The Clark Bar Prospect: Granite-Hosted Sn-Mo-Ag Mineralization in the Northern Talkeetna Mountains, Southern Alaska

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Abstract

Clark Bar is a strongly altered and oxidized zone of Paleocene granitic rocks intruded by aplitic to aphanitic felsic dikes along Clark Creek in the northern Talkeetna Mountains, southern Alaska. Major-, minor-, and trace-element geochemistry of fresh plutonic host rocks, altered rocks, and stream sediment suggest that the prospect has a potential to host granitoid Sn-Mo-Ag mineralization. Regional mapping and lithogeochemistry suggest that many of the Tertiary plutonic rocks exposed in the northern Talkeetna Mountains belong to the "specialized" granite or granophile suite. Much of the area of the northern Talkeetna Mountains where these granites are exposed is prospective for various Sn-, Mo-, and Ag-enriched granophile deposits.

Location

The Clark Bar prospect is located in the northern Talkeetna Mountains (D–4 quadrangle), 15 km north of a conspicuous bend in the westward-flowing Susitna River (fig. 1).

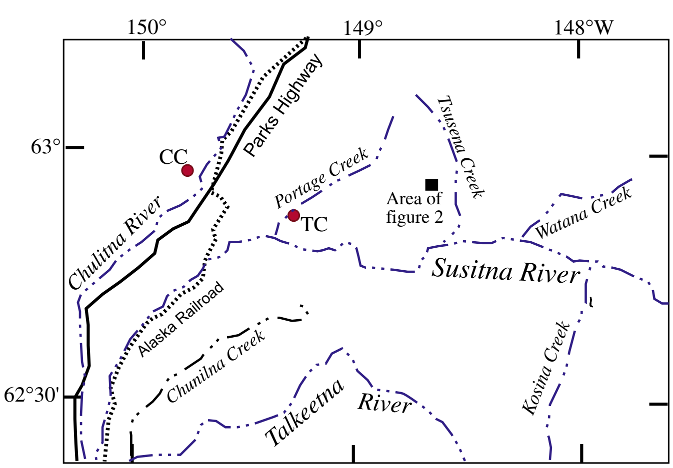

Figure 1. Northern Talkeetna Mountains, southern Alaska, showing locations of Clark Bar prospect (fig. 2) and other prospects mentioned in text. CC, Coal Creek; TC, Treasure Creek.

Topography in the area is steep and glaciated, with elevations ranging from 1,500 ft along the Susitna River to 5,700 ft in the mountains. Bare rock ridges at high elevations give way to discontinuous tundra and shrub vegetation on the side slopes; trees are limited to creek and valley bottoms.

Clark Bar is a conspicuous orange-weathering grus zone, several hundred square meters in area, along a ridge in sec. 14, T. 33 N., R. 3 E., immediately east of Clark Creek, a southeastward-flowing tributary of Tsusena Creek (figs. 1, 2). Access to the prospect is by helicopter only. Tsusena Butte, which has float- and fixed-wing plane access on private lands, is 5 km to the southeast.

Work Done

The Clark Bar prospect was examined briefly and sampled in July 1999 and again in June 2000, when extensive snow cover severely limited the exposures. In July 2001, stream-sediment and panned-concentrate samples were collected from a small tributary draining the prospect for comparison with regional sediment data collected in 1977 (Miller and others, 1978) under the auspices of the Alaska Mineral Resource Appraisal Program (AMRAP).

Two samples of unaltered plutonic rocks from the ridgeline and north-facing slope at Clark Bar were analyzed for major, minor, and trace elements (table 1; see Jackson and others, 1987, for description of methods). Five samples of typical unaltered granite and granodiorite in the nearby area (max 25 km away) were collected for comparison and analyzed by the same methods (fig. 2; table 1).

Seven mineralized and altered rock samples and one sample of poorly developed soil were collected at the Clark Bar prospect and analyzed for various metallic and trace elements (table 2). Stream-sediment and panned-concentrate samples were taken from the stream draining Clark Bar and analyzed for minor and trace elements (table 3). Remainders from the stream-sediment and panned-concentrate samples collected from the same site during a 1977 regional drainage survey (Miller and others, 1978) were reanalyzed by

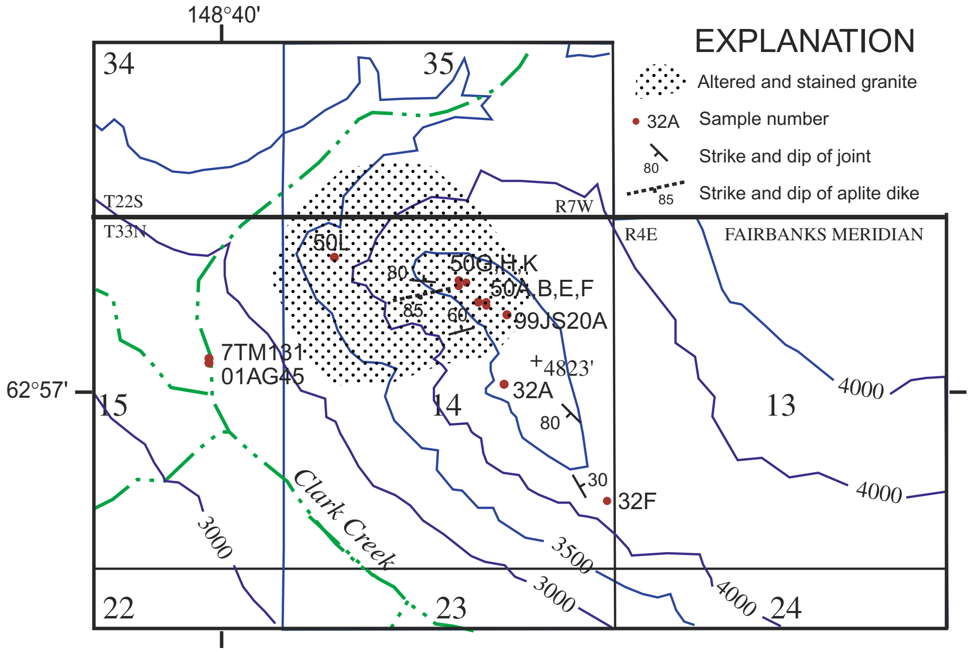

Figure 2. Clark Bar prospect area, northern Talkeetna Mountains, southern Alaska (fig. 1), showing locations of fresh granite (table 1), altered rock and soil (table 2), and stream-sediment and panned-concentrate samples. Field numbers "32" or "50" are preceded by "00JS". Elevations are feet above sea level; section lines are 1 mi apart.

the same methods (see Grimes and Marranzino, 1968, for description) for comparison with the original semiquantitative analytical results (table 3).

Regional Geology

The Clark Bar prospect lies within an overlap assemblage composed of Jurassic and Early Cretaceous flysch, between the Wrangellia and North American tectonostratigraphic terranes (Csejtey and others, 1978; Nokleberg and others, 1994). The flysch is a marine turbidite sequence, dominated by shale, that was previously assigned to the Kahiltna assemblage (Nokleberg and others, 1994). New stratigraphic and provenance data (Eastham and others, 2000; Eastham and Ridgway, 2001), however, suggest that the source of the flysch of the northern Talkeetna Mountains was the Wrangellia terrane to the southeast, with transport directions to the west and northwest. This flysch contrasts with flysch of the type section of the Kahiltna assemblage in the western Alaska Range, which was derived from sources to the northwest and transported eastward and southeastward. These two flysch sequences were deposited in separate basins and may have significantly different overall chemical compositions, a difference that would affect the composition of granitic melts derived from them.

Flysch of the northern Talkeetna Mountains is intruded by abundant granitic stocks of Tertiary age (Csejtey and others, 1978; J.M. Schmidt and others, unpub. data, 2000–2), producing contact aureoles of biotite-, andalusite-, or sillimanite-bearing hornfels. Uncommon mafic to felsic dikes that cut both flysch and plutons in the vicinity of Clark Bar are subvolcanic feeders to Eocene volcanic rocks that once overlay much of the northern Talkeetna Mountains (Csejtey and others, 1978; J.M. Schmidt and others, unpub. data, 2000–2).

Granitic Plutons

Granitic plutons exposed in the northern Talkeetna Mountains are subalkaline, quartz-normative peraluminous to metaluminous, biotite-bearing granite and granodiorite, with varying amounts of hornblende or white mica. The dominant lithology regionally is a fine-grained equigranular, salt-and-pepper granite to granodiorite containing 15 to 30 volume percent quartz, plagioclase greater than K-feldspar, a color index of 4 to 10, and biotite greater than hornblende. Foliated, biotite-rich (color index, ≤35) granodiorite occurs as inclusions in the equigranular rock and is compositionally similar to biotite-quartz-plagioclase gneissic wallrocks derived from the flysch. Granites near the Clark Bar prospect are multiphase, contain both biotite and hornblende, and vary in texture and mineralogy within a few tens of meters.

We sampled fresh intrusive rocks from the Clark Bar prospect and from several nearby plutons (fig. 2; table 1) to determine unmineralized background values and the variation within granites of the northern Talkeetna Mountains. A relatively fresh hornblende-biotite granite (field No. 00JS50G, table 1) and a crosscutting aplite dike (field No. 00JS50E)

Table 1. Major-element-oxide and minor- and selected trace-element analyses of fresh granitic rocks near Clark Creek, Talkeetna Mountains D–4 quadrangle, southern Alaska.

[Major-element-oxide analyses by wavelength-dispersive X-ray fluorescence in weight percent; data for average granite from Carmichael (1982). Minor- and selected trace-element analyses by cold-vapor atomic absorption spectroscopy (Hg), energy-dispersive X-ray fluorescence (Cr, Cs, Rb, Sn, Th, U, Y), fire assay (Au), instrumental neutron-activation analysis (W), or inductively coupled plasma atomic-absorption spectroscopy (all other elements) in parts per million; data for average granite from Krauskopf (1967). Lower limits of detection (in parts per million) of selected trace elements: cold-vapor atomic absorption, Hg (0.02); energy-dispersive X-ray fluorescence, Cr (3), Mo (1), Rb (2), Th (2), U (2), Y (2), and Zr (5); fire assay, Au (0.005); 10-element inductively coupled plasma atomic-emission spectroscopy, Ag (0.08), As (1), Bi (1), Cd (0,05), Cu (0.05), Mo (0.2), Pb (1), and Sb (1); 40-element inductively coupled plasma atomic-emission spectroscopy, Ce (5), La (2), Li (2), Mn (4), Nd (9), Sn (50), Th (6), Y (2) and Zn (2); neutron activation, W (0.5). Do., ditto]

Field No.	Location	Latitude N.	Longitude W.	Description	Low values consistent with granophile suite	High values consistent with granophile suite	Al_2O_3	CaO	Total Fe_2O_3	K_2O	MgO	MnO
00JS50G	Clark Bar---------	62° 57′ 19″	148° 38′ 34″	Hornblende-biotite granite.	MgO, TiO_2, Sr, V	Cs, Zn	13.5	1.05	2.15	4.21	0.11	0.06
00JS50E	Do------------	62° 57′ 19″	148° 38′ 34″	Aplite----------------------	CaO, Ce, FeO, MgO, TiO_2, Ba, Cr, La, Sr, V	SiO_2, Nb, Rb, Th, U, Zn	12.8	.14	.44	4.02	.06	<.01
00JS32A	Ridgeline 0.2 km S.of Clark Bar.	62° 56′ 56″	148° 38′ 11″	Biotite granite; fine-grained, light-colored, most common.	MgO, Ce, Cu, La, V	Cs	14.9	2.23	1.22	3.31	.44	.02
00JS32F	Do---------------	62° 56′ 43″	148° 37′ 39″	Foliated biotite granodiorite.	Cu	Cs, Zn	16.1	4.08	3.46	2.32	1.24	.05
00JS48A	2.5 km SW. of Clark Bar; W. of Clark Creek.	62° 56′ 45″	148° 41′ 55″	Leucocratic granite----------	CaO, FeO, MgO, TiO_2, Cu, Sr, V		13.6	.72	1.96	4.17	.10	.06
00JS39A	3 mi WSW. of Clark Bar	62° 56′ 13″	148° 43′ 36″	Fine-grained biotite granite.	Cu	Cs, Li, Zn	17.1	3.76	2.95	2.68	.97	.03
00JS08W	Devil Creek, 23 km W. of Clark Bar.	62° 54′ 31″	149° 02′ 18″	Equigranular, garnet-bearing muscovite-biotite granite.	CaO, FeO, MgO, TiO_2, Ba, Ce, Cr, Cu, La, Sr, V	SiO_2, Be, Li, Sn, U	14.6	.53	.66	3.42	.04	.10
				Average granite--			13.9	1.33		5.46	.52	.06
				Specialized granite suites--			– –	Depleted	– –	>4.0	Depleted	– –

Na_2O	P_2O_5	SiO_2	TiO_2	LOI	Total	Ba	Be	Ce	Cr	Cs	Cu	Ga	La	Li	Mn	Mo	Nb	Pb	Rb	Sn	Sr	Th	U	V	Y	Zn	Zr
4.22	<0.01	73.3	0.160	0.3	98.76	1,610	3	84	8	23	12	22	43	21	428	2	14	26	138	5	122	9	5	4	42	145	245
3.25	<.01	78.3	.063	1.0	99.07	225	4	11	3	4	11	26	22	10	<4	2	32	12	251	4	13	41	11	<2	41	105	203
3.94	.13	72.0	.215	1.1	98.41	2,170	<1	21	9	24	<2	22	14	17	121	1	<4	16	69	4	576	2	2	6	10	66	144
3.30	.18	68.8	.586	.5	100.12	2,390	2	53	25	15	4	25	25	41	347	2	14	12	60	3	568	4	3	42	8	140	182
4.24	<.01	73.7	.165	.4	98.72	1,680	2	67	9	8	3	21	33	16	351	1	10	14	119	4	123	8	4	3	43	87	251
4.31	. 13	65.3	.551	.7	97.78	3,130	2	109	12	22	2	16	53	61	153	2	22	10	51	3	1,150	2	3	16	3	120	280
4.54	.09	74.0	.031	1.1	98.01	42	8	7	<3	8	<2	25	3	43	646	<1	5	16	193	12	13	<2	7	<2	11	44	35
3.08	.18	72.1	.370	– –	– –	600	5	87	4	5	10	18	40	30	400	2	20	20	150	3	285	17	4.8	20	40	40	180
– –	– –	>73.0	Depleted	– –	– –	Low	High	– –	Low	High	Low	– –	Low	High	– –	High	High	High	High	High	Low	High	High	Low	High	– –	Low

Table 2. Selected trace- and metallic-element analyses of altered rock and soil from the Clark Bar prospect, Talkeetna Mountains D–4 quadrangle, southern Alaska.

[All analyses in parts per million except for Fe (in weight percent); crustal abundances and data for average granite from Krauskopf (1967). Columns for elements anomalous at the 90th- and 98th-percentile levels are in comparison with all altered rocks collected in the northern Talkeetna Mountains (J.M. Schmidt and others, unpub. data, 1999–2001)]

Field No.	Sample description	Elements anomalous at 90th percentile	Elements anomalous at 98th percentile	Ag	As	Au		Ba
						FA	ICP	
99JS20A	Quartz-pyrite cobble from top of orange-stained area.	Au, Be, Pb, W	– – –	0.2	2	0.020	0.2	1,430
00JS50A	Chalky altered leucogranodiorite------------------	Bi	– – –	.3	18	<.005	<.1	1,120
00JS50B	Fracture-controlled iron oxides in biotite granite.	Be,Yb, Zn	Ce, La, Nd, Y	<.08	21	<.005	<.1	1,600
00JS50F	Minor silicified aplite-----------------------------	– – –	– – –	<.08	7	<.005	<.1	853
00JS50H	Pyritic fractures In aplite------------------------	Bi, La, Nd, Th	Ag, Cd, Li, Mn, Pb, Zn	4.9	4	<.005	.2	1,180
00JS50K	Pyrite-quartz veinlet in aplite---------------------	As, Be, Hg	Ag, Bi, Cd, Li, Pb, Sb, Sn, Zn	25.1	47	<.005	.2	396
00JS50L	Dark brown to black Fe oxide-stained aplite---------	Ba, Ga, Mo, Nd	Ag, Bi, Cd, Ce, Cu, La, Mn, Pb, Sn, Th, Zn	26.6	11	<.005	.1	2,220
00JS50C	Orange soil -------------------------------------	Ce, Ho, La, Nd, Th, Yb	Y	<.08	19	<.005	.1	1,440
	~90th percentile for Talkeetna Mountains samples --			≥1.0	≥30	≥.012	≥.3	≥2,000
	~98th percentile for Talkeetna Mountains samples --			≥10.0	≥70	≥.050	≥1.0	≥5,000
	Crustal abundance ---			.07	1.8	<.050	<.05	425
	Average granite ---			.04	1.5	– –	– –	600

Be	Bi	Cd	Ce	Cu	Eu	Fe	Ga	Hg	Ho	La	Li	Mn	Mo	Nd	Pb	Sb	Sn	Th	W	Y	Yb	Zn
3	<1	0.35	43	3.2	<2	1.06	19	<0.02	<4	34	17	73	3.9	26	8	<1	<50	9	4.1	24	2	88
2	2	<.05	45	1.0	<2	.25	25	<.02	<4	26	27	<4	6.5	28	9	<1	<50	10	.6	29	3	12
3	<1	.39	132	4.6	3	1.21	23	<.02	<4	150	9	96	5.9	140	13	<1	<50	9	1.3	70	5	184
2	<1	<.05	23	1.3	<2	.3	16	<.02	<4	21	40	7	1.8	26	8	<1	<50	6	.5	21	2	13
2	2	3.03	74	35.6	<2	2.17	32	<.02	<4	41	186	4,380	1.4	43	367	<1	<50	13	1.3	26	2	597
3	6	8.85	42	91.5	<2	3.67	19	.18	<4	27	180	385	8.8	26	1,120	10	76	<6	1.5	25	2	2,130
2	15	126	108	1,480	<2	8.61	38	.02	<4	58	23	4,150	16.4	56	1,660	<1	81	16	.7	24	2	18,900
2	1	.33	75	3.2	<2	1.8	28	.02	5	42	18	255	5.4	49	13	<1	<50	14	1.3	46	5	112
≥3	≥2	≥1	≥75	≥160	≥3	≥9.0	≥36	≥.1	≥5	≥35	≥50	≥1,400	≥9	≥39	≥14	≥3		≥12	≥3	≥30	≥4	≥140
>4	≥5	≥2	≥100	≥500	– –	≥14.0	≥45	≥.4	≥6	≥50	≥100	≥2,000	>22	≥70	≥100	≥10	≥50	≥14	≥5	≥40	≥5	≥500
2.8	.17	.2	67	55	1.2	5.6	15	.08	1.5	25	20	950	1.5	28	12.5	.2	2	9.6	1.5	33	3	70
5	.18	.2	87	10	1.5	2.7	18	.08	1.9	40	30	400	2	35	20	.2	3	17	2	40	3.8	40

Table 3. Selected trace- and metallic element analyses of stream-sediment and panned-concentrate samples from streams draining the Clark Bar prospect, Talkeetna Mountains D–4 quadrangle, southern Alaska.

[All values in parts per million except for Fe (in weight percent). Analytical methods: cold-vapor atomic-absorption spectroscopy (Hg), instrumental neutron-activation analysis (W), 10-element inductively coupled plasma atomic-emission spectroscopy (Ag, As, Au, Bi, Cd, Cu, Mo, Pb, Y, Zn), 40-element inductively coupled plasma atomic-emission spectroscopy (Ba, Ce, Co, Cr, Fe, Ga, La, Li, Mn, Nb, Nd, Ni, Sc, Sn, Th, V, Y). Original analyses of samples with field Nos. 7TM131C and 7TM131S were by semiquantitative emission spectroscopy. N, not detected at parts-per-million level indicated]

Field No.	Sample type	Type of analysis and year	Ag	As	Au	Ba	Bi	Cd	Ce	Co	Cr	Cu
7TM131S	Stream sediment----	Emission spectroscopy, 1977	N0.5	N200	N10	1,500	N10	N20	– –	10	20	20
7TM131S	do---------------	ICP–AES, INAA, CV–AAS, 2001	.1	6	.1	1,230	<1	.47	251	4	8	11
01AG45DS	do---------------	ICP–AES, INAA, CV–AAS, 2001	.1	7	.3	1,110	1	.7	170	8	10	13.1
7TM131C3	Panned concentrate--	Emission spectroscopy, 1977	N1	N500	N20	300	N20	N50	– –	<10	20	50
01AG45C	do---------------	ICP–AES, INAA, CV–AAS, 2001	<.08	4	<.1	1,200	<1	.3	218	6	7	12.2
	Crustal abundance---------------------------------		.07	1.8	<.05	425	.17	.2	67	25	100	55
	Average granite-----------------------------------		.04	1.5	------	600	.18	.2	87	1	4	10

Fe	Ga	Hg	La	Li	Mn	Mo	Nb	Nd	Ni	Pb	Sc	Sn	Th	V	W	Y	Zn
7	– –	– –	300	– –	1,000	N5	<20	– –	10	70	30	N10	– –	50	N10	100	N200
2.86	4	.04	130	37	658	.8	16	100	4	19	14	<50	18	43	.7	31	131
2.91	20	<.02	89	35	689	.9	17	76	5	19	13	<50	11	62	<.5	38	125
3	– –	– –	200	– –	700	N10	200	– –	<10	50	70	1,000	N200	100	N100	200	N500
3.15	<4	<.02	117	32	709	.7	15	86	4	13	13	<50	15	67	.7	29	113
5.6	15	.08	25	20	950	1.5	20	28	75	12.5	22	2	9.6	135	1.5	33	70
2.7	18	.08	40	30	400	2	20	35	.5	20	5	3	17	20	2	40	40

were sampled from the immediate prospect area (fig. 2). Along the unaltered ridgeline to the south (fig. 2), the predominant biotite granite (field No. 00JS32A) and a common, though less abundant, foliated biotite granodiorite (field No. 00JS32F) were sampled. The samples with field Nos. 00JS48A and 00JS39A, collected 3 and 5 km, respectively, west of Clark Bar, represent the main phases of leucogranite and biotite granodiorite plutons in the Clark-Tsusena River area.

About 23 km west of Clark Bar, a muscovite-biotite-garnet-bearing granite at Devil Creek has been dated at 59±0.2 Ma ($^{40}Ar/^{39}Ar$ age on muscovite; L.W. Snee, written commun., 2001). It is similar in mineralogy and age to the McKinley sequence granites of the Alaska Range (West, 1994), which are peraluminous S-type plutons (Lanphere and Reed, 1985) derived by assimilation of the Jurassic and Cretaceous flysch (Lanphere and Reed, 1985, 1990). Table 1 includes one analysis (field No. 00JS08W) from the Devil Creek stock for comparison with the common biotite-only or biotite-hornblende granites and granodiorites.

Hornblende-biotite granite from the Clark Bar prospect (field No. 00JS50G, table 1) has yielded a preliminary $^{40}Ar/^{39}Ar$ age of 58.5 Ma on biotite (L.W. Snee, written commun., 2001). The similarity of chemistry and tentative age correlation between the Devil Creek stock and the regionally extensive hornblende-biotite granite to granodiorite suggest that they are part of a single intrusive suite emplaced during the late Paleocene. This late Paleocene magmatic suite in the northern Talkeetna Mountains is similar in age and chemistry to the McKinley sequence in the Alaska Range (Lanphere and Reed, 1985, 1990). Any paleogeographic or genetic connection, however, remains to be determined by additional mapping and petrologic and tectonic studies.

"Specialized" Granite Chemistry

Reed (1986b, c), in discussing the origin of Sn deposits, invoked a "specialized" granite, with high SiO_2 content (>73 weight percent), enriched in K, Sn, F, Rb, Li, Be, Nb, Cs, U, Th, B, Mo, and rare-earth elements (REEs) relative to typical calc-alkaline, arc-related granites. Strong (1988), in categorizing granitic-rock-hosted mineral deposits, identified a group of quartz-rich, leucocratic granites enriched in what he termed "granophile" elements. The granophile elements include three subgroups—(1) large, highly charged cations: Sn^{4+}, W^{6+}, U^{6+}, Mo^{6+}; (2) small, varyingly charged cations: Be^{2+}, B^{2+}, Li^{+}, and P and anions; and (3) CO_3^{2-}, Cl^-, F^-; Strong, 1988)—each associated with distinctive mineral deposits. Both subgroups 2 and 3 of granophile elements help control magma-solidification processes (Strong, 1988), which, in turn, control the contents of subgroup 1. Strong interpreted these granophile plutons to be anatectic or partial melts, containing abundant magmatic water, formed at 15- to 25-km depth and intruded to 8- to 15-km depth.

McKinley-sequence granites from the Alaska Range show a twofold enrichment in B, Cs, U, Pb, and Li (Lanphere and Reed, 1985) relative to average granites, suggesting that they have some characteristics of the "specialized" or granophile type. They are corundum normative, contain accessory tourmaline, and have compositions similar to "minimum melts" crystallized at shallow (1.5–3 km) depth (West, 1994).

The granitic plutons of the northern Talkeetna Mountains as a group (table 1) are depleted in Ce, Cu, FeO, La, MgO, TiO_2, and V and enriched in Cs and Sn, consistent with the "specialized" or granophile suite. In particular, the aplite sample from Clark Bar (field No. 00JS50E, table 1) and the two-mica Devil Creek stock sample (field No. 00JS08W) have major- and trace-element compositions characteristic of the granophile suite.

Alteration and Mineralization

At the Clark Bar prospect, biotite granite and granodiorite along the southern ridgeline are in sharp contact to the north with a bright-orange-weathering grus zone (figs. 2, 3*A*, 3*B*) derived from a medium-grained granitoid.

The predominant rock type at the prospect is a biotite-bearing, equigranular, medium-grained (2–4 mm) granite with a low color index (5–12), containing approximately 30 volume percent quartz and traces of weathered sulfide. The granite is crosscut by numerous steep joints and iron-stained fractures that weather to form resistant (quartz rich?) 2- to 10-cm-wide veins forming a boxwork texture surrounding meter-wide patches of grus (fig. 3*C*). Fracture surfaces locally have slickensides along them but show no significant or consistent offset. Some chalky clay-altered light-colored granite is cut by crackle veinlets, a few centimeters long, with associated iron oxides, which form a type of granitic "breccia" texture.

Thin (8–10 cm wide), but uncommon, steeply dipping aplite dikes crosscut the main biotite granite. The aplites have a fine-grained (≤0.5 mm) micrographic texture, contain less than 2 volume percent biotite, are locally altered to chlorite, and contain minor pyrite along fractures and in dark-gray quartz veinlets. No other sulfide minerals were identified at the surface at Clark Bar, owing to the extreme weathering of the rocks.

Geochemistry of Altered Rock Samples and Soil

Seven samples of fractured and veined aplite and granite and of altered, stained, and pyrite-bearing rocks at the Clark Bar prospect were analyzed for metallic and trace elements (figs. 2, 3*D*; table 2). One sample of orange soil derived from barely decomposed granitic material was also analyzed. Results of these analyses were compared with the set of 155 altered and mineralized samples collected in the northern Talkeetna Mountains during 1999–2001 (U.S. Geological Survey, unpub. Data, 2000–2) and with worldwide averages for granites (Krauskopf, 1967). Elemental concentrations anomalous at the 90th- and 98th-percentile levels for the Talkeetna Mountains sample population are identified in table 2.

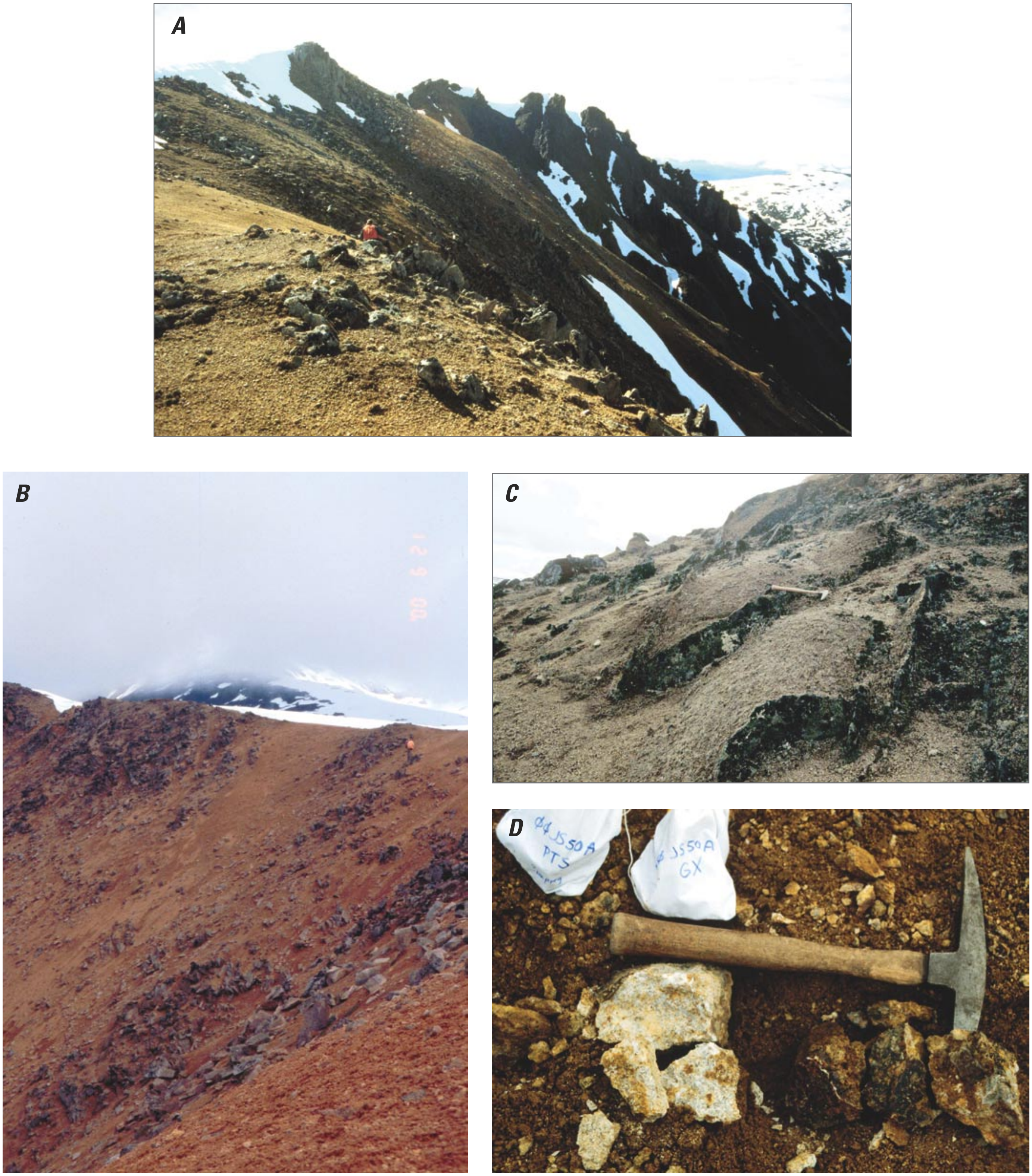

Figure 3. Clark Bar prospect, northern Talkeetna Mountains, southern Alaska (fig. 1). *A*, View southward from approximate location of sample with field No. 00JS50A (fig. 2) toward contact of orange-weathering altered grus zone and fresh granodiorite (dark cliffs in shadows at midground). *B*, View northeastward from approximate location of sample with field No. 99JS20A (fig. 2) toward altered and fractured granite near locations of samples with field Nos. 00JS50G through 00JS50K. *C*, Resistant-weathering quartz-rich joint surfaces and veins in granite, with patches of low-relief grus between. Quartz veins contain disseminated Fe oxides and rare pyrite. *D*, Fe oxide-stained, veined and fractured granite with field No. 00JS50A. Pyrite is only sulfide identified to date at Clark Bar.

Altered rock samples from Clark Bar contain as much as 26.6 ppm Ag, 47 ppm As, 20 ppb Au, 15 ppm Bi, 1,480 ppm Cu, 180 ppb Hg, 16.4 ppm Mo, 1,660 ppm Pb, 10 ppm Sb, 81 ppm Sn, 4.1 ppm W, and 1.89 weight percent Zn.

Ag, As, Bi, Cd, Cu, Li, Mn, Mo, Pb, Sb, Sn, and Zn contents are anomalous at the 90th-percentile level or higher, with values 4.5 to 740 times those of average granites (Krauskopf, 1967) in one to four samples each. One to four samples at Clark Bar are anomalous in each of the elements Ba, Be, Ce, Eu, Ga, Hg, Ho, La, Nd, Th, W, Y, and Yb at the 90th-percentile level for the Talkeetna Mountains, but fall nearer (≤4×) the values for worldwide granitic rocks (Krauskopf, 1967). Only one sample, a silicified aplite (field No. 00JS50F, table 2), has no elements anomalous at the 90th-percentile level or above, or significantly above average granite values, probably because the addition of SiO_2 reduced the relative contents of all other elements.

Ag, As, Ba, Bi, Cd, Cu, Ga, and Zn contents at Clark Bar are consistently higher than worldwide averages for granite (Krauskopf, 1967), although they are not necessarily anomalous relative to the northern Talkeetna Mountains data set (table 2; J.M. Schmidt, unpub. data, 2002). Conversely, Be, Ce La, Hg, Mn, Pb, Th, W, Y, and Yb contents at Clark Bar are low relative to average granites, although they are higher than in many areas of the Talkeetna Mountains (J.M. Schmidt, unpub. data, 2002). All the altered rock and soil samples from Clark Bar contain relatively low Cr (≤4 ppm), Nb (≤19 ppm), Sc (≤9 ppm), Sr(≤100 ppm), and V (≤6 ppm), and no detectable Co (at 2-ppm lower detection limit) or Ni (<3 ppm) (J.M. Schmidt, unpub. data, 2002).

Enrichment in lithophile or granophile elements is characteristic of mineralized systems developed from late magmatic fluids associated with S-type or “specialized” granites discussed above. Of the indicator elements for granophile or “specialized” granite suites (Reed, 1986b, c; Strong, 1988), we have analyses at Clark Bar for Be, Li, Mo, Nb, Pb, Sn, Th, W, and Y, which should be enriched, and Ba, Cr, Cu, La, Sr, and V, which should be depleted. The Clark Bar data are similar to the overall granophile signature but have higher Ba and Cu contents than expected and relatively low Be, Pb, Th, and W contents. This pattern and the occurrence of a few high Au, Bi, and Sb values suggest that the Clark Bar area and similar Paleocene plutons of the northern Talkeetna Mountains could host mineralized systems with Sn-Mo-Ag potential and possible Au or base-metal enrichment.

Stream-Sediment and Panned-Concentrate Data

The elemental concentrations in stream-sediment and panned-concentrate samples collected from a small tributary that drains the northern Clark Bar prospect and flows westward into Clark Creek (fig. 2) are listed in table 3. Two of the samples (field Nos. 7TM131S, 7TM131C) were collected in 1977 as part of the U.S. Geological Survey AMRAP regional drainage-sampling program (Miller and others, 1978). This method reported data in steps (in the series 1, 1.5, 2, 3, 5, 7, 10, 15, and so on), and had high lower detection limits for many elements (Grimes and Marranzino, 1968). During July 2001, we collected new stream-sediment and panned-concentrate samples from the same stream at approximately the same location. The two new samples and the rest of the 1977 stream-sediment sample were analyzed in 2001 by XRAL Laboratories under contract to the USGS; not enough of the 1977 panned-concentrate sample remained to allow its reanalysis.

The stream-sediment and panned-concentrate samples from Clark Bar contain as much as 0.1 ppm Ag, 7 ppm As, 1 ppm Bi, 251 ppm Ce, 8 ppm Co, 20 ppm Ga, 40 ppb Hg, 130 ppm La, 37 ppm Li, 0.9 ppm Mo, 100 ppm Nd, 5 ppm Ni, 14 ppm Sc, and 67 ppm V (table 3). Both the stream-sediment and panned-concentrate samples contain relatively low Cu (≤13.1 ppm), Mn (≤709 ppm) Pb (≤19 ppm) and Zn (≤131 ppm) contents. An analysis of 1,000 ppm Sn in the 1977 panned-concentrate sample was not duplicated in the 2001 sample, possibly owing to a nugget effect from individual grains of cassiterite in the 1977 sample, but no petrographic examination of the sample was completed before its analysis. The stream-sediment samples contain significantly more Ce and V than any of the altered or fresh rocks from the prospect but have Ba, Cr, Ga, Li, Nb, Th and Y contents nearly identical to those of fresh granitic rocks from the area (table 1).

Most metallic and trace elements are not significantly enriched in the panned-concentrate relative to the stream-sediment samples (table 3). Because this heavily glaciated area is dominated by mechanical rather than chemical weathering, the stream sediment itself is a fine-sand-size accumulation of broken rock containing few fines or silt- or clay-size material. Panning to a concentrate, therefore, removes the smaller rock fragments rather than a material of significantly different mineralogy or composition.

Applicable Deposit Models

Alteration minerals and high metallic-element contents at Clark Bar are confined to felsic intrusive rocks, are mainly fracture controlled, and are spatially associated with aplite dikes that crosscut the biotite granite. Mineral-deposit models that are consistent with the geologic setting and lithogeochemistry of the Clark Bar prospect include late-stage magmatic, pneumatolytic, pegmatitic, and early-stage hydrothermal deposit types related to granitic intrusion (table 4). These models include large-tonnage disseminated and high-grade vein deposits related to the latest or most fractionated stages of felsic magmatic intrusion and cooling, as well as the formation of vapor- and water-rich phases.

Strong (1988) developed a classification scheme for granite-related mineral deposits that differentiated porphyry-type hydrothermal systems from granophile late-stage magmatic deposits, which include Sn, W, U, and Mo deposits associated

Table 4. Granophile and granite-related mineral-deposit models applicable to the Clark Bar prospect, Talkeetna Mountains D–4 quadrangle, southern Alaska, and nearby late Paleocene plutons.

[REEs, rare-earth elements. Do., ditto]

Mineral-deposit model	Type of mineralization	Ore characteristics	Igneous rock	Comments	References
Climax Mo (granite molybdenite).	Stockwork veins and veinlets-----	50th-percentile tonnage and grade: 200 million t containing 0.19 weight percent Sn.	High-silica (>75 weight percent SiO_2); granite-rhyolite stocks and radial dikes.	Host rocks at Clark Bar are dominantly intrusive; subvolcanic feeders to nearby Tertiary volcanic rocks may occur.	Ludington (1986), Singer and others (1986).
Granite-related Mo deposits.	Disseminated and stockwork veinlets in pluton and host rocks.	50th-percentile tonnage and grade: 81 million t containing 0.1 weight percent Mo.	Metaluminous to alkaline, high-silica granite and rhyolite.	Host rocks at Clark Bar are metaluminous to peraluminous.	Carten and others (1993), Kirkham and Sinclair (1995).
Granitic pegmatites: rare-element, Li-Cs-Ta family.	Pods of complex mineralogy in schist, gneiss, and felsic intrusions.	Contain Li, Rb, Cs, Be, Sn, Ga, Ta>Nb, B, P, and F.	Peraluminous, S-type granites------------	Similar host rocks occur at Clark Bar--	Černý (1993), Sinclair (1995a).
Granitic pegmatites: rare-element, Nb-Y-F family.	do---------------------------------	Contain Nb>Ta, Ti, Y, Sc, REEs, Zr, U, Th, and F.	Subaluminous to metaluminous granites.	Host rocks at Clark Bar are metaluminous to peraluminous.	Do.
Granophile deposits---------	Pegmatite, greisen, and veins at and near margins of intrusive bodies.	Zoned from Sn, W, As, and U outward to Ni-Co.	Quartz-rich leucocratic granitoids enriched in granophile elements.	Similar host rocks occur at Clark Bar--	Strong (1988).
Low-F porphyry Mo---------	Disseminated and stockwork veinlets in pluton and host rock.	50th-percentile tonnage and grade: 94 million t containing 0.085 weight percent Mo.	Calc-alkaline tonalite, granodiorite, and monzogranite.	Host rocks at Clark Bar are generally more siliceous.	Menzie and Theodore (1986), Theodore (1986), Kirkham and Sinclair (1995).
Polymetallic veins (felsic intrusion associated Ag-Pb-Zn).	Multiphase veins--------------------	50th-percentile tonnage and grade: 0.0076 million t containing 820 g Ag/t.	Calc-alkaline to alkaline small diorite to monzogranite intrusions and plugs.	do--------------------------------------	Cox (1986a), Bliss and Cox (1986).
Polytype W deposits---------	Pegmatite, granite, greisen, replacement, and quartz vein types.	Sn-Mo-Bi; W-Sn; Mo-W; varying proportions.	Granite, commonly siliceous and muscovite bearing.	Similar host rocks occur at Clark Bar--	Sinclair (1995b); Deposit types 1, 2, 3, 5, and 6 of Yidou (1993).
Porphyry Cu-Mo------------	Disseminated and stockwork veinlets in pluton and host rock.	50th-percentile tonnage and grade: 500 million t containing 0.016 weight percent Mo, 1.2 g Ag/t.	Tonalite to monzogranite, commonly porphyritic.	Host rocks at Clark Bar are more siliceous.	Cox (1986b), Singer and others (1986), Kirkham and Sinclair (1995).
Porphyry Sn (subvolcanic Sn).	Disseminated, veinlet and breccia.	Zoned from Sn-B to Sn-Ag-As-Sb-base metals outward.	Intermediate to felsic quartz porphyry stocks and calc-alkaline lavas.	Host rocks at Clark Bar are dominantly intrusive; subvolcanic feeders to nearby Tertiary volcanic rocks may occur.	Reed (1986a), Kirkham and Sinclair (1995).
Sn greisens--------------------	Disseminated mineralization in greisen, and veinlets in host rocks.	50th-percentile tonnage and grade: 7.2 million t containing 0.28 weight percent Sn.	Specialized two-mica, S-type leucogranite.	Similar host rocks occur near Clark Bar.	Menzie and Reed (1986a), Reed (1986b).
Sn polymetallic veins, subvolcanic.	Multistage veins and breccia pipes.	Cu-Zn-Sn-Ag; zoned from Sn-W to Cu-Sn to Pb-Ag outward from center.	Felsic subvolcanic and ignimbritic rocks.	Host rocks at Clark Bar are dominantly intrusive; subvolcanic feeders to nearby Tertiary volcanic rocks may occur.	Togashi (1986).
Sn veins (Cornish lodes)----	Veins, brecciated and banded veins, and replacement lodes.	50th-percentile tonnage and grade: 0.24 million t containing 1.3 weight percent Sn.	Felsic plutonic rocks; specialized two-mica granite common.	Similar host rocks occur at Clark Bar--	Menzie and Reed (1986b), Reed (1986c), Sinclair (1995b).

with quartz-rich leucocratic granitoids. Granophile deposits, according to Strong (1988), form from magmatic water early in the crystallization history of the magmas at higher temperatures and deeper emplacement levels than do typical porphyry deposits, are dominated by oxide minerals rather than sulfides, and commonly contain pegmatitic or other late-stage magmatic textures. Greisenization (white mica, quartz, topaz, tourmaline, fluorite) and the addition of Li, Be, B, F, and Si to wallrocks are typical signs of alteration. In aluminosilicate host rocks, such as those in the vicinity of Clark Bar, Strong's (1988) granophile deposits can include topaz-quartz greisens within a pluton, tourmaline- and mica-rich pegmatites at the contact with wallrocks, and quartz-dominated vein systems in greisenized and hornfels wallrocks (Strong, 1988).

Sn-Ag±Mo-W porphyry, vein, and greisen deposits (Reed, 1986a–c; Yidou, 1993; Kirkham and Sinclair, 1995; Sinclair, 1995a, b) are most consistent with the geologic setting and lithogeochemistry of the Clark Bar area as currently understood. Greisen deposits would occur mainly within the felsic intrusions. Vein systems and related disseminated mineralization could be hosted either by the granites or by the hornfelsed Jurassic and Cretaceous flysch that the granites intruded. Evolved two-mica leucogranites are also associated with the occurrence of rare-element (Cs, Ga, Nb, Rb, REEs, Sc, Ta, Th, U, Y) and Li, U, or Sn pegmatite deposits (Černý, 1993; Sinclair, 1995a) of several types (table 4). The absence of any known calcareous wallrocks in the vicinity of Clark Bar suggests that the potential for related Sn-bearing skarn or replacement deposits (models 14b, 14c; Cox and Singer, 1986) is low. Placers concentrated from a lower-grade disseminated Sn-Mo-Ag lode source are unlikely because they would have had little time to form in this rugged, heavily glaciated area.

Analogs

The Clark Bar prospect is similar to other Sn-, Mo-, or W-mineralized areas of southern Alaska, some of which have been genetically linked to the McKinley sequence or other Paleocene granites (Nokleberg and others, 1987; Hudson and Reed, 1997). The Treasure Creek Mo prospect (Kurtak and others, 1992) lies approximately 40 km southwest of Clark Bar (fig. 1) and 15 km from the Devil Creek two-mica, garnet-bearing stock (table 1). Treasure Creek comprises disseminated sulfide mineralization containing as much as 1.0 weight percent Mo, 2.65 weight percent Zn, and 58 ppm Ag in a silicified and fluorite-altered stock of unknown, probable Tertiary age that crosscuts the Jurassic and Cretaceous flysch of the northern Talkeetna Mountains.

At Coal Creek (fig. 1), an estimated resource of 5 million t of rock containing 0.28 weight percent Sn and 0.5 weight percent Cu is present in sheeted and stockwork veins and disseminated mineralization (Nokleberg and others, 1987; Thurow and Warner, 1994). Grab samples of cassiterite and sulfide mineralization contain as much as 1.5 weight percent Sn, 148 g Ag/t, 0.5 ppm Au, and 720 ppm W (Balen, 1990). Greisenization (topaz, tourmaline, quartz, sericite fluorite) occurs in vein envelopes and as a pervasive alteration of the McKinley-sequence granite, which intrudes Paleozoic argillite and graywacke (Thurow and Warner, 1994).

Two granite-hosted prospects occur in the Alaska Range, where Paleocene McKinley sequence stocks intrude flysch of the Kahiltna assemblage. At Ohio Creek, Nb oxides and mineralized rocks containing as much as 1.25 weight percent W, 5,042 g Ag/t, and 0.1 weight percent Sn are hosted in muscovite-tourmaline greisen and pegmatitic quartz-arsenopyrite veins (Balen, 1990). At Hidden Creek, cassiterite occurs in quartz-tourmaline-muscovite veins that cut the granite. Sn-Ag vein and skarn mineralization at Ready Cash and Boulder Creek/Purkeypile (Balen, 1990; Millholland, 1999) are also genetically related to the McKinley sequence granites.

A similar metallogenetic setting occurs west of the Alaska Range, where felsic plugs of Late Cretaceous or early Tertiary age intrude Late Cretaceous Kuskokwim Group marine sandstone and shale. The Won, Win, and Bismark Creek prospects in the Kuskokwim Mountains are Sn-Ag-rich sheeted or stockwork veins with complex, sulfosalt-rich mineralogy in addition to cassiterite (Hudson and Reed, 1997). Tourmaline is common, and B rather than F is enriched in these shallow-level subvolcanic systems. At Sleitat in the southern Taylor Mountains, a 57-Ma two-mica granite has produced Sn-W mineralization in topaz- and tourmaline-bearing greisen (Burleigh, 1991; Hudson, 2001).

Though varying widely in host rock and geographic location, all these prospects share a close association with late-stage, quartz-rich granites, similar to the granophile and specialized suites discussed above. If all the granitic stocks of the northern Talkeetna Mountains can be shown to be of similar composition and origin, then the northern Talkeetna Mountains could have a potential for deposits of Nb, rare elements, or W, as well as the Sn-Ag-Mo association noted at Clark Bar.

Summary

Although our observations and sampling of the Clark Bar prospect were limited, some conclusions can be drawn concerning the mineral potential of the area. Strongly altered rocks at Clark Bar are enriched in Ag, Be, Ce, La, Li, Mo, Sn, and Zn and somewhat enriched in Bi, Hg, and Sb. Associated Paleocene granitic rocks are silica rich and have a trace-element chemistry consistent with granophile or "specialized," S-type granites. The two-mica, garnet-bearing stock at Devil Creek may be an example of a late-stage, volatile-rich phase of the larger regional composite plutons that are dominantly granodioritic in composition. Both the Clark Bar prospect and the regionally extensive Paleocene plutons have a moderate potential to host Sn-Ag-Mo and or W and rare-element deposits related to the most differentiated, water-rich stages of felsic intrusion.

Grid sampling of rocks and soils and more detailed stream-sediment sampling of all creeks draining the altered area at Clark Bar could determine the extent and metal content of possible mineralization at the prospect. Additional geologic mapping might indicate key indicator minerals in rock samples (muscovite, fluorite, tourmaline, topaz) or panned-stream concentrates (cassiterite, molybdenite, fluorite). Analysis of new and existing samples for such additional elements as F and B, and analytical methods with lower detection limits for such elements as U and W, would narrow down the range of possible deposit models to pursue in this region.

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