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by

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INTRODUCTION

On March 9, 1994, we presented a short course to the Alaska Miners Association on pluton-related deposits in interior Alaska. This course included a variety of data (much of which was in graphical format) not previously released. Subsequently, we have had several requests for reprints and descriptions of the material presented. We are releasing our graphical and tabular data in this less-formal format, in order to make this material available to the geologic public in a relatively timely fashion. We anticipate more formal release of the data and considerably extended discussion of it at some future data. We wish to acknowledge the assistance of the Fairbanks geologic community, including Harry Noyes, Doyon Ltd; Arne Bakke, Amax Gold; Diane Minehane, Steve Masterman, and Dan McCoy, Ryan Lode Mines; Jack DiMarchi, ASA, Inc; Chris Puchner, Nixon Fork Mines; and Karen Clautice, Milt Wiltse, Laurel Burns, and Tom Smith, ADGGS for logistical assistance, permission to view materials, and analytical assistance.

I. OVERVIEW OF PLUTONIC ROCKS AND ORES, INTERIOR ALASKA

The bulk of plutonic rocks in Interior Alaska are of Late Mesozoic to early Tertiary ages (Fig. 1). Age histograms reveal an essentially tri-modal population with peaks at 100-90 Ma (mid Cretaceous), 65-75 Ma (late Cretaceous) and 50-60 Ma (early Tertiary). Each of these major groups of ages reflects some varieties of pluton-hosted/related mineral deposits, and each has characteristic magmatic chemistry. Normative data for Interior Alaska plutonic rocks (Fig. 2) reveals a wide range of compositions, spanning diorite to alkali-feldspar granite, and accompanying mafic minerals. The more mafic rocks tend to contain hornblende and biotite; the more felsic biotite only; and the most felsic contain muscovite and biotite.

Lead and Sr isotopic ratios have been determined for a few plutons in Interior Alaska by previous workers (e.g., Blum, 1982; Aleenikoff et al., 1987; Newberry et al., 1990). Plotting of previous data with our additional data (Tables 1 and 2) reveals systematic increases in radiogenic isotope ratios from the vicinity of the present Denali fault towards the NE (Figs. 3,4). These patterns can be most readily interpreted in terms of a NE-facing (present coordinates!) subduction zone in the general vicinity the present Denali fault, with systematic increases in contamination from continental basement towards the continental interior (to the NE).

Most of our available data is for the mid-Cretaceous plutonic rocks. Classification schemes built around major element data (Figs. 4,5) indicate that the bulk of plutons are I-type (igenous-derived), but some are definitely S-type (sediment-derived). Age categorization (see ahead) indicates that the mid-Cretaceous plutons have I-type characteristics, whereas the younger ones are mixed S- and I- type. Trace element data also indicate that the bulk of plutonic rocks (Fig. 7) are not of A-type (anorogenic) affinity.

Aleinikoff et al. (1987) presented some data for plutons of Interior Alaska; a compilation of all available data, including ours (Table 1) shows that the Alaska plutons closely resemble the subduction-sourced plutons of the western U.S. Cordillera (Fig. 8). Comparison of Pb isotopic ratios of vein/replacement/skarn ores (including our data; Table 3) with those of the plutons shows a strong overlap between the two (Fig. 9) indicating that the Pb (and presumably, many of the other ore components) of veins, skarns, and replacements in and near Interior Alaskan plutons are of predominantly plutonic derivation.

There are a variety of mineralization types associated with plutons in Interior Alaska. Our data indicates significant differences in composition, mineralogy, and textures between plutons associated with different deposit types. Using the oxidation-alkalinity diagram of Leveille et al. (1988), it is clear that the U-related and some Au-related plutons are distinctly alkalic (Fig. 10); Au and Sn systems are highly reduced; Mo and U plutons are oxidized; and W- and Cu-related plutons are of intermediate oxidation character.

There are additional differences between plutons related to different mineralization types in the YTT. Geobarometry based on aplite dike compositions (Fig. 11) indicates that Sn systems are

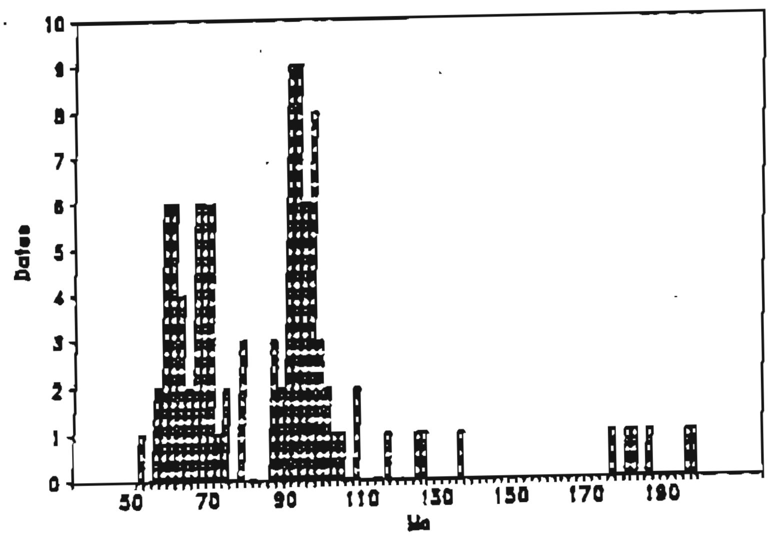


Fig. 1. Histogram of post-Triassic pluton K-Ar ages, Yukon-Tanana Terrane, Alaska. Modified from Burns et al. (1991a).

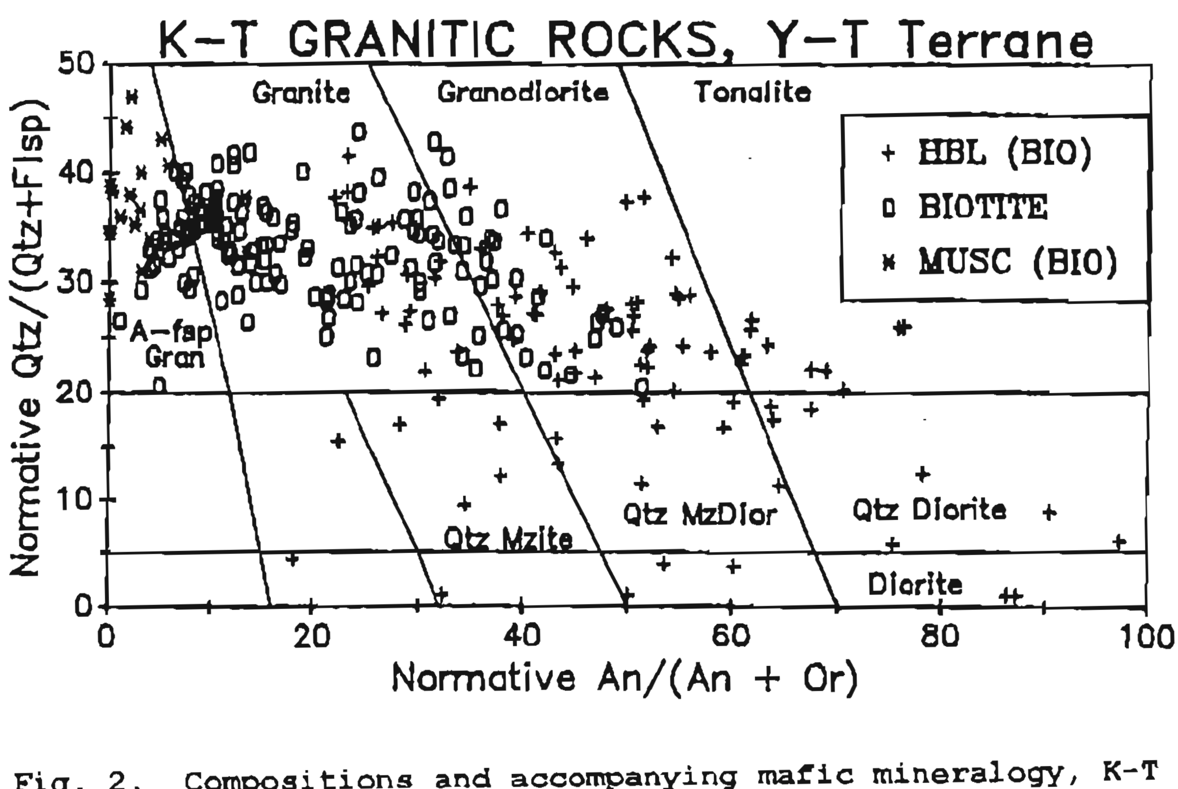


Fig. 2. Compositions and accompanying mafic mineralogy, K-T plutons, Yukon-Tanana terrane. Data from Foster et al. (1978), Luthy et al. (1981), Blum (1982), Burns et al. (1991a) and unpublished field notes

TABLE 1: PB ISOTOPIC RATIOS FOR K-FELDSPARS FROM PLUTONIC ROCKS OF INTERIOR ALASKA

NAME	QUADRANGLE	Pb ISOTOPIC RATIOS		
		206/204	207/204	208/204
Gilmore Dome	Fairbanks	19.114	15.611	38.760
Ft Knox	Fairbanks	18.985	15.606	38.761
Golden Zone	Healy	19.151	15.602	38.687
Liberty Bell	Fairbanks	19.045	15.630	38.730
Ohio Ck	Healy	19.151	15.632	38.733
Pedro Dome	Fairbanks	19.118	15.688	39.146

All ratios determined by ChemPet Research, California employing standard Pb extraction and mass spectrometric techniques

TABLE 2: SR ISOTOPIC DATA FOR PLUTONIC ROCKS OF INTERIOR ALASKA

sample number	87/86Sr measured	87Sr/86Rb calc'd	age (Ma)	Sri calc'd	Location	Rb (ppm)	Sr (ppm)
89rn301	0.71282	0.3731	92	0.71233	Fort Knox	119	909
89Rn370	0.71345	0.5169	92	0.71277	Ester Dome	109	601
JB 1587	0.71513	2.0911	92	0.71240	Silver Fox	248	338
89rn209	0.70505	0.2689	70	0.70478	Golden Zone	77	816
75afr2171	0.71647	1.1418	95	0.71493	Big Delta Quad	127	317

87/86Sr data determined by Krueger Enterprises, using standard extraction and mass spectrometry techniques; Rb and Sr concentrations by XRF analysis, XRAL, Inc.

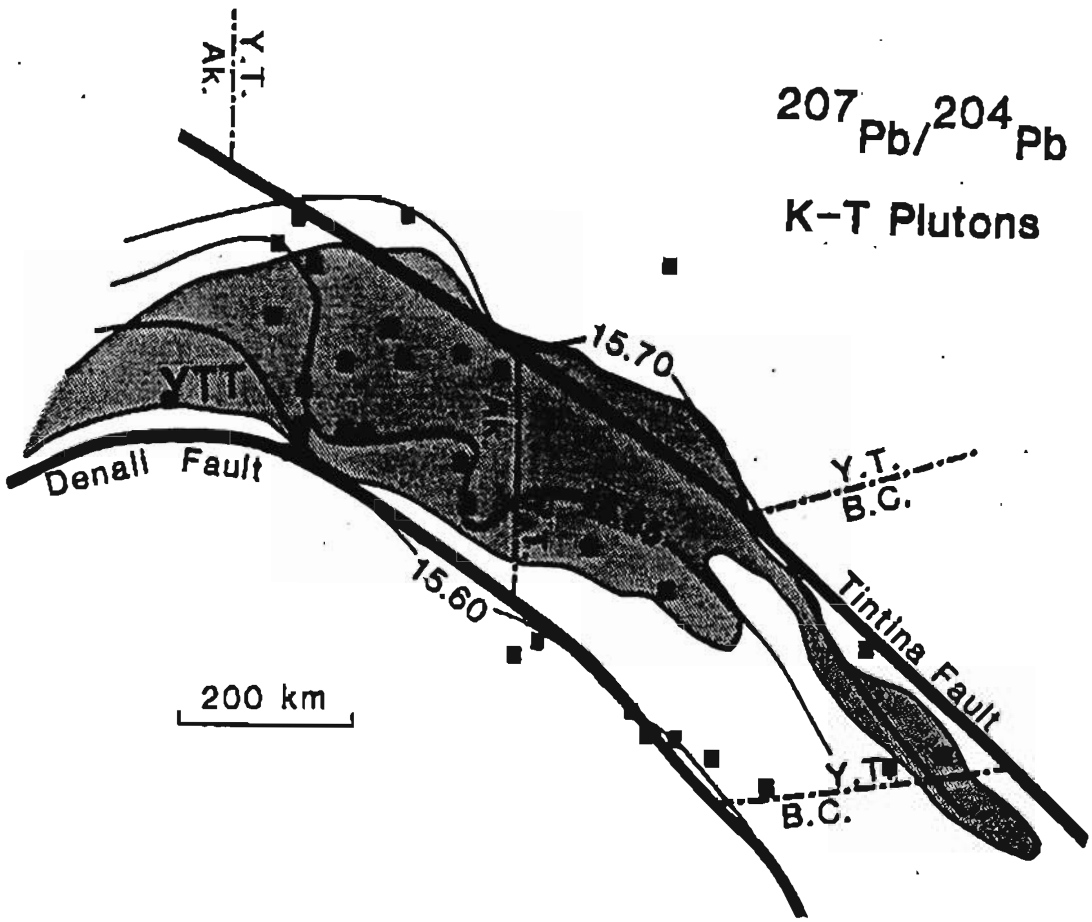


Fig. 3. $^{207}Pb/^{204}Pb$ isotopic ratios for K-feldspars from K-T plutons, YTT and vicinity, plotted on map with movement on Tintina and Denali faults restored to pre-100 Ma. Shaded area represents generalized outrop of YTT Terrane. Contours show gradational NE increase in radiogenic Pb for K-T plutons, cutting across terrane boundaries. Data from Aleinikoff et al. (1987), Godwin et al. (1988), Gacetta and Church (1989), and this study.

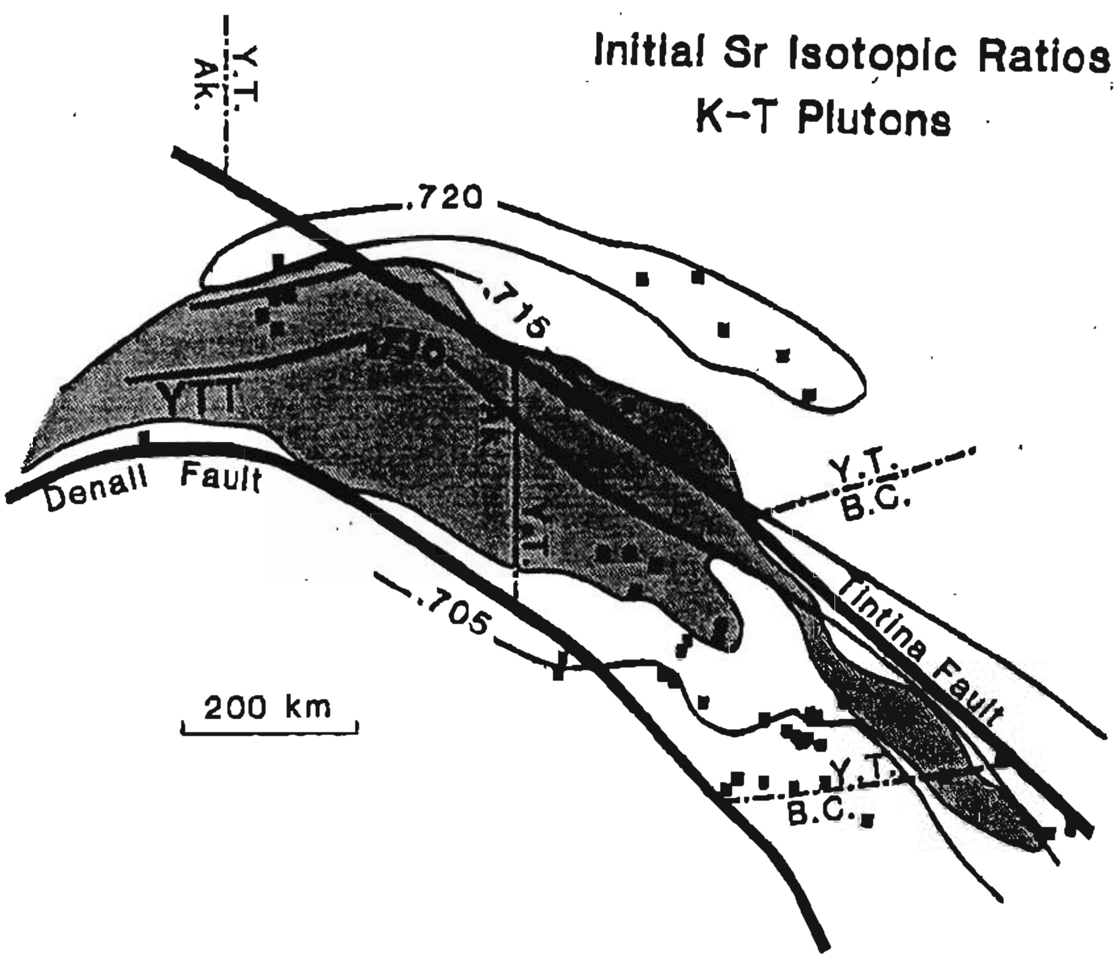


Fig. 4. Initial Sr isotope data for K-T plutons, YTT Terrane and vicinity, plotted on map with pre-100 Ma Tintina and Denali Fault movements restored. Shaded area represents generalized outcrop of YTT terrane. Contours record gradual increase pluton initial Sr isotope ratio from SW to NE, suggesting gradual increase in degree of crustal contamination away from the Denali Fault. Data from LeCouteur and Templeman-Kluit (1976), Morrison et al. (1979), Sinclair et al. (1981), Blum (1982), Kuran et al. (1982), Pigage and Anderson (1985), Newberry et al. (1990), Metz (1991), and this study.

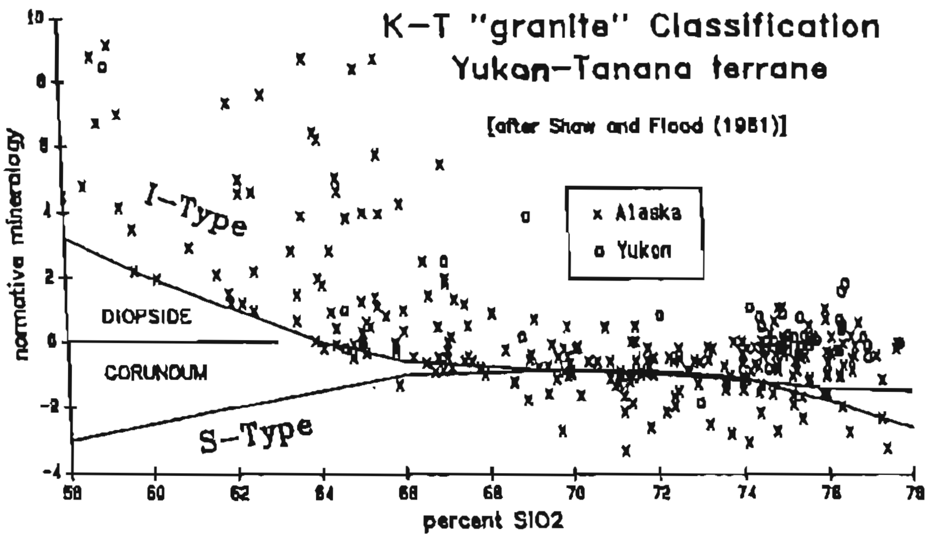


Fig. 5. Classification of K-T YTT granitic rocks based on normative mineralogy vs. silica content plot of Shaw and Flood (1981). The analyses, which are primarily of ca. 90 Ma granodiorite-granite, indicate a predominance of I-type plutons. Data from Burns et al. (1991a), Newberry et al. (1994), Burleigh and Lear (1994), and unpublished data.

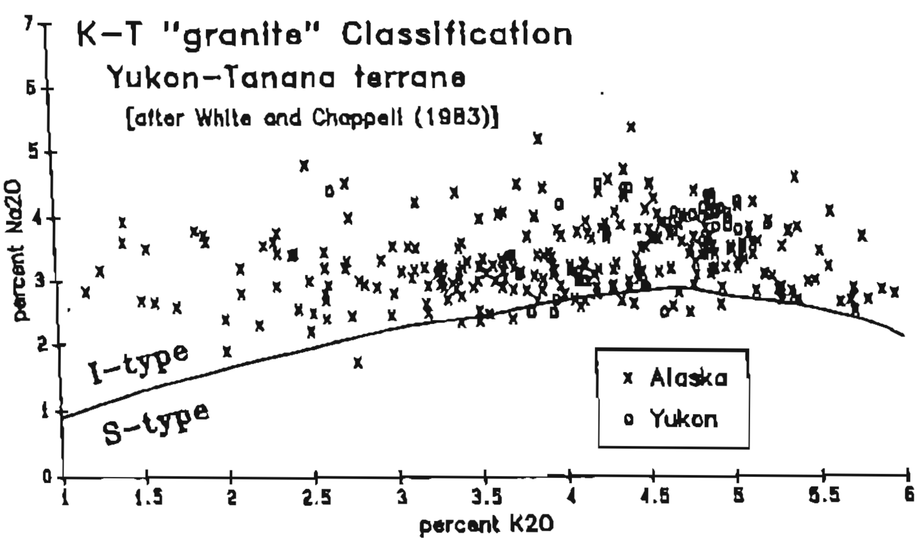


Fig. 6 Classification of K-T YTT granitic rocks based on Na2O vs. K2O plot of White and Chappell (1983). The analyses, which are primarily of ca. 90 Ma granodiorite-granite, indicate a predominance of I-type plutons. Data from sources listed with Fig. 5.

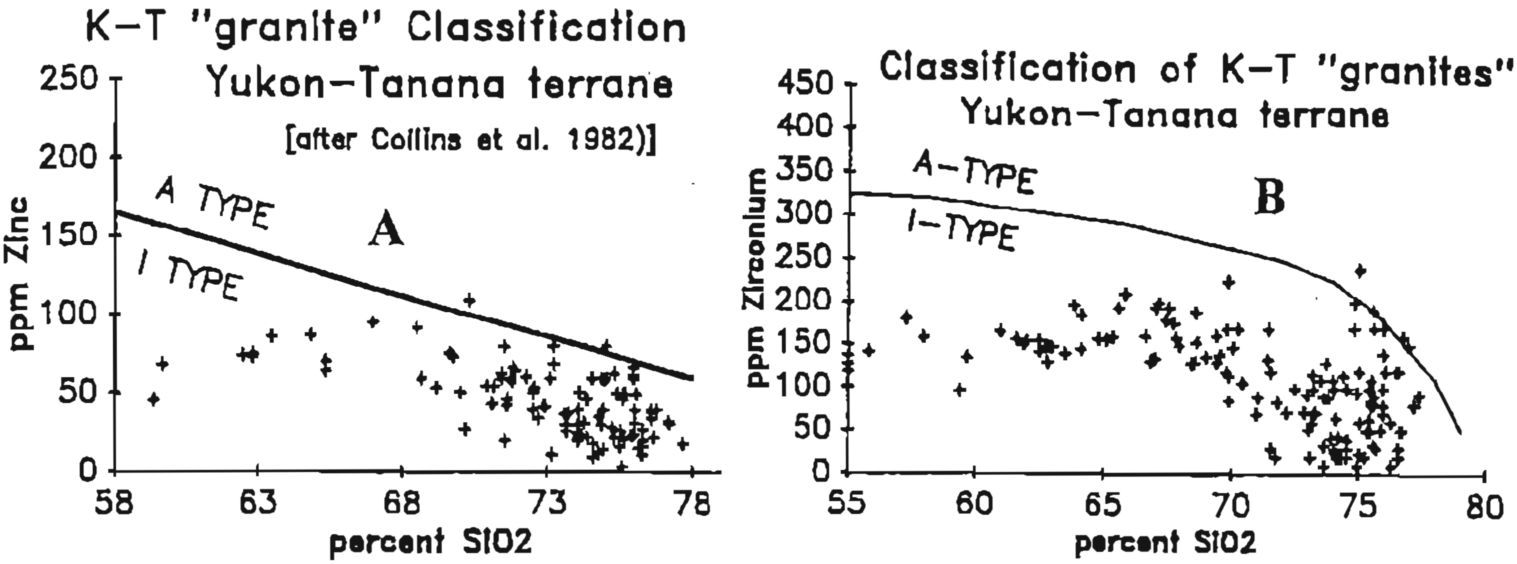


Fig. 7. Classification of K-T YTT granitic rocks based on (A) Zn vs. SiO2 and (B) Zr vs. SiO2 plots of Collins et al. (1982). The analyses, which are primarily of ca. 90 Ma granodiorite-granite, indicate a predominance of I-type plutons. Data from sources listed with Fig. 5.

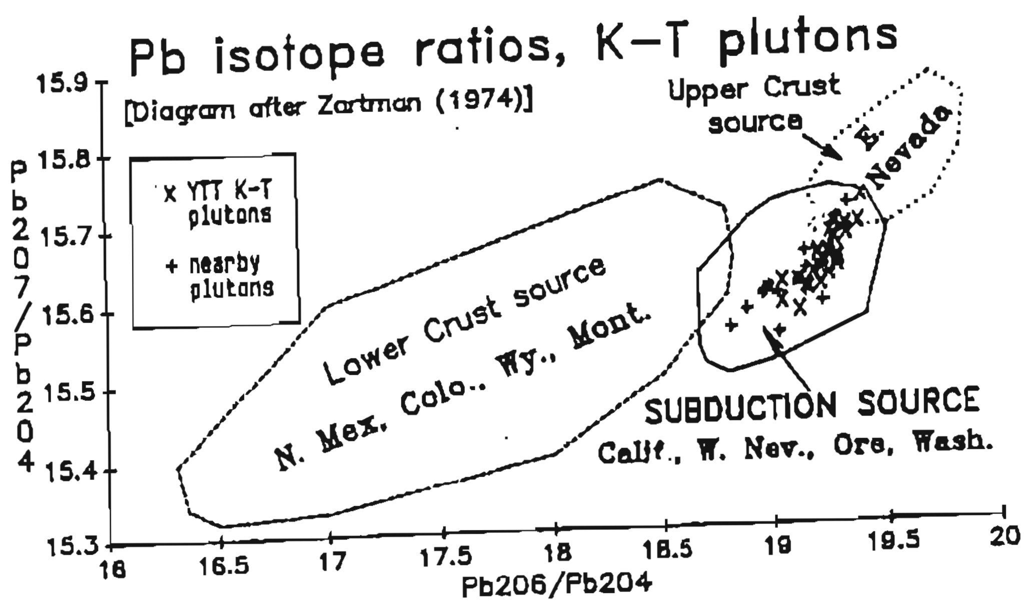


Fig. 8. Pb isotope ratios for K-feldspar from K-T plutons, YTT and vicinity, plotted on discrimination diagram of Zartman (1974). Most of the plutons fall in the field of subduction-sourced; a few plot similar to those with upper crustal sources. Data from Aleinikoff et al. (1987), Gacetta and Church (1989), Church (writ. comm., 1994), and this study.

TABLE 3: PB ISOTOPIC RATIOS FOR INTERIOR ALASKAN ORES

deposit type	Name	quad	Pb isotopic ratios 206/204	207/204	208/204
vein	Hope Crk	Circle	19.203	15.653	39.057
skarn	Happy Mtn	Eagle	19.279	15.652	39.078
skarn	Oscar Z	Eagle	19.327	15.668	39.187
vein	Cummins Claims	Healy	19.083	15.594	38.516
breccia	Golden Zone	Healy	19.114	15.579	38.545
vein	Ready Cash	Healy	19.132	15.6 1	38.647
replmt	Liberty Bell	Fairbanks	19.173	15.649	38.874
skarn	Ag King	Healy	19.114	15.582	38.545
skarn	Coal Crk	Healy	19.03	15.581	38.386
skarn	Stoneboy Ck	Big Delta	19.226	15.597	38.936
skarn	W Fork Susitna	Healy	19.063	15.61	38.228
vein	Grey Lead	Big Delta	19.396	15.728	39.479
vein	McCaulie Glac	Healy	19.008	15.563	38.483

All ratios determined by ChemPet Research, California employing standard Pb extraction and mass spectrometric techniques

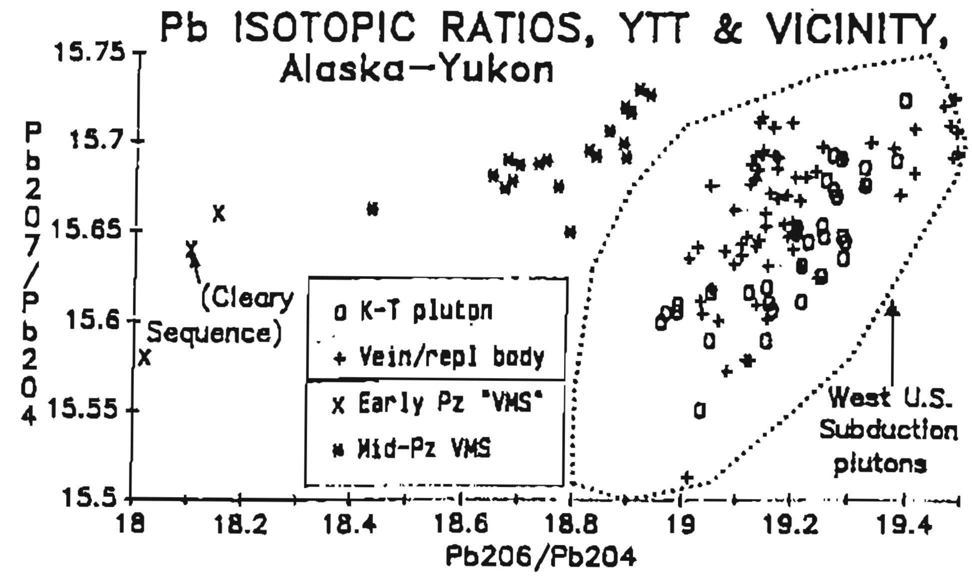


Fig. 9. Comparison between Pb isotope ratios for plutons and for ores, YTT, and vicinity, Alaska-Yukon. Note complete overlap of K-T plutons and nearby veins/replacements vs. separate fields for pre-K stratabound volcanogenic deposits. Data from Aleinikoff et al. (1987), Godwin et al. (1988), Gacetta and Church (1989), Church (writ. comm., 1994), and this study.

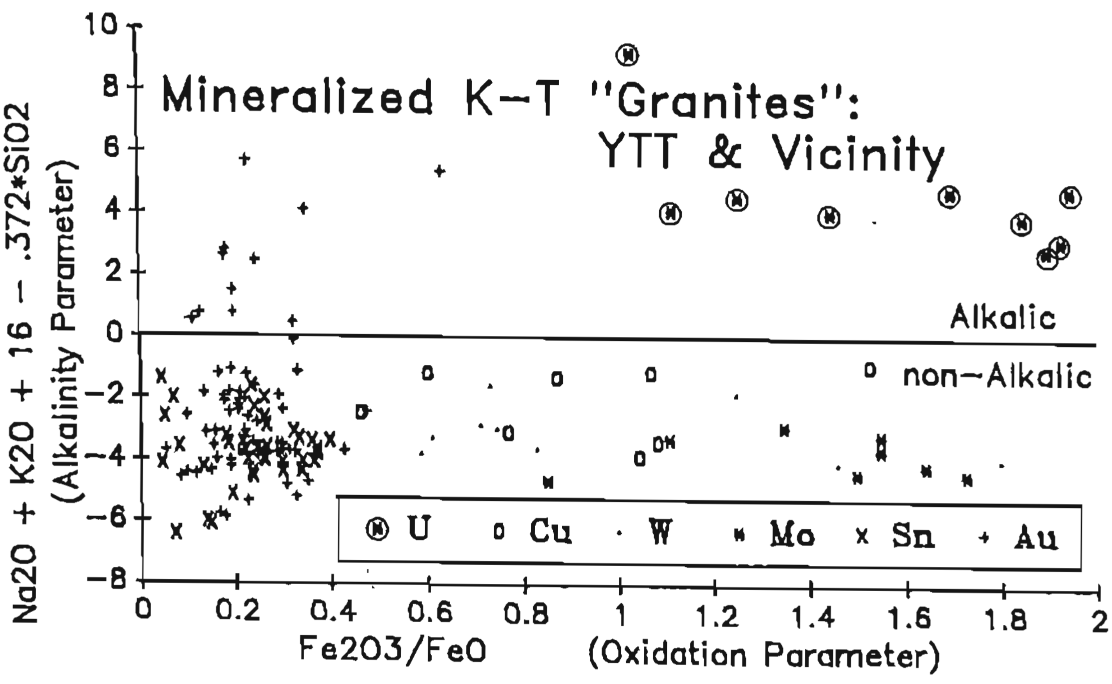


Fig. 10. Alkalinity parameter (from Mutschler et al., 1985) vs. Fe2O3/FeO for least-altered, mineralized, K-T granitic rocks, YTT and vicinity, showing systematic relationship between pluton composition and ore type. Data from Burton (1981), Lynch et al. (1983), Sinclair et al. (1981), Kuran (1982), Burns and Newberry (1987), Blum (1982), Burns et al (1991a), and Newberry et al. (1994).

shallow, W systems are deep, and Mo and Au systems are of intermediate depths. There are also significant differences in degree of fractionation of the melts, as expressed by relative contents of Sr (highest in least fractionated rocks), Ba (intermediate) and Rb (highest in most fractionated rocks) in plutons of the YTT (Fig. 12). Finally, there are spatial patterns for the different mineralization types (Fig. 14), i.e., belts of mineralization of a given age and type. Such belts apparently represent the changing locus of plutonism in the YTT area with time. Table 4 summarizes the differences among plutons associated with the various mineralization types, based on data from Figs. 10-13.

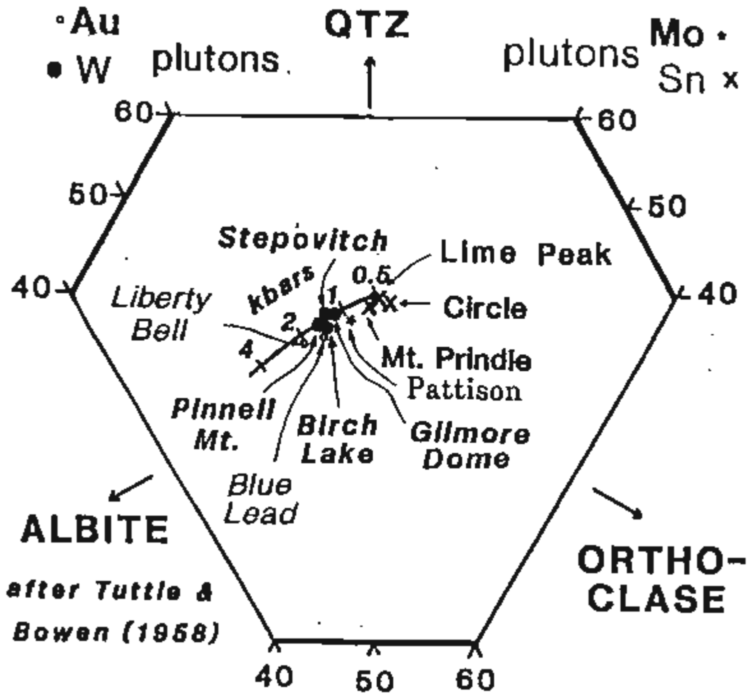


Fig. 11. Aplite geobarometry (normative composition of low-F aplite dikes plotted on composition-pressure diagram of Tuttle and Bowen, 1958) for plutonic rocks of the YTT, Alaska & Yukon. Plutons spatially associated with Au and W mineralization in the area were emplaced at significantly greater depths than those associated with porphyry Mo and greisen Sn mineralization. Data from Blum (1982), Lynch et al. (1983), Allegro (1987), Newberry et al. (1990), Burns et al. (1991a), and Newberry et al. (1994).

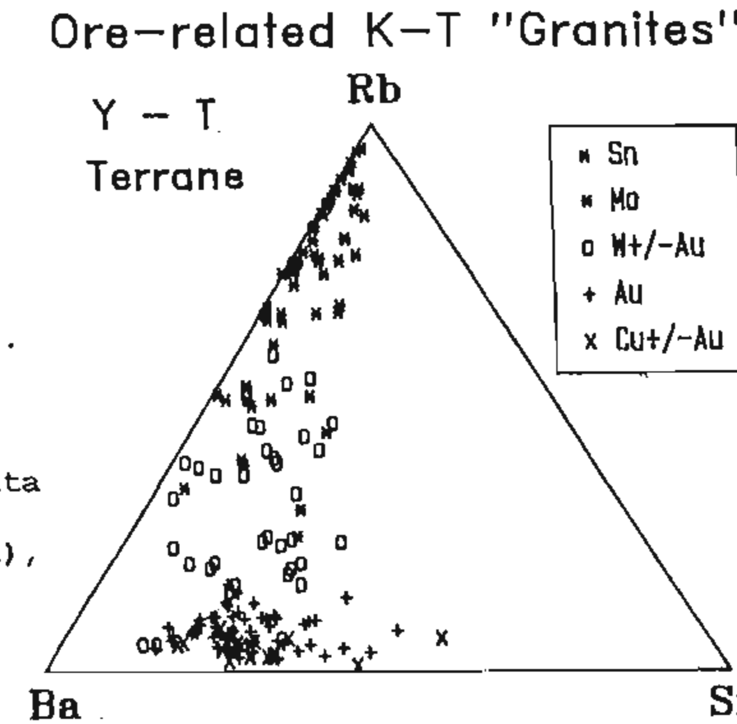


Fig. 12. Relative concentrations of Sr, Ba, and Rb for plutons association with different mineralization types, YTT and vicinity, Alaska & Yukon. Data from sources listed with Fig. 10.

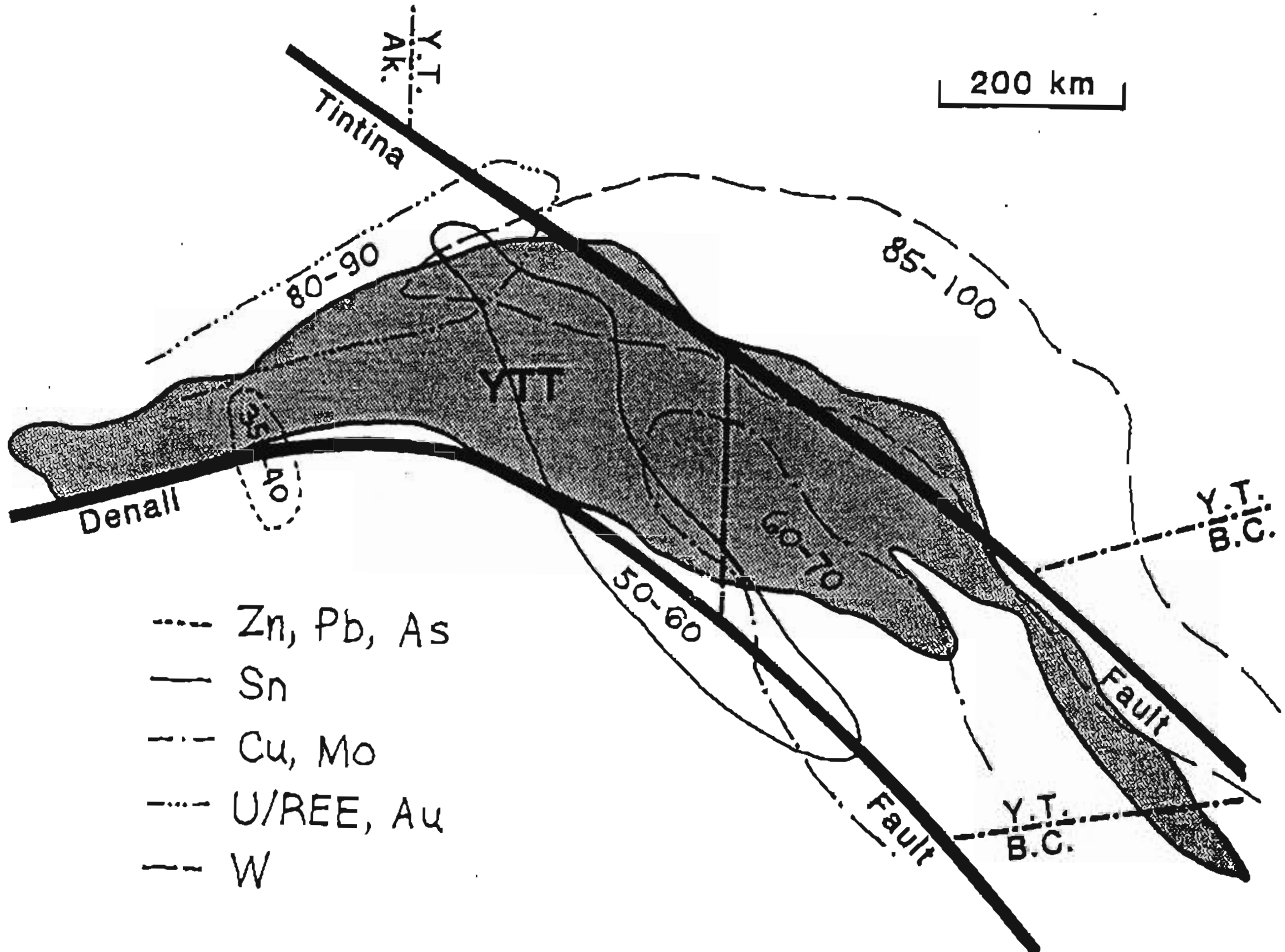


Fig. 13. Pluton-related mineralization-age trends in E-central Alaska, SW Yukon, and NW British Columbia with movement restored on the Tintina and Denali faults. Data from Sinclair (1986), Newberry et al. (1990), and Nokleberg et al. (1987).

TABLE 4: CHARACTERISTICS OF GRANITIC ROCKS ASSOCIATED WITH VARIOUS MINERAL DEPOSIT TYPES YTT AND ADJACENT AREAS, ALASKA AND YUKON

METAL ASSOC	DEGREE OF EVOLUTION	OXIDATION STATE	ALKALIC ?	XYLIZATION PRESSURE	AGE (Ma)
W	moderate	variable	No	1–2 kb	90–100
Mo	high–v.high	high	No	~1 kb?	80–100
U	high?	high	Yes	~1 kb	80–90
Au	low	very low	BOTH	1.5–.5 kb	70–100
Cu	low–v.low	variable	No	~.5 kb	50–70
Sn	very high	very low	No	~.5 kb	50–60
Pb–Zn	moderate	variable	No	<.5 kb?	30–40

II. TYPES OF ALASKAN PLUTON-HOSTED GOLD DEPOSITS

Alaskan pluton-hosted gold deposits can be broadly broken into three varieties: (1) those for which mineralization is essentially contemporaneous with plutonism ("intrinsic"), (2) those for which the pluton is merely the host for much younger gold veining ("extrinsic"), and (3) those for which there is some evidence for early and some evidence for late mineralization ("mixed origin"). The A-J deposit, 5 km E of Juneau, Alaska, is a good example of an extrinsic deposit, as Mesozoic gabbro/diorite sills are cut by veins with K-Ar and Rb-Sr ages of 55 Ma (Newberry and Brew, 1988). The Jualin-Kensington deposits, 100 km NW of Juneau (Fig. 14), are good examples of "mixed-origin" deposits where there is evidence for early, syn-plutonic, quartz-K-feldspar-biotite-chalcopyrite-pyrite alteration carrying anomalous gold (Fig. 15; Leveille, 1990) but main-stage veining occurred approximately 50 Ma later (Newberry and Brew, 1993). Evidence for remobilization of early mineralization is seen at both large and small scale. On the regional scale, gold-bearing "main-stage" veins are restricted to Tertiary shear zones, but significant gold concentrations are restricted to zones containing early potassic alteration. At the detailed scale, outer alteration zones around main-stage veins are significantly depleted in Cu and Au, suggesting that leaching of Au-Cu enriched plutonic rocks ultimately led to metal concentration in main-stage veins (Fig. 15).

Alaskan intrinsic pluton-hosted gold deposits contrast with both extrinsic/mixed deposits and syngenetic, pluton-unrelated deposits in several important ways. First, Alaskan deposits commonly exhibit a halo of mineralization around the causative pluton (Figs. 16-18), typically extending outward 1-3 km. Enrichments in Au, As, and Sb are all common. Secondly, plutonic-related deposits are characterized by an elemental suite significantly different from those of stratabound and extrinsic vein deposits. The Spruce Peak prospect, in Denali National Park (Fig. 19) is one such stratabound syngenetic deposit, which has low concentrations of Te, W, Sn, Mo, Sb, and Bi. Table Mountain, in contrast (Fig. 20) contains cross-cutting mineralization spatially associated with a Cretaceous granite and with felsic dike swarms; the mineralization is strongly enriched in W, Te, Bi, and Sb. Prospects in the Steese area are apparently of both stratabound syngenetic and pluton-related varieties, the pluton-related ones being accompanied by significant Te (Fig. 21).

Both syngenetic and pluton-related gold in Interior Alaska is commonly accompanied by tourmaline. These can be compositionally distinguished as the former show extensive optical and compositional zoning (Fig. 22A), whereas the latter show little zoning (Fig. 22B). Further examples of epigenetic, pluton-related mineralization patterns are shown in the Ester Dome (Fig. 23) and Cleary Summit (Fig. 24) areas, where pluton-related gold mineralization is spatially associated with Cretaceous dikes/plugs and with enrichments in Te and W.

Trace element differences between pluton-associated and syngenetic Au enrichments are depicted by Au vs. Te relationships (Fig. 25) and summarized in Table 5. Pluton-related Au prospects are characterized

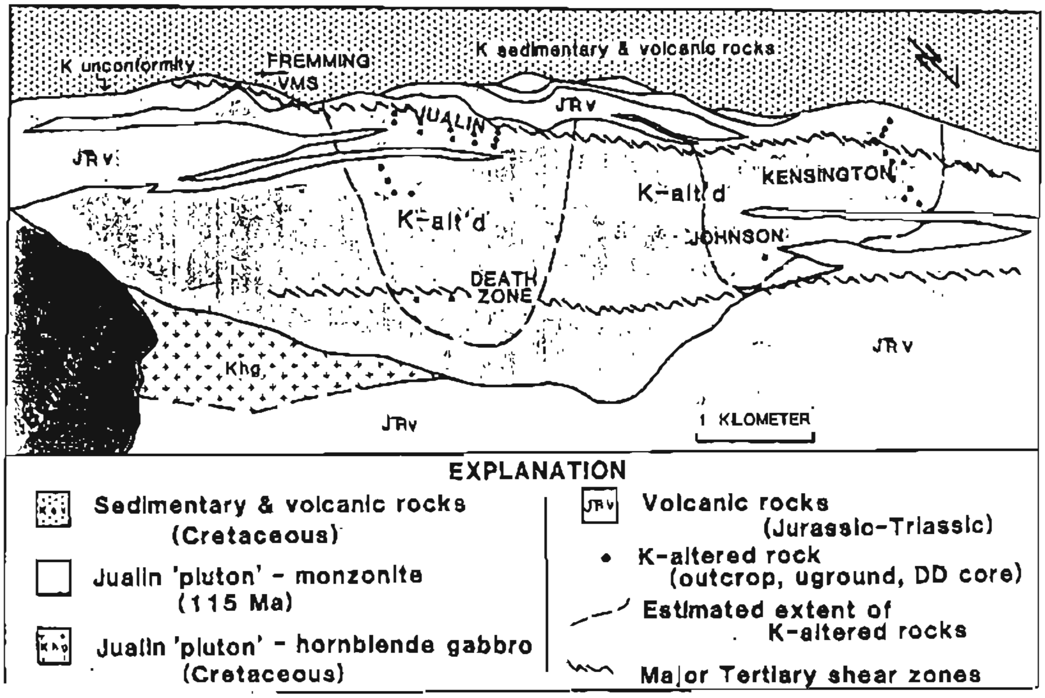


Fig. 14. Simplified alteration-mineralization map, Jualin-Kensington area, SE Alaska, showing spatial association between zones with Cretaceous potassic alteration and gold-bearing veins within Tertiary shear zones. Near-vertical dips in the late-K unconformity on top of the Jualin pluton indicate that the SW direction in present map view corresponds to mid-Cretaceous "up". Modified from Knopf (1911) using data from Leveille (1990) and unpublished field mapping 1985-1993.

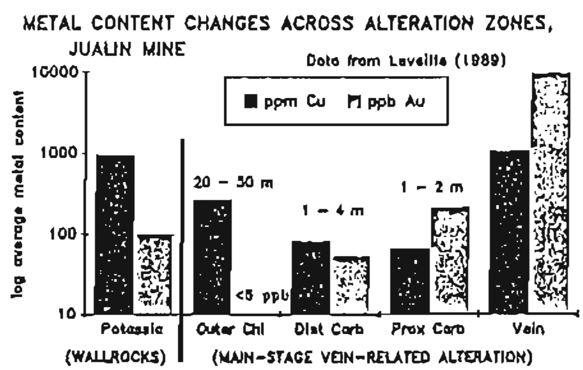


Fig. 15. Metal content changes across alteration zones, Jualin mine, SE Alaska, showing that distal alteration zones are leached of metal, which is concentrated within main-stage veins. Data from Leveille (1990) and unpublished analyses.

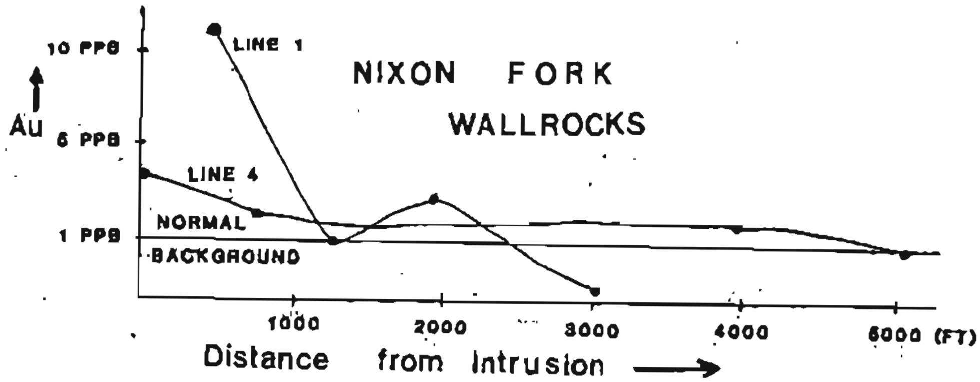


Fig. 16. Gold contents of carbonate host rocks as a function of distance from the Nixon Fork pluton, Nixon Fork Au skarn, showing gradational decrease suggestive of gold addition to carbonates. Data from Cutler (1993).

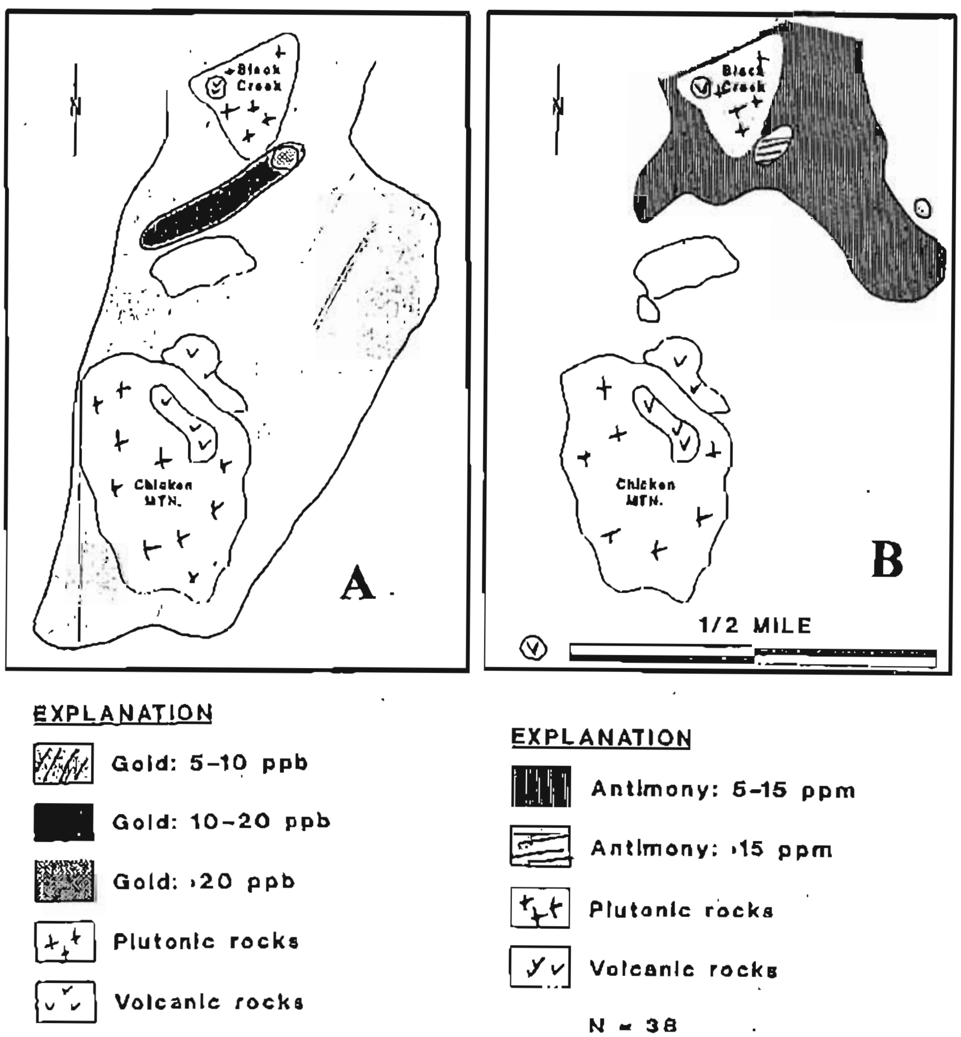


Fig. 17. Metal halos [(A)= Au; (B)= Sb] in sedimentary rocks surrounding the Black Creek and Chicken Mountain stocks, Flat area, SW Alaska. Metal distribution indicates systematic enrichment in metals near the plutons. Modified from Bull (1988).

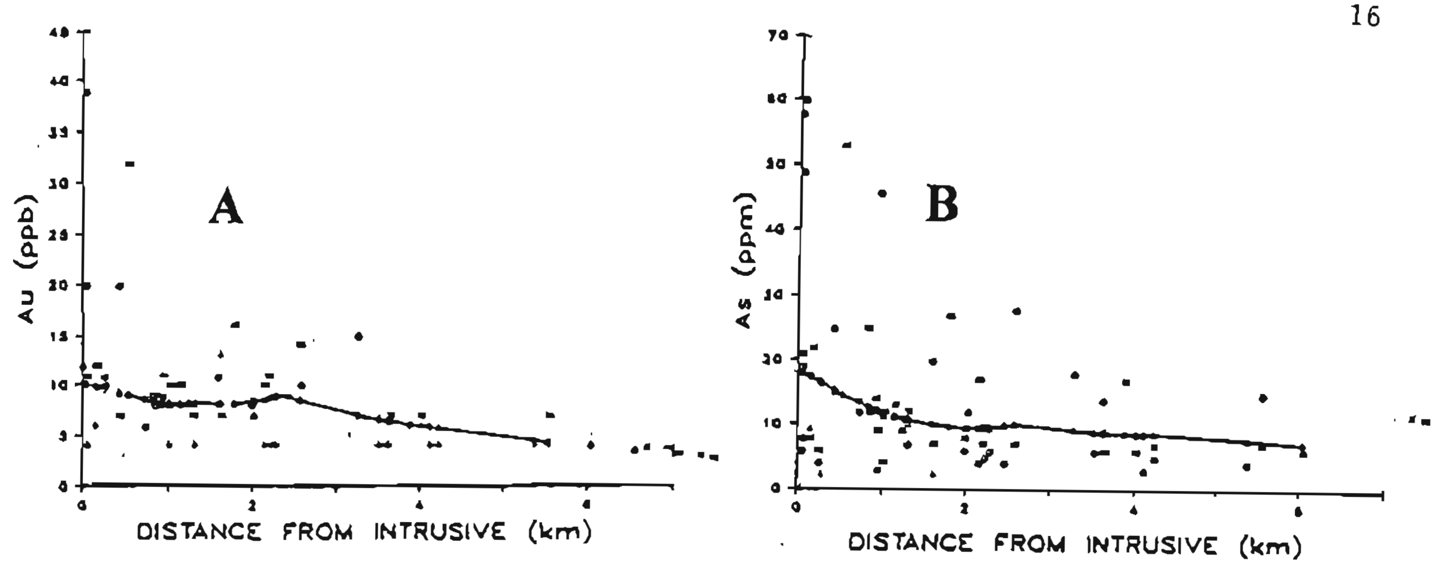


Fig. 18. Raw data and statistically smoothed trends for metal concentrations vs. distance from plutonic rocks [(A)= Au; (B) = As] for sedimentary rocks of the Flat area, SW Alaska. The smoothed trends suggest simple metal enrichment from plutons without significant leaching from sediments. Modified from Bull (1988).

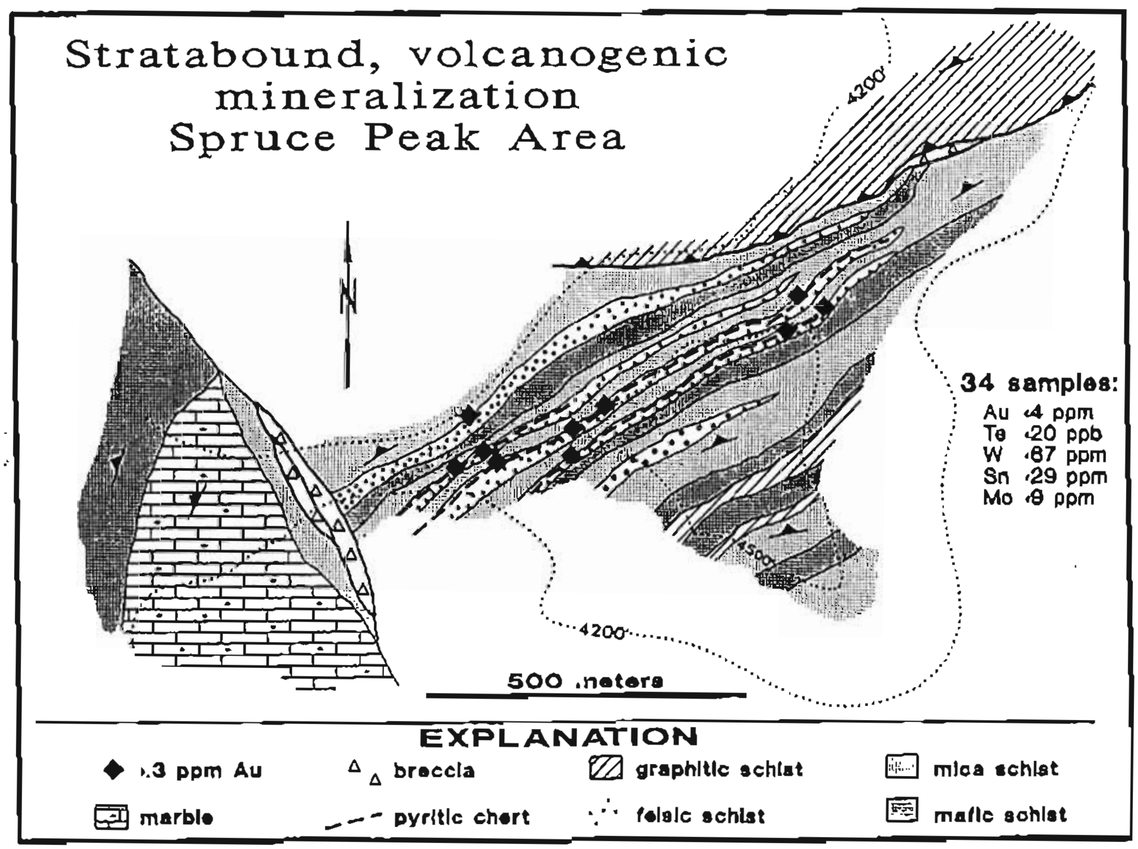


Fig. 19. Simplified geologic plan map of the Spruce Peak area, Kantishna Hills, Denali National Park, showing locations of stratabound Au-As mineralization and average metal concentrations. Modified from Bundtzen (1981) from unpublished field mapping 1989-1990.

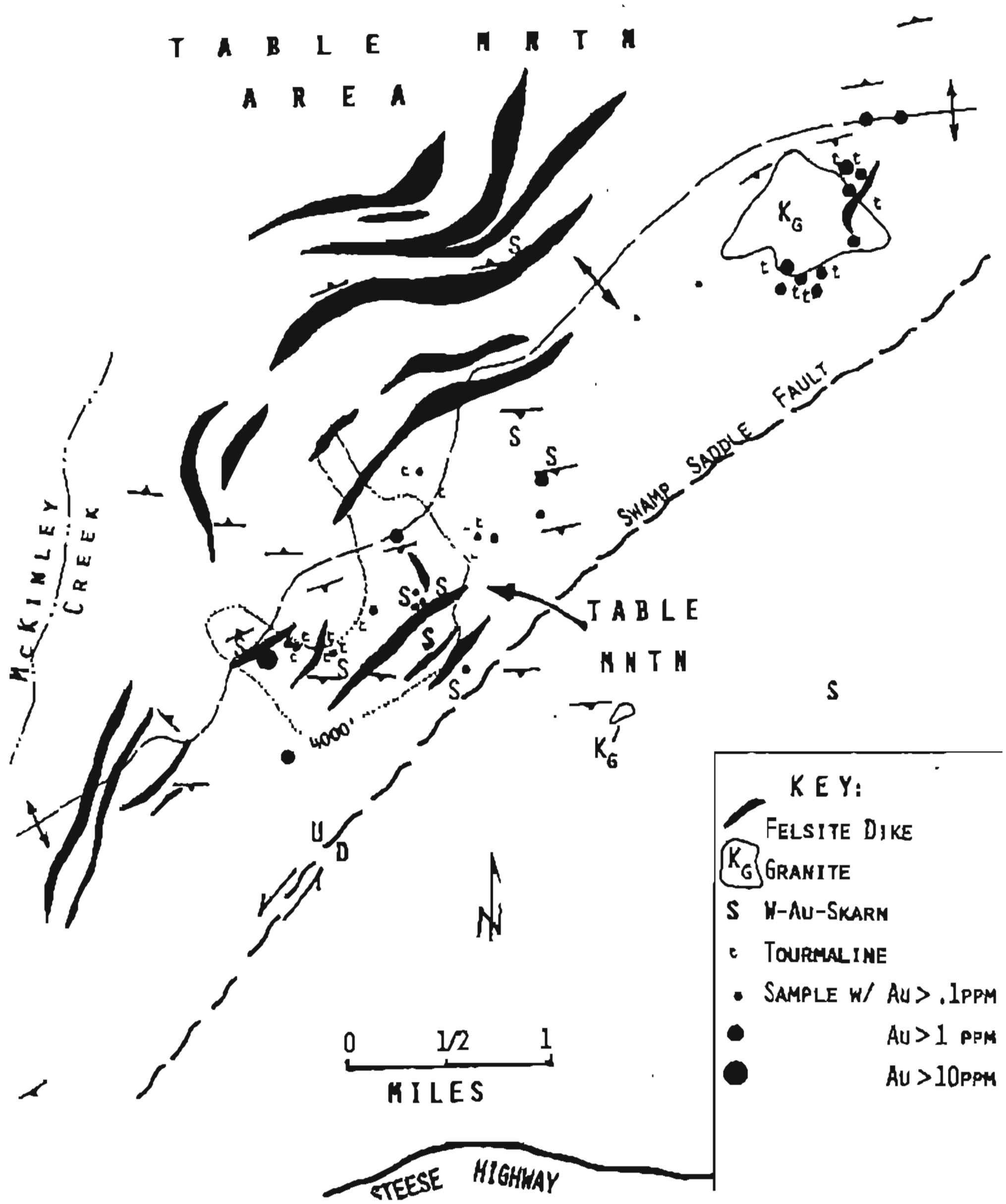


Fig. 20. Simplified plan map of the Table Mountain area, E-central Alaska, showing locations of W-Au skarns, tourmaline alteration, and gold anomalies. Modified from Newberry (1987), Menzie et al. (1987), and unpublished field maps and chemical analyses.

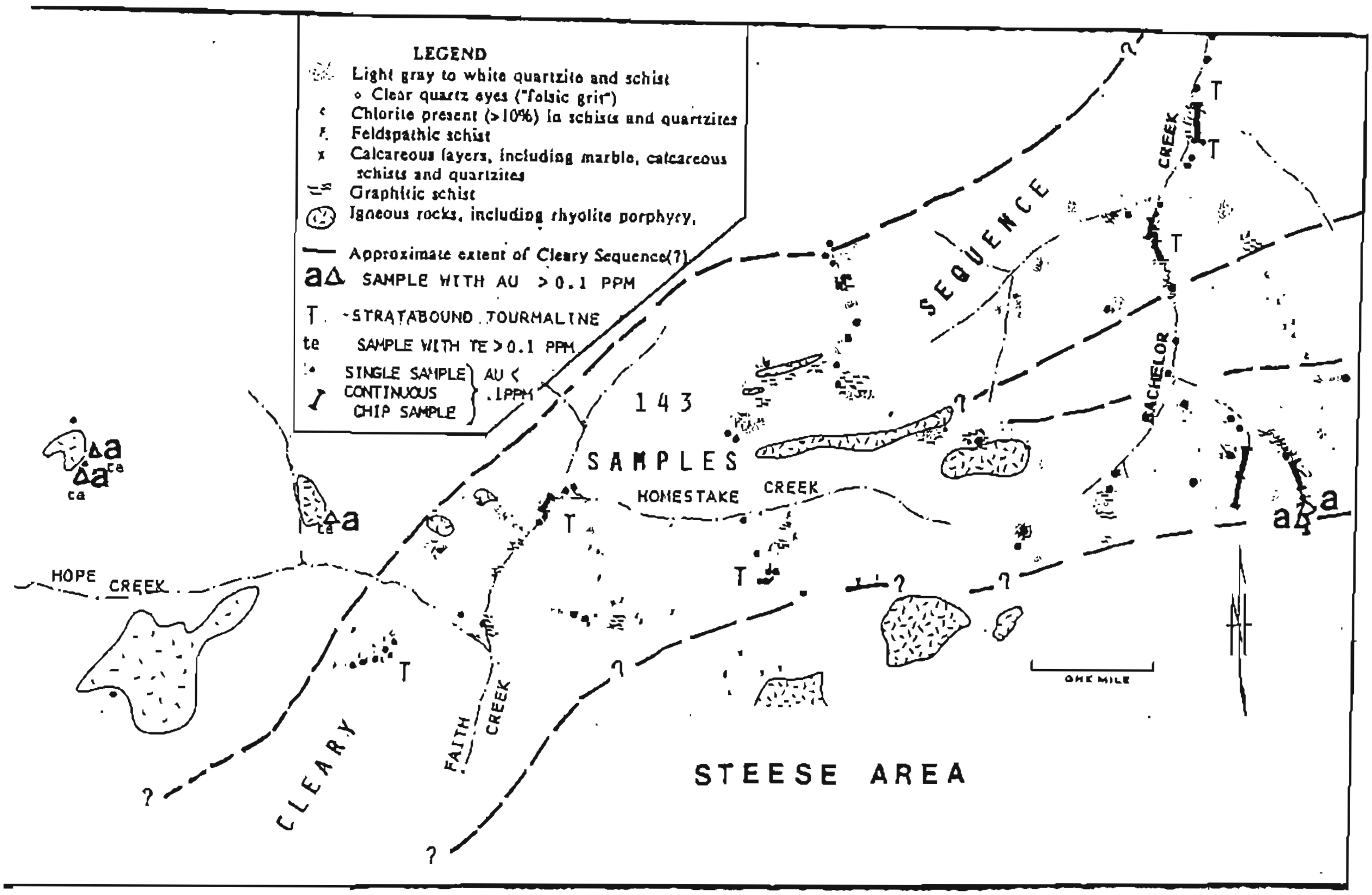


Fig. 21. Simplified map of the Bachelor Creek-Hope Creek area, E-Central Alaska, showing stratabound tourmaline and gold in Cleary Sequence rocks and Au-Te anomalies present with plutonic rocks outside of the Cleary sequence. Modified from Newberry (1987) with data from Clautice (1987).

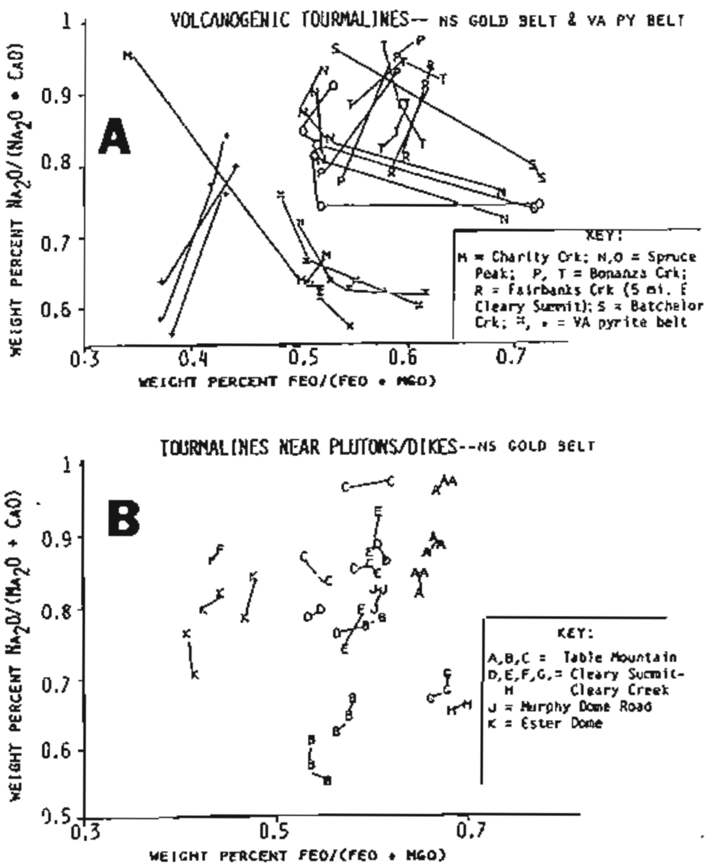


Fig. 22. Microprobe analyses of tourmalines from volcanogenic occurrences (A) and from plutonic-related occurrences (B), showing contrast in chemical zoning patterns for the two. Unpublished microprobe data acquired at Washington State University, Pullman, Wash.

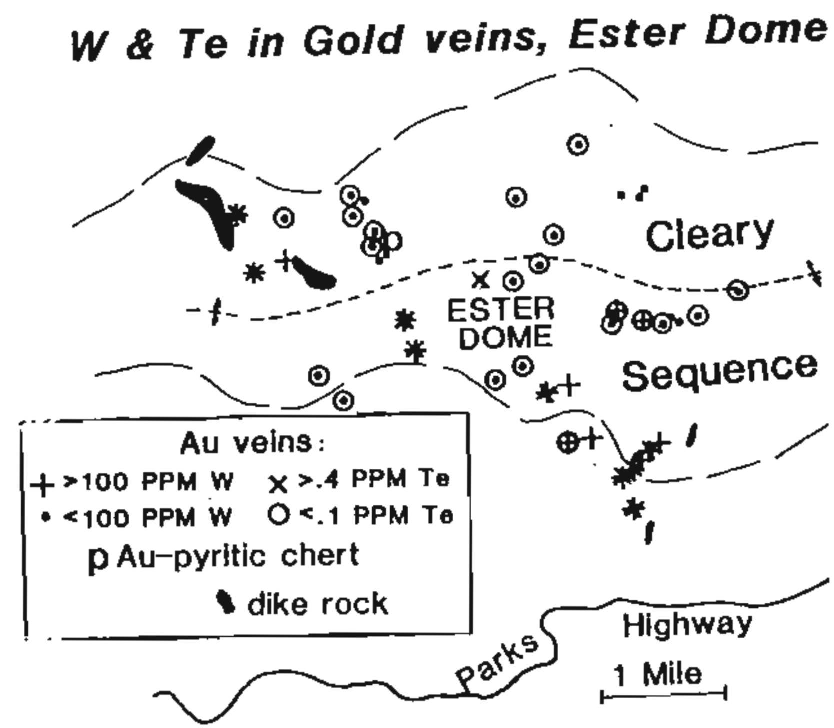


Fig. 23. W and Te concentrations in gold veins near Ester Dome, Fairbanks district, showing high Te-W veins associated with felsic dikes along a NW-trending zone, flanked by zones of low-Te-W veins. Data from Clautice (1987).

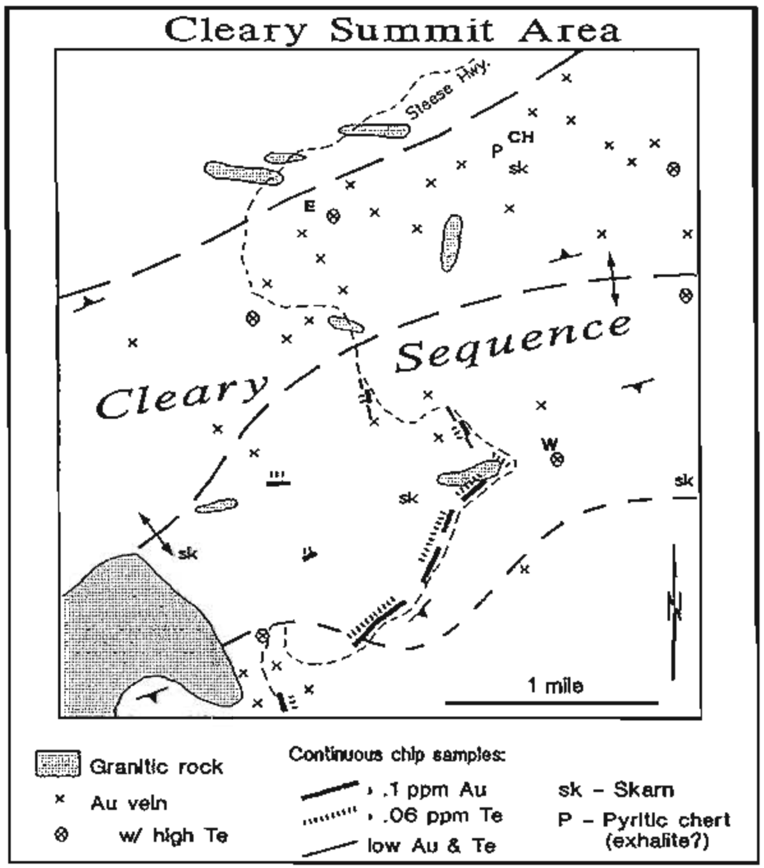


Fig. 24. Te and Au concentrations in rocks and veins, Cleary Summit area, showing systematic association of high Au with Te, suggestive of an igneous-hydrothermal source. Data from Clautice (1987) and unpublished analyses.

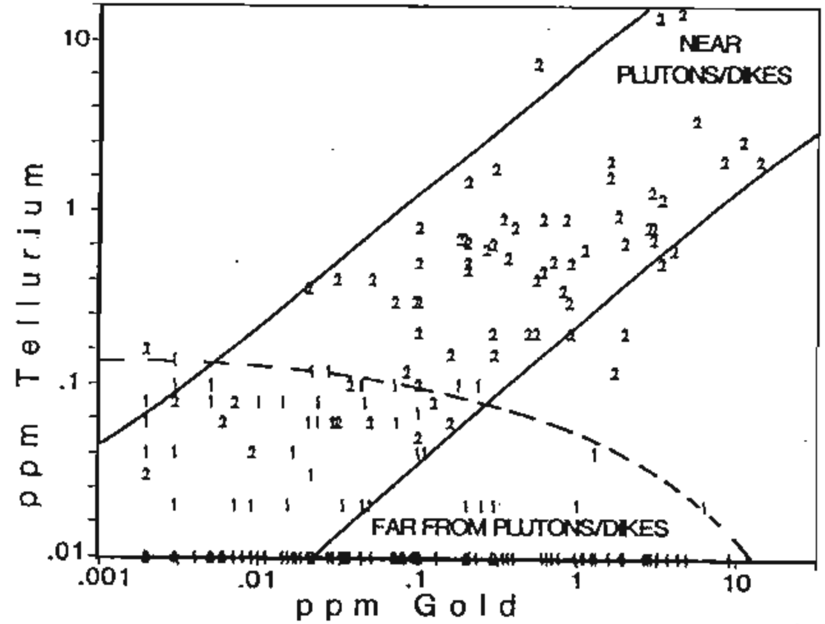


Fig. 25. Concentrations of Te vs. Au for mineralized rocks between Kantishna and Circle, illustrating the occurrence of two types of mineralization--plutonic-related (high Te) and stratabound--low Te. Data from Clautice (1987), Newberry (1987), Allegro (1987), and LeLacheur (1991).

TABLE 5: Characteristics of stratabound vs. pluton-related Au mineralization in and near Cleary Sequence, between Kantishna and Circle (excluding Fairbanks).

"Stratigraphic" Far from plutons, non-vein	Near plutons, in veins
N = 267	N = 38
Te < .1 ppm (96% of values < .02 ppm)	Te = .02 - 7 ppm
W < 50 ppm (97% of values < 4 ppm)	W = 4 - 860 ppm
Au < 1.5 ppm (82% of values < .004	Au = .004 - 3.8 ppm
Zoned tourmalines	Unzoned tourmalines
Minor sericite--fresh feldspars	Abundant sericite--altered feldspars

by high concentrations of Te, W, Bi, and Sb, by unzoned tourmaline, and by abundant sericitic alteration.

Thirdly, mineralogical zoning around the causative pluton/dike swarm is another important aspect of pluton-related deposits. In the Cleary Summit area, for example (Fig. 26), Au-W skarns, sulfosalt-rich deposits, and high Te values are concentrated around a central core of sericite-altered granitic dikes. Arsenopyrite-rich prospects surround this core zone, which are in turn surrounded by Sb-rich, Au-poor veins (Fig. 26). Similar zoning is seen in the Table Mountain area and in the Flat district (Bull, 1988).

Sulfur isotopic data provides one last means of distinguishing pluton-related from syngenetic Au prospects in interior Alaska. Sangster (1980) has shown that volcanogenic sulfur has isotopic values approximately 17 permil lighter than that of ambient seawater, hence average values for syngenetic sulfide can be predicted for a given age rock (Fig. 27). Plotting data from Interior Alaska deposits reveals that stratabound, syngenetic deposits do have significantly different (heavier) sulfur isotopic ratios than do pluton-related prospects (Fig. 28), indicating separate origins. Fairbanks area prospects show a similar pattern (Fig. 29): virtually all the veins and skarns have values of 0 ± 5 permil, in contrast to the 5 to 20 permil values characteristic of nearby volcanogenic deposits.

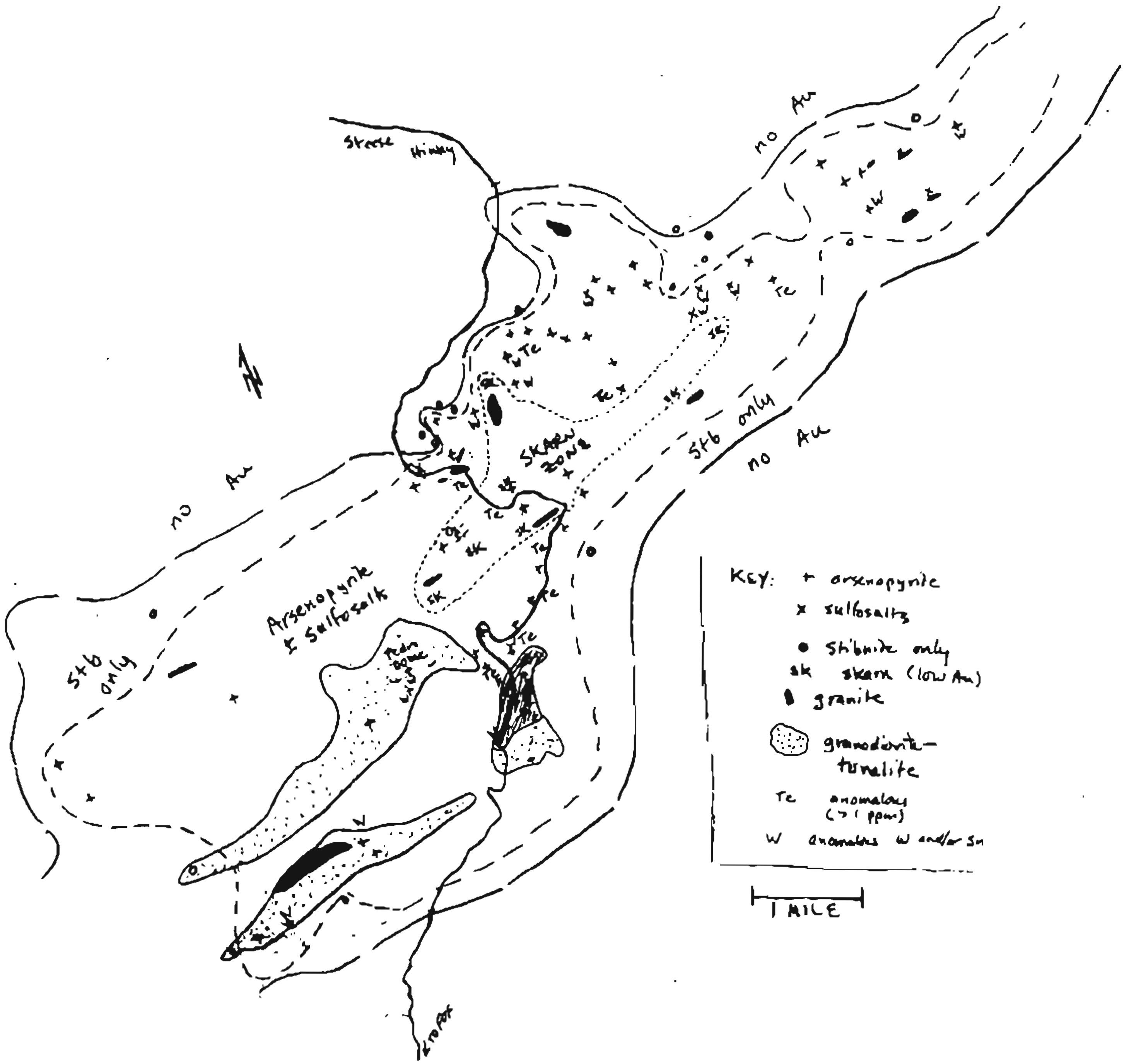


Fig. 26. Sketch map illustrating zoning of mineralization types and minerals, Pedro Dome-Cleary Summit area, Fairbanks district. Data from Sandvik (1964), Chapman and Foster (1969), LeLacheur (1991), and this study.

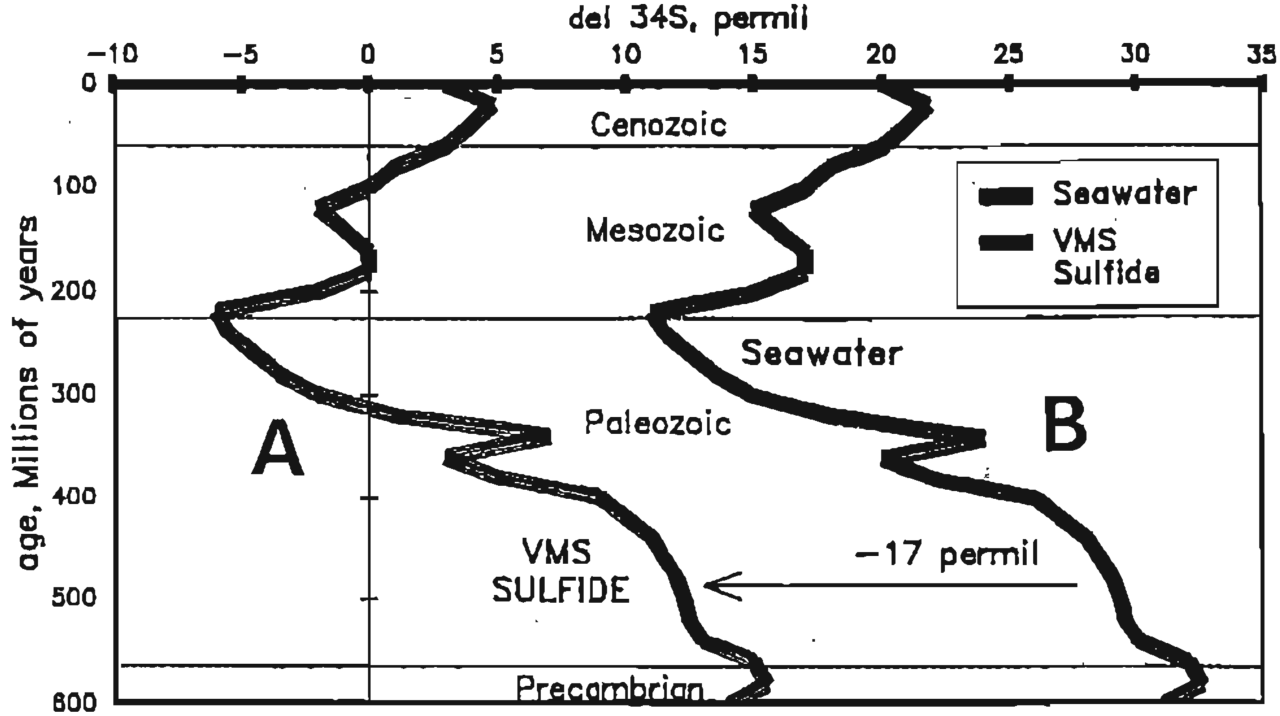


Fig. 27. Variations in sulfur isotope composition of seawater through time (A; from Claypool et al., 1980), and average estimated sulfur isotopic compositions of volcanogenic massive sulfide (VMS) deposits (B) through time, based on Sangster (1980)'s average seawater-VMS difference of 17 permil.

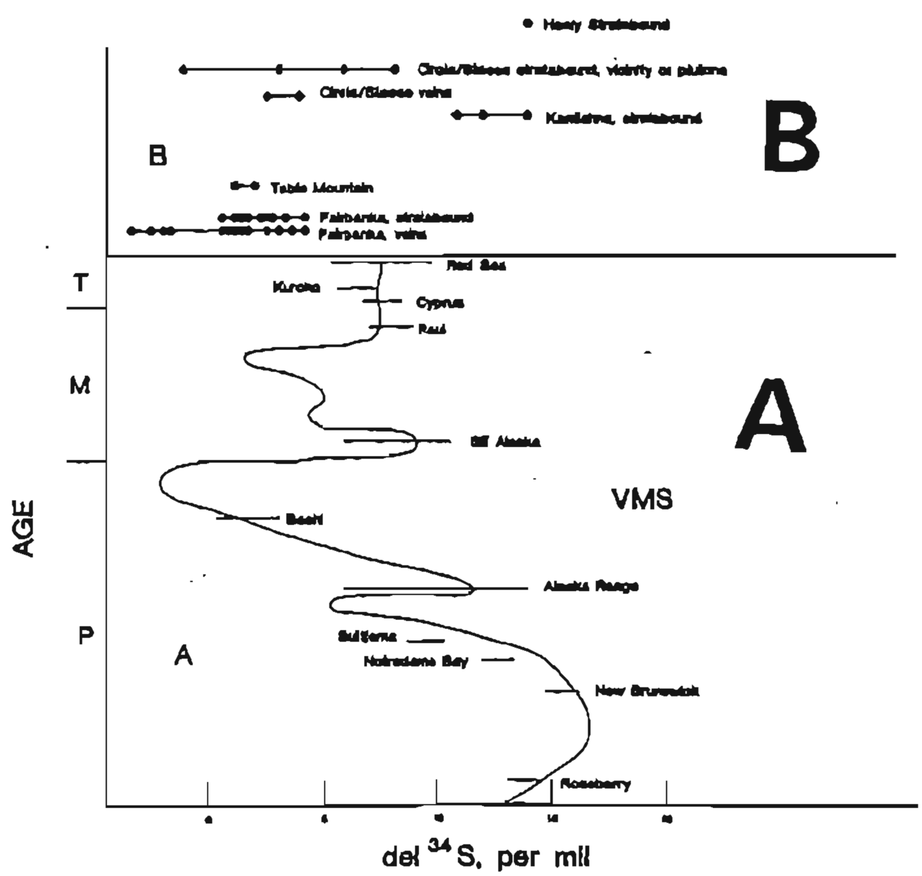


Fig. 28. A. Sulfur isotope ratios vs. time for world-wide VMS deposits superimposed on the model of Fig. 27B, showing good correlation between theory and data. B. Sulfur isotopic variations for interior Alaska deposits. Modified from Newberry and Burns (1988).

III. THE "PORPHYRY" MODEL AND ITS IMPLICATIONS FOR INTERIOR Au

Pluton-related Au deposits in Interior Alaska are both similar to--and different from--other types of plutonic-related deposits. This is best seen by briefly examining the characteristics of these deposit types (Table 6). Common elements (Table 6) include specific plutonic compositions, alteration-mineralization associations, and multiple mineralization types.

World-wide data indicates that porphyry Cu, Mo, and Sn systems can be distinguished by a combination of fractionation and oxidation state parameters (Fig. 30), similar to discriminants developed for prospects in Interior Alaska (Figs. 10-12). The "hole" defined by low oxidation state, little fractionated plutonic rocks (Fig. 30) is apparently filled by pluton-related gold deposits (Fig. 10, 12).

One of the major tenants of the "porphyry" model is that there are two fundamentally different "stages", each with their own alteration-mineralization pattern (Fig. 31). The earlier stage (Fig. 31A) is dominated by plutonic-derived fluids which causes a zoned potassic to propylitic alteration envelope and initial metal deposition. The later stage (Fig. 31B) is dominated by meteoric fluids, which cause sericitic and advanced argillic alteration, and variably-remobilized earlier-deposited metals. In porphyry Cu deposits (Fig. 32A), highest Cu grades are typically present at the sericitic/potassic alteration interface, apparently caused by partial Cu mobilization during sericitic alteration. In porphyry Mo deposits (Fig. 32B), the ore body **is** potassic alteration and sericitic alteration has little effect on the earlier-deposited ores. Finally, in porphyry Sn deposits (Fig. 32C) sericitic alteration completely overprints earlier alteration and ore is restricted to late, through-going veins. Pluton-related Au deposits seem most like porphyry Sn systems, in that sericitic alteration is the most characteristic feature and veins are more characteristic than mineralized stockworks.

Finally, pluton-related systems commonly display a variety of different, but related deposit types, including pluton-hosted veins/stockworks, mineralized pegmatites, country rock-hosted veins, and carbonate-hosted skarns and replacement bodies (Fig. 33). The same pattern of veins + stockworks + skarns/replacements is clearly a feature of Alaskan pluton related deposits (e.g., Figs. 20, 26).

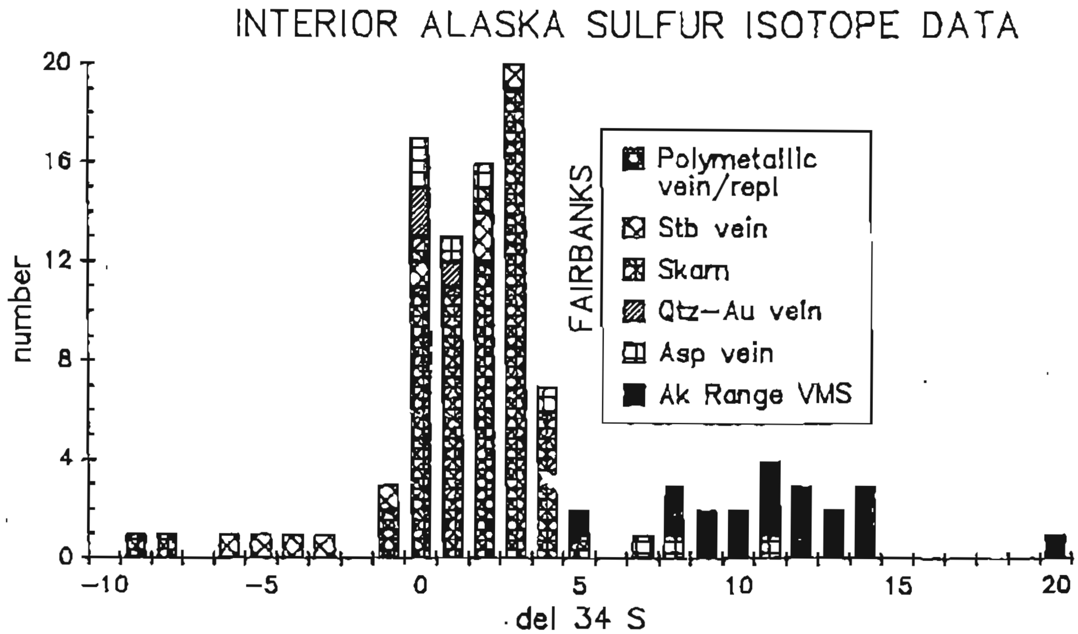


Fig. 29. Summary of S-isotope data, Fairbanks district Alaska, compared to that of Alaska Range VMS deposits. Data from Newberry and Burns (1988), Metz (1991), Lange et al. (1993), and this study.

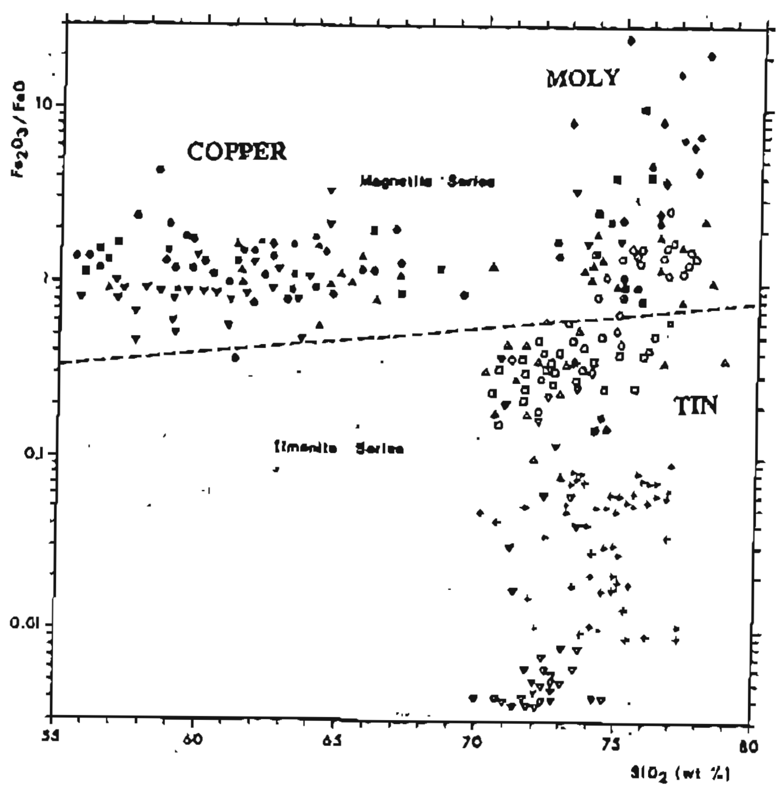


Fig. 30. Compositional differences between plutonic rocks associated with several "porphyry-greisen" type deposits. Modified from Lehmann (1990).

TABLE 6: Significant features of the "Porphyry" Model

1. SPECIFIC PLUTON COMPOSITIONS ⟹ SPECIFIC MINERALIZATION TYPES
   e.g., High Rb, F, ... "tin granite"

2. MULTIPLE INTRUSIONS, ~ SAME AGE, SOME PORPHYRITIC
   e.g., 13 pophyry intrusions at Henderson

3. MULTIPLE, SUPERIMPOSED, ALTERATION ASSOCIATIONS
   early potassic, propylitic; late sericitic, argillic

4. MINERALIZATION VARIABLY REMOBILIZED BY SUCESSIVE ALTERATION EVENTS
   Mo—not much; Cu—some; Sn—lots!!!

5. SEVERAL DIFFERENT TYPES OF MINERALIZATION POSSIBLE FROM ONE SYSTEM
   e.g., pegmatites, plutonic stockwork, external veins, skarn, replacement bodies

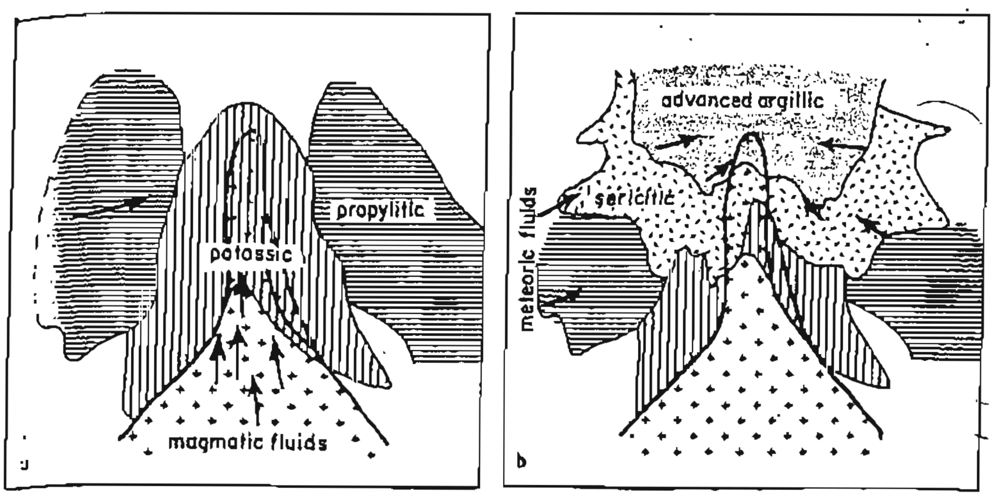


Fig. 31. Hypothesized zoning and fluid evolution in the porphyry deposit model. From Beane and Titley (1981).

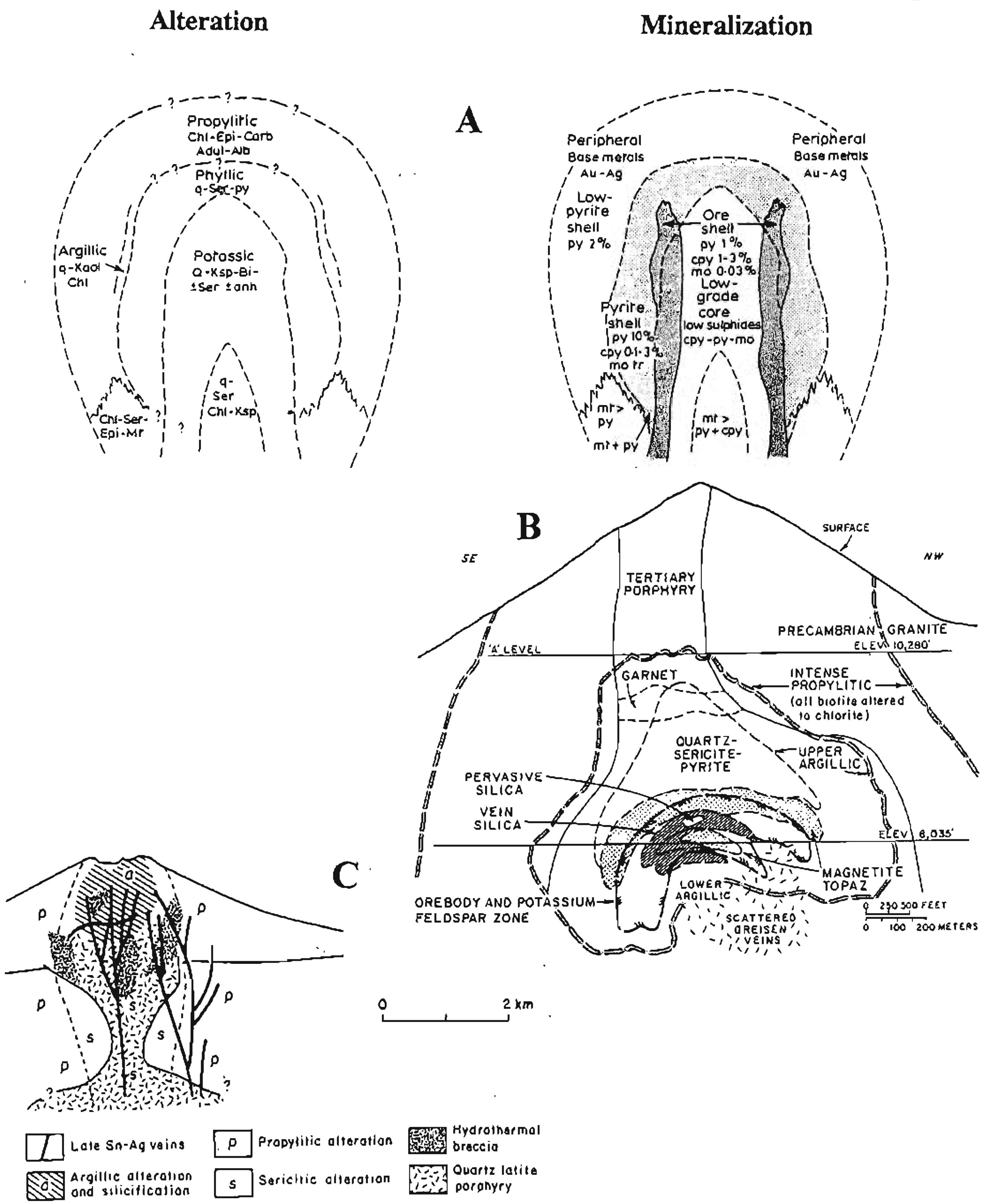


Fig. 32. Alteration-mineralization models for (A) porphyry Cu, (B) porphyry Mo, and (C) porphyry Sn deposits. Modified from Guilbert and Lowell (1974), Grant et al. (1980), and White et al. (1981).

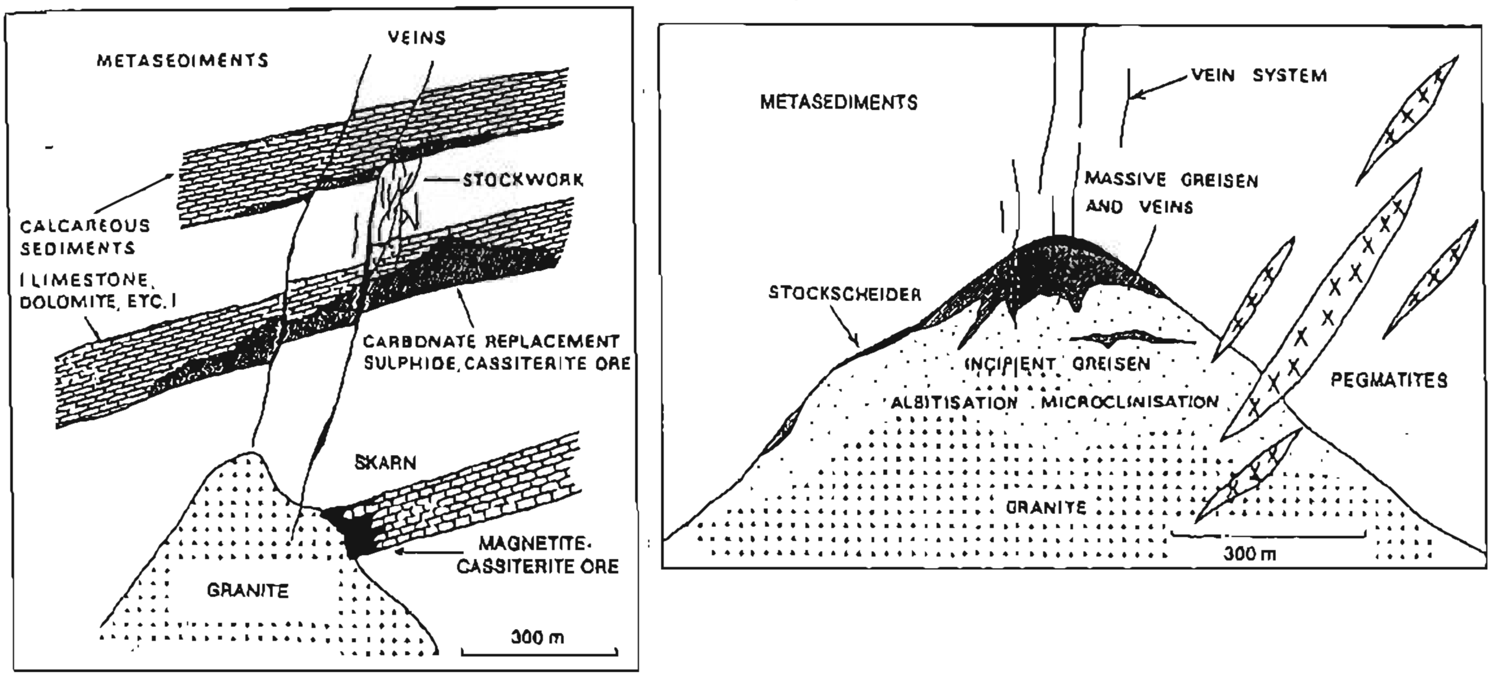


Fig. 33. Multiple settings for mineralization related to tin granites. Modified from Taylor (1979).

IV. INTERIOR ALASKAN PLUTON-HOSTED GOLD DEPOSITS

Au deposits and prospects provisionally identified as pluton-related are present throughout Interior Alaska (Fig. 34), mostly north of the Denali fault system. Overall characteristics of these deposits, including ages, depths, alteration, and trace element chemistry, are summarized in Table 7.

Depths of formation of Alaskan pluton-related gold deposits vary considerably (Fig. 35) as indicated by aplite geobarometry (Fig. 11) and geologic reconstructions (e.g., Bull, 1988). Deeper systems, such as Fort Knox, formed at pressures in excess of 1 kb; shallower systems are sub-volcanic in nature an formed at pressures <300 bars. Within the Fairbanks district, pressures of formation vary from the pluton-hosted Fort Knox system to the veins above plutons on Ester Dome (Fig. 35). The implication is that pluton-hosted gold deposits are as variable as granite-related Sn deposits (Figs. 32C, 33) in terms of their environment of formation. The contrasting environments are illustrated for Livengood (Fig. 36), Granite Creek (Fig. 37), Flat (Fig. 38), Liberty Bell (Fig. 39), Black Mountain (Fig. 40), and Golden Zone (Fig. 41). Of these, Black Mountain appears to be a deeper system; the others, characterized by dike swarms and small plugs, breccias, and co-genetic volcanics, are shallower.

Alaskan pluton-related gold systems also vary in their compositional and isotopic signatures. Initial Sr ratios vary from .705 to .713 (Fig. 42) indicating a range of melt sources from strictly subduction-related (low values) to significantly contaminated with continental material (high values). Major element compositions similarly range from diorite to granite and practically everything in-between (Fig. 43), the essential characteristic being a combination of low oxidation state and elevated alkalinity (Fig. 45). Major element compositions indicate two different plutonic trends (Fig. 44): one, dominated by granodiorite to granite (seen in E-Interior Alaska), the other dominated by diorite to quartz syenite (characteristic of SW Alaska). Both seem equally favorable trends.

Low pluton oxidation state is apparently a pre-requisite to effective concentration of gold in a magma, as illustrated by the comparison between Flat (Fig. 46A) and Chugach (Fig. 46B) plutons. The former, magnetite-absent plutons, show an enrichment in Au with fractionation (silica content); the latter, magnetite-rich plutons, show a depletion in Au with fractionation. The role of magnetite in Au melt concentration is diagramatically illustrated by Fig. 47. Clearly, one important implication is that Au-favorable plutons should be characterized as magnetically flat or low terranes; Au-unfavorable plutons characterized as magnetic anomalies. Regionally, Interior Alaskan plutons characterized by low oxidation states are commonly surrounded by gold placers (Fig. 48), testifying to the relationship between pluton and gold.

One of the key characteristics of Alaskan pluton-related gold is the overlap in K-Ar age between pluton and gold-related veining/alteration (Table 8). All systems dated thus far show alteration-mineralization ages to be within 1 Ma of host pluton age--i.e., essentially contemporaneous. This is in marked contrast to

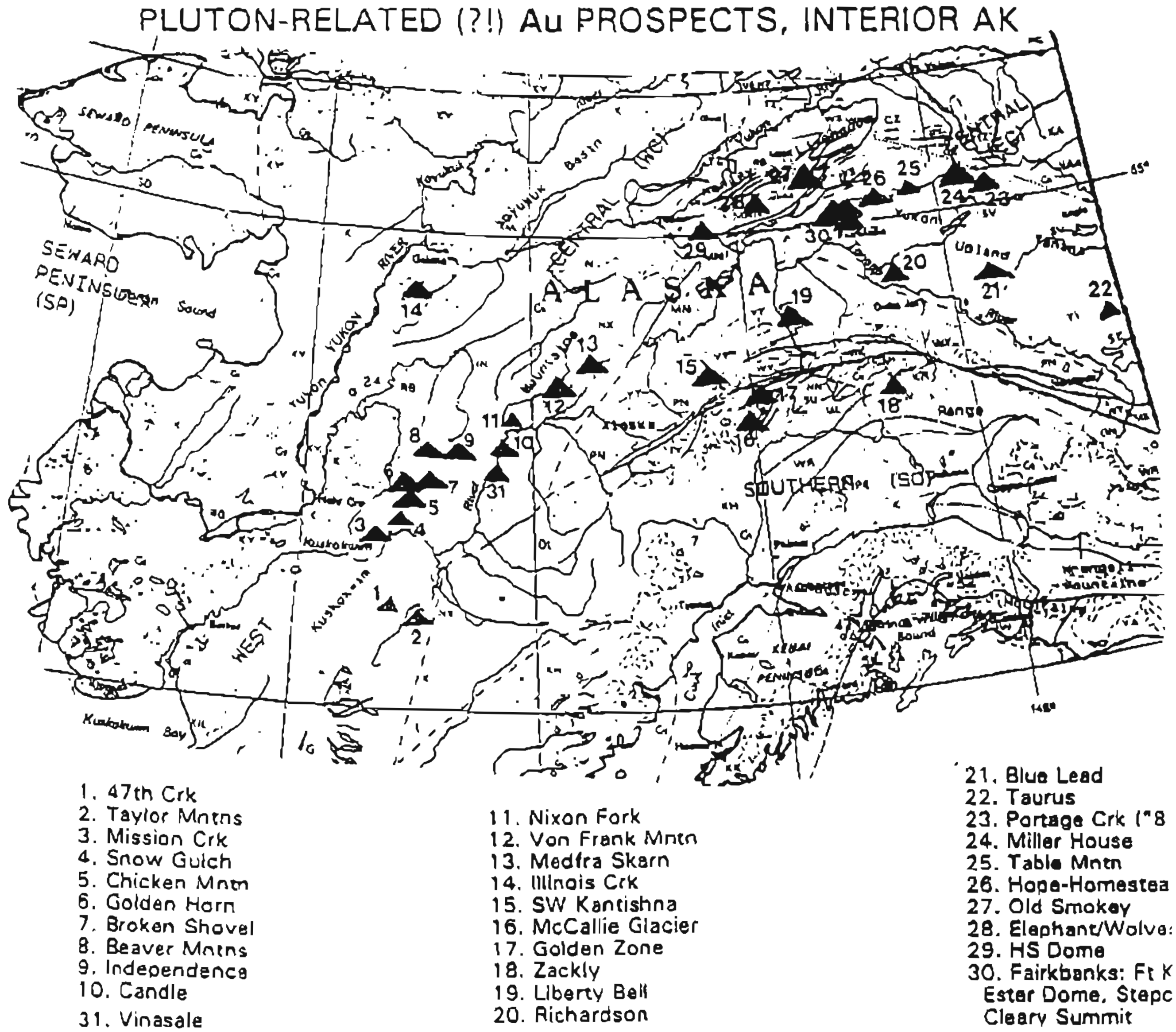


Fig. 34. Locations of hypothesized pluton-related Au deposits, Interior Alaska. Modified from Nokleberg et al. (1987), with data from Allegro (1984), Newberry (1987), Metz (1991), and Szumigala (1993).

TABLE 7: CHARACTERISTICS OF ALASKAN PLUTON-RELATED GOLD DEPOSITS

1. DEPTH: *It varies alot !!!*

sub-volcanic ==> stock w/ breccia pipe ==> stock, no breccia ==> top of batholith.
(< 1/2 kb) (~1.5 kb)

2. TECTONIC SETTING: *also varies??*

CONTINENTAL + ISLAND arc?? rifted arc??? rift??

3. PLUTON COMPOSITIONS/TEXTURES

DIORITE <==> GRANITE (GRANODIORITE MOST COMMON)
MULTIPLE COMPOSITION SUITES ARE VERY COMMON
QUARTZ-RICH, QUARTZ-POOR, AND /OR QUARTZ ABSENT ROCKS PRESENT
some granodiorite or monzodiorite or quartz monzodiorite porphyry is typical-

LOW (primary) MAGNETITE CONTENT!!!!..

4. PLUTON / ALTERATION K/Ar AGES

~ 100 Ma (Liberty Bell) to ~68 Ma (Golden Zone, Flat, ...)
sericitic alteration age = biotite/hornblend pluton age +/- ~2 Ma

5. ALTERATION TYPES/DISTRIBUTION

"POTASSIC" AND/OR "FELDSPATHIC" (minor & early)
SECONDARY BIOTITE (mafic rocks) +/- CALCITE
SECONDARY K-FELDSPAR AND/OR ALBITE +/- CALCITE

SERICITIC / PHYLLIC (MAJOR AND WIDESPREAD!!)
MUSCOVITE - CALCITE +/- ARSENOPYRITE +/- TOURMALINE
((most of the mineralization is associated with this alteration))

PROPYLITIC (widespread and diffuse)
CHLORITE–EPIDOTE–CALCITE (PYRITE)

ARGILLIC (widespread???)
LOCAL (HYPOGENE) KAOLINITE; MOSTLY (SUPERGENE???) SLIME .

6. LOCALIZATION OF MINERALIZATION
PREDOMINANTLY SHEAR ZONES, LARGE VEINS, AND BRECCIA BODIES

7. ELEMENTAL ANOMALIES (rough numbers, parts per million)

Te (.x-x) Bi (x) As (x-1000x Sb (x-100x)
+/- Sn (x-100x) W (x-100x) Mo (x-100x) Cu (x-1000x)

8. SULFIDE MINERALS
ARSENOPYRITE, PYRITE BISMUTHENITE, STIBNITE, Tetradymite
Molybdenite, Pyrrhotite, Stannite, Scheelite

LOW OXIDATION STATE –LOW SULFIDATION STATE
((follows the low plutonic oxidation state))

9. "TYPES"

A. HIGH-SUFIDE "porphyry As Deposits"
abundant very fine Au in arsenopyrite—difficult beneficintion
ASSOCIATED WITH HIGH-Cl BIOTITES
A. LOW-SULFIDE --"porphyry Au"
mostly native Au; minor Bi, Te
ASSOCIATED WITH LOW-Cl BIOTITES
(multiple fluid evolution events???)

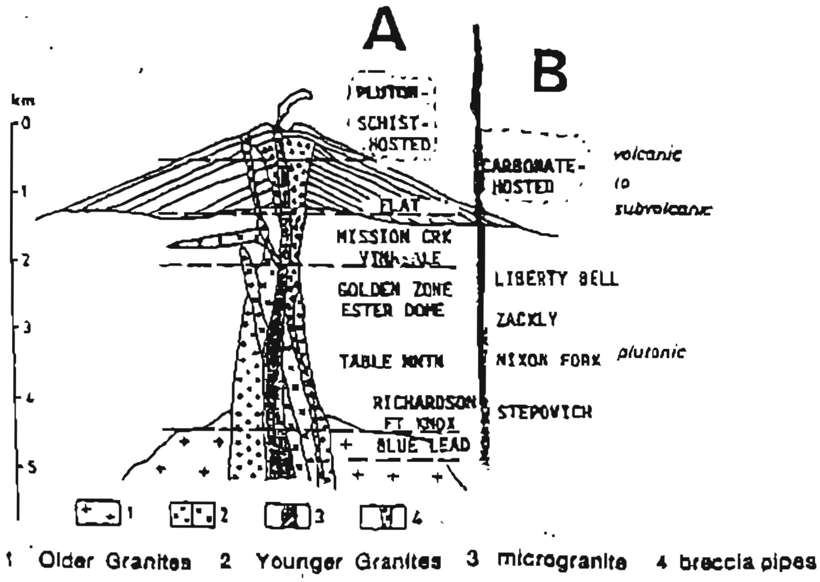


Fig. 35. Proposed structural settings and erosional levels for some pluton-related gold deposits of Alaska: (A) pluton & schist-hosted, (B) Carbonate-hosted. Depths of formation estimated from geologic reconstructions, fluid inclusion data, and aplite geobarometry (Fig. 11), from Bull (1988), Newberry et al. (1990), Hawley and Clark (1974), DiMarchi (1993), Menzie et al. (1987), Szumigala (1993), and Yesilyurt (1994).

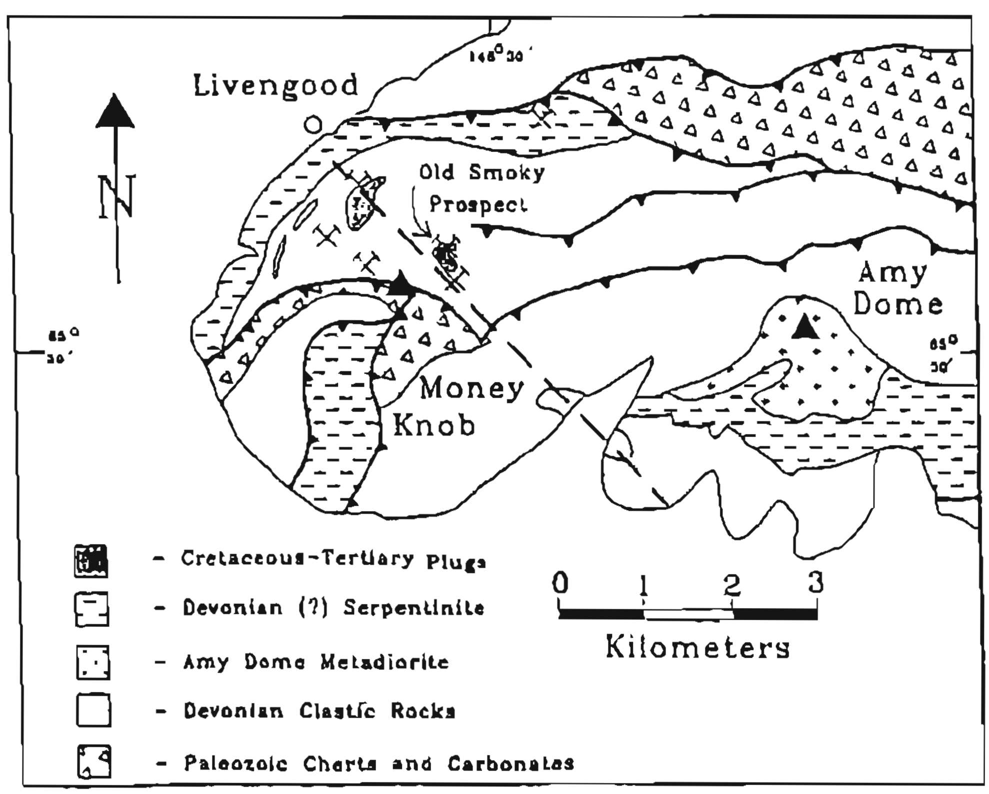


Fig. 36. Geologic map of the Livengood placer district, interior Alaska, from LeLacheur (1991).

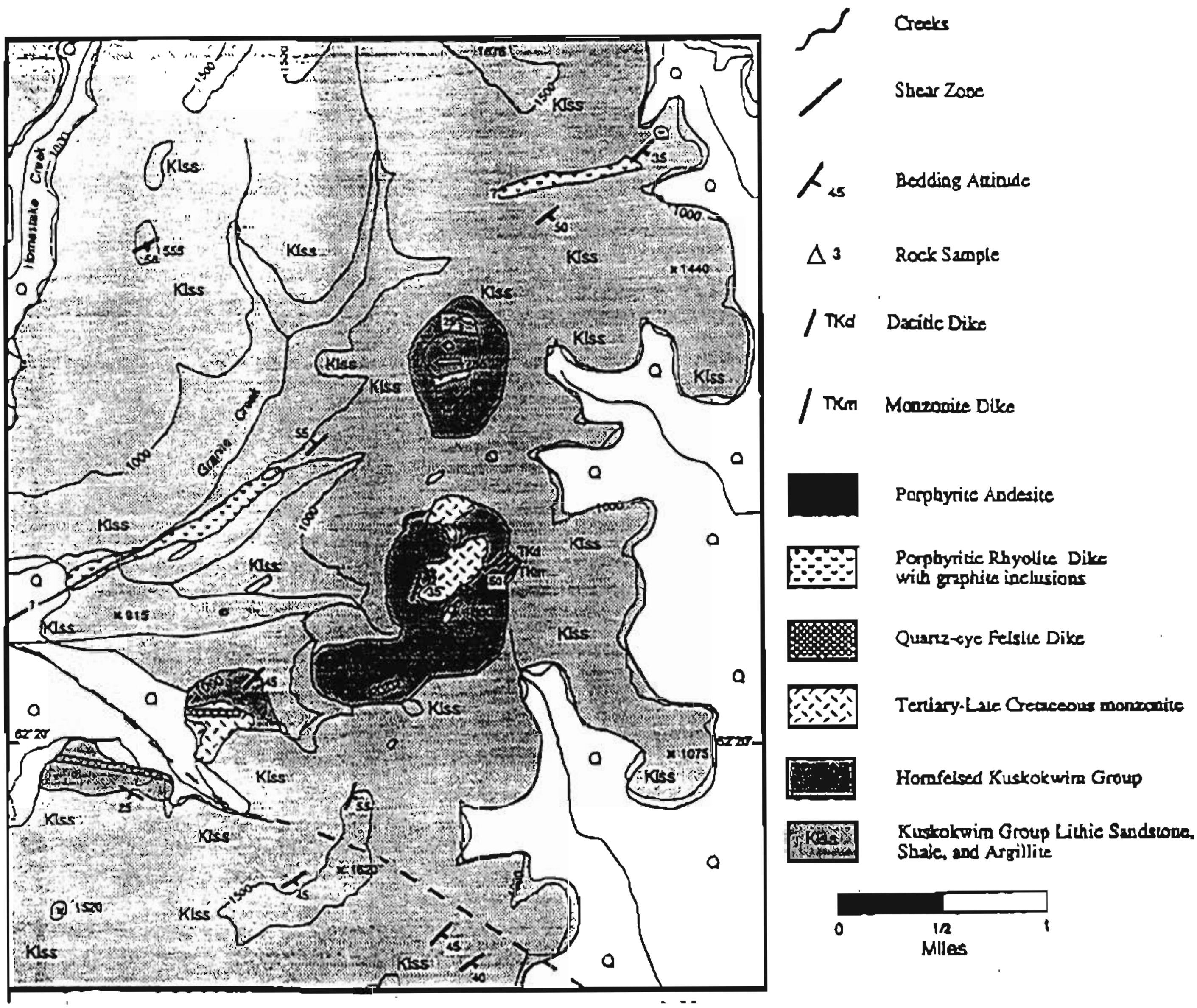
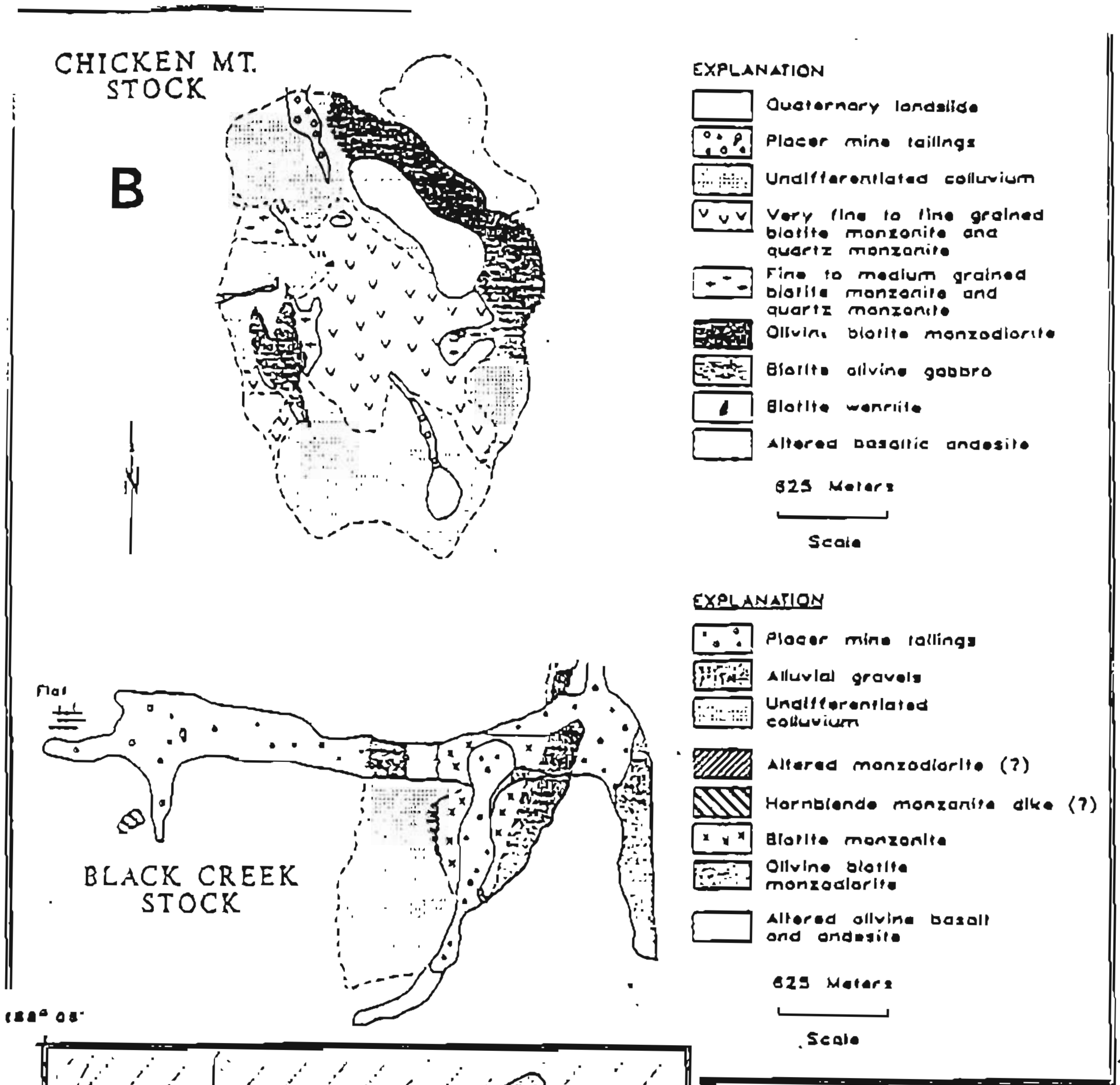


Fig. 37. Geologic map of the granite creek area, SW Alaska, From Szumigala (1993).



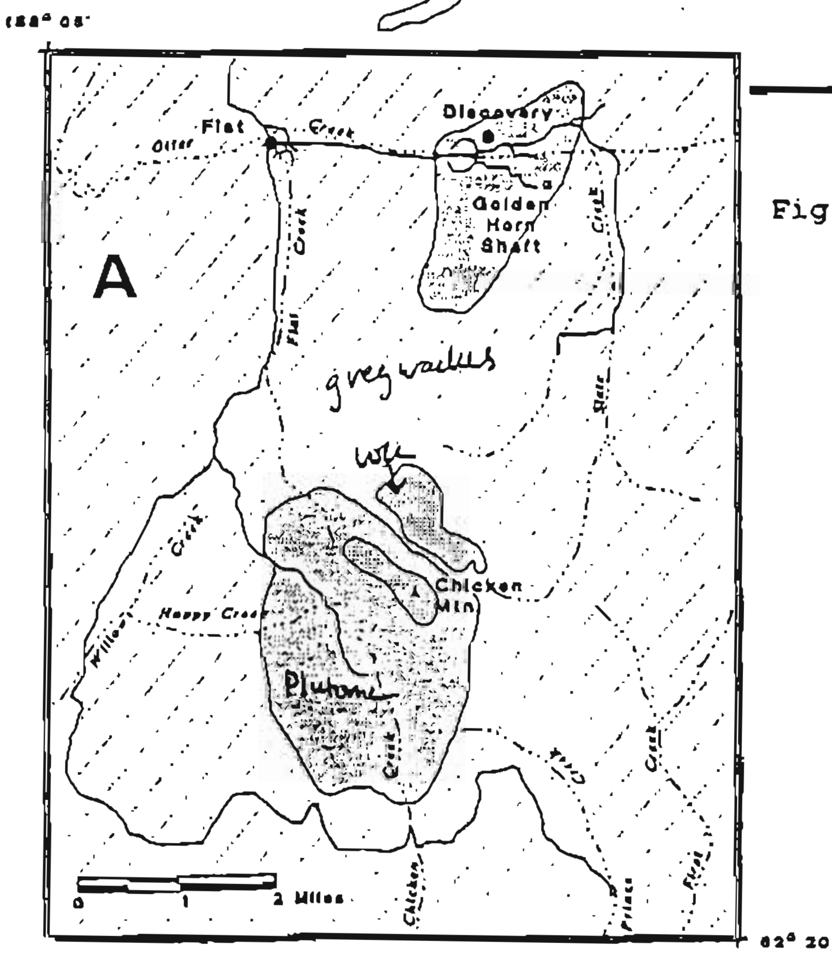


Fig. 38. Simplified (A) and detailed geologic maps of the Flat area, SW Alaska, from Bull (1988).

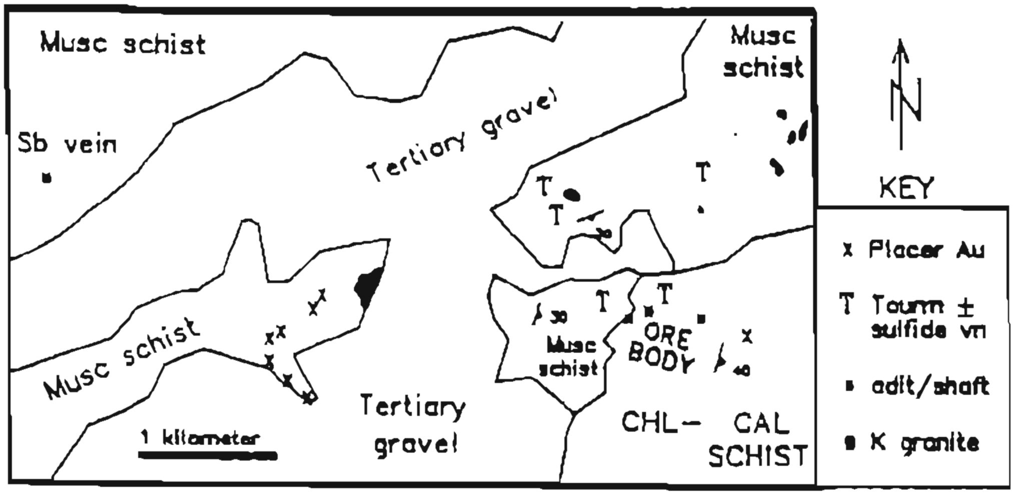


Fig. 39. Geologic sketch map of the Liberty Bell area, N-central Alaska range. Modified from Moffit (1933) and Gilbert and Bundtzen (1979) from unpublished field maps.

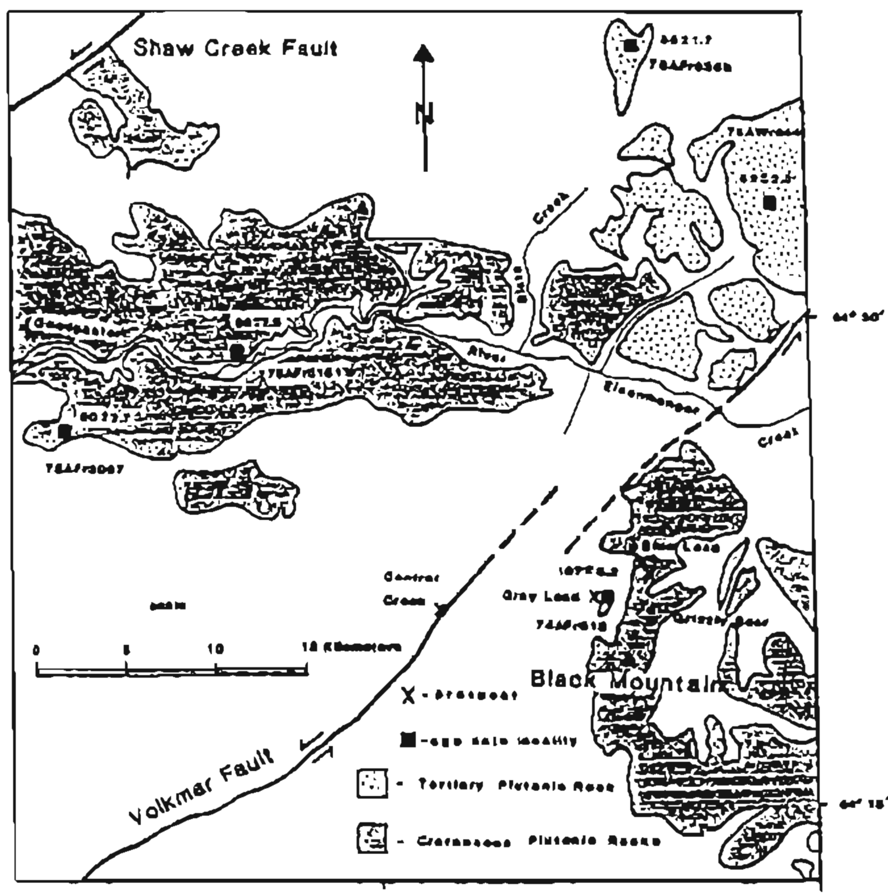


Fig. 40. Simplified geologic map of the Black Mountain district, E-Central Alaska, from LeLacheur (1991).

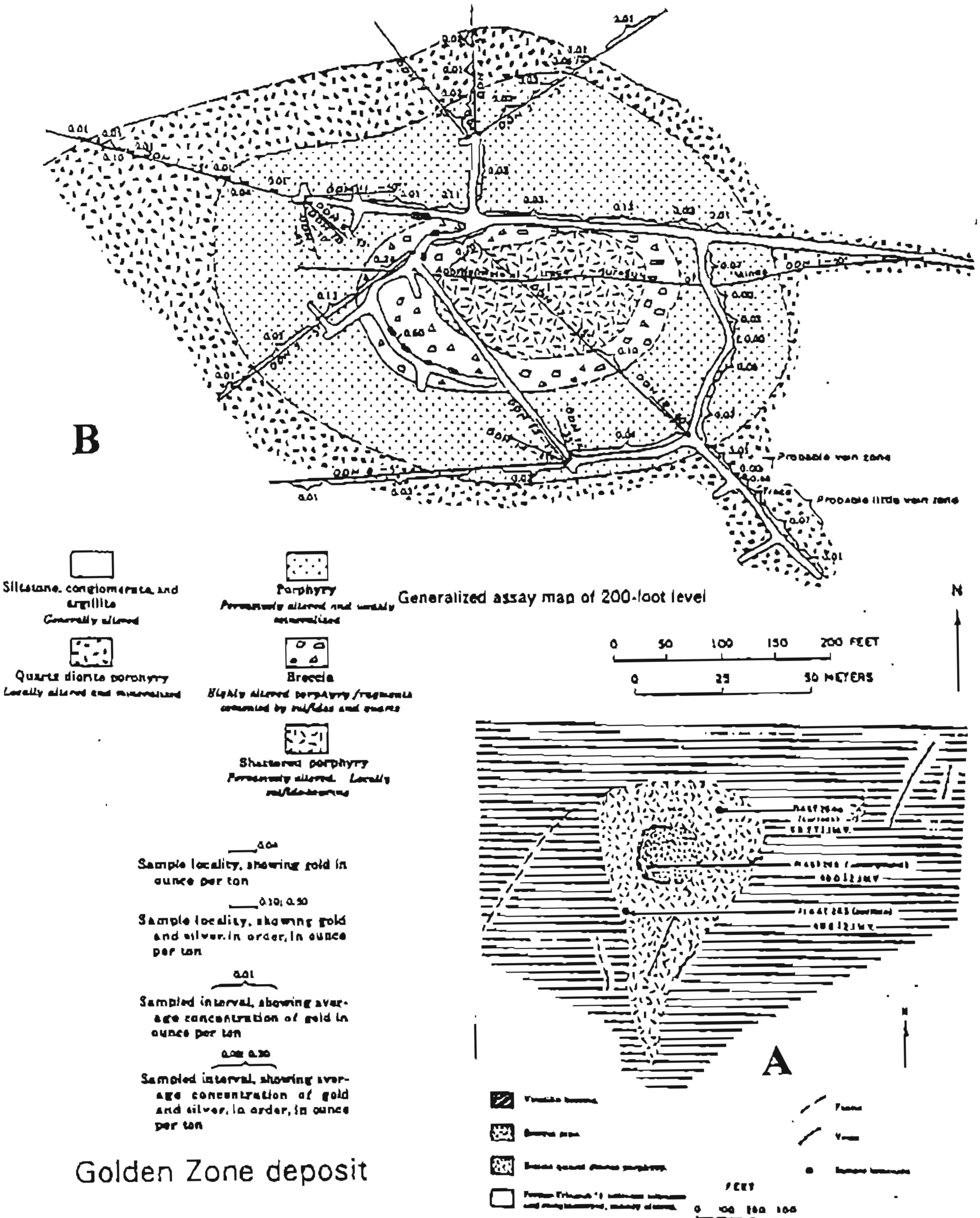


Fig. 41. Generalized (A, from Swainbank et al., 1977) and detailed (B, from Hawley and Clark, 1974) maps of the Golden Zone deposit, S-Central Alaska Range.

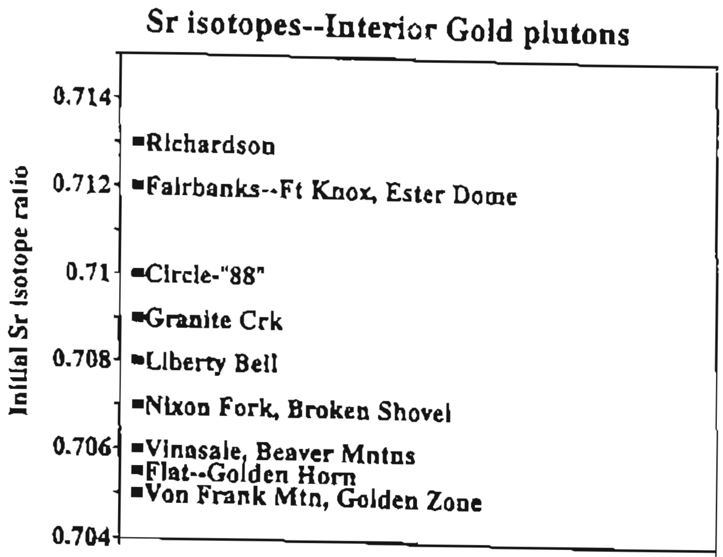


Fig. 42. Initial Sr isotopic ratios for plutons associated with gold deposits, Interior Alaska. Data from Blum (1982), Metz (1991), Szumigala (1993), and this study.

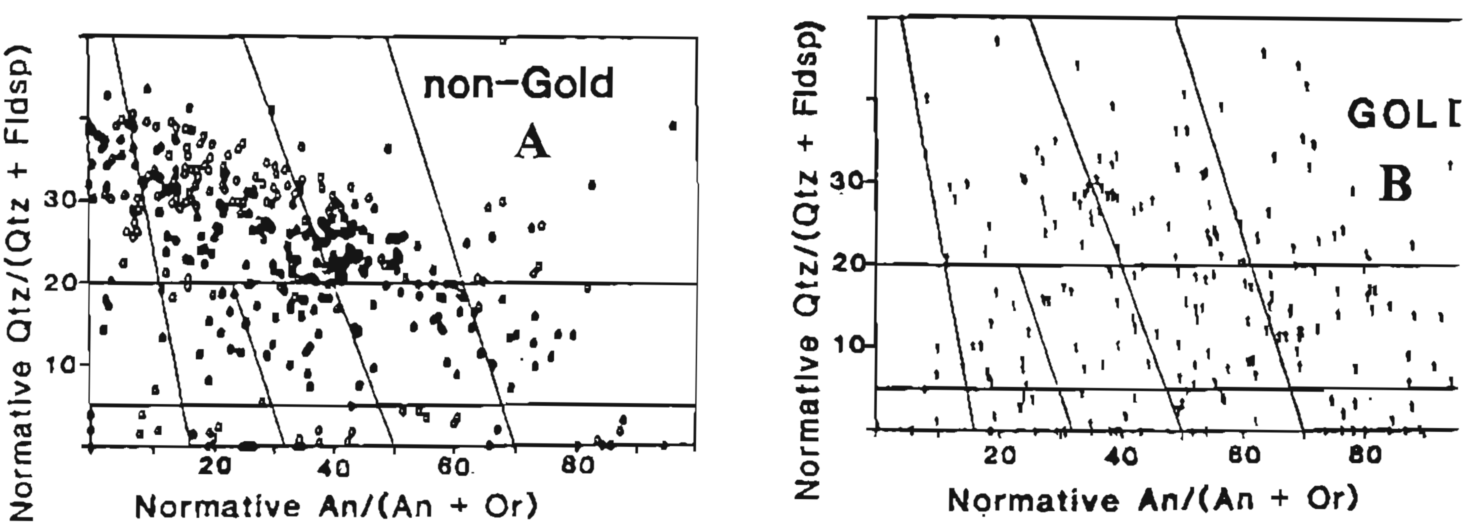


Fig. 43. Compositional contrast (normative data) for plutons (A) not-associated and (B) associated with lode and/or placer gold, Interior Alaska. Data from Burns et al. (1991a).

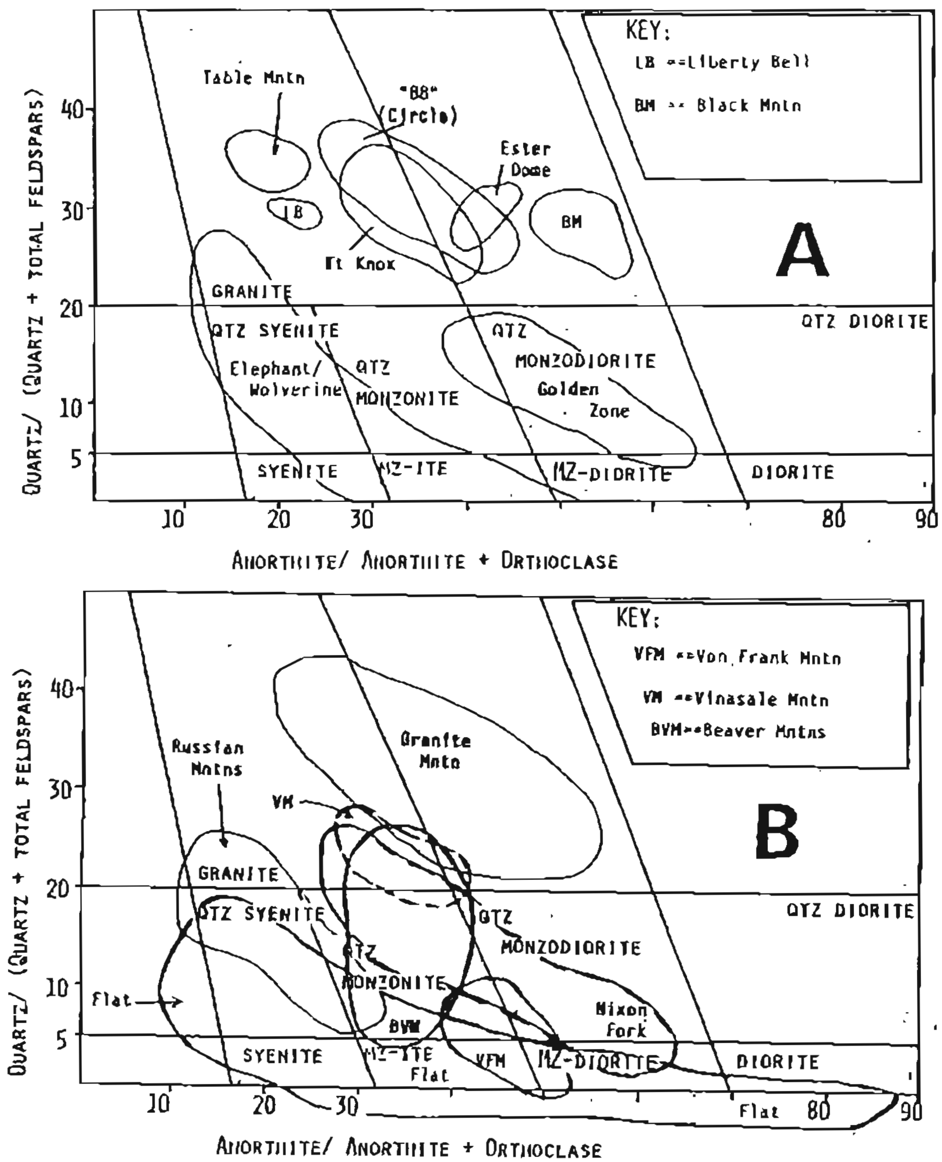


Fig. 44. Ranges in normative composition for plutons associated with lode gold mineralization, (A) Interior Alaska and (B) SW Alaska. Data from Bull (1988), Burns et al. (1991a), Szumigala (1993), Newberry et al. (1994), and unpublished chemical analyses.

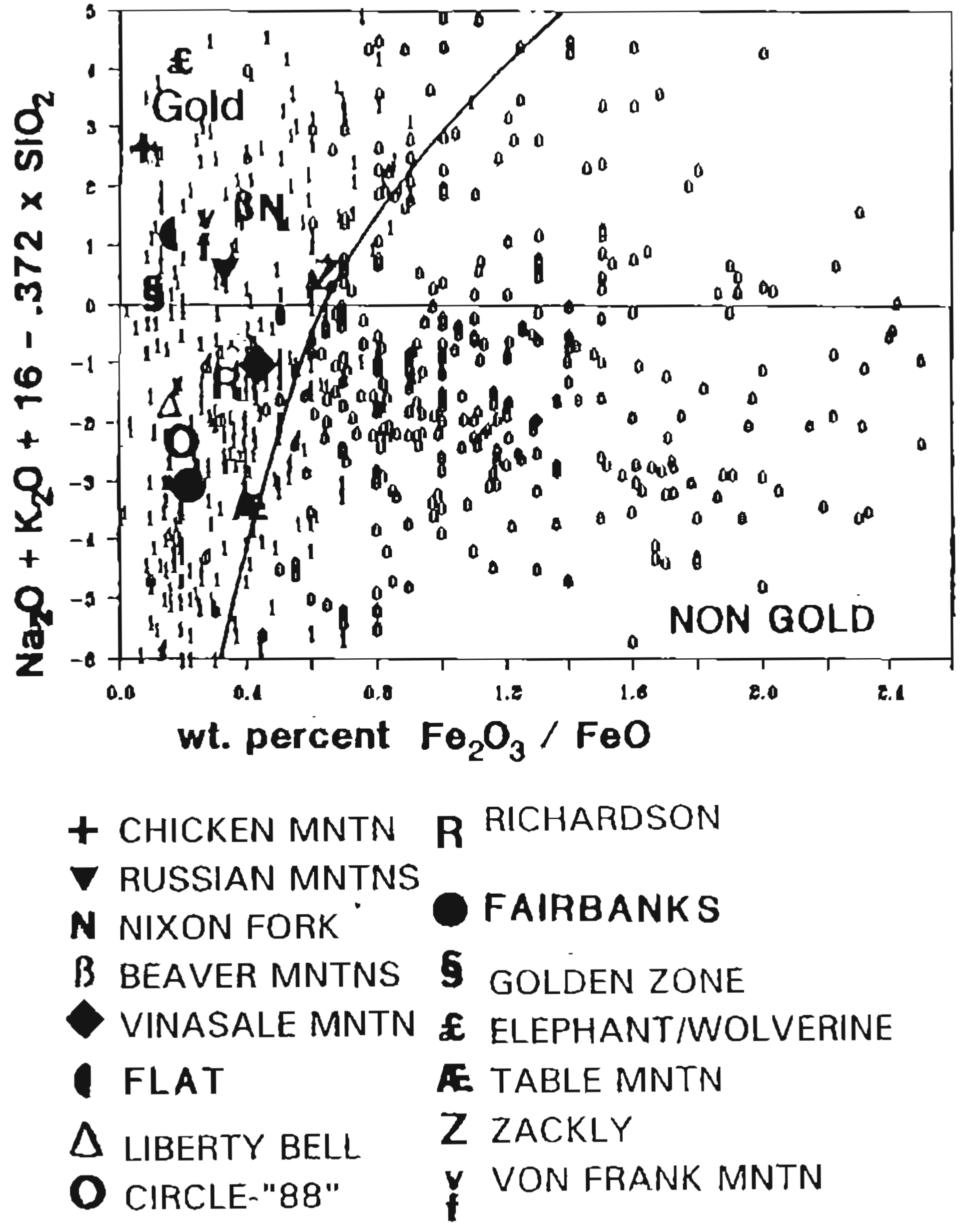


Fig. 45. Alkalinity parameter vs. redox ratio for plutonic rocks from world-wide occurrences, associated with (1) and not associated with (0) lode gold deposits (data from Burns et al., 1991) and for gold-related plutons from Interior and SW Alaska. Sources of data as in Fig. 44.

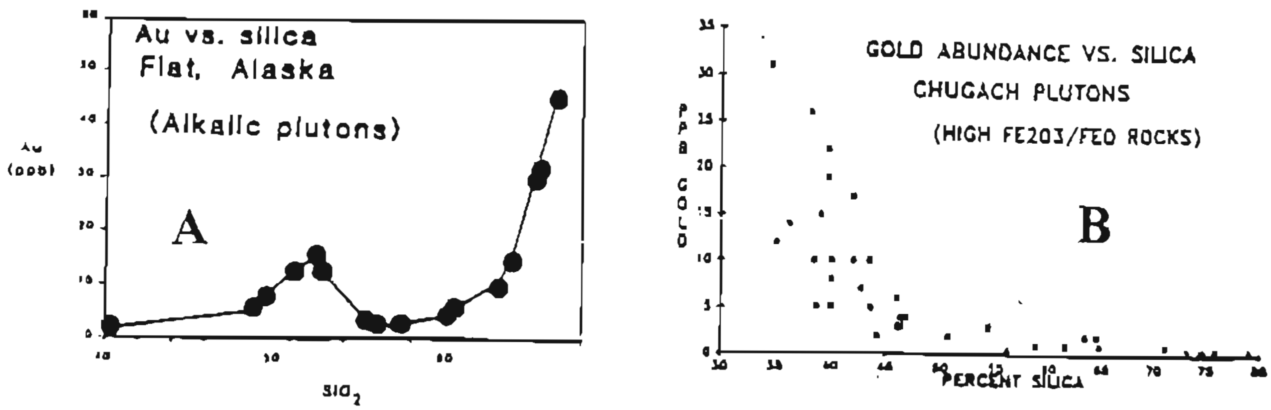


Fig. 46. Comparison of gold concentrations vs. silica content of host pluton for unaltered plutonic rocks of (A) the gold-bearing Flat district, and (B) the gold-absent Chugach Mountains. Data from Bull (1988), Newberry (1986), Foley et al. (1988), Burns et al. (1991b) and unpublished data.

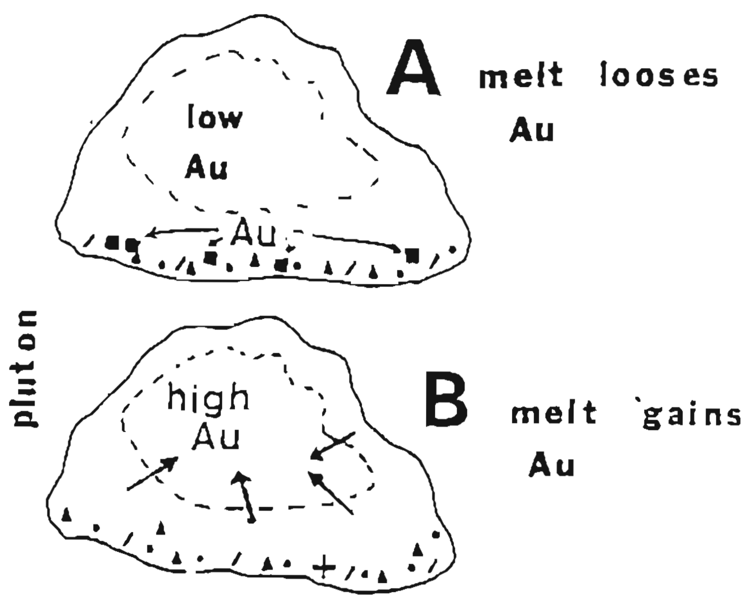


Fig. 47. Models for depletion (A) vs. enrichment (B) of gold in silicate melt during fractional crystallization, due to the presence (A) vs. absence (B) of magmatic magnetite (symbolized as filled squares).

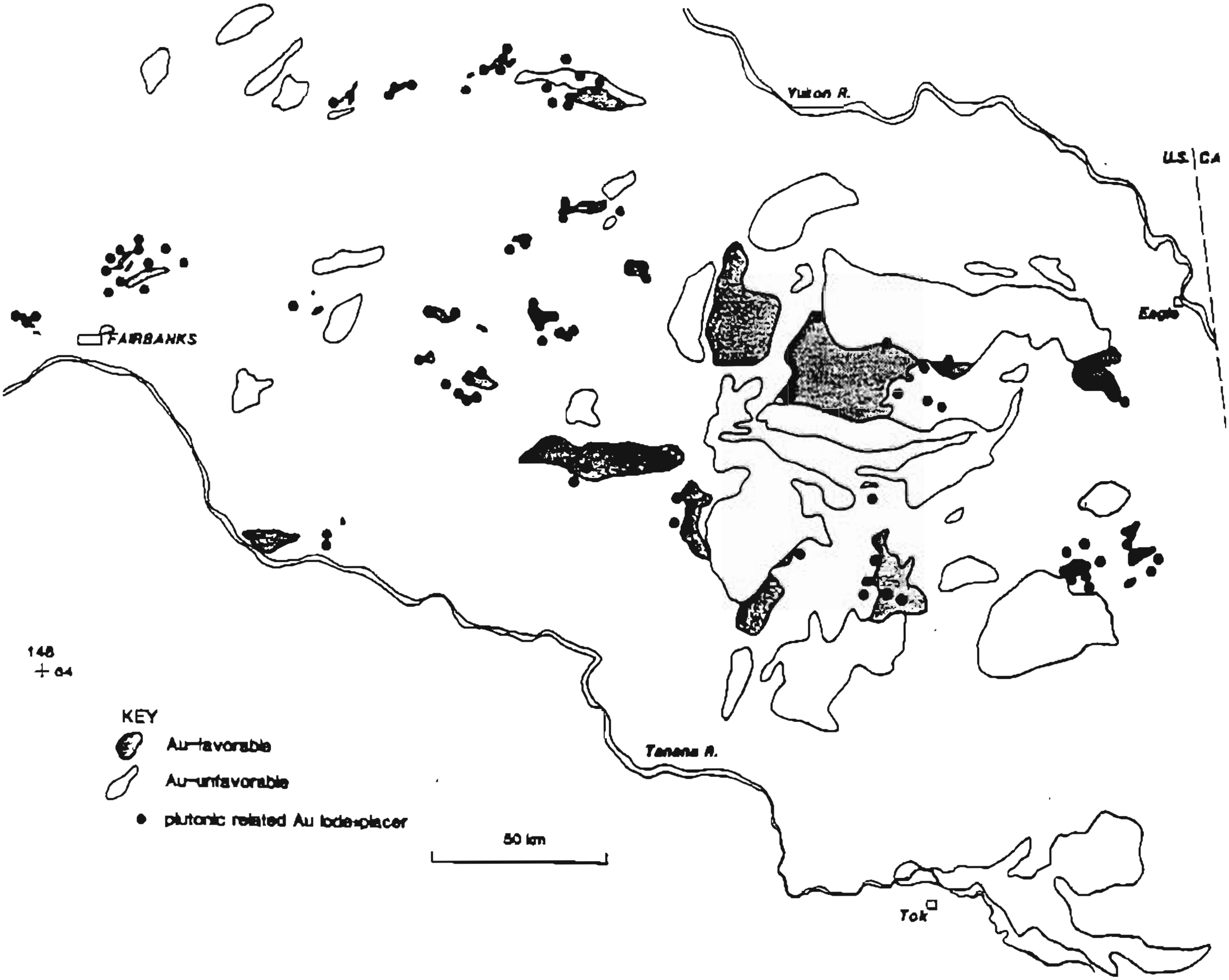


Fig. 48. Locations of lode/placer Au (dots) and Au-favorable (low oxidation state/high alkalinity) plutons, E-Central Alask Data from Berg and Cobb (1967), Nokleberg et al. (1987), and Burns et al. (1991a).

TABLE 8: PLUTON-MINERALIZATION AGE CONTRASTS, INTERIOR AK

(ALL AGES +/- 2 to 4 Ma)

GILMORE DOME (FBX AREA)
PLUTON: 89-92 Ma
SKARN: 93 Ma
MUSCOVITE-ALTERED GRANITE: 90 Ma
Au-As QTZ VEIN (musc selvage): 90, 88 Ma

ESTER DOME (FBX AREA)
PLUTON 89-93 Ma
MUSC-ALT'D GRANITE: 90 Ma
Au VEIN (MUSC SELVAGE): 90 Ma

VINASALE MNTN
GRANODIORITE PORPHYRY: 69 Ma
MUSC-ALTERED PORPHYRY: 68 Ma

TABLE MOUNTAIN
GRANITE: 86 Ma
Au-SKARN: 88 Ma

RICHARDSON DISTRICT
GRANITE: 87-91 Ma
MUSC-ALTD QTZ PORPH: 87-91 Ma

LIBERTY BELL
GRANITE: 93 Ma
MUSCOVITE: 92 Ma

NIXON FORK
QTZ MONZONITE: 69-70 Ma
SER-ALTD QTZ PORPH: 68-69 Ma

ELEPHANT / WOLVERINE
MONZONITE: 90 Ma
SER-ALTD GRANITE: 89 Ma

Data from Allegro (1987), Bundtzen and Reger (1977), Yesilyurt (1994), Swainbank et al. (1977), Szumigala (1993), DiMarchi (1993), Blum (1982), LeLacheur (1991), and unpublished K-Ar dates determined by Kreuger Enterprises, Cambridge, Mass.

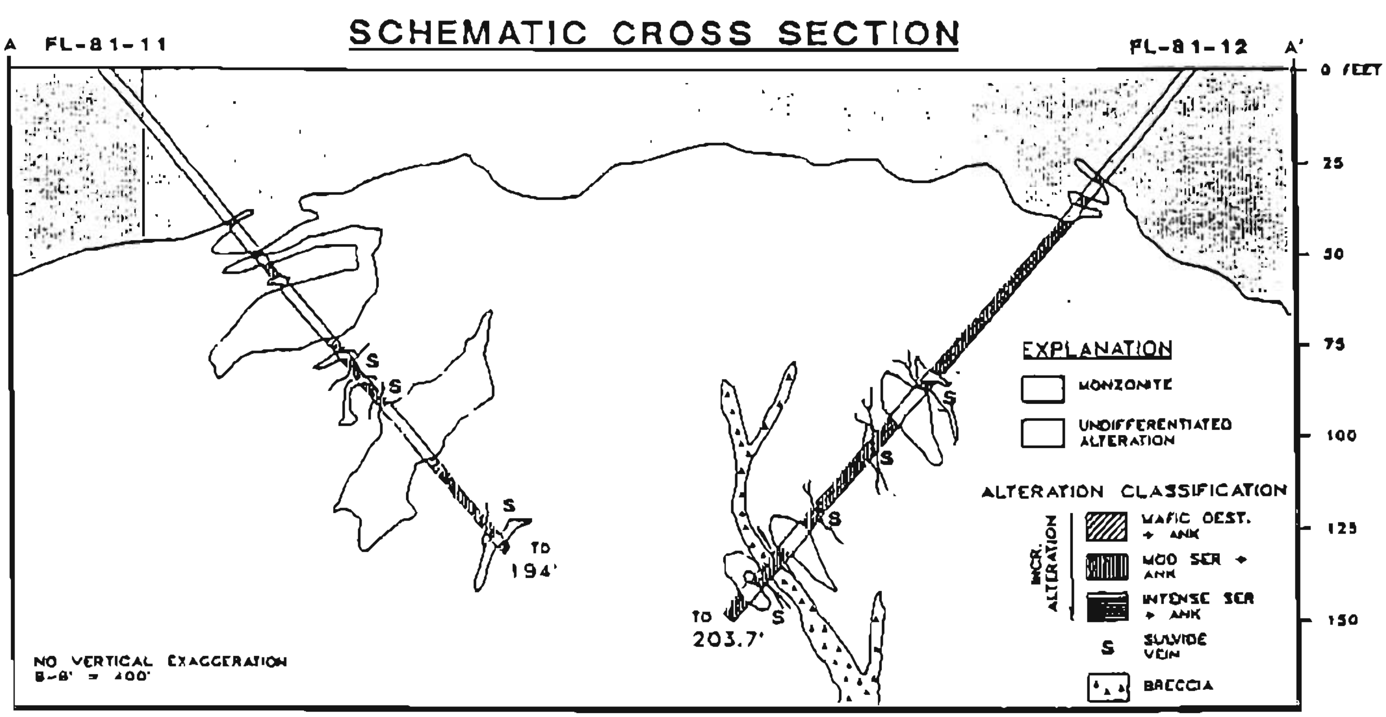


Fig. 49. Schematic alteration cross-section, Golden Horn deposit, from Bull (1988).

"extrinsic" and "mixed-origin" deposits, for which mineralization is 10-100 Ma younger than the host pluton.

The predominant alteration type in Alaskan pluton-related deposits is sericite ± carbonate (e.g., Figs. 41, 49). Tourmaline can be an important alteration mineral, as at Table Mountain (Fig. 20), Liberty Bell (Fig. 39), and Cirque (Fig. 50), where it exhibits little or no chemical zoning (Fig. 22B). White micas exhibit compositions which range from nearly pure muscovite to very Si-Mg,Fe rich (Fig. 51), corresponding to high P/T to low P/T conditions of formation.

The elemental composition of ores from Alaskan pluton-related deposits is such that Bi, Te, and Sb are inevitably enriched with Au (Tables 9-18). Other common ore-related elements include W, Sn, and Mo. As is highly enriched in high-sulfur types (e.g., Golden Zone); Cu is abundant in only a few of the deposits. The relationship between Au and Bi is illustrated by data for Nixon Fork (Fig. 52), showing a nearly 1:1 correlation with Bi approximately 10-20 times Au. A histogram for Te abundances with ores from the Valdez Creek district (Fig. 53) illustrates the contrast between pluton-related Au deposits, such as Silver King, Golden Zone, and McCallie Glacier, and the non-pluton-related Cu-Ag deposits, such as Kathleen-Margaret, Lichen, and Cottonwood.

Mineralization temperatures can be estimated from arsenopyrite compositions, for appropriate sulfide assemblages. In the Fairbanks area, temperatures so estimated range from > 400C for arsenopyrite with potassic alteration at Fort Knox to <350 C for sericite-associated veins and replacements (Fig. 54A). Temperatures of approximately 300-350C are estimated from Flat (Fig. 54B) and deposits of the Alaska Range (Fig. 54C). These ranges are compatible with the "porphyry" model: early higher-temperature alteration/mineralization and later, lower-temperature, pervasive, alteration-mineralization.

Biotites from Alaskan plutons associated with lode/placer Au are uniformly low in F, but show a wide range of Cl contents (Fig. 55). Generally speaking, those plutons associated with high-sulfide deposits have biotites with high Cl contents; those associated with low-sulfide deposits (e.g., Fort Knox) have biotites with low Cl contents. The relationship between these variables is unclear, but in the Fairbanks area plutons, biotites from more mafic plutonic units ("e", Fig. 55) have higher Cl contents, and those from more felsic units ("L", Fig. 55) have lower Cl. Detailed study of elemental changes in Fairbanks plutonic rocks versus fractionation (Fig. 56) indicates an abrupt change at Differentiation Index (sum of normative quartz + orthoclase + albite) 78, most easily explained as a fluid loss event. If this is the case, decrease in sulfide contents of ores and of Cl contents of fluids might be reconciled by a magmatic loss event.

Microprobe analyses of individual biotites from Fairbanks plutons (Fig. 57) show a similar pattern of abrupt change vs. differentiation index, validating the concept of magmatic fluid loss leading to changes in pluton-associated mineralization. Table 19 summarizes these relationships for the Fairbanks area.

A final aspect of plutons related to Au deposits in Alaska is their tectonic setting. There has been considerable speculation in the literature about tectonic settings of granitic rocks; most workers accept the discriminants of Pearce et al. (1984) as providing a framework for such analysis (Fig. 58). There are modest difficulties

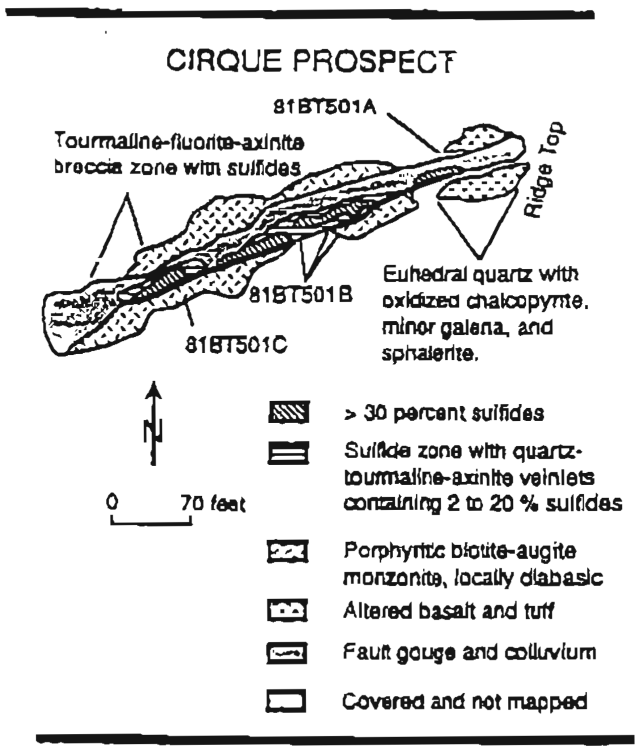


Fig. 50. Alteration-mineralization map of the Cirque prospect, SW Alaska, from Bundtzen et al. (1992).

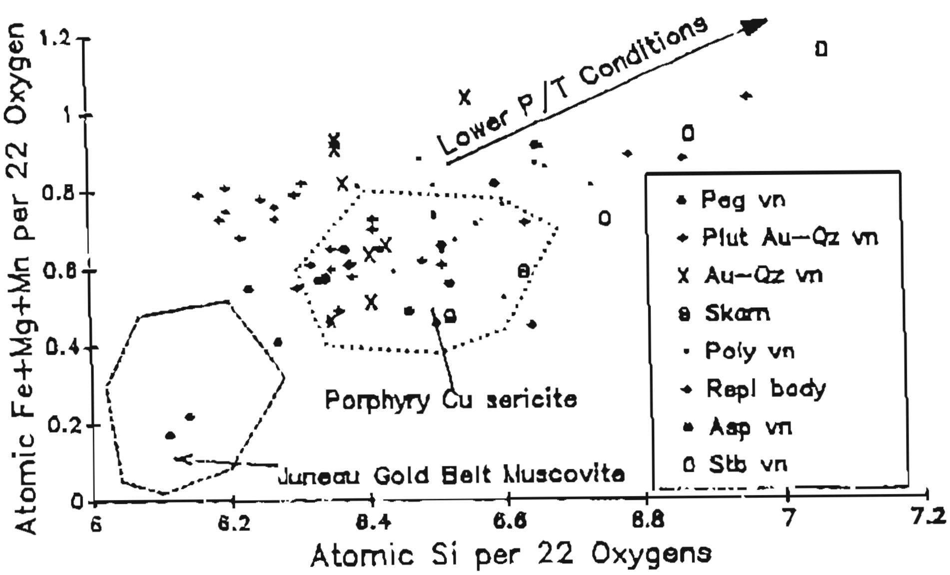


Fig. 51. Compositions of white micas by microprobe analyses from the Fairbanks district, compared to those from the Juneau gold belt (Newberry and Brew, 1988), and typical porphyry Cu deposits (Ayuso, 1987). Unpublished microprobe analyses performed 1987-93 at Washington State University and the University of Alaska.

TABLE 9: ANALYTICAL DATA FOR THE MEDFRA FE-AU SKARN, FROM CLAUTICE ET AL. (1993)

AU	PB	BI	HG	B	TE	SN	AG	CU	ZN	MO	NI	AS	SB	W
<5	41	<1	0.032	368	<0.2	32	2	81	39	<1	145	56	13	<2
7	5	<1	<0.01	81	<0.2	12	0.8	374	39	266	8	13	13	170
16	5	<1	0.038	174	<0.2	<5	1.6	80	1370	158	28	105	25	310
<5	358	≤1	0.031	80	<0.2	<5	2.3	66	111	<1	14	114	69	57
3160	90	2000	0.872	12	3.8	19	5.1	940	101	<1	5	4350	98	17
380	4	6	0.417	10	0.8	30	4.9	6130	71	22	7	2980	146	7
9	6	<1	0.015	14	<0.2	18	1.1	394	135	4	6	14	<5	<2
<5	3	<1	<0.01	24	<0.2	13	0.8	30	107	<1	16	2	<5	<2
<5	<2	<1	0.051	146	<0.2	29	0.9	7	150	5	16	3	<5	8
7	13	<1	0.030	27	<0.2	8	0.5	4	48	<1	13	2	<5	<2
55	49	27	0.075		2.4	46	3.1	26	32	<1	9	149	27	3

all values in ppm's except Au in ppb

TABLE 10: ANALYTICAL DATA FOR THE GOLDEN HORN DEPOSIT, SW ALASKA, FROM BULL (1988)

ROCK TYPE	Au		Ag	As	Ba	Te	Pb	Sb	V	W	In	Hg
vn in monz	1.27	ppm	<5	5400	1500	NA	NA	78.6	NA	22	<200	NA
bx:q-asp-stb	2	ppm	10	18000	20	0.8	150	720	10	<50	20	NA
vn:q-asp-cp	240	"	20	45000	20	0.2	1000	130	10	<50	10	1.8
vn:q-asp-py-cc	25	"	10	18000	50	0.7	1500	280	30	1000	<5	NA
vn:q-asp-py-gl	1.8	"	10	10000	1000	0.5	150	40	100	50	10	0.3
vn:q-asp-sch-cc	84	"	20	3800	<20	<0.2	700	880	10	10000	30	2.2
bx:q-cc-stb	3	"	3	7900	700	NA	30	16	30	70	25	0.2
vn:q-asp-py	40	"	7	16000	30	NA	100	20	15	500	230	0.5
vn:q-asp-py-sch	30	"	200	34000	20	NA	500	24	<10	700	1500	NA
vn:q-cc-asp	16	"	3	23000	<20	NA	100	30	20	700	5	NA
vn in monz:sch	.35	"	0.7	610	1500	NA	70	4	50	<50	65	NA
vn:q-asp-sch	210	"	50	48000	20	NA	1000	120	<10	<50	10	10
vn:q-asp-sch	85	"	70	10000	100	NA	500	190	10	1000	370	NA
vn:q-stb(margin)	1.5	"	10	5000	5000	NA	20	610	100	100	80	1
vn:q-stb	15	"	20	10000	1000	NA	100	72000	50	50	10	0.74
vn:q-stb(margin)	39	"	50	>10000	1500	NA	<10	2800	70	70	25	1.6
vn:q-stb	8.5	"	100	200	1000	NA	200	100000	70	<50	<5	1.2
vn:q-stb	8.6	"	30	2500	70	NA	50	>100000	30	70	<5	0.2
vn:q-stb	7.5	"	100	3200	500	NA	50	>100000	100	<50	<5	1.3
vn:q-cinn(?)	9.2	"	70	4800	1000	NA	100	100	100	<50	40	1.3

all values in ppm's

TABLE 11: ANALYTICAL DATA FOR THE RICHARDSON DISTRICT (UNPUBLISHED INDUSTRY SOURCES)

Au PPB	Ag PPM	Cu PPM	Pb PPM	Zn PPM	Mo PPM	Ni PPM	Co PPM	Bi PPM	As PPM	Sb PPM	Fe PCT	Mn PPM	Hg PPM	Te PPM
1248	<0.2	13	87	60	3	77	79	73	>2000	15	9.96	13644	0.067	5.6
217	<0.2	53	119	411	<1	77	16	24	946	566	>10.00	257	0.286	
26	<0.2	61	47	55	12	21	14	7	1488	319	9.98	135	0.164	
257	3.5	32	275	26	5	7	1	<5	351	45	1.36	47	0.052	
2217	0.4	1	22	<1	<1	6	1	29	7	<5	0.35	31	0.032	1.9
63	<0.2	41	35	24	4	22	5	<5	164	42	4.97	59	0.167	

Au PPB	Ag PPM	Cu PPM	Pb PPM	Zn PPM	Mo PPM	Ni PPM	Co PPM	Bi PPM	As PPM	Sb PPM	Fe PCT	Mn PPM
1059	<0.2	19	14	19	5	31	7	8	926	24	3.40	203
911	0.8	50	13	4	1	10	5	7	317	32	2.11	76
324	<0.2	40	18	43	2	33	14	11	821	15	3.52	360
66	<0.2	30	19	57	2	50	15	10	237	<5	3.95	573
201	<0.2	30	18	32	3	29	4	6	958	19	3.14	181
553	<0.2	21	13	12	2	11	2	24	1068	15	2.18	56
219	<0.2	31	22	49	2	29	7	11	829	12	3.68	297
1151	0.6	20	23	18	<1	9	2	13	>2000	23	1.97	90
32	<0.2	34	18	57	1	33	16	12	254	8	3.73	451
1673	<0.2	29	22	28	2	25	8	8	858	25	1.95	165

TABLE 12: ESTER DOME VEIN GEOCHEMISTRY, FAIRBANKS D-3 QUADRANGLE, FROM ALBANESE (1982) AND LELACHEUR (1991)

ND=not determined
(all in ppm's)

Cu	Pb	Zn	Au	Ag	Te	Sb	Hg	W	As
190	400	22	.6	40.4	0.8	4200	3	60	>1000
114	250	18	136.8	65.	2.0	373	3	1300	>1000
75	11	33	10.7	1.0	2.6	120	ND	40	>1000
74	11	17	2.92	0.9	0.5	25	3	40	>1000
279	9300	496	16.6	41.2	15.0	305	3	420	>1000
111	17	3	1.1	.8	0.6	74	ND	80	>1000
84	8	21	4.27	2.3	2.0	8			650
315	463	4	97.6	44.5	2.3	830	3	270	>1000
145	42	60	2.95	1.3	0.8	610	3	120	>1000

TABLE 13: ORE GEOCHEMISTRY FROM THE GOLDEN ZONE MINE AND VICINITY, FROM HAWLEY & CLARK (1974)

Ag	As	Au[1]	Bi	Co	Cu	Mo	Ni	Pb	Sb	Sn	Zn	Fe
						Arsenopyrite-rich veins						
300	>10,000	38	30	15	700	N	200	1,500	7,000	N	1,500	7
100	>10,000	50	1,000	300	700	N	30	700	700	N	L	20
3	>10,000	10	300	700	500	N	30	20	200	N	N	15
50	>10,000	200	>1,000	150	300	N	5	200	200	70	N	15
7	>10,000	1.0	50	150	1,500	L	70	70	500	15	200	20
3	>10,000	4.8	50	70	500	N	7	L	700	N	N	10
10	>10,000	8.4	100	15	70	N	L	100	700	N	N	10
30	>10,000	38.0	15	10	2,000	N	15	500	500	15	L	3
30	>10,000	25.0	200	N	800	N	N	5,000	700	N	N	15
150	>10,000	4.0	10	N	500	N	50	15,000	>10,000	N	10,000	10
500	>10,000	2.8	300	70	3,000	7	70	3,000	3,000	100	>10,000	20
100	>10,000	3.1	150	150	3,000	7	70	1,000	1,500	10	300	>20
700	>10,000	3.2	150	10	3,000	7	7	3,000	2,000	700	>10,000	>20
150	>10,000	.3	30	15	7,800	10	7	1,000	100	300	7,000	15
10	>10,000	.3	15	70	100	10	50	100	500	150	L	15
1	>10,000	68	100	700	7,000	30	50	100	7,000	N	300	20
20	>10,000	.04	20	N	1,000	L	7	300	150	>1,000	L	8
						Arsenopyrite-rich breccia						
[1]105	>10,000	[1]14.8	50	L	> 5,000	N	L	700	500	50	2,000	15

all values in ppm's

TABLE 14: BEAVER MNTNS GEOCHEMICAL DATA, FROM SZUMIGALA (1993)

sample type	Au ppb	Ag ppm	Cu ppm	Pb ppm	Zn ppm	Mo ppm	As ppm	Sb ppm	Hg ppb	Bi ppm	Sn ppm	W ppm
	236	12.0	261	259	44	<1	1313.8	120.8	2267		9	
	67	31.2	2228	199	182	<1	641.7	171.2	2866		8	
qtz-tour-cp veined lapilli tuff	1569	194.0	2715	5449	304	12	122.8	22.3	462			
qtz stockworks w/ FX	287	6.2	52	1175	1910	3	758.2	11.8	1259		7	
tourm-ax veins or "greisens"		663.4	30000	30000	4000	ND	ND	2000.0		ND	100	
tourm-ax veins or "greisens"		1105.7	200000	ND	2000	ND	ND	200.0		2000	ND	
tourm-ax veins or "greisens"		884.6	210500	ND	800	ND	ND	35.0		ND	100	
tourm-ax veins or "greisens"		331.5	80000	ND	ND	ND	ND	100.0		ND	100	
pyridferrous igneous rocks	ND	7.5	100	ND	200	ND		ND		ND	ND	ND
dissem fracture filling	trace	552.7	5000	7000	900	ND	ND	200.0		100	60	ND
tourm-sulfide bx/veins	686	110.4	20000	ND	ND	ND		ND		ND	ND	300
tourm-sulfide bx/veins in	343	1062.9	100000	ND	ND	ND	10000.0	500.0		ND	ND	
"greisenized" fracture	343	1105.7	100000	ND	ND	ND	10000.0	400.0		ND	ND	
same	trace	44.2	1000	8000	20000	ND	20000.0	200.0		ND	200	
tourm greisen fracture filling	trace	1.0	200	900	1200	ND		5.0	80	50		2.0
tourm greisen fracture filling	trace	7.9	100	2400	2200	ND		ND	130	20		3.0
Monzonite	1400	500	1000	>20000	800	15	>2000	>1000	700	39	140	ND
Monzonite	<50	1	50	300	470	5	100	6	100	4	12	ND
Monzonite	ND	<0.5	10	200	110	7	30	ND	40	ND	7	ND
Monzonite	100	3	100	500	130	7	850	8	<20	6	10	ND
Monzonite	ND	ND	50	50	30	5	220	4	ND	ND	3	ND
Monzonite	ND	2	20	1000	90	5	520	72	240	3	7	ND
Monzonite	100	20.0	10000	200	450	ND	60	30	80	84	50	<50
Monzonite	50	5.0	500	50	95	ND	690	22	450	10	50	ND
Quartz	1800	150.0	>20000	>20000	>2000	ND	1400	>1000	1000	530	50	ND
Quartz	450	200.0	>20000	10000	330	ND	>2000	840	1500	550	100	100
Quartz Vein	ND	50.0	10000	150	500	ND	ND	100		200	50	ND
Unknown	ND	500.0	>20000	20000	1000	5	7000	10000		200	100	50
Quartz Vein	ND	700.0	>20000	150	1000	10	ND	300		500	200	ND
Unknown	ND	500.0	>20000	200	1000	10	500	500		200	100	ND
Monzonite	ND	ND	15	30	ND	ND	ND	ND		ND	<10	ND
Mafic Volcanic	ND	7.0	300	70	85	ND	110	6		2	ND	ND
Intermediate Volcanic	ND	ND	50	30	70	<5	<10	6		ND	ND	ND
Quartz Vein	ND	20.0	700	100	55	ND	40	4		2	30	ND
Breccia	150	1000.0	>20000	1000	30	ND	100	280		570	200	ND

TABLE 15: GRANITE CREEK GEOCHEMICAL DATA, FROM SZUMIGALA (1993)

Au ppb	Ag ppm	Cu ppm	Pb ppm	Zn ppm	As ppm	Sb ppm	Hg ppb	Bi ppm	W ppm
ND	ND	30	50	15	200	62	1500	<10	ND
<50	0.5	70	10	5	100	2	1120	3	ND
ND	1.0	10	ND	5	50	4	5140	1	ND
4100	13.00	70	15	20	>2000	>1000	>10000	7	2.0
6900	38.00	500	300	30	1600	>1000	>10000	190	1.0
ND	0.15	100	ND	350	900	300.0	2500	ND	20.0
23000	15.0	200	200	5	1000	>1000	2600	90	ND
3200	100.0	700	1000	70	110	190	3700	17	ND
300	1.5	10	15	15	900	40	2000	ND	ND
4100	2.0	10	15	5	1000	64	3000	ND	ND
12000	5.0	70	30	ND	570	>1000	2700	150	ND

TABLE 16: GILMORE DOME VEIN GEOCHEMISTRY, FROM ALBANESE (1982) AND LELACHEUR (1991)

Cu	Pb	Zn	Au	Ag	Te	Sb
71	123	74	3.0	9.4	0.7	20
440	135	16	1.6	11.9	1.6	310
82	48	93	0.3	1.1	0.15	32
116	3	3	2.9	0.9	1.8	<1
108	47	34	0.5	0.9	0.2	73

all values in ppm's

TABLE 17: TABLE MOUNTAIN GEOCHEMISTRY, FROM MENZIE ET AL. (1987)

Au	Ag	As	B	Ba	Be	Bi	Co	Cu	La	Mo	Zn	Ni	Pb	Sb	Sc	Sn	V	W
140.00	1.0	10,000G	200	300	20	15	50	300	50	5N	200L	70	10	100N	50	10N	200	50
.25	.5L	700	70	300	150	10N		7	20	5N	200N	7	30	100N	5L	50	15	50N
40.00	1.5L	10,000	1,500	300	1.5	50	70	300	100	5N	200N	70	20	100N	70	30	300	50
.05	.5N	200N	100	3,000	1.5	10N	20	100	150	5N	200N	70	30	200N	70	10N	500	50N
.05N	.5N	200N	20	100	1.0L	10L	30	150	20	5N	200N	70	10L	100N	50	30	500	50N
.10	.5L	200N	15	150	1.0	20	30	200	50	5N	200N	70	10N	100N	70	30	300	50N
.05	.5L	200N	20	70	1.0L	20	30	300	20	5N	200N	50	10N	100N	30	10N	200	50N
.20	.5N	200N	15	30	1.0	20	7	200	30	5N	200N	30	10N	100N	30	15	150	50L

all values in ppm's

TABLE 18: NIXON FORK GEOCHEMISTRY, FROM CUTLER (1993)

Au ppm	Ag ppm	AS ppm	Bi ppm	Cu %	Pb ppm	Zn ppm
4.0	22.6	710.0	112.0	0.8	2.0	126.0
602.1	40.0	10000.0	5070.0	0.8	84.0	164.0
17.5	51.0	10000.0	280.0	1.8	0.0	670.0
10.6	27.6	10000.0	260.0	1.0	42.0	190.0
301.8	161.0	9900.0	4980.0	7.5	64.0	1110.0
16.5	56.4	6860.0	200.0	2.5	0.0	376.0
151.0	151.0	1400.0	1920.0	6.4	20.0	970.0
36.2	38.0	5170.0	600.0	1.2	4.0	258.0
4.1	10.0	10000.0	46.0	0.2	30.0	86.0
7.1	33.6	10000.0	590.0	0.4	276.0	96.0
5.8	8.2	70.0	82.0	0.3	8.0	82.0
41.0	25.6	25.0	462.0	0.8	14.0	178.0
12.9	13.2	60.0	102.0	0.5	4.0	138.0
17.2	17.6	65.0	144.0	0.7	10.0	180.0
5.0	15.4	100.0	38.0	0.7	12.0	200.0
0.4	6.6	45.0	2.0	0.1	0.0	56.0
0.2	1.6	4090.0	2.0	0.0	0.0	24.0
11.4	120.0	10000.0	320.0	1.0	4.0	214.0
0.4	4.0	10000.0	24.0	0.1	0.0	32.0
0.1	2.6	1125.0	6.0	0.0	4.0	32.0
0.0	2.0	125.0	6.0	0.0	6.0	24.0

Au ppm	Ag ppm	As ppm	Bi ppm	Cu %	Pb ppm	Zn ppm
9.6	3.2	0.0	130.0	0.1	38.0	276.0
0.3	0.6	10.0	0.0	0.1	0.0	50.0
22.7	5.6	50.0	242.0	0.7	32.0	246.0
2.2	1.8	0.0	36.0	0.1	12.0	146.0
13.1	3.0	0.0	176.0	0.2	10.0	90.0
3.8	5.0	25.0	32.0	0.4	2.0	120.0
1.3	6.2	0.0	14.0	0.4	0.0	118.0
35.8	23.8	0.0	360.0	1.4	0.0	328.0
66.2	76.0	0.0	740.0	4.4	0.0	970.0
44.9	63.2	180.0	460.0	3.4	14.0	826.0
65.3	82.6	0.0	700.0	4.5	0.0	988.0
57.3	40.2	5.0	740.0	1.9	0.0	500.0
3.5	10.2	15.0	38.0	0.6	0.0	194.0
30.1	16.6	15.0	300.0	1.0	0.0	224.0
0.0	0.0	0.0	0.0	0.0	0.0	34.0
1.0	6.6	135.0	2.0	0.5	0.0	214.0
111.3	9.4	220.0	1920.0	0.5	14.0	110.0
2.4	2.0	70.0	60.0	0.2	0.0	52.0
0.8	18.2	90.0	0.0	1.1	0.0	280.0
1.3	10.0	20.0	0.0	0.6	0.0	182.0
2.9	48.6	80.0	0.0	3.2	0.0	780.0
0.9	12.8	770.0	8.0	0.4	26.0	116.0
96.5	13.2	960.0	1075.0	0.5	0.0	168.0

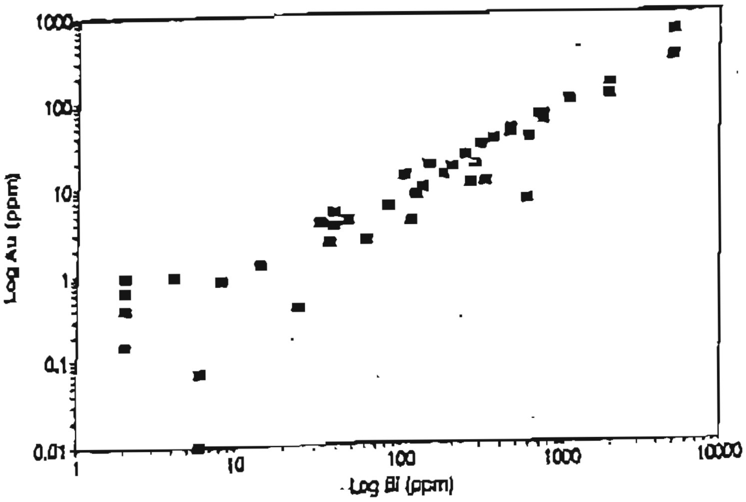


Fig. 52. Gold vs. Bi concentrations, Nixon Fork deposit, after Cutler (1993)

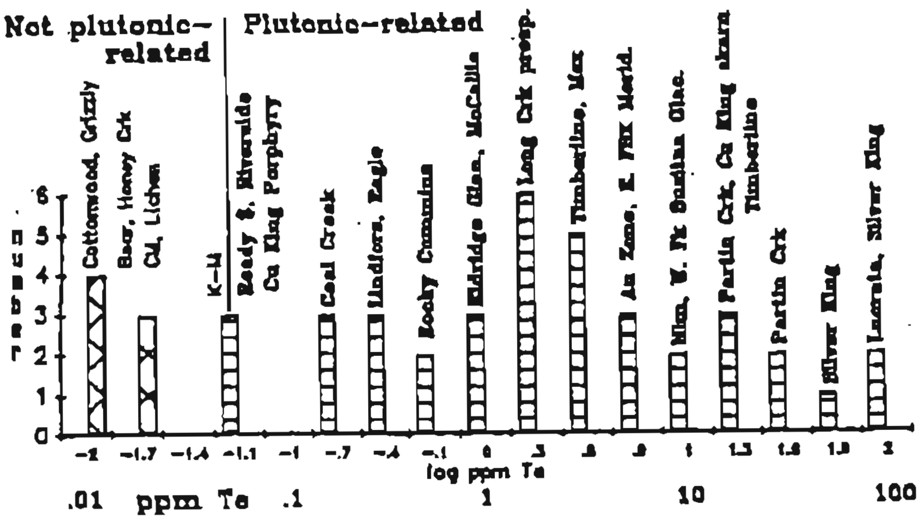


Fig. 53. Histogram of Te concentrations in ores of the Valdez Creek district, central Alaska Range. Unpublished data determined by Graphite Furnace Atomic Absorption at X-Ray Assay Labs, Toronto, Ontario on samples collected by the U.S. Bureau of Mines (Balen, 1990).

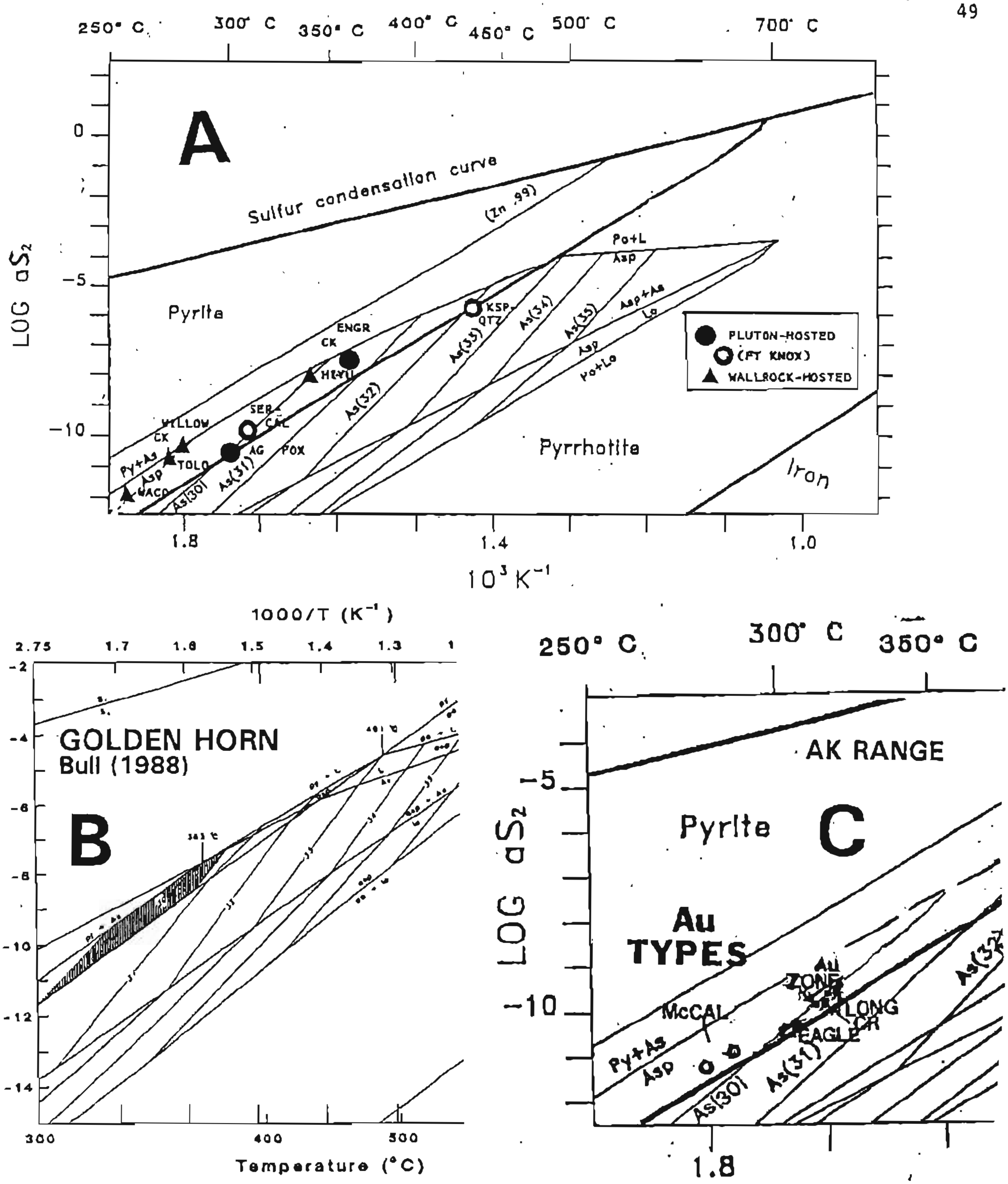


Fig. 54. Arsenopyrite compositions from pyrite-arsenopyrite (+ pyrrhotite) assemblages plotted on the log sulfur fugacity--temperature diagram of Kretschmar and Scott (1976). A= Fairbanks area prospects, B=Golden Horn (Bull, 1988), C=Central Alaska Range Au prospects. Unpublished data determined by microprobe analysis at Washington State University.

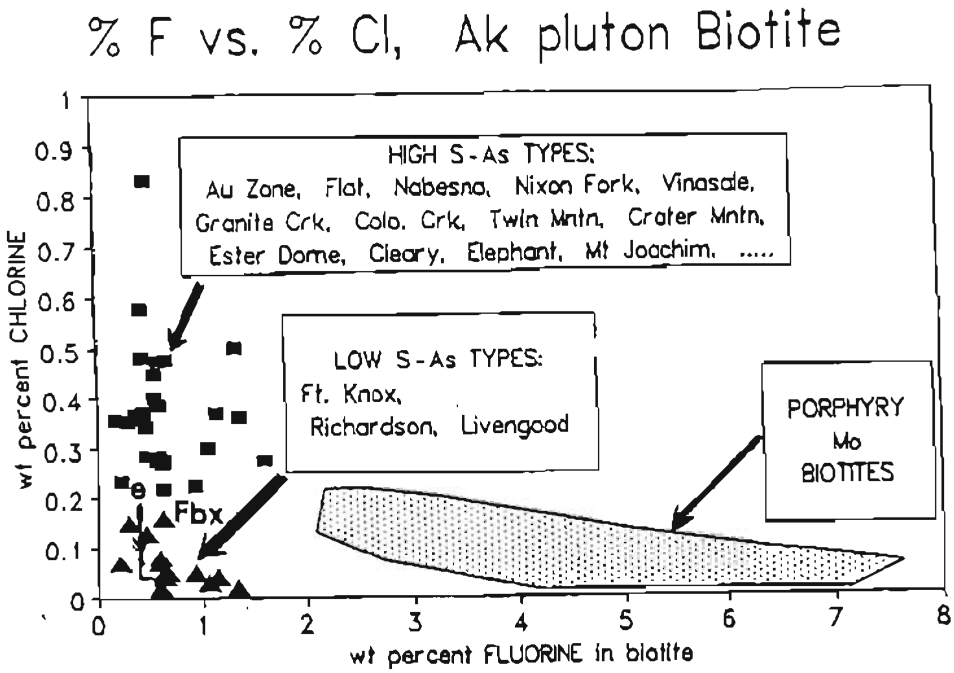


Fig. 55. Halogen compositions of magmatic biotites from plutons hosting/related to gold deposits of Interior and SW Alaska. Filled triangles are data for low As-S deposit; squares identify data from high As-S deposits; "e" and "L" identify early and late biotites (respectively) from Fairbanks area plutonic rocks. Field for porphyry Mo biotites from Speer (1984). Halogen data determined by microprobe analysis at the University of Alaska.

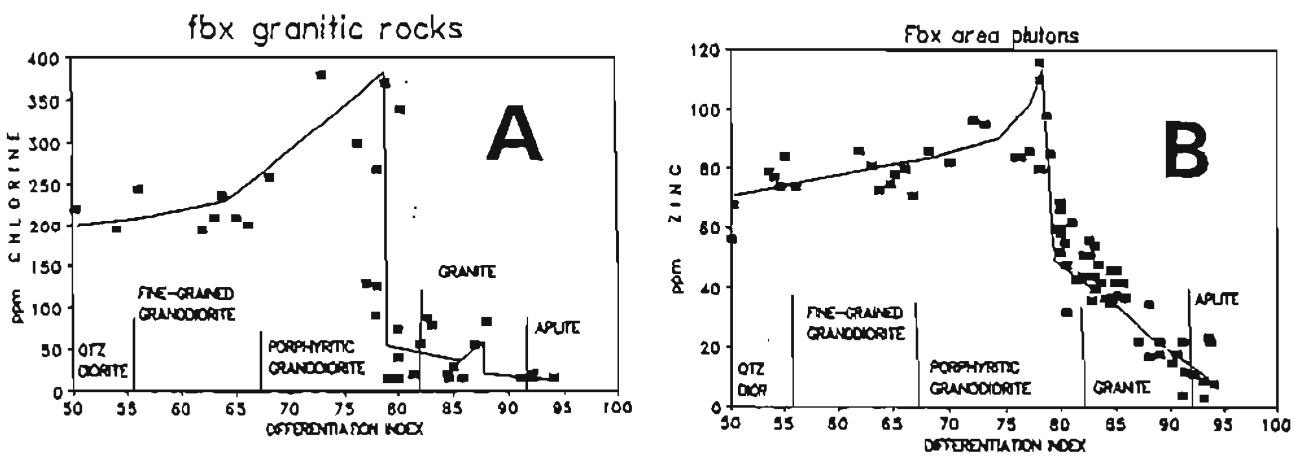


Fig. 56. Chlorine (A) and Zinc (B) contents vs. Differentiation Index (sum of normative quartz + albite + orthoclase) for Fairbanks area plutonic rocks. Major element composition data from Blum (1982) and Burns et al. (1991a); minor element data by standard pressed-pellet XRF techniques determined at the University of Alaska.

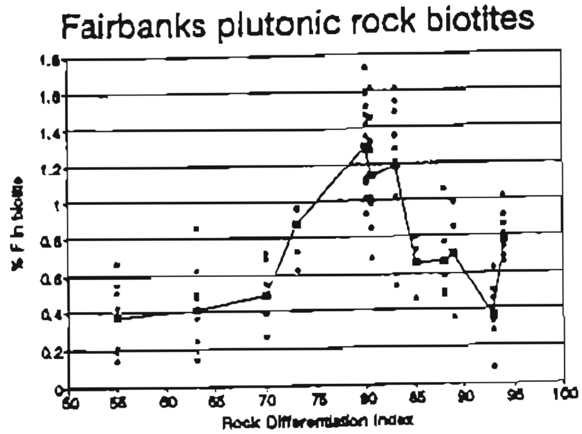


Fig. 57. Biotite Fluorine content vs. host rock D.I. for Fairbanks area rocks. Biotite analyses determined by microprobe at the University of Alaska on rocks previously analyzed for major elements (Burns et al., 1991a).

TABLE 19: Fairbanks area pluton-mineralization systematics

ROCK TYPE	Granodiorite	grd–granite	granite
METALS	As,Sb,Ag Pb,Zn,U (Au–Te)	Au–Te–Bi	W,Mo,Ta (Au–Te)
EXAMPLES	Ester Pedro–Cleary	Ft Knox	Gilmore Dome

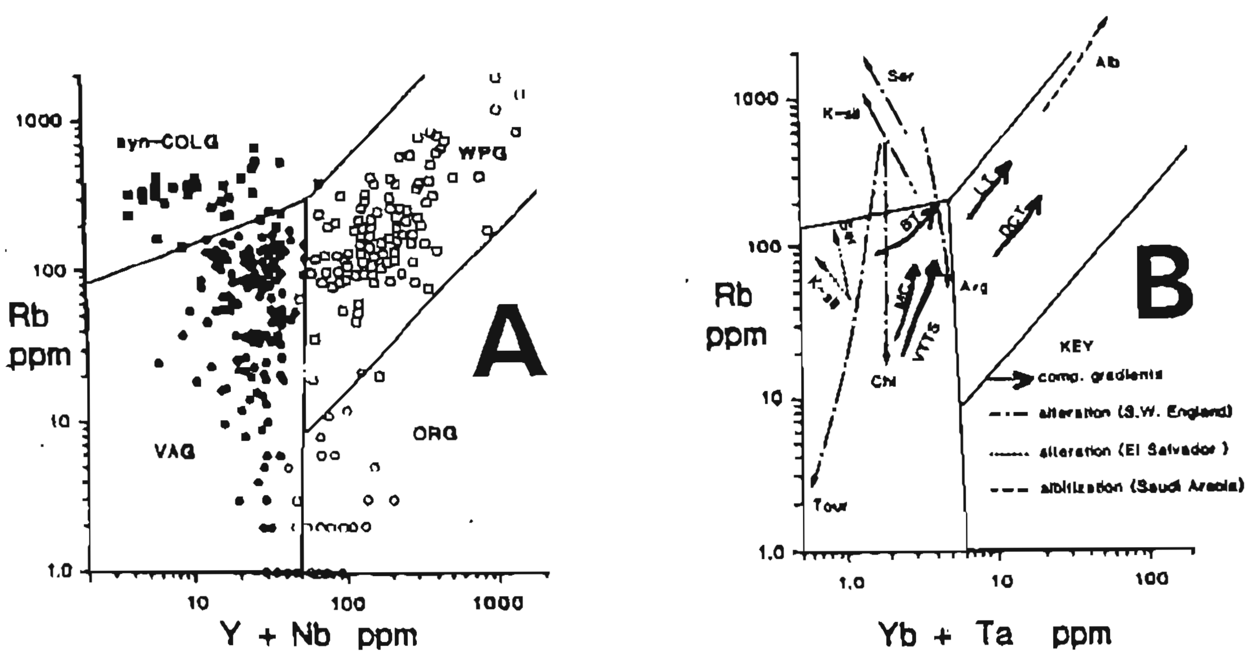


Fig. 58. A. Tectonic classification of granitic rocks based on trace element contents (after Pearce et al., 1984). B. Fractionation and alteration trends for plutonic/volcanic rocks plotted on trace element classification diagrams (after Pearce et al., 1984).

caused by fractionation and alteration (Fig. 58B) but by sticking with relatively unaltered rocks and avoiding obviously fractionated units, such as granite aplite/pegmatite dikes, it is possible to make at least preliminary tectonic assignments.

Tectonic classification diagrams for plutonic rocks of Interior Alaska (Fig. 59) indicate (1) that quartz-rich mid Cretaceous plutons characteristically exhibit volcanic arc signatures (Fig. 59A,B,C,E), (2) that alkalic mid-Cretaceous plutons have within-plate granite signatures (Fig. 59D), and that younger, non-Au related plutons have extensional and collisional, non-arc signatures (Fig. 59 E,F). Similarly, late Cretaceous, Au-associated, quartz-alkalic plutons of SW Alaska have a dominantly arc signature (Fig. 60). 50-55 Ma (Roe and Stone, 1993) basalt dikes and flows of interior Alaska (Fig. 61) also show within-plate (extensional regime) signatures, confirming the extensional character of the associated 50-55 Ma granites.

Tectonic environments in central Interior Alaska systematically change with time (Fig. 62), as shown by a compilation of radiometric dates (Wilson et al., 1985; Burns et al., 1991a) and tectonic discrimination diagrams (Figs. 59-61). Our current data (Table 8) indicates that gold-bearing plutons in Interior Alaska are entirely of the subduction-arc variety. However, slightly auriferous, Ag- and base-metal-rich veins are spatially associated with the extensional-type granites in the Steese, Circle, and Kantishna districts (Bundtzen, 1981; Newberry et al., 1990; Wiltse et al., 1994). Contrast in the two types of precious metal-associated granitic rocks is illustrated by data for the Circle district (Fig. 63), which contains both 90 Ma Au plutons and 55 Ma Sn-Ag plutons. As illustrated by fractionation trends of decreasing TiO_2 vs. elemental abundance, the younger plutons have different initial trace element compositions (e.g., higher Rb, and F), but also different fractionation trends (e.g., strong enrichment in Y, Ni, Rb, F, Cl) which are probably caused by late biotite crystallization.

In summary, there are a variety of ages and types of plutons in Interior Alaska. Gold-related plutons, however, possess distinctive and diagnostic features, including age, oxidation state, tectonic setting, trace element compositions, and alteration types. The successful search for additional lode gold resources in Interior Alaska can make use of these distinctive characteristics.

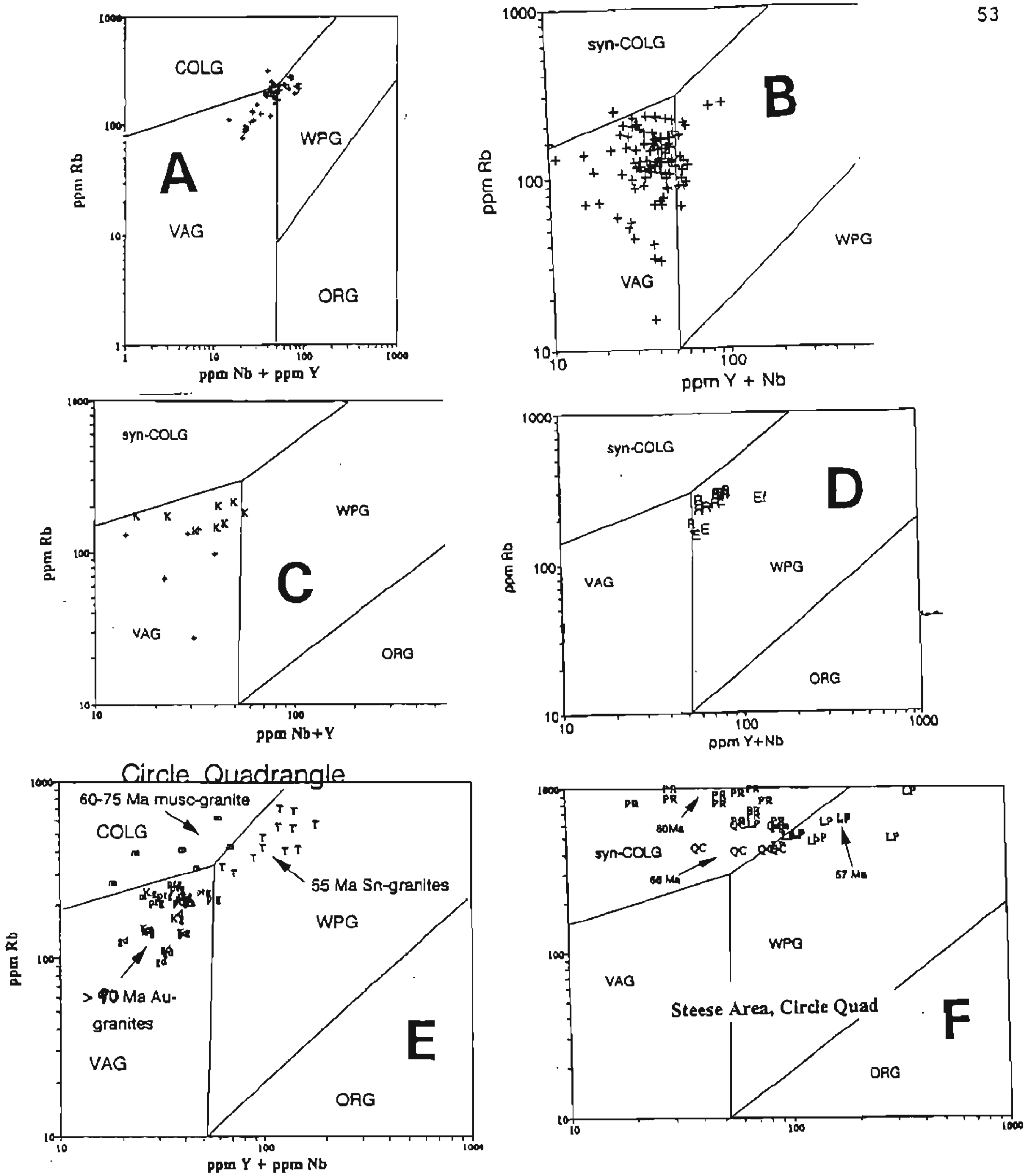


Fig. 59. Tectonic classification diagrams (after Pearce et al., 1984) for ca. 90 Ma plutonic rocks from (A) the Fairbanks area, (B) Eagle quadrangle, (C), Tanacross and N Nabesna quadrangle, and (D) Tanana quadrangle; (E) 55-90 Ma plutons of E-central Circle quadrangle, and (F) 55-70 Ma plutons of the Steese area, Circle quadrangle (LP=Lime Peak, QC=Quartz Creek, PR=Prindle), showing contrast in tectonic settings. Data from Burns et al. (1991a), Burleigh and Lear (1994), Newberry et al. (1994), and unpublished XRF analyses performed at the University of Alaska.

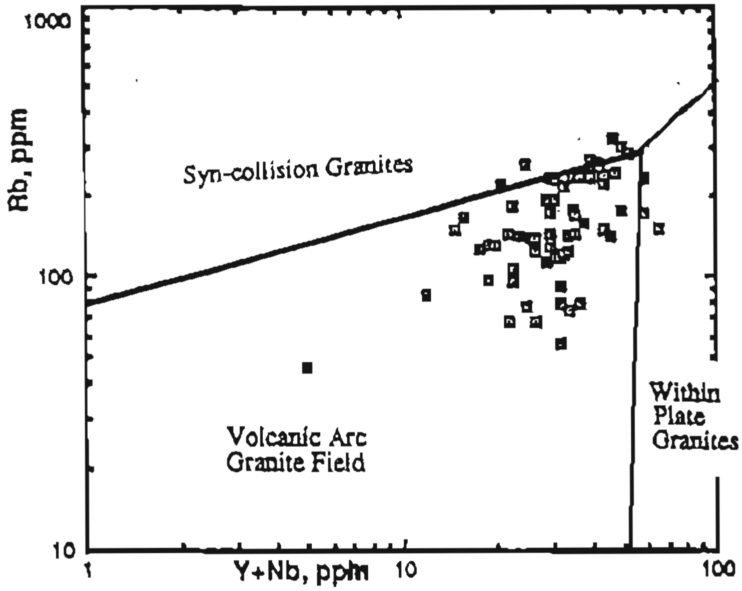


Fig. 60. Tectonic classification diagrams (after Pearce et al., 1984) for 60-70 Ma plutons of the Kuskokwim Mntns (Szumigala, 1993).

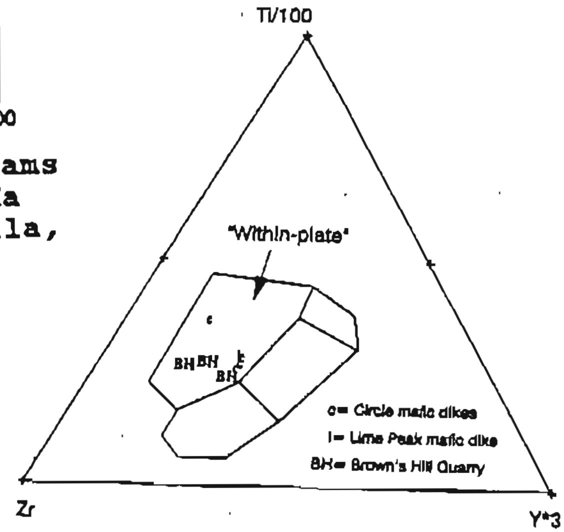


Fig. 61. Trace element data for 50-55 Ma mafic rocks of interior Alaska plotted on the tectonic classification diagram of Pearce and Cann (1973). Data from Burns et al. (1991a), Newberry et al. (1994), and unpublished ADGGS analyses.

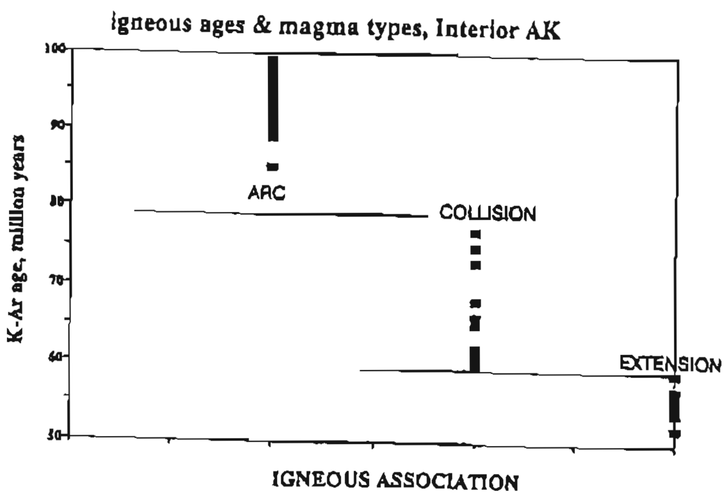


Fig. 62. Summary of pluton tectonic setting vs. age for Cretaceous-Tertiary plutons of central Interior Alaska.

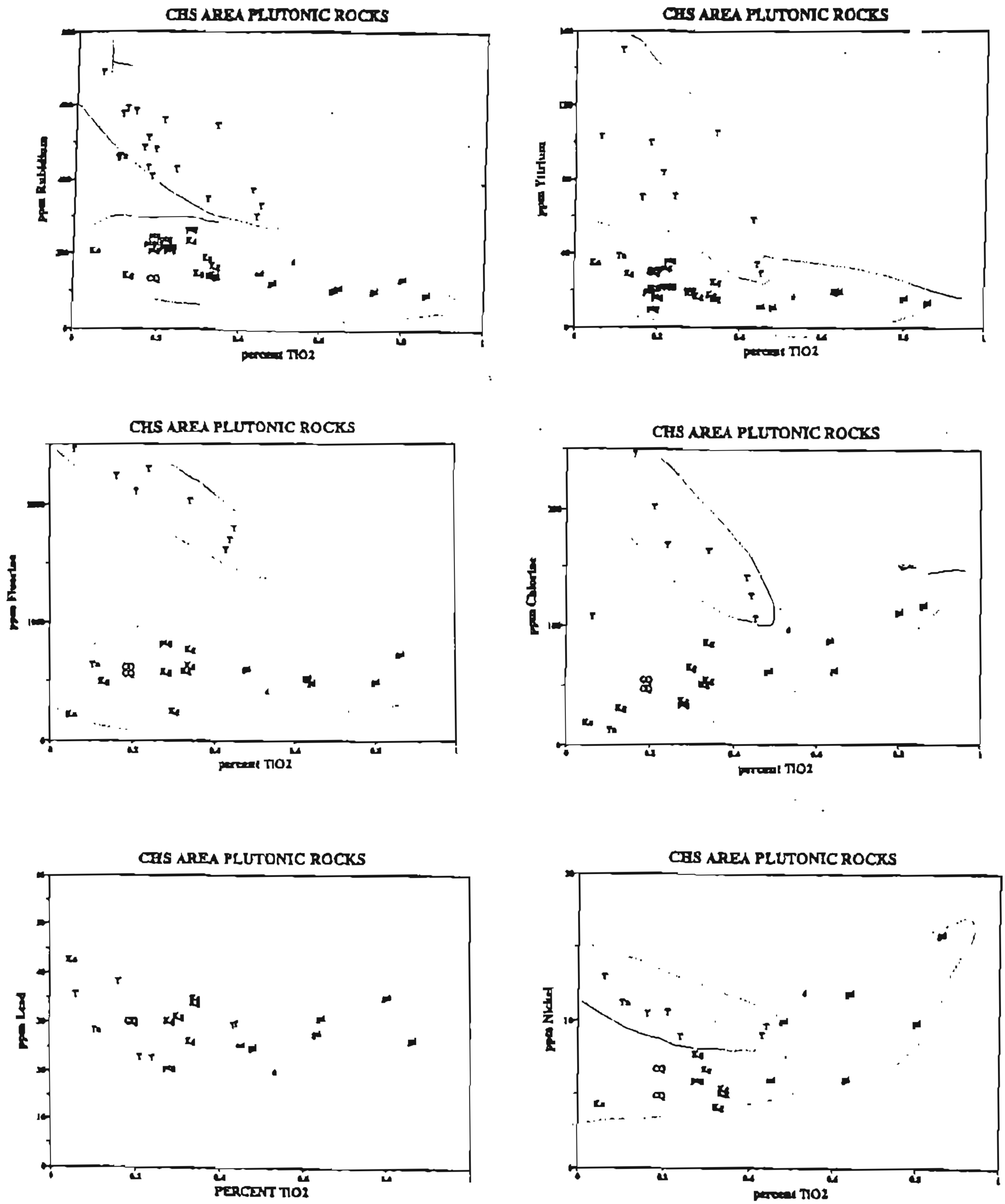


Fig. 63. Trace element vs. TiO_2 plots for Cretaceous (gd, Kg, d, Ka, and CQ) and Tertiary (T, Ta) plutonic rocks of the Circle Mining district. Data from Newberry et al. (1994).

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