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Interpretation of Exploration Geochemical Data from the Ugashik, Bristol Bay, and Western Karluk Quadrangles, Alaska

By S. E. CHURCH, J. G. FRISKEN, and F. H. WILSON

U.S. GEOLOGICAL SURVEY BULLETIN 1858

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Interpretation of Exploration Geochemical Data from the Ugashik, Bristol Bay, and Western Karluk Quadrangles, Alaska

By S.E. Church, J.G. Frisken, *and* F.H. Wilson

ABSTRACT

Analysis of the geochemical data obtained from exploration geochemical studies of the Bristol Bay, Ugashik, and western Karluk quadrangles, Alaska, defines the general limits of several porphyry copper-molybdenum target areas, at least some of which were previously known. Widespread geochemical anomalies and hydrothermally altered rock are associated with an inferred Oligocene to Pliocene intrusive complex in the southern part of the Ugashik-Karluk study area. Two of these areas, one a porphyry copper-molybdenum system associated with a composite Oligocene intrusion (the Rex prospect), and the other a porphyry molybdenum system associated with Pliocene intrusive activity (the Mike prospect), are outlined by copper-molybdenum-tungsten anomalies, surrounded by drainage basins containing base- and precious-metal anomalies. Of the two areas, the Mike prospect appears to have the more favorable geochemical expression for mineralization. Aeromagnetic studies of this area suggest several buried plutons beneath these and adjacent geochemical anomalies. Suites of elements present suggest porphyry-type mineralization. Further examination of several of these areas may be warranted.

Additional evidence of mineralization is associated with an area of possible hydrothermal alteration on Cape Igvak and may be associated with a pluton of Pliocene age. Miocene mineralization on Cape Kubugakli appears to be restricted to quartz veins within the outcrop pattern of intrusive rocks. The intrusive rocks appear, from the aeromagnetic anomaly, to extend offshore to the east. Cape Kubugakli has produced an estimated 5 kg (160 oz) of placer gold.

Factor analysis of the stream-sediment data defines one general mineralization factor, whereas the data from the nonmagnetic heavy-mineral concentrates panned from stream sediments define several mineralization factors. Two of the factors defined by the stream sediments outline areas of hydrothermal alteration; a zone of propylitic alteration associated with the early Tertiary volcanic and hypabyssal rocks is suggested by boron in the nonmagnetic heavy-mineral concentrates.

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INTRODUCTION

The U.S. Geological Survey is required by the Alaska National Interest Lands Conservation Act (ANILCA, Public Law 96–487) to survey certain Federal lands to determine their mineral resources. As a part of the Alaska Mineral Resource Assessment Program (AMRAP), a multimedia, multidisciplinary study of the geology, geophysics, and geochemistry of the Ugashik, Bristol Bay, and western Karluk quadrangles (together referred to as the "Ugashik-Karluk study area" in this report) was undertaken during the summers of 1979–1982. Two days of additional work were done in the summer of 1986. This report presents an interpretation of the semiquantitative geochemical data collected during the course of this investigation. We refer extensively to geochemical maps (Church and others, 1988; Frisken, Church, and others, 1988; Wilson and O'Leary, 1986, 1987) and to mineralogical maps of the nonmagnetic heavy-mineral concentrates panned from stream sediments (Frisken, Church, and Willson, 1988). In addition, we have included results of evaluations of the Mike and Rex properties made by the exploration group at the Kennecott Corporation.

Geographic Setting

The Ugashik-Karluk study area is on the Alaska Peninsula (fig. 1) between lat 56° and 57° N. The northern boundary of the study area cuts across Becharof Lake and the southern boundary is just north of Aniakchak Crater. The eastern and western boundaries

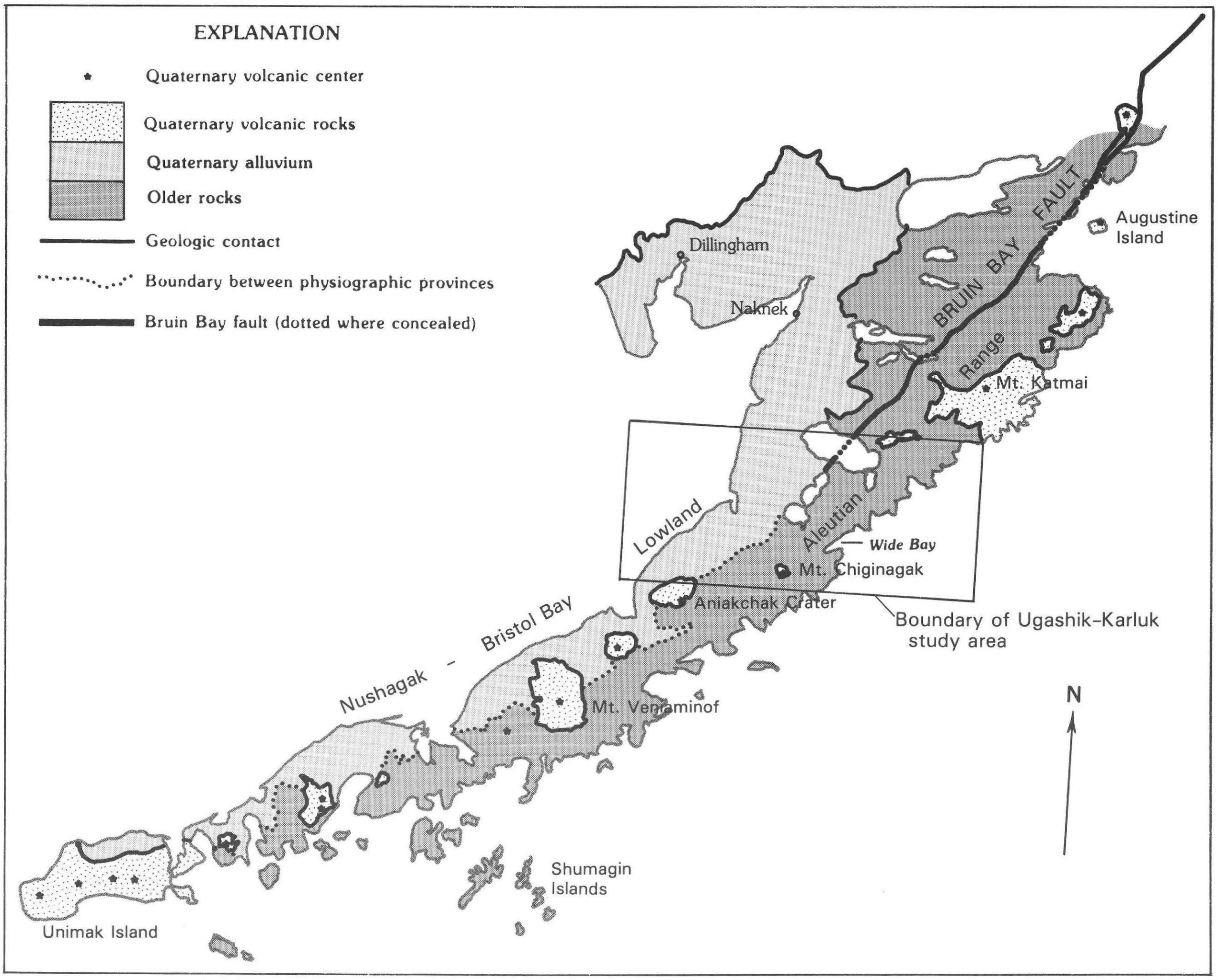


Figure 1. Index map of the Alaska Peninsula showing location of the Ugashik-Karluk study area, Ugashik, Bristol Bay, and western Karluk quadrangles, Alaska. Physiographic provinces, major faults, Quaternary volcanoes, and major geographic features of the Alaska Peninsula are shown for reference.

of the study area are the coast lines. Two physiographic provinces are present: the Nushagak–Bristol Bay Lowland, along the coast of Bristol Bay, and the Aleutian Range (Wahraftig, 1965). The Nushagak–Bristol Bay Lowland is characterized by broad coastal plains, low topographic relief, many bogs and small lakes, and slow, meandering streams. Few samples were collected in this province. In sharp contrast, the Aleutian Range is composed of Quaternary volcanic cones, flows, and stratovolcanoes that partly cover older sedimentary and igneous rocks. Elevations exceed 2,000 m (6,500 ft) at Mount Chiginagak. Streams in the Aleutian Range follow steep gradients down youthful valleys. Glaciers are present on some of the dormant volcanic peaks, where ice flows to elevations below 300 m (1,000 ft) on the coast of Wide Bay. The Aleutian Range ends abruptly at the Pacific coast, but the rocks that form the Aleutian Range appear to extend offshore into Shelikof Strait (Burk, 1965; Detterman and others, 1983; von Huene and others, 1985). The axis of the Aleutian Trench is about 320 km (200 mi) to the southeast, off the Pacific coast of Kodiak Island (Jacob and others, 1977; von Huene and others, 1985).

Regional Geologic Setting

The Alaska Peninsula marks the transition zone between the volcanic island arc of the Aleutian Islands and the continental magmatic arc of southern Alaska. At the northern end of the Alaska Peninsula, what has been defined as the "Alaska Peninsula terrane" is structurally separated into the Iliamna and Chignik subterranes by the Bruin Bay fault, north of Becharof Lake (Wilson and others, 1985). This fault was intermittently active from Late Jurassic time to Middle Tertiary time (Detterman and others, 1987). South of Becharof Lake all exposed Mesozoic rocks belong to the Chignik subterrane. The southernmost exposure of the Iliamna subterrane is on one small island on the south side of Becharof Lake.

The Nushagak–Bristol Bay Lowland is dominantly composed of unconsolidated Quaternary alluvium and glacial deposits; however, small areas of late Tertiary and Quaternary volcanic rocks are present (Detterman and others, 1983, 1987). Plutonic rocks of Jurassic to middle Tertiary age, which form the Alaska–Aleutian Range batholith, are exposed north of lat 57° N. (Reed and Lanphere, 1969, 1973). They are also known to occur in the subsurface to the south (Brockway and others, 1975). These rocks intrude a thick section of Mesozoic and Tertiary clastic sedimentary rocks recording fore-arc basin sedimentation. The Mesozoic sedimentary rocks were derived largely from the erosion of the Jurassic volcanic arc and batholith, and they include shale, siltstone, sandstone, and conglomerate deposited in a nonmarine and nearshore marine environment; some deep-water turbidite occurs in the Middle Jurassic (Callovian) Shelikof Formation (Allaway and others, 1984; Detterman and others, 1987). Some volcanic tuffs and agglomerate are preserved in the Lower Jurassic Talkeetna Formation (Detterman and others, 1987).

Minor folding and uplift of the Mesozoic sedimentary rocks occurred prior to early Tertiary volcanism. Starting in the early Eocene, calc-alkaline volcanism commenced forming the Meshik arc (Wilson, 1985). This early phase of volcanic and intrusive activity was followed by a second pulse beginning in the late Miocene forming the Aleutian volcanic arc (Burk, 1965; Wilson and Shew, 1988; Detterman and others, 1983, 1987; Wilson, 1985). Most of the folding and faulting on the Alaska Peninsula commenced in Miocene time and continued through Quaternary time. For a regional summary of the stratigraphy of the Alaska Peninsula, the reader is referred to Wilson and others (1985).

Mineral Occurrences on the Alaska Peninsula

Known mineral occurrences on the Alaska Peninsula are dominated by porphyry-type copper-molybdenum sulfide systems. For the Chignik–Sutwik Island study area, immediately to the south, Wilson and Cox (1983) described porphyry mineralization associated with early Tertiary to Quaternary rocks of intermediate composition that intrude marine and nonmarine clastic rocks. Copper- and molybdenum-rich porphyry systems are characterized by drainage basins in which stream sediments are anomalous in copper and molybdenum, usually associated with tungsten, surrounded by drainage basins in which stream sediments are anomalous in lead, zinc, bismuth, arsenic, and precious metals. Drainage-basin anomalies show overlapping, zoned geochemical patterns. Rocks exposed in these basins typically show argillic, sericitic, or phyllic alteration associated with veins and disseminated molybdenite, chalcopyrite, and scheelite. Surrounding the exposures of intense alteration are zones of propylitically altered rock containing both disseminated and vein pyrite and lesser amounts of galena, sphalerite, arsenopyrite, precious metals, barite, and tourmaline. Minor gold is commonly associated with the porphyry systems, and some placer gold may be found in streams surrounding the centers of mineralization. Weathering and oxidation of exposed pyrite commonly produces characteristic yellow-brown and reddish color anomalies. Our observations indicate that similar geologic and geochemical features are associated with possible centers of mineralization in the Ugashik-Karluk study area.

Acknowledgments.—We thank the Kennecott Corporation and Koniag Incorporated for permission to use their unpublished geologic mapping and geochemical data from the Mike and Rex prospects in this report. A.L. Miesch and R.R. Tidball reviewed portions of the manuscript and made valuable comments on the discussion of the statistical data. Their contributions to the manuscript are appreciated.

GEOLOGY OF THE UGASHIK-KARLUK STUDY AREA

Geologic mapping in the Ugashik-Karluk study area by Detterman and others (1983, 1987) forms the geologic base for the interpretations made in this bulletin (fig. 2). The description of the stratigraphy (fig. 3) has been simplified for the purpose of clarity.

The oldest rocks exposed in the Ugashik-Karluk study area are Permian limestone (Hanson, 1957) that crops out on a small island offshore of Cape Kekurnoi on the Pacific coast. On shore are small outcrops of Triassic limestone, shale, and minor clastic and volcanic rock that were deposited in a shallow-water, quiet basin environment and that are now exposed along the Pacific coast at Puale Bay and to the north towards Alinchak Bay.

The Alaska–Aleutian Range batholith includes rocks of Jurassic, Cretaceous, and early Tertiary age (Reed and Lanphere, 1969, 1973). The Jurassic plutonic rocks of the batholith were emplaced to form the core of the Alaska Peninsula; they are contemporaneous with the Lower Jurassic Talkeetna Formation, which consists of volcanic rocks and tuffaceous sandstone, in part, and the Lower and Middle Jurassic Kialagvik Formation, which consists of shallow-water marine sandstone and shale. Later, the Middle Jurassic Shelikof Formation, composed of volcanically derived sandstone, conglomerate, siltstone, shale, and minor deep-water turbidite, was deposited. The Shelikof Formation is widely exposed along the Pacific coast of the study area, and the Kialagvik Formation is exposed at Wide Bay on the axis of the anticline centered in Wide Bay (Allaway and Miller, 1984). During Late Jurassic time, the Naknek Formation was deposited, derived from the erosion of the Alaska–Aleutian Range batholith, followed by nearly continuous deposition of the overlying thin-bedded feldspathic siltstone and sandstone. Detterman and others (1987) stated that in the study area the Lower Cretaceous part of the Staniukovich Formation has been removed by erosion and that the thin-bedded sandstone and shale that overlie the Naknek may be considered a member of the Naknek Formation. For simplicity, these two units will be referred to as the "Naknek Formation" in this report. The lower, conglomeratic part of the Naknek Formation was deposited in a nonmarine, fluvial environment, whereas the upper sandstone and shale, containing limestone concretions, represent a marine environment. Overlying these rocks is the Chignik Formation of Late Cretaceous age, which was deposited in a cyclical fluvial to nearshore marine sedimentary environment (Detterman, 1978). The Upper Cretaceous Hoodoo Formation, which interfingers with and overlies the Chignik Formation, is a turbidite indicating a deeper water environment.

The Meshik arc formed during Eocene to early Miocene time (Wilson, 1985). It is best exposed on the northwest side of the Aleutian Range, in the southern part of the study area. Basaltic and andesitic calc-alkaline volcanic rocks of the Meshik Formation and the volcaniclastic, nonmarine sedimentary rocks of the upper part of the Tolstoi Formation constitute the Meshik arc in the study area. The Paleocene and Eocene Tolstoi Formation is a nonmarine clastic unit, whereas the Miocene Bear Lake Formation is primarily a nearshore marine deposit containing some nonmarine rocks. In the southern part of the study area, along the Pacific coast, the Mesozoic sedimentary rocks contain many hypabyssal dikes and sills too small to be shown at the 1:250,000 scale of the published maps (Detterman and others, 1987).

Further calc-alkaline magmatism during late Miocene to Quaternary time (Wilson and Shew, 1988) formed the bulk of the plutons throughout the area. Quaternary volcanism produced the volcanic peaks and stratovolcanoes that dominate the landscape. Most of the young volcanoes lie west of the axis of the Aleutian Range, where they form two northeast-trending segments, one in the southern Ugashik quadrangle and one near the south shore of Becharof Lake. Upper Miocene and Pliocene plutons intruded folded Mesozoic sedimentary rocks along the Pacific coastline. Aeromagnetic studies (Case and others, 1987) suggest that other plutons may be present in the subsurface.

The overall geologic structure of the Alaska Peninsula north of Wide Bay is a gentle, broad arch, the axis of which parallels the Bruin Bay fault. Gentle anticlines and synclines are superimposed on this broad arch. South of Wide Bay, structures are much tighter and anticlines are aligned in a northeast-trending en echelon pattern. The folding and extensive intrusive activity has deformed rocks as young as Pliocene (Burk, 1965, p. 137). Normal faulting, largely associated with folding, has caused numerous offsets in the older lithologic contacts.

EXPLORATION GEOCHEMISTRY

Sample Media and Data Collection

Heavy-mineral-concentrate and stream-sediment samples were collected from active stream channels draining areas of 5–16 km^2 (2–6 mi^2). During the reconnaissance geochemical sampling program, 586 stream-sediment samples and 569 heavy-mineral-concentrate samples from stream sediments were collected. Both sample media were collected by wet sieving through a 10-mesh stainless steel screen. At each site, one 35-cm (14-in.) gold pan full of sediment was collected and about 0.5 kg (1 lb) of minus-2-mm material was retained as the stream-sediment sample. The remaining material was panned at the site to produce the heavy-mineral concentrate (Detra and others, 1981).

The minus-2-mm stream-sediment samples were dried in an oven and then shipped to the laboratory, and there they were sieved through an 80-mesh screen. This fraction was ground between ceramic plates to minus-150 mesh and retained for chemical analysis. The heavy-mineral concentrates from stream sediments were dried in an oven and then shipped to the laboratory, where they were sieved to minus-20 mesh. Following removal of the light-mineral fraction by flotation in bromoform (specific gravity about 2.8), the heavy-mineral fraction was separated into three magnetic splits with a Frantz isodynamic magnetic separator. The most magnetic fraction (C1) contained magnetite and rock fragments including large amounts of magnetite. The second fraction (C2) was of intermediate magnetic susceptibility and consisted of rock fragments as well as most of the more magnetic mafic silicates. The nonmagnetic fraction (C3) contained the high-specific-gravity rock-forming minerals such as

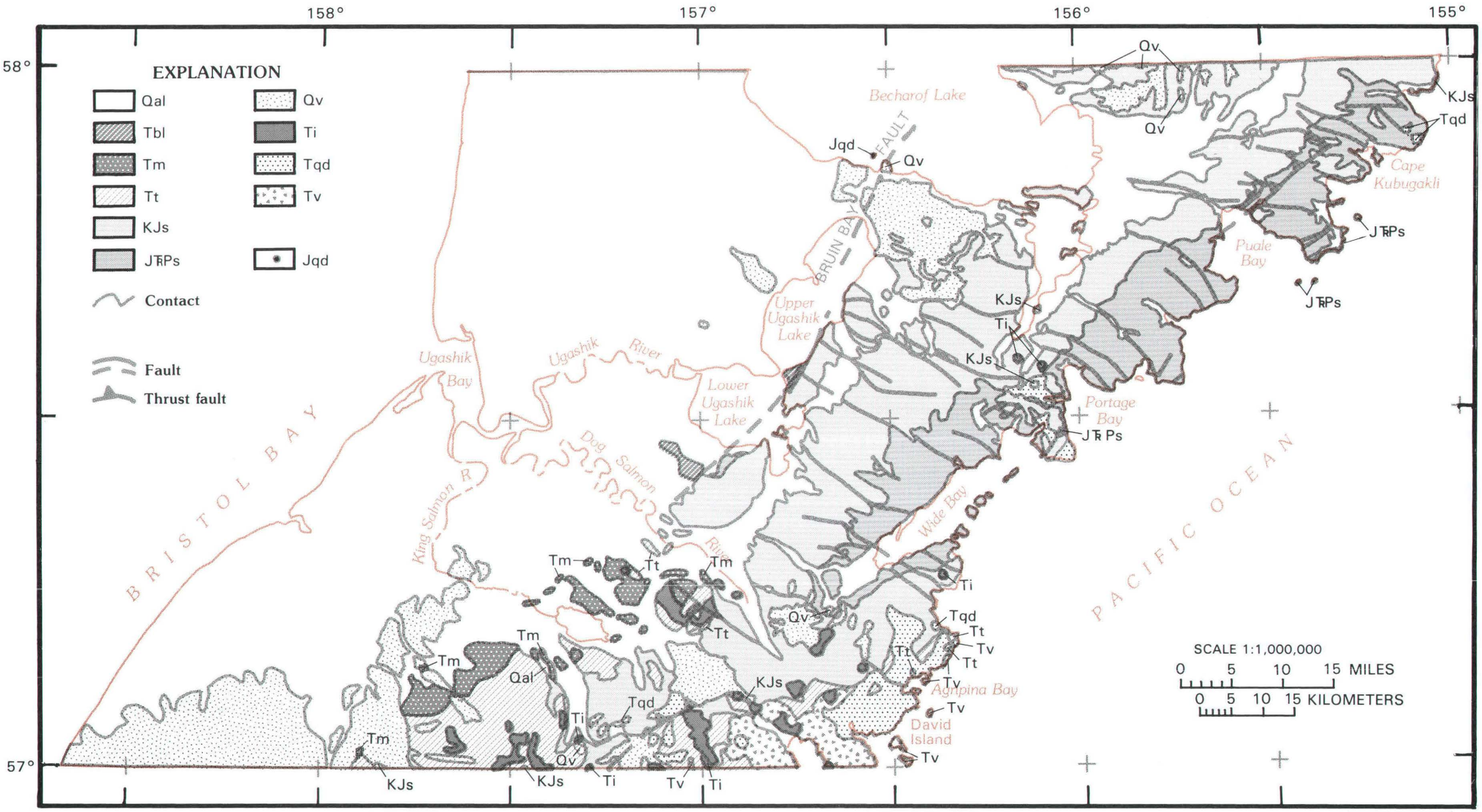


Figure 2. Simplified geologic map of the Ugashik, Bristol Bay, and western Karluk quadrangles (Detterman and others, 1983, 1987). Geologic units: Qal, Quaternary alluvium; Qv, Quaternary volcanic rocks; Tbl, Tertiary sandstone, siltstone, and conglomerate of the Bear Lake Formation; Tm, Tertiary volcanic flows, breccia, and sediment of the Meshik Formation; Tt, Tertiary volcaniclastic sediment of the Tolstoi Formation; Tv, Tertiary (generally Miocene to Pliocene) andesite and basalt; Ti, Tertiary (Miocene to Oligocene) hypabyssal hornblende andesite and dacite; Tqd, Tertiary (generally Pliocene) hornblende quartz diorite and quartz monzonite; KJs, Cretaceous and Jurassic clastic sediment of the Hoodoo, Chignik, and Naknek Formations; JTrPs, Jurassic, Triassic, and Permian clastic sediment, limestone, and metamorphic rocks of the Shelikof, Kialagvik, and Talkeetna Formations; and Jqd, Jurassic granodiorite of the Alaska–Aleutian Range batholith exposed on a small island in Becharof Lake just west of the Bruin Bay fault. Faults dashed where approximately located; sawteeth on upper plate of thrust faults.

System	Series	Age	Thickness (meters)	Unit	Lithology	Correlation of map units
QUATERNARY	Holocene and Pleistocene	1.6 Ma	10-1700	Surficial deposits and volcanic rocks, undivided	Volcanic rocks, sand, silt, and gravel	Qal, Qv
TERTIARY	Pliocene	5.3 Ma	570-730 subsurface	Milky River Fm.	Sandstone, siltstone, clay, and conglomerate	Tmr, Tv, Tqd
	Miocene	23.7 Ma	100-1030 mainly subsurface	Bear Lake Fm.	Sandstone, siltstone, lignite, and conglomerate	Tbl
	Oligocene	36.5 Ma	500-1675	Meshik Fm.	Volcanic flows, breccia tuff, and minor sediments	Tm, Ti
	Eocene	57.8 Ma				
	Paleocene	66.4 Ma	500-1500	Tolstoi Fm.	Sandstone, siltstone, lignite, and conglomerate	Tt
CRETACEOUS	Late		0-30	Hoodoo Fm.	Dark siltstone and shale	KJs
			0-100	Chignik Fm.	Siltstone, sandstone, mudstone, and shale	
		97.5 Ma				
	Early	144 Ma				
JURASSIC	Late		0-150	Staniukovich Fm.	Thin Sandstone	
			1000-2500	Naknek Fm.	Sandstone, conglomerate, siltstone, and shale	
		163 Ma				
	Middle		800-1500	Shelikof Fm.	Siltstone, shale, sandstone, and conglomerate	Jqd
			425-850	Kialagvik Fm.	Sandstone, siltstone, shale, and mudstone	
		187 Ma				
	Early	208 Ma	425	Talkeetna Fm.	Tuff, limestone, and sandstone	JŦPs
TRIASSIC	Late	230 Ma	760	Unnamed rocks	Limestone, conglomerate, and basalt	
	Middle	240 Ma				
	Early	245 Ma				
PERMIAN	Late	258 Ma				
	Early		30	Unnamed rocks	Limestone	

apatite, zircon, rutile, and sphene, as well as minerals that might indicate mineralization, such as epidote, tourmaline, fluorite, barite, scheelite, and the sulfide minerals. This least magnetic fraction of the heavy-mineral concentrate was then split if adequate sample was recovered. One portion was used for mineral identification (486 of 569 samples), and a second portion was ground for spectrographic analysis. For simplicity, the stream-sediment samples and the nonmagnetic heavy-mineral-concentrate samples from stream sediments are referred to as the "SS samples" and the "NMHMC samples," respectively, throughout the remainder of this bulletin.

Stream-sediment, rock, and nonmagnetic heavy-mineral-concentrate samples were analyzed by a six-step, semiquantitative direct-current–arc emission spectrographic method (Grimes and Marranzino, 1968). In addition, atomic-absorption spectrophotometry was used to determine copper, lead, and zinc in the SS samples by means of a nitric acid partial digestion procedure (Ward and others, 1969). Gold in some of the rock samples was also determined by atomic absorption. Some of the silver values, especially those determined near the limit of detection by direct-current–arc emission spectrography, were not reproducible when checked by atomic-absorption methods; sample sites that are anomalous only in silver should be viewed with skepticism. The SS and NMHMC data were reported in Detra and others (1981). Rock samples were collected at many of the field stations during the geologic mapping. Geochemical results from the analysis of rock samples were reported in and summarized by Wilson and O'Leary (1986, 1987).

Data Presentation

Geologic mapping in the study area (Detterman and others, 1983, 1987) forms the geologic framework for geochemical interpretations. A simplified geologic map of the study area is shown as figure 2 and the stratigraphic column as figure 3; this base is used as an underlay for figures that are referenced in the interpretative discussions that follow. In table 1, we list statistical summaries of geochemical data from the analysis of stream-sediment samples as well as from nonmineralized intrusive, volcanic, and sedimentary rocks (Wilson and O'Leary, 1986, 1987). In figure 4, the elemental distributions of the stream-sediment data are shown by the boxplot method of Tukey (1977). The maximum value, 95th percentile, upper quartile, median, lower quartile, and minimum values are shown for the elements listed in table 1. Censored distributions, that is, those elements whose concentrations could not be determined in all samples because of a lack of instrumental sensitivity or calibration, are not shown in their entirety in figure 4.

Comparison of the geometric means for most elements for the three rock units shows no large geochemical variation among rock types; by inference, threshold values determined from the SS samples are therefore applicable to the entire Ugashik-Karluk study area because of the low variance among rock types. Direct comparison of stream-sediment and rock data is difficult because of the significant difference in the sampling media and because rock samples represent point-source information, whereas SS samples represent an integrated sample over the upstream basin and include possible contributions from glaciation. No effort was made to separate SS samples into classes on the basis of the dominant rock type in the drainage basin. Empirical comparison of the variations between the geometric means for the stream-sediment data and the plutonic rocks are the most pronounced. Higher median values for calcium, strontium, and barium in the plutonic rocks suggest a higher plagioclase content in the rock samples than found in the average stream-sediment composition. This tendency occurs in the volcanic rocks as well, but it is less pronounced. The median stream-sediment values for iron, titanium, manganese, vanadium, and chromium are higher than those for the three rock groups sampled and suggest that the SS samples are enriched in heavy minerals, such as pyroxene (iron, chromium), amphibole (titanium, manganese), and (or) magnetite (iron, titanium, vanadium, chromium), relative to the rocks. The high-energy environment encountered in the mountainous terrain, where mechanical weathering processes are much more important than chemical weathering, favors a concentration of heavy minerals in the stream sediments.

Factor analysis of the geochemical data from the stream sediments and the nonmagnetic heavy-mineral concentrates was used to define geochemical suites. In this report, we emphasize the places within the study area for which mineralization is suggested by clusters of anomalous geochemical values, hydrothermal alteration, and (or) sulfide mineralogy. Data from different media were compared to evaluate the spatial distribution of

Figure 3 (facing page). Generalized stratigraphy of the Ugashik, Bristol Bay, and western Karluk quadrangles, Alaska (Detterman and others, 1983, 1987). Igneous rocks shown in the far right-hand column are Qv, Holocene and Pleistocene basaltic andesite and basalt flows and volcaniclastic deposits including some air-flow tuff; Tv, Tertiary (generally Miocene to Pliocene) andesite and basalt, locally propylitically altered; Ti, Tertiary (generally Miocene to Oligocene) hypabyssal hornblende andesite and dacite; Tqd, Tertiary (generally Pliocene) hornblende quartz diorite and quartz monzonite; and Jqd, Middle Jurassic medium- to coarse-grained, hypidiomorphic granular granodiorite of the Alaska–Aleutian Range batholith.

Table 1. Comparison of geometric and arithmetic means for elements determined in stream sediments and in various nonmineralized intrusive, volcanic, and sedimentary rocks[1] from the Ugashik, Bristol Bay, and western Karluk quadrangles, Alaska.

[Dashes indicate no data]

Element[2]	Detection limit[3]	Geometric mean	Geometric deviation[4]	Arithmetic mean	Standard deviation
		Stream sediments			
Mg	0.02	1.4	1.6	1.6	0.91
Ca	0.05	1.3	1.7	1.5	0.71
Fe	0.1	5.8	2.1	7.4	4.9
Ti	0.005	0.58	1.8	0.66	0.3
B	10	25	2.2	39	60
Be	1	1.0	1.1	1.0	0.1
Sr	100	370	1.9	520	840
Ba	20	470	1.5	510	220
Sc	5	33	1.5	36	16
La	20	25	1.4	28	14
Y	10	28	1.4	30	11
Zr	20	120	1.7	150	120
Mn	10	960	1.9	1200	780
V	10	320	2.0	450	660
Cr	10	79	1.9	100	99
Ni	5	30	1.8	37	30
Co	5	18	1.8	22	20
Cu	5	42	2.0	59	86
Cu*	5	28	1.9	37	54
Mo	5	9.8	2.0	14	23
Ag	0.5	0.9	2.0	1.3	1.9
Pb	10	13	1.7	17	29
Pb*	5	15	1.7	18	19
Zn*	5	60	1.6	71	110
		Intrusive rocks			
Mg	0.02	1.5	2.1	2.0	1.6
Ca	0.05	2.1	1.8	2.4	1.2
Fe	0.1	4.1	1.6	4.6	2.0
Ti	0.005	0.35	1.7	0.39	0.19
B	10	26	2.5	46	70
Be	1	1.2	1.3	1.2	0.4
Sr	100	530	1.6	590	330
Ba	20	570	2.0	700	460
Sc	5	29	1.9	36	21
La	20	25	1.4	27	11
Y	10	29	1.7	33	16
Zr	20	110	2.0	140	82
Mn	10	820	1.8	940	440
V	10	220	1.6	240	120
Cr	10	45	2.6	70	75
Ni	5	15	2.3	21	18
Co	5	17	2.0	21	15
Cu	5	38	2.3	51	40
Cu*	5	32	2.2	41	28
Mo	5	9.0	2.4	15	22
Ag	0.5	--	--	--	--
Pb	10	17	1.7	20	18
Pb*	5	14	1.7	15	7.8
Zn*	5	32	2.0	40	30

geochemical anomalies in different media in relation to geologic setting and geophysical data. The threshold used for determining anomalous concentrations for each element in each of the different media is given in table 2. The threshold values were determined using both statistical methods (mean plus twice the standard deviation) and visual inspection of histograms (Church and others, 1988; Frisken, Church, and others, 1988).

Table 1. Comparison of geometric and arithmetic means for elements determined in stream sediments and in various nonmineralized intrusive, volcanic, and sedimentary rocks[1] from the Ugashik, Bristol Bay, and western Karluk quadrangles, Alaska—Continued.

Element[2]	Detection limit[3]	Geometric mean	Geometric deviation[4]	Arithmetic mean	Standard deviation
		Volcanic rocks			
Mg	0.02	1.7	2.5	2.4	2.1
Ca	0.05	1.9	2.3	2.4	1.6
Fe	0.1	4.0	1.9	4.8	2.8
Ti	0.005	0.38	2.1	0.47	0.25
B	10	23	1.9	29	25
Be	1	1.1	1.3	1.1	0.3
Sr	100	600	1.9	720	420
Ba	20	460	2.2	630	680
Sc	5	27	1.9	32	19
La	20	35	1.7	40	22
Y	10	25	1.7	28	15
Zr	20	100	1.6	120	68
Mn	10	680	2.0	830	530
V	10	210	1.8	240	130
Cr	10	73	3.1	130	160
Ni	5	30	2.8	51	59
Co	5	20	1.9	25	16
Cu	5	32	2.5	47	40
Cu*	5	27	2.4	38	35
Mo	5	9.8	1.7	11	5.0
Ag	0.5	0.8	2.3	1.3	2.0
Pb	10	15	1.8	19	21
Pb*	5	18	1.5	20	19
Zn*	5	46	2.4	77	150
		Sedimentary rocks			
Mg	0.02	1.3	1.9	1.6	0.8
Ca	0.05	1.1	2.0	1.7	1.8
Fe	0.1	4.0	1.9	4.9	3.5
Ti	0.005	0.36	1.8	0.43	0.24
B	10	27	2.2	38	58
Be	1	1.1	1.1	1.1	0.3
Sr	100	370	1.9	450	280
Ba	20	500	1.9	590	350
Sc	5	26	1.7	30	16
La	20	27	1.5	30	12
Y	10	26	1.7	30	16
Zr	20	82	1.8	93	43
Mn	10	660	2.0	830	690
V	10	210	1.7	235	110
Cr	10	63	2.2	85	72
Ni	5	32	2.1	42	35
Co	5	15	1.9	18	12
Cu	5	36	2.3	50	49
Cu*	5	33	2.1	42	31
Mo	5	7.7	1.4	8.0	2.5
Ag	0.5	0.65	1.4	0.68	1.2
Pb	10	13	1.4	14	7.0
Pb*	5	19	1.5	20	7.6
Zn*	5	60	1.9	70	49

[1]Rock data summarized from Wilson and O'Leary (1986, 1987).

[2]Cu*, Pb*, and Zn* determined by atomic-absorption methods; all others determined by direct-current-arc emission spectrography.

[3]Concentrations of Mg, Ca, Fe, and Ti are in percent; all others in parts per million.

[4]The geometric deviation is expressed as the log of the concentration of the element.

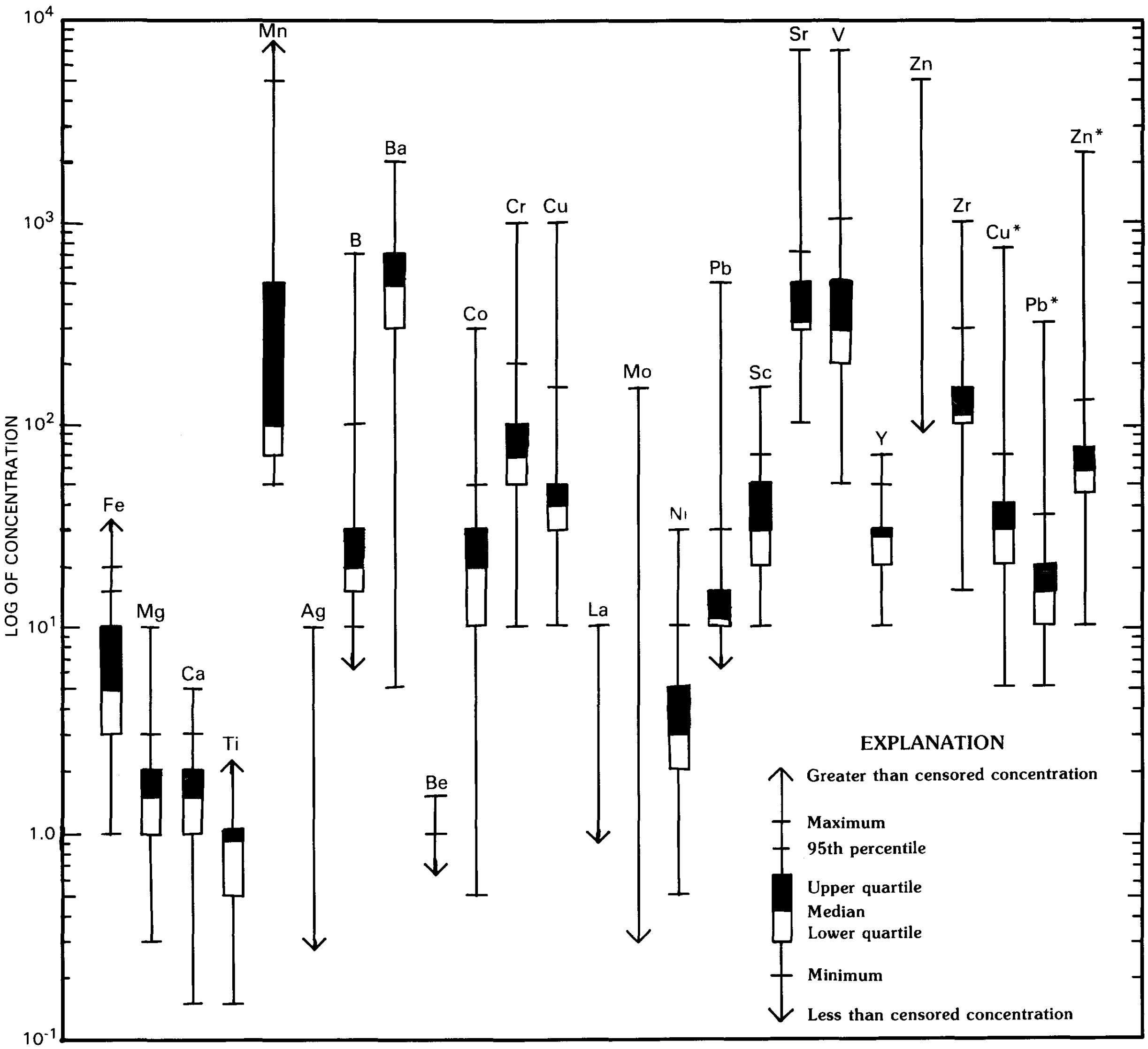


Figure 4. Boxplot of the geochemical data for stream-sediment samples, Ugashik-Karluk study area. Analyses by emission spectrography except where atomic absorption indicated by asterisk. Concentrations of iron, magnesium, calcium, and titanium are expressed in weight percent; all others expressed in parts per million.

FACTOR ANALYSIS

Methods

Factor analysis is a mathematical technique that, according to Johnston (1980, p. 127–128), serves three objectives when evaluating multivariant data sets:

1. To identify groups of inter-correlated variables,
2. to reduce the number of variables being studied, and
3. to rewrite the data set in an alternative form.

When applied to geochemical data, factor analysis groups elements within a data set that behave similarly. When applied to a set of data in which each element has a high detection ratio (that is, where most of the values for each element in the data set are determinate), factor analysis reduces the variables to a smaller number of more easily represented factors. Factor analysis utilizes the correlation matrix to group variables, mathematically reducing a large number of variables to a few that show geochemically coherent behavior. The factors define the mathematical structure within the data set and may be interpretable in terms of geochemical processes or suites of lithologically related minerals. The reader is referred to Davis (1973, p. 473–536) or Johnston (1980, p. 127–182) for further discussion of the factor analysis method.

We used the R-mode factor analysis program available from the U.S. Geological Survey's STATPAC

Table 2. Threshold values of elements by sample medium, Ugashik, Bristol Bay, and western Karluk quadrangles, Alaska.

[Dashes indicate no data; < indicates concentration less than the stated value; MF maps in the Ugashik, Bristol Bay, and western Karluk quadrangle folio indicated to show from which sources the data have been taken]

Element[1]	Stream sediment			Stream sediment[2] anomalous value (MF-1539-F)	Panned concentrate[2] anomalous value (MF-1539-G)	Rock[2] anomalous value (MF-1539-C)
	90th percentile	95th percentile	98th percentile			
B	73	110	220	70	1000	--
Ba	760	820	1100	--	5000	1000
Nb	--	--	--	--	100	--
Ni	71	99	130	70	200	--
Co	36	44	66	30	100	--
Cu	110	170	270	100	200	100
Cu*	55	75	120	--	--	100
Mo	--	5.7	13	<5	10	5
W	--	--	--	--	<100	--
Sn	--	--	--	--	50	--
Bi	--	--	--	--	<20	--
Au	--	--	--	--	<20	--
Au*	--	--	--	--	--	0.1
Ag	--	--	0.8	<0.5	1.5	1.0
Ag*	--	--	--	--	--	0.7
Pb	23	34	53	--	100	30
Pb*	25	36	55	30	--	30
Zn	--	--	320	--	<500	200
Zn*	100	130	210	100	--	100
Cd	--	--	--	--	<100	--
As	--	--	--	--	<500	200

[1]Element concentrations all in ppm; Cu*, Au*, Ag*, Pb*, and Zn* determined by atomic-absorption methods; all others determined by direct-current-arc emission spectrography.

[2]Only those elements that were plotted on the MF maps were assigned threshold values.

library (VanTrump and Miesch, 1977) for the analysis of the geochemical data from the SS and NMHMC samples. For the SS samples, a varimax solution was obtained from log-transformed data for 18 elements for which detection ratios (DR in table 3) were greater than 0.70; beryllium (detection ratio of 0.55) was also included in this solution. The program first determines the principal components from the correlation matrix. The number of factors (no more than a maximum of 10) was determined from the discontinuity criterion described by Rummel (1970, p. 364). There was a significant break in the eigenvalue curve between factor 6 (1.09) and factor 7 (0.78). The six factors are rotated using Kaiser's orthogonal varimax criteria, and the factor loadings (SSF 1–6) are given in table 3. Seventy-five percent of the total variance of the data is explained by the six factors.

The elements lanthanum, molybdenum, silver, and arsenic have detection ratios of 0.28, 0.065, 0.043, and 0.003, respectively, and therefore these elements were excluded from the factor analysis solution. Correlation analysis was performed for each of these elements, whose distributions were highly censored, to determine their possible geochemical associations. A subset of data for which each of the elements had unqualified values was extracted from the stream-sediment-sample data set. For example, in the case of lanthanum all the samples in the

Table 3. Factor loadings for the first six factors after varimax rotation of the stream-sediment data, Ugashik, Bristol Bay, and western Karluk quadrangles, Alaska.

[The six stream-sediment factors (SSF 1–6) explain 75 percent of the total variance in the data set. Factor loadings less than 0.40 are indicated by the dashes unless the value was quite close, in which case it is enclosed in parentheses]

Element[1]	SSF-1	SSF-2	SSF-3	SSF-4	SSF-5	SSF-6	Detection ratio[2]
Mg	0.78	--	--	--	--	--	1.0
Ca	0.62	--	--	--	--	(0.35)	1.0
Fe	0.87	--	--	--	--	--	0.98
Ti	0.85	--	--	--	--	--	0.73
B	--	0.47	--	--	--	--	0.97
Be	--	--	--	--	--	--	0.55
Sr	--	--	--	--	--	0.95	0.99
Ba	--	0.41	--	--	--	--	1.0
Y	0.72	--	--	--	--	--	1.0
Zr	--	--	--	--	0.91	--	0.99
Sc	0.52	--	0.68	--	--	--	1.0
Mn	0.86	--	--	--	--	--	0.99
V	0.75	--	(0.38)	--	--	--	1.0
Cr	--	--	0.48	0.64	--	--	1.0
Ni	--	--	--	0.78	--	--	1.0
Co	--	--	0.82	--	--	--	1.0
Cu	--	0.64	--	0.50	--	--	1.0
Cu*	--	0.75	--	--	--	--	1.0
Pb	--	0.79	--	--	--	--	0.76
Pb*	--	0.89	--	--	--	--	1.0
Zn*	--	0.85	--	--	--	--	1.0

[1]Element concentrations determined by atomic-absorption methods indicated by asterisk.

[2]The elements La, Mo, Ag, and As have detection ratios of 0.28, 0.065, 0.043, and 0.003, respectively; because they are highly censored, these elements were not included in the factor analysis solution.

SS data set that had detectable values of lanthanum (that is, concentrations greater than or equal to the limit of detection for lanthanum (20 ppm)) were extracted into a separate data set. Meaningful values of r, the correlation coefficient, were chosen from the tables published by Fisher (1970, p. 211); the degrees of freedom were 2 fewer than the number of samples and the 5 percent level-of-significance column was used. This same procedure was used for molybdenum, silver, and arsenic. The following geochemical associations are suggested for these elements: lanthanum correlates with magnesium, calcium, iron, manganese, vanadium, yttrium, and zirconium; molybdenum correlates with cobalt and copper; silver correlates with manganese, and with lead and zinc determined by atomic absorption; and arsenic does not show any significant correlation. These correlations suggest that lanthanum is a member of SSF–1, and that molybdenum and silver are members of SSF–2 (table 3). No statistically rigorous significance can be inferred from this treatment of the data. These elements, when included in the elemental suite for a given factor, are always enclosed in brackets, for example, SSF–1: iron, manganese, titanium, magnesium, vanadium, yttrium, calcium, scandium, [lanthanum].

A different kind of factor analysis solution was derived for the geochemical data from the NMHMC samples. The log-transformed data for 18 elements that had detection ratios (DR) greater than about 0.5 (table 4) were used. Silver (DR of 0.28) and tin (DR of 0.38) were also included in the final solution. After derivation of the principal components, rather than use the varimax rotation, the first six principal-component vectors were rotated to oblique positions representing the six extreme variables. The extreme-variable solution showed the best relationship to the observed mineralogical suites found in the NMHMC samples (Frisken, Church, and Willson, 1988). The factor loadings (PCF 1–6) are given in table 4. Seventy-nine percent of the variance in the data is explained.

The elements zirconium, beryllium, zinc, arsenic, molybdenum, cadmium, tungsten, gold, and bismuth have detection ratios of 0.14, 0.035, 0.088, 0.069, 0.040, 0.025, 0.025, 0.023, and 0.017, respectively. Because the distributions for these elements were highly censored, they were not included in the factor analysis solution. Correlation analysis of subsets of the NMHMC data was used to define geochemical associations for these

Table 4. Factor loadings for the first six factors calculated by means of an extreme-variable, oblique solution for the nonmagnetic heavy-mineral-concentrate data, Ugashik, Bristol Bay, and western Karluk quadrangles, Alaska.

[The six panned-concentrate factors (PCF 1–6) explain 79 percent of the total variance in the data set. Factor loadings having values less than 0.40 are indicated by the dashes]

Element[1]	PCF-1 (Nb)	PCF-2 (Mg)	PCF-3 (Co)	PCF-4 (Sr)	PCF-5 (Ag)	PCF-6 (B)	Detection ratio[2]
Mg	--	1.00	--	--	--	--	1.0
Ca	--	0.88	--	--	--	--	1.0
Fe	--	--	1.00	--	--	--	0.99
Ti	0.91	--	--	--	--	--	0.59
B	--	--	--	--	--	1.00	0.95
Sr	--	--	--	1.00	--	--	0.94
Ba	--	--	0.59	0.62	--	--	0.86
La	0.98	--	--	0.44	--	--	0.99
Y	0.68	--	--	--	--	--	1.0
Nb	1.00	--	--	--	--	--	0.54
Sc	--	0.93	--	--	--	--	0.97
Mn	--	0.89	--	--	--	--	1.0
V	0.68	0.75	--	--	--	--	1.0
Cr	--	0.97	--	--	--	--	0.99
Ni	--	--	0.57	--	--	--	0.92
Co	--	--	1.00	--	--	--	0.92
Cu	--	--	0.73	--	--	--	0.75
Sn	0.93	--	--	--	--	--	0.38
Pb	--	--	0.87	--	0.43	--	0.54
Ag	--	--	--	--	1.00	--	0.28

[1]Element concentrations determined by atomic-absorption methods indicated by asterisk.

[2]The elements Zr, Be, Zn, As, Mo, Cd, W, Au, and Bi have detection ratios of 0.14, 0.035, 0.088, 0.069, 0.040, 0.025, 0.025, 0.023, and 0.017, respectively; because these elements are highly censored, they were not included in the factor analysis solution.

elements. A subset of data for which each of the elements had unqualified values was extracted from the NMHMC data set in the same manner as described above for the stream-sediment data. Meaningful values of r, the correlation coefficient, were chosen from the tables published by Fisher (1970, p. 211); the degrees of freedom were 2 fewer than the number of samples and the 5 percent level-of-significance column was used. The following geochemical associations are suggested for these elements: zirconium correlates with titanium, vanadium, yttrium, and [thorium]; beryllium correlates with no other element; zinc correlates with copper, molybdenum, and cadmium; arsenic correlates with gold; molybdenum correlates with iron, lead, and zinc; cadmium correlates with iron, silver, lead, and zinc; tungsten correlates with copper; gold correlates with silver, arsenic, and tin; and bismuth correlates with copper and zinc. This procedure suggests that zirconium is a member of PCF–1 and that the ore metals (zinc, arsenic, molybdenum, cadmium, tungsten, gold, and bismuth) are associated with the two mineralization factors PCF–3 and PCF–5 (table 4). No statistically rigorous significance can be inferred from these associations. These elements, when included in the elemental suite for a given factor, are always enclosed in brackets, for example, PCF–1: niobium, lanthanum, tin, titanium, vanadium, yttrium, [zirconium], [thorium].

Geologic Significance of the Factor Solutions

The factor sample-scores from the stream-sediment data (SSF) appear to be generally related to rock compositions, whereas the sample-scores obtained from the NMHMC data (PCF) appear to be related to mineral suites. The map area defined in particular by panned concentrate factor 2 (PCF–2: magnesium, chromium, scandium, manganese, calcium, vanadium; point-plot data, fig. 5) and by factor 1 from the stream-sediment data (SSF–1: iron, manganese, titanium, magnesium, vanadium, yttrium, calcium, scandium, [lanthanum]); contoured data, fig. 5) appears to coincide with the drainage areas where volcanic rocks crop out, especially with rocks of the Meshik Formation. The elements that make up these two factors occur at high concentrations in basaltic rocks such as those that are a component of the Meshik Formation (Detterman and others, 1987), and they also match the area of high contributions of nonmagnetic pyroxenes present in the NMHMC fraction (Frisken, Church, and Willson, 1988). Likewise, associations of nickel, chromium, copper (SSF–4, fig. 6) with mafic volcanic rocks presumably reflects the presence of amphibole or pyroxene.

Stream-sediment factor 3 (SSF–3: cobalt, scandium, chromium, [molybdenum]) is associated with areas underlain by Quaternary volcanic rocks (fig. 7) including Aniakchak Crater (lat 57° N. to 57°10′ N. and long 157°45′ W. to 158°30′ W.) in the Chignik quadrangle, the southeastern flank of Mount Peulik, Mount Chiginagak, and the area of Quaternary volcanic rocks northeast of Becharof Lake and northwest of the Kejulik River (lat 57°55′ N. to 58° N. and long 155°45′ W. to 156° W.). The Quaternary volcanic rocks are also delineated by PCF–2 (magnesium, chromium, scandium, manganese, calcium, vanadium; fig. 5); however, SSF–3 also delineates the area from north of Portage Bay to Puale Bay. This last area is underlain mainly by volcaniclastic sedimentary rocks of the Jurassic Shelikof Formation (R.L. Detterman, oral commun., 1987). Comparison with the mineralogical data (Frisken, Church, and Willson, 1988) from analysis of the NMHMC samples shows that all of these sites contain abundant detrital mafic minerals. Because most of the Mesozoic sedimentary rocks, which were derived from erosion of the Alaska-Aleutian Range batholith, contain 5–10 percent amphibole and (or) biotite, it is not surprising that PCF–2 also delineates the Mesozoic sedimentary rocks. Areas of hydrothermally altered rock in the Agripina Bay batholith and areas immediately adjacent to it on the west side of the batholith are also delineated by SSF–3.

Stream-sediment factor 5 (SSF–5: zirconium) correlates spatially with PCF–1 (niobium, lanthanum, tin, titanium, yttrium, [zirconium]) and with abundant zircon in the corresponding nonmagnetic heavy-mineral-concentrate samples (Frisken, Church, and Willson, 1988). The two factors SSF–5 and PCF–1 coincide with the outcrop pattern of the Naknek Formation (fig. 8). The distribution of zirconium in SSF–5 uniformly covers the outcrop area of the Naknek Formation, whereas PCF–1 reflects a more diverse suite of heavy minerals. Most of the tin geochemical anomalies are associated with the PCF–1 suite and appear to be derived from the Upper Jurassic Naknek and Upper Jurassic and Lower Cretaceous Staniukovich Formations. These rocks contain abundant granitic and metamorphic clasts derived from the deroofing of the Jurassic part of the Alaska-Aleutian Range batholith.

Stream-sediment factor 6 (SSF–6: strontium, [calcium]; fig. 9) reflects the presence of carbonate. Along the Pacific coast, SSF–6 coincides with the area underlain by the Shelikof and Naknek Formations, which contain limestone concretions (Detterman and others, 1983; Allaway and Miller, 1984). The two stream-sediment factors SSF–5 and SSF–6 are mutually exclusive and are interpreted to reflect different marine depositional environments. The two factors SSF–5 and PCF–1 are interpreted to reflect a shallow marine, littoral environment of the Naknek Formation, whereas the presence of carbonate concretions (SSF–6) reflects a quieter, deeper water environment, perhaps rich in organic material.

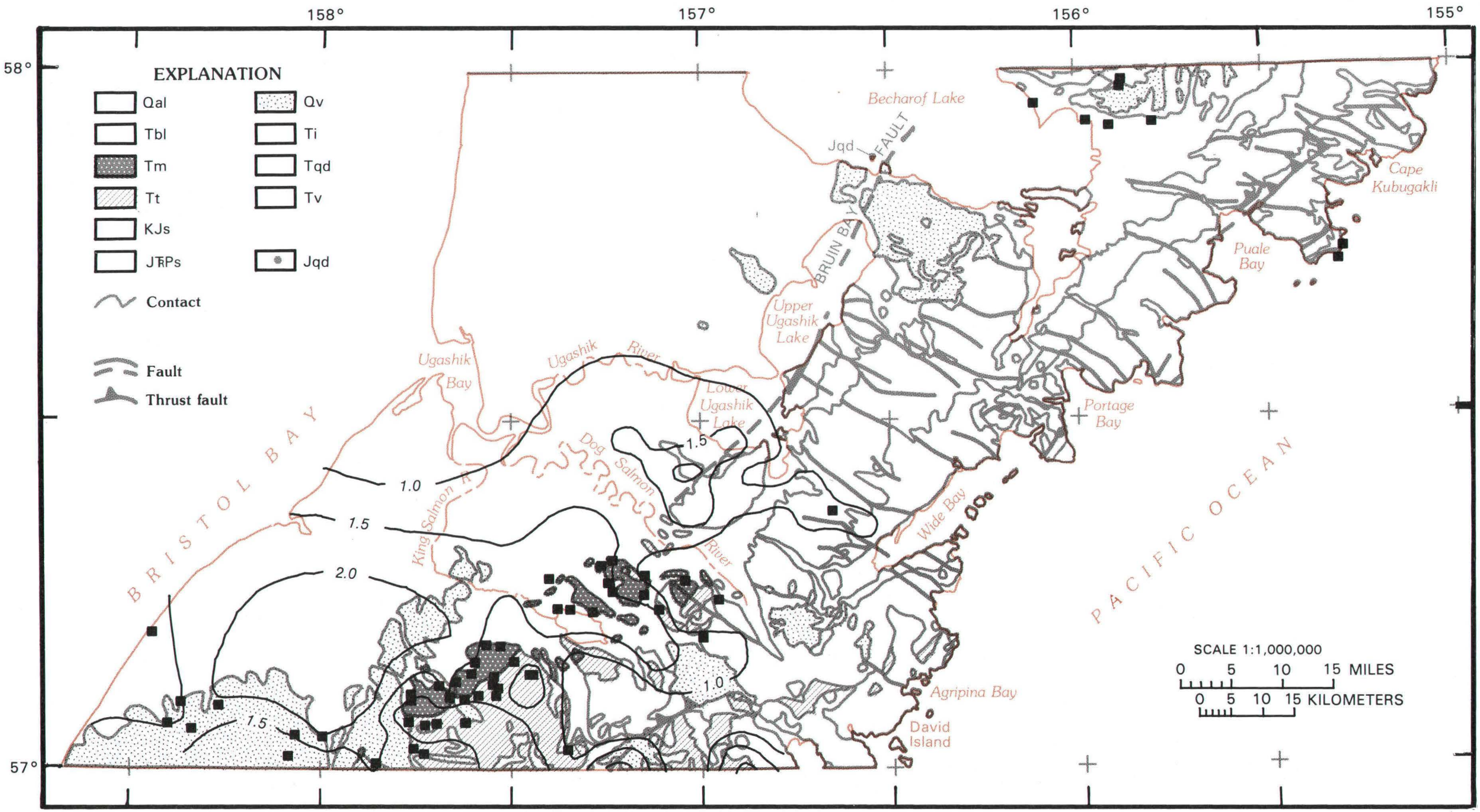


Figure 5. Map of the Ugashik-Karluk study area showing the correlation of stream-sediment factor 1 (SSF–1: iron, manganese, titanium, magnesium, vanadium, yttrium, calcium, scandium, [lanthanum]) and heavy-mineral-concentrate factor 2 (PCF–2: magnesium, chromium, scandium, manganese, calcium, vanadium) with mafic volcanic rocks (Qv and Tm) and volcaniclastic sediments (Tt). SSF–1 is shown as a contour plot of factor sample-scores (2.0 = 99th percentile, 1.5 = 92nd percentile, 1.0 = 80th percentile), and PCF–2 is shown as a point plot of factor sample-scores (90th percentile shown as a filled square). See figure 2 for explanation of other geologic map symbols.

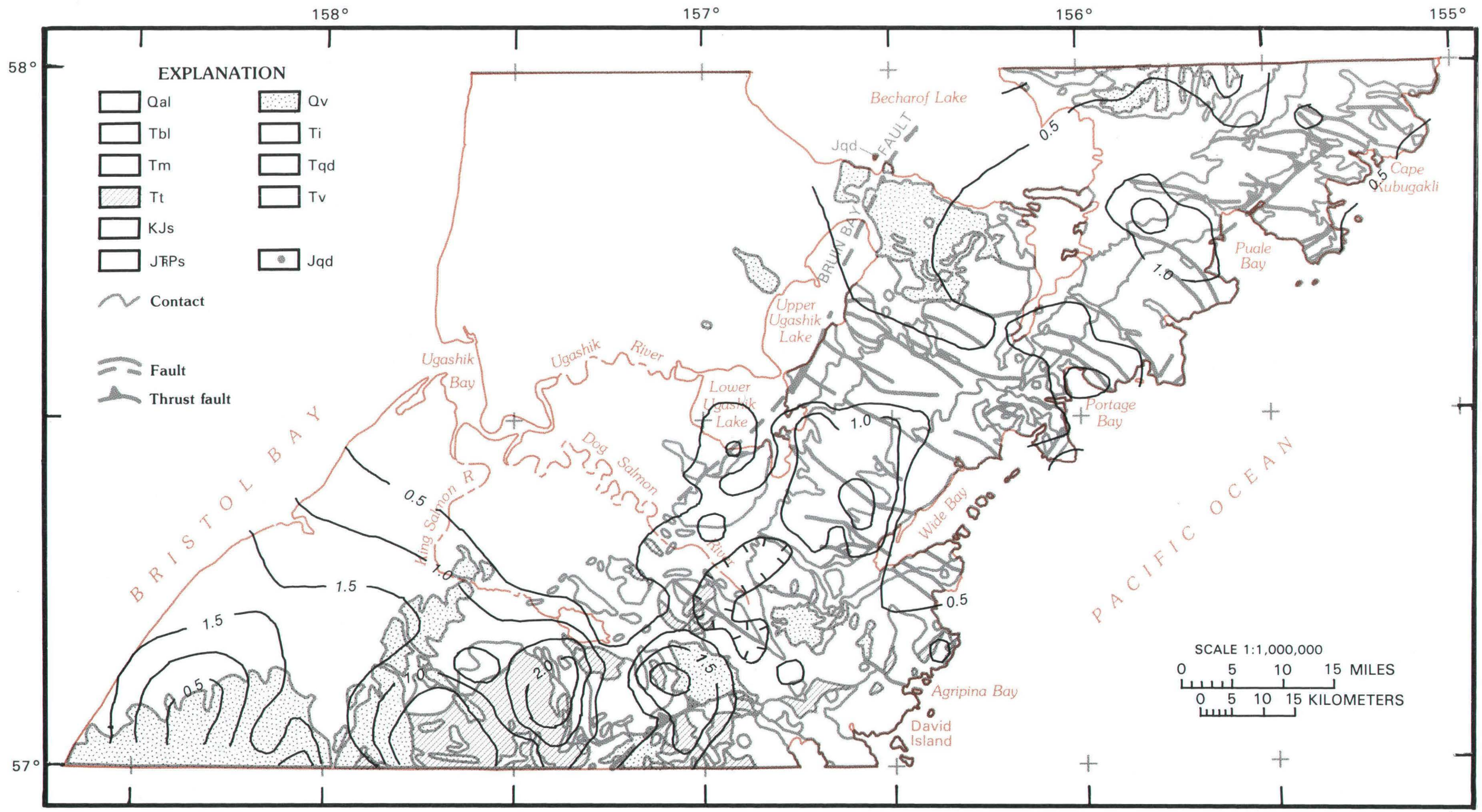


Figure 6. Map of the Ugashik-Karluk study area showing the correlation of stream-sediment factor 4 (SSF–4: nickel, chromium, copper) with Quaternary volcanic rocks (Qv) and with the Tolstoi Formation (Tt). SSF–4 is shown as a contour plot of factor sample-scores (2.0 = 97th percentile, 1.5 = 92nd percentile, 1.0 = 85th percentile, 0.5 = 70th percentile); hachured contours indicate lows. See figure 2 for explanation of other geologic map symbols.

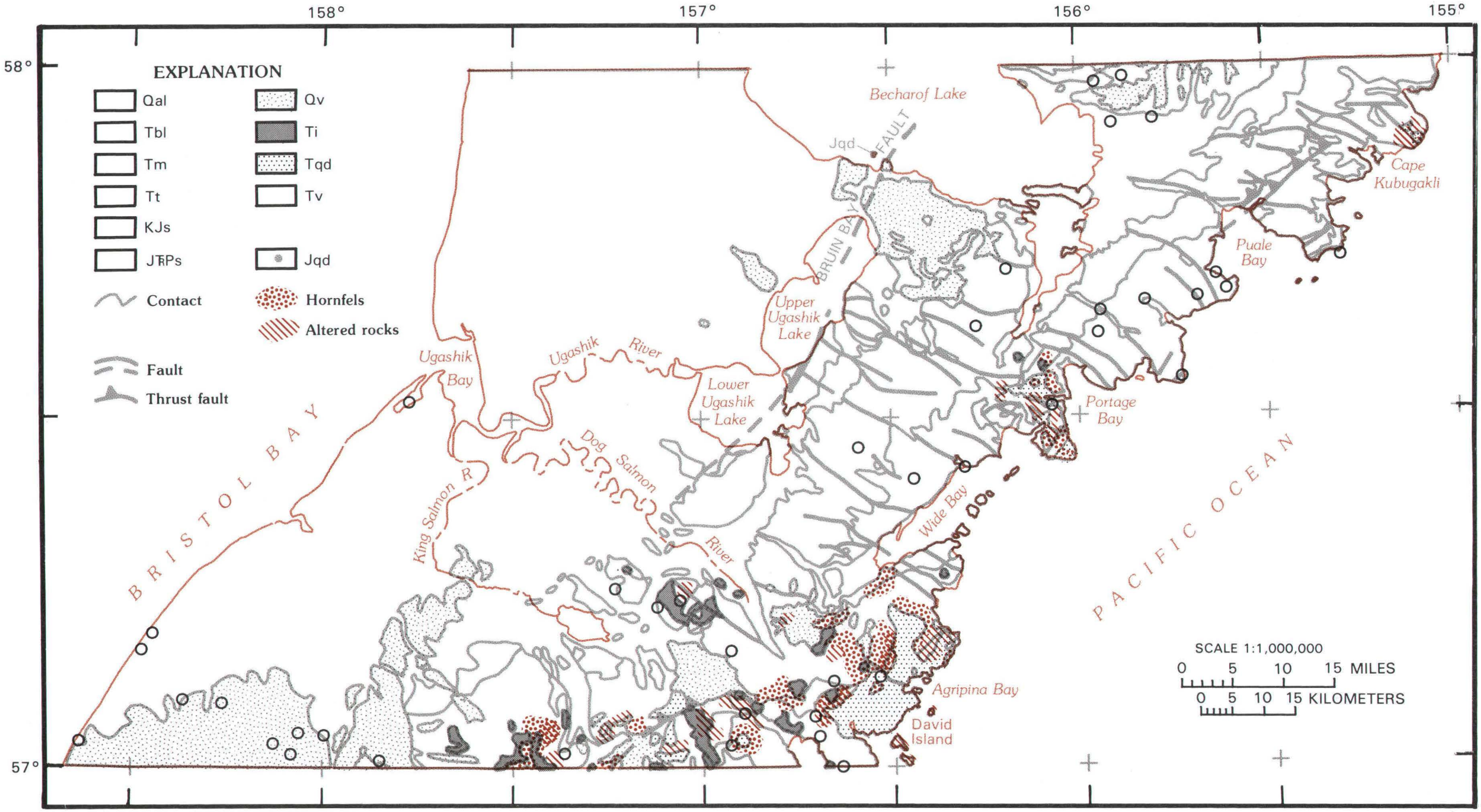


Figure 7. Map of the Ugashik-Karluk study area showing the correlation of stream-sediment factor 3 (SSF–3: cobalt, scandium, chromium, [molybdenum]) with mafic volcanic rocks (Qv) and with areas of hydrothermal alteration associated with Tertiary igneous centers (Ti and Tqd). SSF–3 is shown as a point plot of factor sample-scores (90th percentile shown as an open circle). See figure 2 for explanation of other geologic map symbols.

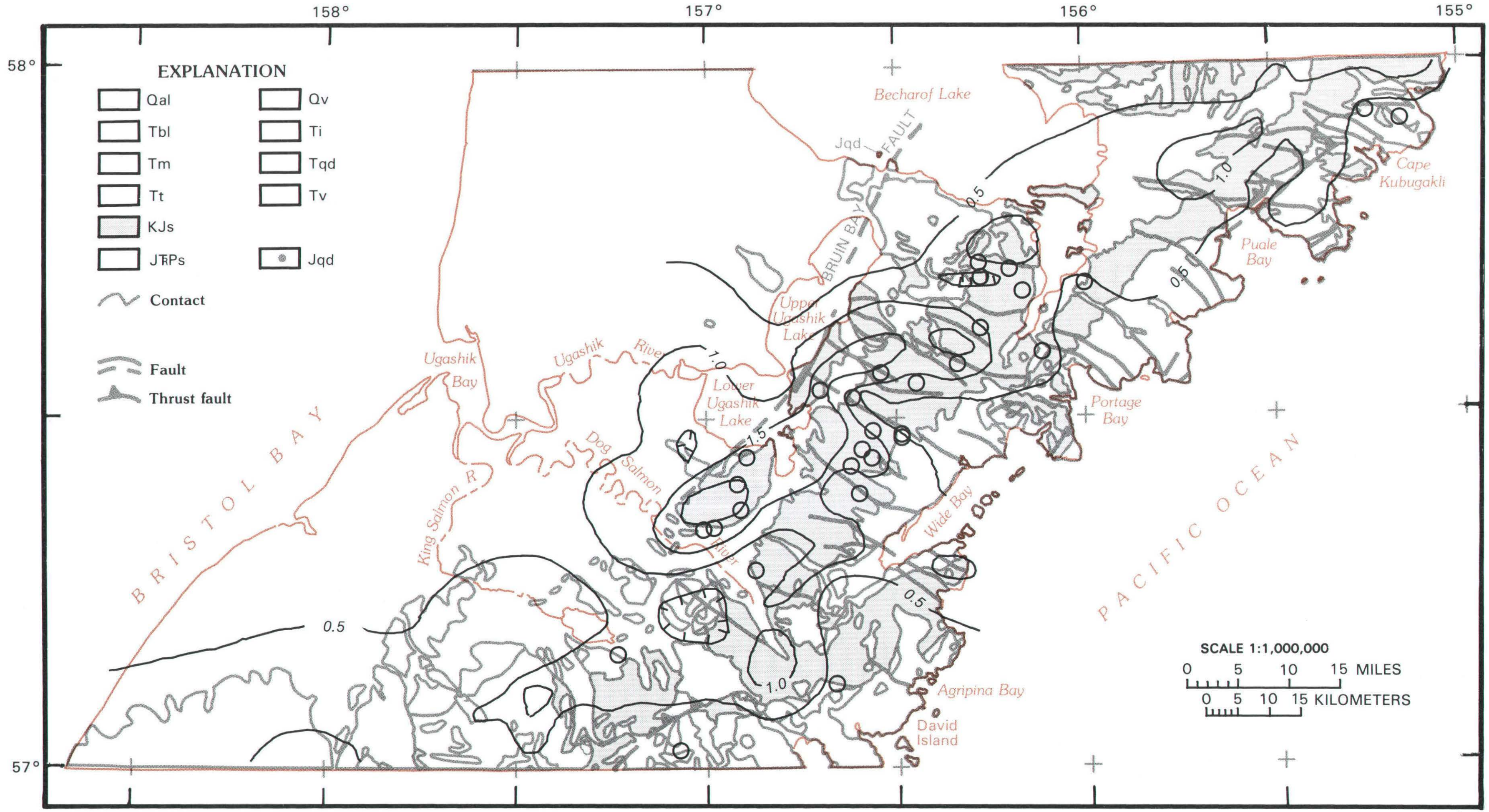


Figure 8. Map of the Ugashik-Karluk study area showing the correlation of stream-sediment factor 5 (SSF–5: zirconium) and heavy-mineral-concentrate factor 1 (PCF–1: niobium, lanthanum, tin, titanium, yttrium, vanadium, [zirconium]) with conglomeratic sections of the Naknek Formation (KJs). PCF–1 is shown as a contour plot of factor sample-scores (2.0 = 99th percentile, 1.5 = 95th percentile, 1.0 = 85th percentile, 0.5 = 70th percentile), and SSF–5 is shown as a point plot of factor sample-scores (95th percentile shown as an open circle); hachured contours indicate lows. See figure 2 for explanation of other geologic map symbols.

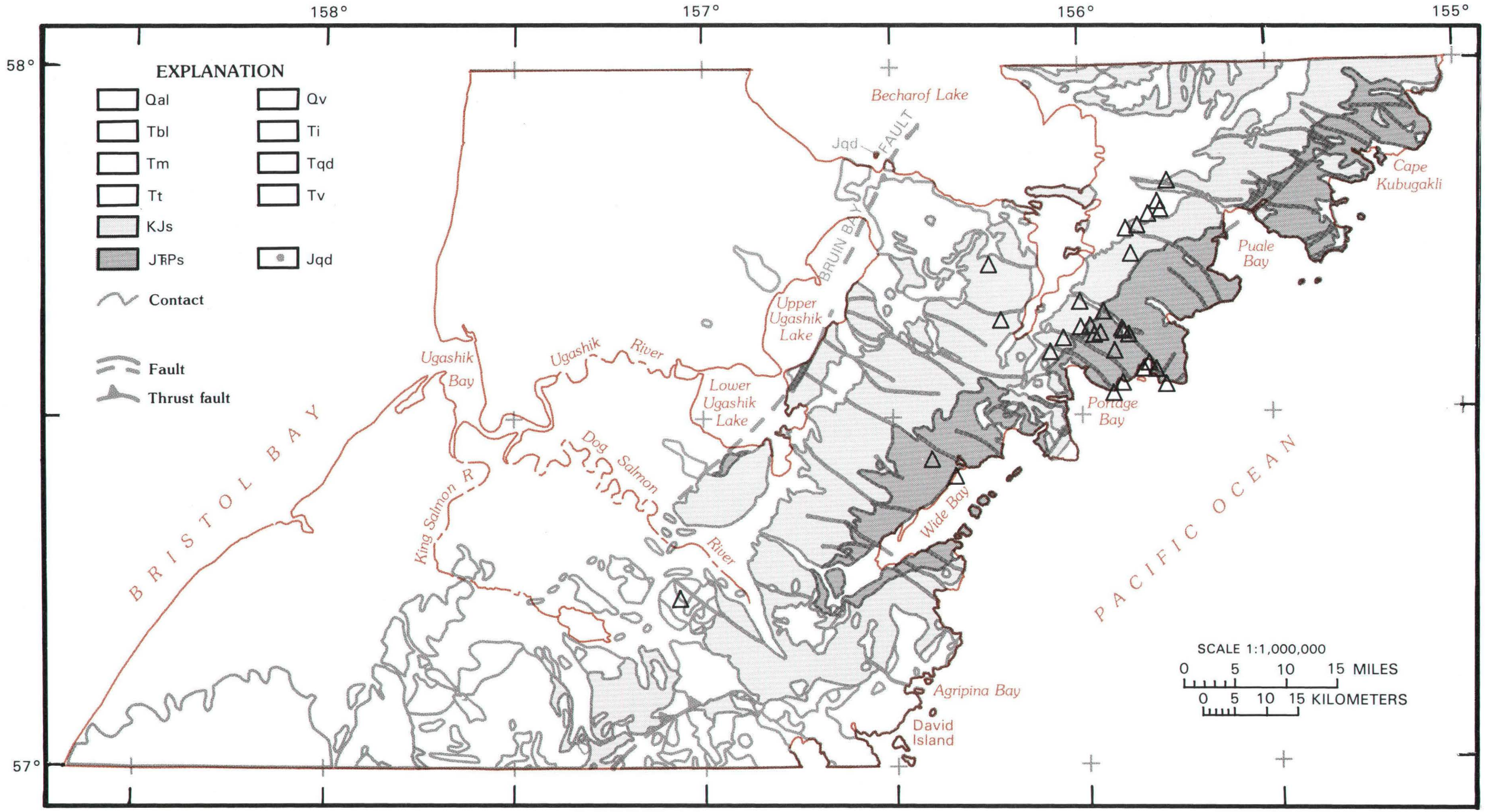


Figure 9. Map of the Ugashik-Karluk study area showing the correlation of stream-sediment factor 6 (SSF–6: strontium, [calcium]) with the Shelikof and Naknek Formations (JT̄RPs and KJs). SSF–6 is shown as a point plot of factor sample-scores (95th percentile shown as an open triangle). See figure 2 for explanation of other geologic map symbols.

The remaining factors, from both SS and NMHMC samples, reflect either mineralization or hydrothermal alteration associated with it. SSF–2 (lead, zinc, copper, boron, barium, [silver]) defines base-metal anomalies associated with intrusive centers of Tertiary age (fig. 10), whereas factors PCF-3–PCF-6 identify particular suites of elements (table 4) associated with individual centers of mineralization. In figure 11, we distinguish five areas that are delineated by factor sample-scores where widespread, multi-element geochemical anomalies occur:

A, Area surrounding the Rex prospect of Oligocene age (lat 57°10′ N. to 57°20′ N. and long 156°50′ W. to 157°10′ W.)

B, Large area outlined by widespread pyrite in the NMHMC samples (lat 57° N. to 57°07′ N. and long 157° W. to 157°30′ W.), which also includes the Mike prospect

C, Area of the outcrop pattern of the Pliocene quartz-diorite and granodiorite at Agripina Bay

D, Area of the outcrop pattern of Pliocene granodiorite at Cape Igvak, southwest of Portage Bay

E, Area of the outcrop pattern of the Miocene(?) granodiorite at Cape Kubugakli

Mineralized rock associated with the Rex prospect is also shown by PCF–5 (silver, lead, [gold], [arsenic], [tin]) in figure 12. The area surrounding the Mike prospect and the Oligocene altered rock near the Agripina Bay batholith are also delineated by this factor. The Portage Bay localities are indicated by several SS samples and the altered zone underlain by the granodiorite at Cape Kubugakli by three sample sites. Finally, possible sulfide mineralization may be indicated by PCF–5 in a broad area underlain by Naknek Formation and Quaternary volcanic rocks northwest of the Kejulik River near lat 57°50′ N. to 58° N. and long 155°15′ W. to 156° 15′ W.

The geochemical assemblage from PCF–3 (cobalt, iron, copper, lead, nickel, barium, [zinc], [molybdenum], [cadmium], [tungsten], [bismuth]) outlines hydrothermally altered areas where pyrite is abundant and some chalcopyrite occurs (fig. 13) as shown by the NMHMC samples (Frisken, Church, and Willson, 1988). An area of abundant pyrite extends from the headwaters of Pumice Creek east to the head of Wide Bay. There is a strong spatial correlation with the Pliocene intrusive rocks (Wilson and Shew, 1988) associated with the Mike prospect, but the geochemical association of this factor with the Agripina Bay batholith, also of Pliocene age, and the Oligocene intrusive rocks (Wilson and Shew, 1988) at the Rex prospect is much less pronounced.

Boron (PCF–6, fig. 14) shows a strong association with the areas of hydrothermal alteration associated with dikes and sills of Oligocene age. Comparison with the mineralogical data (Frisken, Church, and Willson, 1988) shows that this factor may reflect the presence of tourmaline in the concentrates in areas where there is mineralized rock. Some tourmaline was also found in the area north and west of the Mike prospect and at the head of Wide Bay. This factor also reflects a zone of propylitic alteration overlying the Agripina Bay batholith (the Kilokak Creek area) as well as along its western margin.

The geochemical association strontium, barium, and lanthanum (PCF–4) may reflect barite and pyrite in veins distal to mineralized rock at the Mike prospect and the Agripina Bay batholith. In addition, barite and pyrite, in some places associated with chalcopyrite, occurs in samples collected in the area of widespread pyrite exposed from the headwaters of Pumice Creek to Wide Bay (area B, fig. 15). There are two other occurrences northeast of the head of Portage Bay and at Puale Bay. In addition, the area along the northwest side of Wide Bay is outlined by this factor. The area is underlain by the Shelikof Formation, and the NMHMC samples from this area may include sedimentary barite; however, the minerals pyrite, chalcopyrite, and scheelite were found in NMHMC samples from some of these drainage basins. Some of the area north of Portage Bay is also outlined by PCF–4.

DRAINAGE BASIN ANALYSIS

Comparison of the geochemical data with the geologic map and the geophysical data defines ten areas that may have mineral endowment (fig. 16). Five of these areas were delineated by factor analysis. The Rex prospect (area 1, also defined as area A from the factor sample-scores) is associated with a composite Oligocene intrusive center. Much of the southern part of the study area (areas 2–5, which are coincident with area B) is strongly altered and contains numerous dikes and sills, probably of Oligocene to Pliocene age. Area 3 is defined by the factor sample-scores around the Mike prospect. Similar geochemical suites define anomalous areas that extend to the south into the Chignik and Sutwik Island quadrangles (Cox and others, 1981). Areas 6 and 7 include all of the outcrop area of the Pliocene Agripina Bay batholith (areas C and D as defined by the factor sample-scores), and area 8 is associated with Miocene alteration at Cape Kubugakli (area E as defined by factor sample-scores). Area 9 encompasses the folded Mesozoic strata on the west side of Wide Bay, and area 10 includes the Naknek Formation and the overlying Quaternary volcanic rocks north of the east end of Becharof Lake, northwest of the Kejulik River. Detailed summaries of the geochemical suites and ore-related minerals for each of the sites discussed below are given in table 5.

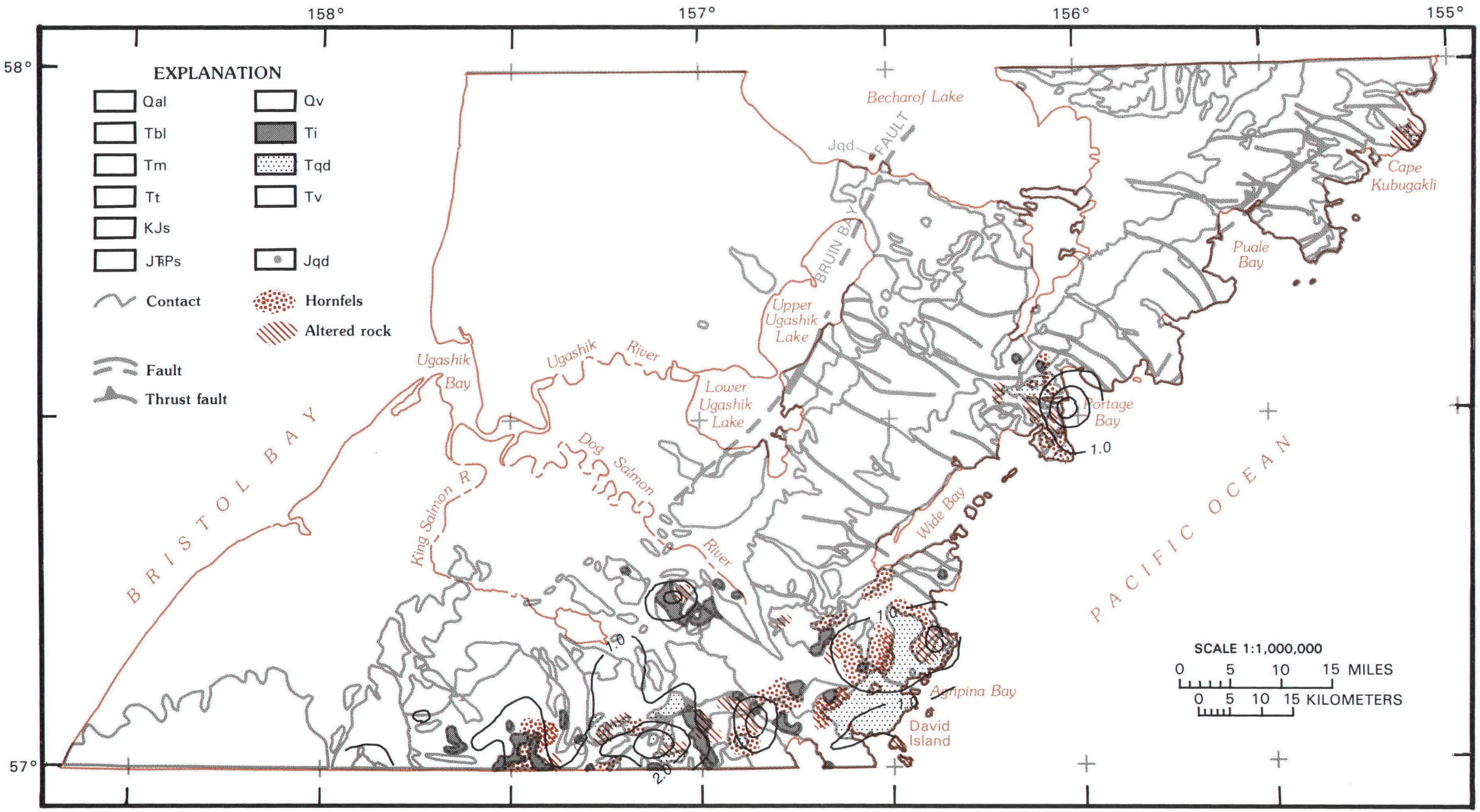


Figure 10. Map of the Ugashik-Karluk study area showing the correlation of stream-sediment factor 2 (SSF–2: lead, zinc, copper, boron, barium, [silver]) with areas of hydrothermal alteration associated with Tertiary intrusive rocks (Ti and Tqd). SSF–2 is shown as a contour plot of factor sample-scores (3.0 = 98th percentile, 2.0 = 95th percentile, 1.0 = 90th percentile). See figure 2 for explanation of other geologic map symbols.

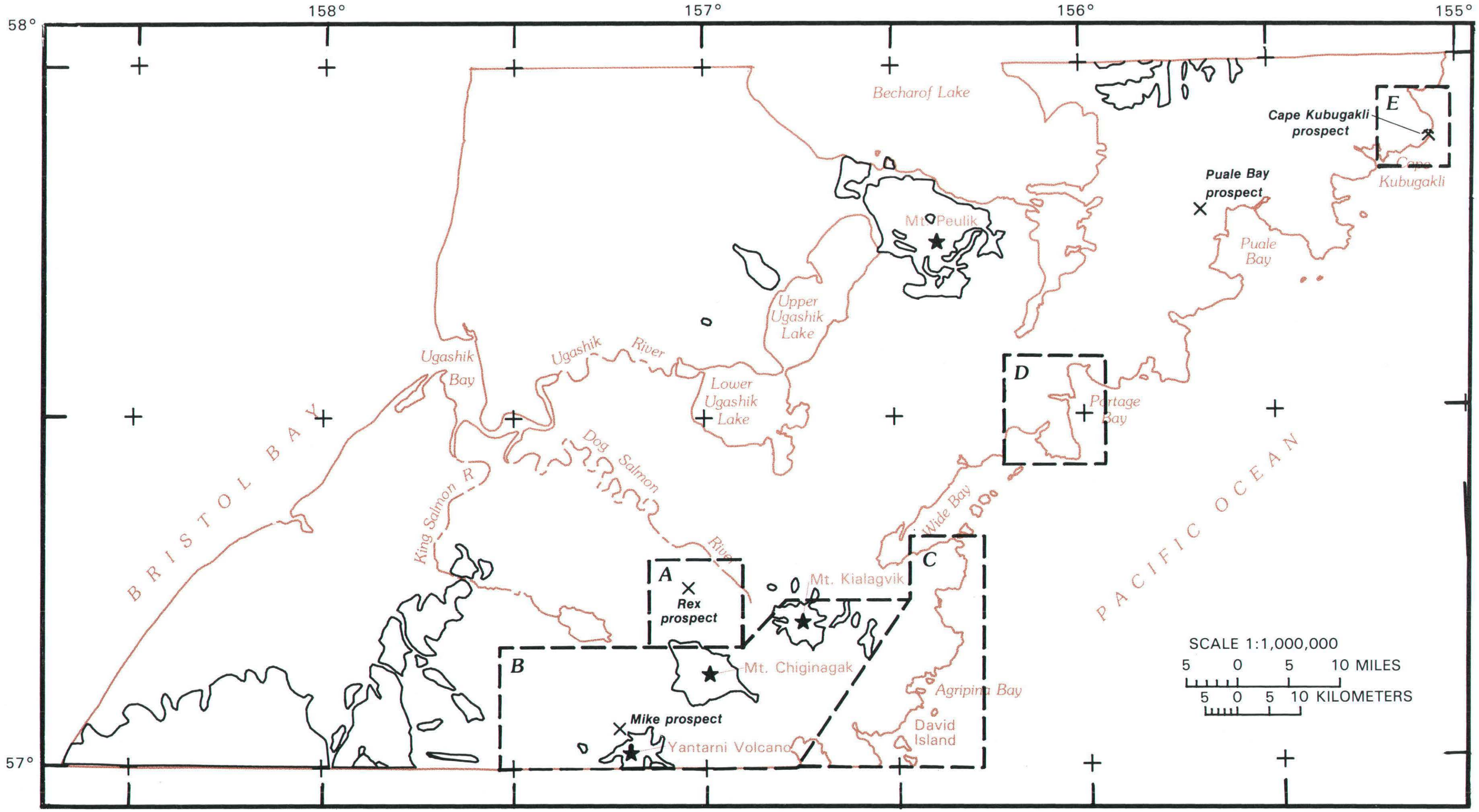


Figure 11. Map showing five major areas of prominent geochemical anomalies in the Ugashik-Karluk study area (heavy dashed lines): the area of the Rex prospect (A), the area of widespread pyrite and inferred Oligocene to Pliocene intrusive activity (B), the Agripina Bay batholith (C), the Portage Bay area (D), and the Cape Kubugakli area (E). Major Quaternary volcanic centers are labeled and the Quaternary lava flows are shown by the thin black lines.

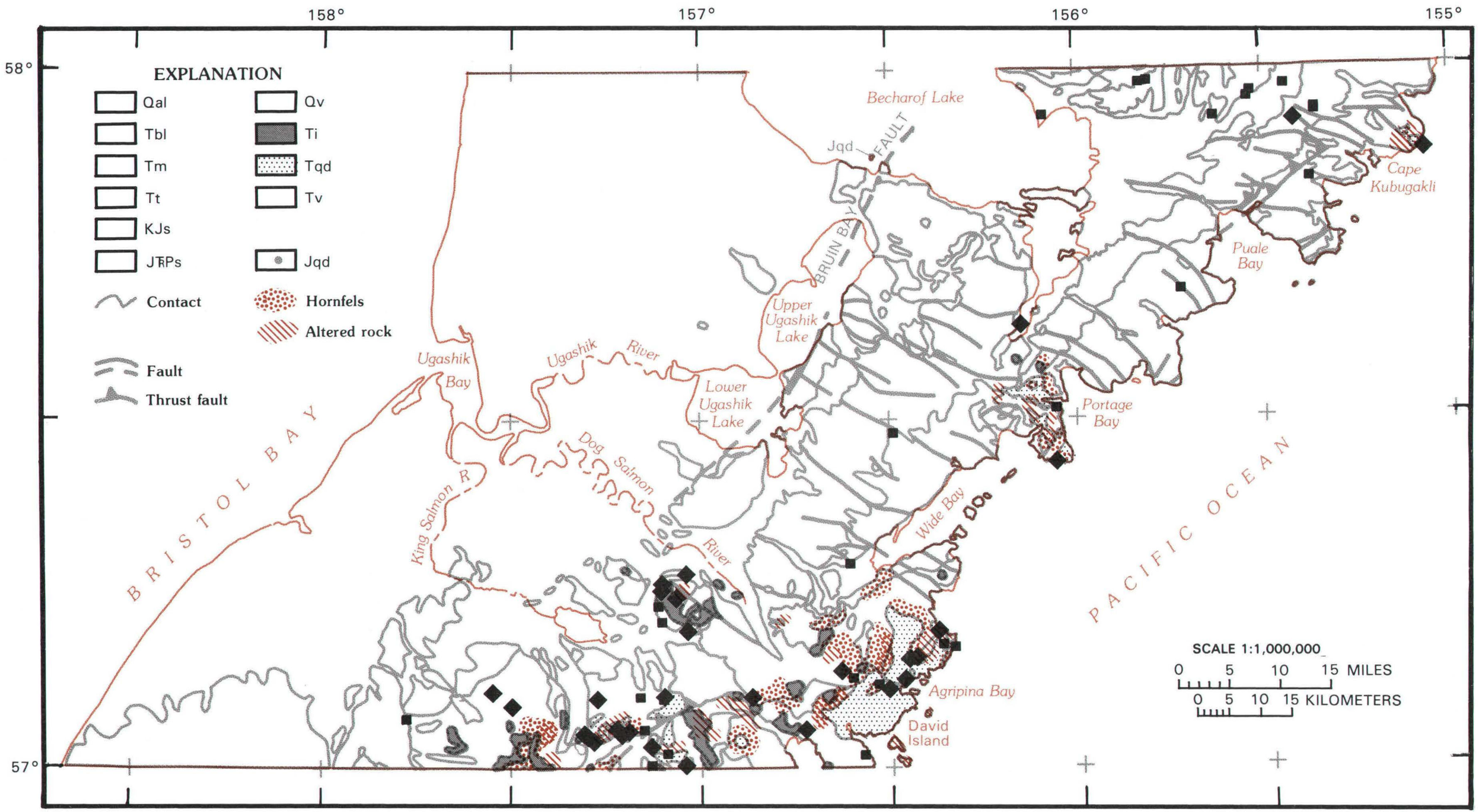


Figure 12. Map of the Ugashik-Karluk study area showing the correlation of heavy-mineral-concentrate factor 5 (PCF–5: silver, lead, [gold], [arsenic], [tin]) with areas of hydrothermal alteration associated with Tertiary intrusive bodies (Ti and Tqd). PCF–5 is shown as a point plot of factor sample-scores (95th percentile shown as a filled diamond; 90th percentile shown as a filled square). See figure 2 for explanation of other geologic map symbols.

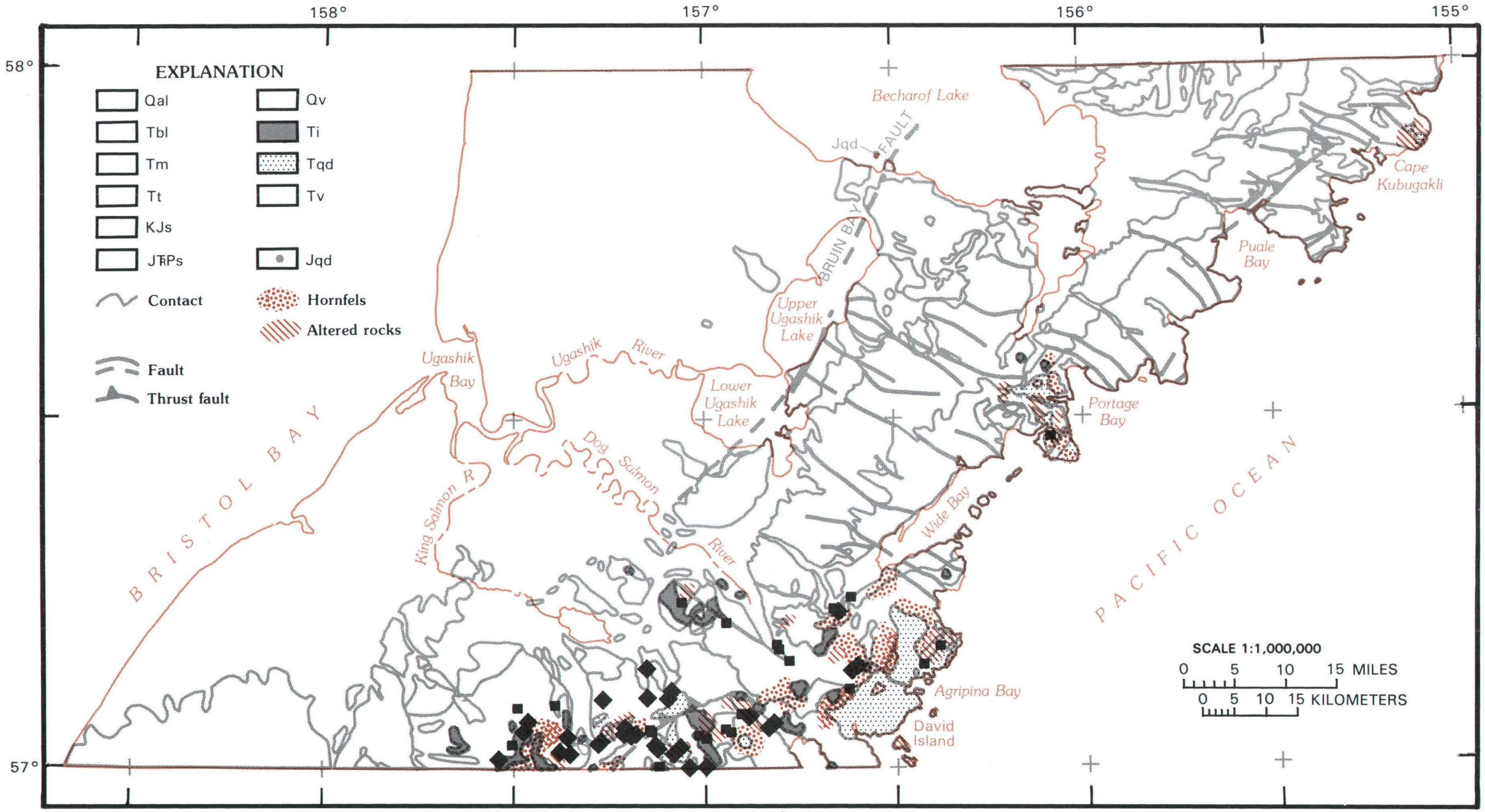


Figure 13. Map of the Ugashik-Karluk study area showing the correlation of heavy-mineral-concentrate factor 3 (PCF–3: cobalt, iron, copper, lead, nickel, barium, [zinc], [molybdenum], [cadmium], [tungsten], [bismuth]) with areas of hydrothermal alteration associated with Tertiary intrusive bodies (Ti and Tqd). PCF–3 is shown as a point plot of factor sample-scores (95th percentile shown as a filled diamond; 90th percentile shown as a filled square). See figure 2 for explanation of other geologic map symbols.

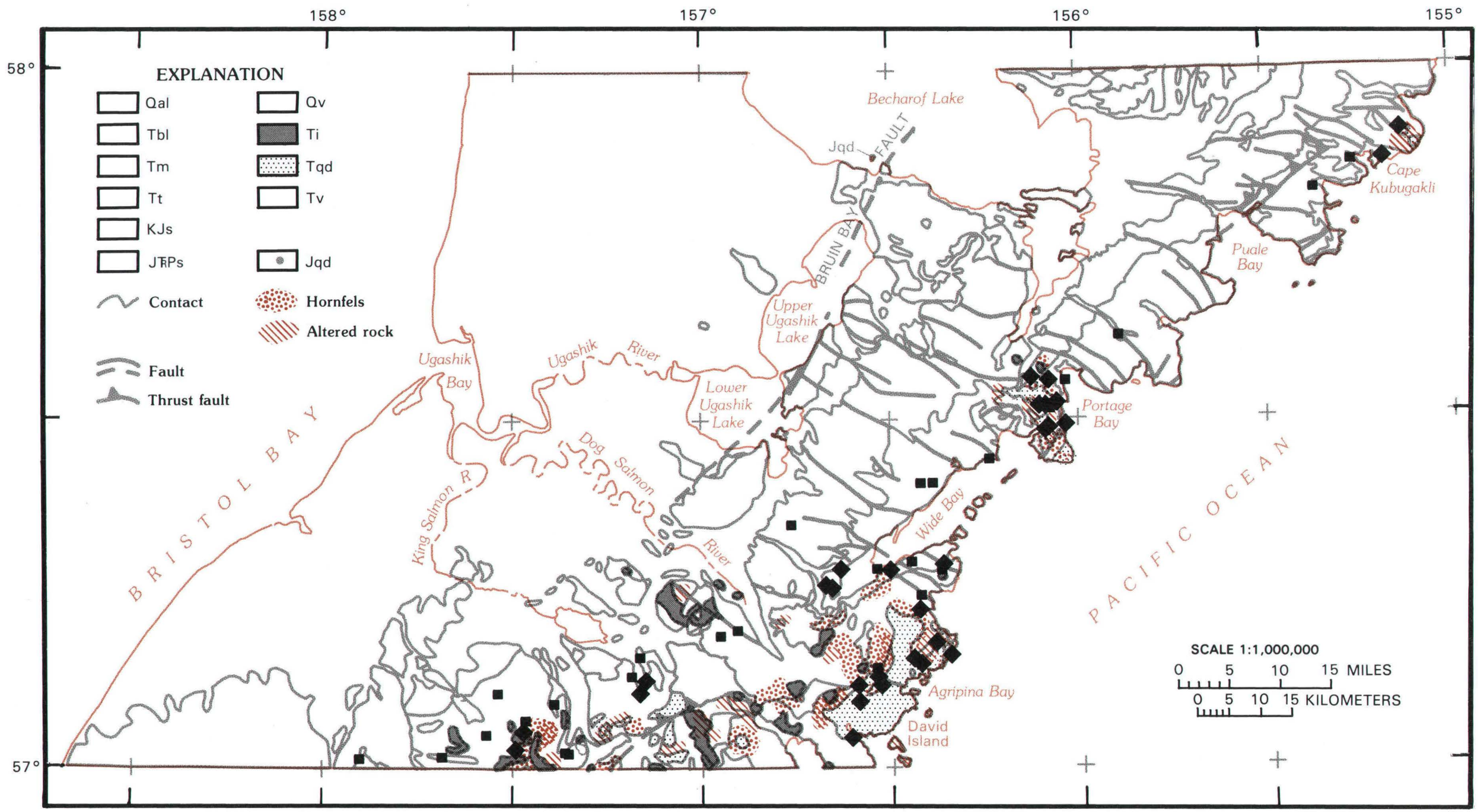


Figure 14. Map of the Ugashik-Karluk study area showing the correlation of heavy-mineral-concentrate factor 6 (PCF–6: boron) with areas of hydrothermal alteration associated with Tertiary intrusive bodies (Ti and Tqd). PCF–6 is shown as a point plot of factor sample-scores (95th percentile shown as a filled diamond; 90th percentile shown as a filled square). See figure 2 for explanation of other geologic map symbols.

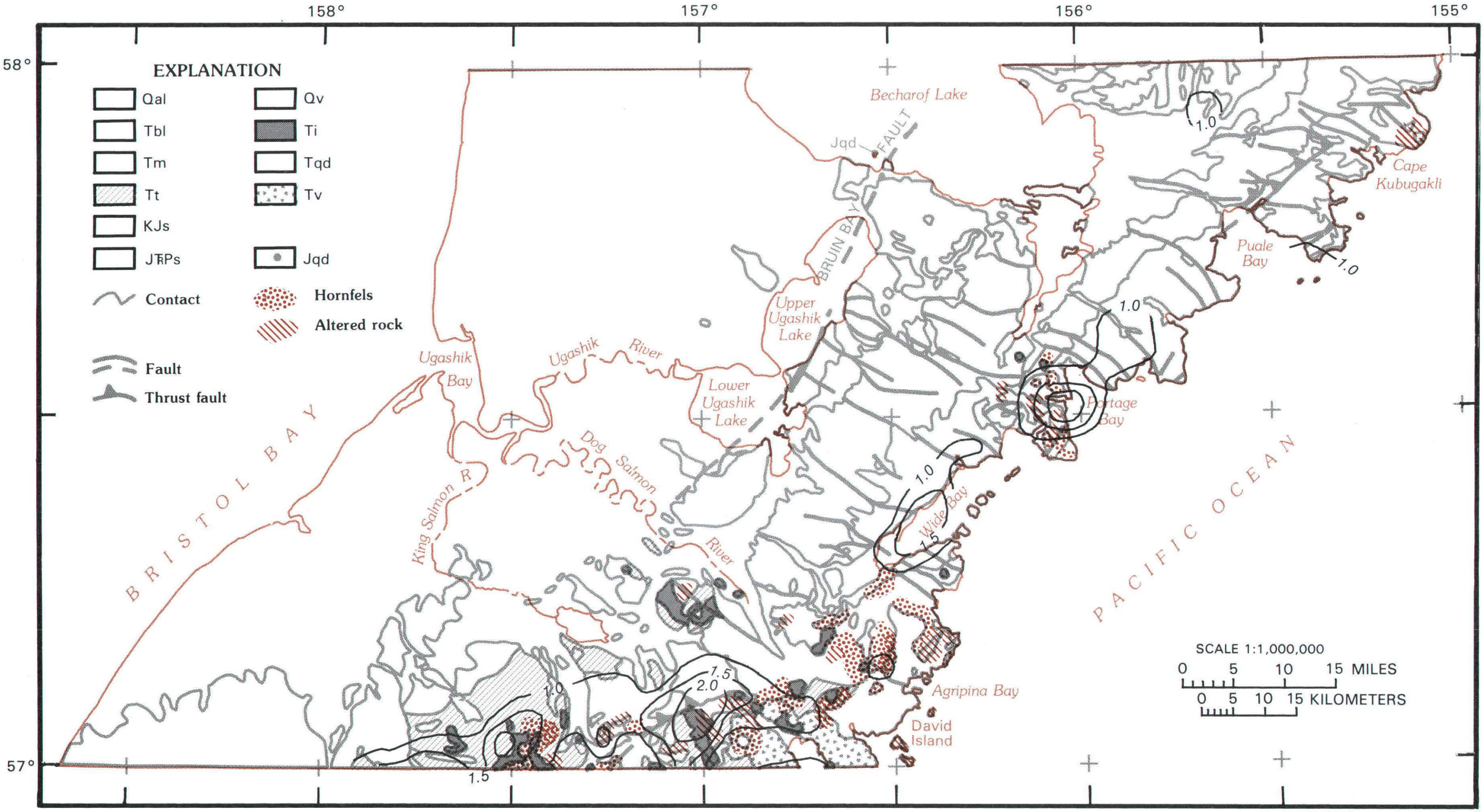


Figure 15. Map of the Ugashik-Karluk study area showing the correlation of heavy-mineral-concentrate factor 4 (PCF–4: strontium, barium, lanthanum) with sedimentary rocks of the Tolstoi Formation (Tt) and areas of altered volcanic rocks (Tv) overlying the intrusive rocks (Ti) in the southern part of the study area. PCF–4 is shown as a contour plot of factor sample-scores (2.0 = 98th percentile, 1.5 = 95th percentile, 1.0 = 90th percentile). See figure 2 for explanation of other geologic map symbols.

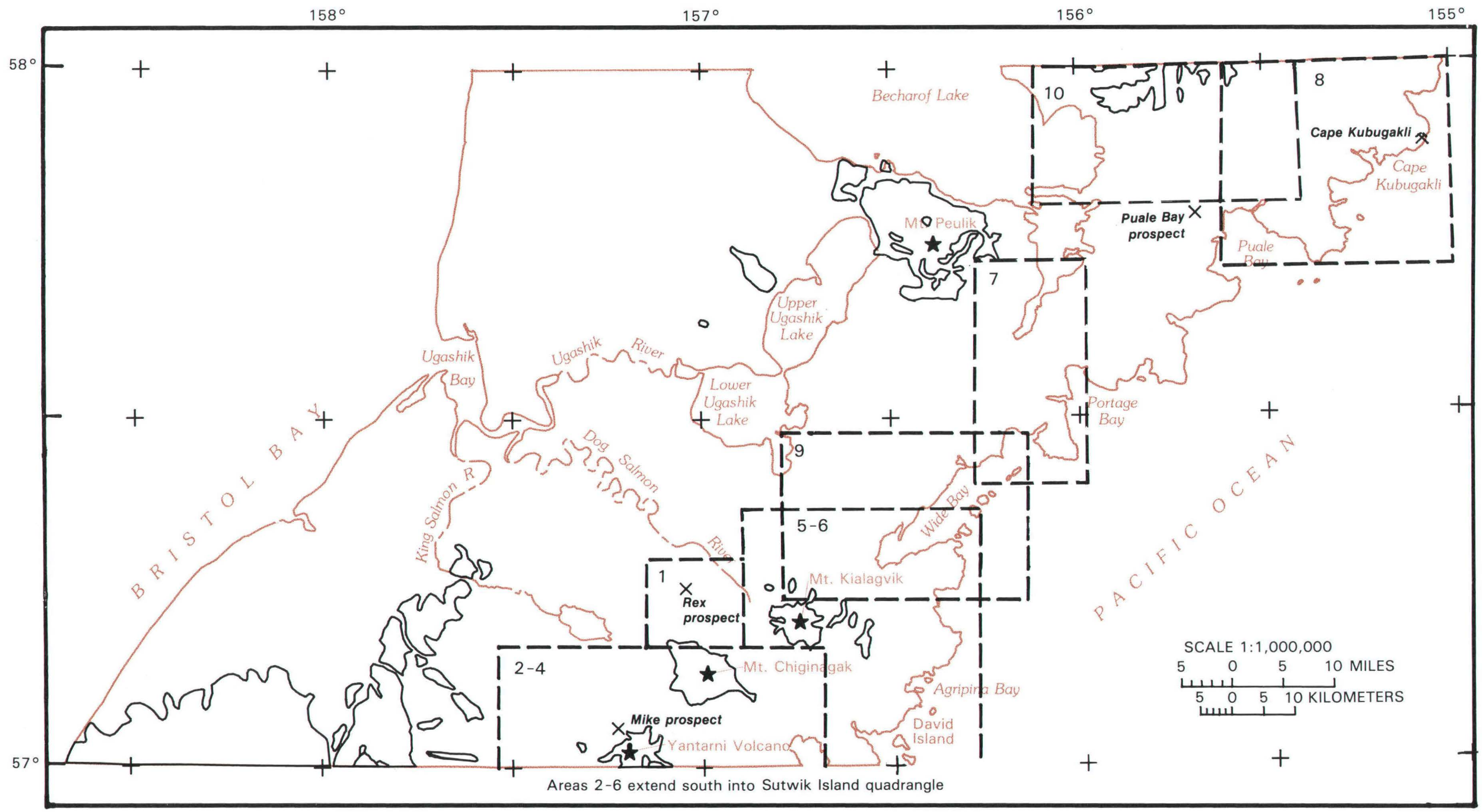


Figure 16. Map showing possible mineralized areas in the Ugashik-Karluk study area. Outlined areas (heavy dashed lines) defined on the basis of geochemical data (table 5). Detailed maps of specific areas are shown in the following figures: area 1, figure 17; areas 2–4, figure 18; areas 5–6, figure 20; area 7, figure 21; area 8, figure 22; area 9, figure 23; area 10, figure 24. Major Quaternary volcanic centers are labeled and the Quaternary lava flows are shown by the thin black lines.

Table 5. Summary of geochemical suites and associated minerals found in mineralized areas in the Ugashik, Bristol Bay, and western Karluk quadrangles, Alaska.

[Dashes indicate no data; MF maps in the Ugashik, Bristol Bay, and western Karluk quadrangles folio indicated to show from which sources the data have been taken]

General area	Anomalous concentrations of elements in stream-sediments (MF-1539-F)	Anomalous concentrations of elements in nonmagnetic, heavy-mineral panned-concentrate samples (MF-1539-G)	Minerals found in the nonmagnetic heavy-mineral panned concentrates (MF-1539-H)[1]	Anomalous concentrations of elements in mineralized rock (MF-1539-C)
1. Rex prospect	Cu, Mo, Ag, Pb, Zn, Co, Ni	Cu, Mo, Ag, Pb, Ni, Co, As, W, Au, Bi, Ba	py, cpy, sch, gold	Cu, Mo, Pb, Zn, Ba, Ag
2. West of Painter Creek and east of Pumice Creek	Cu, Ag, Pb, Zn, B, Ni, Co	Cu, Ag, Pb, Zn, B, Ni, Co, As, Bi, Cd, Ba	py, cpy, sph, cin, tour, bar	--
3. Mike prospect	Cu, Mo, Ag, Pb, Zn, B, Ni, Co	Cu, Mo, W, Ag, Pb, Zn, As, Cd, Ba, Ni, Co, B, Bi, Au	py, cpy, mly, sph, gal, tour, bar, cin, rutile	Cu, Mo, Pb, Zn, Ba, Au, Ag
4. Mt. Chiginagak-Chiginagak Bay	Cu, Mo, Ag, Pb, Zn, B, Co	Cu, Mo, Pb, Ag, Zn, B, As, Co, Ba	py, tour, bar	Cu, Pb, Zn
5. Mt. Kialagvik to west of Agripina Bay batholith	Cu, Mo, Pb, Ag, Zn, B, Co	Cu, Mo, W, Pb, Ag, Zn, B, Co, As, Bi, Ba	py, cpy, sch, gold, bar, tour	Pb, Cu, Mo, Zn, Ba
6. Agripina Bay batholith	Cu, Mo, Ag, Pb, Zn, B, Co	Cu, Mo, Ag, Pb, Zn, B, Co, As, Au, Cd, Sn, Ba	py, cpy, gal, gold, cin, tour, bar	Cu, Mo, Pb, Zn, Ba, Au, As
7. Portage Bay	Mo, Ag, Pb, Zn, B, Co	Cu, Pb, Ag, Zn, B, Co, As, W, Cd, Sn, Bi	py, cpy, gal, sph, sch, tour, rutile	Cu, Mo, Pb, Ba, As, Ag
8. Cape Kubugakli	Mo	Cu, B, Au, Ag, W, Co	py, cpy, tour, sch	Cu, Mo, Pb, Zn, Au, Ag
9. West side of Wide Bay	Ag, Co	Cu, Ag, Pb, Ni, Ba	py, sch, tour, bar	Cu, Zn, Ag
10. East of Becharof Lake and north of the Kejulik River	Ag, Co	Cu, Ag, Pb, Cd, Ba, Sn	cpy, py, bar	--

[1]The following abbreviations have been used in the table and in figures 17, 18, 20-24: py, pyrite; cpy, chalcopyrite; sch, scheelite; tour, tourmaline; bar, barite; mly, molybdenite; gal, galena; cin, cinnabar; and sph, sphalerite.

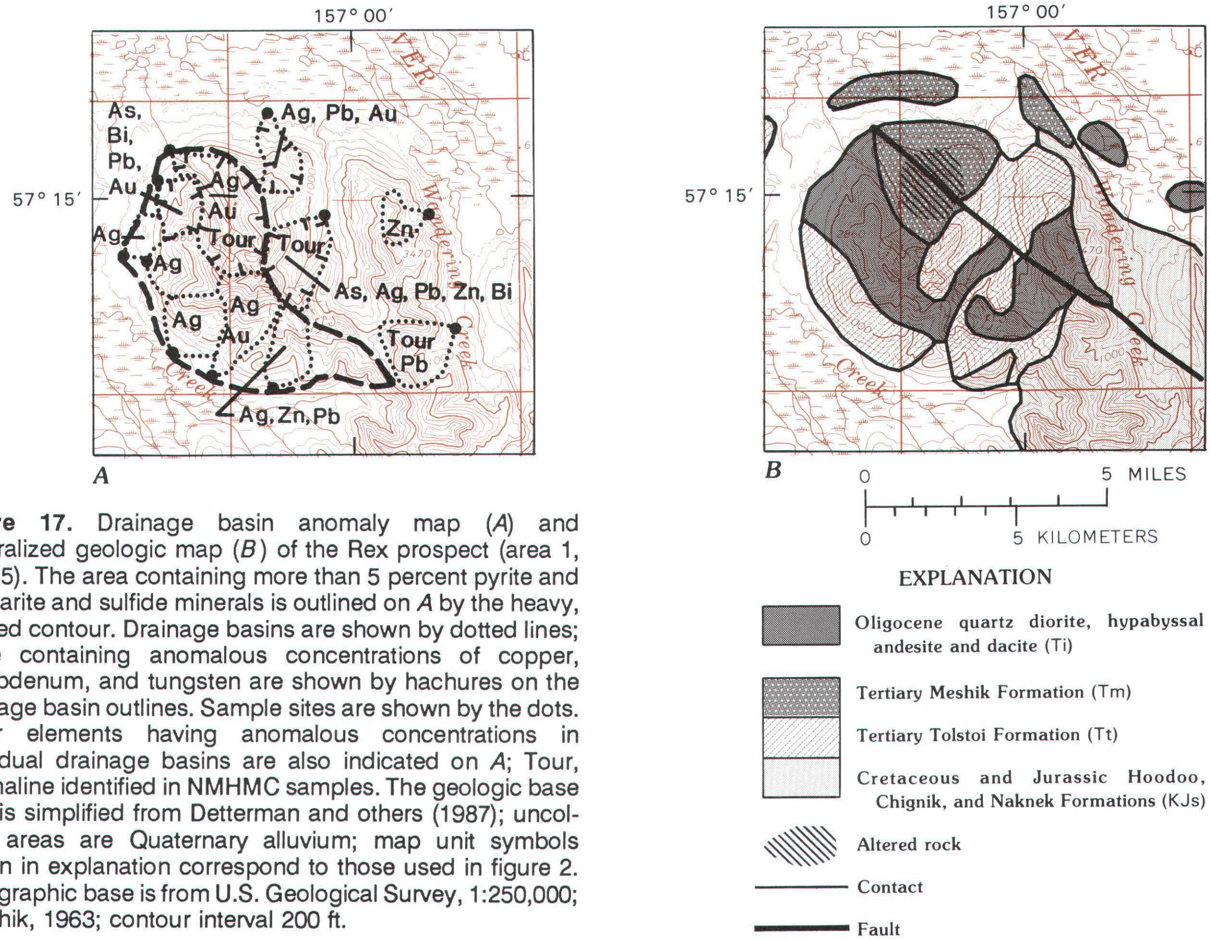


Figure 17. Drainage basin anomaly map (*A*) and generalized geologic map (*B*) of the Rex prospect (area 1, table 5). The area containing more than 5 percent pyrite and (or) barite and sulfide minerals is outlined on *A* by the heavy, dashed contour. Drainage basins are shown by dotted lines; those containing anomalous concentrations of copper, molybdenum, and tungsten are shown by hachures on the drainage basin outlines. Sample sites are shown by the dots. Other elements having anomalous concentrations in individual drainage basins are also indicated on *A*; Tour, tourmaline identified in NMHMC samples. The geologic base map is simplified from Detterman and others (1987); uncolored areas are Quaternary alluvium; map unit symbols shown in explanation correspond to those used in figure 2. Topographic base is from U.S. Geological Survey, 1:250,000; Ugashik, 1963; contour interval 200 ft.

Rex Prospect

The Rex prospect (area 1) is associated with a composite Oligocene hypabyssal intrusion in the Chignik and Tolstoi Formations. The country rocks are hornfelsed, silicified, and propylitically altered sandstone and shale. The western side of the mountain has been intensely altered and andesitic dikes are pervasive; pyrite is common (Detra and others, 1982). The Rex prospect is located on a series of copper-molybdenum-tungsten anomalies defined by SS samples. The anomalous drainage basins are surrounded by drainage basins containing anomalous concentrations of lead, zinc, silver, gold, and bismuth as determined from both SS and NMHMC samples. Gold is common in the panned concentrates surrounding the prospect. The distributions of the geochemical anomalies are shown in figure 17. The geochemical anomalies from this area appear to define a porphyry copper-gold system.

The Rex prospect was evaluated by the Kennecott Corporation (Bear Creek Mining Company) in 1977 following a reconnaissance stream-sediment geochemical survey in 1975 (J. Hammitt, written commun., 1986). The descriptive data given below were taken from a company report and are published here with permission of Kennecott Corporation and Koniag, Incorporated. Their data outline an area of pronounced copper, molybdenum, lead, zinc, silver, and gold anomalies in the area as determined from both stream-sediment and rock geochemistry. Copper anomalies are in the range of 500–1,000 ppm, and anomalous molybdenum concentrations (20–30 ppm) surround the core of the intrusion. Rock-chip samples from one small area in the NW¼ sec. 19 showed high values for both copper and molybdenum indicating a relatively uniform grade of mineralization. Elsewhere, sporadically high concentrations of copper were found, but mineralization did not appear to be of uniform grade. Concentrations of lead and zinc are sporadically high peripheral to the central copper and molybdenum anomaly, entirely consistent with our stream-sediment and NMHMC sampling.

Chalcopyrite and molybdenite at the Rex prospect are confined almost exclusively to the zone of potassic alteration within the intrusive rocks. Sulfide content of this core area is in the range of 2–3 percent. Rock-chip geochemistry indicates a good correlation of gold with copper content (0.8 ppm Au at 1 percent Cu, or about

0.8 g/T (0.023 oz Au/T) at 1 percent Cu). Chalcopyrite is present both as disseminated and stockwork ore, whereas molybdenite is locally present in the stockwork. Pyrite is the only other sulfide in the ore zone. The boundary of the core area, which covers about 2.5 km^2(1 mi^2), is surrounded by a halo in the country rocks that contains 5–10 percent pyrite. Weathering of hornfelsed and pyritized sediments and volcanic rocks produces a pronounced reddish-brown color anomaly. Zones of phyllic alteration are minor (NE¼ sec. 24 and NW¼ sec. 19). The dominant alteration seen at the prospect is propylitic. Intrusive rocks near the top of the ridges contain disseminated chalcopyrite (500–1,000 ppm Cu). A zone of mineralized rock, associated with an area of secondary biotite alteration about 150 m (500 ft) in width and containing about 0.2 percent Cu, can be outlined on the basis of work carried out by the staff of the Kennecott Corporation.

Mike Prospect

The Mike prospect, a large color anomaly (area 3), as well as the adjacent anomalous areas to the west (area 2) and east (area 4), are shown in figure 18. The Mike prospect is centered on a large copper-molybdenum anomaly defined by stream-sediment data. Surrounding drainage basins contain anomalous concentrations of copper, lead, zinc, silver, arsenic, cadmium, and bismuth that extend south into the Sutwik Island quadrangle (Cox and others, 1981). The area of the Mike prospect is a felsic dike and sill complex that intruded sandstone and siltstone of the Naknek Formation (Detra and others, 1982). Pyrite is abundant in the NMHMC samples as well as are many sulfides, hydrothermal barite, and tourmaline. Geochronologic studies of this area (Wilson and Shew, 1988) indicate that the Mike prospect is associated with intrusive rocks of Pliocene age and that the hydrothermal alteration is also of Pliocene age. Intense sericitic and phyllic alteration surrounds a well-developed stockwork in the core area of the prospect.

Field investigations at the Mike prospect were carried out by the exploration staff of the Kennecott Corporation (Bear Creek Mining Company) in 1977. The following summary is from their studies. Cretaceous and Jurassic sedimentary rocks over an 8-km^2 (3-mi^2) area were domed, hornfelsed, and altered by a late-stage composite hypabyssal rhyolitic stock and numerous sills (silica values ranged from 77.9 to 81.5 percent SiO_2). This central rhyolitic intrusion and the surrounding domed sedimentary rocks were then crosscut by a quartz-eye porphyry dike system (73.9 percent SiO_2). This central rhyolitic stock is surrounded by numerous dacitic dikes to the north and west. Small stocks of quartz monzonite and quartz monzonite porphyry occur in the area of the central rhyolitic sill as well as to the northeast of the main rhyolite stock (fig. 19).

The central rhyolitic stock is a mixture of silicified rhyolite and quartz monzonite. Silica flooding made it difficult to distinguish the intrusive rocks from the silicified sediments in the field. Small pebble dikes present in some parts of the system suggest that they were near the top of the intrusion. An area of intense quartz stockwork veining and silica flooding in the west-central part of the rhyolitic stock shows intense sericitic alteration and overlaps the silica core. Potassium contents are low (2.4–3.7 percent K_2O). Sulfides, dominated by pyrite, reach 5–10 percent over a 2.5-km^2 (1-mi^2) area and grade outward to 1–2 percent over an 8-km^2 (3-mi^2) area. Average molybdenum contents of samples from the core area were about 130 ppm. Molybdenum occurs as fine-grained molybdenite along small quartz-filled fractures, but it also occurs locally in coarse quartz veins and veinlets. Lesser amounts of molybdenum occur sporadically in the hornfelsed sediments at the margin of the rhyolitic stock (see area outlined by the 40-ppm-Mo contour defined on the basis of rock-chip sampling). Copper contents of samples from the zone of molybdenum mineralization were generally low, in the range of 10–50 ppm. Chalcopyrite was absent. Lead, zinc, and silver anomalies are also low over this zone. Lead and zinc anomalies, as well as small amounts of sphalerite and galena, were observed in the hornfelsed sediments peripheral to the rhyolite stock west of the main zone of molybdenum mineralization. Tin and tungsten anomalies were also observed in rocks in the mineralized zone of the rhyolite stock. Fluorine values average 710 ppm, but range to as much as 2,100 ppm in the central zone of molybdenum mineralization. A strong correlation of molybdenum and fluorine exists in the zone of molybdenum mineralization. No fluorite was observed at the surface. Magnetite and hematite are both present in the veins. The abundance of pyrite and the low molybdenum contents of the quartz-eye porphyry dikes suggest that the molybdenum-mineralization event occurred prior to the intrusion of the dikes.

Results of shallow drilling (fig. 19) by Bear Creek Mining Company in 1977 indicated weak molybdenite mineralization along the entire length of core 77–1. This drill hole penetrated 33 m (108 ft) of silicified rhyolite (76.5 percent SiO_2; 3.5 percent K_2O) averaging 1–2 percent pyrite and 35 ppm Mo. Drill hole 77–2 penetrated 6 m (19 ft) of rhyolite sill (76.5 percent SiO_2; 4.1 percent K_2O) averaging 3 percent pyrite and 18 ppm Mo and 18 m (58 ft) of silicified sediments averaging 1–2 percent pyrite and 10 ppm Mo. Drill hole 77–3 penetrated 22 m (73 ft) of altered

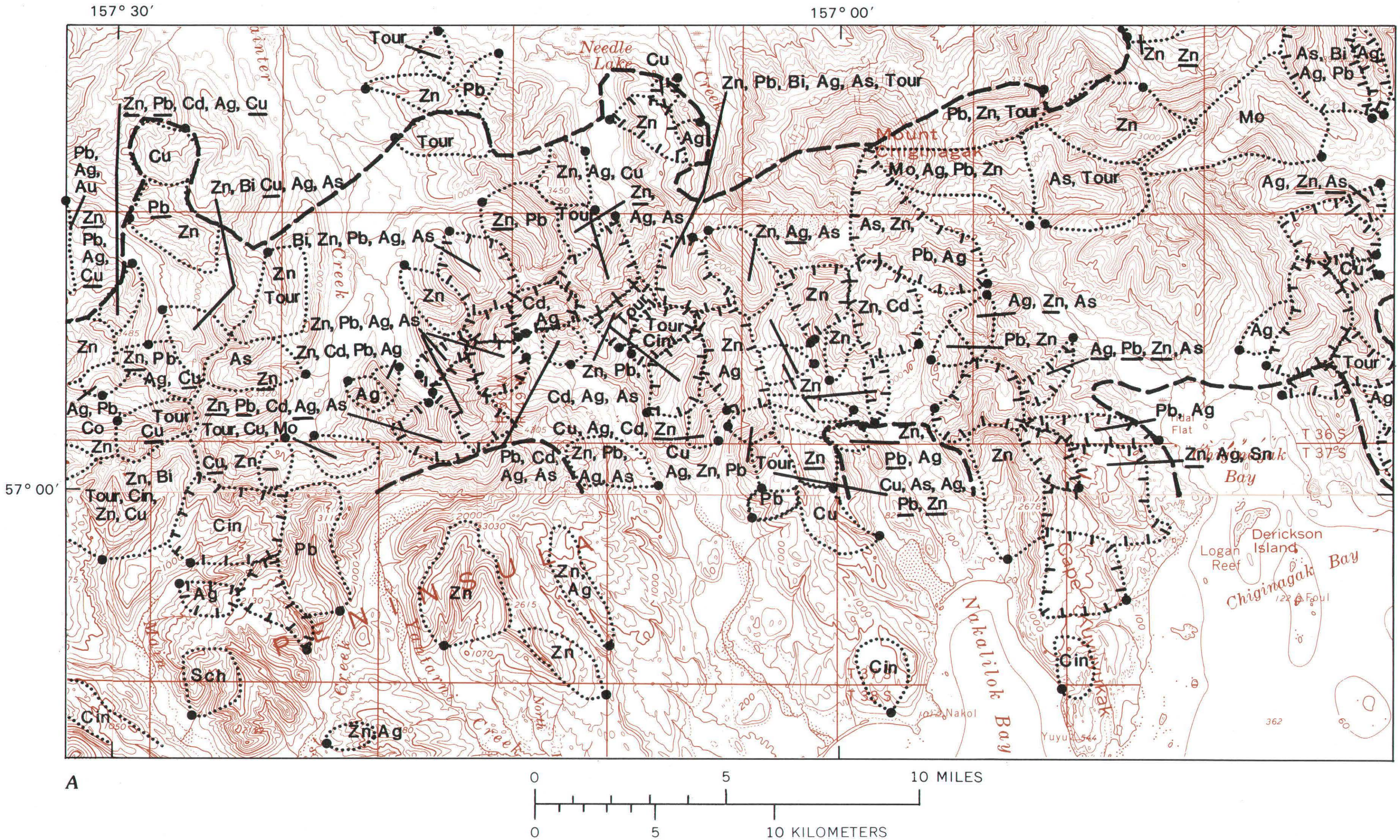
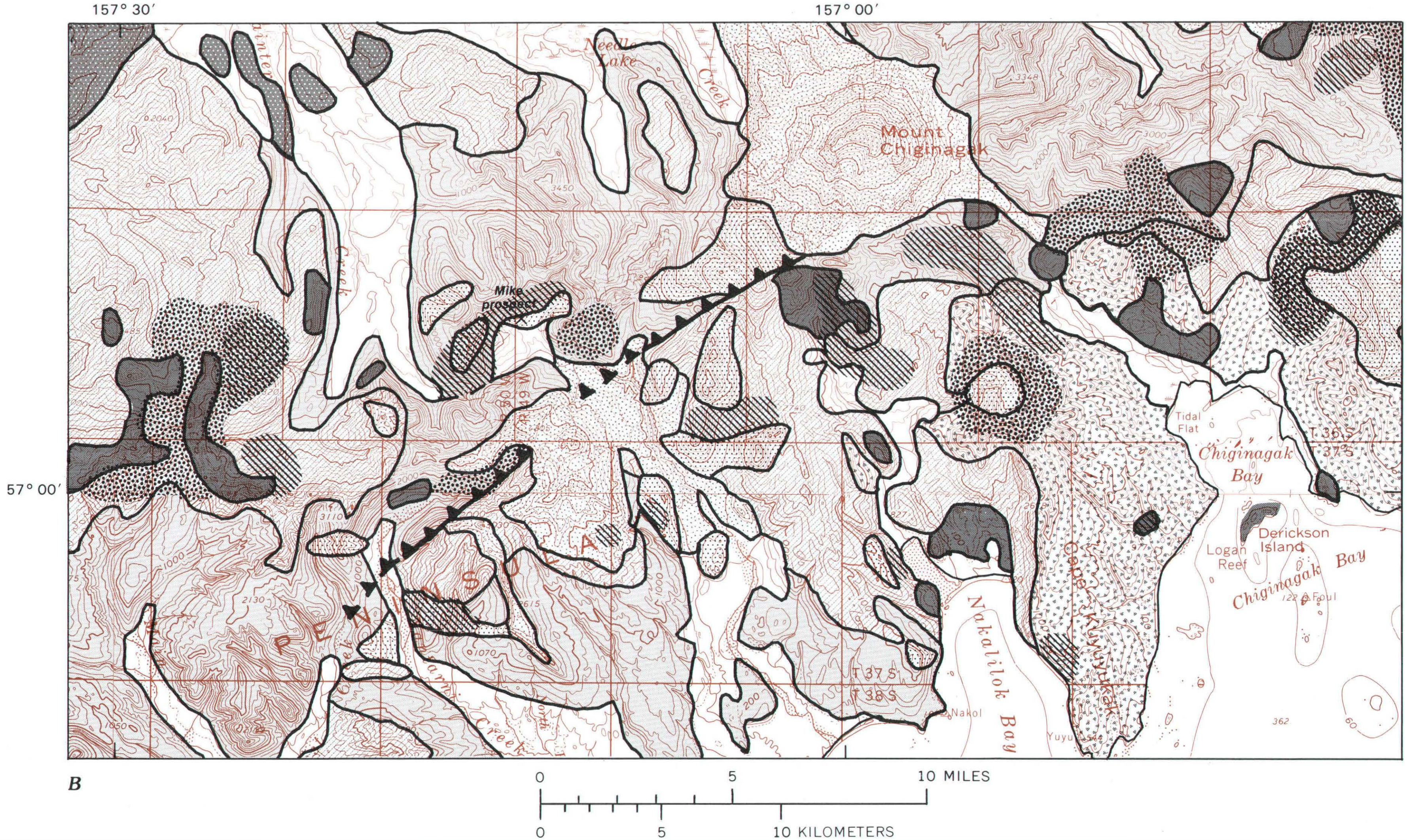


Figure 18 (above and facing page). Drainage basin anomaly map (*A*) and generalized geologic map (*B*) of the area surrounding the Mike prospect (areas 2–4, table 5).The area shown extends south into the Chignik–Sutwik Island study area (Cox and others, 1981). The area containing more than 5 percent pyrite and (or) barite and sulfide minerals is outlined on *A* by the heavy, dashed contour. Drainage basins are shown by dotted lines; those containing anomalous concentrations of copper, molybdenum, and tungsten are shown by hachures on the drainage basin outlines. Sample sites are shown by the dots. Other elements having anomalous concentrations in individual drainage basins are also indicated on *A*; if the element was anomalous in both the SS and the NMHMC media, the element symbol is underlined. Heavy minerals identified in the NMHMC samples are also indicated (Cin, cinnabar; Sch, scheelite; and Tour, tourmaline). The geologic base map is simplified from Detterman and others (1981, 1987); uncolored land areas are Quaternary alluvium; map unit symbols shown in explanation correspond to those used in figure 2. Topographic base is from U.S. Geological Survey, 1:250,000; Ugashik, 1963; Sutwik Island, 1963; contour interval 200 ft.



B

EXPLANATION

- Quaternary volcanic rocks (Qv)
- Pliocene to Oligocene basalt, andesite, and dacite (Tv)
- Tertiary quartz diorite (Tqd)
- Tertiary intrusive rocks (Ti)
- Tertiary Meshik Formation (Tm)
- Tertiary Tolstoi Formation (Tt)
- Cretaceous and Jurassic Hoodoo, Chignik, and Naknek Formations (KJs)
- Hornfels
- Altered rock
- Contact—Dashed where approximately located
- Thrust fault- Dashed where concealed; sawteeth on upper plate

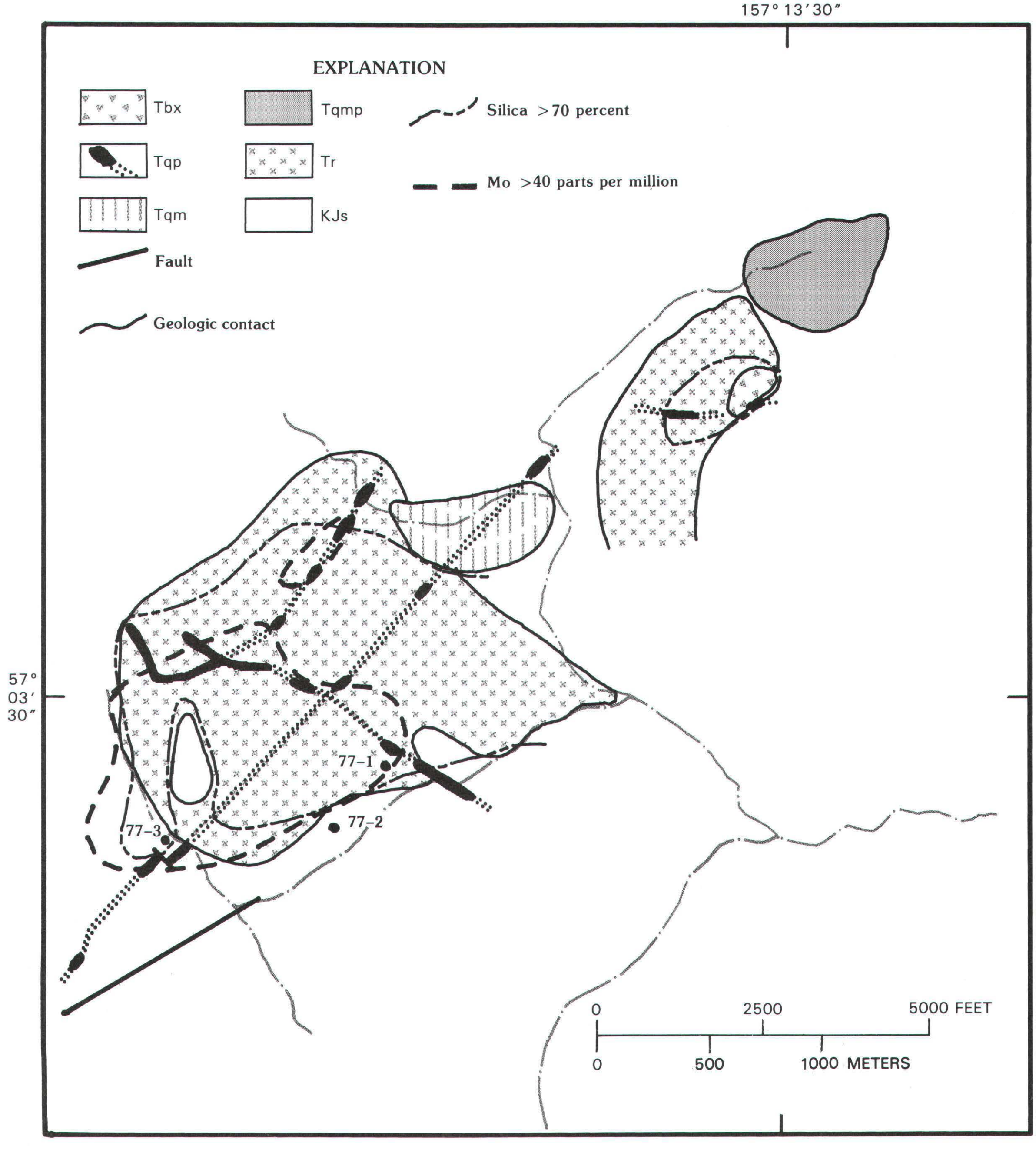


Figure 19. Generalized geologic and geochemical map of the Mike prospect (fig. 18) showing the rhyolitic intrusion (Tr); the quartz monzonite porphyry (Tqmp); the quartz monzonite (Tqm); the late-stage quartz porphyry dikes (Tqp, dotted where approximately located); and the breccia pipe (Tbx) and associated zones of silica enrichment and molybdenum mineralization. The surrounding country rocks are Cretaceous and Jurassic sedimentary rocks (KJs); geologic map courtesy of Kennecott Corporation (published with permission). Sites of the drill holes are also indicated (77–1, 77–2, and 77–3).

quartzitic siltstone averaging 1–3 percent pyrite and 125 ppm Mo, the bottom 7 m (22 ft) averaging 253 ppm Mo, where the hole was lost due to caving. Fluorite was observed in this core.

A small quartz monzonite stock, about 2.5 km^2 (1 mi^2), intruded the rhyolitic stock on the east side (fig. 19), and a second small quartz monzonite stock intruded sediments about 1.6 km (1 mi) east-northeast of the rhyolitic stock. A large breccia pipe (120 by 215 m, or 400 by 700 ft) also occurs near this second quartz monzonite body. Copper contents of these small stocks range from 500 to 1,000 ppm; one sample from a copper skarn in sediments adjacent to a dacite dike contained 3,450 ppm Cu. Molybdenum concentrations of samples from the quartz monzonite stocks ranged between 10 and 20 ppm. One grab sample from the breccia pipe contained 160 ppm Mo. Reconnaissance geological investigations summarized here suggest mineralization associated with a low-fluorine porphyry molybdenum system at the Mike prospect.

Geochemical anomaly patterns indicated by SS and NMHMC samples from area 2 are similar to those associated with the quartz monzonite stocks in the area of the Mike prospect. These geochemical anomalies occur in an area of widespread sericitically altered rock probably underlain by intrusive rocks (table 5). Like the stream-sediment geochemical anomaly pattern associated with the Mike prospect, this anomaly can also be traced into the Sutwik Island quadrangle to the south. The geochemical anomaly is not as pronounced as that of the Mike prospect, but contains essentially the same suite of elements. An extensive area of hornfelsed country rock and a small area of hydrothermal alteration were mapped in area 2 (Detterman and others, 1983). The area may contain high-level base- and precious-metal vein systems overlying porphyry-type systems at depth.

Area 4, east of the Mike prospect and south of Mount Chiginagak to Cape Kuyuyukak, is an area of scattered copper-molybdenum-lead-zinc-cobalt-silver-arsenic anomalies determined on the basis of SS and NMHMC samples from drainage basins where the country rock contains numerous dikes and sills. This pattern of anomalies may have been partially obscured by the Quaternary volcanic activity associated with Mount Chiginagak. Extensive areas of hydrothermal alteration and hornfelsed rock were noted in the Naknek, Chignik, Hoodoo, and Tolstoi Formations during field mapping in area 4 (Detterman and others, 1983). The area may contain high-level base- and precious-metal vein systems overlying porphyry-type systems at depth.

The SS and NMHMC samples from the Kialagvik Creek area draining the northeast side of Mount Kialagvik, area 5, contained anomalous concentrations of many elements (fig. 20). Stream sediments and panned concentrates from the drainage basins contained anomalous concentrations of copper, molybdenum, tungsten, lead, zinc, silver, arsenic, and bismuth. A small area of pyritic alteration was also mapped northwest of Mount Kialagvik and south of Goblet Creek (Detterman and others, 1983). Drainage basins in this area contain anomalous amounts of copper and zinc associated with tourmaline in the NMHMC samples; this set of anomalies may also be related to this episode of mineralization.

Agripina Bay Batholith

Geochemical anomalies determined from SS and NMHMC samples spatially associated with the Agripina Bay batholith of Pliocene age (area 6) are shown in figure 20. Both the Tertiary volcanic rocks and the Upper Jurassic Naknek Formation along the borders of the Agripina Bay batholith are extensively altered near hypabyssal dikes and sills of Oligocene and younger age. Some extensively hornfelsed and hydrothermally altered volcanic and hypabyssal rocks overlying and intruded by the Pliocene Agripina Bay batholith give Oligocene ages. Hydrothermally altered rock and geochemical anomalies associated with the batholith may also reflect the Oligocene intrusive event. The factor analysis of the NMHMC samples discussed above (PCF–6, fig. 14) clearly shows a boron signature associated with the hypabyssal rocks to the west of the batholith, as well as with the older rocks intruded by the Agripina Bay batholith. Epidote was common in the heavy-mineral concentrates collected from drainage basins between Chiginagak Bay and Imuya Bay to the north. Furthermore, there were copper-molybdenum-tungsten-lead-zinc-silver-arsenic-gold anomalies in the SS and NMHMC samples associated with cinnabar, hydrothermal barite, and tourmaline. These anomalies are particularly pronounced at Cape Kilokak (fig. 20), where small inliers of hornfelsed and altered Naknek, Chignik, Hoodoo, and Tolstoi Formations are completely surrounded by the Pliocene Agripina Bay batholith. The data suggest that base- and precious-metal vein mineralization largely affected the rocks surrounding the Agripina Bay batholith and may be older than the dated intrusive phases of the batholith.

Pyritic Lode Mineralization on the Eastern End of David Island

Case and others (1987) noted a magnetic low over David Island, and Wilson and O'Leary (1986, 1987) reported anomalous values for copper, lead, and molybdenum in samples from David Island. In the summer of 1986, we visited David Island to examine it for possible mineralized rock. We observed a large area at the eastern end of David Island where a massive pyritic lode, estimated to be 3–6 m (10–20 ft) thick, is exposed at wave base on the south side of the small point at the

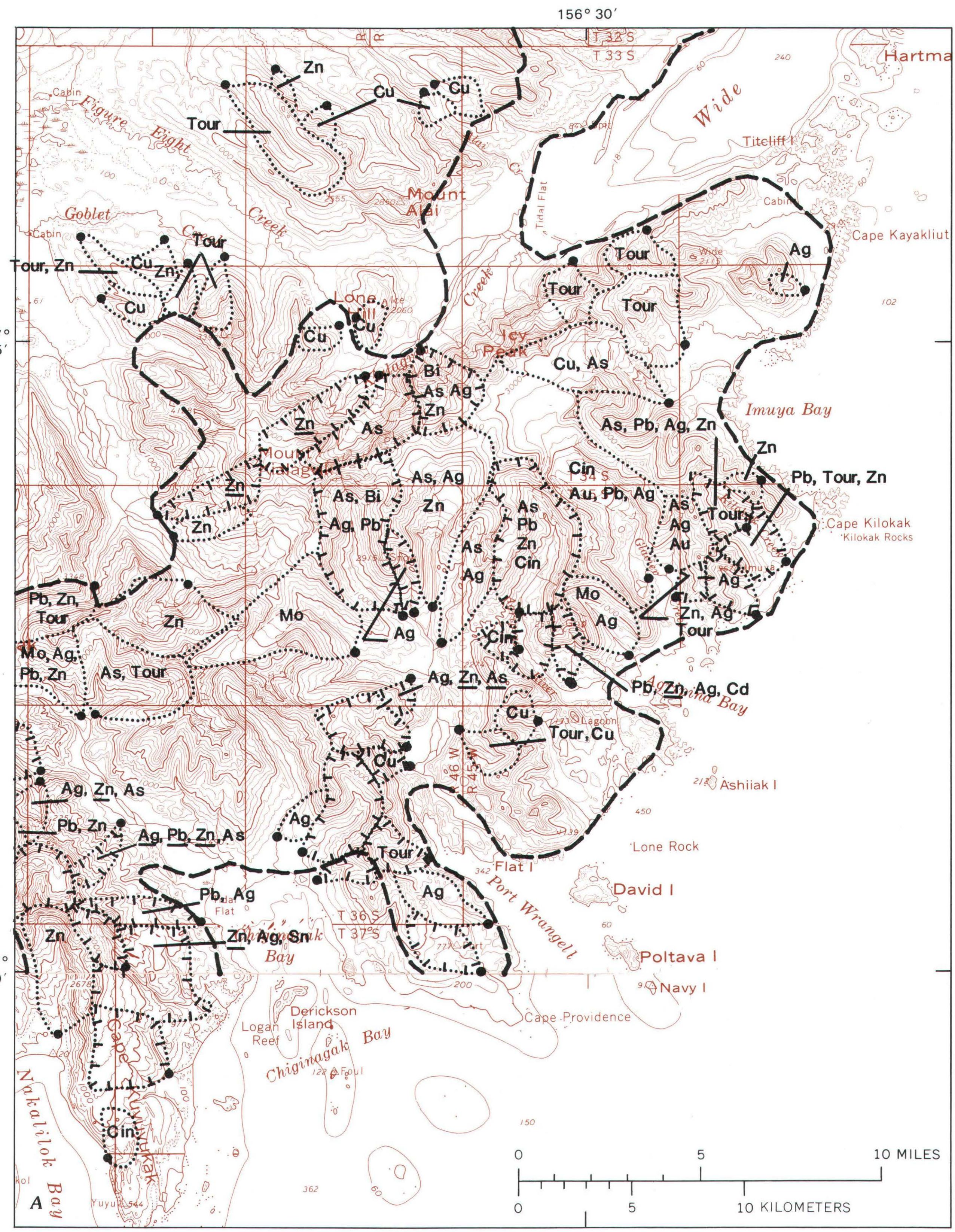
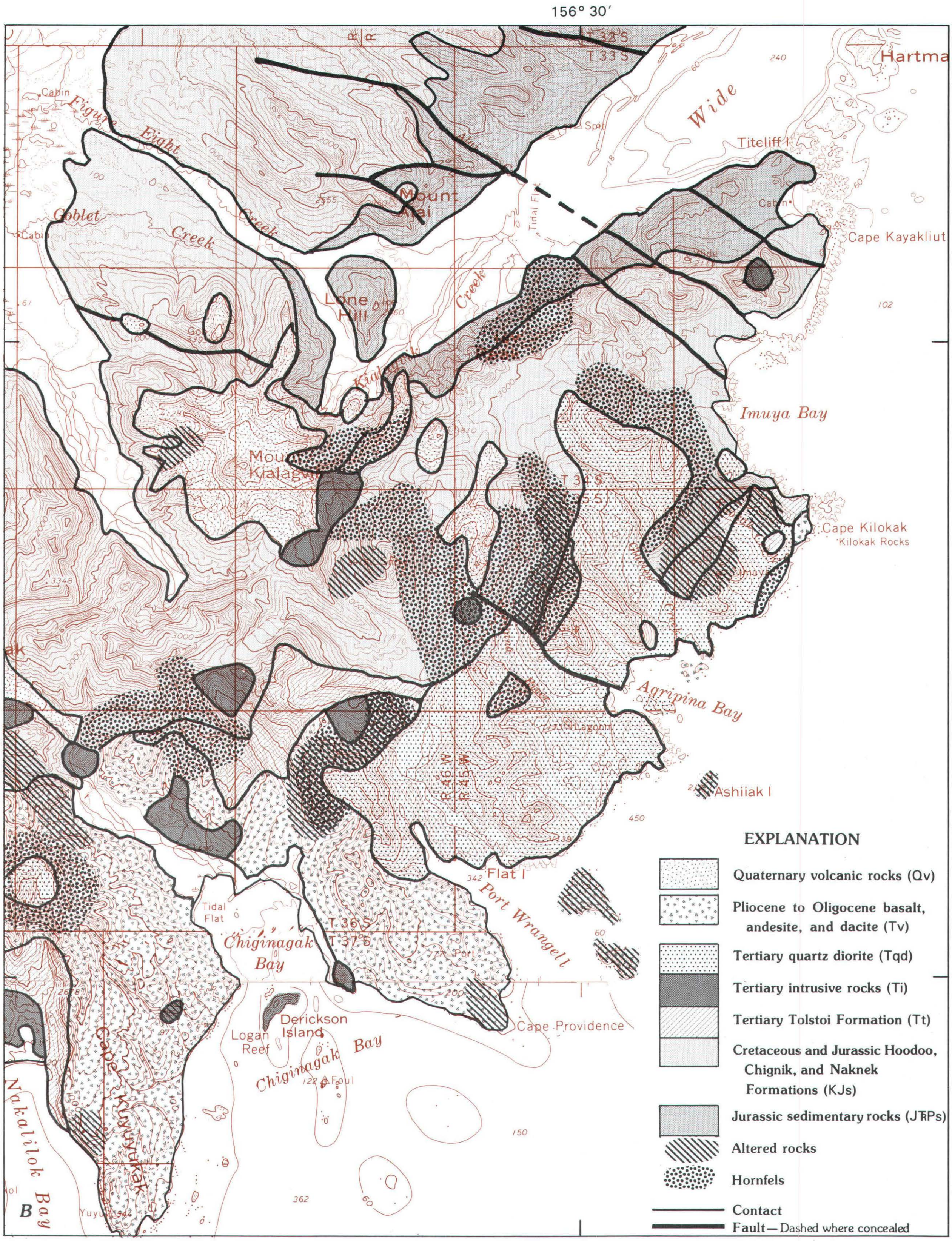


Figure 20 (above and facing page). Drainage basin anomaly map (*A*) and generalized geologic map (*B*) of the Agripina Bay batholith (areas 5–6, table 5). The area containing more than 5 percent pyrite and (or) barite and sulfide minerals is outlined on *A* by the heavy, dashed contour. Drainage basins are shown by dotted lines; those containing anomalous concentrations of copper, molybdenum, and tungsten are shown by hachures on the drainage basin outlines. Sample sites are shown by the dots. Other elements having anomalous concentrations in



individual drainage basins are also indicated on *A*; if the element was anomalous in both the SS and the NMHMC media, the element symbol is underlined. Heavy minerals identified in the NMHMC samples are also indicated (Cin, cinnabar; Tour, tourmaline). The geologic base map is simplified from Detterman and others (1981, 1987); uncolored land areas are Quaternary alluvium; map unit symbols shown in explanation correspond to those used in figure 2. Topographic base is from U.S. Geological Survey, 1:250,000; Ugashik, 1963; Sutwik Island, 1963; contour interval 200 ft.

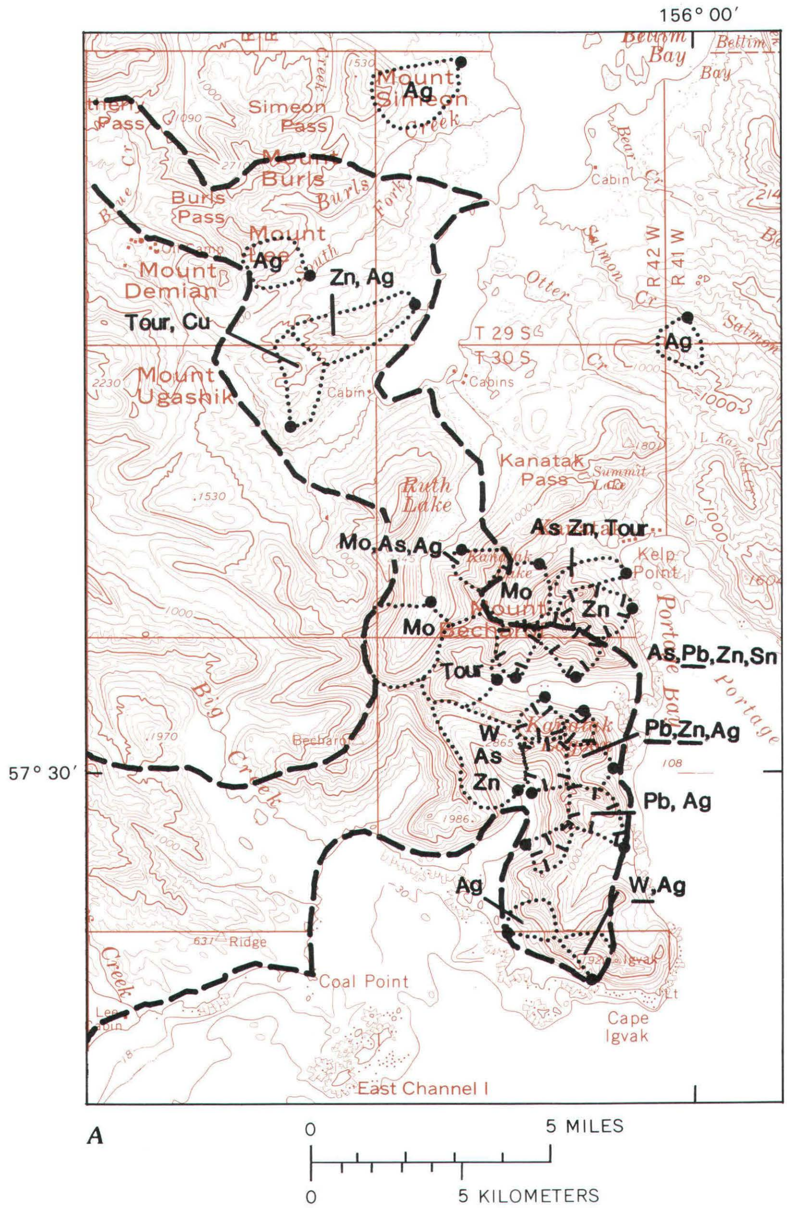
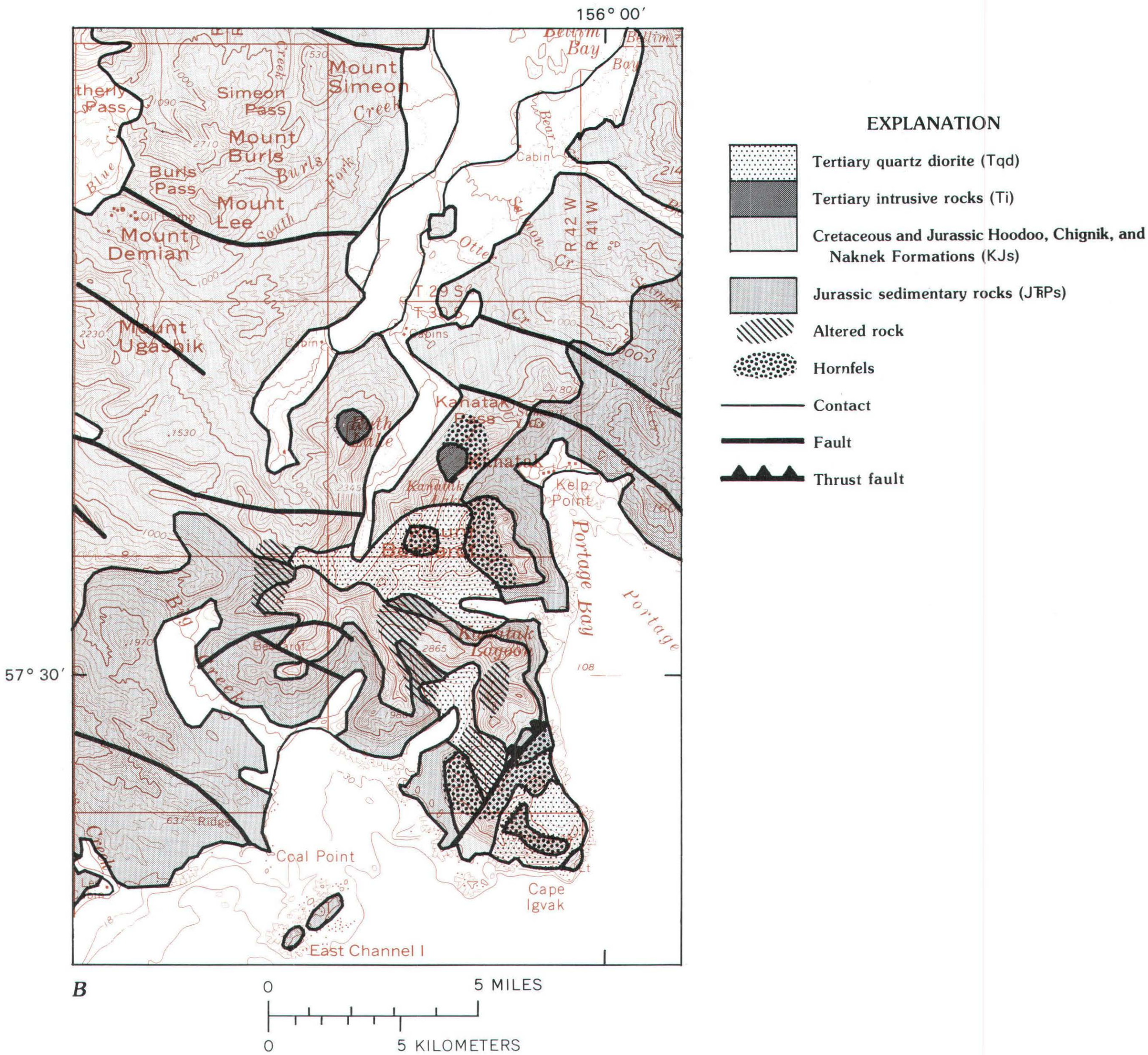


Figure 21 (at left and facing page). Drainage basin anomaly map (*A*) and generalized geologic map (*B*) of the Portage Bay area (area 7, table 5). The area containing more than 5 percent pyrite and (or) barite and sulfide minerals is outlined on *A* by the heavy, dashed contour. Drainage basins are shown by dotted lines; those containing anomalous concentrations of copper, molybdenum, and tungsten are shown by hachures on the drainage basin outlines. Sample sites are shown by the dots. Other elements having anomalous concentrations in individual drainage basins are also indicated on *A*; if the element was anomalous in both the SS and the NMHMC media, the element symbol is underlined. Heavy minerals identified in the NMHMC samples are also indicated (Tour, tourmaline). The geologic base map is simplified from Detterman and others (1987); uncolored land areas are Quaternary alluvium; map unit symbols shown in explanation correspond to those used in figure 2. Topographic base is from U.S. Geological Survey, 1:250,000; Ugashik, 1963; Karluk, 1963; contour interval 200 ft.

eastern end and along the northeast shore of the main part of the island. Analyses of grab samples from these localities showed anomalous concentrations of arsenic, bismuth, and antimony. No anomalous concentrations of gold or silver were found. Hydrothermal alteration is widespread. No stream-sediment samples were taken on the island.

Pacific Coastal Areas from Portage Bay to Cape Kubugakli

Similar geochemical anomalies, although from seemingly somewhat smaller areas of mineralized rock associated with intrusive rocks west of Portage Bay from Mount Becharof south to Cape Igvak (area 7; fig. 21), may also indicate porphyry and related mineralization (table 5). Numerous lode claims for iron have been filed in the Portage Bay area (Cobb, 1978) surrounding the Pliocene pluton near Cape Igvak. These claims were not examined in the field. The geochemical data show a higher proportion of tungsten and arsenic relative to other porphyry copper-molybdenum areas in the study area. The magnetic fraction (C2) of the heavy-mineral concentrates contained garnet and scheelite. Abundant rutile was also seen in one of the NMHMC samples from this area. Chemical digestion of the nonmagnetic fraction revealed that additional sulfides were separated into the magnetic fraction because they were coated with iron-oxides. Some C2 samples contained as much as 200 ppm arsenic and 500 ppm zinc. Four samples contained



B

small amounts of gold. The iron lode claims may be located on possible iron skarn deposits.

In addition to the mineralization associated with the Pliocene intrusive body west of Portage Bay, numerous scattered silver, copper, and barium anomalies and several gold (silver, copper) lode and placer claims occur northeast and northwest of the Portage Bay area (MacKevett and Holloway, 1977; Cobb, 1978). Small dikes and sills are numerous in the folded Mesozoic strata. Pyrite in heavy-mineral concentrates from the Shelikof Formation occurs predominantly in botryoidal form and the associated cobalt concentrations are low, less than 70 ppm. Threshold values for cobalt were selected such that sedimentary pyrite does not affect the geochemical anomaly distribution pattern.

A few of the SS samples showed evidence of mineralization at Cape Kubugakli (area 8; fig. 22). Between 1915 and 1923, small-scale placer mining at Cape Kubugakli produced an estimated 5 kg (160 oz) of gold derived from quartz stringers in felsic dikes (Cobb, 1978). Stibnite, tetrahedrite, galena, molybdenite, and magnetite also occur at this locality. Both propylitic and sericitic alteration were observed in the area. The alteration assemblage at Cape Kubugakli has been dated as Miocene (Wilson and Shew, 1988). No analyses of the carbonate rocks intruded by this pluton were made, but the geologic environment is permissive for the formation of a carbonate-hosted gold deposit.

Mineralization in the area northwest of Cape Kubugakli (fig. 22) and east of the Kejulik River is

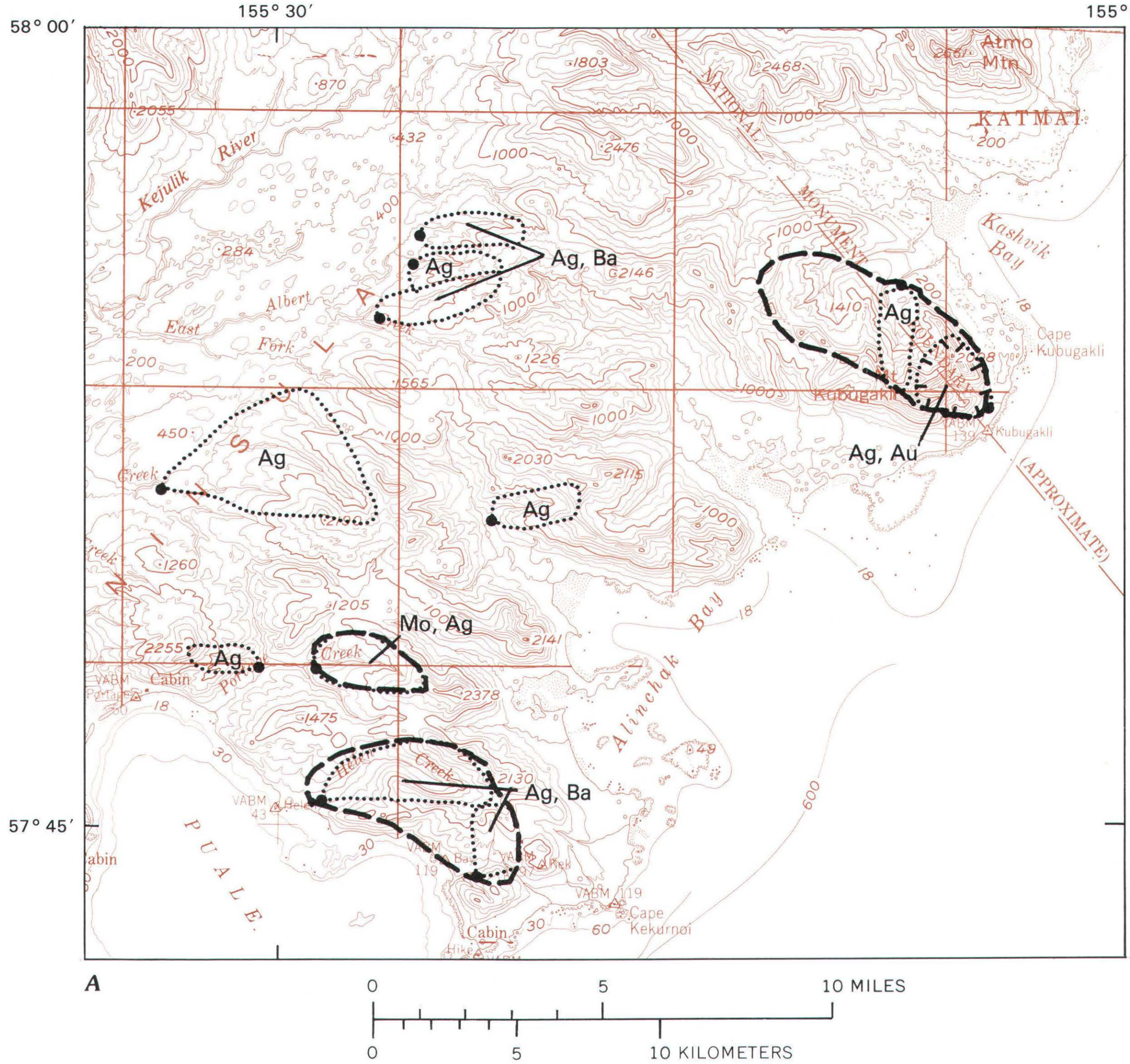
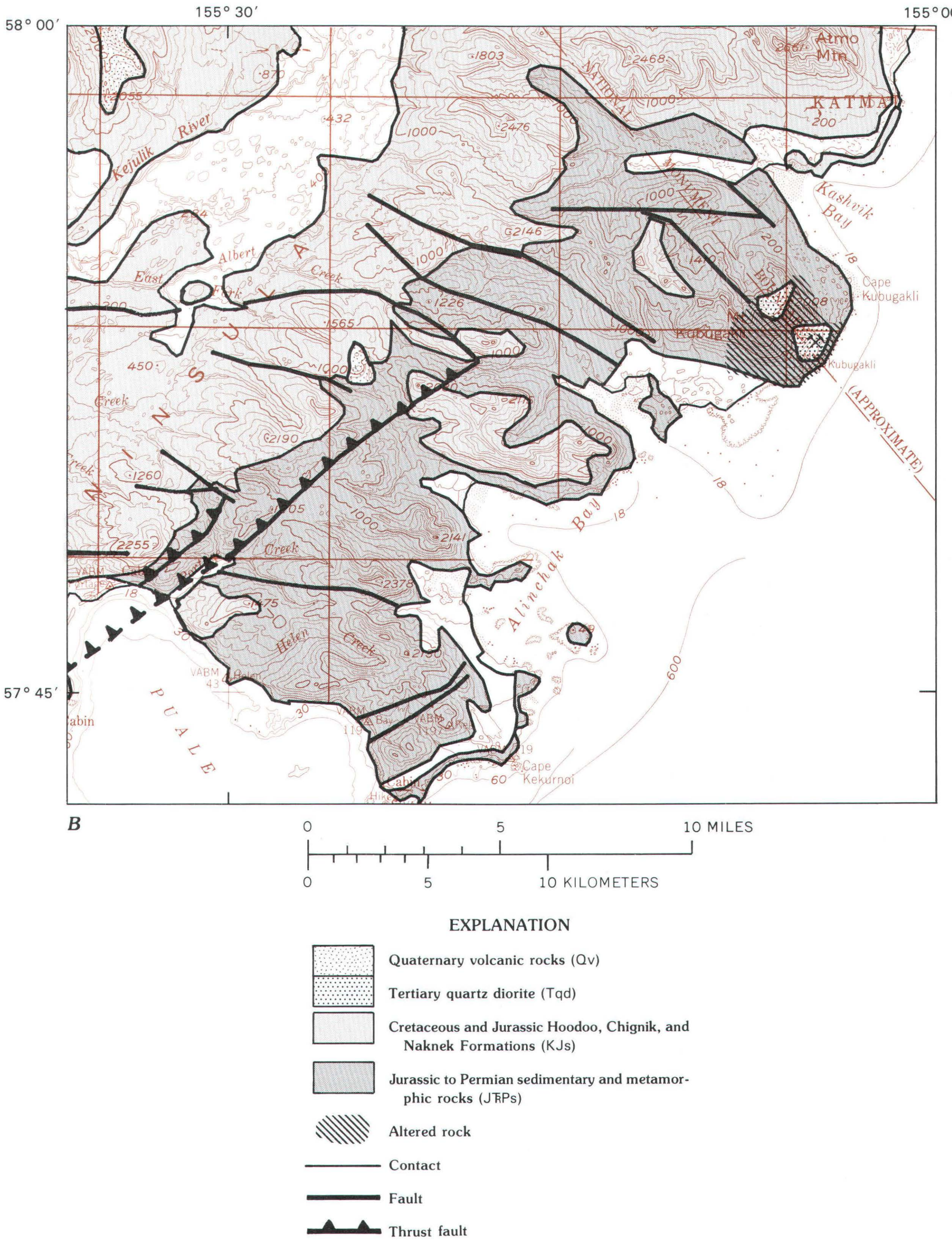


Figure 22 (above and facing page). Drainage basin anomaly map (*A*) and generalized geologic map (*B*) of the Cape Kubugakli area (area 8, table 5). The area containing more than 5 percent pyrite and (or) barite and sulfide minerals is outlined on *A* by the heavy, dashed contour. Sample sites are shown by the dots. Drainage basins are shown by dotted lines; those containing anomalous concentrations of copper, molybdenum, and tungsten are shown by hachures on the drainage basin outlines. Other elements having anomalous concentrations in individual drainage basins are also indicated on *A*. The geologic base map is simplified from Detterman and others (1987); uncolored land areas are Quaternary alluvium; map unit symbols shown in explanation correspond to those used in figure 2. Topographic base is from U.S. Geological Survey, 1:250,000; Karluk, 1963; contour interval 200 ft.

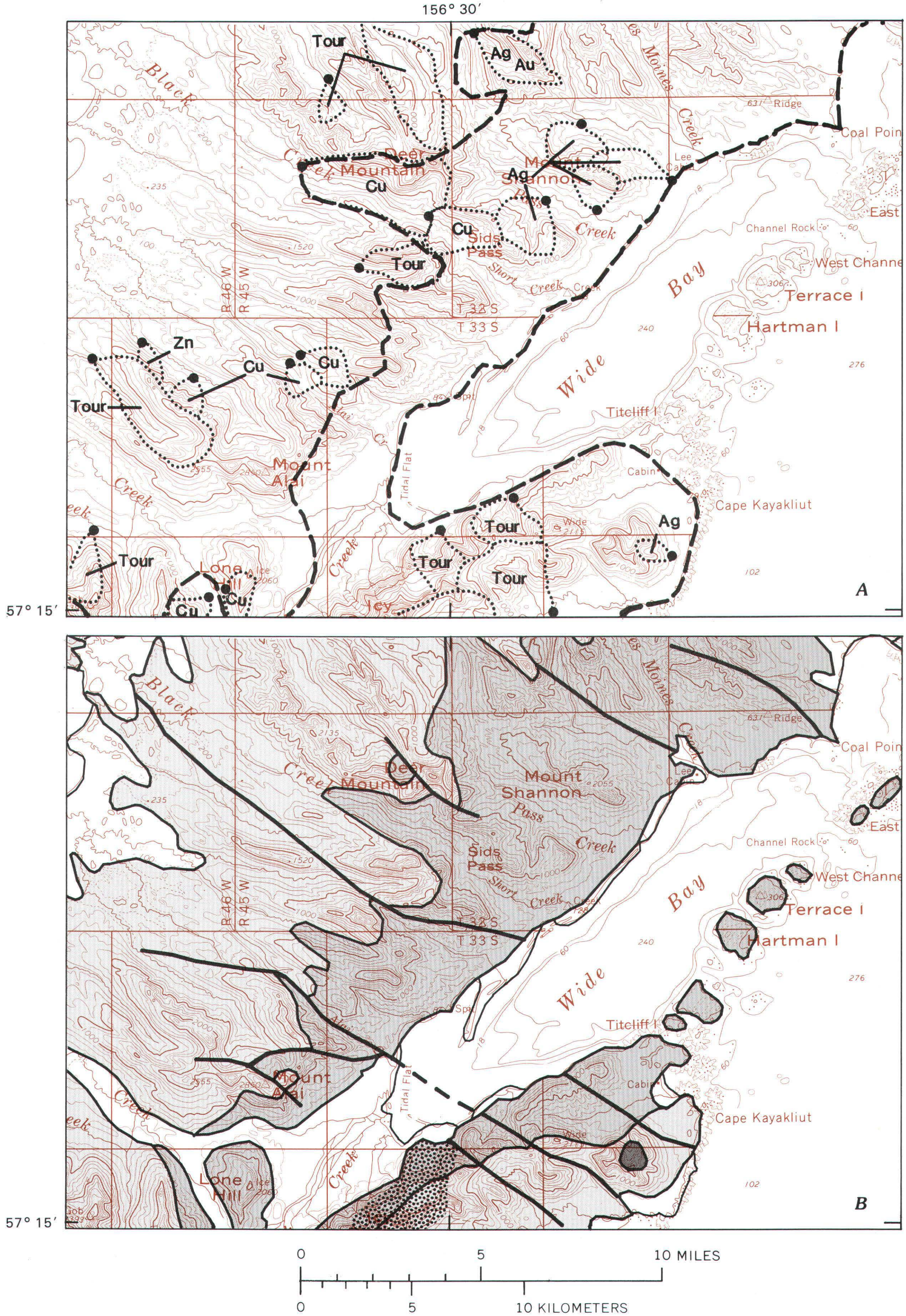
suggested by a few low-level silver and barium drainage-basin anomalies shown by the heavy-mineral concentrates. Some of these sites contain minor epidote, possibly reflecting propylitic alteration. Some of the geochemical anomalies may reflect hydrothermal vein activity associated with poorly exposed hydrothermal systems, but none of the anomalies occurs in areas of mapped altered rock or exposed intrusive rocks.

The geochemical data for the area immediately northeast of Puale Bay define several drainage basins along Portage Creek where anomalous concentrations of silver, barium, and molybdenum were determined from NMHMC samples (fig. 22). A fluorescent mineral, perhaps powellite, may account for the molybdenum anomaly. The geochemical anomalies in the Portage Creek area may be related to the faulting mapped in this drainage basin by Detterman and others (1983).

The area along the northwest side of Wide Bay (area 9; fig. 23) showed scattered anomalies of copper, silver, gold, lead, and barium as determined from the NMHMC samples and from observations of scheelite, tourmaline, and barite in the NMHMC samples. No



igneous rocks or areas of altered rock were shown on the 1:250,000-scale map of this area, although numerous small dikes and sills cut both the Shelikof and Naknek Formations (R.L. Detterman, oral commun., 1987). Pyrite is abundant in most of the NMHMC samples, but is predominately botryoidal or stalactitic in form rather than crystalline or massive as found in areas 1–8. Cobalt values for NMHMC samples containing high percentages of sedimentary or botryoidal pyrite are about a factor of ten lower (20–70 ppm) than cobalt in


156° 30′
Tour
Ag
Au
Black
Moines
Creek
631 Ridge
Coal Poin
Deer
Creek Mountain
Cu
Mount Shannon
Ag
Pass
Lee Cape
East
Creek
Channel Rock
Cu
Sids Pass
Tour
Short Creek
West Channe
Bay
Terrace I
R 46 W
R 45 W
T 32 S
T 33 S
Hartman I
240
Zn
Cu
Cu
Wide
276
Tour
Spit
Titcliff I
Mount Alai
Cabin
Tidal Flat
Creek
Cape Kayakliut
Tour
Ag
Tour
Tour
Tour
Lone Hill
Cu
Cu
Creek
Icy
102
A
57° 15′
Black
Moines
Creek
Ridge
Coal Poin
Deer Mountain
Mount Shannon
Pass
East
Creek
Channel Rock
Sids Pass
Short Creek
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T 33 S
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Wide
Titcliff I
Mount Alai
Cabin
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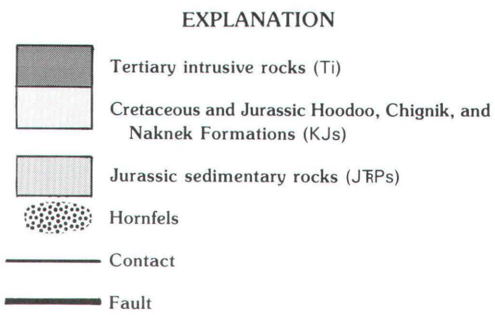


Figure 23 (above and facing page). Drainage basin anomaly map (*A*) and generalized geologic map (*B*) of the west side of Wide Bay (area 9, table 5). The area containing more than 5 percent pyrite and (or) barite and sulfide minerals is outlined on *A* by the heavy, dashed contour. Sample sites are shown by the dots. Drainage basins are shown by dotted lines; those containing anomalous concentrations of elements are indicated on *A*. Heavy minerals identified in the NMHMC samples are also indicated (Tour, tourmaline). The geologic base map is simplified from Detterman and others (1987); uncolored land areas are Quaternary alluvium; map unit symbols shown in explanation correspond to those used in figure 2. Topographic base is from U.S. Geological Survey, 1:250,000; Karluk, 1963; contour interval 200 ft.

NMHMC samples derived from hydrothermally altered areas (200–700 ppm). The botryoidal pyrite and perhaps the associated barite are probably syngenetic and do not reflect hydrothermal processes. The highly permeable sedimentary rocks and numerous small normal faults would, however, provide excellent conduits for hydrothermal fluids if intrusive rocks occur at depth (fig. 23). Southwest of Deer Mountain are several scattered copper anomalies determined from NMHMC samples associated with tourmaline.

Area Northeast of Becharof Lake and Northwest of the Kejulik River

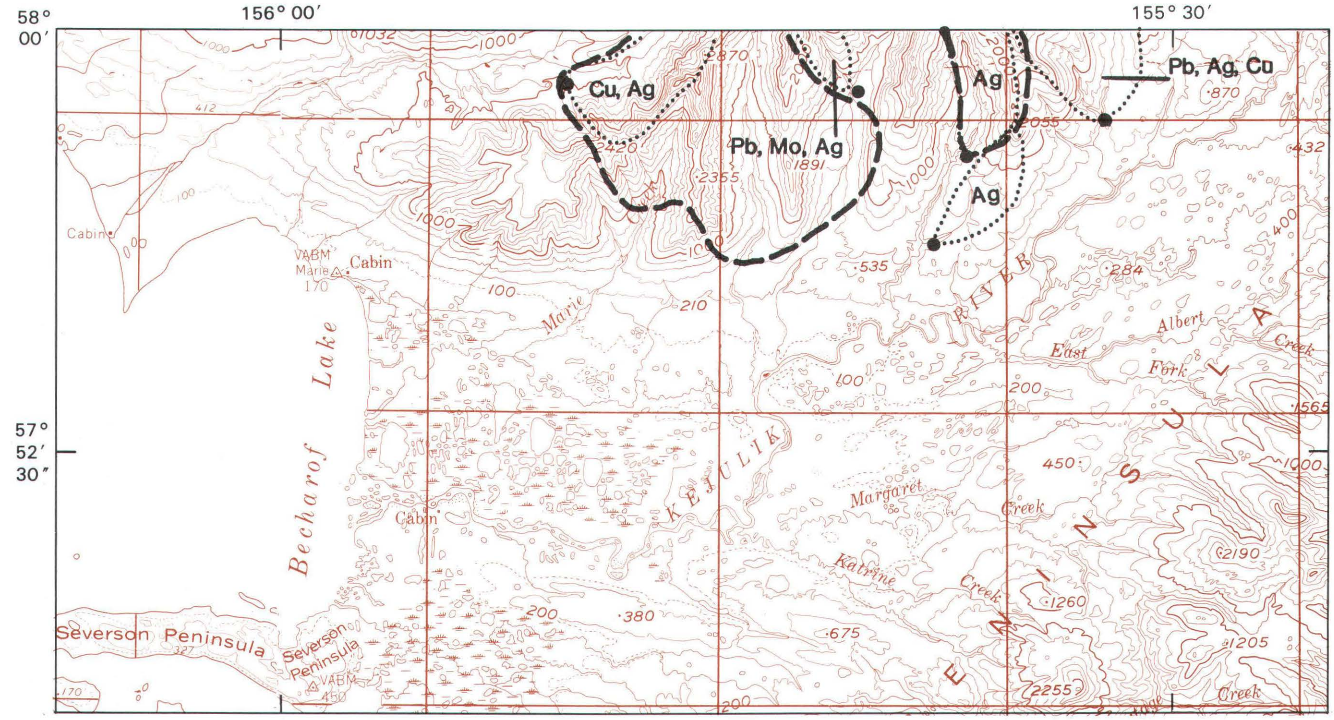
Mineralized rock in area 10, north of the east end of Becharof Lake and northwest of the Kejulik River (fig. 24), is characterized by anomalous copper, silver, lead, and barium determined from NMHMC samples. Chalcopyrite and barite were seen in one sample, and pyrite in both crystalline and botryoidal forms was the dominant sulfide in most samples. A small area of altered rock was mapped (Detterman and others, 1983), but no intrusive rocks are exposed. Botryoidal pyrite is dominant and the cobalt content of pyrite is apparently low. Dikes and sills are present in the Naknek Formation: the anomalies may represent high-level galena-chalcopyrite-barite veins over a buried intrusive body. Work in the Mount Katmai study area immediately north of the Ugashik-Karluk study area indicates a copper-gold porphyry system may be associated with the Kejulik volcanic field (S.E. Church, unpub. data, 1986).

SUMMARY AND COMPARISON WITH AREAS OF KNOWN MINERALIZATION

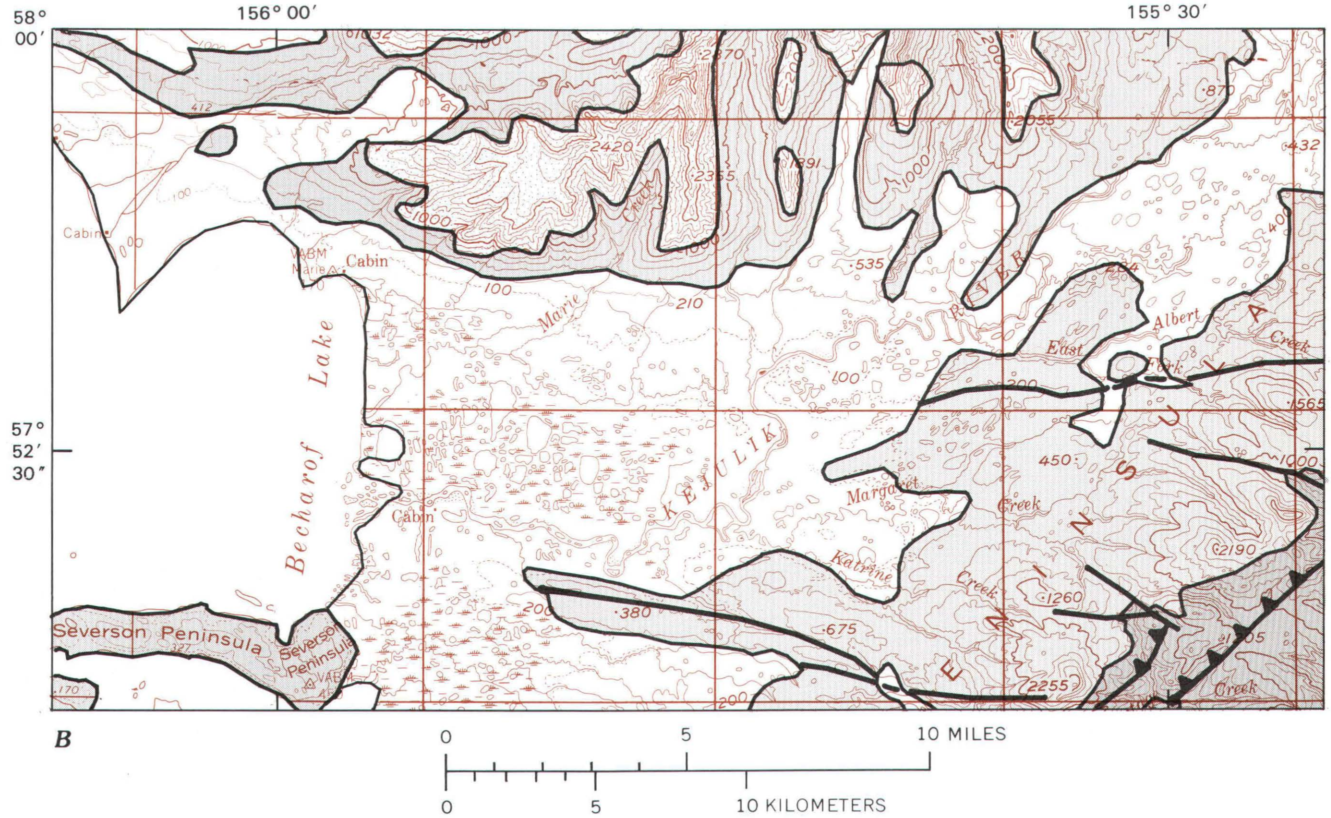
Mineralization on the Alaska Peninsula, particularly sulfide mineralization associated with porphyry-type systems, has been previously recognized. Hollister (1978, p. 72–73) summarized the geologic data for eight porphyry copper sulfide systems from the Alaska Peninsula, south of Lake Iliamna, that had been described in the published literature. Work in the Chignik-Sutwik Island AMRAP study area immediately to the south also delineated several porphyry-type systems (Cox and others, 1981). Both factor analysis and drainage-basin analysis of the stream sediment and nonmagnetic, heavy-mineral-concentrate geochemical data delineate several areas of possible sulfide mineralization associated with Tertiary intrusive activity in the Ugashik-Karluk study area. Geochemical anomalies and geologic features of these deposits are very similar to those described for the Chignik and Sutwik Island quadrangles. Detailed studies of the copper-molybdenum mineralization at Bee Creek, in the Chignik quadrangle about 120 km (75 mi) southwest of the Rex prospect, showed that the Bee Creek sulfide system is associated with a Pliocene calc-alkaline porphyry system. Drilling at the Bee Creek prospect indicated that deposition of chalcopyrite and associated sulfides in the arkosic Naknek Formation were deposited by saline hydrothermal fluids that were driven out from the intrusion into the surrounding sedimentary rocks (Wilson and Cox, 1983).

At the Rex prospect, in the Ugashik-Karluk study area, a porphyry copper-gold system of Oligocene age (area 1), shows concentrically zoned alteration patterns and is defined by a zoned geochemical pattern in the drainage-basin anomalies. An aeromagnetic low within the target area defined by the geochemical data is interpreted as an indication of hydrothermal alteration (Case and others, 1987). Hydrothermal veins containing base metals surrounding the central core of mineralized rock are also common. The presence of gold in the NMHMC samples in the area north and west of the Rex prospect indicates a gold halo around the sulfide system. This model is typical of our field observations in the areas surrounding sulfide mineralization and is typical of copper porphyry-type systems in volcanic arcs (Cox and Singer, 1986, p. 110–119). The geochemical anomalies defined in table 5 for areas 1–6 are characteristic of those associated with copper porphyry mineralization.

Geochemical anomalies similar to the Rex prospect were noted for drainage basins near the plutons


58° 00′
156° 00′
155° 30′
57° 52′ 30″
Cu, Ag
Pb, Mo, Ag
Ag
Ag
Pb, Ag, Cu
Cabin
VABM Marie 170
Cabin
Becharof Lake
Marie
KEJULIK
RIVER
East Fork
Albert Creek
Margaret Creek
Katrine Creek
Severson Peninsula
Severson Peninsula
VABM 450
PENINSULA

A


58° 00′
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Cabin
VABM Marie
Cabin
Becharof Lake
Marie
KEJULIK
RIVER
East
Fork
Albert Creek
Margaret
Creek
Katrine Creek
Severson Peninsula
PENINSULA
0 5 10 MILES
0 5 10 KILOMETERS

B

EXPLANATION

Quaternary volcanic rocks (Qv)

Cretaceous and Jurassic Hoodoo, Chignik, and Naknek Formations (KJs)

Jurassic sedimentary rocks (JŦPs)

Contact

Fault

Thrust fault

Figure 24 (above and facing page). Drainage basin anomaly map (*A*) and generalized geologic map (*B*) of the Kejulik River area (area 10, table 5). The area containing more than 5 percent pyrite and (or) barite and sulfide minerals is outlined on *A* by the heavy, dashed contour. Sample sites are shown by the dots. Drainage basins are shown by the dotted lines; those containing anomalous concentrations of elements are indicated on *A*. The geologic base map is simplified from Detterman and others (1987); uncolored land areas are Quaternary alluvium; map unit symbols shown in explanation correspond to those used in figure 2. Topographic base is from U.S. Geological Survey, 1:250,000; Ugashik, 1963; contour interval 200 ft.

on Cape Igvak (area 7) and Cape Kubugakli (area 8). Small geochemical anomalies were found in the Kejulik volcanic field on the north side of the study area, east of Becharof Lake (area 10). Work in the Mount Katmai study area (S.E. Church, unpub. data, 1986) indicates a possible copper-gold porphyry system beneath one of the major intrusive centers in the Kejulik volcanic field.

The most probable areas for the discovery of either porphyry or hydrothermal vein-type mineralization are in the southern part of the Ugashik quadrangle (areas 2–6) in the extensively altered Tertiary volcanic rocks of the Meshik arc (Detterman and others, 1983). Drainage-basin geochemical anomalies in areas 2–6 continue into the northern Chignik–Sutwik Island study area immediately to the south (Cox and others, 1981). Case and others (1987) indicated that the volcanic rocks in areas 2–6 may be underlain by several buried plutons, and the mapping by Detterman and others (1983) indicates extensive alteration and areas of hornfelsed rock. The geochemical data identify numerous drainage basins characterized by copper-molybdenum-tungsten anomalies, the surrounding drainage basins characterized by base- and precious-metal anomalies. These base-metal anomalies are probably indicative of the hydrothermal vein systems that surround large copper-molybdenum porphyry systems.

The Mike prospect (area 3) differs from other areas of sulfide mineralization within the study area. It shows widespread silica "flooding" and MoS_2 mineralization and represents a low-fluorine porphyry molybdenum system associated with a felsic porphyry stock. Areas of similar mineralization on the Alaska Peninsula are not known, but should be anticipated in a convergent volcanic-arc environment (Westra and Keith, 1981; Cox and Singer, 1986, p. 120–122). The Mike prospect was investigated by Kennecott Corporation (Bear Creek Mining Company) in 1977; their work outlined an area of molybdenum mineralization having an average grade of 0.2 percent MoS_2.

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