howie, 1955).

The value of Co/Ni ratio in magmatic iron ores has been suggested as an index of the degree of fractionation (Landergren, 1948, p. 122–129; Davidson, 1962, p. 79); however, Sen, Nockolds, and Allen (1959) and Frietsch (1970, p. 93–104) reported that this ratio doesn't always increase in magnetite with increasing magmatic fractionation. Frietsch further noted that the ranges of the Co/Ni ratios for magnetites of magmatic, volcanic-sedimentary, and metasomatic origin were similar, suggesting that the ratio is unrelated to origin.

The Co/Ni ratio for this group of Alaskan magnetic concentrates, as derived from the geometric means (table 8), is slightly below unity. This suggests an influence from sources in ultramafic magmatic rocks, because many of the concentrates from this source have remarkably high nickel content, locally as great as 20–40 times the mean content. Where the cobalt contents of the magnetic concentrates are consistently higher than the nickel contents, the abundance data are a strong confirmation that the magnetites were derived from silicic igneous rocks.

The inflections on the regional cumulative curve for nickel (fig. 10), which suggest four populations of nickel-bearing magnetic concentrates, may be interpreted to show that the data for nickel are more sensitive to the geologic source of the concentrates than are the other chemical data. The samples are from geologically diverse source materials. The four branches of the curve, from low values to high values for nickel, may reflect derivation of the concentrates respectively from silicic rocks, intermediate rocks, ultramafic rocks, and mineralized rocks. The presence of threshold amounts of nickel, where the magnetic concentrates are derived from ultramafic or mafic rocks, probably should be regarded as normal instead of being thought of as possibly indicating mineralization, because of the natural enrichment of nickel in these rocks.

Although most of the cobalt and nickel deposits reported by Berg and Cobb (1967) are in southeastern Alaska, none of the concentrates came from the vicinity of these deposits, and none of the concentrates from the Bradfield Canal, Juneau, and Ketchikan quadrangles is anomalous for either cobalt or nickel (table 1). Other areas in which the analyzed magnetic concentrates lack anomalous cobalt or nickel content are the McCarthy, Nabesna, and Valdez quadrangles in southern Alaska; the Iliamna and Russian Mission quadrangles in southwestern Alaska; the Medfra, Nome, Norton Bay, and Teller quadrangles in west-central Alaska; and the Eagle and Fairbanks quadrangles in east-central Alaska.

SOUTHERN ALASKA

One magnetic concentrate (2199) from the Anchorage quadrangle has a weakly anomalous cobalt content, and two (2190 and 2203) have anomalous nickel content (table 1). Strangely, the cobalt-enriched sample, the source of which is downstream from exposures of ultramafic rocks in the western Chugach Mountains (Clark and Bartsch, 1971; Clark, 1972), has no anomalous nickel content, even though nickel was shown by Clark and Bartsch (1971, p. 14) to be six times as abundant as cobalt in these rocks. The nickel-rich magnetic concentrate from Wolverine Creek (2203), which lacks anomalous cobalt content, was collected downstream from the Wolverine ultramafic complex, where dunite and peridotite were found by Clark (1972, p. 10) to contain 1500–3000 ppm nickel and 150–300 ppm cobalt. Quartz diorite and mica schist (Capps, 1915, pl. 3) would appear to be the source rocks for the magnetic concentrate (2190) from Willow Creek with weakly anomalous nickel content, but glacial erosion in the area may have contributed detritus, including nickel-bearing magnetite, from otherwise unrecognized ultramafic source rocks (Paige and Knopf, 1907, p. 65–67; Capps, 1915, p. 38–39).

Of the magnetic concentrates from the Mount Hayes quadrangle, five from the Slate Creek area (230, 232, 238, 241, and 293) have anomalous contents of both cobalt and nickel (table 1), one from the Rainbow Mountain area (1511) has anomalous cobalt content, and another from the same area has anomalous nickel content. Gabbro is in part the source for samples 230 and 232 (Rose, 1967, fig. 1). Possibly similar rocks, or even pyroxenite, peridotite, and hornblendite locally rich in magnetite, are partial sources for the other anomalous magnetite concentrates from the Slate Creek area. Details of the bedrock in the eastern part of this area are lacking, but an extension of ultramafic rocks toward the east is probable (Rose, 1967, p. 8 and table 3). Samples 1511 and 1513 are from the vicinity of copper, lead, gold, silver, and nickel prospects in the Rainbow Ridge area (Hanson, 1963, p. 67–70), where the nickel and part of the copper are associated with ultramafic igneous rocks.

One magnetic concentrate (1023) from the Mount McKinley quadrangle contains anomalous amounts of nickel (table 1). The sample is from Caribou Creek at the mouth of Last Chance Creek, a tributary from the southeast. Quartz lodes with stibnite are found in contorted hornblende gneiss at this junction (Capps, 1919, p. 108; Wells, 1933, p. 353), and magnetite is a common mineral in sluice-box concentrates from Caribou Creek (Capps, 1919, p. 92). The source of the magnetite that

has anomalous nickel content may be the hornblende gneiss.

Magnetic concentrate 1290 has anomalous cobalt and nickel contents, and sample 1336 has anomalous nickel content (table 1). These samples come from two gold placers about 1.5 km apart on Cache Creek in the Talkeetna quadrangle. Cache Creek lies in a glacial trough (Mertie, 1919, p. 242–248) between hills of Mesozoic slate and graywacke and Eocene gravel, sand, clay, and lignite (Capps, 1913, fig. 6). Glacial deposits mask the sources of the gold, platinum, cassiterite, scheelite, and magnetite found in the placers, but these minerals have been interpreted to be of local provenance (Mertie, 1919, p. 245–246). However, other studies have shown that the gravels above the slate and graywacke are derived from distant sources in the Alaska Range (Robinson and others, 1955, p. 14). The presence of the detrital platinum indicates that the source area contained some ultramafic rocks, to which these nickel-enriched magnetic concentrates might be attributed.

Anomalous cobalt content is present in a magnetic concentrate (2181) from the gold placer on Albert Creek in the Talkeetna Mountains quadrangle (table 1). Albert Creek drains an area underlain by Mesozoic volcanic and sedimentary rocks and generally covered by glacial and fluvioglacial deposits (Cobb, 1973, p. 29). A little detrital platinum has been reported with the gold, but local sources have not been identified for these placer minerals. The lack of anomalous nickel content in the magnetic concentrate suggests that silicic rocks more than ultramafic rocks have been a source for the detrital magnetite.

SOUTHWESTERN ALASKA

Two magnetic concentrates (928 and 929) from gold placers on Marvel Creek in the Bethel quadrangle of southwestern Alaska have anomalous amounts of nickel but lack anomalous cobalt content (table 1). The stream drains an area underlain by Cretaceous sedimentary rocks, chiefly interbedded graywacke and siltstone with lesser amounts of conglomerate, into which are intruded small stocks of granite and dikes and sills of gabbro and basalt (Hoare and Coonrad, 1959). Other metals such as copper, zinc, silver, and gold are also anomalous in these concentrates, but the sources of the nickel-rich magnetite are uncertain; seemingly the mafic rocks are insufficiently abundant to account for it.

The magnetic concentrate (268) from the Arolik River in the Goodnews quadrangle, which has anomalous nickel content and background cobalt content (table 1), was collected at a site about 11 km downstream from a gabbroic stock and exposures of mafic volcanic rocks (Hoare and Coonrad, 1961a). Doubtless these rocks are the source of this threshold anomaly in the magnetic concentrate.

Cobalt and nickel contents are each anomalous in magnetic concentrates 542 and 553 collected south of Red Mountain in the Hagemeister Island quadrangle (table 1). Neither element is strongly anomalous, but the source is probably the nearby pluton of ultramafic rocks (Hoare and Coonrad, 1961b). The area is the site of major platinum placers (Mertie, 1940a, pl. 8).

Weakly anomalous values for cobalt and nickel are found for sample 3797 from Hatchet Creek in the Lake Clark quadrangle (table 1). Mineral deposits have not been identified in the area (Cobb, 1972g). Hatchet Creek rises in a terrane of Mesozoic mafic lavas and traverses a sequence of Paleozoic metamorphosed sedimentary rocks (Capps, 1935, pl. 2) to enter the northern end of Lake Clark. Had the magnetic concentrate been anomalous only for cobalt and nickel, then its source might have been attributed to the lavas, but sample 3797 also contains anomalous amounts of copper and zinc. Thus, a source including some base-metal sulfide minerals is not wholly improbable.

WEST-CENTRAL ALASKA

Magnetic concentrates 400 and 3041, from the Bendeleben quadrangle in west-central Alaska, have weakly anomalous cobalt content and strongly anomalous nickel content (table 1). Both samples come from streams that drain areas underlain by Precambrian carbonaceous siltite, although the stream that provided sample 3041 also drains an area of Paleozoic limestone (C. L. Sainsbury, oral commun., 1972). Gold content is anomalous in sample 400 and zinc content is anomalous in 3041. Gold placer prospects have been noted in the areas (Cobb, 1972h). Relatively large amounts of cobalt (geometric means of 13–17.5 ppm) and nickel (42–70 ppm) are reported (Miller and Grybeck, 1973, table 4) in stream sediments from areas underlain by the Paleozoic limestone and Precambrian metamorphosed sedimentary rocks east of the Darby Mountains and a few kilometers south of the source for sample 3041. However, Miller and Grybeck (1973, p. 6) noted that these sedimentary rocks are characterized by low geometric mean values for cobalt and nickel. Therefore, they postulated that the high tenors for these elements in the alluvium must be caused by the introduction of debris from the diabase stocks and plugs, which are common to the area and in which high values were found for cobalt and nickel. The strongly

anomalous nickel content in the magnetic concentrate from a tributary to the Tubutulik River (3041) east of the Darby Mountains appears to confirm this interpretation of the source. Presumably the presence of diabase is to be expected near the source of sample 400, or possibly the lava field east of the sample site supplied nickel-rich magnetite.

The amount of cobalt is anomalous in one magnetic concentrate (444) in the Candle quadrangle (table 1), and the nickel content is anomalous in two (2491 and 2696), but the three localities are scattered in the western part of the quadrangle. The cobalt-rich concentrate is from Dime Creek at the discovery claim of placer deposits in which chromium, gold, and platinum are reported (Cobb, 1972u). The sample locality is in a small plug of basalt (Patton, 1967). Normal stream sediment from this part of Dime Creek was found by Elliott and Miller (1969, p. 28) to have threshold cobalt content, about 50 ppm, and low amounts of nickel. Magnetic concentrates 2491 and 2696 come from the Bear Creek gold and platinum placer and from east of the Spruce Creek gold placer, respectively (Cobb, 1972u), which are both close to and downstream from intrusive masses of basalt (Patton, 1967). Stream sediments from these localities were shown by Elliott and Miller (1969, p. 13) to have low background values for cobalt and high background values for nickel. For sample 2696, the anomalous value for nickel appears to be influenced by the presence of copious tramp iron in the magnetic concentrate, because five other samples from the vicinity (2690, 2693, 2695, 2698, and 2712) lack anomalous nickel (table 1).

One magnetic concentrate with anomalous amounts of cobalt and nickel (1831) and five with background cobalt content and anomalous nickel content (1804, 1815, 1838, 1867, and 1883) were obtained from the Flat and Willow Creek areas in the Iditarod quadrangle (table 1). Sample 1831, which had anomalous cobalt content and highly anomalous nickel content, is from the Granite Creek gold placer; and 1838, which has anomalous amounts of nickel, is from a tributary placer. Mertie (1936, p. 221) remarked that the creek was not well named, because its valley is underlain mainly by sandstone and argillite with only a few dikes of granite. The fact that chromite is present with the placer gold (Cobb, 1972i) indicates an influence on the detrital minerals by some mafic or ultramafic rock, as do the anomalous values for nickel in the magnetic concentrates. Possibly this source is the two small stocks of pyroxene diorite and gabbro shown by Mertie and Harrington (1916, pl. 11) as intrusive into the metasedimentary rocks between Flat and Granite Creek on the north and south sides of Otter Creek. The concentrate from Otter Creek (1867) is evidently influenced by the northern mafic stock, and those from Flat Creek (1883) and Chicken Creek (1804 and 1815) apparently are influenced by the southern stock. The presence of mafic intrusives was mentioned by Maloney (1962, p. 8, figs. 2 and 3), but their distribution was not shown.

Faintly anomalous cobalt content is detected in one magnetic concentrate (1917) from Candle Creek in the McGrath quadrangle (table 1), but the sample has only background amounts of nickel. The walls of the Candle Creek valley are reported to be largely composed of sandstone and shale intruded in the upper reaches of the valley by quartz monzonite, and the divide at the head of the valley is capped by basalt (Mertie, 1936, p. 197). Locally derived detrital gold, cinnabar, and scheelite are present in the Candle Creek placer; their source is thought to be the intrusive quartz monzonite (Mertie, 1936, p. 197). The source of the magnetite with anomalous cobalt content is less certain. Because cobalt is enriched and nickel is not, the material might well be derived from the quartz monzonite, but the influence of the basalt is uncertain.

A magnetic concentrate (56) from the mouth of Solomon Creek in the Ruby quadrangle contains anomalous amounts of nickel, and one from Glen Gulch (59) has highly anomalous cobalt and nickel content (table 1). Both sites have gold placers developed on phyllitic bedrock (Mertie, 1936, p. 157, 164; White and Stevens, 1953, p. 1). Granite is intrusive into the phyllites, but it has not been identified at the immediate sites of these placers. Gabbroic greenstone is present in the general area (Chapman and others, 1963, p. 37–38) but seemingly too far south to be a possible source for the extremely anomalous sample from Glen Gulch. The origin of these anomalous samples is thus unresolved. The one from Glen Gulch probably is worth further investigation to account for its high cobalt content.

A magnetic concentrate (2956) from the Kwiniuk River in the Solomon quadrangle (table 1) has weakly anomalous cobalt and nickel content and one (2887) from Cheenik Creek has threshold amounts of nickel. The drainage basin of the Kwiniuk River is underlain by limestone, dolomite, and black shale (West, 1953, pl. 1). The upstream end of the basin reaches the contact betweeen these sedimentary rocks and an intrusive body of granite. The Cheenik Creek sample was collected at the contact between an undivided igneous complex, consisting mainly of granite with some diorite and greenstone, and a unit of metamorphic rocks composed of schists and limestone (West, 1953, pl. 1; Miller and others, 1972, map). The specific source of the anomalous magnetite is not apparent.

EAST-CENTRAL ALASKA

Weakly anomalous nickel content was recorded in a magnetic concentrate (3646) from upper Portage Creek in the Circle quadrangle in east-central Alaska (table 1), where mica schist, quartz-mica schist, and chlorite schist are intruded by biotite granite (Nelson and others, 1954, p. 11, fig. 4). Stream and bench gravels in Portage Creek were mined for placer gold, and detrital minerals containing, variously, bismuth, copper, rare earths, tin, and tungsten have been noted in the concentrates (Cobb, 1972o), but nothing has been reported that suggests the slight nickel enrichment of this magnetic concentrate is other than a normal increase related to some as yet unknown mafic source rock.

Three (74, 1446, and 1455) of the four magnetic concentrates with anomalous nickel content from the Livengood quadrangle (table 1) are from an area influenced by the abnormally nickeliferous serpentinite near Livengood (Foster, 1969, p. 2, fig. 3). Doubtless the anomalous nickel content in these concentrates reflects this source. The most nickel rich of the three (1455) also contains weakly anomalous amounts of cobalt. Sample 97 from Fairbanks Creek in the southeastern part of the quadrangle contains anomalous amounts of nickel but only background amounts of cobalt (table 1). Gold, tin, tungsten, and bismuth minerals have been recognized in the Fairbanks Creek gold placer, but independent nickel minerals have not been noted (Cobb, 1972q); the concentrates are dominated by garnet, ilmenite, magnetite, and rutile, and also contain native bismuth, galena, arsenopyrite, wolframite, and cassiterite (Prindle and Katz, 1909, p. 187–190). Possibly the source of the nickel-enriched magnetic concentrates is the basalt on Fourth of July Hill adjacent to the placer (Prindle and Katz, 1909, p. 186; Prindle, 1913, pl. 8).

The magnetic concentrate (1499) that has weakly anomalous cobalt content from the Tanacross quadrangle (table 1) is from a tributary to the Tok River that drains an area underlain by phyllite, schist, and metadiorite (Foster, 1970). The same sample is also anomalous in copper and zinc, but no mines are recorded for this area (Cobb, 1972r). However, samples of intrusive rocks and altered zones nearby were shown to be highly anomalous in copper, gold, silver, and zinc but were rather low in cobalt (Clark and Foster, 1969, p. 11 and fig. 1).

Anomalous nickel content in magnetic concentrate 2418 from the gold placers in Rhode Island Creek in the Tanana quadrangle (table 1) is accompanied by anomalous amounts of gold, copper, and lead. Gold, lead, tin, and mercury have been found in the placers (Cobb, 1972s) along with other detrital minerals among which pyrite is particularly common (Waters, 1934, p. 237–238). The nickel in this sample may be related to sources for the magnetite in small masses of serpentinized intrusive rocks similar to those exposed farther east in the Tofty area (Wayland, 1961, pl. 40), but this is uncertain. A more likely possibility is that tramp iron is present in the magnetic concentrate, or that gabbroic and similar rocks occur in the headwaters of Rhode Island Creek.

INDIUM AND THALLIUM

Eighty-five percent of the 131 magnetic concentrates analyzed for indium and thallium contain less than 0.2 ppm of each (table 1). The maximum value found for indium is 0.5 ppm and the maximum for thallium is 1 ppm. For the samples with values above the lower limit of detection (0.2 ppm), the geometric mean for indium is 0.23 ppm and for thallium is 0.27 ppm (table 8); these means are, respectively, twice as great and half as great as the average abundance of these elements in the Earth's crust (Krauskopf, 1967). Considering that the largest part of the analyses shows less than 0.2 ppm indium, it is probable that the average magnetic concentrate from Alaska is not enriched in indium over the crustal abundance of 0.1 ppm. For similar reasons, the average magnetic concentrate from Alaska probably contains less than one-fourth of the normal crustal abundance of 0.45 ppm thallium. Thus, magnetic concentrates are not accumulators of these elements.

Indium and thallium rarely form independent minerals, but tend to be dispersed in silicates or to be in sulfides (Rankama and Sahama, 1950, p. 723–727). The most important sulfide hosts are sphalerite for indium and galena for thallium. The correlation coefficients, discussed later, show that indium correlates positively with zinc and thallium with lead. From these observations it may be concluded that indium and thallium, in the few magnetic concentrates where they rise above the limits of detection, most likely are present in sulfides incorporated as minor minerals in the magnetite or as accessory minerals trapped between grains in the magnetic concentrates.

Too few samples contained indium and thallium in amounts greater than the limit of detection to permit appropriate statistical treatment of these data. No anomalous values are given for these elements in table 9, both to conform to the lack of statistical treatment and in recognition that the abundances of indium and thallium in the magnetic concentrates seldom exceed crustal abundance for these elements and the sample medium is not a collector for them. However, some interesting chemical relations are lost thereby that can

be brought out by regarding all values of 0.2 ppm or more as weakly anomalous for indium and thallium in these magnetic concentrates. Southwestern and west-central Alaska are the principal centers for these elements. Indium is present above the limit of detection in magnetic concentrates from eleven quadrangles, but thallium is so determined in only three quadrangles—Bendeleben, Candle, and Solomon—where the thallium-bearing concentrates appear to be derived from sources in intrusive granitic and alkalic rocks. Thallium is particularly uncommon outside these three quadrangles, and it is most common in the Solomon quadrangle. Only three concentrates, 3044 from the Bendeleben quadrangle, and 2959 and 2982 from the Solomon quadrangle, contain both indium and thallium above the limit of detection.

The association of indium-bearing magnetic concentrates with zinc-rich samples is shown in table 1; all 18 indium-bearing concentrates contain zinc and eight have anomalous zinc content. The 23 thallium-bearing samples all contain lead, but only two have anomalous lead content. A strong correlation also exists between thallium and equivalent uranium. Of the 23 thallium-bearing concentrates, 22 also contain equivalent uranium, of which 17 are anomalous. Inasmuch as the equivalent uranium is dominantly associated with hematitic crusts on magnetite and the thallium is probably in inclusions of galena in the magnetite or in detrital particles of galena associated with the magnetic concentrates, the relation between thallium and equivalent uranium is not chemical. It is geologic, and is caused by derivation from the same sources in alkalic rocks.

The distributions of indium and thallium in magnetic concentrates from the Candle and Solomon quadrangles are discussed in other sections of the text. What follows is a review of the sparse data on other parts of Alaska.

SOUTHERN ALASKA

Two magnetic concentrates (2134 and 2438) from the McCarthy quadrangle in southern Alaska and one (2181) from the Talkeetna Mountains quadrangle contain indium above the limit of detection but lack thallium (table 1). Zinc content is anomalous in all three samples. Samples 2134 and 2438 are associated respectively with the Nikolai Butte copper deposit (MacKevett and Smith, 1968; 1972) and the Kennicott copper deposits (MacKevett, 1971). Sample 2181 is from a group of concentrates from gold placers along Crooked Creek (Cobb, 1972d). All these concentrates from Crooked Creek are enriched in zinc, but base-metal deposits are unreported.

SOUTHWESTERN ALASKA

Two magnetic concentrates (918 and 928) from the Bethel quadrangle in southwestern Alaska contain indium above the limit of detection, as does one concentrate each from the Goodnews (149), Iliamna (3778), and Russian Mission (67) quadrangles. None has detectable thallium (table 1). Anomalous amounts of zinc are present in the two concentrates from the Bethel quadrangle, one of which (928) is from a gold placer (Cobb, 1972e), but neither comes from an area known for base-metal mineralization. Sample 149 was collected from a gold placer in the Goodnews quadrangle (Cobb and Condon, 1972), and the concentrate has anomalous silver content but lacks anomalous zinc content. Sample 3778 has anomalous amounts of zinc and is from a region in the Iliamna quadrangle where many copper lodes have been identified, but none has been described at the site of this sample (Detterman and Cobb, 1972). The magnetic concentrate (67) with detectable indium from the Russian Mission quadrangle otherwise has no anomalous metal content. The sample is from the Ophir Creek gold placer, in which base metals are unreported (Hoare and Cobb, 1972).

WEST-CENTRAL ALASKA

Indium- and thallium-bearing magnetic concentrates from west-central Alaska (table 1), other than those from the Candle and Solomon quadrangles (see below), include two concentrates (3044 and 3069) from Rock Creek in the Bendeleben quadrangle and one (1917) from the McGrath quadrangle. Both samples from the Bendeleben quadrangle show the presence of indium, but only 3044 has thallium above the limit of detection. Mineral deposits have not been reported for the two localities on Rock Creek, nor have geochemical anomalies been observed (Miller and Grybeck, 1973, p. 30–31), but several gold placers have been noted in the general area (Cobb, 1972h). The sample from the McGrath quadrangle has anomalous amounts of base metals and cadmium and is from a gold placer (Cobb, 1972j).

EAST-CENTRAL ALASKA

The only magnetic concentrate from east-central Alaska with detectable indium is sample 3646 from the Circle quadrangle (table 1). A variety of elements, including zinc, are present in anomalous amounts in the concentrate, and the sample is from a locality about 2.4 km upstream from the Portage Creek zinc lode occurrence (Cobb, 1972o). Thallium is below the limit of detection, and lead content is not anomalous.

CANDLE QUADRANGLE RESULTS

Eighty-five magnetic concentrates analyzed for this study come from the western half of the Candle quadrangle. The locations of the samples and the results of the analyses are listed in table 1.

The geology of the area sampled in the Candle quadrangle is presented in figures 21 and 22, adapted from Patton (1967). The area is predominantly underlain by younger volcaniclastic rocks, flows, and granitic intrusives, though parts of it are underlain by Paleozoic limestone and schist. Three units of volcaniclastic and volcanic rocks were recognized by Patton (1967). The oldest unit consists of Jurassic(?) and Cretaceous andesitic and trachyandesitic crystal tuff, lithic tuff, tuffaceous volcanic graywacke, massive andesitic breccia, agglomerate, conglomerate, and intercalated flows of porphyritic pyroxene andesite and basalt. A unit of slightly younger age comprises Cretaceous volcanic graywacke and conglomerate, which is composed mainly of andesitic rock detritus and which locally contains large quantities of granitic debris and fine-grained tuff. The youngest of these units consists of Tertiary(?) and Quaternary flows of gray to dark-red vesicular olivine basalt with some black, dense, glassy basalt. Cretaceous granitic rocks, principally hornblende and pyroxene monzonite, syenite, and biotite-quartz monzonite, intrude the older rocks. Much of the granitic detritus in the Cretaceous volcanic graywacke is lithologically identical to the granitic plutons. Where these plutons intrude the Jurassic(?) and Cretaceous andesites, the volcanic rocks are said (Patton, 1967) to be hornfelsic and propylitically altered to a hard, pale-green aggregate of chlorite, epidote, calcite, and sodic plagioclase. Many small intrusive bodies of hybrid diorite, syenite, and monzonite cut the volcanic rocks in the vicinity of the granitic plutons. In questionable Tertiary and early(?) to middle Pleistocene time, the flows of olivine basalt were extruded and spread out over a terrain of moderate relief (Patton, 1967).

Only 34 localities are shown on figures 21 and 22 for the 85 magnetic concentrates from the Candle quadrangle, because the scale of the maps causes many individual sample localities to overlap. This distribution results from the fact that some localities were sampled in detail, or were visited several times over the years by geologists of the U.S. Geological Survey, each of whom collected one or more concentrates at the site. Discrimination of the closely adjacent samples listed for one locality on figures 21 and 22 can be made by reference to table 1.

Five of the sample localities shown on figures 21 and 22 each provided 5 to 10 magnetic concentrates. The individual concentrates were collected mainly from closely adjacent localities, but several concentrates are duplicates from the same site. Gross variations in the trace-element composition of concentrates from the same locality could be expected if the samples represented highly diverse sources, or if the magnetite contained unusually diverse inclusions or unsystematic intermixtures of accessory minerals. In order to prepare maps showing the distribution of the minor metals in the magnetic concentrates from the Candle quadrangle, it was necessary to reach an average value for each metal at every locality where two or more samples are represented. These averages are given in table 12, which also identifies the sample numbers at each locality.

The statistical procedures used to obtain single values for each metal at the localities that had 5 to 10 samples afford an opportunity to test the variance for each element at each site (table 13), and to compare this variance with the relative standard deviation of the analytical method, as shown in table 5. The relative standard deviations in percent are shown in table 14.

In the data from localities A–E (table 13), all the relative standard deviations shown for silver are much smaller, and those for bismuth average slightly smaller, than the relative standard deviations found for these elements in the 30 replicate subsamples of sample 3799 (table 5). For the other elements, the relative standard deviations obtained from the 5 to 10 samples that represent each of these localities are all much greater than the comparable figures obtained for the subsamples of 3799. The largest variations within table 13 are for equivalent uranium, silver, cadmium, and copper, and the smallest variations are for cobalt.

The relative standard deviation for equivalent uranium at locality D of table 13 is zero because all values were below the limit of determination. Otherwise, the high relative standard deviations for equivalent uranium further substantiate that the hematitic coatings on magnetite, which vary greatly in thickness, are the predominant source of the radioactivity (see table 11).

The large relative standard deviations for silver and cadmium in table 13 are caused by setting the values too low for the lower limit of determination for these two elements. On both tables 5 and 13, the contents of silver and cadmium in the concentrates were in the lowest ranges of reported values. This is the range most affected by instrumental noise.

The average relative standard deviation for bismuth at localities A–E, table 13, is a little less (33 percent) than the relative standard deviation for the analytical procedure (36.6), but at one locality it is considerably greater, and overall there is a range from 19 to 51 per-

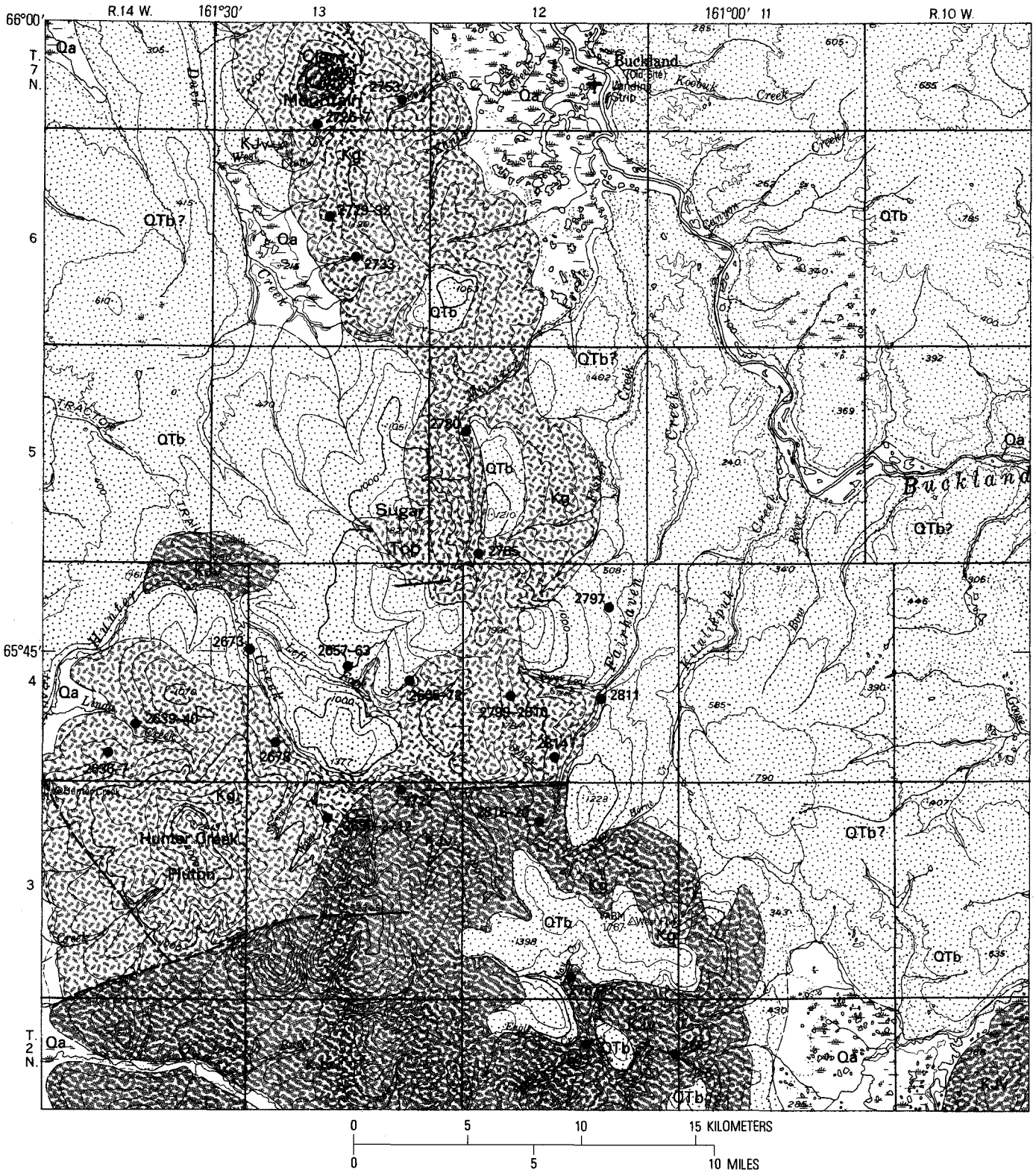
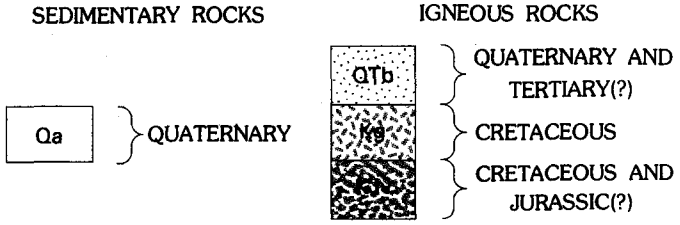


FIGURE 21.—Geologic map showing the distribution of analyzed magnetic concentrates from the northwestern part of the Candle quadrangle, Alaska.

CORRELATION OF MAP UNITS

Geology generalized from Patton (1967)



SEDIMENTARY ROCKS

Qa ALLUVIUM (QUATERNARY)—Flood-plain deposits of gravel, sand, and silt, and terraced alluvial silt

IGNEOUS ROCKS

QTb BASALT (QUATERNARY AND TERTIARY?)—Flows of gray to dark-red vesicular olivine basalt; some black dense glassy basalt

Kg GRANITIC ROCKS (CRETACEOUS)—Chiefly hornblende and pyroxene monzonite and syenite; some biotite-quartz monzonite

KJv ANDESITIC VOLCANIC ROCKS (CRETACEOUS AND JURASSIC?)—Includes a wide variety of andesitic flows and volcaniclastic rock

Contact—Dashed where approximately located, inferred, or indefinite

Fault—Dashed where approximately located or inferred

●2502 Locality of magnetic concentrate—Shows Alaskan placer concentrate file number. Where two or more concentrates are from the same locality, the range in file numbers is given

cent. These differences are not great, but they are interpreted to indicate an erratic presence of bismuth in magnetic concentrates from the same general area, possibly attributable to minor minerals included in the magnetite or accessory minerals in the magnetic concentrate.

The departure of the relative standard deviations for cobalt, copper, nickel, lead, and zinc from the relative standard deviations for these metals in the replicate analyses (table 14), shows the influence of the localities, methods of collection, and methods of preparation on the composition of these magnetic concentrates.

The large relative standard deviation for copper at localities A–E, compared to the relative standard deviation for copper in the replicate analyses (table 14), probably indicates the variable presence of chalcopyrite or other copper sulfide minerals as minor minerals included in magnetite, or the variable presence of such sulfides as accessory minerals in the magnetic concentrates.

Remarkable similarities exist in the relative standard deviations for nickel, lead, and zinc at localities A–E, but most are much greater than the relative standard deviations for these elements in the subsamples of 3799 (table 14). Nickel fits in this group only because the single aberrant value for sample 2696 at locality D has been excluded as caused by abundant tramp iron (see discussion of mineralogy). If this value were retained in the analysis of variation, then the coefficient of variation for nickel would be 150 percent, making nickel the most erratic of the elements in these concentrates. The consistency with which nickel otherwise appears suggests that the value reported for 2696 should be dropped, and that the amount probably should have been given as about 55 ppm instead of 570 ppm. The similar relative standard deviations for nickel, lead, and zinc at localities A–E, and the fact that these measures are much greater than those for the replicate subset (table 14), suggest that the mode of occurrence of these elements in the magnetic concentrates (sorption, substitution, minor included minerals, or accessory minerals) is sufficiently consistent that the collecting and processing of the samples do not exaggerate differences in distribution, as they apparently did for equivalent uranium.

The low relative standard deviations for cobalt at localities A, B, C, and E, table 13, are as much as twice as great as the relative standard deviation for that element in the method used for analysis (table 5). The amount of variation probably is as low as can be expected for material from several sources at each locality. Indeed, these low relative standard deviations may indicate that the main mode of occurrence for cobalt in magnetic concentrates from the Candle quadrangle is diadochic substitution in magnetite. No other mode would reduce the values resulting from diverse provenance, collection, and preparation to so narrow a range.

The distribution of the anomalously abundant elements in the magnetic concentrates from the Candle quadrangle is based on threshold values given in table 9, which do not differ greatly from the regional values. Copper, nickel, and lead in the Candle quadrangle have slightly lower thresholds, and zinc has a slightly higher threshold, than the regional values. The order of discussion follows that used for the region.

EQUIVALENT URANIUM

Most of the low values for detected equivalent uranium in the magnetic concentrates from Alaska are in samples from the Candle quadrangle, where only 20 percent of the samples have radioactivities above

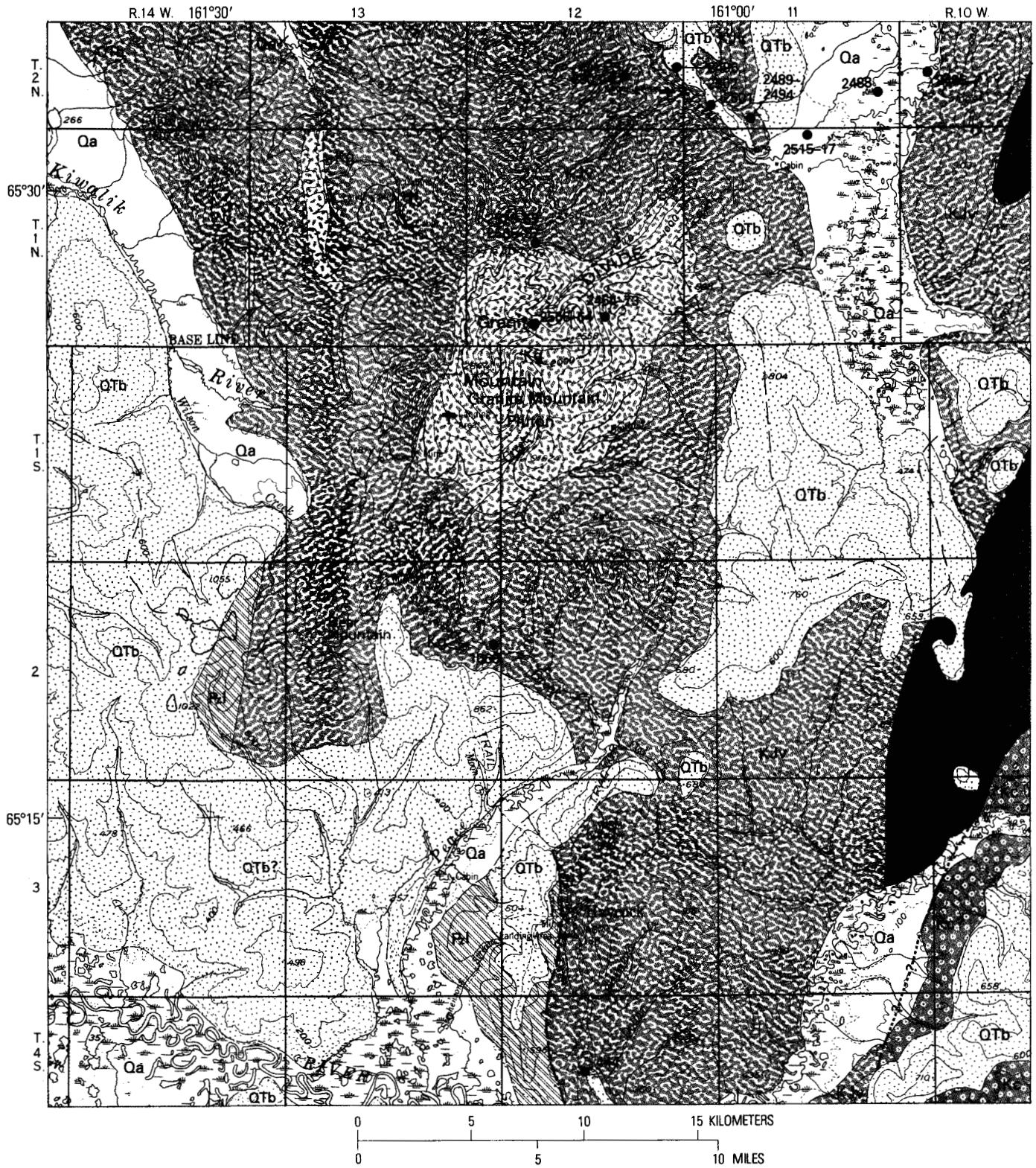
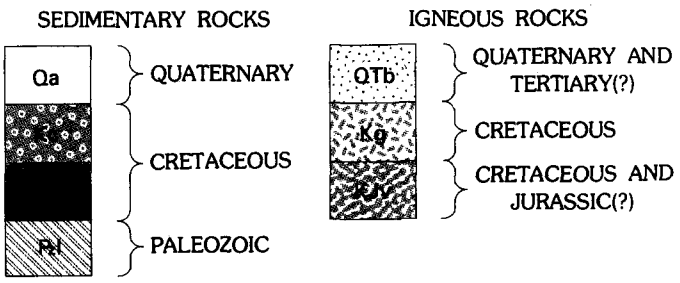


FIGURE 22.—Geologic map showing the distribution of analyzed magnetic concentrates from the southwestern part of the Candle quadrangle, Alaska.

CORRELATION OF MAP UNITS

Geology generalized from Patton (1967)



SEDIMENTARY ROCKS

Qa ALLUVIUM (QUATERNARY)—Flood-plain deposits of gravel, sand, and silt, and terraced alluvial silt

Kc MIXED SEQUENCE (CRETACEOUS)—Consists of calcareous graywacke, calcareous mudstone, volcanic graywacke, and volcanic conglomerate

Kv VOLCANIC GRAYWACKE AND CONGLOMERATE (CRETACEOUS)—Composed chiefly of andesitic volcanic rock detritus; locally includes notable amounts of granitic rock detritus and fine-grained tuffaceous material

PzI LIMESTONE (PALEOZOIC)—Chiefly recrystallized limestone and dolomite. Includes calcareous mica schist and dark phyllite

IGNEOUS ROCKS

QTb BASALT (QUATERNARY AND TERTIARY?)—Flows of gray to dark-red vesicular olivine basalt; some black dense glassy basalt

Kg GRANITIC ROCKS (CRETACEOUS)—Chiefly hornblende and pyroxene monzonite and syenite; some biotite-quartz monzonite

KJv ANDESITIC VOLCANIC ROCKS (CRETACEOUS AND JURASSIC?)—Includes a wide variety of andesitic flows and volcaniclastic rocks

——— Contact—Dashed where approximately located, inferred, or indefinite

——— Fault—Dashed where approximately located or inferred; dotted where concealed; queried where doubtful

●2501 Locality of magnetic concentrate—Shows Alaskan placer concentrate file number. Where two or more concentrates are from the same locality, the range in file numbers is given

background (table 1). The radioactive samples contain from 40 to 160 ppm equivalent uranium with a geometric mean of 65 ppm (table 8). The distribution of equivalent uranium in magnetic concentrates from the Candle quadrangle appears as a straight-line cumulative frequency curve (fig. 1). This line is located left of the regional curve and the curve for equivalent uranium in magnetic concentrates from the Solomon quadrangle.

The 17 magnetic concentrates with above-background amounts of equivalent uranium come from only nine localities in the Candle quadrangle (figs. 23 and 24). The highest value for equivalent uranium (160 ppm) was measured in sample 2722 from outside the southeastern contact of the Hunter Creek pluton (fig. 21), the next highest value (120 ppm) was determined on sample 2538 from the Granite Mountain pluton (fig. 22). Other radioactive magnetic concentrates derived from streams draining the granitic rocks of the Hunter Creek pluton are: 2640, 70 ppm; 2665, 80 ppm; 2667, 60 ppm; 2668, 50 ppm; 2669, 100 ppm; 2785, 50 ppm; 2799, 40 ppm; and 2808, 80 ppm. A magnetic concentrate (2797) from the area of basalt immediately east of the eastern margin of the Hunter Creek pluton showed 50 ppm equivalent uranium and reflects the presence of the pluton. Other radioactive magnetic concentrates from the Granite Mountain pluton are: 2549, 50 ppm; 2556, 40 ppm; 2560, 40 ppm; 2570, 100 ppm; and 2571, 70 ppm. The most southerly magnetic concentrate (444) from the Candle quadrangle is also slightly radioactive (40 ppm equivalent uranium). This sample seems to be derived solely from andesitic volcanic rocks, but the mere appearance of this radioactivity may indicate the presence there of previously unrecognized granitic rocks.

Most of the radioactive magnetic concentrates from the Candle quadrangle are derived from the marginal parts of the Hunter Creek and Granite Mountain plutons. Owing to the zoned character of these plutons, the rocks along the margins have syenitic composition (Miller, 1970; 1972). The radioactive magnetic concentrates are probably from this syenite.

COPPER, LEAD, ZINC, AND CADMIUM

Copper shows three populations, lead shows two populations, and zinc and cadmium show one population each in the magnetic concentrates from the Candle quadrangle (figs. 2–5). The cumulative frequency distribution curves of copper, lead, and zinc in this quadrangle are similar to the regional distribution curves except in the high-value portions, where the regional curves show a positive skewness, indicating that the magnetic concentrates with the higher metal contents are not from the Candle quadrangle. The geometric means of copper, lead, and cadmium are close to the regional means, but that of zinc is less than the regional mean (table 8).

Of the magnetic concentrates from the Candle quadrangle, 50 are clearly ascribable to sources in the granitic plutons, and 22 are derived from areas of

TABLE 12.—*Values used to plot equivalent uranium and 11 elements in magnetic concentrates from 34 localities in the Candle quadrangle, Alaska*

[Data are in parts per million. Numbers in parentheses below the element symbols are the lower limits of determination. N = not detected; L = detected, but the concentration is below the limit of determination; n.d. = not determined]

File numbers at each locality	eU (30)	Ag (0.2)	Bi (5)	Cd (0.2)	Co (1)	Cu (1)	Ni (1)	Pb (5)	Zn (1)	Au (0.2)	In (0.2)	Tl (0.2)
262	N	L	20	L	55	15	30	55	35	0.7	L	L
276	N	.2	10	.4	50	15	45	55	30	L	L	L
444	40	.4	10	.4	150	50	85	50	630	n.d.	n.d.	n.d.
1060	N	.4	10	.2	70	15	100	20	270	n.d.	n.d.	n.d.
2464, 2468, 2469, 2473	N	.4	15	.2	60	25	90	70	90	L	L	L
2485, 2487	N	.5	15	.4	60	40	65	35	120	n.d.	n.d.	n.d.
2488	N	.6	10	.2	75	35	85	35	150	n.d.	n.d.	n.d.
2489, 2491, 2492, 2494	N	1	15	.4	65	50	175	40	90	L	L	.3
2496, 2502	N	.3	15	.2	65	50	55	20	85	L	L	L
2501	N	.4	10	.4	65	70	85	110	100	n.d.	n.d.	n.d.
2503, 2504	N	.4	10	.4	55	50	50	30	100	n.d.	n.d.	n.d.
2509	N	.6	10	.4	40	15	25	30	65	1.5	L	L
2515, 2517	N	.6	10	.2	55	25	60	50	270	n.d.	n.d.	n.d.
2528, 2538, 2543, 2549, 2567, 2568, 2570, 2571, 2575, 2587	40	.3	10	.3	70	25	100	40	120	L	L	.3
2556, 2557, 2558, 2559, 2560, 2561, 2562, 2564	N	L	10	.4	65	10	100	35	160	.2	L	L
2636, 2637	N	.2	10	.4	30	10	50	30	35	L	L	L
2639, 2640	70	.2	10	.2	50	10	50	30	90	n.d.	n.d.	n.d.
2657, 2661, 2663	N	.2	5	.2	30	10	45	15	45	n.d.	n.d.	n.d.
2665, 2667, 2668, 2669, 2672	60	.3	10	.3	30	10	45	15	45	L	L	.2
2673	N	.4	15	.4	65	15	60	25	85	n.d.	n.d.	n.d.
2678	N	L	5	L	50	L	55	10	140	n.d.	n.d.	n.d.
2690, 2693, 2695, 2696, 2698, 2712	N	.6	10	.3	45	40	55	25	90	n.d.	n.d.	n.d.
2722	160	L	10	.4	20	15	35	40	30	L	L	L
2726, 2727	N	.2	10	.4	65	10	150	15	45	n.d.	n.d.	n.d.
2729, 2730, 2732	N	.2	10	.4	60	10	120	15	70	L	.2	L
2733	N	.4	10	L	55	10	50	15	30	n.d.	n.d.	n.d.
2753	N	L	15	L	70	10	180	20	85	n.d.	n.d.	n.d.
2780	N	L	10	L	30	10	45	30	50	n.d.	n.d.	n.d.
2785	50	.4	5	.4	30	15	50	40	140	n.d.	n.d.	n.d.
2797	50	.2	15	.4	25	5	20	15	75	n.d.	n.d.	n.d.
2799, 2802, 2804, 2805, 2806, 2807, 2808, 2810	N	.2	10	.3	25	5	40	20	45	L	L	L
2811	N	.2	10	.4	55	10	50	25	80	n.d.	n.d.	n.d.
2814	N	.2	10	.4	20	5	35	25	30	n.d.	n.d.	n.d.
2816, 2818, 2820	N	.4	10	L	40	25	40	25	50	n.d.	n.d.	n.d.

andesitic and basaltic rocks (figs. 21, 22, 25, and 26). If the arithmetic means of copper, lead, zinc, and cadmium in all 85 magnetic concentrates are estimated (Miesch, 1963) from the geometric mean and geometric deviation (table 8), it is seen that the estimated mean contents of the four elements are about twice the average abundances reported for these elements in granite (table 15). These high values are in part attributable to the 22 concentrates from andesitic and basaltic provenances that are included in the total. These 22 concentrates have averages of 38 ppm copper, 39 ppm lead, 133 ppm zinc, and 0.3 ppm cadmium.

TABLE 13.—*Variation in chemical composition of multiple magnetic concentrates from five areas represented by single plotted localities in the Candle quadrangle, Alaska*

[Data are in parts per million. Entries shown in table 1 as not detected are here assigned a numerical value equal to one-third the lower limit of determination: eU = N = 10 ppm here. Entries shown in table 1 as detected below the limit of determination are here assigned numerical values equal to one-half the lower limit of determination: Ag = L = 0.1; Bi = L = 2.5; Cd = L = 0.1; Cu = L = 0.5 ppm here]

File number	eU	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
A. Locality at 65°28'45" N.; 161°11'00" W.									
2528	10	0.8	20	0.8	75	60	45	35	55
2538	120	.4	10	.8	70	30	100	55	120
2543	10	.1	10	.1	75	15	100	40	120
2549	50	.1	20	.1	60	20	100	45	100
2567	10	.2	10	.4	65	15	160	60	160
2568	10	.2	10	.1	75	5	100	15	110
2570	100	.2	10	.4	65	0.5	120	35	190
2571	70	.4	2.5	.1	75	0.5	85	60	170
2575	10	.2	5	.1	70	5	85	45	160
2587	10	.2	10	.2	45	90	65	30	80
Arithmetic mean	40.0	.28	10.7	.31	67.5	24.1	96.0	42.0	126.5
Standard deviation	42.7	.21	5.5	.28	9.5	29.2	30.8	14.2	42.8
Relative standard deviation (percent)	107	75	51	92	14	120	32	34	34
B. Locality at 65°26'45" N.; 161°11'15" W.									
2556	40	0.1	10	0.4	65	10	100	25	150
2557	10	.2	.5	.2	65	5	85	30	180
2558	10	.2	10	.4	60	0.5	70	35	130
2559	10	.1	10	.8	75	10	85	35	160
2560	40	.1	10	.2	70	5	100	30	180
2561	10	.2	5	.4	65	10	100	25	160
2562	10	.1	10	.4	65	5	80	40	180
2564	10	.1	5	.4	60	20	180	60	130
Arithmetic mean	17.5	.14	8.1	.4	65.6	8.2	100.0	35.0	158.8
Standard deviation	13.9	.05	2.6	.18	4.9	5.8	34.1	11.3	21.0
Relative standard deviation (percent)	79	36	32	46	7.6	71	34	32	13
C. Locality at 65°44'15" N.; 161°18'00" W.									
2665	80	0.6	5	0.4	30	5	40	15	35
2667	60	.4	10	.1	35	10	50	15	30
2668	50	.2	10	.6	30	5	45	10	75
2669	100	.2	10	.4	30	5	45	15	50
2672	10	.1	5	.1	25	20	45	15	35
Arithmetic mean	60	.3	8.0	.3	30.0	9.0	45.0	14.0	45.0
Standard deviation	33.9	.2	2.7	.2	3.5	6.5	3.5	2.2	18.4
Relative standard deviation (percent)	57	67	34	66	11	72	8	16	41
D. Locality at 65°41'00" N.; 161°23'00" W.									
2690	10	1.5	10	0.2	60	20	65	20	90
2693	10	.6	10	.4	40	35	25	20	100
2695	10	.2	10	.4	35	40	50	20	75
2696	10	.4	10	.4	35	55	570[1]	35	75
2698	10	.4	15	.4	40	65	60	20	140
2712	10	.4	10	.1	50	15	25	35	35
Arithmetic mean	10	.58	10.8	.32	43.3	38.3	55	25	85.8
Standard deviation	0	.47	2.0	.13	9.8	19.4	19.0	7.7	34.6
Relative standard deviation (percent)	0	80	19	42	23	51	35	31	30
E. Locality at 65°44'00" N.; 161°12'30" W.									
2799	40	0.4	5	0.4	30	5	45	30	75
2802	10	.2	10	.6	25	5	30	15	75
2804	10	.2	10	.1	25	5	40	20	45
2805	10	.4	10	.4	30	5	45	15	35
2806	10	.2	5	.1	30	5	50	15	35
2807	10	.1	5	.4	30	5	45	15	35
2808	80	.1	10	.1	25	10	40	30	45
2810	10	.2	10	.4	25	5	40	25	30
Arithmetic mean	22.5	.23	8.1	.31	27.5	5.6	41.9	20.6	46.9
Standard deviation	25.5	.11	2.6	.19	2.7	1.8	5.9	6.8	18.1
Relative standard deviation (percent)	113	52	32	60	9.7	31	14	33	39

[1]Thought to be a reporting error from tramp iron; hence, arithmetic mean, standard deviation, and relative standard deviation calculated without this value.

TABLE 14.—*Relative standard deviations, in percent, for eight elements in five sets of samples from single plotted localities in the Candle quadrangle, Alaska, compared to relative standard deviations for subsamples of file number 3799*

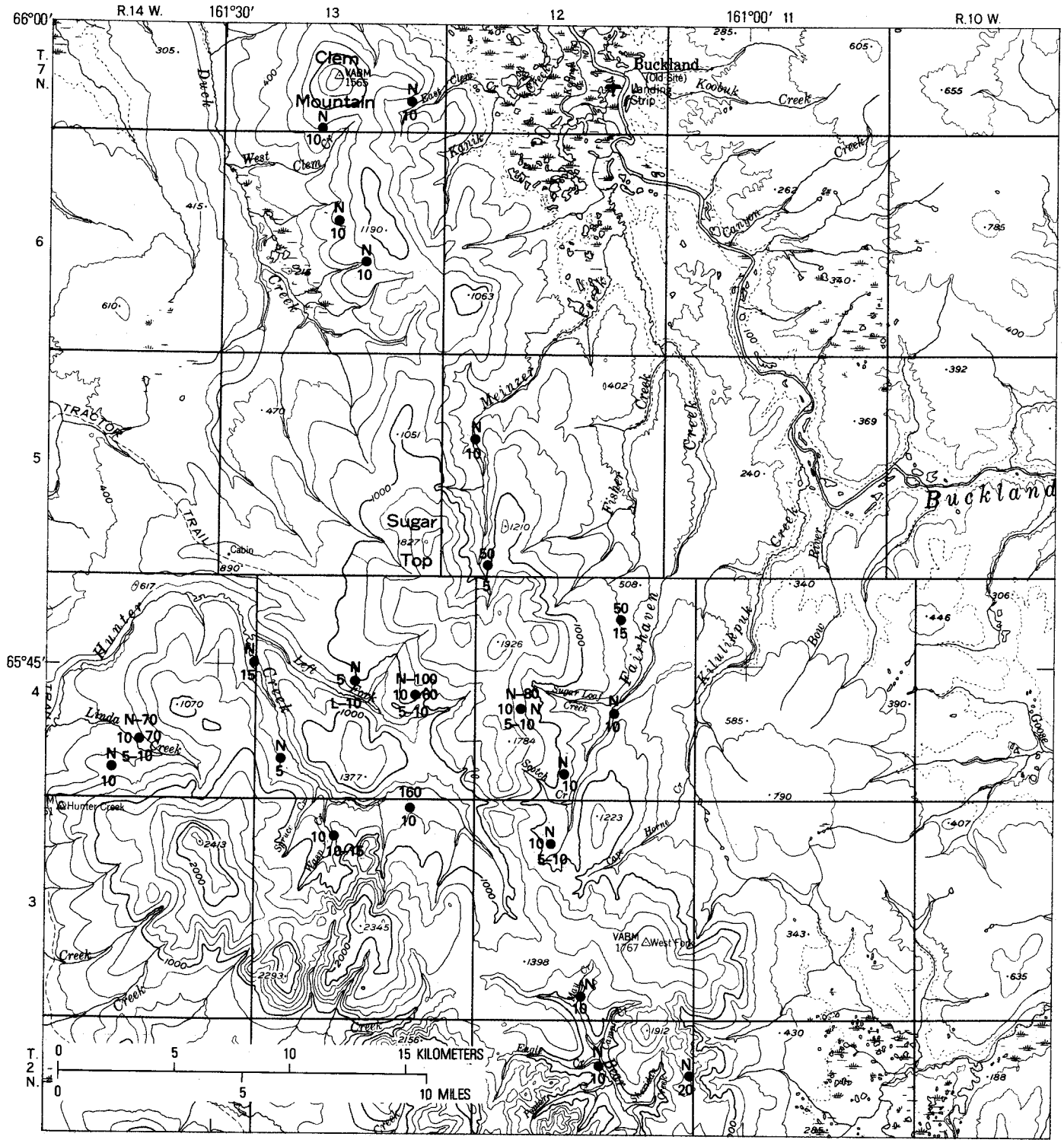
Sample set[1]	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
A	75	51	92	14	120	32	34	34
B	36	32	46	7.6	71	34	32	13
C	67	34	66	11	72	8	16	41
D	80	19	42	23	51	35	31	40
E	52	32	60	9.7	31	14	33	39
Subsamples of 3799[2]	130	37.6	25.0	6.4	20.1	7.8	3.6	7.1

[1]Letters refer to sample sets listed in Table 13.
[2]Data from Table 5.

These are greater than the world averages for lead, zinc, and cadmium in basalt (table 15), but are less than the world average for copper in basalt. In addition, the 50 magnetic concentrates from the granitic rocks in the Candle quadrangle have averages for these elements that are about 50 percent greater than the world average for granitic rocks; they contain 16 ppm copper, 29 ppm lead, 78 ppm zinc, and 0.3 ppm cadmium. Thus, the magnetic concentrates appear to be slight accumulators of these metals on the basis of this general data.

However, in the Darby and Kachauik plutons in the Bendeleben and Solomon quadrangles, which are similar to those in the Candle quadrangle, the geometric mean values for copper (5–13 ppm) and lead (53–72 ppm) in sediments from streams draining the granitic rocks suggest that these plutons are depleted in copper and enriched in lead compared to the average granite (Miller and Grybeck, 1973, table 4). Thus, the magnetic concentrates may accumulate copper, but their high lead content may simply reflect the composition of the source plutons. Equivalent data are lacking for zinc and cadmium. In the area of the Granite Mountain pluton in the Candle quadrangle, copper and lead in stream sediments derived from the granitic rocks are about 70 and 100 ppm, respectively (Elliott and Miller, 1969). If these figures are at all representative of the copper and lead content in the rocks of the Granite Mountain pluton, then the magnetic concentrates are not accumulators of these metals. However, Elliott and Miller (1969) carefully stated that their collections of stream sediments were made in areas of known mineralization with the result that average values from the reported results may be biased upward.

A comparison shows that the 50 magnetic concentrates from streams that drain granitic plutons have a

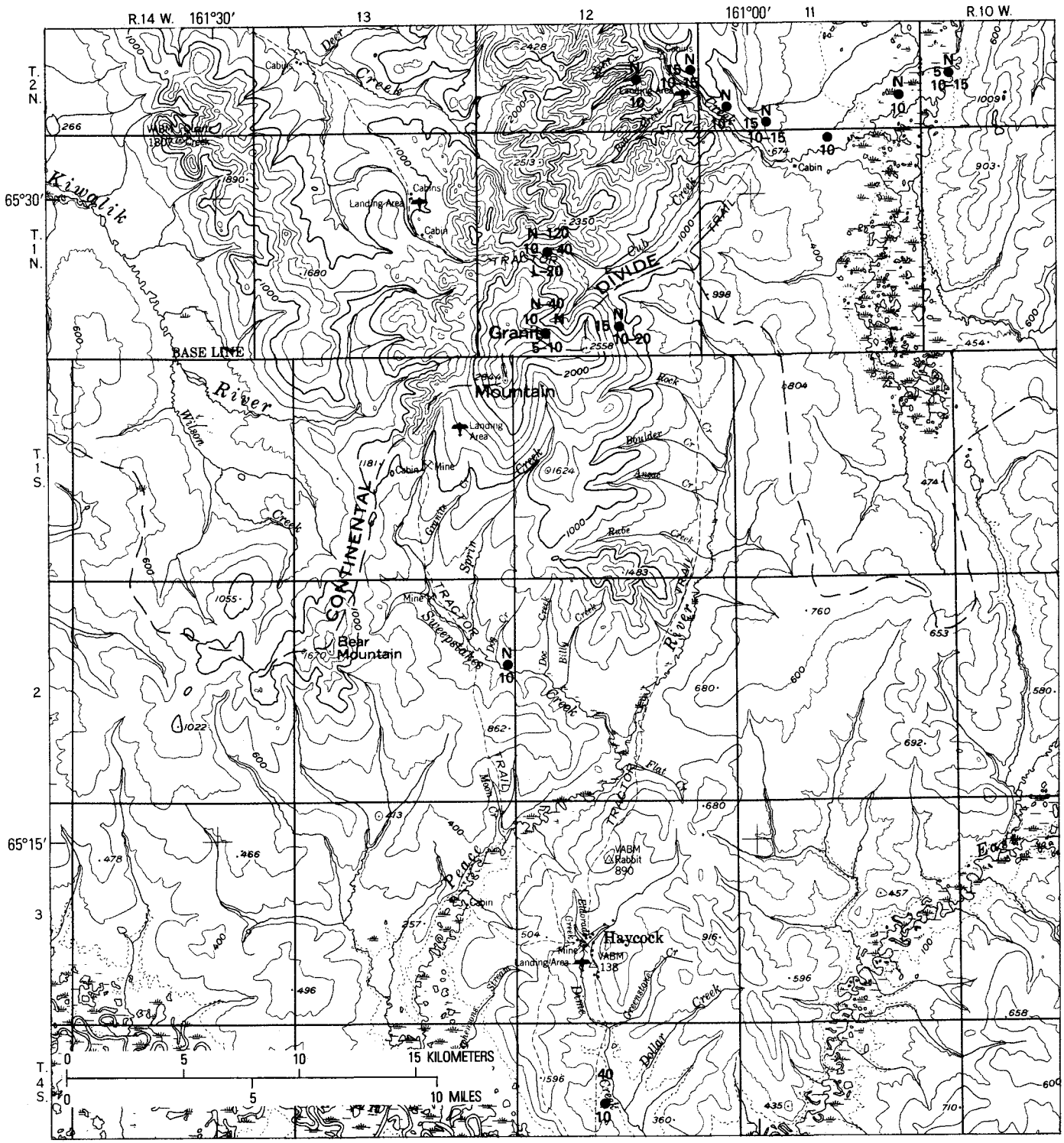


EXPLANATION

N–120
10 ● 40
L–20

Locality of magnetic concentrate showing eU and Bi in parts per million. Top figure is equivalent uranium and bottom figure is bismuth; more than one figure indicates range in values where multiple samples taken from the same locality; right figure is average for equivalent uranium and left figure is average for bismuth, where two or more samples are represented. N=not detected; L=present but below the limit of determination

FIGURE 23.—Map showing equivalent uranium and bismuth in magnetic concentrates from the northwestern part of the Candle quadrangle, Alaska.

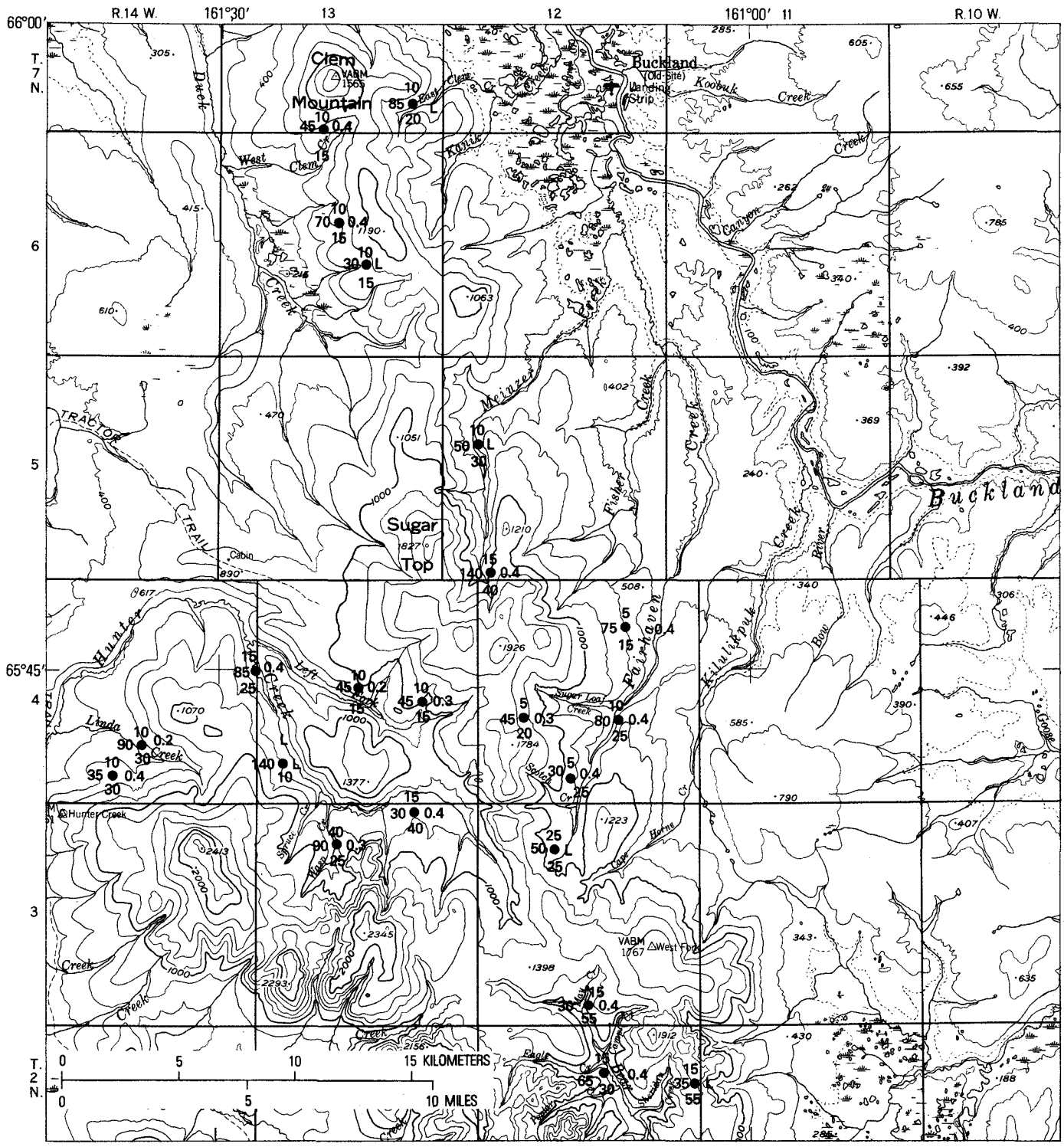


EXPLANATION

N–120
10 ● 40
L–20

Locality of magnetic concentrate showing eU and Bi in parts per million. Top figure is equivalent uranium and bottom figure is bismuth; more than one figure indicates range in values where multiple samples taken from the same locality; right figure is average for equivalent uranium and left figure is average for bismuth, where two or more samples are represented. N=not detected; L=present but below the limit of determination

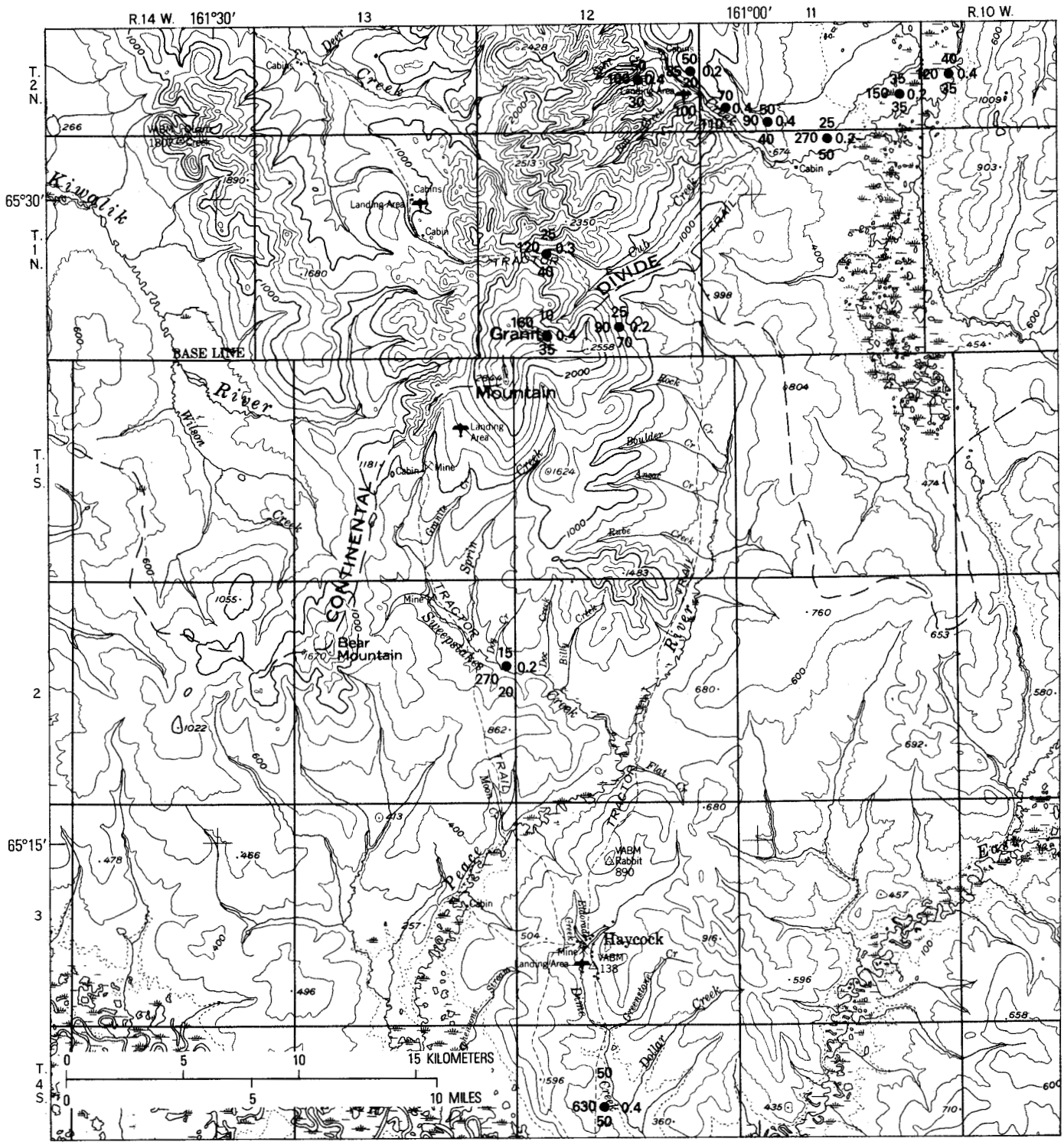
FIGURE 24.—Map showing equivalent uranium and bismuth in magnetic concentrates from the southwestern part of the Candle quadrangle, Alaska.



EXPLANATION

15
80 ● 0.4 Locality of magnetic concentrate showing Cu, Pb, Zn, and Cd in parts per million. Top figure is copper; bottom is lead; left is zinc; right is cadmium; average values used at sites having multiple samples; L=present but below the limit of determination
25

FIGURE 25.—Map showing copper, lead, zinc, and cadmium in magnetic concentrates from the northwestern part of the Candle quadrangle, Alaska.



EXPLANATION

15
80 ● 0.3
25

Locality of magnetic concentrate showing Cu, Pb, Zn, and Cd in parts per million. Top figure is copper; bottom is lead; left is zinc; right is cadmium; average values used at sites having multiple samples; L=present but below the limit of determination

FIGURE 26.—Map showing copper, lead, zinc, and cadmium in magnetic concentrates from the southwestern part of the Candle quadrangle, Alaska.

TABLE 15.—*Average abundances of copper, lead, zinc, and cadmium in the crustal materials of the Earth compared with their abundances in magnetic concentrates from the Candle quadrangle, Alaska*

[Data are in parts per million]

Element	Average abundance (as shown in Krauskopf, 1967)			Abundance in Candle quadrangle magnetic concentrates	
	Crust	Granite	Basalt	Geometric mean	Estimated arithmetic mean
Copper	55	10	100	15	23
Lead	12.5	20	5	27	32
Zinc	70	40	100	79	95
Cadmium	0.2	0.2	0.2	0.38	0.46

lower percentage of anomalous values than the 22 concentrates from provenances of andesite and basalt:

Element	Percent of anomalous values in concentrates	
	Granitic provenance	Andesitic and basaltic provenance
Copper	20	68
Lead	8	4
Zinc	18	27
Cadmium	0	0

The presence of two principal sources for the magnetic concentrates provides a possible explanation for the multiple population values (figs. 2–3) for copper (three populations) and lead (two populations). Concentrates from the granitic provenance yield lower mean values for copper, lead, and zinc than the concentrates from andesitic and basaltic provenances. However, the kind of bedrock does not appear to be a factor in the single populations found for zinc and cadmium (figs. 4–5).

The magnetic concentrates containing the largest amounts of copper, lead, and zinc in the Candle quadrangle are from the Bear Creek area and the Granite Mountain pluton. High values for copper are particularly common along Bear Creek, where normal samples of stream sediments are reported to be anomalously rich in lead, zinc, and copper, and where galena, sphalerite, and pyrite have been found in andesite (Miller and Elliott, 1969, p. 14). Only one anomalous value for lead and one for zinc are noted among the nine magnetic concentrates that had anomalous copper content from Bear Creek (table 1). Greatly anomalous amounts of lead and zinc are seen in the magnetic concentrates from the north-central part of the Granite Mountain pluton (table 1 and fig. 26).

The area along Bear Creek that yielded the copper-rich samples is known to have sulfide-bearing quartz-calcite veins and disseminated galena, sphalerite, and pyrite in andesite (Herreid, 1965; Berg and Cobb, 1967, p. 114); and it has been a source for placer gold (Miller and Elliott, 1969, p. 14).

Lesser anomalies for copper and zinc were found among the magnetic concentrates from the southern part of the Hunter Creek pluton (fig. 25), but concentrates from the northern part of the pluton are lean in base metals.

In the andesites south of the Granite Mountain pluton two magnetic concentrates with anomalous zinc content are shown on figure 26. One concentrate (1060), which lacks anomalous copper and lead content, is from Sweepstakes Creek. The other (444), from Dime Creek, has highly anomalous amounts of zinc and copper, and high background amounts of lead (table 1). Gold placers are reported upstream from both the Sweepstakes Creek and Dime Creek localities (Cobb, 1972u).

Thus, further exploration for base metals could be productive in the Bear Creek area, the northern part of the Granite Mountain pluton, the southern part of the Hunter Creek pluton, and the area around Sweepstakes Creek and Dime Creek.

The areal distribution of cadmium-bearing magnetic concentrates in the Candle quadrangle is irregular (figs. 25 and 26), and none of the concentrates is anomalous in cadmium (table 1). Most, but not all, of the samples with high values for cadmium are anomalously rich in zinc. Possibly the cadmium is present in inclusions of sphalerite in the magnetite, or in accessory sphalerite in the concentrate.

SILVER AND GOLD

All 85 magnetic concentrates from the Candle quadrangle were analyzed for silver, but only 25 were analyzed for gold (table 1). The distribution of silver shows one population in the Candle quadrangle (fig. 6). The geometric means of silver and gold are lower for the quadrangle than for the region, and the geometric deviations for these elements in the quadrangle are much lower than those for the region (table 8). Using 1 ppm as the anomalous value for silver and for gold (table 9), only two concentrates are anomalous for silver and and one for gold (table 1; figs. 27 and 28).

The concentrates with anomalous silver content are from Bear Creek (2492) and the southwestern part of the Hunter Creek pluton (2690). These are the same areas that yielded concentrates containing anomalous amounts of base metals (figs. 25 and 26).

Gold is detected in only four of the 25 magnetic concentrates analyzed and gold content is anomalous in only one, sample 2509 from the confluence of Eagle Creek with Bear Creek (fig. 27). Several gold placers

are situated downstream from the site of 2509 (Cobb, 1972u).

BISMUTH

Bismuth has a nearly normal distribution in magnetic concentrates from the Candle quadrangle; its mean value is 10 ppm (table 8). The cumulative frequency curve for bismuth in magnetic concentrates from the quadrangle coincides with the regional curve (fig. 8) except in the high-value and low-value branches, showing that the magnetic concentrates from the Candle area are neither extremely rich nor extremely lean in bismuth compared to the region as a whole.

The threshold anomalous value for bismuth was taken as 15 ppm (table 9). Low anomalous values of 15–20 ppm bismuth are found in magnetic concentrates from drainage basins underlain by both granitic rocks and volcanic rocks (figs. 23 and 24). In general, samples from the northern part of the Granite Mountain pluton (2464, 2468, 2469, 2528, and 2549) tend to be slightly richer in bismuth than samples from the Hunter Creek pluton (2673, 2698, 2753, and 2797) or from the andesite and basalt (262, 2487, 2491, 2492, 2494, and 2502). The Granite Mountain pluton and the volcanic rocks around Bear Creek are thus weakly mineralized with bismuth as well as the base metals.

COBALT AND NICKEL

Cobalt in magnetic concentrates from the Candle quadrangle shows two populations and negative skewness (figs. 9, 19). Nickel has only one population and an indistinct positive skewness (figs. 10, 20). The geometric means of both elements (table 8) in samples from the Candle quadrangle are higher than those for the region as a whole or for the Solomon quadrangle; however, neither element in the samples from the Candle quadrangle reaches the extreme anomalous values found for some magnetic concentrates from elsewhere in Alaska (table 1). Threshold anomalous values of 90 ppm cobalt and 170 ppm nickel were set for magnetic concentrates from the Candle quadrangle (table 9).

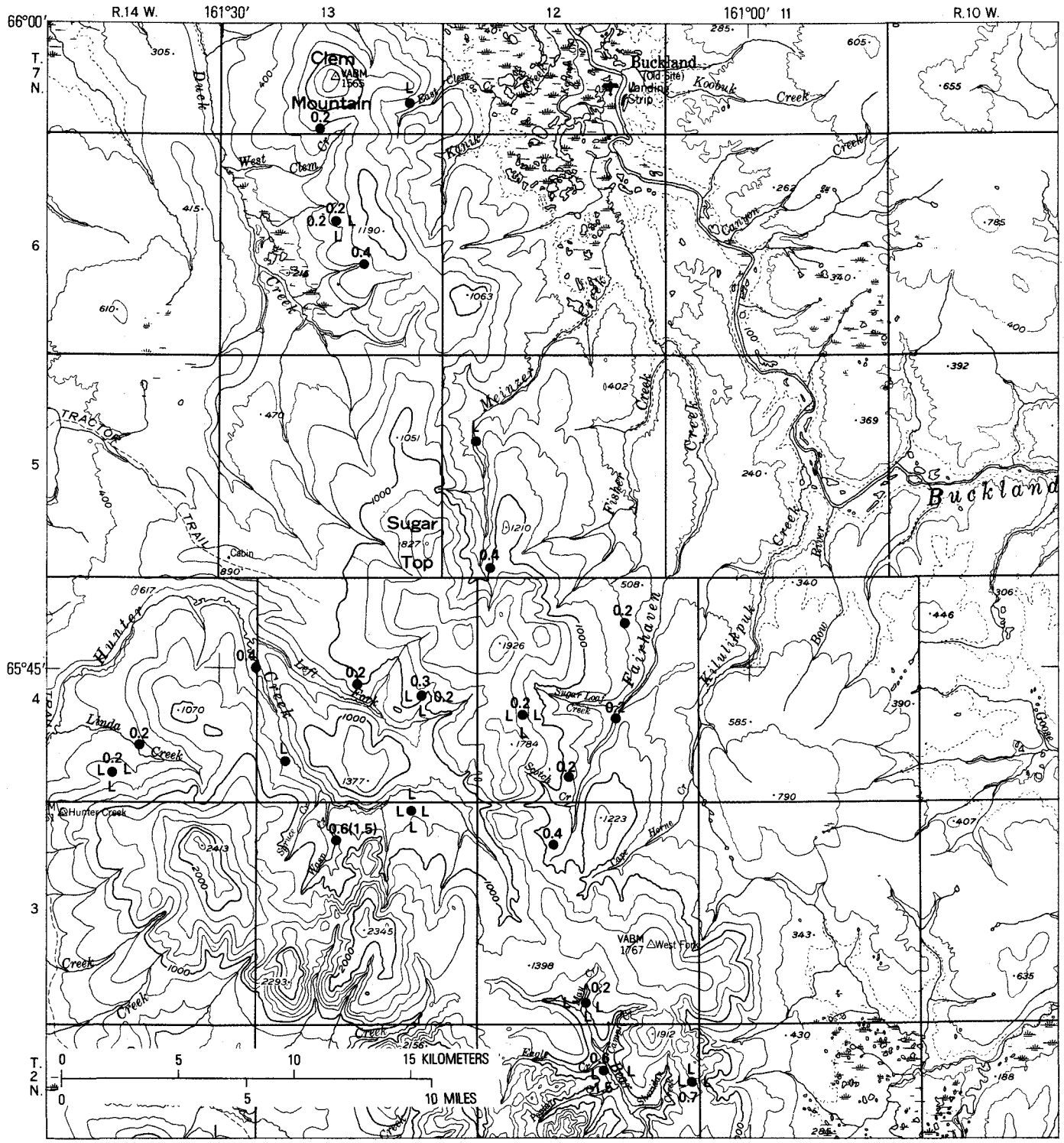
The Co/Ni ratio, derived from the geometric means (table 8), is 0.73, somewhat lower than the regional ratio of 0.88 and notably less than the ratio of 1.55 for magnetic concentrates from the Solomon quadrangle. The decreased ratio in the Candle quadrangle results from the high mean value of nickel. As noted above in the regional results section, this high nickel content suggests sources in mafic rather than silicic rocks. However, the distribution shown in figures 29 and 30 seems to conflict with this interpretation.

Three categories of rock units are shown in table 16, representing the major sources for the magnetic concentrates, and the Co/Ni ratios for the concentrates are listed by provenance. The arithmetic mean values for the Co/Ni ratios in magnetic concentrates from basaltic and andesitic source areas, 0.95 and 1.05, respectively, both resemble the ratio of 1.1 reported for magnetite from mafic magmatic rocks in northern Sweden (Frietsch, 1970, p. 95). The Co/Ni ratio for magnetic concentrates from granitic source areas in the Candle quadrangle is only 0.66. From the general considerations previously given, that the concentration of cobalt varies less with magmatic differentiation than the concentration of nickel, and that nickel tends to be depleted in silicic rocks, it would seem reasonable to expect a larger Co/Ni ratio in magnetic concentrates derived from granite than in those derived from basalt, even if they are not part of the same differentiation sequence. However, the data belie the assumption.

The two populations recognized for cobalt (fig. 9) apparently reflect the high mean values in the magnetic concentrates from basaltic and andesitic provenances and the low mean value for samples from granitic sources (table 16). The narrow differences found for the mean values of nickel from these three sources accounts for the single population recognized in figure 10. The negative skewness in the cumulative frequency of cobalt and the slight positive skewness in the cumulative frequency of nickel in figures 9 and 10 reflect the low values for cobalt and high values for nickel in table 16.

The areas where high values are found for cobalt and nickel in these magnetic concentrates are roughly coincident, reflecting the common association of the two elements in nature. However, the highest values for the individual elements are not in the same sample. In fact, the sample (444) that has the richest cobalt content (150 ppm) contains only 85 ppm nickel, which is just half the threshold value for nickel (table 9). The sample comes from Dime Creek, which drains an area underlain by andesite. Furthermore, the highest acceptable value for nickel (440 ppm) is in a sample (2491) that contains only 50 ppm cobalt. This sample comes from a provenance of basalt and andesite. Sample 2696 showed greater nickel content (570 ppm), but this value probably reflects the presence of tramp iron.

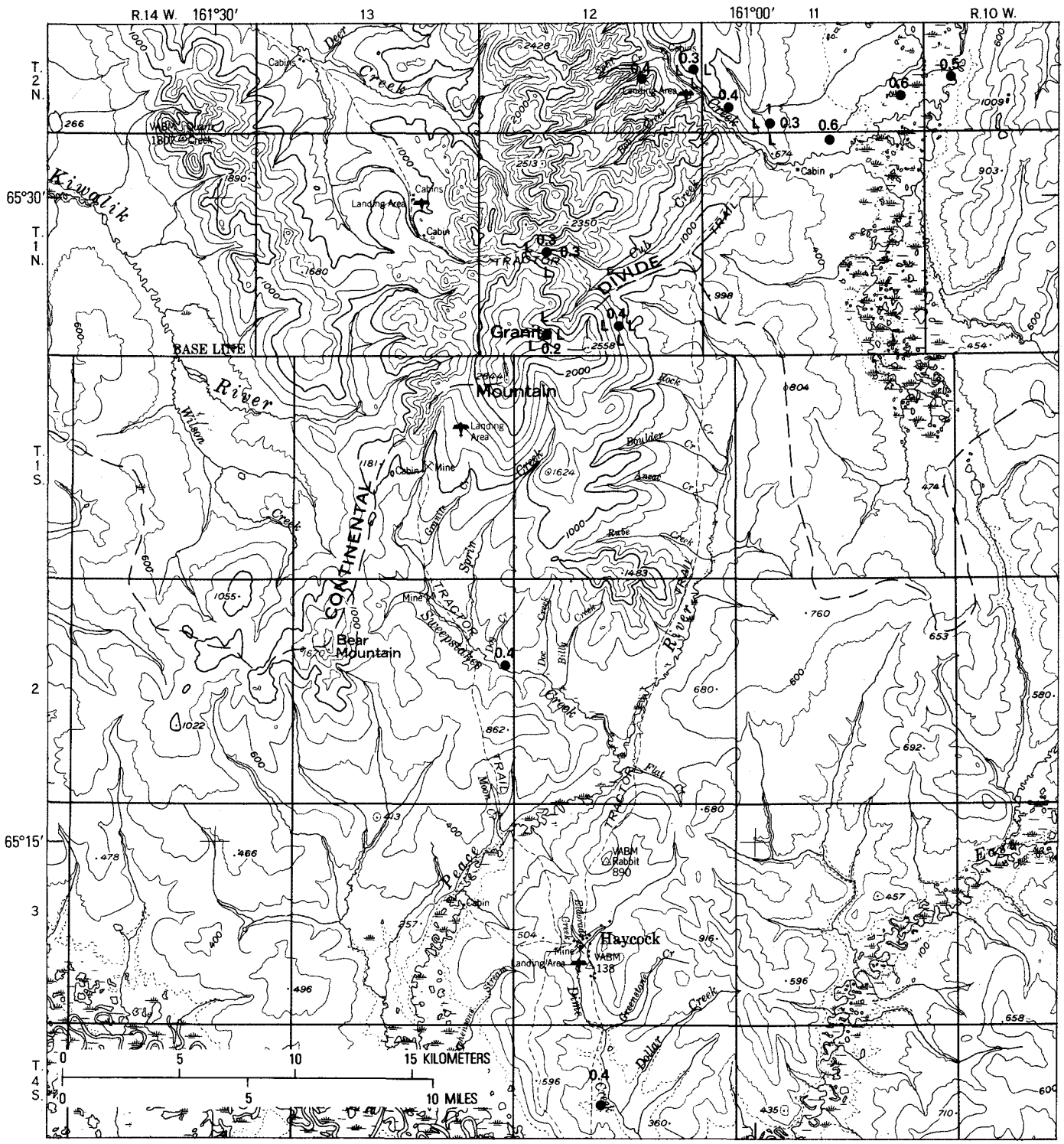
The sample (444) from Dime Creek is the only one that has anomalous cobalt content (table 1 and figs. 29–30), but values between background (55 ppm) and threshold (90 ppm) are numerous, as would be expected from the means. Anomalous nickel content is present in three other magnetic concentrates: 2564, 2727, and 2753 (table 1). All are from areas underlain by granitic rocks: 2564 is from the central part of the Granite Mountain pluton, and the others are from the northern extension of the Hunter Creek pluton.



EXPLANATION

0.6(1.5) / 0.2 ● 0.3 / L — Locality of magnetic concentrate showing Ag, Au, In, and Tl in parts per million. Top figure is silver, averaged where multiple samples were analyzed and showing in parentheses a single anomalous value among a multiple of analyses; bottom figure is gold; left figure is indium; right figure is thallium; lack of figure or letter indicates not determined; L = present but below the limit of determination

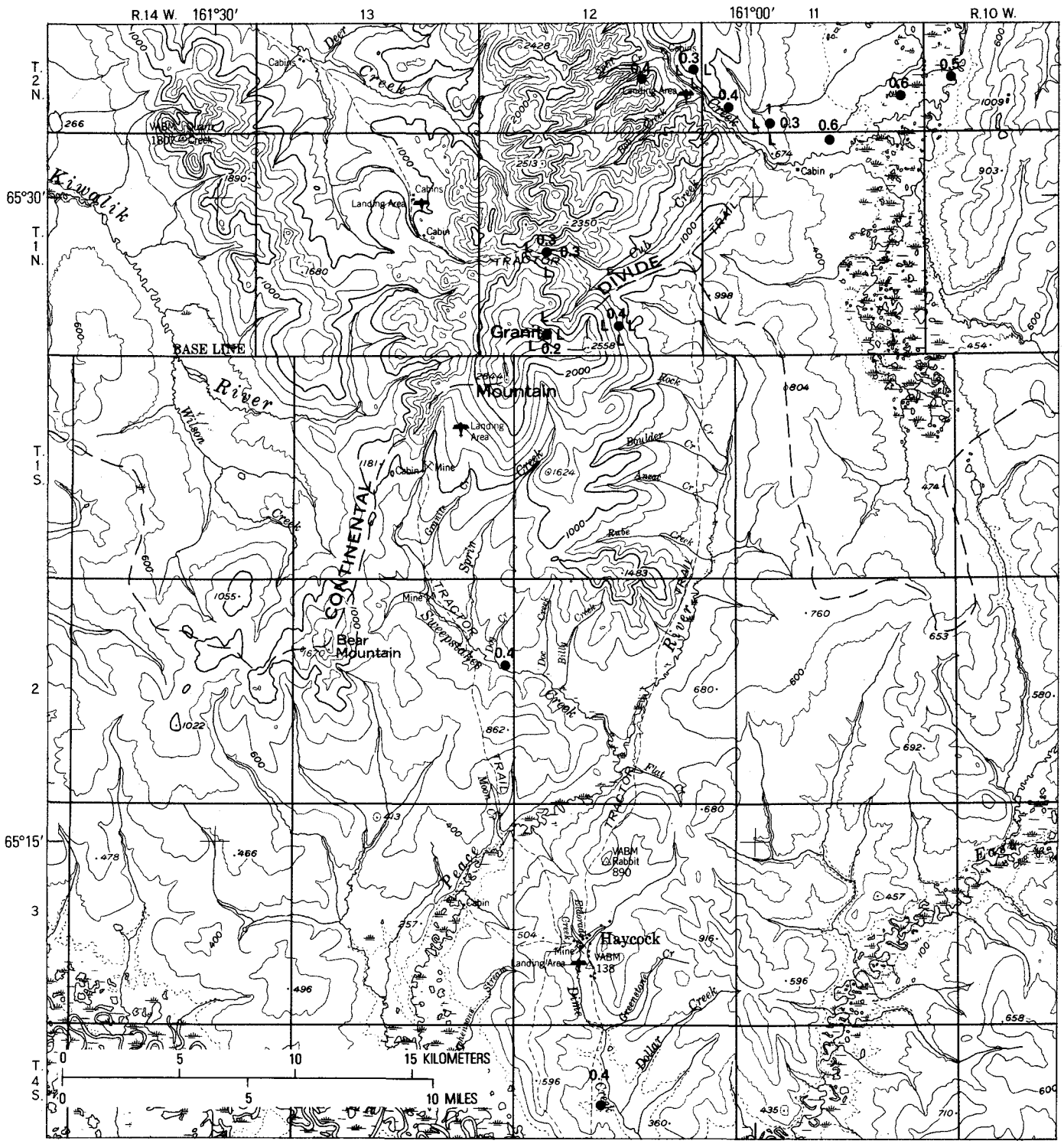
FIGURE 27.—Map showing silver, gold, indium, and thallium in magnetic concentrates from the northwestern part of the Candle quadrangle, Alaska.



EXPLANATION

0.6(1.5) / 0.2 ● 0.3 / L — Locality of magnetic concentrate showing Ag, Au, In, and Tl in parts per million. Top figure is silver, averaged where multiple samples were analyzed and showing in parentheses a single anomalous value among a multiple of analyses; bottom figure is gold; left figure is indium; right figure is thallium; lack of figure or letter indicates not determined; L=present but below the limit of determination

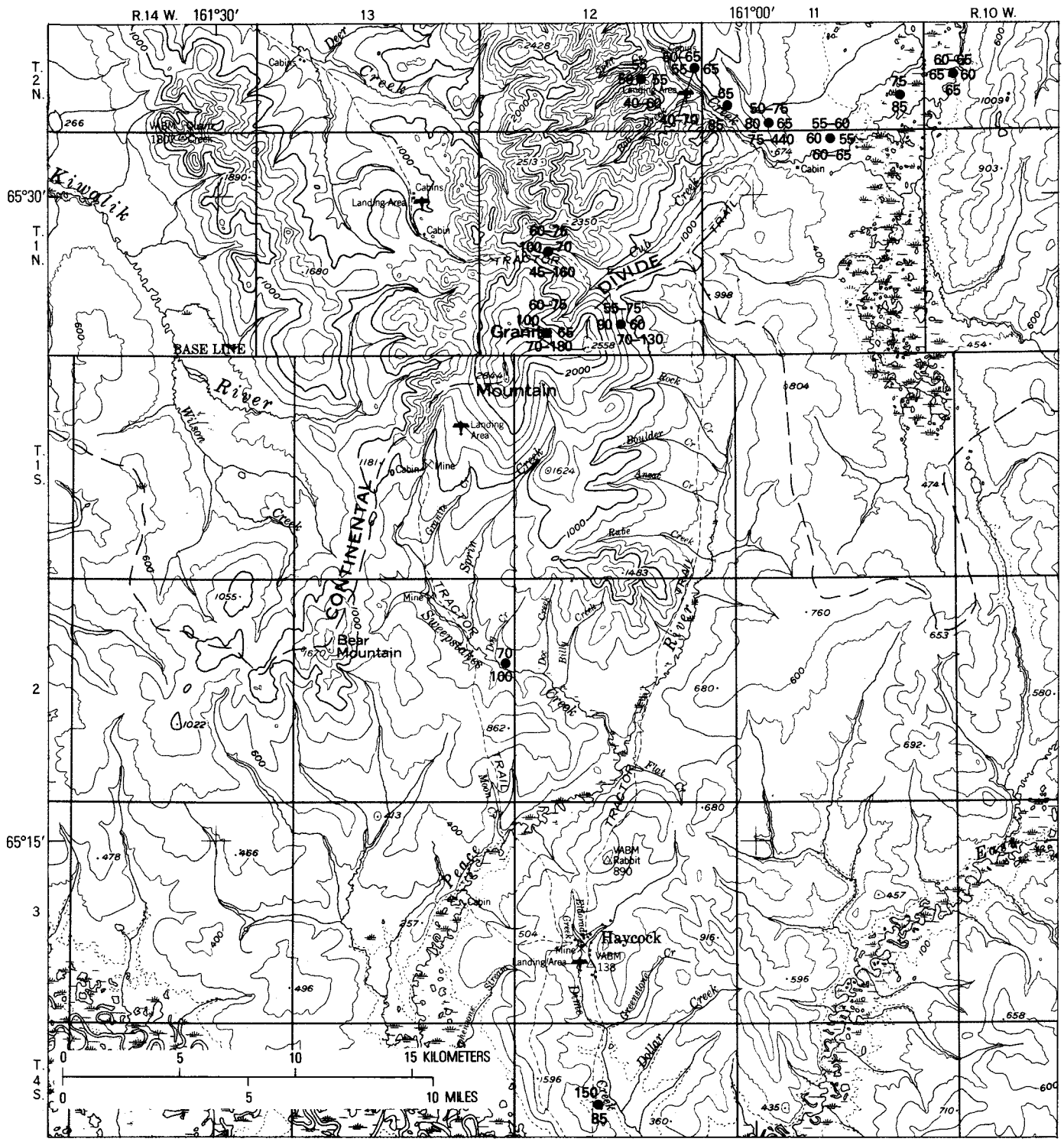
FIGURE 28.—Map showing silver, gold, indium, and thallium in magnetic concentrates from the southwestern part of the Candle quadrangle, Alaska.



EXPLANATION

0.6(1.5) / 0.2 ● 0.3 / L — Locality of magnetic concentrate showing Ag, Au, In, and Tl in parts per million. Top figure is silver, averaged where multiple samples were analyzed and showing in parentheses a single anomalous value among a multiple of analyses; bottom figure is gold; left figure is indium; right figure is thallium; lack of figure or letter indicates not determined; L=present but below the limit of determination

FIGURE 28.—Map showing silver, gold, indium, and thallium in magnetic concentrates from the southwestern part of the Candle quadrangle, Alaska.

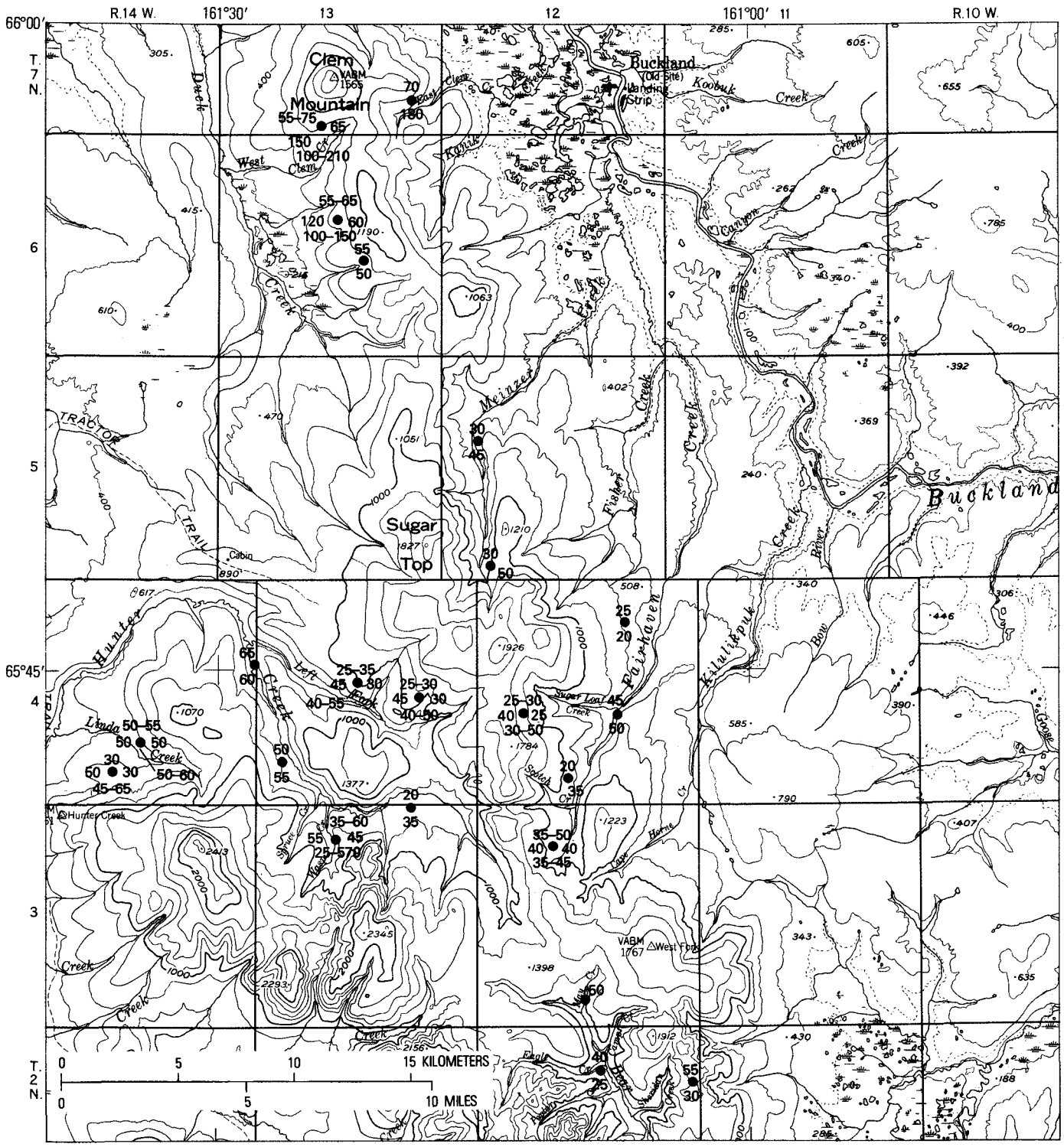


EXPLANATION

60–65
65 ● 60
65

Locality of magnetic concentrate showing Co and Ni in parts per million. Top figure is cobalt and bottom figure is nickel; more than one figure indicates range in values where multiple samples taken from the same locality; right figure is average for cobalt and left figure is average for nickel, where two or more samples are represented

FIGURE 30.—Map showing cobalt and nickel in magnetic concentrates from the southwestern part of the Candle quadrangle, Alaska.



EXPLANATION

55–75
150 ● 65
100–210

Locality of magnetic concentrate showing Co and Ni in parts per million. Top figure is cobalt and bottom figure is nickel; more than one figure indicates range in values where multiple samples taken from the same locality; right figure is average for cobalt and left figure is average for nickel, where two or more samples are represented

FIGURE 29.—Map showing cobalt and nickel in magnetic concentrates from the northwestern part of the Candle quadrangle, Alaska.

that are intruded by dikes and plugs of Permian(?) diabase and serpentinite.

Relatively few prospects or mineral occurrences have been reported from the area of figures 31 and 32. Streams draining the northeastern flank of the Darby Mountains in the area of figure 31 have been found to contain rare-earth-bearing and radioactive minerals, as well as columbium, tin, tungsten, and copper minerals (West, 1953, p. 6-7; Cobb, 1972v). Also in the area of figure 32, a copper prospect was reported to the north of the Portage Roadhouse (Smith and Eakin, 1911, p. 134-135; Cobb, 1972v), and placer occurrences of radioactive minerals and rare-earth- and tungsten-bearing minerals were noted in short streams reaching the beach along the east side of Golovnin Bay (West, 1953, p. 4-5; Cobb, 1972v).

The results of geochemical exploration of the eastern part of the Solomon quadrangle have been discussed by Miller and Grybeck (1973) as part of a survey covering 3600 km² in the Solomon and Bendeleben quadrangles. In this work, 422 stream-sediment samples were taken. The <80-mesh fraction was analyzed spectrographically for 30 elements, and gold was determined by atomic absorption. These authors found that the samples yielded a wide range in background values for most elements, depending on the kind of bedrock underlying the respective streams. For example, the geometric mean of copper ranged from 5 ppm in streams draining the Darby pluton to 55 ppm in streams draining the Devonian limestone and dolomite (Miller and Grybeck, 1973, p. 3). Other elements displayed similar source-related ranges in mean abundances; therefore, the need to consider the bedrock of the source areas was stresssed for interpreting the results of the geochemical survey. The discussions of minor elements in magnetic concentrates, below, point out certain areas from which Miller and Grybeck obtained samples with anomalous compositions.

Figures 31 and 32 show only 41 localities for the 101 magnetic concentrates from the Solomon quadrangle. Many individual localities overlap at the scale of these figures, because in some areas a closely spaced net of samples was used, and elsewhere, over many years, some localities were revisited and sampled by several geologists from the U.S. Geological Survey, each of whom collected one or more concentrates at the site. Discrimination between the closely adjacent samples shown at one locality on figures 31 and 32 can be made from the information in table 1.

Six of the localities shown in figures 31 and 32 each provided 5 to 8 magnetic concentrates (table 17). The relative standard deviations (table 18) for the results of the analyses of samples from these localities can be compared with the similar measure from the replicate sample used for the whole data set (table 5) to estimate the variation caused by sampling at different sites in the same general area (table 19).

Only silver shows less average variation in the six localities from the Solomon quadrangle than in the replicate analyses. Bismuth is about the same. Variations for the other elements tend to be many times greater than the variations found in the analyses of the replicate sample. Thus, the local influence of source rocks on the minor elements in the magnetic concentrates from the Solomon quadrangle appears to be quite large. Therefore, knowledge of the source rocks is greatly important in the determination of anomalous values for the minor elements in the magnetic concentrates from the Solomon quadrangle. Threshold values for given elements will vary in relation to the predominant source rock. Most of the magnetic concentrates are derived from the zoned plutons, but there are not sufficient chemical or mineralogical data on source rocks available to permit the setting of specific anomalous values. Threshold values for the Solomon quadrangle have been selected to fit the data for that quadrangle only rather than for the whole Alaska region (table 9). Thus, the threshold for equivalent uranium in magnetic concentrates from this quadrangle, 220 ppm, is about twice as great as the thresholds set for the Candle quadrangle or for the whole region. On the other hand, the threshold values for cobalt (40 ppm), copper, (15 ppm), nickel (20 ppm), lead (50 ppm), and zinc (80 ppm) are considerably lower than the values used for the Candle quadrangle or for the region as a whole. Threshold values for silver (1 ppm), cadmium (1 ppm), and gold (1 ppm) are the same throughout, and the threshold for bismuth is set slightly higher at 15 ppm (table 9).

EQUIVALENT URANIUM

The cumulative frequency distribution curve for equivalent uranium in magnetic concentrates from the Solomon quadrangle (fig. 1) represents a single population and lies well to the right of the curve for the Candle quadrangle. For a given cumulative percentage of samples, the equivalent uranium (radioactive intensity) of the magnetic concentrates from the Solomon quadrangle is much higher than that of the samples from the Candle quadrangle. For example, 10 percent of the magnetic concentrates from the Solomon quadrangle have equivalent uranium equal to or higher than 280 ppm, whereas the top 10 percent of the samples from the Candle quadrangle have only 58 ppm or more of equivalent uranium. Large differences exist between the geometric means for equivalent uranium (table 8) in the samples from the Solomon quadrangle

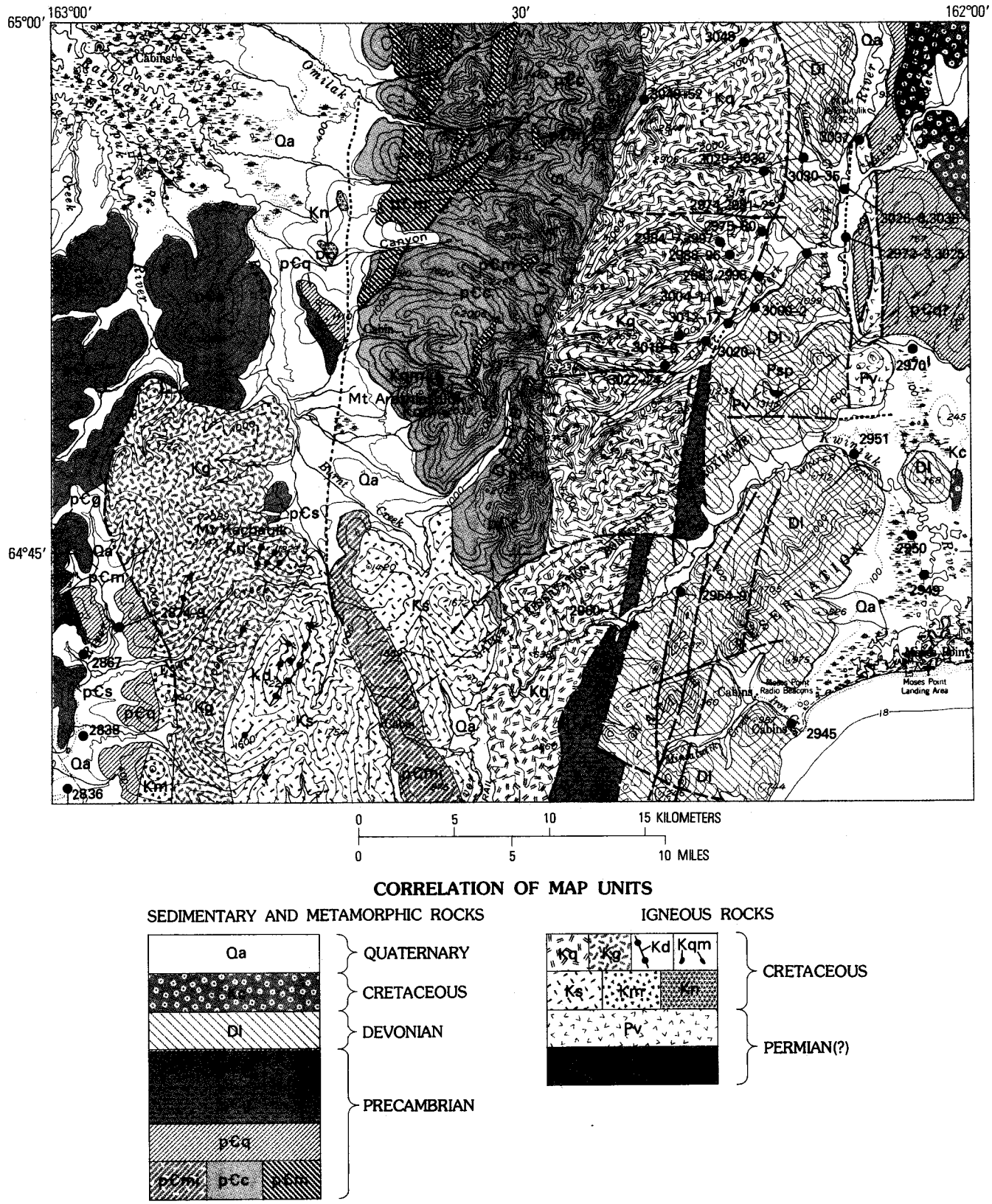


FIGURE 31.—Geologic map showing the distribution of analyzed magnetic concentrates from the northeastern part of the Solomon quadrangle, Alaska.

EXPLANATION

Geology and explanation generalized from Miller and others, 1972

SEDIMENTARY AND METAMORPHIC ROCKS

Qa ALLUVIUM (QUATERNARY)—Silt, sand, and gravel in floodplains and tidal flats, and in colluvial, morainal, and outwash deposits

Kc CONGLOMERATE (CRETACEOUS)—Poorly sorted, thick-bedded, cobble and boulder conglomerate; clasts chiefly limestone with subordinate greenstone (Pv) and schist

Dl LIMESTONE AND DOLOMITE (DEVONIAN)—Chiefly white, massive limestone interbedded with gray to black thin-bedded dolomite

pCs SCHISTOSE MARBLE (PRECAMBRIAN)—Thin-bedded, schistose marble with minor graphitic, chloritic, and calcic schists

pCg GRAPHITIC SCHIST AND METASILTSTONE (PRECAMBRIAN)—Chiefly gray-black, quartz-muscovite-graphite schist with minor schistose marble

pCq QUARTZ-MICA SCHIST (PRECAMBRIAN)—Chiefly quartz-mica schist with lesser amounts of greenschist, graphitic schist, and marble

pCmi MIGMATITIC ZONE (PRECAMBRIAN)—Lithologically similar to metamorphic complex (pCc) but with granitic dikes, stocks, and bosses of probable Cretaceous age too abundant and intimately associated with metamorphic rocks to map separately

pCc METAMORPHIC COMPLEX (PRECAMBRIAN)—Chiefly high-grade pelitic schist and gneiss with intercalated marble, calc-silicate gneiss, and minor amphibolite

pCm MARBLE (PRECAMBRIAN)—Chiefly white crystalline marble made up of calcite which may contain one or more of: diopside, forsterite, and phlogopite

IGNEOUS ROCKS

Kq QUARTZ MONZONITE OF DARBY PLUTON (CRETACEOUS)—Light-colored, massive, coarse-grained quartz monzonite

Kg GRANODIORITE OF KACHAUIK PLUTON (CRETACEOUS)—Light-colored, massive to porphyritic, medium-grained granodiorite and quartz monzonite

Kd ALKALINE DIKES (CRETACEOUS)—Pulaskite and other alkaline dikes intruded into Kachauik pluton

Kqm QUARTZ MONZONITE (CRETACEOUS)—Light-colored, fine-grained quartz monzonite; intrusive into metamorphic complex (pCc) and migmatitic zone(pCmi)

Ks MONZONITE AND SYENITE OF KACHAUIK PLUTON (CRETACEOUS)—Light- to medium-dark-colored, porphyritic and trachytoid, coarse-grained monzonite and syenite

Km GNEISSIC MONZONITE OF KACHAUIK PLUTON (CRETACEOUS)—Light- to medium-dark-colored, gneissic to trachytoid monzonite

Kn NEPHELINE SYENITE OF DRY CANYON PLUTON (CRETACEOUS)—Light-colored, porphyritic to trachytoid, medium-grained nepheline syenite (foyaite)

Pv MAFIC VOLCANIC ROCKS (PERMIAN?)—Sheared and altered mafic volcanic and hypabyssal intrusive rocks

Psp SERPENTINITE (PERMIAN?)—Serpentinite associated with sheared diabase

——— Contact—Dashed where approximately located, inferred, or indefinite

——— Fault—Dashed where approximately located, inferred, or indefinite; dotted where concealed

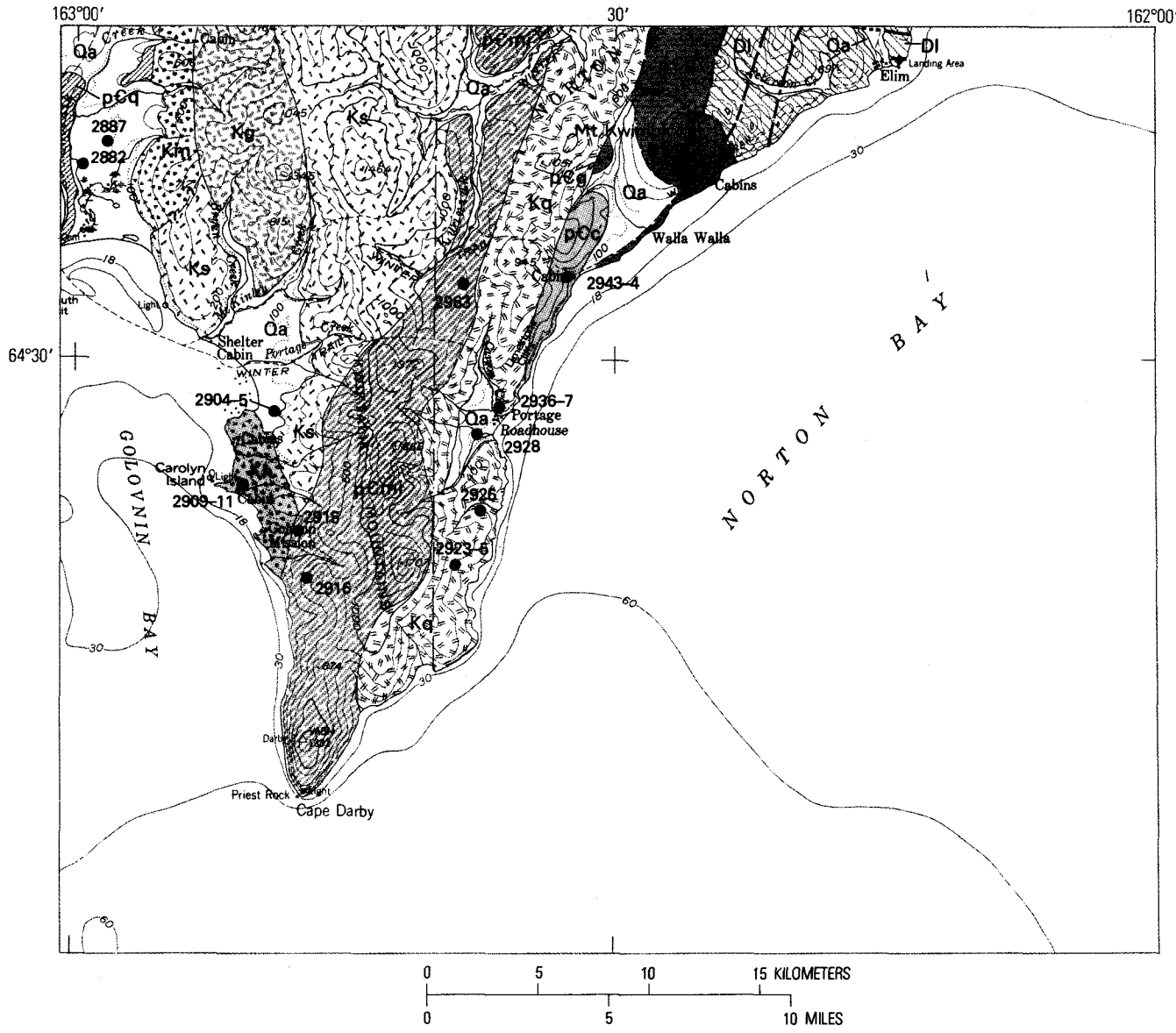
●2488 Locality of magnetic concentrate—Shows Alaskan placer concentrate file number. Where two or more concentrates are from the same locality, the range in file numbers is given

(124 ppm) and the Candle quadrangle (65 ppm). For these reasons the local threshold anomalous value of 220 ppm was assigned to equivalent uranium in the Solomon quadrangle (table 9).

The distribution of equivalent uranium in magnetic concentrates from the northeastern part of the Solomon quadrangle is shown in figure 33 and that for the east-central part of the quadrangle is given in figure 34. The magnetic concentrates richest in equivalent uranium, all regarded as anomalous, are from Clear Creek and its western tributaries that drain the east side of the Darby pluton (figs. 31 and 33). The samples from the west side of the pluton are rich in equivalent uranium but not anomalously rich. Thus, the alkalic quartz monzonite of the Darby Mountains is the source of the radioactive magnetic concentrates. Seemingly the core of the Darby pluton yields more highly radioactive magnetic concentrates than the eastern flank, because the concentrates from the most westerly tributaries to Clear Creek are the most radioactive, and the radioactivity generally increases westward. Concentrates from the limestone and dolomite east of the Darby pluton are weakly radioactive or lack detectable radioactivity; a condition found also in the magnetic concentrates from the schists on the west side of the Kachauik pluton (figs. 33–34). The hybrid diorite, the monzonite and syenite, and the migmatitic complex at the southern end of Kachauik pluton, and the gneissic monzonite on the southwestern side of this pluton, likewise are the sources of magnetic concentrates with undetectable radioactivity (fig. 34). The quartz monzonite at the southern end of the Darby pluton yielded weakly radioactive magnetic concentrates (fig. 34).

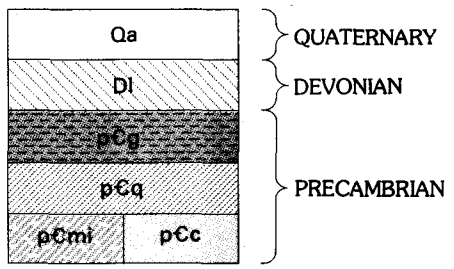
The Darby pluton was found by Miller and Grybeck (1973, p. 6) to be the source of <80-mesh fractions of stream sediments that have high background values for both uranium and thorium, the values for uranium being only about 20 percent of those for thorium.

Samples from two localities on the Kwiniuk River (fig. 33) clearly demonstrate that the radioactive magnetic concentrates are diluted by influx of non-



CORRELATION OF MAP UNITS

SEDIMENTARY AND METAMORPHIC ROCKS



IGNEOUS ROCKS

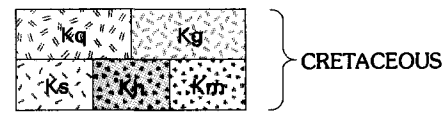


FIGURE 32.—Geologic map showing the distribution of analyzed magnetic concentrates from the east-central part of the Solomon quadrangle, Alaska.

radioactive magnetic concentrates. At the locality represented by samples 2960 and 2961, which are derived dominantly from quartz monzonite, the values for equivalent uranium are 60 ppm and 200 ppm—averaging 130 ppm. About 5 km downstream and farther from the quartz monzonite, at the locality represented by samples 2954–2959, the values for equivalent uranium range from 60 ppm to 110 ppm and average 90 ppm. Between these localities two small tributaries enter the Kwiniuk River from areas of lime-

EXPLANATION

Geology and explanation generalized from Miller and others, 1972

SEDIMENTARY AND METAMORPHIC ROCKS

Qa ALLUVIUM (QUATERNARY)—Silt, sand, and gravel in floodplains and tidal flats, and in colluvial, morainal, and outwash deposits

Dl LIMESTONE AND DOLOMITE (DEVONIAN)—Chiefly white, massive limestone interbedded with gray to black, thin-bedded dolomite

pCg GRAPHITIC SCHIST AND METASILTSTONE (PRECAMBRIAN)—Chiefly gray-black, quartz-muscovite-graphite schist with minor schistose marble

pCq QUARTZ-MICA SCHIST (PRECAMBRIAN)—Chiefly quartz-mica schist with lesser amounts of greenschist, graphitic schist, and marble

pCmi MIGMATITIC ZONE (PRECAMBRIAN)—Lithologically similar to metamorphic complex (pCc) but with granitic dikes, stocks, and bosses of probable Cretaceous age, too abundant and intimately associated with metamorphic rocks to map separately

pCc METAMORPHIC COMPLEX (PRECAMBRIAN)—Chiefly high-grade pelitic schist and gneiss with intercalated marble, calc-silicate gneiss, and minor amphibolite

IGNEOUS ROCKS

Kq QUARTZ MONZONITE OF DARBY PLUTON (CRETACEOUS)—Light-colored, massive, coarse-grained quartz monzonite

Kg GRANODIORITE OF KACHAUIK PLUTON (CRETACEOUS)—Light-colored, massive to porphyritic, medium-grained granodiorite and quartz monzonite

Ks MONZONITE AND SYENITE OF KACHAUIK PLUTON (CRETACEOUS)—Light- to medium-dark-colored, porphyritic and trachytoid, coarse-grained monzonite and syenite

Kh HYBRID DIORITE OF KACHAUIK PLUTON (CRETACEOUS)—Medium- to dark-colored, coarse-grained hybrid diorite with abundant biotite. May be border phase of monzonite and syenite of Kachauik pluton

Km GNEISSIC MONZONITE OF KACHAUIK PLUTON (CRETACEOUS)—Light- to medium-dark-colored, gneissic to trachytoid monzonite

——— Contact—Dashed where approximately located, inferred, or indefinite

——— Fault—Dashed where approximately located, inferred, or indefinite; dotted where concealed

●1060 Locality of magnetic concentrate—Shows Alaskan placer concentrate file number. Where two or more concentrates are from the same locality, the range in file numbers is given

stone, slate, and schist, and they contribute nonradioactive magnetic concentrates to the suite from the quartz monzonite. Further downstream, the Kwiniuk River flows past the localities for samples 2951, 2950, and 2949 in that order, and these magnetic concentrates have 50 ppm, 60 ppm, and 40 ppm of equivalent uranium, respectively. Successive downstream tributaries have introduced nonradioactive or weakly radioactive magnetic concentrates from the limestone.

Similar processes of dilution of radioactive magnetic concentrates may explain why equivalent uranium values are lower at the southern end of the Darby pluton (fig. 34) than in the northeastern part of the intrusive complex (fig. 33). Samples from the eastern flank of the Kwiktalik Mountains (fig. 34) are weakly radioactive, whereas those from the western flank of these mountains lack detectable radioactivity. The weakly radioactive magnetic concentrates along the east side of the Kwiktalik Mountains are derived from several rock types including both the quartz monzonite of the Darby pluton and the migmatitic complex in the center of the mountains. The nonradioactive samples from the western flank of the Kwiktalik Mountains are from the migmatitic complex and other rocks. Perhaps admixture of nonradioactive magnetic concentrates from the migmatitic complex with radioactive ones from the quartz monzonite accounts for the low equivalent uranium values in samples from the southern end of the Darby pluton.

The equivalent uranium in the magnetic concentrates from the Clear Creek area of the Solomon quadrangle (fig. 33) is compared in table 20 with that reported by West (1953, p. 6) for the original heavy-mineral concentrates from which the magnetites were removed for the present study. The equivalent uranium in the original concentrates and that in the derivative magnetic fractions display a linear relationship: the radioactivity of the original heavy-mineral concentrate is always higher than that of the magnetic concentrate, and the correlation coefficient for equivalent uranium in the two kinds of concentrates is 0.77 (fig. 35). A positive relationship at the 99.5-percent confidence level exists between the values for equivalent uranium in the two kinds of concentrates. The strength of this relationship is remarkable, because the radioactivity of the original heavy-mineral concentrate is due to radioactive elements in hematite, allanite, sphene, zircon, and uraniferous titanium niobate minerals (West, 1953, p. 6), whereas the radioactivity of the magnetic concentrates has been shown in this investigation to be associated with hematitic crusts on the detrital magnetite (table 11).

COPPER, LEAD, ZINC, AND CADMIUM

The distributions of the values for copper, zinc, and cadmium in magnetic concentrates show one population in the Solomon quadrangle (figs. 2, 4, and 5), whereas the values for lead show two populations (fig. 3). The cumulative curves for copper and zinc in the magnetic concentrates from the Solomon quadrangle lie to the low-value side of the curves for these elements in magnetic concentrates from the Candle

TABLE 17.—*Values used to plot equivalent uranium and 11 elements in magnetic concentrates from 41 localities in the Solomon quadrangle, Alaska*

[Data are in parts per million. Numbers in parentheses below element symbols are the lower limit of determination for each element. N = Not detected; L = Detected, but the concentration is below the limit of determination; n.d. = Not determined]

File numbers at each locality	eU (30)	Ag (0.2)	Bi (5)	Cd (0.2)	Co (1)	Cu (1)	Ni (1)	Pb (5)	Zn (1)	Au (0.2)	In (0.2)	Tl (0.2)
2836	N	L	15	L	55	10	75	25	35	n.d.	n.d.	n.d.
2838	N	0.2	10	0.4	60	15	70	20	55	n.d.	n.d.	n.d.
2867	N	L	25	0.4	50	10	70	15	35	n.d.	n.d.	n.d.
2874, 2879	N	0.6	5	0.3	60	3	85	1,100	45	n.d.	n.d.	n.d.
2882	N	0.2	5	L	75	5	160	10	55	L	L	L
2887	N	0.4	5	L	85	L	250	5	75	n.d.	n.d.	n.d.
2904, 2905	N	0.2	10	L	45	3	30	10	40	1.4	L	L
2909, 2910, 2911	N	L	10	0.4	40	3	25	20	30	L	L	L
2915	N	0.4	10	0.4	40	10	30	15	80	L	L	L
2916	N	0.4	10	0.2	35	10	30	10	60	n.d.	n.d.	n.d.
2923, 2924, 2925	30	0.4	10	0.4	30	10	15	20	80	n.d.	n.d.	n.d.
2926	50	L	10	L	30	10	15	15	45	n.d.	n.d.	n.d.
2928	N	L	10	0.4	30	L	20	15	35	L	L	L
2936, 2937	30	L	5	L	30	L	25	10	40	n.d.	n.d.	n.d.
2943, 2944	30	0.2	10	0.2	50	10	85	15	40	n.d.	n.d.	n.d.
2945	N	L	10	L	40	30	40	20	35	n.d.	n.d.	n.d.
2949	40	0.2	10	0.4	25	L	15	15	50	n.d.	n.d.	n.d.
2950	60	0.2	10	0.6	30	5	20	15	55	L	L	L
2951	50	0.4	10	0.4	35	5	20	20	75	n.d.	n.d.	n.d.
2954, 2956, 2957, 2958, 2959	90	0.2	10	0.3	45	5	70	20	150	L	L	L
2960, 2961	130	0.4	10	0.6	30	3	15	40	55	0.1	L	0.2
2963	50	L	10	0.2	30	L	20	15	55	L	L	L
2970	N	0.2	10	0.6	35	5	50	15	75	L	L	L
2972, 2973, 3025	80	0.4	10	0.3	30	5	20	25	75	L	L	L
2974, 2981, 2982	110	0.2	10	0.2	30	5	15	30	50	L	0.3	0.2
2975, 2976, 2977, 2978, 2980	140	0.2	10	1.2	30	5	20	30	45	L	L	0.2
2983, 2989, 2990, 2998	240	0.2	15	0.6	25	5	15	50	65	L	L	0.3
2984, 2985, 2986, 2987, 2997	130	1.6	15	0.4	25	5	15	35	65	n.d.	n.d.	n.d.
2988, 2992, 2993, 2994, 2995, 2996	390	0.2	15	0.4	25	5	10	40	60	n.d.	n.d.	n.d.
3000, 3001, 3002	150	0.4	10	0.4	25	5	15	25	70	L	L	0.2
3004, 3005, 3006, 3007, 3008, 3009, 3010, 3011	140	0.4	15	0.3	25	5	15	35	60	L	L	0.4
3012, 3013, 3014, 3015, 3016, 3017	110	0.3	15	0.4	30	3	15	30	80	L	0.2	L
3018, 3019	290	0.6	15	L	30	3	15	35	50	L	L	0.3
3020, 3021	180	0.2	15	0.2	30	3	15	35	50	L	L	0.4
3022, 3023, 3024	150	0.7	10	0.2	30	5	15	30	50	0.2	0.2	0.3
3026, 3028, 2036	70	0.2	15	0.3	25	10	40	25	50	L	L	L
3029, 3032, 3033	225	0.2	10	0.4	25	5	15	30	80	n.d.	n.d.	n.d.
3030, 3031, 3034, 3035	145	0.5	10	0.5	30	5	15	30	65	n.d.	n.d.	n.d.
3037	90	0.2	10	0.4	45	10	100	25	120	n.d.	n.d.	n.d.
3048	210	0.4	15	0.4	35	10	20	120	100	n.d.	n.d.	n.d.
3049, 3050, 3052	120	0.2	10	0.6	30	10	15	50	65	L	L	0.2

quadrangle and from the region as a whole. The geometric means for copper (7 ppm) and zinc (58 ppm) are much lower than those for the region as a whole (copper, 16 ppm; zinc, 85 ppm) or for the Candle quadrangle (copper, 15 ppm; zinc, 79 ppm in table 8). The cumulative curves for lead are much the same for the Solomon quadrangle (26 ppm), for the region as a whole (26 ppm), and for the Candle quadrangle (27 ppm). Among these four elements in the magnetic concentrates from the Solomon quadrangle, lead and cadmium have strong positive skewness toward high values. The geometric mean of cadmium from this quadrangle (0.44 ppm in table 8) is slightly higher than the regional value (0.39 ppm) or the value for the

TABLE 18.—*Variations in chemical composition of multiple magnetic concentrates from six areas represented by single plotted localities in the Solomon quadrangle, Alaska*

[Data are in parts per million. Entries shown in table 1 as not detected are here assigned a numerical value equal to one-third the lower limit of detection: eU = N = 10 ppm here. Entries shown in table 1 as detected below the limit of determination are here assigned numerical values equal to one-half the lower limit of determination: Ag = L = 0.1; Bi = L = 2.5; Cd = L = 0.1; Cu = L = 0.5 ppm here]

File number	eU	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
A. Locality at 64°44'00" N.; 162°19'15" W.									
2954----------	80	0.1	10	0.1	35	5	15	15	50
2956----------	100	.6	10	.6	95	10	280	40	500
2957----------	60	.1	10	.1	30	.5	15	15	65
2958----------	110	.2	5	.4	35	10	20	20	70
2959----------	110	.2	10	.4	30	5	20	15	65
Arithmetic mean-	92	.24	9	.32	45	6	70	21	150
Std. dev.-------	21.67	.2	2.28	.2	28.06	4.0	117.4	10.8	195.8
Relative std. dev. (percent)	23.5	83.3	25.3	62.5	62.4	66.6	167.7	51.4	130.5
B. Locality at 64°54'15" N.; 162°13'45" W.									
2975----------	110	0.1	15	0.1	35	5	15	30	45
2976----------	210	.2	10	.4	25	5	10	25	45
2977----------	130	.4	10	.4	30	.5	15	35	55
2978----------	190	.1	15	5.5	30	5	15	45	50
2980----------	60	.4	10	.1	35	5	40	15	35
Arithmetic mean-	140	.2	12	1.3	31	4.1	19	30	46
Std. dev.-------	60.8	.15	2.7	2.35	4.2	2.0	11.9	11.2	7.4
Relative std. dev. (percent)	43.4	75.0	22.5	180.8	13.5	48.8	62.6	37.3	16.1
C. Locality at 64°53'45" N.; 162°16'30" W.									
2984----------	150	0.6	5	0.2	25	0.5	15	45	60
2985----------	100	.4	35	.4	30	10	15	30	85
2986----------	90	.2	10	.4	20	5	10	35	55
2987----------	170	6.5	10	.4	25	5	15	45	65
2997----------	150	.2	20	.4	20	5	10	25	65
Arithmetic mean-	132	1.6	16	.36	24	5.1	13	36	66
Std. dev.-------	34.9	2.8	11.9	.08	4.2	3.36	2.7	8.9	11.4
Relative std. dev. (percent)	26.4	175.0	74.3	22.2	17.5	65.8	20.8	24.7	17.3
D. Locality at 64°53'15" N.; 162°16'00" W.									
2988----------	150	0.2	10	0.4	20	5	10	25	55
2992----------	560	.2	10	.6	30	5	15	40	90
2993----------	410	.1	15	.1	25	5	10	40	65
2994----------	310	.2	15	.6	30	10	15	35	75
2995----------	500	.4	40	.4	25	10	10	70	30
2996----------	410	.2	10	.6	20	5	10	35	50
Arithmetic mean-	390	.2	16.7	.45	25	6.7	11.7	40.8	60.8
Std. dev.-------	145.5	.09	11.7	.2	4.5	2.6	2.6	15.3	20.8
Relative std. dev. (percent)	37.3	45.0	70.0	44.4	18.0	38.8	22.2	37.5	34.2
E. Locality at 64°52'00" N.; 162°17'00" W.									
3004----------	100	0.4	15	0.1	30	10	15	20	55
3005----------	140	.2	15	.4	30	5	20	25	70
3006----------	100	.2	15	.6	25	5	20	35	55
3007----------	100	.2	10	.1	25	5	10	20	50
3008----------	120	1.0	10	.4	20	.5	10	35	55
3009----------	200	.2	15	.6	20	10	10	65	60
3010----------	140	.1	15	.1	30	10	10	35	65
3011----------	210	.4	10	.2	25	5	15	35	80
Arithmetic mean-	138.8	.33	13.2	.3	25.6	6.3	13.8	33.8	61.3
Std. dev.-------	44.2	.28	2.0	.21	4.2	3.4	4.4	14.3	9.9
Relative std. dev. (percent)	31.8	84.8	19.7	70.0	16.4	54.0	31.9	42.3	16.2
F. Locality at 64°51'30" N.; 162°16'15" W.									
3012----------	60	0.4	10	0.4	35	0.5	15	20	95
3013----------	70	.2	10	.4	25	5	10	45	65
3014----------	110	.4	15	.4	30	.5	15	25	80
3015----------	50	.2	10	.1	45	5	15	30	65
3016----------	140	.4	15	.6	35	5	15	25	75
3017----------	240	.4	15	.4	30	5	15	35	95
Arithmetic mean-	111.7	.3	12.5	.38	33.3	3.5	14.2	30	79.2
Std. dev.-------	71.4	.1	2.7	.16	6.8	2.3	2.0	8.9	13.6
Relative std. dev. (percent)	63.9	33.3	21.6	42.1	20.4	65.7	14.1	29.7	17.2

Candle quadrangle (0.38 ppm), reflecting the fact that the highest value reported for cadmium in table 1 (5.5 ppm) is from the Solomon quadrangle.

TABLE 19.—*Relative standard deviations, in percent, for eight elements in six sets of samples from single plotted localities in the Solomon quadrangle, Alaska, compared to relative standard deviations for subsamples of file number 3799*

Sample set[1]	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
A	83.3	25.3	62.5	62.4	66.6	167.7	51.4	130.5
B	75.0	22.5	180.8	13.5	48.8	62.6	37.3	16.1
C	175.0	74.3	22.2	17.5	65.8	20.8	24.7	17.3
D	45.0	70.0	44.4	18.0	38.8	22.2	37.5	34.2
E	84.8	19.7	70.0	16.4	54.0	31.9	42.3	16.2
F	33.3	21.6	42.1	20.4	65.7	14.1	29.7	17.2
Subsamples of 3799[2]	130.0	37.6	25.0	6.4	20.1	7.8	3.6	7.1

[1]Letters refer to sample sets listed in Table 18.

[2]Data from Table 5.

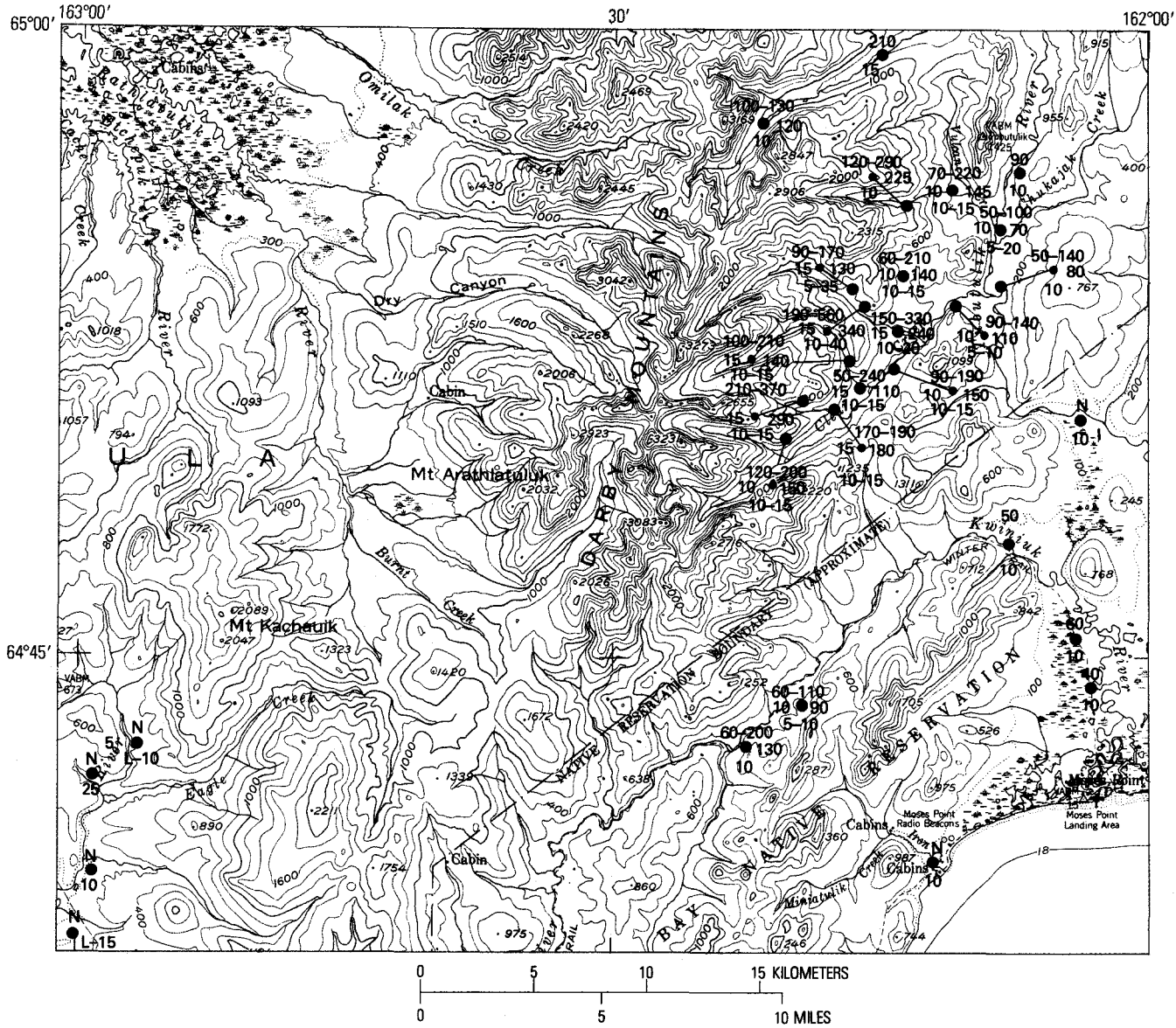
Copper content is less than the lower limit of detection (1 ppm) in 20 percent of the magnetic concentrates from the Solomon quadrangle. Only one sample (2945) contains as much as 30 ppm copper; all other samples have no more than 15 ppm copper (figs. 36 and 37). Indeed, the local threshold for copper was taken as 15 ppm for magnetic concentrates from the Solomon quadrangle, in contrast to the regional threshold of 25 ppm (table 9). Thus, the area represented on figures 36 and 37 has sparse indication of copper in this sample medium.

Among the magnetic concentrates from the Solomon quadrangle, more anomalous values are reported in table 1 for lead and zinc than for either copper or cadmium:

Element	Threshold value (ppm)	Number of anomalous magnetic concentrates
Copper	15	4
Lead	50	7
Zinc	80	16
Cadmium	1	1

The threshold values for lead and zinc in the Solomon quadrangle are less than those used for the region as a whole, but the threshold for cadmium (1 ppm) is the same as that used for magnetic concentrates from the whole region and from the Candle quadrangle.

Quartz monzonite of the Darby pluton and Devonian limestone were the principal source rocks for the magnetic concentrates that have anomalous amounts of copper, lead, and zinc (figs. 31, 32, 36, and 37). The single sample with anomalous cadmium content came from a drainage basin in Precambrian graphitic schist and metasiltstone (figs. 31 and 36).

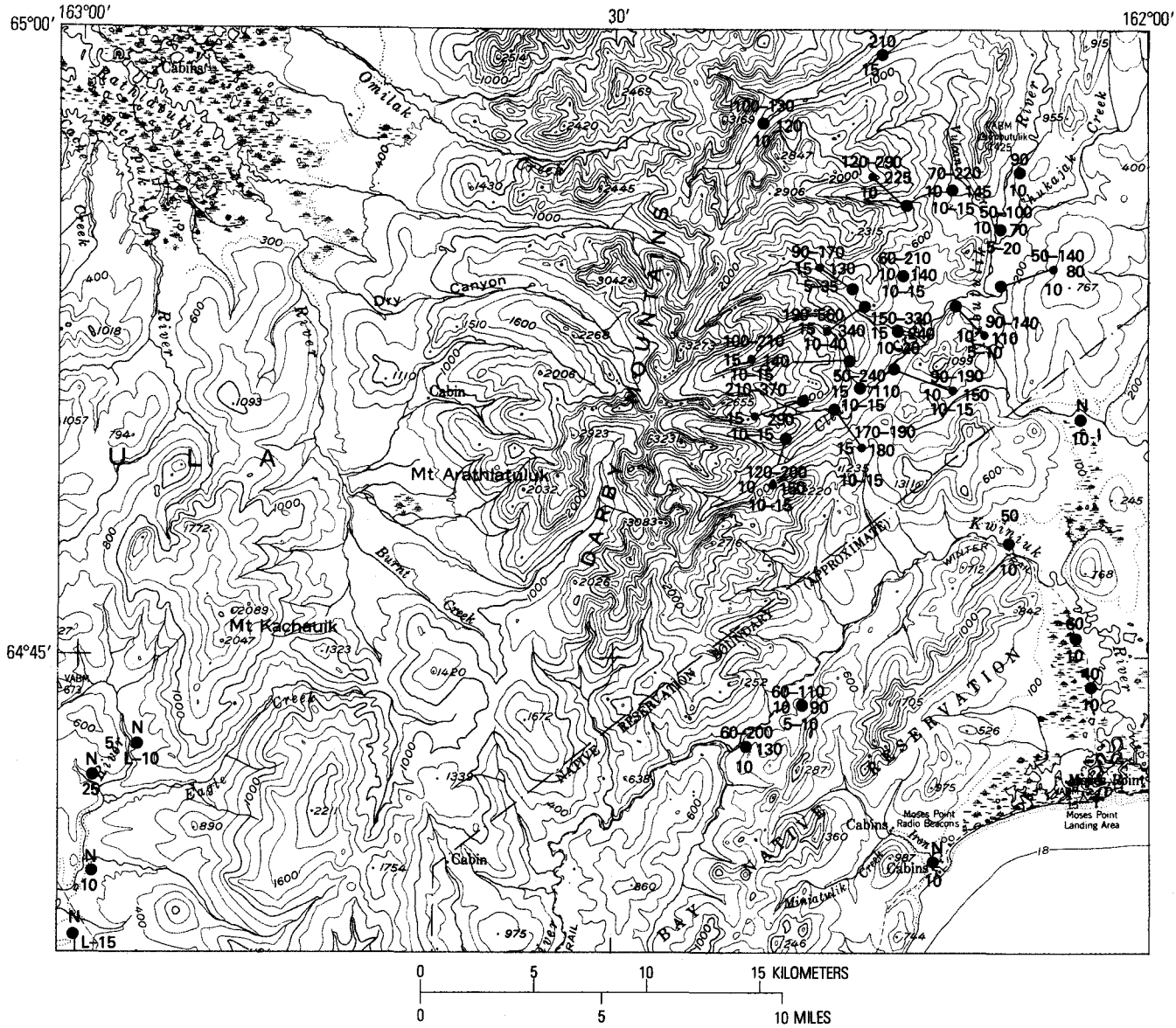


EXPLANATION

N–40 15 ● 30 L–10	Locality of magnetic concentrate showing eU and Bi in parts per million. Top figure is equivalent uranium and bottom figure is bismuth; more than one figure indicates range in values where multiple samples taken from the same locality; right figure is average for equivalent uranium and left figure is average for bismuth, where two or more samples are represented. N=not detected; L=present but below the limit of determination

FIGURE 33.—Map showing equivalent uranium and bismuth in magnetic concentrates from the northeastern part of the Solomon quadrangle, Alaska.

The few samples that have anomalous copper content are scattered over several source areas that are mainly underlain by Devonian limestone (2945 and 3028), quartz monzonite of the Darby pluton (2924), and the Precambrian schistose marble and quartz-mica schist (2838). None of these samples comes from an area previously reported to contain copper (Cobb, 1972v; Miller and Grybeck, 1973, p. 6); and only one (2924) contains an anomalous amount of any other base metal (95 ppm zinc). Typically, the samples that have anomalous copper content also contain anomalous amounts of cobalt and nickel. This association of enriched minor elements was noted in the <80-mesh fraction of stream sediments from the area east of the



EXPLANATION

N–40 15 ● 30 L–10	Locality of magnetic concentrate showing eU and Bi in parts per million. Top figure is equivalent uranium and bottom figure is bismuth; more than one figure indicates range in values where multiple samples taken from the same locality; right figure is average for equivalent uranium and left figure is average for bismuth, where two or more samples are represented. N=not detected; L=present but below the limit of determination

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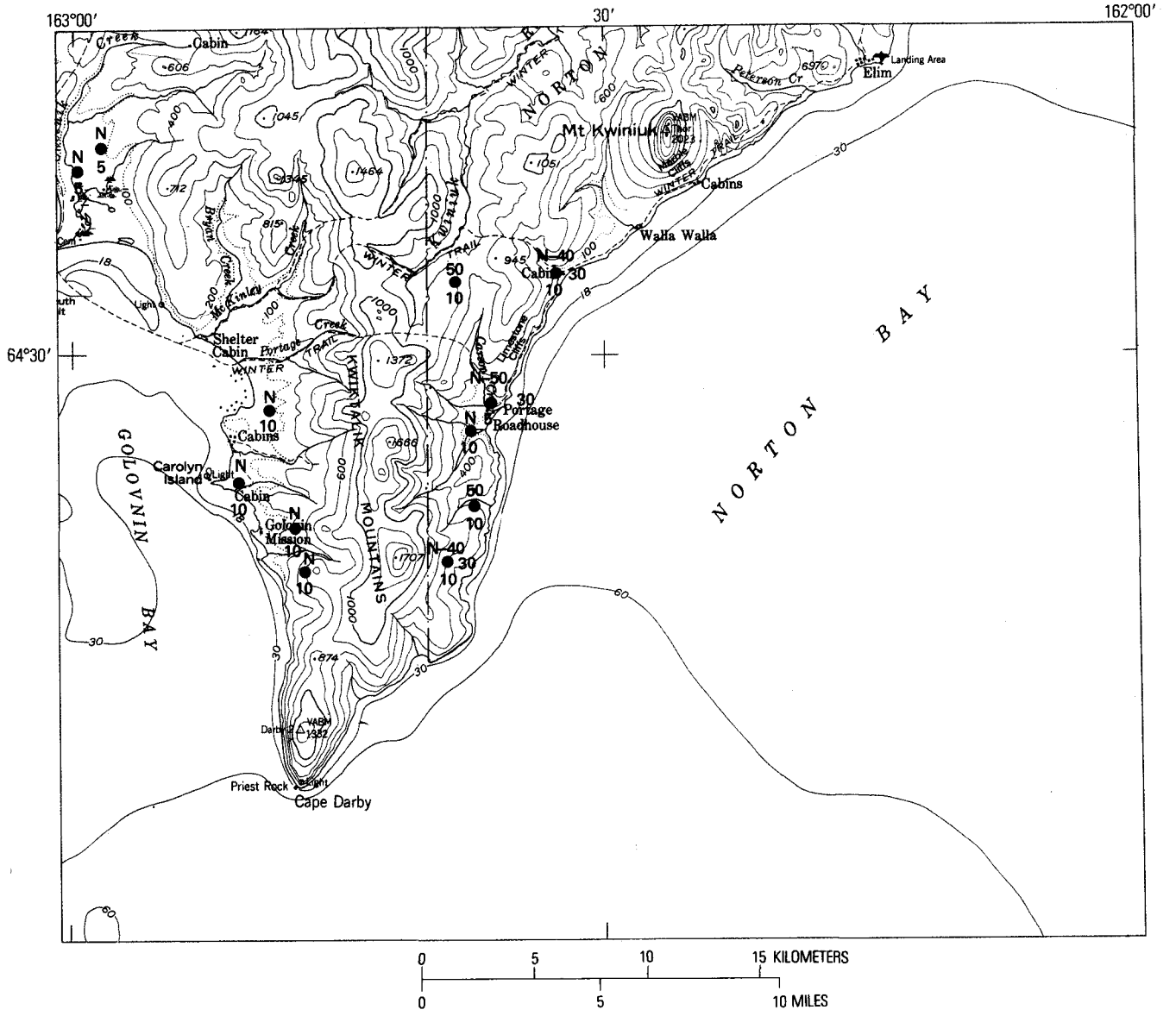
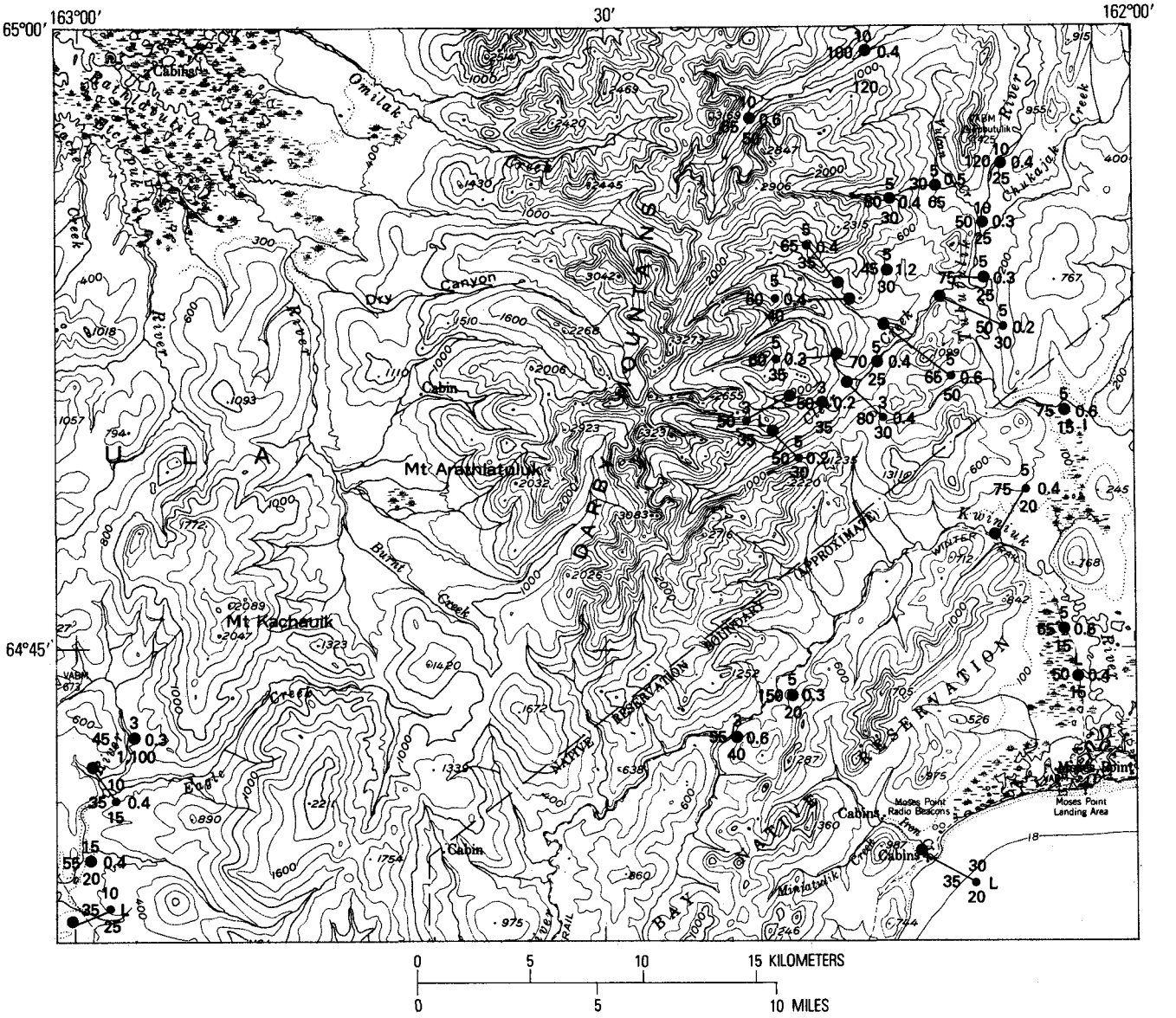


FIGURE 34.—Map showing equivalent uranium and bismuth in magnetic concentrates from the east-central part of the Solomon quadrangle, Alaska.

Darby Mountains by Miller and Grybeck (1973, p. 5), who attributed it to the presence of many dikes and plugs of diabase that intrude the faulted carbonate rocks.

Samples containing anomalous amounts of lead in the magnetic concentrates are from streams that drain the quartz monzonite of the Darby pluton (2995, 3009, and 3048), contacts between the pluton and the Devonian limestone (2960 and 2983) or the Precambrian metamorphic complex (3049), and contacts of the granodiorite of the Kachauik pluton with the Precambrian quartz-mica schist (2874). This last source yielded the second most lead-rich magnetic concentrate (2874) from the Alaskan samples, which had



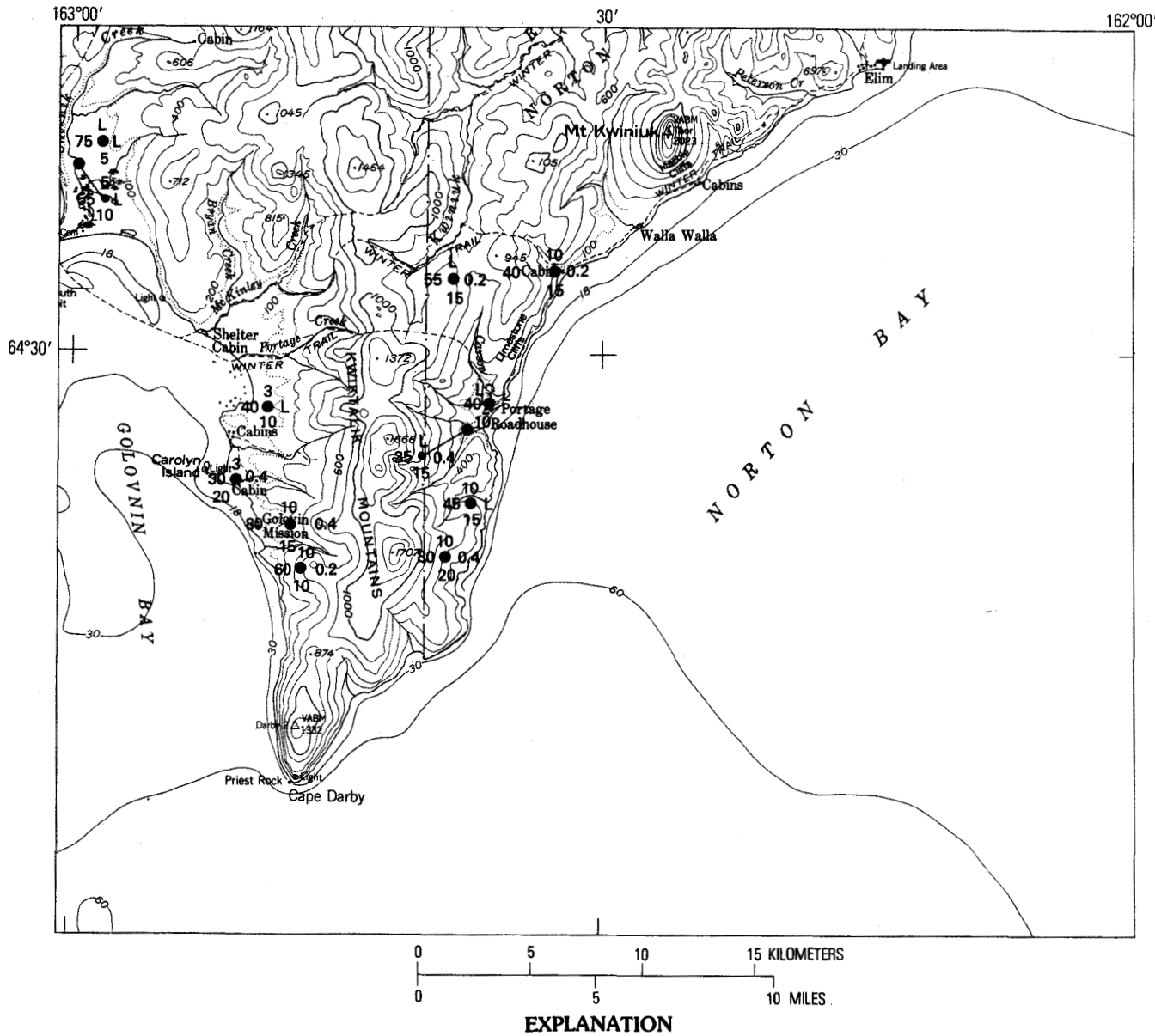
EXPLANATION

10 65 ● 0.6 50	Locality of magnetic concentrate showing Cu, Pb, Zn, and Cd in parts per million. Top figure is copper; bottom is lead; left is zinc; right is cadmium; average values used at sites having multiple samples; L=present but below the limit of detection

FIGURE 36.—Map showing copper, lead, zinc, and cadmium in magnetic concentrates from the northeastern part of the Solomon quadrangle, Alaska.

and is from a fault zone in the Devonian limestone about 3 km northeast of the gossan noted by Miller and Grybeck (1973, p. 39) to have anomalous zinc, lead, copper, and barium content.

Virtually all the samples considered anomalous for zinc in the Solomon quadrangle contain less zinc than the threshold amounts used for Alaska as a whole (120 ppm) or for the Candle quadrangle (140 ppm). Anomalous amounts of other metals are rarely associated with the concentrates having anomalous zinc content (table 1). Samples 2915, 2956, 3036, 3037, and 3048 have anomalous cobalt and (or) nickel content. Anomalous copper content is associated with the zinc in sample 2924, and anomalous lead content is present in 3048. Samples 2992, 3017, and 3032 contain anomalous amounts of equivalent uranium. Six of the magnetic concentrates (2915, 2923, 2924, 3036, 3037, and 3048) that have anomalous amounts of zinc are



EXPLANATION

10
65 ● 0.6
50

Locality of magnetic concentrate showing Cu, Pb, Zn, and Cd in parts per million. Top figure is copper; bottom is lead; left is zinc; right is cadmium; average values used at sites having multiple samples; L=present but below the limit of detection

FIGURE 37.—Map showing copper, lead, zinc, and cadmium in magnetic concentrates from the east-central part of the Solomon quadrangle, Alaska.

unassociated with described mineral occurrences (Cobb, 1972v), but the others are from streams which contain placer deposits of various minerals (West, 1953, p. 6-7): copper, rare earth, tin, tungsten, and radioactive minerals are reported in tributaries to Clear Creek (source of 2985, 2992, 3011, 3012, 3014, 3017, and 3025); and columbium, rare earths, and radioactive minerals have been found in tributaries to Vulcan Creek (source of 3032 and 3035).

Only one magnetic concentrate (2978) from the Solomon quadrangle has an anomalous amount of cadmium (5.5 ppm; fig. 36), and its cadmium content is the highest shown in table 1. The source of this sample was not known as a mineral prospect (Cobb, 1972v), nor did the area yield <80-mesh fractions of stream sediments with detectable cadmium (Miller and Grybeck, 1973, p. 38). However, the lower limit of detection for cadmium (20 ppm) in the <80-mesh fractions is too high to show low values such as those reported for the magnetic concentrates. Possibly the source of the high

cadmium in this single sample is a minor sulfide mineral included in the magnetite, or an accessory sulfide mineral trapped in the magnetic concentrates. The area seems unlikely to be a source for cadmium.

Anomalous amounts of copper, lead, and zinc tend to be in the magnetic concentrates from the northern Darby Mountains, particularly around the quartz monzonite in the northern part of the Darby pluton. These anomalies may reflect a southern expression of mineralization noted in the Bendeleben quadrangle at the Omilak mine and the Foster prospect (Miller and Grybeck, 1973, fig. 1, p. 4). The highest anomalous values, however, are reported from the southern part of the area, and the strongest indications for anomalous contents of lead and zinc are from the fractured Devonian limestone and dolomite where they are intruded by the quartz monzonite and various dike swarms. Possibly the area of the Norton Bay Native Reservation deserves further investigation because the strongest copper (2945) and zinc (2956) anomalies are found there. Anomalous amounts of copper and zinc are also present in the southern part of the reservation on the southeastern flank of the Kwiktalik Mountains (2838, 2923, and 2924), and to the north of the reservation as far as Vulcan Creek, a tributary of the Tubutulik River (2985, 2992, 3011, 3012, 3014, 3017, 3025, 3028, 3032, 3035, 3036, and 3037). The area along the Kachauik River underlain by metamorphic rocks and granitic intrusives appears to be favorable for lead (2874). Anomalous amounts of lead also occur in the central part of the Darby pluton, where equivalent uranium content is also highly anomalous (2983 and 2995), but the area is probably less favorable than the limestone wallrocks to the east.

SILVER AND GOLD

Silver in magnetic concentrates from the Solomon quadrangle shows a single population of values with a cumulative frequency curve similar to that for the Candle quadrangle but notably different from the regional curve, especially in the high-value tail (fig. 6). Of the 101 samples from the Solomon quadrangle that were analyzed for silver, about 25 percent (table 1) contain less than the limit of determination for silver (0.2 ppm). The regional background for silver is 0.2 ppm, and the backgrounds for the Solomon and Candle quadrangles are a bit higher at 0.27 ppm, but the threshold value of 1 ppm for silver is the same for all three areas (table 9). Of the 41 magnetic concentrates from this quadrangle analyzed for gold (table 1), only three have gold content above the limit of determination of 0.2 ppm.

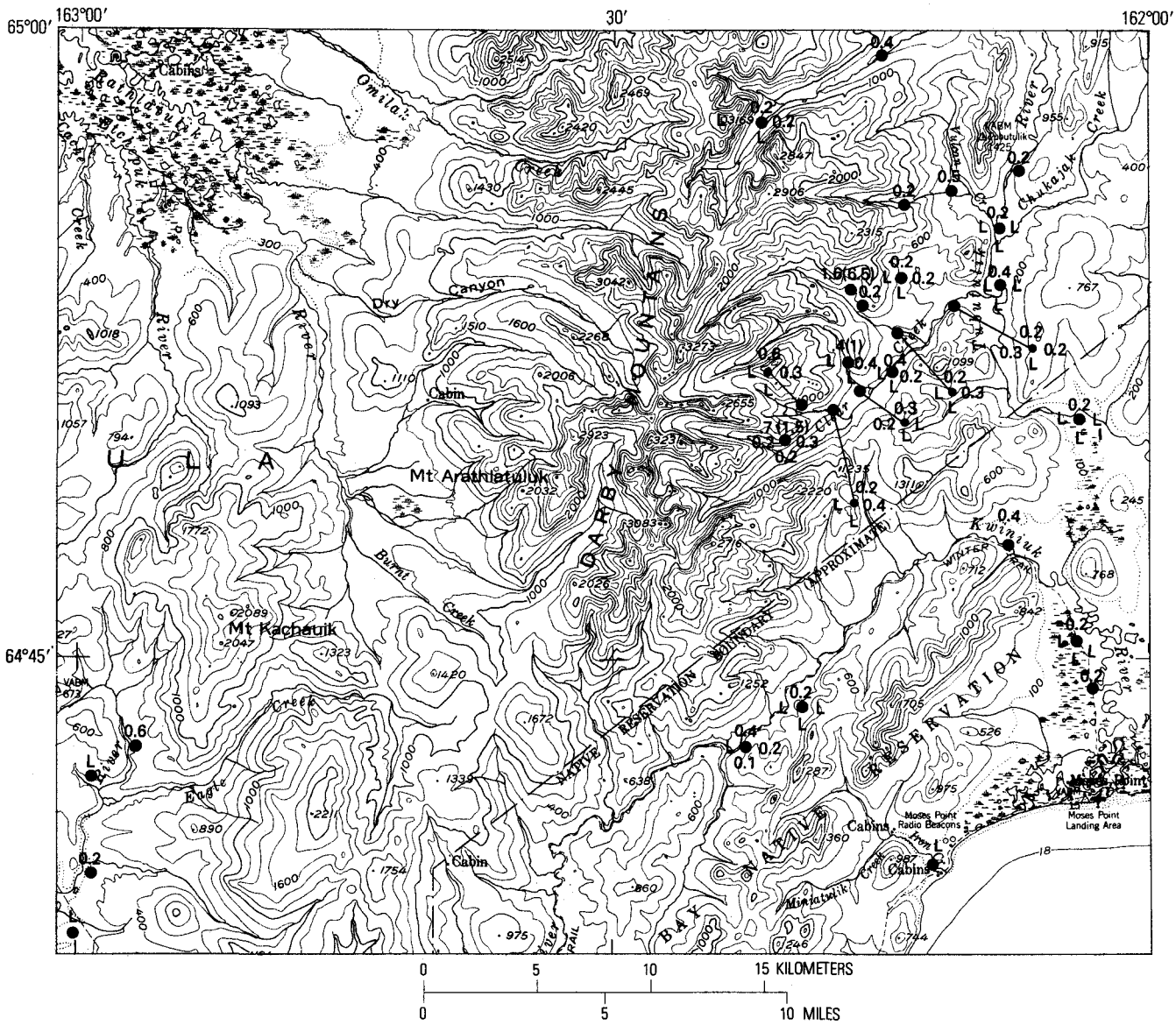
Three magnetic concentrates (2987, 3008, and 3024) from the Solomon quadrangle are anomalous for silver (table 1), and these are all from a small area on the east side of the Darby pluton (figs. 31, 32, 38 and 39). This area, underlain by quartz monzonite, is drained by the headwaters and western tributaries of Clear Creek. None of the silver-rich concentrates contains anomalous amounts of any other element, but their content of equivalent uranium is among the high background values for the Solomon quadrangle.

The silver-rich magnetic concentrates at the head of Clear Creek (3024) and on a western tributary to Clear Creek (3008) are not associated with any reported prospect or mineral occurrence (Cobb, 1972v), but the concentrate from another western tributary (2987), which also has anomalous silver content, is from a site reported to have detrital radioactive minerals and minerals containing rare earths, columbium, tin, and tungsten (West, 1953, p. 6–7). All three sites are at or near localities sampled by Miller and Grybeck (1973, fig. 1, p. 29) and found to have less than 0.5 ppm silver in the <80-mesh fraction of stream sediments. The anomalous values for silver in the magnetic concentrates are not much above threshold; hence, it is inferred from these low anomalous values and from their sparsity that the area affords scant potential for silver.

Gold is detected in only three of the 41 analyzed magnetic concentrates from the Solomon quadrangle (table 1), and one of these (2905) contains the low anomalous amount of 1.4 ppm gold (fig. 39). The source area for this sample (fig. 32) is the contact of the hybrid diorite with the monzonite and syenite units of the Kachauik pluton (Miller and others, 1972, fig. 1) south of Portage Creek. Samples of the <80-mesh fraction of stream sediment from this area were reported by Miller and Grybeck (1973, p. 41) to have less than the lower limit of determination of gold (10 ppm), and no mineral occurrence or prospect is described in this area (Cobb, 1972v; Miller and Grybeck, 1973). The gold-bearing concentrate 2905 does not have anomalous silver content, but weakly anomalous amounts of cobalt and nickel were found in it (table 1). These factors, combined with the low values for gold reported by Miller and Grybeck (1973, p. 41), are interpreted to mean that the gold in the magnetic concentrates is probably present as a fortuitous grain and that the area is not especially enriched in the element.

BISMUTH

Bismuth is present above the lower limit of determination of 5 ppm in 100 of the 101 magnetic concentrates from the Solomon quadrangle (table 1). By contrast, bismuth was found to be below the limit of determination in 9 percent of the samples in the regional

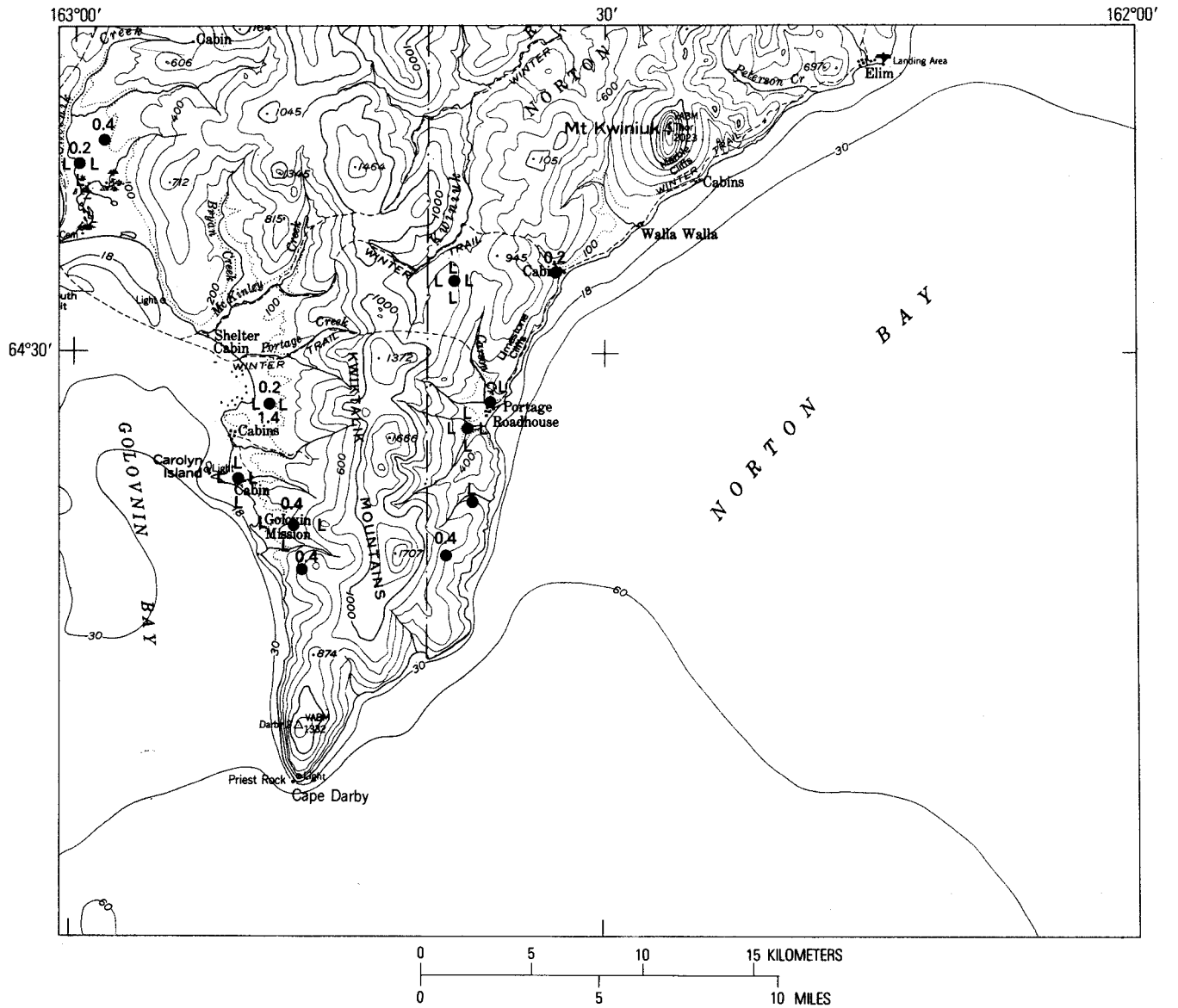


EXPLANATION

1.6(6.5) / L ● 0.3 / 0.2 — Locality of magnetic concentrate showing Ag, Au, In, and Tl in parts per million. Top figure is silver, averaged where multiple samples were analyzed and showing in parentheses a single anomalous value among the multiple analyses; bottom figure is gold; left figure is indium; right figure is thallium; lack of figure or letter indicates not determined; L = present but below the limit of determination

FIGURE 38.—Map showing silver, gold, indium, and thallium in magnetic concentrates from the northeastern part of the Solomon quadrangle, Alaska.

results (table 8). In the Solomon quadrangle, the analytical values for bismuth are divided into two populations showing a positive skewness toward an excess of high values (fig. 8). However, the maximum value observed for bismuth in the quadrangle, 40 ppm in file number 2995 (figs. 33 and 34), is considerably less than the highest value found for the region as a whole, 90 ppm in sample number 59 from the Ruby quadrangle (table 1). Nevertheless, the results of the analyses show that the Solomon quadrangle covers a part of the bismuth-enriched area of the Seward Peninsula, and the geometric mean value for bismuth in magnetic concentrates from the Solomon quadrangle (11 ppm) is slightly greater than the regional geometric



EXPLANATION

0.4(I) L ● 0.3 1.4 — Locality of magnetic concentrate showing Ag, Au, In, and Tl in parts per million. Top figure is silver, averaged where multiple samples were analyzed and showing in parentheses a single anomalous value among the multiple analyses; bottom figure is gold; left figure is indium; right figure is thallium; lack of figure or letter indicates not determined; L=present but below the limit of determination

FIGURE 39.—Map showing silver, gold, indium, and thallium in magnetic concentrates from the east-central part of the Solomon quadrangle, Alaska.

mean of 10 ppm (table 8). The threshold of 15 ppm for bismuth is also slightly greater in the Solomon quadrangle than for the region as a whole (table 9).

Twenty-five concentrates contain anomalous amounts of bismuth (table 1), mainly confined at one reporting interval above the threshold of 15 ppm; one sample (2867) contains 25 ppm bismuth and one (2995) has 40 ppm. Equivalent uranium and nickel content are most commonly associated with bismuth, but in nine of the samples the anomalous bismuth content is unaccompanied by anomalous amounts of other elements.

Most of the magnetic concentrates with anomalous bismuth content are from Clear Creek and its

tributaries where these streams drain the quartz monzonite of the Darby pluton (2975, 2978, 2990, 2993, 2994, 2995, 2997, 3004, 3005, 3006, 3009, 3010, 3019, 3021, 3023, and 3048; fig. 31) or the contact zone between the quartz monzonite and the unit of Devonian limestone and dolomite (2983, 3001, 3014, 3016, and 3017; fig. 31). Several samples with anomalous bismuth content from the same general area are derived from areas underlain by fractured limestone (3034 and 3036). The only magnetic concentrates that have anomalous amounts of bismuth and lack detectable radioactivity are from the area in the southwestern part of figure 31, which is underlain by Precambrian quartz-mica schist (Miller and others, 1972, fig. 1).

Many bismuth-rich samples from Clear Creek and its tributaries come from localities reported to have scheelite, cassiterite, radioactive columbium-bearing minerals, and detrital rare-earth minerals (2983, 2990, 2993, 2994, 2995, and 2997); or just the latter two types of minerals (2975 and 2978); or detrital rare-earth minerals (3014, 3016, 3017, 3019, and 3021) (West, 1953, p. 6–7). Bismuth-bearing minerals were not noted in the earlier literature (Cobb, 1972v). Bismuth anomalies exceeding 10,000 ppm were found by Miller and Grybeck (1973, p. 4) in <80-mesh fractions of stream sediments from a strongly mineralized area at the north end of the Darby Mountains in the Bendeleben quadrangle, and the low-level anomalies in the magnetic concentrates from the Solomon quadrangle may reflect a southern extension of the metallization. No mineralization has been reported in association with the bismuth anomalies in magnetic concentrates from the Precambrian quartz-mica schist in the southwestern part of the area covered by figure 31 (Cobb, 1972v), nor was bismuth detected in the <80-mesh fractions of stream sediments collected there by Miller and Grybeck (1973, p. 38).

COBALT AND NICKEL

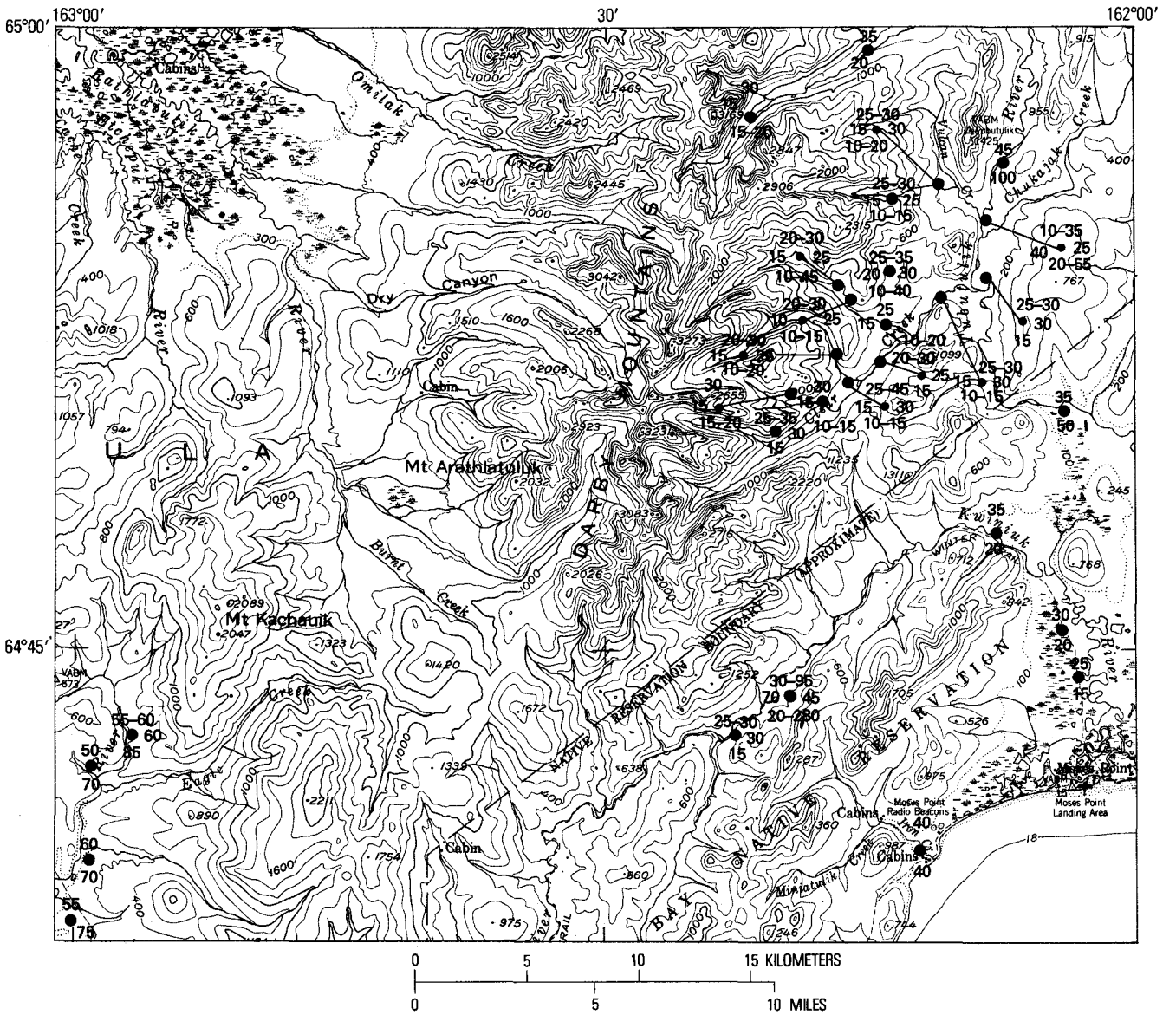
Both cobalt and nickel show two populations and a positive skewness of values in the 101 magnetic concentrates from the Solomon quadrangle (table 1, figs. 9 and 10), but their respective geometric means (31 ppm and 20 ppm) are less than those for the region as a whole (44 ppm and 50 ppm; table 8). Threshold values for cobalt and nickel in the samples from the Solomon quadrangle are much lower than threshold values for these elements in magnetic concentrates from the Candle quadrangle or from Alaska as a whole (table 9). Using these low threshold values of 40 ppm cobalt and 20 ppm nickel leads to the classification of 18 samples as anomalous for cobalt and 40 as anomalous for nickel (table 1).

The presence of two populations of values for both cobalt and nickel, and the geographic distribution of the anomalous samples, fit closely the geologic features of the Solomon quadrangle (figs. 31, 32, 40, and 41). The low-concentration populations for each element come dominantly from source areas in the granitic rocks, particularly in the Darby pluton; and the high-concentration populations are mainly from source areas in the Precambrian metasedimentary and metamorphic rocks or the Devonian limestone and dolomite.

Of the 18 magnetic concentrates that have anomalous cobalt content, nine are from areas underlain by Precambrian quartz-mica schist, metavolcanic rocks, schistose marble, metamorphic complex, and migmatitic rocks (2836, 2838, 2867, 2874, 2879, 2882, 2915, 2943, and 2944), and three are from sources in the Devonian limestone and dolomite (2945, 2956, and 3037). Contacts between the sedimentary rocks and the plutonic intrusive rocks are the source of two cobalt-rich samples (2887 and 3015). The gneissic monzonite, monzonite and syenite, and hybrid diorite units of the Kachauik pluton are the sources for four concentrates that have anomalous cobalt content (2904, 2905, 2910, and 2911).

Twelve of the 40 concentrates containing anomalous amounts of nickel are from sources in Precambrian quartz-mica schist and metavolcanic rocks, schistose marble, metamorphic complex, and migmatitic rocks (2836, 2838, 2867, 2874, 2879, 2882, 2915, 2916, 2943, 2944, 2963, and 2970), and 12 are also from areas underlain by Devonian limestone and dolomite (2945, 2950, 2951, 2956, 2958, 2959, 2972, 3026, 3028, 3034, 3036, and 3037). Contacts between various sedimentary rocks and intrusive granitic rocks are sources for four magnetic concentrates with anomalous nickel content (2887, 2980, 2998, and 3049). Hybrid diorite, monzonite, and syenite of the Kachauik pluton provide five anomalous samples (2904, 2905, 2909, 2910, and 2911), and the quartz monzonite of the Darby pluton is the source of seven (2928, 2936, 2937, 3005, 3006, 3019, and 3048).

The common association of anomalous amounts of cobalt and nickel with such sedimentary and metasedimentary rocks as the Devonian limestone and dolomite, Precambrian schistose marble, and Precambrian quartz-mica schist seems most likely to be attributable to sources for the magnetite in the numerous dikes and plugs of mafic volcanic rocks that intrude the sedimentary rocks (Miller and others, 1972, p. 4).

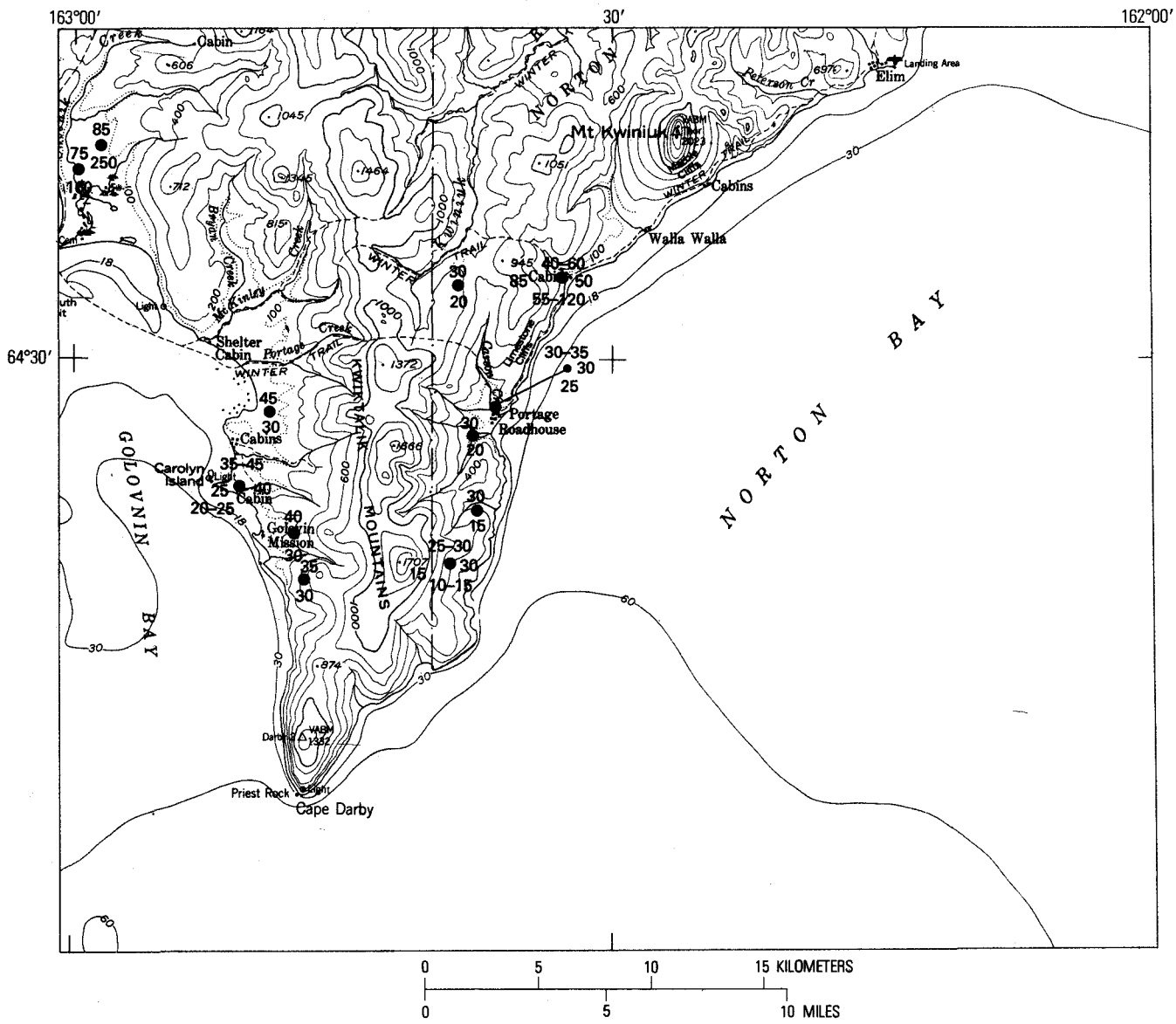


EXPLANATION

25–30 85 ● 50 55–120	Locality of magnetic concentrate showing Co and Ni in parts per million. Top figure is cobalt and bottom figure is nickel; more than one figure indicates range in values where multiple samples taken from the same locality; right figure is average for cobalt and left figure is average for nickel, where two or more samples are represented

FIGURE 40.—Map showing cobalt and nickel in magnetic concentrates from the northeastern part of the Solomon quadrangle, Alaska.

Samples that have anomalous cobalt content tend also to contain anomalous amounts of nickel (table 1). The three samples with the most cobalt, 2882 and 2887 from the area of Cheenik Creek (fig. 41) and 2956 from the Kwiniuk River area in the Norton Bay Native Reservation (fig. 40), are also the richest in nickel. All three samples are located outside the areas of the granitic plutons. The plutons were not recognized as source areas for <80-mesh stream sediments anomalously rich in cobalt, but nickel was more than ordinarily abundant in that sample medium at those sites (Miller and Grybeck, 1973, p. 38–39). The magnetic concentrate from the Kwiniuk River area was taken from a sample that had previously been reported to contain copper- and tungsten-bearing minerals (West, 1953, p. 6), but the results of the



EXPLANATION

10–20 20 ● 15 20–280	Locality of magnetic concentrate showing Co and Ni in parts per million. Top figure is cobalt and bottom figure is nickel; more than one figure indicates range in values where multiple samples taken from the same locality; right figure is average for cobalt and left figure is average for nickel, where two or more samples are represented

FIGURE 41.—Map showing cobalt and nickel in magnetic concentrates from the east-central part of the Solomon quadrangle, Alaska.

chemical analyses show it to have only an anomalous zinc content associated with the cobalt and nickel.

Most of the magnetic concentrates from localities in the Norton Bay Native Reservation contain anomalous amounts of nickel, but only four have anomalous cobalt content, and only one each is associated with anomalous amounts of copper (2945; 30 ppm) and zinc (2956; 500 ppm). Most of the anomalous values are low, in contrast to those in samples from other areas in Alaska. Variations in the lithology of the source rocks from which magnetic concentrates are derived account for the low anomalous values of cobalt and nickel.

A high value for lead, 110 ppm, is associated with anomalous cobalt and nickel values in sample 2874 from the Kachauik River. Anomalous amounts of cobalt and nickel are also found in the magnetic con-

centrates from the Tubutulik River area (fig. 40), where copper and zinc values are also anomalous.

INDIUM AND THALLIUM

Analyses for indium and thallium were made on 41 of the magnetic concentrates from the Solomon quadrangle with a lower detection limit of 0.2 ppm for each element. Only five samples were found to contain 0.2 ppm or more indium, and 19 samples had 0.2 ppm or more thallium (table 1, figs. 38, 39). The geometric means for indium and thallium, 0.22 ppm and 0.28 ppm, respectively, are extremely close to the regional geometric means (table 8).

Several geologically different source areas yielded magnetic concentrates with measurable thallium and indium, but the principal sources are in the Darby pluton and the Devonian limestone and dolomite, or along contacts between these units (figs. 31, 32, 38, and 39). The values for indium reflect no essential difference for source, but the high values for thallium, including the greatest found (1 ppm in sample 3005), are identified with sources in the quartz monzonite of the Darby pluton. Except for equivalent uranium and bismuth, other metals are seldom associated in anomalous amounts with indium and thallium. The presence of indium and thallium in the magnetic concentrates has no apparent relation to known metallic mineral deposits in the Solomon quadrangle, although the distribution of these elements conforms broadly to the more favorable sites recognized for copper and zinc.

SOURCES OF THE ANOMALOUS ELEMENTS

The results of the radiometric and chemical analyses of the 347 magnetic concentrates from Alaska reveal that about 70 percent of these samples contain anomalous amounts of equivalent uranium, silver, bismuth, cadmium, cobalt, copper, nickel, lead, or zinc (table 1), either singly or in varied combinations. The principal constituent mineral in the analyzed concentrates is magnetite, but other minerals are present. If the probable source or sources of the anomalous elements in the magnetic concentrates can be established with some degree of confidence, then the results of selective analyses of this kind of concentrate could be used more effectively to evaluate geochemically the mineral potential of a given area. Accordingly, the mineralogical composition of the magnetic concentrates was investigated.

The mineralogical composition of 67 of the 347 analyzed magnetic concentrates was semiquantitatively determined by Keith Robinson using optical and X-ray diffraction techniques. The 67 samples were selected on the basis of their chemical characteristics to be a representative subsample of the 347 magnetic concentrates. With a few deliberately chosen exceptions, such as sample 3779 which contains an unusually high tenor in copper, the distribution of the elements is similar to that in the whole population. Of the 67 samples, 80 percent contain anomalous amounts of one or more of the elements for which the whole 347 were analyzed, and 20 percent contain only background amounts of these elements.

Another factor evaluated in the mineralogical examination was the solubility of the various minerals composing the magnetic concentrate in the dissolution procedure used to prepare the sample for analysis by atomic absorption. If one or more minor minerals included in the grains of magnetite, or one or more accessory minerals trapped among the grains of magnetite in the concentrate, were found to be insoluble in the acid digestion, then they could not have been sources for minor metals reported in the results of the analyses. For this evaluation, a mineralogical study was made of the insoluble residues left from the acid digestion and recovered by filtering the leachate.

MINERALOGICAL COMPOSITION OF MAGNETIC CONCENTRATES

The presence in magnetite of trace amounts of elements such as those discussed here has been substantiated by previous research and is well documented (table 6). It is also generally recognized, as described above, that the trace elements may be chemically hosted in the magnetite itself, or they may be mechanically hosted through their presence in trace minerals or accessory minerals.

The procedures used in the present mineralogical evaluation deal mainly with the accessory minerals that are present in the magnetic fraction of the panned concentrates. The practical consequence of preparation is that small and variable quantities of other minerals—even some nonmagnetic minerals—will be associated with the grains of the magnetic aggregate as trapped intergranular particles. The role of these particles in contributing to anomalous values for the elements needs evaluation.

The mineralogical composition and anomalous element content in the 67 magnetic concentrates chosen for this examination are identified in table 21. All but six of the concentrates contain more than 50 percent magnetite, and 39 of the concentrates contain 90–99 percent magnetite. The six samples with less than 50 percent magnetite (56, 2121, 2418, 2696, 2785, and 3646) are diluted by ilmenite, rutile, sulfide minerals,

TABLE 21.—*Appearance, metal content, and mineralogical composition of a subset of 67 magnetic concentrates from Alaska*

[Mineralogical analyses by Keith Robinson, U.S. Geological Survey. Tr = trace, less than 1 percent; P = present in abundances up to 2 percent; – = absent]

File Number	Appearance of concentrate under binocular microscope	Elements present in anomalous amounts	Mineralogical composition (approximate percentage)											
			Magnetite	Tramp iron	Metallic spherules	Hematite coating	Ilmenite	Chlorite	Mica	Amphibole	Feldspar	Quartz	Native gold	Other minerals and rock fragments
1	Clean, well-sorted, euhedral magnetite.	----------	97	--	--	--	--	Tr	--	Tr	Tr	--	--	----------
56[1]	Gold particles common; trace of tramp iron.	Ag, Bi, Cu, Ni, Pb.	20	Tr	--	--	25	--	--	--	--	Tr	30	Pyrite and marcasite, 20-25 percent; trace or iron sulfate.
59[1]	Contains metallic spherules and gold.	Ag, Bi, Cd, Co, Cu, Ni, Pb, Zn.	95	P	P	Tr	Tr	--	--	--	--	--	Tr	Trace of rutile(?).
84	Clean, euhedral magnetite	----------	97	--	--	--	--	--	Tr(?)	Tr(?)	--	--	--	----------
148	Clean magnetite----------	----------	97	--	--	--	--	--	Tr	--	--	--	--	Trace of pyrite and marcasite.
196	Clean, euhedral magnetite---	Ag----------	97	--	--	--	--	--	Tr	--	--	--	--	Trace of garnet.
232	Clean, round magnetite------	Co, Ni---------	75	--	--	--	25	Tr	--	--	--	--	--	----------
262	Coated, euhedral magnetite	Bi----------	75	--	--	Tr	15	Tr	--	--	--	--	--	Rutile, 10 percent.
293[1]	Relatively clean magnetite; tramp iron, and slate.	Co, Ni---------	80	Tr	--	--	20	P	--	Tr	--	Tr	Tr	Traces of pyrite, marcasite, garnet, zircon, spinel, scheelite, cinnabar, epidote, and slate.
482	Relatively clean magnetite with some particles of glassy volcanic rock.	Ag, Cd, Zn-----	95	--	--	--	Tr	--	--	--	--	--	--	Traces of zircon, volcanic glass, and unidentified silicate minerals.
535	Clean magnetite ----------	----------	90	--	--	--	<10	--	--	--	--	--	--	Trace of unidentified silicate minerals.
553[1]	Clean, very fine grained magnetite.	Bi, Co, Cu, Ni-	99	Tr	--	--	--	--	--	--	--	Tr	--	Do.
682	Clean magnetite ----------	----------	99	--	--	Tr	--	--	--	--	--	--	--	Do.
928[1]	Clean, fine grained, well rounded magnetite.	Cu, Ni, Zn-----	75	25	Tr(?)	--	--	--	--	--	--	--	--	Do.
929[1]	Clean, fine grained, well rounded magnetite; tramp iron and magnetic spherules common.	Ag, Bi, Co, Cu, Ni, Zn.	90	10	P	--	--	--	--	--	--	Tr	Tr	----------
1026	Relatively clean magnetite.	----------	99	--	--	Tr	--	--	--	--	--	Tr	--	Trace of hopeite(?)
1336	Clean, very fine grained magnetite.	Ni, Pb, Zn-----	90	--	--	--	10	--	--	--	--	--	--	----------
1455[1]	Tramp iron present---------	Co, Cu, Ni, Zn	95	5	--	--	--	--	--	--	--	--	--	Trace of unidentified silicate minerals.
1457	Clean magnetite with trace of brown coating.	Cu, Zn---------	95	--	--	Tr	--	--	--	--	--	P	--	----------
1469	Clean magnetite----------	----------	95	--	--	--	--	P	--	P	Tr	3	--	----------
1479	Do----------	Cu----------	95	--	--	--	--	P	--	--	Tr	3-5	--	Trace of zircon.
1507	Do----------	Cu----------	85	--	--	--	5	5	P	--	--	P	--	----------
1831[1]	Metallic spherules---------	Ag, Bi, Co, Cu, Ni, Pb, Zn.	>95	--	Tr	--	--	P	P	P(?)	--	--	--	----------
1867[1]	Hematitic coating on magnetite; tramp iron present.	Ag, Cd, Cu, Ni, Pb, Zn.	>90	P	--	P	P	P	--	P	--	P	Tr	----------
2121[1]	Abundant metallic spherules.	Ag, Cu, Zn-----	25	--	75	--	--	--	--	--	--	--	Tr	Trace of cuprite(?) and anatase(?).
2148	Relatively clean magnetite.	Ag, Cu, Zn-----	90	--	--	--	5	--	--	--	5	--	--	----------
2162	Do ----------	Cu, Zn---------	90	--	--	--	5	P	--	--	P	P	--	Garnet ≤2 percent.
2182	Do ----------	Zn----------	95	--	--	Tr(?)	Tr	P	--	--	--	P	--	Zircon ≤ 2 percent.
2192	Do ----------	Ag, Cu---------	>98	--	--	Tr	--	--	--	--	--	--	--	Trace of unidentified silicate minerals.
2203	Very fine grained magnetite.	Cu, Ni, Zn-----	95	--	--	--	--	2-3	--	--	--	P	--	Garnet ≤2 percent.

2418[1]	Mainly tramp iron; some metallic spherules.	Ag, Cu, Ni, Pb-	7	85	P	--	5	--	--	--	--	P	P	----------
2438	Relatively clean magnetite; trace of tramp iron.	Cu, Zn---------	93	Tr	--	Tr	5	P	--	--	P	--	--	Trace of cinnabar.
2488	Relatively pure magnetite with slight coating.	Cu, Zn---------	>98	--	--	Tr	Tr	--	--	--	--	Tr	--	----------
2492	Do----------	Ag, Bi, Cu-----	>90	--	--	Tr	<5	--	--	2	--	3	--	----------
2509	Relatively clean magnetite with slight coating.	----------	>90	--	--	Tr	<5	--	--	--	Tr	P	--	Rutile, 5 percent.
2543	Do----------	Zn----------	80	--	--	Tr	20	--	--	--	--	P	--	----------
2637	Relatively clean magnetite	----------	90	--	--	--	5	--	--	Tr	Tr	P	--	Zircon, 3 percent.
2696	Abundant silicates---------	Cu, Ni---------	<40	--	--	--	--	2-3	--	20	40	--	--	----------
2729	Magnetite has coating------	----------	97	--	--	Tr	--	3	--	--	--	--	--	----------
2733	Relatively pure magnetite, has slight coating.	----------	>95	--	--	Tr	<5	--	--	--	--	--	--	----------
2785	Magnetite has coating------	Zn----------	40	--	--	P	30	--	--	--	--	>5	--	Rutile, 20 percent.
2808	Abundant ilmenite, rutile, and silicates.	----------	55	--	--	--	20	P	P	P	P	10	--	Rutile, 10 percent; unidentified silicates present.
2811	Do----------	----------	<70	--	--	Tr	15	1	--	--	--	--	--	Rutile, 15 percent.
2874	Clean magnetite----------	Co, Ni, Pb-----	>98	--	--	--	--	--	Tr	--	--	--	--	----------
2879	Relatively clean magnetite with trace of coating.	Co, Ni---------	>97	--	--	Tr	--	--	P	--	--	P	--	----------
2882	Clean magnetite----------	Co, Ni---------	>97	--	--	--	Tr	--	--	--	--	--	--	----------
2887	Relatively clean magnetite with trace of coating.	Co, Ni---------	>97	--	--	Tr	--	Tr(?)	--	--	--	--	--	Trace of serpentinite.
2943	Clean magnetite----------	Co, Ni---------	90	--	--	--	--	P	P	--	--	P	--	----------
2944	Magnetite has coating------	Co, Ni---------	60	--	--	P	15	--	--	--	3	20	--	----------
2978	Do----------	eU, Bi, Cd-----	65	--	--	Tr	<10	P	2	Tr	4	20	--	----------
2992	Do----------	eU, Zn---------	60	--	--	P	20	--	4	--	4	10	--	----------
2996	Do----------	eU----------	75	--	--	P	10	--	5	--	--	10	--	----------
3006	Strong coating on magnetite	Bi, Ni---------	60	--	--	2-3	--	5	--	--	Tr	30	--	----------
3010	Do----------	eU, Bi---------	70	--	--	2-3	--	P	--	--	P	25	--	----------
3011	Do----------	eU, Zn---------	70	--	--	3	--	P	3	--	3	20	--	----------
3016	Do----------	eU, Bi---------	70	--	--	3	--	2	5	--	2-3	<20	--	----------
3031	Do----------	eU----------	75	--	--	2	<5	P	Tr	--	8	12	--	----------
3072	Do----------	eU----------	80	--	--	3-4	--	--	--	--	--	10	--	Rutile, 5 percent; celsian present; trace of zircon.
3339	Do----------	Cu----------	70	--	--	Tr	--	5	--	--	--	25	--	----------
3343	Do----------	Cu----------	70	--	--	2-3	10	P	5	--	--	10	--	----------
3646[1]	Fine grained, well rounded magnetite; tramp iron and metallic spherules present.	eU, Ag, Bi, Cu, Ni, Zn.	>15	30	20	P	5	--	--	--	P	15	P	Cassiterite, 10 percent; garnet and zircon present.
3689	Clean magnetite with a trace of coating.	Ag, Cu, Pb-----	>97	--	--	Tr	--	--	--	--	--	P	--	Trace of zircon.
3704	Do----------	Cu----------	80	--	--	Tr	10	<5	--	--	--	5	--	----------
3776	Clean magnetite----------	Cu, Zn---------	90	--	--	--	--	5	--	P	--	5	--	----------
3779	Magnetite is coated; copper minerals are present.	Ag, Cu, Zn-----	50	--	--	Tr	>5	--	--	--	--	40	--	Chalcopyrite, 5 percent; traces of azurite, malachite, and calcite.
3798	Magnetite is coated--------	Cu----------	90	--	--	5	--	1	--	--	--	4	--	----------
4905	Very fine grained magnetite with coating.	Cu----------	95	--	--	>4	--	--	--	--	--	Tr	--	----------

[1]Magnetic concentrates classed in table 30 as abnormal owing to the presence of tramp iron, magnetic spherules, and gold.

gold, quartz, hematitic coatings, a diverse array of silicate minerals, metallic spherules, and tramp iron. Many of those samples that contain more than 50 percent of magnetite also have these diluents to a lesser degree.

MAGNETITE, ILMENITE, AND RUTILE

No magnetic concentrate was found to be 100 percent magnetite, although some are very nearly pure (553, 682, 1026, 2192, 2488, 2874, 2879, 2882, 2887, and 3689). In the samples that have the highest percentages of magnetite, the magnetite itself tends to be very clean and free from hematitic stains and coating. Ilmenite and rutile generally are present as complex crystallographic intergrowths within the grains of detrital magnetite.

Magnetite was hand-picked from nine concentrates and analyzed by E. L. Mosier to compare the composition of magnetite to that of the magnetic concentrates. The results are given in table 22 and are discussed in later sections that describe the frequency of association of elements with specific minerals.

HEMATITE

Hematite forms surface coatings on detrital grains of magnetite and quartz. It also serves as a cementing agent to bind other grains, including nonmagnetic grains, to magnetite, as noted below. Hematitic coatings are readily removed from the magnetite by ultrasonic cleaning or acid digestion.

SULFIDE MINERALS AND GOLD

Pyrite, marcasite, and cinnabar are the principal sulfide minerals identified in the concentrates (table 21). Chalcopyrite is sufficiently abundant in one sample (3779) to give a large copper anomaly and probably to be the source for anomalous silver and zinc content. The sulfide minerals other than marcasite and cinnabar are associated with the magnetite as crystalline intergrowths. Pyrite, marcasite, cinnabar, and chalcopyrite are attached to the magnetite by secondary cementing agents such as hematite.

Native gold is found as discrete particles, or as

TABLE 22.—*Minor elements in hand-picked magnetite from Alaskan placers*

[Semiquantitative spectrographic analyses of hand-picked magnetite by E.L. Mosier, U.S. Geological Survey, November 13, 1972; data on magnetic concentrates from table 1. All data are in parts per million. n.d. = not determined. N = not detected at lower limits of determination, which for the analyses of the hand-picked magnetite, are Bi, 2ppm; Cd, 2 ppm, Co, 10 ppm; Ni, 10 ppm; Zn, 100 ppm; Au, 5 ppm; In, 2 ppm; Tl, 5 ppm; and Sn, 10 ppm]

File number	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn	Au	In	Tl	Sn
						Hand-picked magnetite						
59	1,000	30	N	100	70	100	5,000	150	∿1,000	N	N	500
928	5	N	N	30	20	N	50	1,000	N	N	N	10
929	10	5	N	20	20	15	50	1,000	10	N	N	10
1455	1.5	N	N	200	10	1,000	10	500	N	N	N	50
1831	1	N	N	50	7	700	50	2,000	N	N	N	200
1867	1.5	N	N	50	10	300	100	10,000	N	N	N	300
2121	1.5	N	N	N	300	30	7	N	N	N	N	30
2148	1	N	N	N	<1	10	10	150	N	N	N	N
3646	0.2	10	N	70	20	200	300	300	N	N	N	5,000
						Magnetic concentrate						
59	340	90	2.5	1,000	470	830	4,700	220	N	n.d.	n.d.	n.d.
928	.4	10	.4	65	190	280	35	700	4.9	0.5	<0.2	n.d.
929	68	20	.6	75	70	350	50	1,300	n.d.	n.d.	n.d.	n.d.
1455	.8	5	.4	190	60	970	10	170	135	<.2	<.2	n.d.
1831	1	20	.6	130	25	820	85	930	n.d.	n.d.	n.d.	n.d.
1867	43	10	1.5	70	230	600	530	140	n.d.	n.d.	n.d.	n.d.
2121	33	10	.5	45	220	100	45	180	n.d.	n.d.	n.d.	n.d.
2148	1	5	.4	65	2,000	110	55	230	n.d.	n.d.	n.d.	n.d.
3646	18	70	.2	80	220	300	45	150	640	.2	<.2	n.d.

grains cemented to the magnetite by secondary minerals. In one sample the fragments of detrital gold are coated by very fine grained particles of magnetite. Native gold embedded in magnetite, as reported by Eakin (1914, p. 28), is not observed in this group of 67 samples, unless the gold particles coated with magnetite may be so considered.

The minor metals in Alaskan placer gold have been reviewed by Mertie (1940b), and one sample (56) of detrital gold in the magnetic concentrates from Solomon Creek in the Ruby quadrangle is analyzed in the present work (table 23).

TABLE 23.—*Minor elements in a particle of placer gold from Solomon Gulch in the Ruby quadrangle, Alaska*

[Laser probe analysis of sample 56 by J.M. Nishi, U.S. Geological Survey, November 1, 1972]

Major elements	Significant trace elements	Minor trace elements
Au Ag	Si	Ba, Mg, Mn, Pb, Fe, V, Cu, Ti, Ca.

QUARTZ AND COMMON SILICATE MINERALS

Quartz and common silicate minerals such as chlorite, mica, amphibole, and feldspar are present, and occasionally unexpectedly abundant, in the magnetic concentrates. Neither quartz nor feldspar would be expected, but hematitic coatings and intergrowths with other minerals have caused a feeble magnetism, and some particles have been trapped among clots of magnetite grains. Both of these circumstances account for the persistence of these nonmagnetic minerals into the magnetic concentrate. Some grains of chlorite, micas (mainly phlogopite and biotite), and amphiboles (commonly tremolite) find their way into the magnetic concentrate largely as the result of entrapment with the magnetite or because of magnetic inclusions. Where hematitic coatings on quartz and magnetite are common, many of the magnetite grains are cemented to grains of quartz or to grains of the common silicate minerals. Crystalline intergrowths of magnetite with quartz and the common silicate minerals are abundant in some concentrates.

OTHER MINERALS

A number of other accessory minerals are in the magnetic concentrates, including: iron sulfate, garnet, zircon, spinel, scheelite, epidote, hopeite, cuprite, anatase, serpentinite, celsian, cassiterite, azurite, malachite, and calcite. Several unidentified silicate minerals were noted, and volcanic glass, slate, and serpentinite were found in one sample each. As with the common silicate minerals, various intergrowths of these other minerals with magnetite partly account for their presence in the magnetic concentrate, but cementation to magnetite by hematite or other agents and mechanical entrapment among grains of magnetite also are important factors in their presence. There is no practicable or feasible method for the separation of the quartz, common silicate minerals, and other minerals from the detrital magnetite, because of the common occurrence of intergrown grains or cemented particles.

The iron sulfate in sample 56 appears to be a secondary mineral phase produced by the oxidation of pyrite and marcasite. It may have formed in air after the concentrate was panned.

Garnet and zircon are the most common of the other silicate minerals observed in the magnetic concentrates. Garnet is present in five and zircon in eight samples (table 21). Unidentified silicate minerals are reported in three concentrates, but the remainder of the other minerals, and the volcanic glass, slate, and serpentinite are each recorded only once. Thus, spinel, scheelite, and epidote are in sample 293; cuprite and anatase are in sample 2121; and azurite, malachite, and calcite are in sample 3779.

Hopeite, a hydrated zinc orthophosphate mineral, is tentatively identified as a trace amount in sample 1026 from the Mount McKinley quadrangle, but the magnetic concentrate is not enriched in zinc (table 1). Indeed, this sample lacks anomalous amounts of any metal, and the equivalent nonmagnetic concentrate, where hopeite might be expected to be concentrated, has less than 200 ppm zinc (Hamilton and others, 1974). This casts doubt upon the quantity present and upon the identification of hopeite itself.

The mineralogical identifications of scheelite in sample 293, cuprite in sample 2121, celsian (barium feldspar) in sample 3072, cassiterite in sample 3646, and azurite and malachite in sample 3779 are chemically confirmed through the presence of tungsten, barium, and tin, respectively reported for samples 293, 3072, and 3646 by Hamilton and others (1974), and through the anomalous copper content in samples 2121 and 3779 (table 21). Nickel, a common minor element in ultramafic rocks, is anomalous in sample 2887 (table 21), in which accessory serpentinite was identified.

METALLIC SPHERULES AND TRAMP IRON

Metallic spherules are present in samples 59, 928, 929, 1831, 2121, 2418, and 3646, and tramp iron is in samples 56, 59, 293, 553, 928, 929, 1455, 1867, 2418, 2438, and 3646. Both the spherules and the tramp iron adhere to grains of magnetite by ferromagnetic attrac-

tion, are cemented to the magnetite as particulate encrustations by secondary cementing agents such as hematite or limonite, or occur as loose intergranular particles. The metallic spherules are smooth to scoriaceous, light- to dark-colored metallic particles. The tramp iron is in the form of small metallic slivers evidently derived from the blades and tracks of earth-moving equipment, steel sluice boxes, drill bits, and other tools.

Metallic spherules of various sorts have long been noted in heavy-mineral concentrates from many sources. These spherules have been variously identified as industrial byproducts such as fly ash and welding beads or spatter (Handy and Davidson, 1953; U.S. Army Corps of Engineers, 1961; Fredriksson and Martin, 1963; Charles Milton, written commun., 1972); as fusion products formed by natural processes such as volcanic activity (Fredriksson and Martin, 1963), lightning, and forest fires (Overstreet and others, 1963); or as extraterrestrial material such as meteoric dust, ablation products from iron meteorites, or tektites (Crozier, 1960, 1961, 1962; Finkelman, 1972; Fredriksson and Gowdy, 1963; Kaye and Mrose, 1965; Langway and Marvin, 1964; Schidlowski and Bitzkowski, 1972; Skolnick, 1961; and Thiel and Schmidt, 1961). Much interest attaches to the spherules and tramp iron for their contributions to the minor-element geochemistry of the magnetic concentrates. The origin of the tramp iron is reasonably apparent, but that of the magnetic spherules affords some room for further research and may not be attributable to a single process for all spherules.

More attention to the general distribution of such spherules in Alaskan surficial materials is needed. The scope of the present investigation did not permit resolving with certainty the most probable origin of these Alaskan metallic spherules. The presence of all the observed spherules in concentrates from placer mines (tables 1 and 24), and the association of some of the spherules with tramp iron (tables 21 and 24), are tentatively interpreted to indicate that the spherules probably originated through activities related to placer mining, and that they are welding beads. However, the chemical composition of the metallic spherules casts some doubt on a single-source hypothesis and leaves open the possibility of extraterrestrial origin.

Samples 2121 and 3646 both contain many metallic spherules, which were hand picked under a binocular microscope for analysis. Spherules from sample 2121 are quite clean and bright, whereas those from magnetic concentrate 3646 are dull and rusty. Six subsamples of spherules were prepared from sample 2121 and given the numbers 2121a–2121f. Five were picked from sample 3646 and given the numbers 3646a–3646e. Laser-probe analyses of these metallic spherules were made by J. M. Nishi, U.S. Geological Survey, and the results are given in table 25. Many of the elements commonly associated with particulate matter from welding (Brown and others, 1972, table 5) are lacking in these metallic spherules. However, detailed microscopic and chemical analyses are needed to determine if the spherules are manmade or are of extraterrestrial origin.

TABLE 24.—*Sources of magnetic concentrates containing metallic spherules and tramp iron, Alaska*

File No.	Quadrangle	Source	Fig. No. in Cobb, 1973	Metallic particles present (x) or absent (---)	
				Spherules	Tramp iron
56	Ruby-------	Placer at mouth of Solomon Creek----------	54	---	x
59	----do.----	Placer on Glen Gulch----------	54	x	x
293	Mount Hayes	Placer on Slate Creek----------	8	---	x
553	Hagemeister Island.	Squirrel Creek placer----------	15	---	x
928	Bethel-----	Marvel Creek placer----------	12	x	x
929	----do.----	----do.----------	12	x	x
1455	Livengood--	Amy Creek, cleanup from Mr. Wells' placer--	55	---	x
1831	Iditarod---	Concentrate from Frank Salem Cut, Granite Creek placer.	49	x	---
1867	----do.----	Concentrate from Riley Dredge on Otter Creek	49	---	x
2121	Bethel-----	Sluice concentrate from Marvel Creek placer-	12	x	---
2418	Tanana-----	Sluice concentrate from Johnson and Johnson placer on lower Rhode Island Creek.	47	x	x
2438	McCarthy---	Sluice box concentrate from Chititu Mines placer on Rex Creek.	9	---	x
3646	Circle-----	Sluice box concentrate from H. C. Carstens placer mine on Portage Creek.	43	x	x

TABLE 25.—*Results of laser-probe analyses of hand-picked metallic spherules from placers in Alaska*

[Analyses by J.M. Nishi, U.S. Geological Survey, November 1, 1972; N = not detected at lower limit of determination. Numbers in parentheses below the element symbols show the lower limits of determination]

Subsamples of 2121	Data in percent			Data in parts per million			
	Fe (0.05)	Ca (0.05)	Ti (0.001)	Cu (5)	Pb (20)	Mn (10)	Zr (20)
a	10	0.1	0.01	70	N	1,000	N
b	10	.05	.05	100	N	2,000	N
c	2	N	.07	15	N	1,000	N
d	7	N	.002	N	N	100	N
e	5	N	.07	5	N	1,000	N
f	3	N	.01	N	N	1,000	N
Subsamples of 3646							
a	10	.05	.015	7	30	500	N
b	7	N	.03	N	N	2,000	70
c	20	N	.01	20	N	500	N
d	10	N	.05	5	N	3,000	N
e	15	N	.007	15	N	300	N

[1]Elements that were looked for but not detected are listed here with their lower limits of determination: in percent, Mg, 0.02; in parts per million, Ag, 0.5; As, 100; Au, 5; B, 5; Ba, 5; Be, 0.5; Bi, 20; Cd, 100; Co, 20; Cr, 5; La, 100; Mo, 2; Nb, 10; Ni, 10; Sb, 50; Sc, 20; Sn, 10; Sr, 10; V, 10; W, 50; Y, 50; and Zn, 50.

Tramp iron was hand picked from magnetic concentrate 2418, divided into three parts, and the parts were analyzed spectrographically by E. L. Mosier, U.S. Geological Survey (table 26). The iron, chromium, and manganese contents are within ranges of values that would be expected from steels used in machinery, structural elements, and hand tools around placer mines.

MINERALOGICAL COMPOSITION OF INSOLUBLE RESIDUES

Chemical digestion of the magnetic concentrates in preparation for analysis by atomic absorption was not entirely complete. The mineralogical composition of the residues of the 67 samples was examined in order to determine what minerals and other components of the magnetic concentrates were taken into solution and thereby contributed to the measured content of minor elements, and to determine what components were resistant to digestion and are unlikely to have contributed minor elements. This study showed that the magnetite is largely, but not completely, digested. Ilmenite and rutile, although commonly slightly leached on the surface, are essentially unaffected by the chemical treatment. Such leaching as is present may, in part, be attributed to the solution of magnetite intergrown with the ilmenite or rutile. Hematite coatings, sulfide minerals, and gold were taken completely into solution. No effects could be detected on the quartz, common silicate minerals, and other minerals, except that the quartz and silicates attained a high gloss indicative of the digestion of various surface coatings. Such coatings themselves have been found by other investigators to be sources for trace elements (Chao, 1972; Goni, 1966). Carbonate minerals were dissolved. Generally, the metallic spherules and tramp iron were taken completely into solution. Thus the significant result of the chemical digestion of the magnetic concentrates is that magnetite, hematite, sulfide minerals, native gold, carbonate minerals, metallic spherules, surface coatings, and tramp iron are mainly taken into solution and the other minerals are not.

TABLE 26.—*Results of semiquantitative spectrographic analyses of tramp iron from a placer concentrate from lower Rhode Island Creek, Tanana quadrangle, Alaska*[1]

[Analyses by E.L. Mosier, U.S. Geological Survey, November 13, 1972; G = greater than value shown; L = present, but below limits of determination. Numbers in parentheses below the element symbols show the lower limits of determination]

Subsamples of 2418	Data in percent		Data in parts per million							
	Fe (0.05)	Ti (0.002)	Co (5)	Cu (5)	Ni (5)	Pb (10)	Cr (10)	Mn (10)	Sn (10)	Y (10)
a	G20	L	100	200	300	10	300	1,500	20	20
b	G20	L	70	300	1,000	L	500	1,500	20	15
c	G20	0.002	30	200	300	10	300	1,500	15	15

[1]Elements that were looked for but not detected are listed here with their lower limits of determination: in percent, Ca, 0.05; Mg, 0.02; in parts per million, Ag, 0.5; As, 200; Au, 10; B, 10; Ba, 20; Be, 1; Bi, 10; Cd, 20; La, 20; Mo, 5; Nb, 10; Sb, 100; Sc, 5; Sr, 100; V, 10; W, 50; Zn, 200; and Zr, 10.

Two samples (56 and 293) that had particles of native gold left residues containing more than 1 percent silver chloride crystals, formed artificially as a precipitate from solution. However, the analyses of the solutions themselves disclosed far less than 1 percent silver. The solution from sample 56 had 600 ppm silver and that from sample 293 had only 0.4 ppm silver (table 1). Silver chloride crystals from sample 293 were analyzed spectrographically by E. L. Mosier, U.S. Geological Survey, who reported major silver, minor gold, and traces of silicon, iron, magnesium, manganese, titanium, copper, and mercury.

FREQUENCY OF ASSOCIATION OF ANOMALOUS AMOUNTS OF ELEMENTS WITH SPECIFIC MINERALS

To facilitate the isolation of the probable host minerals or materials for the anomalous concentrations of metals found in the 67 magnetic concentrates, the frequency of association of anomalous elements with specific minerals was determined (table 27) from the data on the 67 magnetic concentrates in table 21. Table 27 shows, for example, that all nine magnetic concentrates containing anomalous amounts of equiv-

TABLE 27.—*Frequency of association of specific minerals with anomalous element content in magnetic concentrates from Alaska, in percent*

[Data on minerals and anomalous elements from table 21]

Elements present in anomalous amounts	Number of samples	Minerals or material							
		Magnetite	Tramp iron	Metallic spherules	Hematitic coating	Ilmenite	Rutile	Pyrite and marcasite	Gold
eU	9	100	11	11	100	55	0	0	11
Ag	15	100	40	40	47	60	7	7	40
Bi	12	100	42	33	67	50	17	8	33
Cd	4	100	50	25	75	100	25	0	50
Co	13	100	38	23	23	38	8	8	23
Cu	30	100	33	23	50	47	3	3	23
Ni	22	100	45	27	27	45	4	9	31
Pb	8	100	50	38	38	63	12	12	50
Zn	23	100	30	26	52	61	9	0	22
None	13	100	0	0	46	46	23	8	0
		Chlorite	Mica	Amphiboles	Garnet	Feldspar	Quartz	Zircon	Other minerals
eU	9	55	66	11	11	78	100	11	22
Ag	15	13	13	20	13	13	53	7	80
Bi	12	50	25	25	8	42	75	8	50
Cd	4	50	25	50	0	25	50	25	75
Co	13	38	31	15	8	8	46	8	46
Cu	30	40	10	17	10	20	70	3	57
Ni	22	40	18	18	9	14	59	4	54
Pb	8	25	25	25	0	0	50	0	63
Zn	23	35	13	13	13	26	61	9	61
None	13	38	23	38	0	38	38	0	62

alent uranium also contain the mineralogical association of magnetite and quartz coated with hematite. This observation supports the data previously presented that hematitic coatings on grains in the magnetic concentrates are the main sources of radioactivity. Similarly, the 13 concentrates lacking anomalous metal content all lack tramp iron, metallic spherules, and gold.

Table 27 can only be used, however, in connection with the mineralogical study that showed the virtual complete insolubility of ilmenite, rutile, chlorite, mica, amphiboles, garnet, feldspar, quartz, zircon, and other silicate minerals, and with the data in tables 22, 23, 25, and 26 showing the trace-element compositions of hand-picked detrital magnetite, native gold, metallic spherules, and tramp iron (table 28).

Magnetite alone could be a sufficient source for anomalous amounts of silver, copper, nickel, lead, and zinc (table 28), but the presence of native gold would add to the values reported for silver, copper, and lead. Further additions to copper and lead would be contributed by the metallic spherules, and the presence of tramp iron would notably raise the values for cobalt, copper, and nickel in the magnetic concentrates.

Undoubtedly these accessory minerals have added to the values reported for these elements, but the accessories are present in only some, not all, of the anomalous concentrates. Thus, detrital native gold is found in 40 percent of the silver-rich concentrates, 23 percent of the cupriferous concentrates, and 50 percent of those with anomalous lead content. Metallic spherules are present in 23 percent of the cupriferous concentrates and 38 percent of those with anomalous lead content. Tramp iron is in 38 percent of the cobalt-rich magnetic concentrates, 33 percent of those with anomalous copper content, and 45 percent of those with anomalous nickel content. As previously stated, tramp iron, metallic spherules, and native gold are lacking from the 13 nonanomalous magnetic concentrates in table 21.

TABLE 28.—*Regional threshold values for eight elements in Alaskan magnetic concentrates compared to possible source minerals*

[All data are in parts per million; -- indicates no data available]

Element	Regional threshold value (table 9)	Estimated mean values			Native gold (table 22)
		Hand-picked magnetite (table 21)	Metallic spherules (table 24)	Tramp iron (table 25)	
Ag	1	1.5	<0.5	<0.5	Major
Bi	14	∿2	<20	<10	--
Cd	1	<2	<100	<20	--
Co	95	∿60	< 20	∿65	--
Cu	25	∿50	∿20	∿230	Minor
Ni	240	∿260	<10	∿500	<10
Pb	60	∿70	∿10	∿10	Minor
Zn	120	∿1,600	∿25	<200	<100

Where there is a one-to-one correspondence between anomalous metal values and a particular source, as between equivalent uranium and the hematitic coating, table 27 is useful in isolating the possible source. The significance of the intermediate percentage values, however, is not so readily apparent. A method to isolate their possible significance can be applied through the use of a system of residuals. If the percentages in table 27 obtained for the 13 nonanomalous magnetic concentrates are assumed to represent normal mineralogical backgrounds, the subtraction of these values from those of the anomalous concentrates should isolate potential host materials of the anomalies. However, the method has the unfortunate effect of eliminating magnetite, because it is present in every magnetic concentrate. As a consequence, conclusions cannot be drawn about what elements are concentrated in the magnetite. However, the values of the residuals given in table 29 further emphasize the roles of tramp iron, metallic spherules, hematitic coatings, and native gold in augmenting or establishing anomalous abundances of these metals. The data in table 29 also support the mineralogical observation that the silicate minerals do not contribute appreciably to the material taken into solution. The large residual for quartz associated with anomalous equivalent uranium is accounted for by the association of quartz with hematitic coatings.

The role of the copper sulfide and copper carbonate minerals, which was revealed in table 21, is obscured by the method of residuals (table 29). For example, magnetic concentrate 3779, with 25,000 ppm copper (table 1), was found to have 5 percent chalcopyrite and traces of azurite and malachite. The accessory chalcopyrite is the principal source for the anomalous copper in sample 3779, but this fact is not made apparent by the residuals.

The 67 magnetic concentrates were divided on the basis of the mineralogical data in table 21 into two groups called normal magnetic concentrates and abnormal magnetic concentrates. The normal concentrates are those in which magnetite is the only or the predominant contributing mineral for the elements listed in table 1. The abnormal concentrates are those containing tramp iron, metallic spherules, and native gold in addition to magnetite. Three samples were omitted from this classification: 2148, because the spectrographic analysis of the hand-picked magnetite (table 22) indicates a possible error in the value for copper reported in table 1; 2438, because it contains

TABLE 29.—*Residuals of association of elements present in anomalous amounts with specific minerals in magnetic concentrates from Alaska*

[Residuals are obtained by subtracting the percentages for nonanomalous samples in table 27 from those for the anomalous samples]

Elements present in anomalous amounts	Minerals or material							
	Tramp iron	Metallic spherules	Hematitic coating	Ilmenite	Rutile	Pyrite and marcasite	Gold	
eU	11	11	54	9	0	0	11	
Ag	40	40	1	14	0	0	40	
Bi	42	33	21	4	0	0	33	
Cd	50	25	29	54	2	0	50	
Co	38	23	0	0	0	0	23	
Cu	33	23	4	1	0	0	23	
Ni	45	27	0	0	0	0	31	
Pb	50	38	0	17	0	4	50	
Zn	30	26	6	15	0	0	22	
	Chlorite	Mica	Amphiboles	Garnet	Feldspar	Quartz	Zircon	Other minerals
eU	17	43	0	11	40	62	11	0
Ag	0	0	0	13	0	15	7	18
Bi	12	2	0	8	4	37	8	0
Cd	12	2	12	0	0	12	25	13
Co	0	8	0	8	0	8	8	0
Cu	2	0	0	10	0	32	3	0
Ni	2	0	0	9	0	21	4	0
Pb	0	2	0	0	0	12	0	1
Zn	0	0	0	13	0	23	9	0

unidentified sulfide minerals sufficient to override values for the metals attributable to magnetite and tramp iron; and 3779, because the anomalous copper content is clearly in accessory chalcopyrite. In addition to the comparison between the normal and the abnormal magnetic concentrates, the values for the metals in hand-picked magnetite were also compared to the values in both the normal and the abnormal magnetic concentrates.

In order to determine the significance of contributions made by the magnetite to the anomalous metals, a statistical test was conducted on the 67 concentrates that were examined mineralogically. The test determines whether the difference between the means of two samples is truly significant or accidental:

$$\sigma_D = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}$$

where σ_D=standard error or deviation of the differences between two sample means
σ_1=standard deviation of the first sample
σ_2=standard deviation of the second sample
N_1=number of observations in the first sample
N_2=number of observations in the second sample

For the purpose of the test, the confidence limit was set at 95 percent, or two standard deviations. Thus, for each element, if the difference between its mean value in the abnormal samples and its mean value in the normal samples is greater than two standard deviations of the differences between their two means, $2\sigma_D$, then it is probable that the difference is significant and not due to chance. If the difference between the means is significant, then the contaminants or particulate gold are the most probable sources of the anomalous values or lead to an enhancement of anomalous values. If, on the other hand, the difference between the means is not significant, then the chances are equal that magnetite is the source of the anomalous elements. These differences are shown in table 30 and discussed by groups of elements below.

COPPER, LEAD, AND ZINC

The results indicate that metallic contaminants, and possibly particulate gold, significantly influence the anomalous values for copper, but for lead and zinc the probability is equal that the anomalous values are produced by the magnetite or by the metallic contaminants and gold. The results of the spectrographic analyses for copper (table 22) in hand-picked grains of magnetite from samples whose original analyses indicated anomalous copper content, also support this conclusion.

Although the test for lead indicates that there is an equal probability of the anomaly being in the magnetite or in the metallic contaminants and gold, too few anomalous values for lead are present to constitute a diagnostic test, and the results of the spectrographic analyses of the hand-picked grains are inconclusive.

The test for zinc appears conclusive, indicating the equal probability of the anomaly being in magnetite or the contaminants. Spectrographic analyses of hand-picked magnetite suggest the presence of high zinc values in magnetite.

SILVER

The results of the tests for silver given in table 30 resemble the results for lead and zinc, suggesting an equal probability that an anomalous content of silver is present in the magnetite or in the contaminants. If, however, the abnormal magnetic concentrates are restricted to those that contain particulate gold, the values for $2\sigma_D$ and $(\overline{A}-\overline{N})$ are changed to 128 and 135 respectively, and a significant difference is found favoring the accessory gold as the source for the anomalous silver. This relation is also seen in the analyses of the nonmagnetic concentrates from Alaska, where silver content is strongly anomalous in the gold-rich samples (Hamilton and others, 1974).

BISMUTH AND CADMIUM

The tests for bismuth and cadmium are inconclusive owing to a lack of sufficient anomalous values; in fact, cadmium values were anomalous in only four samples. However, there is a faint indication that anomalous bismuth values may originate in the metallic contaminants rather than in the magnetite (table 30). For cadmium a possible source in magnetite is suggested (table 30), which may reflect the geochemical association of cadmium and zinc, the latter being enriched in the magnetite.

COBALT AND NICKEL

The tests for cobalt (table 30) resemble those of lead, zinc, and silver and suggest the equal probability of the anomaly being in magnetite or in the contaminants. Spectrographic analyses reported in table 22 support this conclusion, and show that some magnetite has anomalous cobalt content.

The results of the statistical test (table 30) suggest that the metallic contaminants significantly con-

TABLE 30.—*Relations between values for metals in normal and abnormal magnetic concentrates and between normal magnetic concentrates and hand-picked magnetite from the abnormal concentrates, Alaska*

[Means: $\overline{N}$ = normal magnetic concentrates; $\overline{A}$ = abnormal magnetic concentrates; $\overline{H}$ = hand-picked magnetite. σ_1 = standard deviation of the first sample; σ_2 = standard deviation of the second sample. σ_1^2 = variance of the first sample; σ_2^2 = variance of the second sample. N_1 = number of observations in the first sample; N_2=number of observations in the second sample. σ_D = standard error or deviation of the difference between two sample means]

	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn
Normal magnetic concentrate (table 1)								
Total (ppm)	19.8	447	20.2	2,630	1,027.5	5,525	2,480	7,865
No. samples	52	52	52	52	52	52	52	52
Mean ($\overline{N}$ ppm)	0.4	9	0.4	51	20	106	48	151
σ_1^2	0.09	16	0.64	576	400	42,025	22,500	159,201
σ_1	0.3	4	0.8	24	20	205	150	399
Abnormal magnetic concentrate (table 1)								
Total (ppm)	1,224.8	285	8.2	1,940	2,130	5,205	5,715	4,030
No. samples	12	12	12	12	12	12	12	12
Mean ($\overline{A}$ ppm)	102	24	0.7	162	178	434	476	336
σ_2^2	33,856	729	0.49	71,289	25,921	91,204	1,790,244	168,921
σ_2	184	27	0.7	267	161	302	1,338	411
Relation of abnormal magnetic concentrate to normal magnetic concentrate								
$\sigma_D = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}$	53.12	7.81	0.22	77.15	46.56	91.69	386.81	130.91
$2\sigma_D$	106.24	15.62	0.44	154.30	93.12	183.38	773.62	261.82
$\overline{A} - \overline{N}$	101.6	15	0.3	111	158	328	428	185
$2\sigma_D >$ or $< \overline{A} - \overline{N}$	>	>	>	>	<	<	>	>
Difference	None	None	None	None	Significant	Significant	None	None
Hand-picked magnetite (table 22)								
Total (ppm)	1,038.5	50	8	525	457	2,350	5,567	15,000
No. samples	8	8	8	8	8	8	8	8
Mean ($\overline{H}$ ppm)	130	6	1	66	57	294	696	1,875
σ_2^2	129,904	100	0	3,844	10,000	134,689	3,034,564	11,175,649
σ_2	352	10	0	62	100	367	1,742	3,343
Relation of hand-picked magnetite to normal magnetite concentrate								
$\sigma_D = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}$	127.43	3.58	0.1	22.16	35.46	132.83	616.24	1,183.22
$2\sigma_D$	254.86	7.16	0.2	44.32	70.92	265.66	1,232.48	2,366.44
$\overline{N} - \overline{H}$	-129.6	3	-0.6	-15	-37	-188	-648	-1,724
$2\sigma_D >$ or $< \overline{N} - \overline{H}$	>	>	<	>	>	>	>	>
Difference	None	None	Significant	None	None	None	None	None
Relation of hand-picked magnetite to abnormal magnetic concentrate								
$\sigma_D = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}$	138.05	8.55	0.20	80.12	58.39	156.32	726.98	1,187.86
$2\sigma_D$	276.1	17.1	0.4	160.24	116.78	312.64	1,453.96	2,375.72
$\overline{A} - \overline{H}$	-28	18	-0.3	96	121	140	-220	-1,539
$2\sigma_D >$ or $< \overline{A} - \overline{H}$	>	>	>	>	>	>	>	>
Difference	None	Significant	None	None	Significant	None	None	None

tribute to the anomalous values for nickel in the magnetic concentrates, although nickel is known to be a common trace element in magnetite. This conclusion is supported by the results of the spectrographic analyses given in table 22, where all the values for nickel except one (sample 1455) are clearly less than those reported for the whole magnetic concentrate.

EQUIVALENT URANIUM

The data on the mineralogical sources for the radioactivity reported as equivalent uranium in the magnetic concentrates from Alaska are given in tables 10, 11, 19, 21, and 27, where it can be seen that the principal source is hematite, which forms coatings and cement on other minerals in the concentrate. The main minerals with hematitic coatings are magnetite and quartz.

GOLD, INDIUM, AND THALLIUM

Particulate gold, either as a minor mineral included in magnetite at the time of crystallization of the magnetite, or as an accessory mineral trapped in the magnetic concentrate, is thought to be the most probable source for the gold reported in the magnetic concentrates (table 1) despite the very poor correlation between the presence of mineralogically identified native gold and the presence of chemically determined gold (tables 1 and 21). Of the 67 concentrates examined mineralogically (table 21), eight concentrates were found to contain native gold. Only two of these (293 and 3646) had been analyzed chemically, and both contained gold. On the other hand, 11 others among the 67 concentrates had chemically detectable gold, but this gold was not observed in the mineralogical study. How much of the chemically determined gold is actually particulate native gold is, therefore, uncertain.

Indium is known to be geochemically associated with tin in minerals from cassiterite deposits on the Seward Peninsula, Alaska (Sainsbury, 1963; 1964; 1969). Of the 67 magnetic concentrates examined mineralogically, three samples (928, 2729, and 3646) have detectable indium; none contains indium-bearing magnetite (table 22), although one (3646) contains 10 percent cassiterite (table 21) and the other two are from tin-bearing areas (Hamilton and others, 1974). Evidently most of the indium in the cassiterite-rich sample can be attributed to the cassiterite, although the magnetite itself contains 5,000 ppm tin (table 22). In the magnetic concentrates 928 and 2729, which have 20 ppm and 50 ppm tin, respectively (Rosenblum and others, 1974), the indium is probably not in the magnetite, because magnetite from sample 928 lacks indium (table 22). Each of these magnetic concentrates is derived from sources known to contain some cassiterite.

Thallium tends to be associated geochemically with zinc and lead, but among the 67 magnetic concentrates examined mineralogically, neither of the thallium-bearing samples (2978 and 3010) is enriched in zinc or lead (table 1, and Rosenblum and others, 1974). These two samples are from the Seward Peninsula, an area where thallium is generally present in small amounts in rocks and minerals associated with tin deposits (Sainsbury and others, 1968, p. F29), but tin is quite sparse in both the magnetic concentrates (Rosenblum and others, 1974) and in the nonmagnetic concentrates (Hamilton and others, 1974). Accessory sulfide minerals with which the thallium might be associated were not seen in these magnetic concentrates (table 21). Low concentrations of thallium have been noted in endogenetic iron hydroxides (Vlasov, 1966, p. 521); thus, the thallium may be in the hematitic coatings on these samples. Slight support for this interpretation arises from the fact that both samples 2978 and 3010 have hematitic coatings. The coating on 3010 is described (table 20) as heavier than that on sample 2978, and 3010 has slightly more thallium (0.3 ppm) than 2978 (0.2 ppm).

ROLE OF ANOMALOUS ENVIRONMENTS

The preceding data insufficiently reflect the role of anomalous environments as contributors to the contaminants that appear to increase the metal content of magnetic concentrates. Native gold is a contaminant of the magnetic concentrates from placer deposits, which are intrinsically anomalous environments, and it raises the local values for gold and silver in magnetic concentrates. The mining of placer gold results in the further contamination of magnetic concentrates by tramp iron, certainly, and by metallic spherules, possibly. The presence of these contaminants is, then, the result of an anomalous environment, and they tend to raise the values of bismuth, copper, and nickel in the magnetic concentrates above values that might have been obtained if the locality had not been mined. As a consequence, the opportunity for a spurious anomaly in bismuth, copper, or nickel exists, but spurious values can be identified from the mineralogy of the concentrate.

Hematitic coatings and cement on grains of magnetite and quartz are a common contaminant in the magnetic concentrates. These coatings are the principal source for equivalent uranium and may be the source for thallium. However, environments having naturally anomalous radioactivity are necessary to

produce hematitic coatings enriched in equivalent uranium. Thus, the hematitic coatings in the magnetic concentrate indicate whether or not an anomalous environment existed.

Magnetite itself is the probable source for anomalous values in cobalt, nickel, copper, and zinc in the magnetic concentrates. Consequently, environments anomalous in these elements could be directly identified from the magnetic concentrates without need of the additional values for contaminants.

RELATIONS AMONG THE ELEMENTS

CORRELATIONS

Geochemically coherent elements tend strongly to be found together, and in polymetallic mineral deposits there is generally a positive correlation of geochemically coherent elements. That is, a sample enriched in one element tends to be enriched also in associated coherent elements. The degree of dependency is usually measured by correlation coefficients which show a value of +1 for a perfect direct correlation, a value of −1 for a perfect inverse correlation, and a value of 0 for no correlation at all. Values between +1 and −1 indicate degree of direct (positive) or inverse (negative) relations. Because the correlation coefficient is a measure of the degree of association between two elements, a positive correlation coefficient may be used to indicate the value of one element as a pathfinder for less readily detected elements in geochemical exploration.

REGIONAL

The correlation coefficients between the logarithms of the concentrations of the elements in the magnetic concentrates from Alaska are given in table 31. Those values shown as "L" (below the limit of determination), "N" (not detected), or "---" (not determined) in table 1 are not included in the computations for table 31; thus, the correlation coefficients are only approximate. Gold, indium, and thallium pairs represent censored data, and only a few pairs are available for treatment, thus severely weakening the significance of the correlations.

The dependency of the pairs of elements can be classed as very significant positive correlation at the 99 percent confidence level and significant positive correlation of the 95 percent confidence level. These levels are a function of the number of element pairs. An examination of the correlation coefficients in table 31 shows that certain elements tend to be associated in the magnetic concentrates from Alaska:

Very significant positive correlation:	Cu-Pb, Cu-Zn, Cu-Ag, Cu-Co, Cu-Ni, Cu-Au; Pb-Zn, Pb-Ag, Pb-Cd, Pb-Co, Pb-Bi, Pb-Ni, Pb-eU; Zn-Ag, Zn-Co, Zn-Ni, Zn-In; Ag-Co, Ag-Bi, Ag-Ni; Cd-Bi; Co-Ni; Bi-Au, Bi-Eu.
Significant positive correlation:	Pb-Tl, Ag-Au, Ni-Au.

Cobalt and nickel have a very significant positive correlation coefficient of 0.75, showing the strong positive relation between concentrations of cobalt and nickel in magnetic concentrates. These two elements are typically geochemically coherent. Their strong association in the concentrates probably indicates their substitution for Fe^{+2} in the magnetite lattice.

Copper has very significant positive correlation coefficients with silver, lead, zinc, cobalt, nickel and gold. Very significant positive correlation coefficients also exist between lead and silver and between zinc and cobalt. These associations suggest a relation between these elements based on their presence in minor sulfide minerals.

Equivalent uranium has a very significant positive correlation with lead and bismuth. The source of most of the equivalent uranium in the magnetic concentrates is hematitic coatings on other minerals. Doubtless some lead is also present in the exogenetic hematite derived from hydrous iron oxides, which are notorious scavengers of heavy metals (Jenne, 1968). Also of interest is the possible association of the original sources for the lead and the equivalent uranium. Lead tends to be enriched in acidic igneous rocks, as do the radioactive elements, and the bulk of the concentrates showing equivalent uranium are from streams draining granitic rocks which have anomalous lead content (Miller and Grybeck, 1973, p. 3).

The high positive correlation shown in table 31 for equivalent uranium with gold (0.67) is not significant, as it is based on too few samples. The association of equivalent uranium and gold depicts a placer source for the samples with the magnetic concentrate contaminated with gold. Zinc and indium have a very significant positive correlation coefficient (0.56), which may reflect the geochemical association of indium and zinc in sphalerite (Rankama and Sahama, 1950, p. 725). Sphalerite is probably a minor mineral included in the

TABLE 31.—*Correlation coefficients of the logarithms of the concentrations of equivalent uranium and 11 elements, and number of pairs, in 347 magnetic concentrates from Alaska*

[Values on the left side show number of element pairs; those on the right are correlation coefficients]

	eU	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn	Au	In	Tl
eU	eU	0.11	0.27	0.18	-0.24	-0.16	-0.40	0.46	-0.14	0.67	-0.74	0.29
Ag	98	Ag	.22	.10	.31	.54	.30	.36	.21	.43	.11	.27
Bi	120	247	Bi	.29	.03	-.02	-.01	.32	.08	.42	-.23	.36
Cd	94	213	225	Cd	0	-.09	-.06	.33	.01	.09	.39	-.23
Co	123	273	318	242	Co	.45	.75	.20	.41	.23	.38	-.08
Cu	103	247	289	223	316	Cu	.39	.21	.43	.49	.28	.01
Ni	123	273	318	242	347	316	Ni	.15	.28	.31	.37	-.10
Pb	123	273	318	242	347	316	347	Pb	.20	.31	.23	.47
Zn	123	273	318	242	347	316	347	347	Zn	.31	.56	.31
Au	3	29	35	26	40	38	40	40	40	Au	.04	--
In	8	17	19	12	20	18	20	20	20	10	In	--
Tl	22	18	23	15	23	20	23	23	23	0	3	Tl

magnetite, because it was not detected as an accessory mineral in the concentrates (table 21).

Very significant to significant positive correlations are shown in table 31 for copper and gold (0.49), gold and silver (0.43), gold and bismuth (0.42), and lead and thallium (0.47). Many of these could be expected. Copper sulfide minerals may be present in source areas for placer gold, or copper may be alloyed with the native gold. Silver is a common alloy with the Alaskan native gold. The association of bismuth with gold seemingly reflects areas of complex sulfide ores and gold, and the bismuth may be in minor sulfide minerals in the magnetite; it is probably in galena, although the correlation coefficient of bismuth with lead (0.32) is a little lower than that with gold. Bismuth is found in galena but is rarely present in sphalerite (Rankama and Sahama, 1950, p. 740), a condition reflected by the very low positive correlation coefficient found for bismuth with zinc (0.08; table 31). The significant correlation coefficient between thallium and lead, compared to the nonsignificant correlation between thallium and bismuth, lends a little support to the possibility that thallium is in minor inclusions of galena in magnetite.

Cadmium displays no correlation (0.01) with zinc in table 31. This contradicts the well-known natural geochemical association of cadmium with zinc. The reason for this apparent contradiction seems to be analytical bias. Most of the magnetic concentrates contain 0.2–0.6 ppm cadmium. Owing to drift and fluctuation of the meter on the atomic absorption instrument, the values for cadmium in that range are imprecise. In the data in table 1, some high concentrations of cadmium are found in zinc-rich samples: for example, file number 59 from the Ruby quadrangle, number 1867 from the Iditarod quadrangle, and number 1917 from the McGrath quadrangle.

Strong significant negative correlations are shown in table 31 for equivalent uranium and indium (−0.74) and equivalent uranium and nickel (−0.40). Only eight pairs are represented for equivalent uranium and indium; thus, the value of the correlation coefficient may not be reliable. The negative correlation between equivalent uranium and nickel seems readily explained by the types of source rocks with which these two elements are associated. The radioactive magnetic concentrates come from sources in granitic rocks which are lean in nickel. Magnetic concentrates enriched in nickel are derived from ultramafic rocks poor in radioactive elements.

CANDLE QUADRANGLE

Correlation coefficients were computed for equivalent uranium and 11 elements in the 85 magnetic concentrates from the Candle quadrangle. Table 32 shows the results of the correlation analysis. Gold, indium, and thallium are not discussed in this section because they each form no more than three correlated pairs with the other elements. For the other element pairs, the degrees of correlation are again classed as very significant or significant positive correlation related to the number of element pairs. The observed positive correlations are:

TABLE 32.—*Correlation coefficients of the logarithms of the concentrations of equivalent uranium and 11 elements, and numbers of pairs, in 85 magnetic concentrates from the Candle quadrangle, Alaska*

[Values on the left side show number of element pairs; those on the right are correlation coefficients]

	eU	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn	Au	In	Tl
eU	eU	-0.12	0.01	0.38	-0.30	0.13	-0.11	0.14	-0.45	--	--	-1.00
Ag	12	Ag	.23	-.27	.29	.50	.07	.29	.17	1.00	--	--
Bi	16	61	Bi	.25	.24	.40	.09	.16	0	.68	--	.50
Cd	13	47	55	Cd	-.05	-.03	-.03	-.03	-.25	.66	--	--
Co	17	63	80	56	Co	.40	.53	.42	.65	-.95	--	1.00
Cu	15	60	77	54	78	Cu	.27	.45	.32	.52	--	.84
Ni	17	63	80	56	82	78	Ni	.24	.41	-.83	--	.91
Pb	17	63	80	56	82	78	82	Pb	.38	-.15	--	.93
Zn	17	63	80	56	82	78	82	82	Zn	-.76	--	.99
Au	0	1	3	2	3	3	3	3	3	Au	--	--
In	0	1	1	0	1	1	1	1	1	0	In	--
Tl	2	1	2	0	2	2	2	2	2	0	0	Tl

Very significant positive correlation: Cu-Pb, Cu-Zn, Cu-Ag, Cu-Co, Cu-Bi; Pb-Zn, Pb-Co; Zn-Co, Zn-Ni; Co-Ni.

Significant positive correlation: Cu-Ni, Pb-Ag, Pb-Ni, Ag-Co, Co-Bi.

The pairs of elements with very significant positive correlations in magnetic concentrates from the Candle quadrangle are the same as for the regional data, except that the copper-nickel pair has dropped from very significant to significant positive correlation. A stronger copper-bismuth association is found in the Candle area than in the whole group, reflecting, possibly, the presence of polymetallic sulfide deposits (Miller and Elliott, 1969) and, certainly, bias in the samples toward mineralized areas. Equivalent uranium shows negative correlations with cobalt, nickel, and zinc in the Candle quadrangle as well as in the region as a whole. The classical trace-element geochemistry of igneous rocks would explain the inverse relation of the radioactive material with cobalt and nickel, but it is quite unexpected to find that zinc seemingly is not enriched in the hematitic coatings which provide the radioactivity. Inasmuch as the abundances of cadmium in the magnetic concentrates from the Candle quadrangle are in the range of values associated with instrumental noise, its negative correlations with most elements in table 32 are not reliable.

SOLOMON QUADRANGLE

Correlation coefficients of minor elements in 101 magnetic concentrates from the Solomon quadrangle, Alaska, are given in table 33. Again, the three elements gold, indium, and thallium are excluded from the following discussion because of the few pairs represented in the data set for the Solomon quadrangle. Using the same two degrees of correlation as previously, it is seen that many pairs have significant positive correlation coefficients:

Very significant positive correlation: Co-Ni, Cu-Ni, Pb-Zn, Pb-Bi, Pb-eU, Bi-eU.

Significant positive correlation: Pb-Cd, Zn-Co, Cd-Bi.

The very high positive correlation of the pair cobalt-nickel, characteristic of the whole data set, is excellently shown in the magnetic concentrates from the Solomon quadrangle, where the correlation coefficient is 0.83 (table 33). These elements are reported (Miller and Grybeck, 1973, p. 6) to be enriched in stream sediments derived from plugs and dikes of diabase. Possibly the strong correlation coefficient for them in the concentrates also is a reflection of sources in mafic rocks.

Equivalent uranium shows a consistent high positive correlation with lead (tables 31–33). The correlation coefficient for this pair reaches its greatest value, 0.54, in the Solomon quadrangle, from which the largest number of Alaskan radioactive magnetic con-

TABLE 33.—*Correlation coefficients of the logarithms of the concentrations of equivalent uranium and 11 elements, and numbers of pairs, in 101 magnetic concentrates from the Solomon quadrangle, Alaska*

[Values on the left side show number of element pairs; those on the right are correlation coefficients]

	eU	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn	Au	In	Tl
eU	eU	0.10	0.34	0.17	-0.22	-0.15	-0.37	0.54	0.08	1.00	-0.79	0.22
Ag	64	Ag	.05	-.22	.07	.01	-.02	.08	.14	1.00	.01	-.23
Bi	80	77	Bi	.25	-.09	.06	-.22	.35	.07	--	-.90	.37
Cd	59	63	71	Cd	.07	-.16	0	.29	0	--	--	-.23
Co	80	78	101	71	Co	.18	.83	-.16	.22	1.00	.25	-.16
Cu	65	63	83	58	83	Cu	.27	-.11	-.04	--	--	.05
Ni	80	78	101	71	101	83	Ni	-.25	.08	.97	.05	.03
Pb	80	78	101	71	101	83	101	Pb	.22	-.92	.06	.39
Zn	80	78	101	71	101	83	101	101	Zn	-.26	.18	.17
Au	2	2	4	1	4	4	4	4	4	Au	--	--
In	5	5	5	3	5	3	5	5	5	1	In	--
Tl	19	15	19	13	19	16	19	19	19	0	2	Tl

centrates were collected. Anomalous amounts of lead are present in stream sediments derived from granitic plutons and the contact zones of these plutons in areas of above-normal radioactivity (Miller and Grybeck, 1973, p. 5–6). The association is genetic, as the source for both the lead and the radioactive elements is granite, but the correlation is enhanced by exogenetic processes that have added radioactive hematitic coatings to grains of magnetite. Equivalent uranium also has a very significant positive correlation coefficient with bismuth (table 33). This may be related to the association of bismuth with lead, indicated in table 33 by the very significant correlation coefficient of 0.35 between lead and bismuth, and to the association of bismuth with the metamorphic rocks that are adjacent to the granitic plutons, as shown by samples of stream sediments (Miller and Grybeck, 1973).

The very significant negative correlation between equivalent uranium and nickel in magnetic concentrates from the Solomon quadrangle (table 33) confirms the relation brought out in the regional data (table 31), and reflects the geochemical differences between the granitic source rocks of the radioactive elements and the mafic and ultramafic sources of the nickel.

Copper in magnetic concentrates from the Solomon quadrangle is negatively correlated with lead and zinc (table 33). Magnetic concentrates from the Solomon quadrangle are notably deficient in copper compared to the regional average (table 8) and have similar to slightly lower means for lead and zinc. These characteristics of distribution are borne out by the negative correlation coefficient. However, copper has a very significant positive correlation (table 33) with nickel (0.27). Lead has very significant positive correlations with bismuth and zinc, but lead is negatively correlated with cobalt and nickel (table 33).

Similar relations for copper, lead, zinc, cobalt, and nickel are described for stream sediments from the Solomon quadrangle (Miller and Grybeck, 1973, p. 5–6), and are related to source rocks. The significant association of copper with nickel is related to sources in diabase dikes and plugs, whereas the lead and zinc are related to sources in granitic plutons. However, in the data from the magnetic concentrates (table 33), zinc shows no significant correlation with nickel, but it has a significant positive correlation coefficient (0.22) with cobalt.

Although the magnetic concentrates from both the Candle and Solomon quadrangles are partly derived from granitic rocks, the mean contents of copper and zinc (table 8), as well as the associations of copper, lead, and zinc (tables 32 and 33) are quite different in the two areas. This may indicate fundamental differences in the compositions of the granitic rocks in the two areas. The magnetic concentrates that have high values for equivalent uranium are derived from alkalic plutons. Alkalic plutons seem to be deficient in copper, and to yield magnetic concentrates that have no correlation or negative correlation between copper and lead and between copper and zinc.

PROMINENT GEOCHEMICAL HIGHS

The varied distribution of anomalous amounts of metals in magnetic concentrates from Alaska is shown

in table 1. The table is not intended for use in defining areas of anomalous metal content, because for some quadrangles only a few concentrates have been analyzed, and most of those samples were taken at known mineralized areas. For several quadrangles, only single concentrates have been analyzed, and they also are apt to be from known mineralized areas.

The data in table 1 show that copper anomalies occur in 82 percent of the 33 quadrangles, and zinc anomalies occur in 70 percent; the other 10 elements reach anomalous concentrations in no more than half (17) of the quadrangles. Possibly the ease with which copper and zinc can substitute for Fe^{+2} in magnetite accounts for their more common occurrence in anomalous amounts in the magnetic concentrates. Their presence may also be related to the geochemistry of the source region. Gold, indium, and thallium are poorly represented in table 1, partly because only 131 of the 347 magnetic concentrates were analyzed for these elements. Of the other nine elements, equivalent uranium, bismuth, and cadmium are the least commonly anomalous and the least widespread. About half (52 percent) of the quadrangles yielded lead-rich magnetic concentrates. Lead does not readily replace iron in magnetite, but it may be associated with silver in accessory sulfide minerals and gold, as it has approximately the same percent frequency of anomalous occurrences as silver. Cobalt and nickel can readily substitute for iron in magnetite, but despite this geochemical advantage, cobalt anomalies are present in only 42 percent of the quadrangles and nickel anomalies occur in 48 percent. However, these anomalies are more common in samples from mafic provenances, whereas the majority of the analyzed samples are from granitic provenances. Silver and gold contents also tend to be more frequently anomalous in magnetic concentrates from specific areas. Thus, certain general areas in Alaska yield magnetic concentrates that are characterized by particularly prominent geochemical highs. These localities are summarized below under the major regional divisions used in discussions of the distribution of the elements.

COPPER AND SILVER IN SOUTHEASTERN ALASKA

Notable anomalies for copper and silver are found in six of the nine samples collected in the Ketchikan quadrangle in southeastern Alaska.

MULTIELEMENT HIGHS IN SOUTHERN ALASKA

A number of prominent highs for various multielement combinations of copper, zinc, silver, cobalt, and nickel are present in magnetic concentrates from quadrangles in southern Alaska. High values for copper, zinc, and gold are found in samples from the McCarthy quadrangle (table 1); copper and silver have anomalously high associated values in the Valdez quadrangle; zinc anomalies are present in concentrates from the Anchorage, Talkeetna, and Talkeetna Mountains quadrangles; and cobalt and nickel attain high values in samples from the Mount Hayes quadrangle.

BASE METALS IN SOUTHWESTERN ALASKA

Magnetic concentrates from the Bethel and Iliamna quadrangles in southwestern Alaska yield anomalously high values for the base metals (table 1). Prominent highs are found for copper and zinc, with associated silver and gold along Marvel Creek and Cripple Creek, which are tributaries to the Salmon River in the Bethel quadrangle. The northern shore of Iliamna Lake in the Iliamna quadrangle is the source of the most copper-rich sample listed in table 1.

WEST-CENTRAL ALASKA

EQUIVALENT URANIUM IN THE BENDELEBEN, CANDLE, AND SOLOMON QUADRANGLES

The principal sources of radioactive magnetic concentrates are in the Bendeleben, Candle, and Solomon quadrangles, although measurable equivalent uranium was detected in samples from several other areas (table 1). In the Bendeleben and Solomon quadrangles the concentrates have 40 to 560 ppm equivalent uranium, but most of the values are in the range from 120 to 140 ppm. In the Candle quadrangle the equivalent uranium ranges in value from 40 to 160 ppm with a mean of 65 ppm. The magnetic concentrates with the highest radioactivity are from tributaries to Clear Creek in the northeastern part of the Solomon quadrangle. The sources are alkalic granitic rocks of Middle Cretaceous to Late Cretaceous age (Miller and others, 1972, p. 5–7) having affinities with the alkalic rocks of the Candle quadrangle, which are the sources of somewhat less radioactive magnetic concentrates. The most radioactive concentrates from the Candle quadrangle are derived from the northwestern margin of the Granite Mountain pluton. Miller (1970) described this pluton as consisting of a core of equigranular quartz monzonite surrounded successively outward by massive to porphyritic monzonite, nepheline syenite, and garnet syenite. Samples from the core lack radioactivity or are only weakly radioactive. The most radioactive samples are from the outer wall of the pluton. According to Miller (1970), CaO, MgO, FeO, and Fe_2O_3 increase outward in the pluton as SiO_2 decreases. Possibly the increasing radioactivity of the magnetites, which is parallel to this outward variation in the

composition of the pluton, is related to the changing calcium content of the pluton.

LEAD, COBALT, BISMUTH, AND OTHER ELEMENTS

Magnetic concentrate 59 from Glen Gulch in the Ruby quadrangle, west-central Alaska, yields the highest values for lead (4,700 ppm), cobalt (1,000 ppm), and bismuth (90 ppm) in this set of samples. Other metals in the same sample, including copper, zinc, cadmium, nickel, and silver, are also abundant. Poorman Creek in the same quadrangle has yielded anomalously high values in silver, bismuth, copper, nickel, and lead, but no samples from this area are included in this report.

There are prominent high values for silver, bismuth, copper, nickel, and zinc in samples from the Iditarod quadrangle. One of these samples is also enriched in lead and cadmium.

Unusually high values for cobalt and nickel are present in two concentrates (400 and 3041, table 1) from the Bendeleben quadrangle.

Cape Creek in the Teller quadrangle is the source of a magnetic concentrate (497) which contains high values for zinc and bismuth. Indeed, west-central Alaska is a bismuth province.

SILVER AND GOLD IN EAST-CENTRAL ALASKA

High values for silver and gold are common in magnetic concentrates from the Circle, Eagle, Livengood, and Tanana quadrangles in east-central Alaska (table 1). Nickel and zinc are also enriched in samples from the Livengood quadrangle, and bismuth attains a high value in the only concentrate from the Circle quadrangle.

GEOLOGIC AND GEOCHEMICAL INTERPRETATION

REGIONAL

The most probable modes of occurrence for anomalous element content in the magnetic concentrates are as follows (table 34):

(1) silver, copper, lead, zinc, cobalt, and nickel substituted for iron in the magnetite structure;
(2) equivalent uranium, copper, lead, and zinc held by surface sorption on magnetite;
(3) copper, cadmium, gold, indium and thallium in trace minerals; and
(4) equivalent uranium, silver, bismuth, cadmium, copper, gold, indium, and thallium in accessory minerals.

TABLE 34.—*Summary of probable modes of occurrence of elements present in anomalous amounts in magnetic concentrates from Alaska*

[X = occurrence likely from data; -- = occurrence unlikely from data; E = equal probability between substitution and accessory minerals; n.d. = no data or insufficient data]

Possible mode of occurrence	Source of evidence	Elements present in anomalous amounts											
		eU	Ag	Bi	Cd	Co	Cu	Ni	Pb	Zn	Au	In	Tl
Substitution in magnetite	Literature	--	X	--	--	X	X	X	--	X	--	--	--
	Geol. assoc.[1]	--	--	--	--	X	X	X	--	X	--	--	--
	Mineralogy	--	--	--	n.d.	E	--	--	E	E	n.d.	n.d.	n.d.
	Correlation[2]	--	X	--	--	X	X	X	--	X	--	n.d.	n.d.
Surface sorption----	Literature	X	n.d.	n.d.	n.d.	n.d.	X	n.d.	X	X	--	n.d.	n.d.
	Geol. assoc.[1]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Mineralogy	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Correlation[2]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Trace minerals----	Literature	X	X	X	X	X	X	X	X	X	X	X	X
	Geol. assoc.[1]	X	X	n.d.	X	X	X	X	X	X	X	X	X
	Mineralogy	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Correlation[2]	--	X	X	n.d.	X	X	X	X	X	X	X	X
Accessory minerals----	Literature	X	X	X	X	n.d.	X	n.d.	X	X	X	X	X
	Geol. assoc.[1]	X	X	X	X	X	X	X	X	X	X	X	X
	Mineralogy	X	X	X	n.d.	E	X	X	E	E	n.d.	n.d.	n.d.
	Correlation[2]	X	X	X	n.d.	X	X	X	X	X	X	n.d.	n.d.

[1]Geologic association in mineral deposits or occurrences.
[2]Abundances and correlation coefficients.

Although the mineralogical studies (table 30) suggest that anomalous amounts of cobalt and nickel could occur either in substitution for iron or in accessory minerals, the high correlation coefficient for this pair of elements (table 31) favors the substitution mode. Mineralogical data also show an equal probability that lead and zinc are present in substitution for iron in the magnetite structure or in accessory minerals in the magnetic concentrate. The least probable mode of occurrence shown in table 34 is substitution of bismuth, gold, indium, and thallium in the structure of magnetite.

The data in table 34 indicate that the least understood aspect of minor elements in magnetite is the role of surface sorption. Research is needed to determine the effect of sorption on magnetic concentrates used as a geochemical sample medium.

The enrichment of trace elements in detrital magnetite or in magnetic concentrates does not necessarily mean that the source rocks have a superior potential for economic mineralization. The metal-bearing ore solutions may have been dispersed instead of concentrated if conditions were not favorable for the deposition of ore. However, the anomalously high contents of minor elements are guides to areas deserving further exploration, because many of the anomalous concentrates are derived from areas of known lode or placer deposits or mineral occurrences. The mineralized areas are well reflected by the regional data in table 1. The significance of these data is made more manifest in table 35 which shows how many known deposits of each type of metal are associated with anomalous magnetic concentrates, and in table 36, where the data are grouped by associations of metals in known lode deposits or mineral occurrences.

Twenty-four of the 36 copper deposits are associated with copper-rich magnetic concentrates (table 35); the other 12 are reflected by anomalous lead, zinc, silver, cobalt, or nickel content. The 19 lead-bearing deposits are reflected in only eight magnetic concentrates with anomalous lead content, but they are completely reflected by various combinations of anomalous amounts of base metals, silver, or gold (table 1). Magnetic concentrates collected near 10 of the 13 zinc deposits have anomalous zinc content, and samples from near the other three deposits are anomalous in other metals. Of interest is the number of tungsten deposits or occurrences associated with magnetic concentrates that contain anomalous amounts of copper (table 35). This geochemical association is one that requires follow-up investigations to determine if skarn-type tungsten-copper deposits or porphyry-type deposits may contribute some of the copper.

Very strong correlations are found between polymetallic lode deposits or occurrences and anomalous metal content in the magnetic concentrates (table 36). Indeed, the polymetallic deposits seldom lack accompanying anomalous magnetic concentrates.

Magnetic concentrates may be used satisfactorily as a sample medium for geochemical exploration in subarctic and arctic environments. The data presented here show that anomalous amounts of copper and zinc indicate sulfide mineralization; where combined with other anomalous amounts of elements such as silver, bismuth, and lead, they indicate polymetallic sulfide deposits. Anomalous silver content usually indicates silver and gold deposits, mainly gold. Anomalous cobalt and nickel content usually indicates the presence of chromite and, locally, sulfide deposits associated with mafic and ultramafic rocks. Anomalous amounts of lead and gold usually indicate lead

TABLE 35.—*Number and type of known mineral deposits or occurrences located near anomalous magnetic concentrates in Alaska*

[Data from table 1; numbers in parentheses represent high-background but nonanomalous samples; RE = rare-earth minerals; FM = minerals with fissionable materials]

Type of mineral deposit or occurrence	Total number of deposits	Anomalous element content in nearby samples									
		eU	Cu	Pb	Zn	Ag	Bi	Co	Ni	Cd	Au[1]
RE and (or) FM	24	11(1)	1(1)	3(7)	6(4)	1(4)	11	0(1)	3(1)	0	0(1)
Copper	36	2(1)	24	9(1)	20(2)	7(6)	7(1)	6(2)	11	2	3
Lead	19	0	13	8	9(1)	3(4)	4	3	4	2	0(1)
Zinc	13	1	11	5	10(1)	4(3)	4	2(1)	0	2	1
Silver	22	0	14	7	11(1)	6(4)	6	4(1)	8	2	1
Bismuth	6	1	4	2	2(1)	2(1)	3	0	1	0	2
Cobalt	1	0	1	0	1	1	1	0	1	0	0
Gold	77	3	43(3)	23	34(7)	22(12)	21(1)	11(2)	27(1)	5	20(5)
Mercury	14	0	10	6	10(2)	5(1)	5	2	7	2	4
Tungsten	33	4(1)	16(1)	10	12(5)	9(2)	8	3(2)	10(1)	3	7(1)

[1]Incomplete data.

TABLE 36.—*Number and type of polymetallic deposits or occurrences located near anomalous magnetic concentrates in Alaska*

[Data from table 1; numbers in parentheses represent high-background but nonanomalous samples]

Type of lode deposits	Total number of deposits	Anomalous element content in nearby samples						
		Cu	Pb	Zn	Ag	Bi	Co	Ni
Cu-Zn-------	1	1	0	1	0	0	0	0
Cu-Au-------	3	1	2	0(1)	0	0(1)	1	1
Cu-Bi-------	1	0	0	0	0	1	0	0
Cu-Pb-Ag----	3	2	0	1	0	0	1	1
Cu-Zn-Ag----	1	1	0	1	0	0	0(1)	1
Cu-Pb-Zn----	1	1	0	1	0	0	1	0
Cu-Ag-Au----	2	1	0	1	1	0	1	1
Cu-Pb-Zn-Ag-	1	1	0	1	0(1)	0	0	0
Cu-Bi-Au-W--	1	1	0	0	0	0	0	0
Bi-Au-W-Sb--	1	1	0	1	0	0	0	0
Co-Au-------	1	1	0	1	1	1	0	1
Pb-Sb-------	1	1	0	0	0	0	0	0
Polymetallic	9	7	6	6(1)	4(2)	4	1	4
Totals------	26	19	8	14(2)	6(3)	6(1)	5(1)	9

sulfide deposits and gold deposits, but not all lead and gold deposits have corresponding anomalous values for lead and gold in magnetic concentrates. Lead and gold content in the magnetic concentrates is more due to chance than are the concentrations of the elements above. However, lead and gold deposits are often indicated by anomalous amounts of copper, zinc, and silver. As this investigation shows, copper and zinc in the magnetic concentrates are useful pathfinders for base-metal and precious-metal deposits; cobalt and nickel are useful pathfinders for ultramafic rocks; and equivalent uranium may indicate alkalic granitic rocks.

CANDLE QUADRANGLE

The copper, lead, zinc, gold, silver, and bismuth content in magnetic concentrates from the Candle quadrangle is generally greatest near the contacts of the granitic bodies with their wall rocks or in fractured areas of the wall rocks. A possible explanation is that these are the elements that largely remain in the residual magma throughout the main stage of crystallization. In the following stages of crystallization the late solutions enriched in these metals tend to move toward low-pressure areas such as faults and fractures, carrying with them, or precipitating, magnetites enriched in these elements. Thus, the concentrations of the minor elements in the magnetic concentrates can probably be used not only as guides to the loci of possible mineralization, but also for an interpretation of the directions of flow of the metal-bearing solutions. For example, during the intrusion of the Granite Mountain pluton into its wall rocks, the residual solutions appear to have moved toward low-pressure areas to the north and northeast of the intrusive, identified by faults and fractures in the wall rock, and deposited various base and precious metals. In this same pluton, high values for equivalent uranium in the magnetic concentrates are confined to the area of the pluton. This may be because the radioactive elements are incorporated in accessory minerals in the granitic rock rather than in vein minerals.

Similar distributions of the minor metals are found in magnetic concentrates from the area of the Hunter Creek pluton. The high values for copper, lead, and zinc in the southern and southwestern parts of the Hunter Creek pluton may indicate the migration of minor elements along pressure and temperature gradients toward these areas, leaving only uneconomic disseminated deposits or uneconomic veinlets in the pluton.

SOLOMON QUADRANGLE

The minor-element contents of the magnetic concentrates from the Solomon quadrangle are quite different from those of the Candle quadrangle, although granitic rocks are dominant sources in both quadrangles. Except for bismuth and equivalent uranium, the abundances of the minor elements are remarkably low in the concentrates from the Solomon quadrangle. Thus, fundamental differences exist between the trace-element geochemistry of the granitic plutons in the Solomon quadrangle and those in the Candle quadrangle. The minor elements are so sparse in the magnetic concentrates from the plutons in the Solomon quadrangle, it seems likely that these rocks are barren of base metal deposits. Even where the base metals are enriched in the wall rocks of the plutons in the Solomon quadrangle, the values are much lower—particularly for copper—than in similar settings in the Candle quadrangle.

Some of the magnetic concentrates with anomalous amounts of minor elements are from metamorphic rock terrane in the Solomon quadrangle. During metamorphism, most minor elements would be locally released during mineral phase transformations. Although remaining largely in place, these minor elements can be expected to follow Goldschmidt's rules for camouflage, admission, and capture by the crystal lattices of newly formed minerals. Owing to the high degree of disorder of crystal structures during metamorphism, a greater tolerance for minor elements may be possible in metamorphic magnetites than in magnetites of igneous origin.

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