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NORTH STAR GOLD BELT, ALASKA: A BRIEFING REPORT TO ASSIST IN MAKING A ROCKVAL MINERAL RESOURCE ANALYSIS

By

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NORTH STAR GOLD BELT, ALASKA: A BRIEFING REPORT TO ASSIST IN MAKING A ROCKVAL MINERAL RESOURCE ANALYSIS

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INTRODUCTION

The North Star Gold Belt (NSGB) project was conceived in order to estimate lode gold resources in the belt by finding the best geologic analogies for the Belt and using these for comparison. Our initial model was based on Archean volcanogenic gold deposits, such as Homestake, S.D. and Agnico-Eagle, Quebec. However, field and petrographic work conducted during 1987-88 have demonstated that Archean deposits are not good models for the NSGB (Newberry et al., 1988). Instead, our work has indicated that gold deposits in the NSGB are related both to late preCambrian/early Paleozoic volcanogenic systems and to Cretaceous/Tertiary plutonism. Therefore a complete mineral assessment of the gold in the NSGB requires evaluation of both environments. To accomplish the evaluation we provide (1) an assessment of the geologic/ore deposit models and their applicability to the study area and (2) grade, tonnage, prospect distribution (etc.) models applicable to the particular deposit types. In this report we will briefly present the following as a guide to the mineral resource assessment:

1. an overview of the geology of the NSGB area, outlining the basic reasons for suspecting two sources of gold and including descriptions of the "type" deposits,

2. a description of geologic analogs to the metavolcanic belt of the NSGB area and a qualitative evaluation of their applicability to the NSGB area, and

3. a description of analogs to plutons in the NSGB area and a quantitative evaluation of their applicability to the area.

I. GENERAL GEOLOGY OF THE NORTH STAR GOLD BELT AREA

The North Star Gold Belt of Interior Alaska (Fig. 1) is mostly comprised of late Proterozoic to early Paleozoic sedimentary and volcanic rocks, metamorphosed to greenschist facies, and mid-Cretaceous to early Tertiary plutons and dikes. Metavolcanic rocks (Cleary Sequence) are broadly bi-modal (abundant high- and low-SiO_2 rocks, with lesser intermediate compositions), and are locally associated with Au-rich, cherty pyritic rocks ("exhalites"), tourmaline-rich cherts, and layered massive sulfides of volcanogenic origins (Smith and others, 1981). Figure 2 (Bundtzen, writ. comm., 1987) shows typical stratigraphic columns through the metavolcanic sequence. Stratabound metal deposits are especially associated with the felsic members of the sequence.

Age of the Cleary Sequence is late Proterozoic/early Paleozoic as indicated by (1) Oldhamia (a Cambrian trace fossil) in rocks depositionally overlying the Cleary Sequence (Pessel et al., 1987), (2) Ordovician-aged plutons intrusive into the Cleary Sequence-bearing package in the Kantishna Hills (Bundtzen, pers. commn. 1988), and (3) early Paleozoic age galena in stratabound deposits in the Kantishna Hills (discussed below).

Plutons and dikes in the NSGB area vary in composition from tonalite to granite and are moderately- to non-alkalic in chemistry (Blum, 1983; Burns et al., 1987). Lamprophyre dikes are locally present. Estimated depths of emplacement vary from about 4-5 km for the mid-Cretaceous plutons to about 1.5-2 km for the early Tertiary plutons (Burns and Newberry, 1987). The older, generally more mafic, plutons are spatially associated with scheelite-gold skarns in the NSGB area (Newberry, 1987).

Mineralization in the area includes stratabound metal deposits which are especially associated with the felsic members of the meta-volcanogenic sequence. Other mineralization, including some veins and carbonate replacements, has some non-volcanogenic component. Veins and carbonate replacements in the NSGB are rich in arsenopyrite-gold-scheelite +/-Au-tellurides or galena-sphalerite-gold-Ag-sulfosalts, with variably prominant secondary tourmaline. The veins and replacement bodies are commonly, but not exclusively, in spatial association with plutons and dikes.

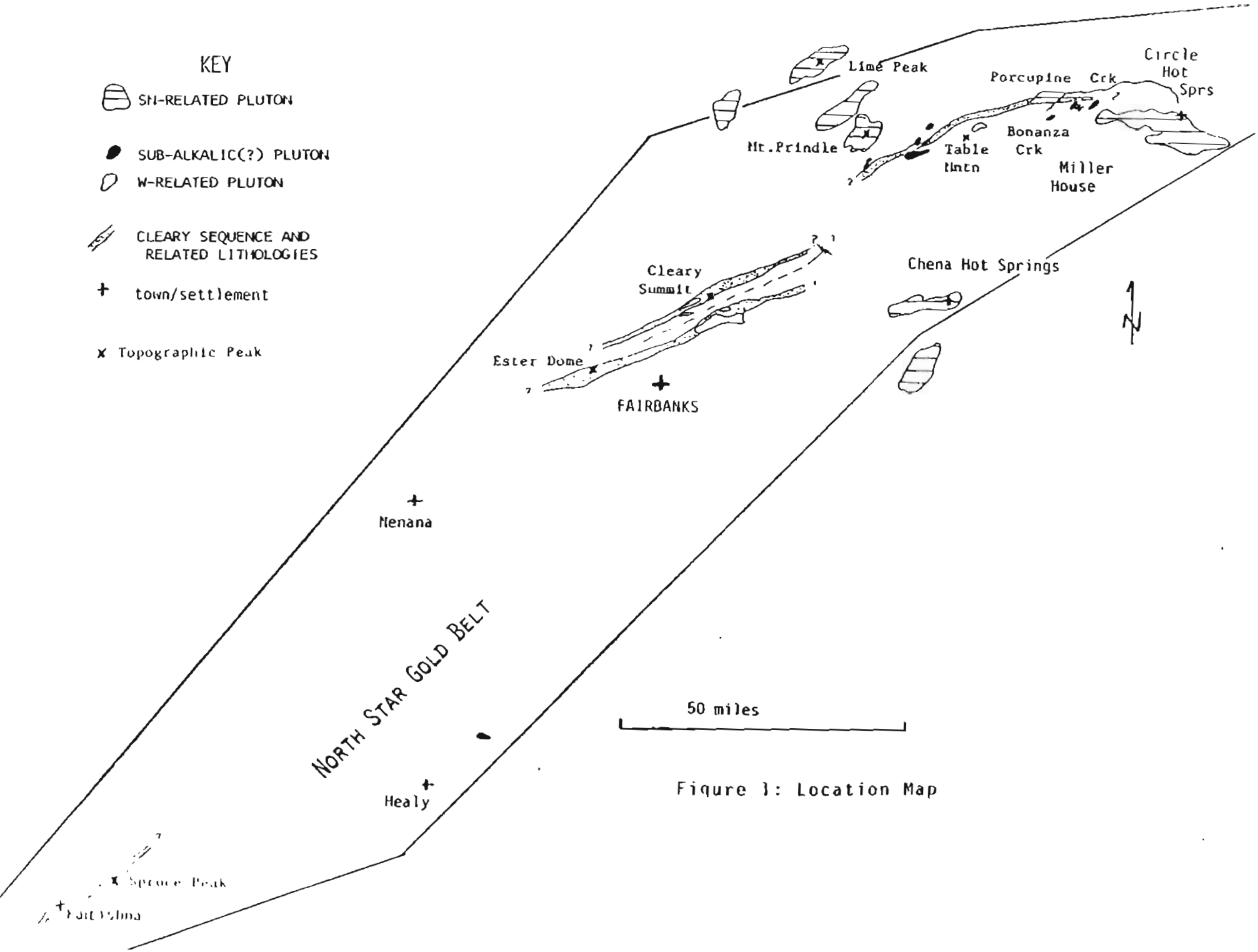


Figure 1: Location Map

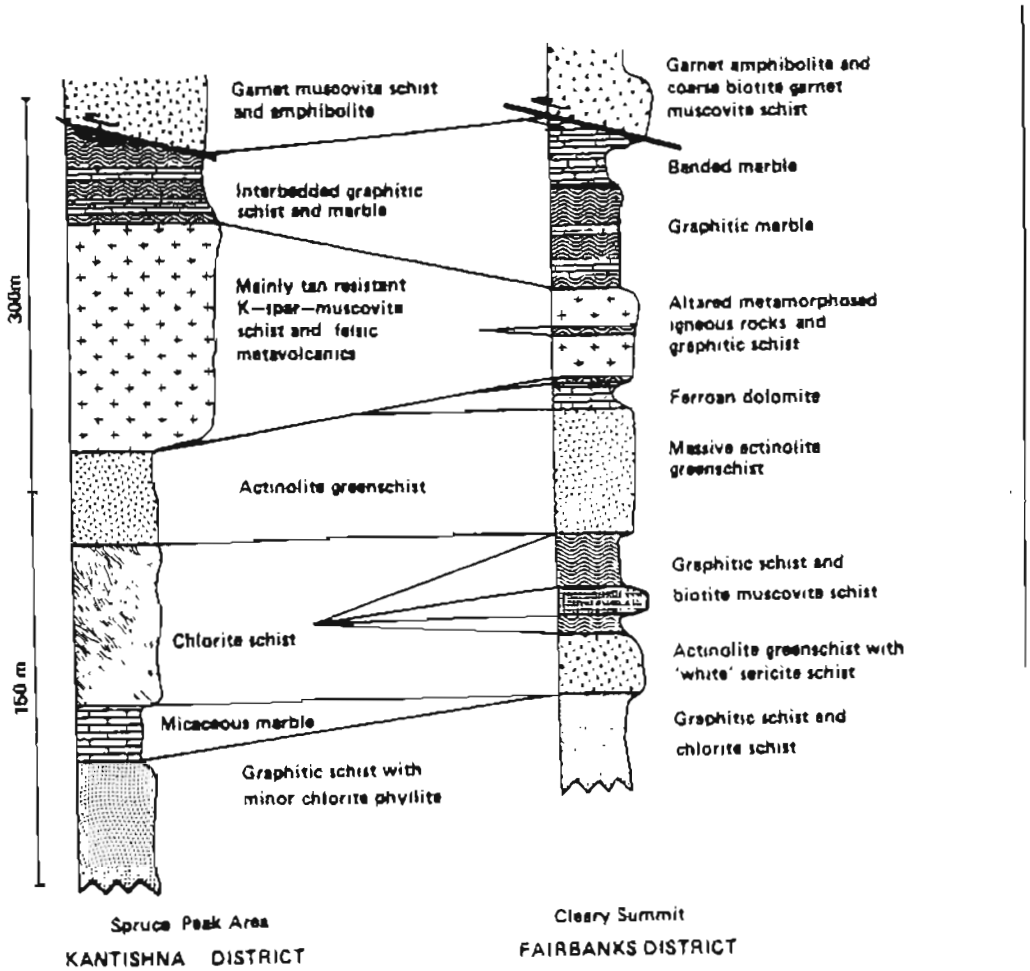
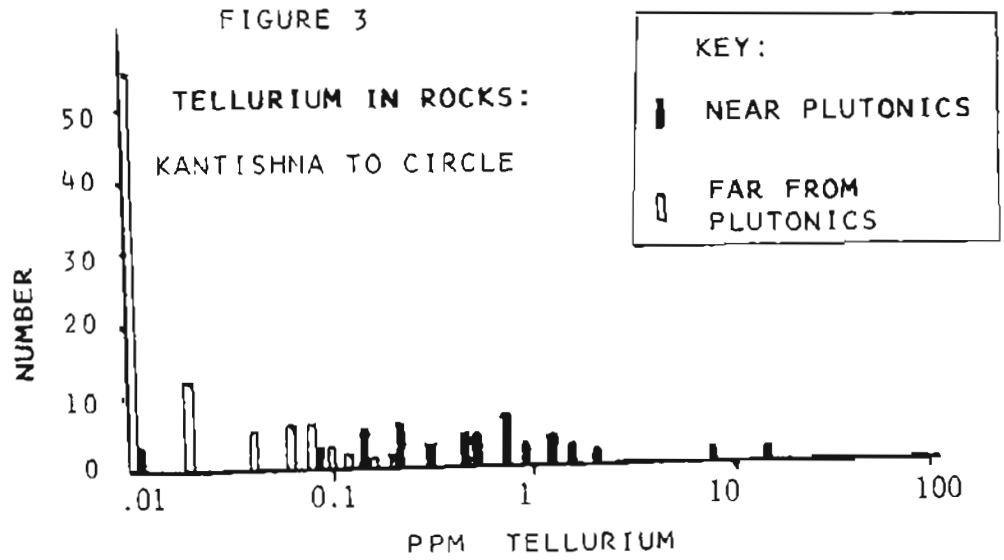


Fig. 2 Stratigraphy of Cleary Sequence in the Fairbanks & Kantishna areas
Bundtzen, writ. comm., 1987



Several lines of evidence (described in greater detail in Newberry et al., 1988) indicate that some veins and stratabound Au anomalies are causually related to some of the plutons. These lines of evidence include the following:

1. High--up to 16 ppm--tellurium values (generally not characteristic of submarine volcanogenic systems) are commonly present in rocks and ores near some plutons in the area (Fig. 3), but are low in Cleary Sequence lithologies away from plutons, dikes, and visibly altered rocks.

2. High tin and tungsten vaues are common in veins and rocks near some plutons (Figs.4, 5), but values of <50 ppm are characteristic of Cleary Sequence away from plutons (Fig. 5).

3. Compositionally zoned tourmalines--similar to tourmalines seen around volcanogenic deposits world-wide--are characteristic of Cleary Sequence away from plutons, but compositionally unzoned tourmalines are common in veins and stratabound occurrences near plutons (Fig. 6).

4. Pb isotope ratios for veins and stratabound bodies near plutons are similar to values for the plutons (Fig.7) whereas Pb isotope ratios for stratabound occurrences far from plutons (Fig. 7) are quite different from plutonic ratios.

5. S isotope ratios for veins and stratabound bodies near plutons are close to "magmatic" values (Fig. 8); stratabound bodies far from plutons have sulfur isotope ratios similar to early Paleozoic VMS deposits from around the world (Fig. 8); and stratabound bodies at intermediate distances from plutons have intermediate S isotope ratios (Fig. 8).

6. Compositions (Figs. 9, 10) of minerals (arsenopyrite, sphalerite, white micas, carbonates) from some stratabound deposits near plutons (e.g., Eldorado deposit, Cleary area) indicate low P/T conditions of deposition (T~300-350 C, P < 1 kb), compatible with fluid inclusion data for veins, but dissimilar from P/T conditions for regional metamorphism (T~450-500 C, P > 3 kb) in the gold belt. Compositions of these same minerals from stratabound deposits far from plutons (e.g., Lloyd prospect, Kantishna) yield P/T compatible with regional metamorphic conditions.

The available data suggest that (1) volcanogenic and remobilized volcanogenic (2) plutonic-hydrothermal and (3) mixed volcanogenic and plutonic-hydrothermal deposits are present in the NSGB

Fig. 4. Distribution of anomalous Sn & W in veins, northern Fairbanks district

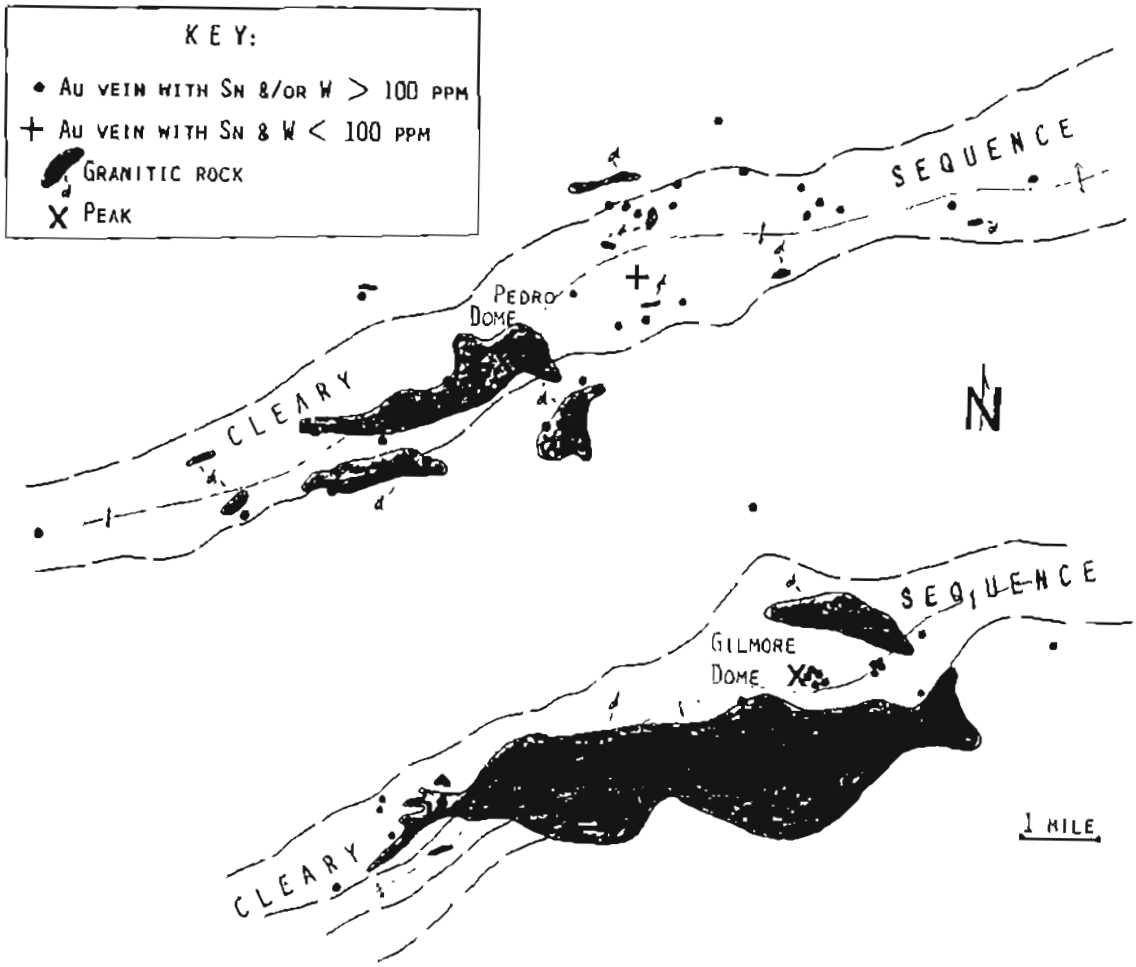
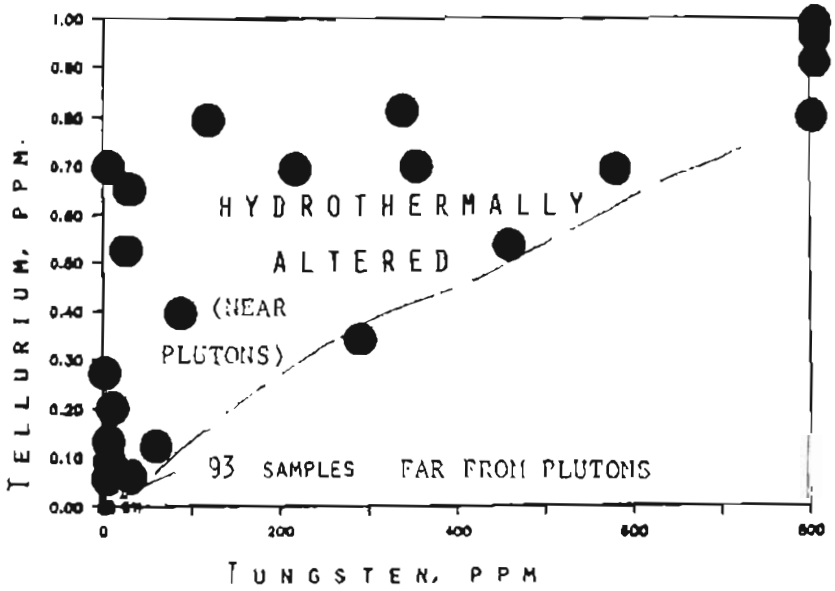


FIG. 5

Te vs. W, Cleary Sequence



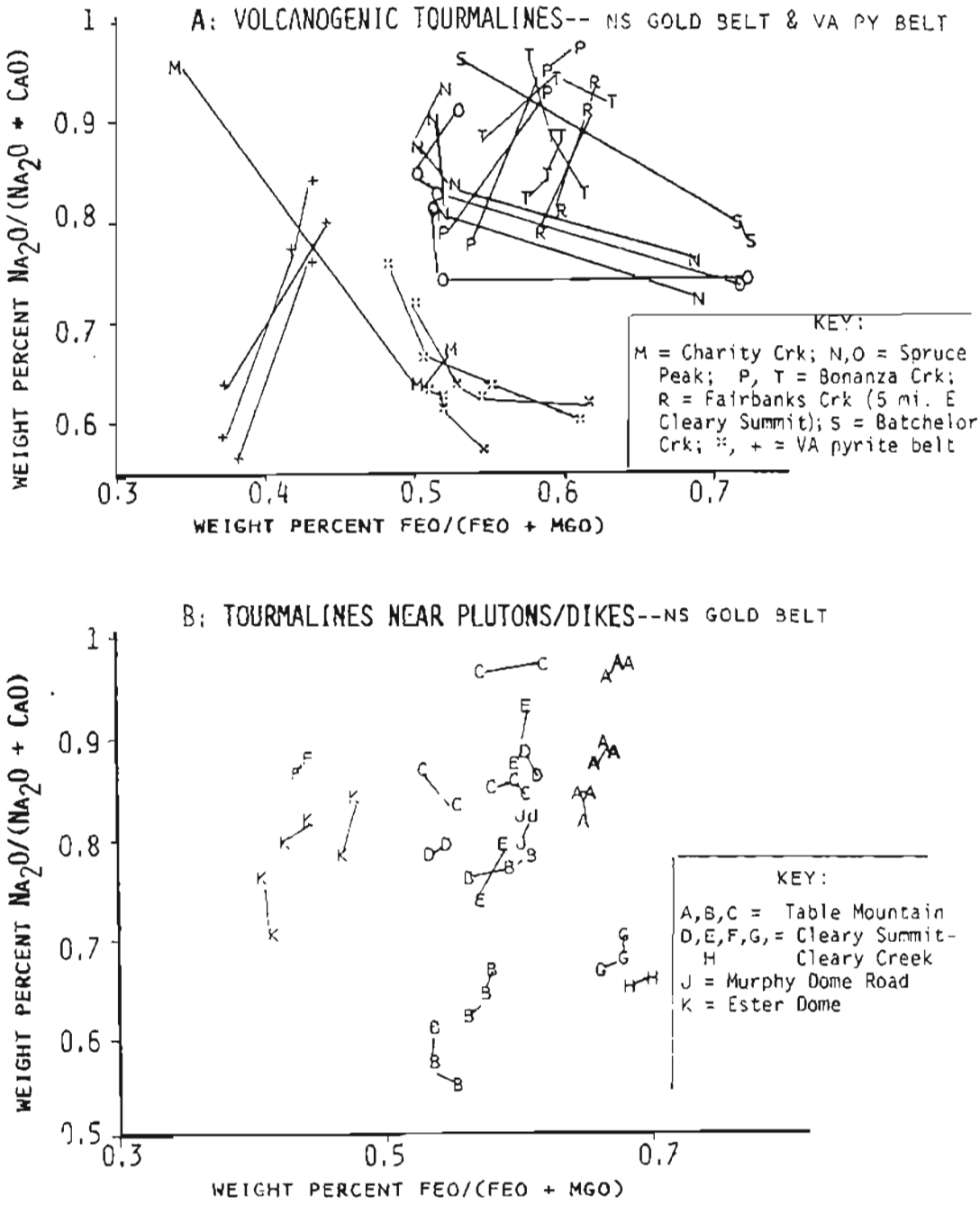


Figure 6: Compositional zoning (via microprobe analysis) of tourmalines near (B) and far (A) from plutons, North Star Gold Belt area. Note minor compositional zoning (short core-to-rim compositional tie-lines) in near-plutonic tourmalines (B) and major compositional zoning (long tie-lines) in volcanogenic tourmalines, far from plutons (A). Tourmalines from the Va pyrite belt are volcanogenic tourmalines for comparison to NSGB.

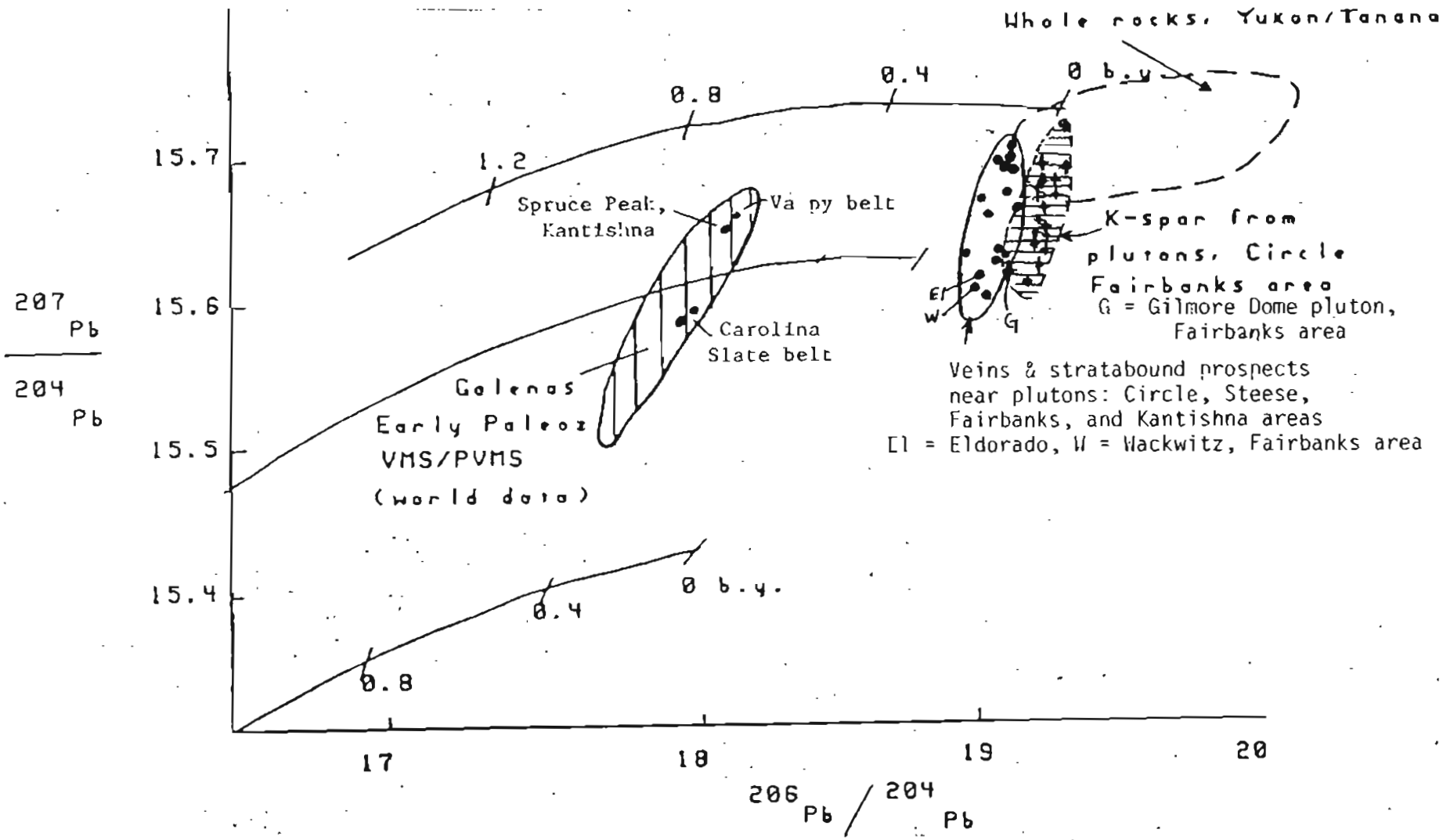


FIGURE 7: Pb isotope ratios for ores (dots) and plutonic K-feldspars (crosses) from the North Star Gold Belt and Virginia - Carolina belts (ores) and from the Yukon-Tanana Terrane (plutons). Note that the Spruce Peak prospect has ratios like the Va-Ca belts; stratabound & vein deposits near plutons have plutonic & near-plutonic ratios.

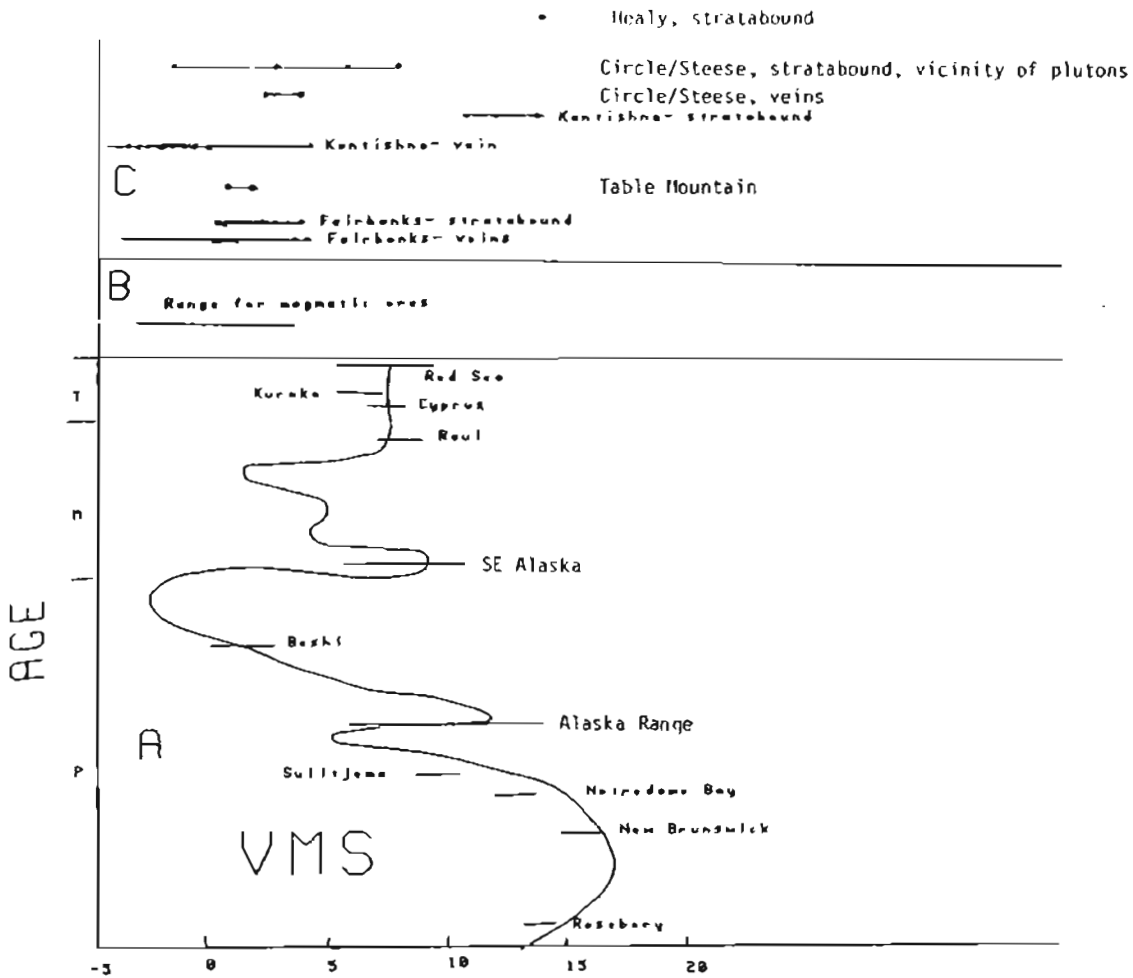


FIGURE 8: Sulfur isotope ratios of NSGB ores (C) compared to plutonic-associated ores (B) and submarine volcanogenic ores (A). Note that stratabound ores in the NSGB area far from plutons have S isotopic ratios similar to early Paleozoic VMS; stratabound and vein ores near plutons have ratios similar to plutonic-associated; and stratabound ores at intermediate distances from plutons (Circle/Steese areas) have intermediate S isotopic ratios--possibly reflecting mixing of VMS- and plutonic-derived sulfur

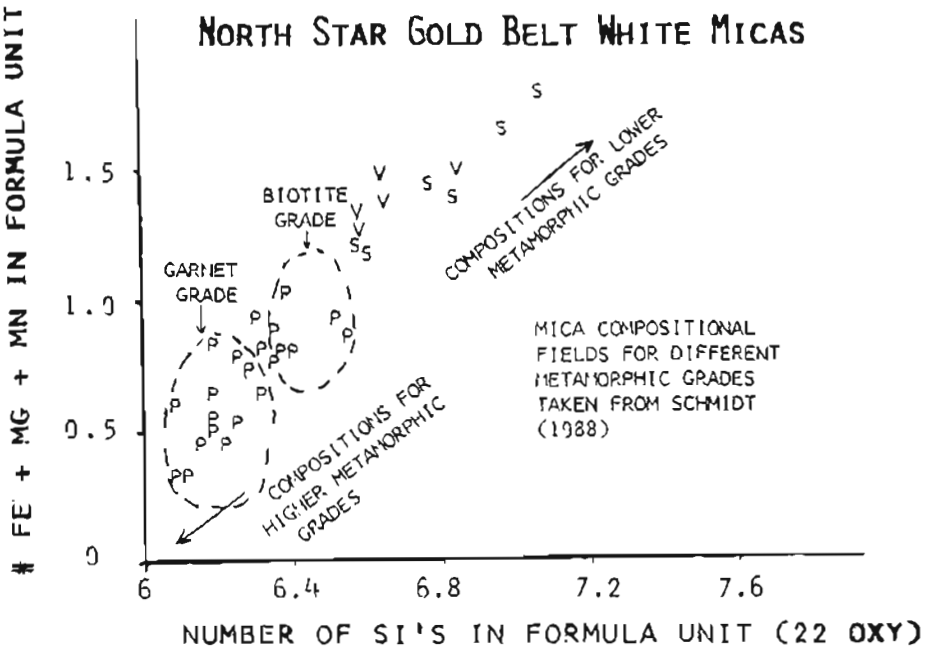


Figure 9: Compositions of primary metamorphic (P) white micas from Cleary Sequence rocks (including white schist from the Eldorado prospect), showing overlap with the biotite and garnet grade compositional fields (after Schmidt, 1988), in agreement with the biotite to garnet grade metamorphism of these rocks. Compositions of vein (V) white micas from the Fairbanks area and stratabound (S) white micas from the Eldorado prospect indicate formation at sub-biotite grade conditions. These data are compatible with V and S mica formation during the low P/T Cretaceous intrusive event but are incompatible with a simple regional metamorphic history for the Eldorado prospect.

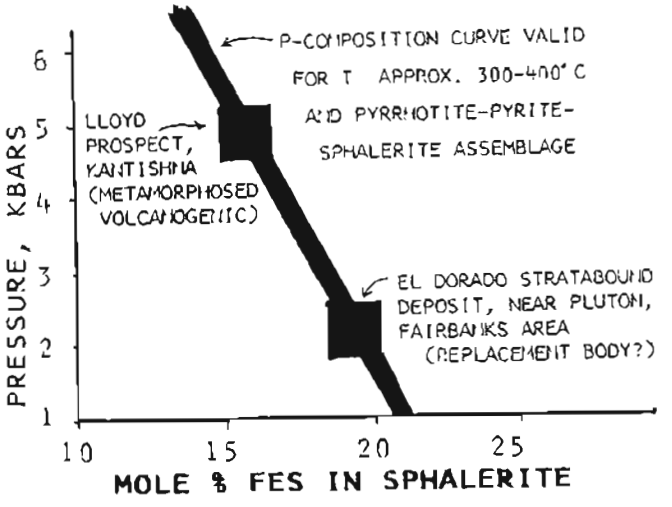


Figure 10: Compositions of sphalerite from the Eldorado stratabound prospect (near pluton; Fig. 13) indicating a low pressure environment of formation, contrasted with the Lloyd volcanogenic prospect, which has experienced moderate-pressure metamorphism.

area. "Type" examples of each end member lode deposit source and the more common mixture of sources are given below.

The Spruce Peak Mineralized zone, Kantishna Hills: a metamorphosed volcanogenic prospect

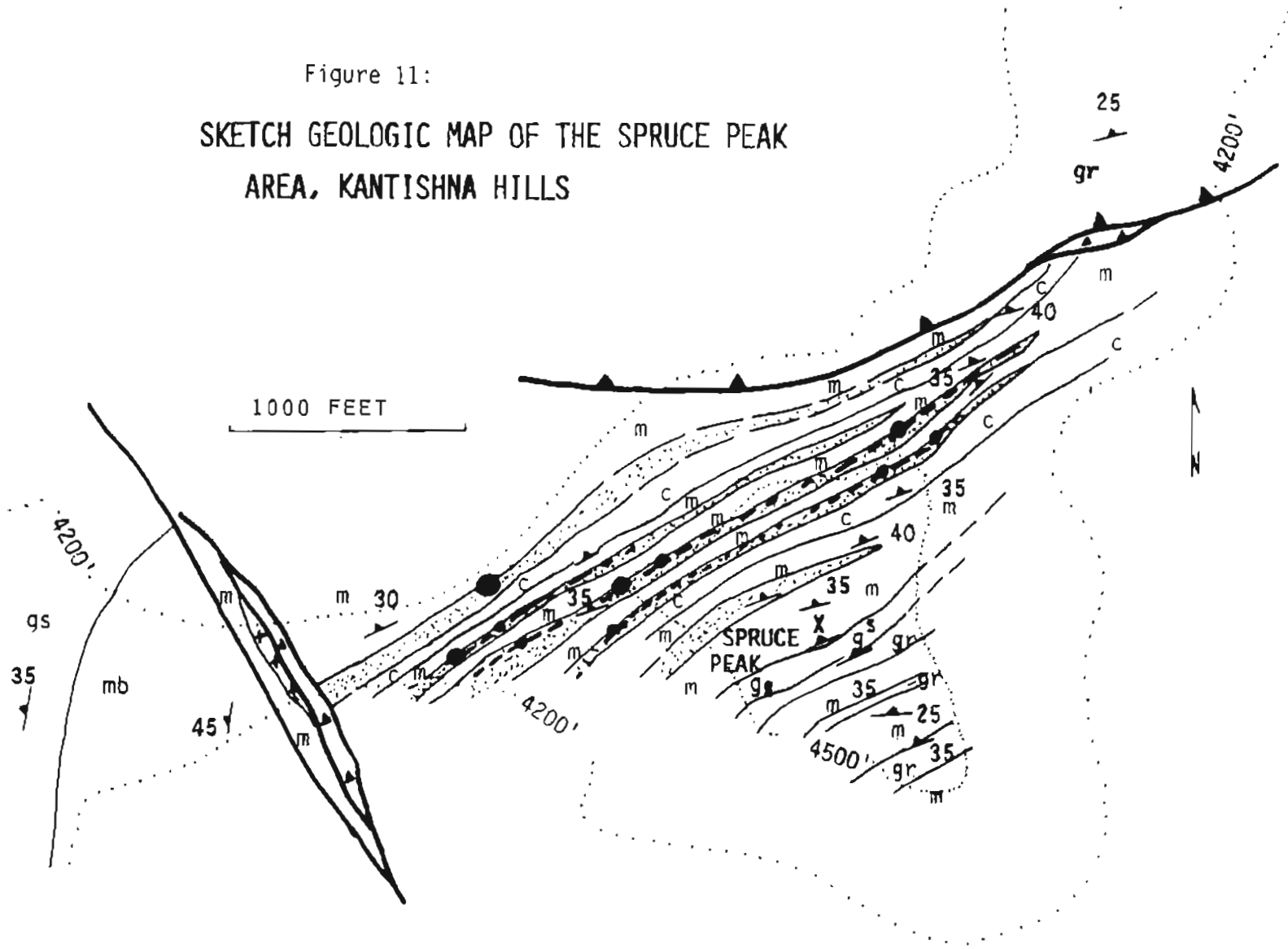
Spruce Peak (Fig. 1) is an example of a volcanogenic prospect--with little plutonic complication--in the NSGB area. A geologic map (Fig. 11) of the Spruce Peak area (modified in part from Bundtzen, 1981) shows a NE-striking, NW-dipping, sequence of metamorphic rocks dominated by chlorite-rich (mafic to intermediate) and feldspar-quartz-rich (felsic) lithologies interpreted as metavolcanic rocks. Zoned tourmalines are common in the felsic schists. Stratabound gold occurs in pyritic quartzites (metacherts?) and in pyritic felsic schists (meta-altered felsic volcanic rocks?), spatially associated with felsic schists. Non-stratabound gold is also present, as mineralized fault zones and replacements (?) in sparse carbonate rocks, near both the faults and a Tertiary(?) dike.

Several discrete gold-bearing horizons appear to be present (Fig. 11) with mineralization strike lengths of 500 m - 1 km and widths of .5 - 2 m. Exposures are not adequate to establish whether these are originally different lenses or are isoclinally folded exposures of a single mineralized layer. Assays indicate the pyritic cherts are locally enriched in As (up to 1%), Ba (up to .3%), Sb (up to 80 ppm), and Zn (up to 300 ppm). Gold grades vary considerably in rocks of the Spruce Peak area, from < 10 ppb to > 5 ppm, but grades of 0.3 ppm to 1 ppm are consistantly present in two of the more laterally extensive horizons (Fig. 11). Although no systematic sampling or exploration has been attempted, the observed continuity of mineralized outcrop implies that tonnages of 0.1 - 1 million tons with grades of .1 - 1 ppm Au are likely to be present.

Geochemical examination of the Spruce Peak area shows low (< 20 ppb) Te and low (< 70 ppm) W and Sn, both in mineralized and un-mineralized rocks, features characteristic of Cleary Sequence away from plutons. Samples from a carbonate replacement near a vein have near-plutonic S and Pb isotope ratios, while a sample from a pyritic chert far from the fault has a typical early Paleozoic VMS Pb isotope signature (Fig. 7). White micas in felsic schists have low celadonite components, indicative of mid-greenschist facies metamorphism (Fig. 9). Tourmalines from sulfidic quartzites (Fig. 6) are strongly zoned, similar to tourmalines from other VMS deposits worldwide.

Figure 11:

SKETCH GEOLOGIC MAP OF THE SPRUCE PEAK AREA, KANTISHNA HILLS



KEY:

- + MAFIC DIKE
- ▲ QUARTZ VEIN
- STRATABOUND PYRITIC CHERT (META-EXHALITE?)
- CHIP/GRAB SAMPLE WITH
  - ● >.3 PPM AU
  - ● >1 PPM AU
  - ● >5 PPM AU

- gs GREENSCHIST (CHL-ACTINOLITE SCHIST
- mb MARBLE
- m MICA (MUSC>BIO>CHLORITE) SCHIST
- gr GRAPHITIC SCHIST
- c CHLORITE±MUSCOVITE SCHIST
- PYRITE-MUSCOVITE-FELDSPAR-QUARTZ SCHIST (FELDSPATHIC SCHIST)
- / FAULT

The Table Mountain Mineralized Zone, Steese Area: an epigenetic, hydrothermal Au prospect

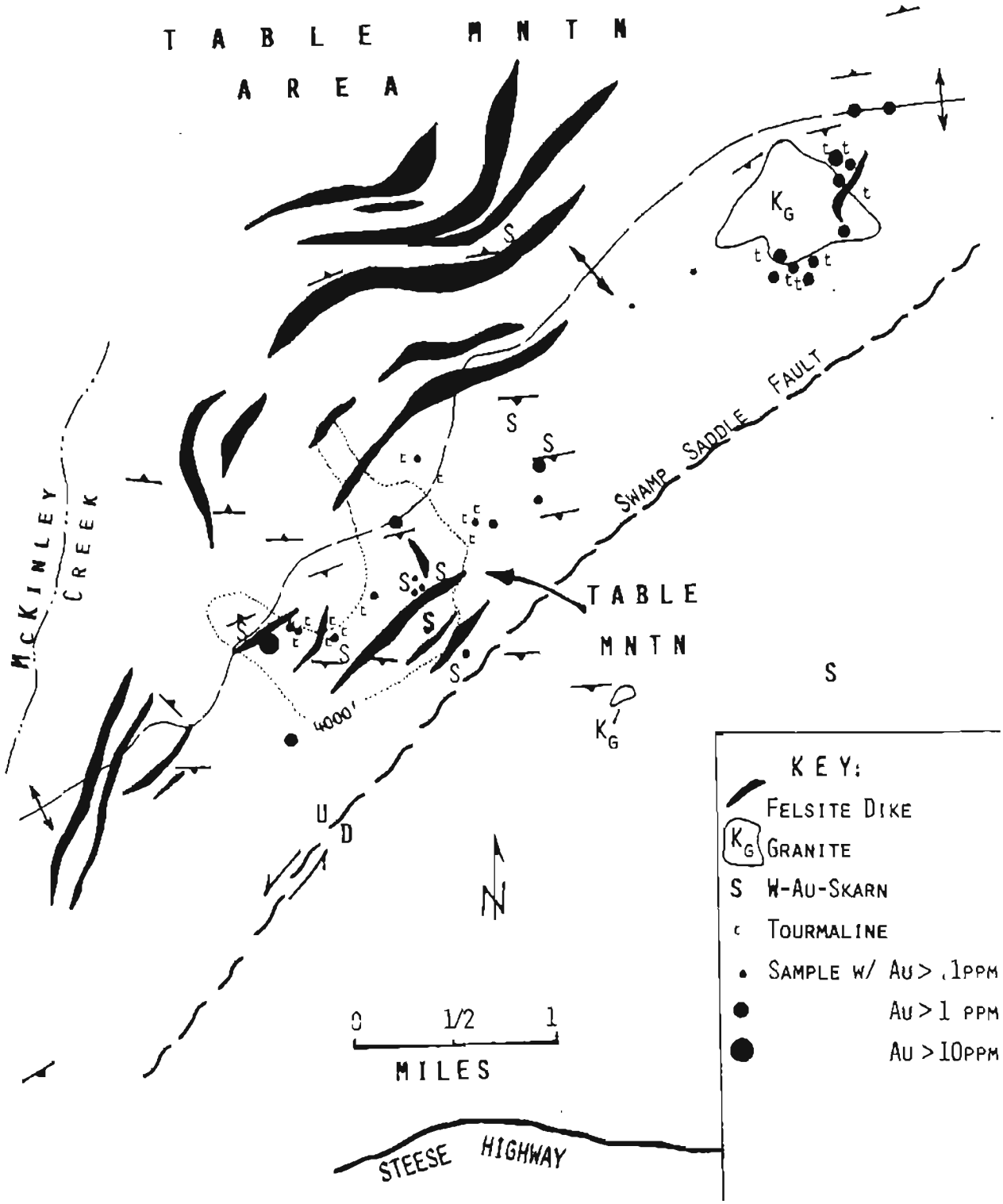
Geology and mineralization in the Table Mountain area are discussed more thoroughly in Menzie et al. (1987) and Newberry (1987): some salient points are abstracted here. The Table Mountain area (Fig.1) is located along an antiform formed of quartzite, chlorite-biotite-quartz schist, calc-schist, and marble (Fig. 12). These lithologies are typical of the Fairbanks schist; none of the diagnostic metavolcanic lithologies of Cleary sequence are present. Mapping in the Table Mountain area suggests the Table Mountain rocks are approximately 300-500 meters stratigraphically beneath Cleary sequence (Pessel et al., 1987). A mid-Cretaceous (?), sub-equigranular monzogranite stock is present at the north end of the area, and a younger swarm of strongly altered, slightly alkalic (Burns et al., 1987) felsite dikes occurs throughout the area.

Mineralization in the Table Mountain area (Fig. 12) occurs as W-Au skarns, interpreted as older than the felsite dikes, (Newberry, 1987), tourmaline-sulfide-quartz veins, and sulfide-rich, hornfelsed biotite quartzites . The skarns are dominated by high-iron pyroxene and lesser subcalcic garnet (Newberry, 1987), similar to "reduced" tungsten skarns worldwide. Gold grades of up to 1 ppm and tungsten up to .7% have been identified, with highest grades in the pyroxene-rich skarns.

Quartz-tourmaline veins are most abundant near the antiform axis (Fig. 12). Other minerals present include pyrrhotite, arsenopyrite, scheelite, carbonates, stibnite, and tellurium minerals (the latter identified from assay results). Grab samples of vein material contain up to 13 ppm Au. Sulfide-rich schists occur throughout the Table Mountain area. These rocks contain 3-5%, stratiform to slightly cross-cutting, 1-5 mm long, sulfide "streaks". Sulfides commonly replace cordierite/feldspar porphroblasts in the quartzites and schists. High arsenopyrite and gold contents in these rocks are limited to exposures near dikes and near the monzogranite stock.

The best mineralized areas currently known in the Table Mountain area constitute two zones, one about 1/2 mile x 1 1/2 miles, centered on Table Mountain, and the other about 1/2 mile x 1/2 mile, centered on the Pinnell Mountain monzogranite (Fig. 12). Large reserves of mineralized rock with grades in the .1 - 1 ppm Au range are probably present in this area (Pessel and Newberry, 1987).

FIGURE 12: SIMPLIFIED GEOLOGIC MAP OF THE TABLE MOUNTAIN AREA



High tellurium (up to 16 ppm), W (> 1%), and Sn (> 250 ppm) in veins/breccias in the area identify the mineralization as being related to plutonic-hydrothermal activity. Near 0 per mil sulfur isotopic ratios also suggest a plutonic-hydrothermal mineralization system. Tourmalines with little compositional zoning (Fig. 6), different from VMS-type tourmalines, are characteristic and again suggest an origin independent of volcanogenic activity. High salinity, low CO_2 fluid inclusions (Menzie et al., 1987) in quartz-tourmaline veins also most likely indicate a plutonic-hydrothermal source.

The mineralogy-metallogeny of the Table Mountain mineralization is similar to world-wide plutonic-related gold mineralization (Table I). Given the stratigraphic setting (below Cleary Sequence) and the abundant evidence for plutonic- hydrothermal activity, the Table Mountain mineralization is a clear end-member example of a plutonic-hydrothermal system in the NSGB.

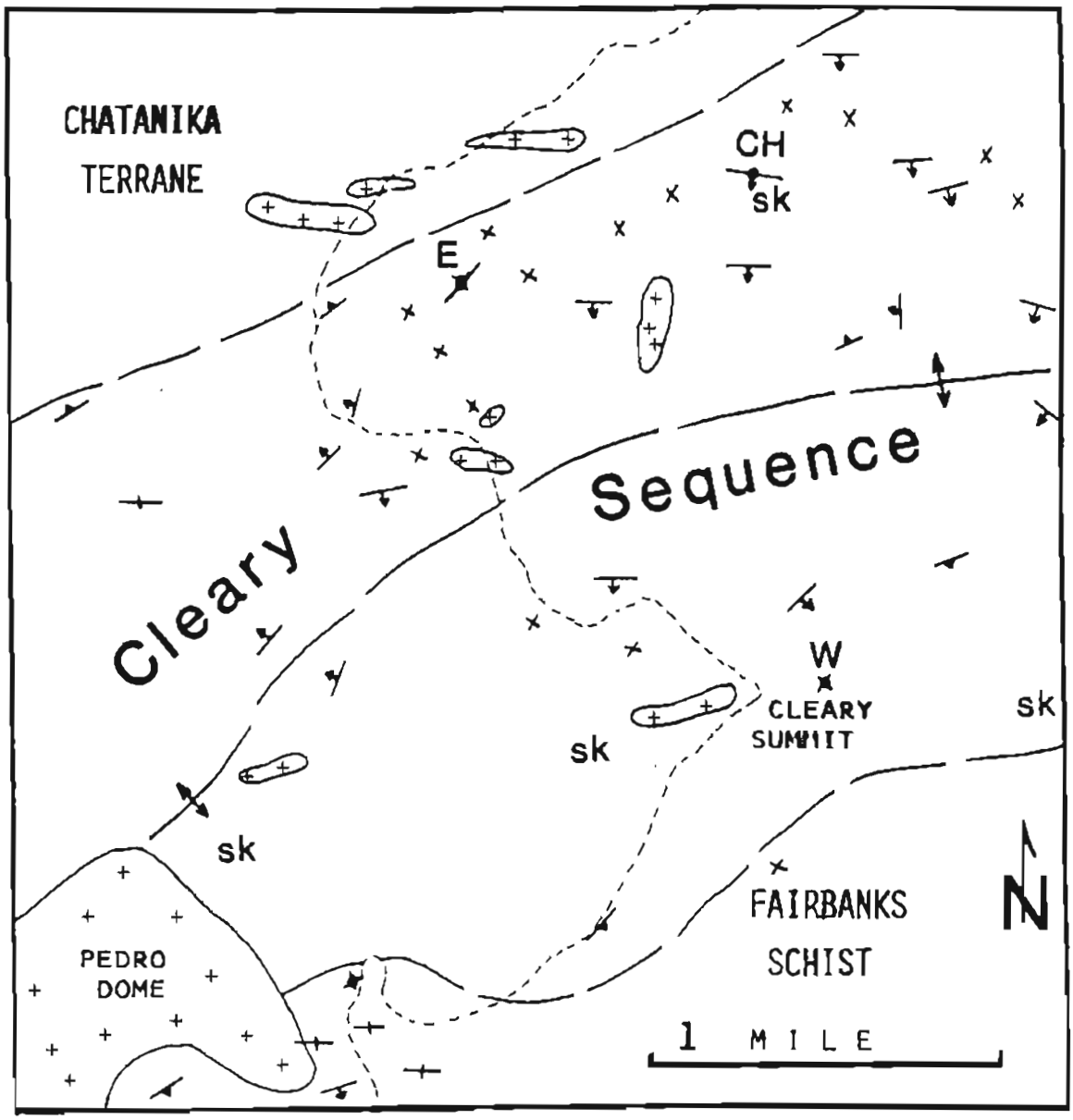
The Pedro Dome - Cleary Creek Mineralized area; Mixed (?) epigenetic/volcanogenic deposits

Mineralization in the Pedro Dome - Cleary Creek area is centered on the intersection of an antiform in Cleary sequence rocks with a NW-trending belt of granitic dikes (Fig. 13). Most of the major deposits are located in Cleary Sequence and near plutonic/dike rocks. Cleary Sequence in this area contains abundant feldspathic quartz schist (meta-felsic volcanics), amphibolites (meta-mafic volcanics), and biotite-chlorite-muscovite-quartz schists (meta-greywacke ? and meta-intermediate volcanic?), with minor limestone beds. Both zoned and unzoned tourmalines are present (Fig. 6); high tourmaline abundances have been noted in some of the veins.

The plutonic rocks of the Pedro Dome - Cleary Creek area are variably altered, medium to coarse-grained, granodiorite and granite. Dikes are biotite-quartz porphyries of granitic(?) composition. Small pyroxene-rich skarns ("sk", Fig. 13) are present in the vicinity of plutons and dikes.

Pedro Dome - Cleary Creek mineralization has been described in the older literature as veins and limestone replacement bodies (jasperoids); more recent workers have suggested that the stratiform siliceous pyritic rocks are meta-exhalites and that the mineralization is volcanogenic-derived. Ore specimens from the Eldorado deposit ("E", Fig. 13) are laminated galena-sphalerite-quartz-white mica-carbonate rocks; dump specimens from the Cleary Hill mine (CH, Fig. 13) include quartz-sulfide-

FIGURE 13: SIMPLIFIED GEOLOGY OF THE PEDRO DOME-CLEARY CK. AREA



K E Y:

GRANITIC ROCK

FOLIATION

VEIN W/ ATTITUDE

X VEIN WITHOUT ATTITUDE

• VEIN W/ ANOMALOUS Te

VEIN DEPOSITS:

CH CLEARY HILL

E ELDORADO

W WACKWITZ

Sk SKARN OUTCROP/FLOAT

carbonate vein material, laminated sulfidic chert, veined and sericitized feldspathic quartz schist, marble, and pyroxene skarn. Ores from the other deposits are mostly quartz veins in schist and minor skarn.

Compositional data suggest some of the mineralization is related to igneous processes. Most of the veins in the area contain anomalous W and/or Sn (Fig. 4) and several contain anomalous Te (Fig. 13). Arsenopyrite from sulfidic chert (Cleary Hill mine) contains 30.5-30.6 Atomic % As, which implies temperatures of deposition of about 300-350 C; sphalerite from layered sulfide ore at El Dorado is high-iron, yielding formation pressure of about 1 kb. White mica from laminated El Dorado ore is very high in celadonite component (Fig. 9), indicating much lower P/T conditions of formation than the surrounding (upper greenschist) metamorphic rocks. Finally, carbonate from the laminated El Dorado ore is a high-Mn ankerite, dissimilar from regional carbonates, but similar in composition to carbonates from replacement deposits such as Gilman, Colorado and East Tintic, Utah (Laznicka, 1986).

Pb isotope ratios from layered sulfide ore from Eldorado and vein ore from Wackewitz (W, Fig. 13) are similar to Pb isotope ratios from nearby plutonic rocks (Fig. 7) and dissimilar from early Paleozoic VMS (e.g., Kish and Feiss, 1982). S isotope ratios from both vein and stratiform ores (Fig. 8) are more compatible with magmatic sulfur than with early Paleozoic VMS sulfur.

In summary, geochemical, mineralogical, and isotopic data indicate there is definitely a hydrothermal-plutonic component to both vein and stratiform ores in the Pedro Dome - Cleary Creek area. The fact that mineralization is largely limited to Cleary sequence lithologies, the presence of "exhalative-looking" rocks, and the presence of well-zoned (VMS type?) tourmalines in the general area all point to a volcanogenic component to the ores as well.

II. SOUTHERN APPALACHIAN GOLD BELTS OF CAMBRIAN-EOCAMBRIAN AGE: ANALOGS TO THE "CLEARY SEQUENCE" OF INTERIOR ALASKA

General characteristics

Numerous belts of late Proterozoic to mid-Paleozoic volcanogenic massive sulfides +/- gold veins are recognized in the Appalachian- Caledonian region of the northern hemisphere. Stephens et al. (1984) recognize that these belts are associated with volcanic sequences of varying ages and tectonic settings. Sangster (1984) has shown that the metallogeny and grade/tonnage characteristics of the deposits in these belts vary with the age and tectonic setting of the volcanic rocks, hence not all the VMS/gold belts are good analogs to the NS Gold belt.

Of the various Appalachian-Caledonian mineral belts, those of the SE Piedmont region, U.S.A. are broadly similar in age and tectonic setting to the North Star Gold Belt (Abrams and McConnell, 1984; Neathery and Hollister, 1984). These SE Piedmont belts (Fig. 14) are the Ashland-Wedowee belt (Alabama-Georgia), the Dahlonega gold belt (Georgia), the Kings Mountain Belt (N. Carolina-S. Carolina), Carolina slate belt (N. Carolina-S. Carolina-Georgia) and the Virginia pyrite belt (Virginia-Maryland). Of these 5 belts, the most "outboard" two, the Virginia pyrite belt and the Carolina slate belt, are closest in age and setting, and, as described herein, are the best available analogs to the NSGB. These two belts, referred to herein as the Virginia (VA) and Carolina (CA) belts, will be considered in greater detail.

The Virginia and Carolina belts consist of late Proterozoic to mid-Paleozoic rocks, as indicated by Pb-U dating of zircons in metafelsites and by fossil and stratigraphic evidence. Ranges in Pb-U ages are 740- 520 m.y. (Feiss, 1982). Each belt consists of sub-belts, containing volcanic rocks of contrasting age and somewhat contrasting tectonic setting. The CA belt, for example, has been subdivided into the 'Older' belt (740-620 m.y.) with clear calc-alkalic arc affinities and the 'Younger' belt (580-520 m.y.) with primitive arc/fore arc affinities (Bland, 1978). Portions of the VA and CA belts may be en echelon segments of the same belt, but there is no consensus in the literature.

The lithologies present in the CA and VA belts are dominated by pelitic schists (or higher grade equivalents), amphibolites, and felsic metavolcanics. Intermediate composition metavolcanic rocks are difficult to recognize, due to absence of distinctive characteristics, but are thought to be approximately

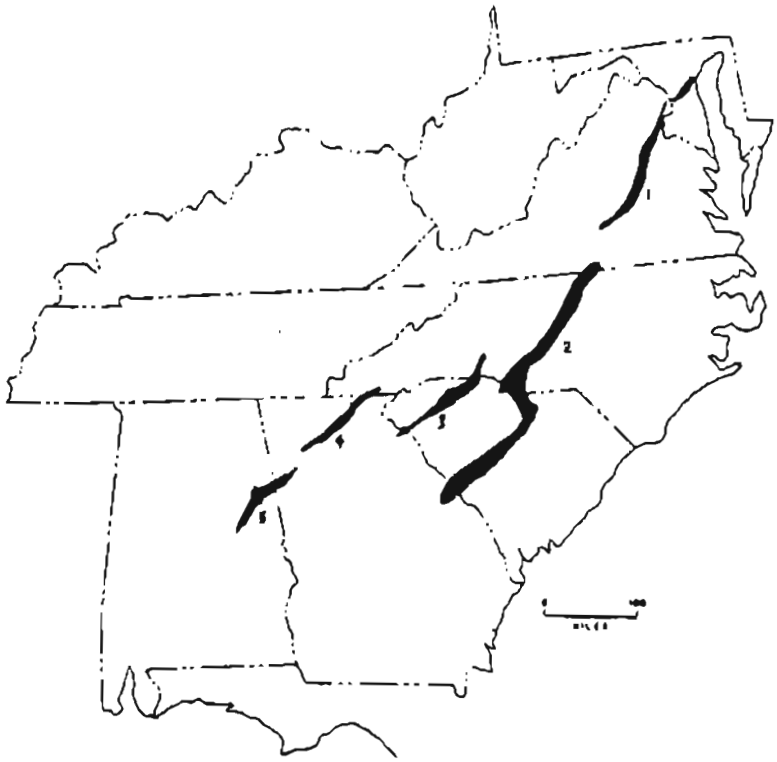


Figure 14: late preCambrian-early Paleozoic volcanogenic gold belts of the SE US Piedmont. 1= Virginia pyrite belt, 2 = Carolina slate belt, 3= Kings Mountain belt, 4 = Dahlonega belt, 5 = Ashland-Wedawee belt

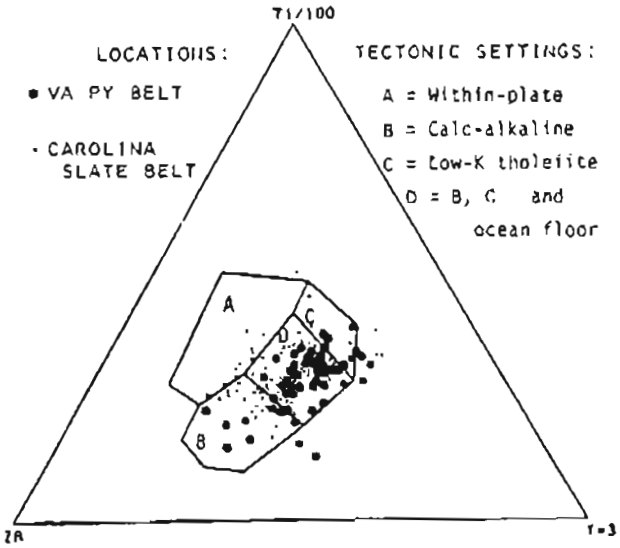


Figure 15A: Ti-Zr-Y diagram for metabasaltic rocks of the Va pyrite and Carolina slate belts, showing generally non-rift affinities for these rocks

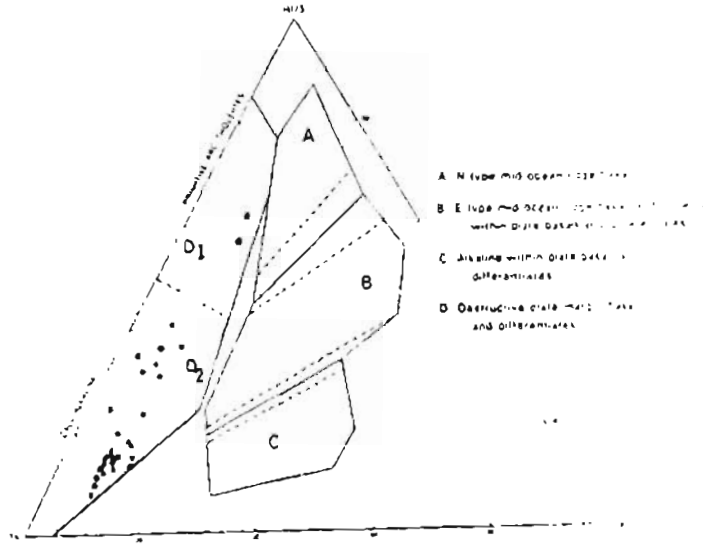


Figure 15B: Th-Hf-Ta diagram for metavolcanic rocks of the Virgina pyrite belt, showing calc-alkalic affinities for these rocks

as abundant as the mafic rocks and considerably less abundant than felsic rocks (Pavlides et al., 1982; Feiss, 1982).

The Chopawamsic Formation in the northern part of the Virginia belt is a typical example of the Virginia-Carolina belts. It is about 2000 meters thick. Commonly it consists of about 50% quartitic and intermediate volcanic(?) schist, 15% amphibolite and 35% felsic (metavolcanic) schist. Small amounts of carbonate rock are also present. Most of the metasedimentary rocks have compositions which indicate a greywacke protolith although metamorphism obscures original sedimentary structures (Pavlides et al., 1982). Metavolcanic rocks have very limited strike continuity; the formation is characterized by erratic changes in lithology along strike (Pavlides, 1981).

Most workers have noted calc-alkalic affinities for the Virginia- Carolina belt volcanic rocks, based on major and immobile trace element abundances, and call on an island arc setting for the belts (Black, 1977; Bland, 1978; Whitney et al., 1978; Pavlides, 1981; Rogers, 1982; Feiss, 1982). Such features include generally low Ta, light REE, and Ti contents (e.g., Fig. 15), which rule out exclusively alkalic and MORB affinities. As discussed by Bland (1978) and Rogers (1982), the low-andesite (bi-modal) character of the CA-VA belt rocks is compatible with primitive arc, fore-arc, back-arc, and rifted arc settings, and does not--in the absence of confirming trace element data--indicate a rift setting. There are, however, some variations in trace element chemistry, such that individual sub-belts probably represent somewhat different tectonic settings, e.g., the Albemarle portion of the CA belt (Fig. 15) , which has some within-plate basalt affinities. These geochemical features make settings involving rifting alone not viable, although there may be some rift component to some portions of some belts.

All the SE Piedmont gold belts contain some small (.1-5 million tons) volcanogenic massive sulfide deposits, most of which are enriched in Zn> Pb~Cu. Pyrite-pyrrhotite-gold rich massive sulfides (lacking appreciable base metals) are also present. The Carolina belt also contains stratabound gold in sericitically altered felsic metavolcanic/metaplutonic(?) rocks, which are thought to represent hot-springs altered, hypabyssal felsic intrusions (Klein and Criss, 1988) or exhalites (Worthington and Kiff, 1970; Butler, 1981). These rocks are siliceous quartzites and sericite-rich feldspar-quartz schists, with disseminated pyrite, and minor pyrrhotite, sphalerite, galena, chalcopyrite, and bismuth minerals. Stratabound tourmaline is present with many of the stratabound gold deposits, especially those in the Virginia belt. The tourmaline characteristically possesses strong compositional zoning (Fig. 6).

Tellurium is usually present in only small amounts (< 1- < < 1 ppm) in deposits of the CA-VA belts. Four samples from the Va-Ca belts analyzed for this study all had < .02 ppm Te. The Brewer deposit,

S.C.--which has been interpreted as an early Paleozoic hypabyssal intrusive/breccia pipe complex (Feiss, 1982b)--has high topaz, tellurium, fluorine, uranium, lanthanum, and tin contents. This deposit is not typical of the VA-CA belts, either geologically or geochemically. Other deposits of the belts have low Sn and lack topaz (Carpenter, 1976). Tungsten is uniformly low in all known deposits of the VA-CA belts (Pardee and Park, 1948).

Gold deposits in the SE Piedmont belt include both volcanogenic deposits (as above) and more commonly, vein deposits. As illustrated for the Virginia pyrite belt (Fig.16), the distribution of the vein Au deposits is complicated, as the belt of gold vein deposits is not entirely restricted to the belt of volcanic rocks and volcanogenic deposits. Also, a few gold veins occur in and near younger plutonic rocks. For example, the Telluride deposit in the Mineral district is located adjacent to, and thought to be genetically related to, the Columbia pluton (Pardee and Park, 1948).

Mineralogically, gold-bearing veins of the SE Piedmont area contain mostly quartz. Pyrite is the most common sulfide, but chalcopyrite, sphalerite, galena, and arsenopyrite are widely distributed in small amounts. Bismuth minerals occur at many deposits, as do carbonate minerals. Telluride minerals and fluorite are notably absent, except where deposits are in and adjacent to granites.

Pb isotope data suggests that veins far from plutons in the VA-CA belt were derived from VA-CA belt rocks during regional metamorphism (Kish and Feiss, 1982; LeHuray, 1982). As all the veins are small and have had negligible gold production (< 50,000 oz, total for all veins far from plutons in the S.E. Piedmont), their importance lies not in their gold resources but in indicating attributes of metamorphic (vs. plutonic-related) veins in this environment.

Comparison with Cleary Sequence

Cleary Sequence and correlated rocks of the North Star gold belt closely resemble those of the Virginia and Carolina belts in age, general lithologies, and isotopic and trace element characteristics. Age of the Cleary Sequence is late Proterozoic/early Paleozoic, as previously indicated.

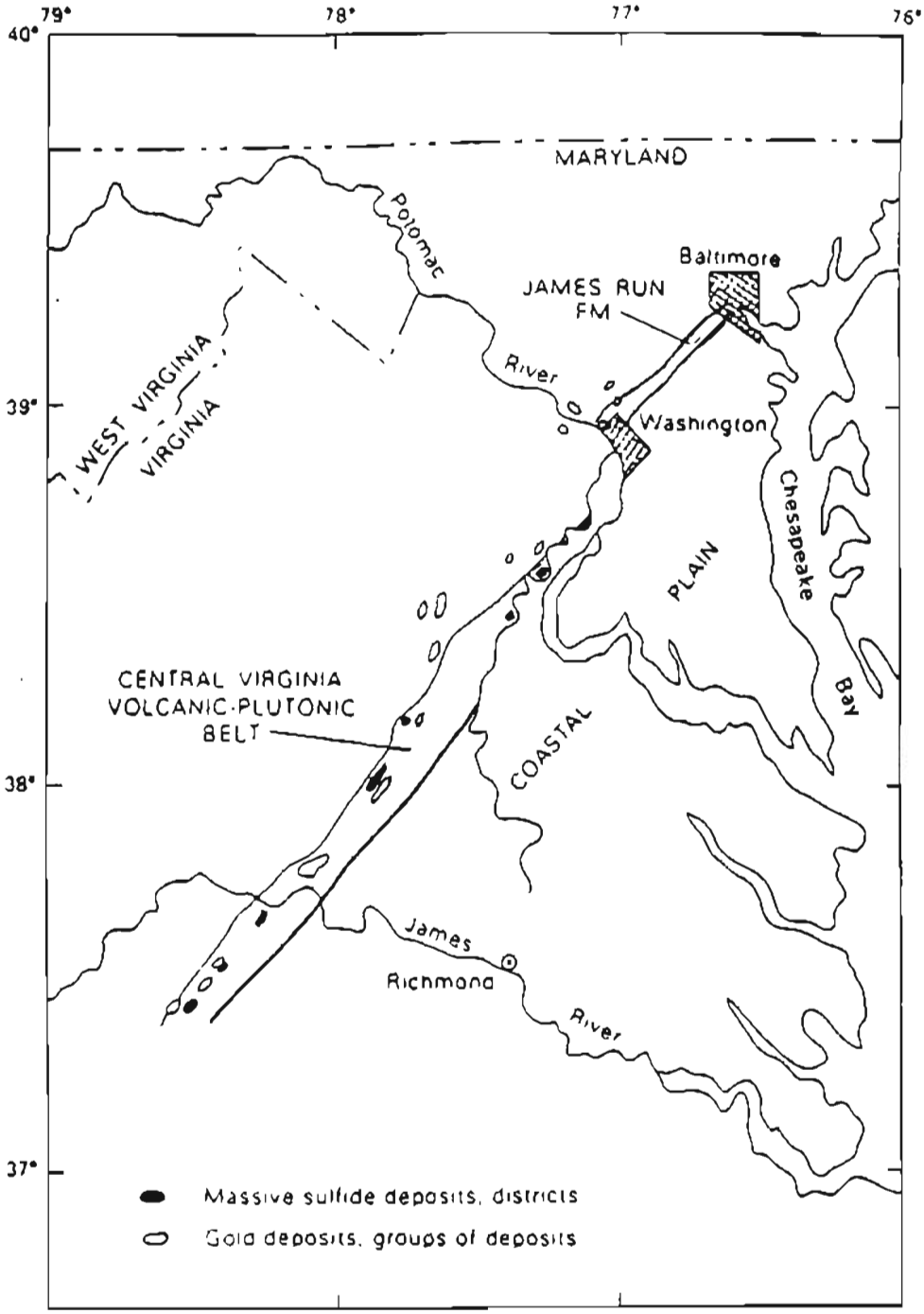


FIG. 16. Generalized map showing the trend of the central Virginia volcanic plutonic belt and the distribution of deposits and groups of deposits of massive sulfides and gold. Taken from Pavlides et al. (1982).

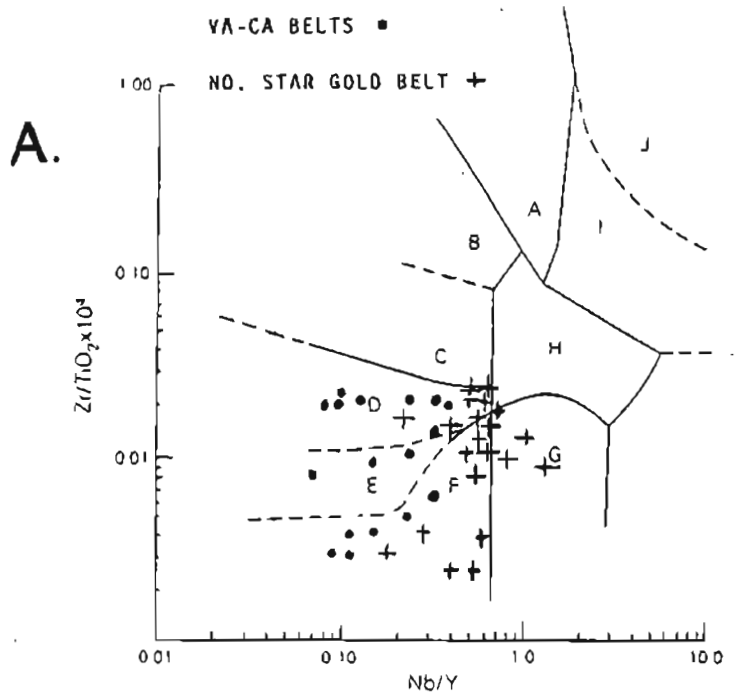
Important mineralogical similarities between the NSGB belt and the Virginia-Carolina belts include the presence of stratabound, zoned tourmaline (Fig. 6) and the virtual absence of stratabound ankerite in both belts.

Although commonly described as a bimodal volcanic package typical of a continental rift (Smith and Metz, 1984), Cleary Sequence and correlated rocks contain chlorite and hornblende-bearing schists with andesitic--as well as basaltic--trace element characteristics (Fig. 17). Compositional data discussed below suggest the Cleary Sequence rocks--similar to VA-CA belt rocks-- are more likely related to a primitive volcanic arc than to a continental rift.

Plots of Cleary Sequence and correlated rocks of the NSGB (Fig. 18) mostly fall in the "calc-alkalic" portion of a Hf-Th-Ta diagram, and the low-K tholeiite/calc-alkalic basalt portions of a TiO2-Zr-Y diagram (Fig. 17b), essentially identical to rocks of the Virginia-Carolina belts (Figs. 15A, 15B). Variations in trace element characteristis, however (Figs. 17, 18) may indicate that the NSGB is a composite belt, like the VA-CA belts, and that several tectonic settings are represented.

Rare earth element plots of mafic rocks from the NSGB and VA-CA belts (Fig. 19) exhibit relatively flat and depleted patterns, similar to those of arc-related tholeiites and different from alkalic and high-K (rift-related) basalts. REE plots for intermediate composition rocks from the NSGB resemble those of the VA-CA belts and continental margin, subduction-related andesites (Fig. 20). Finally, the gradual increase in REE concentration from mafic to felsic rocks of the NSGB (Figs. 19, 20) suggests a geochemical evolution seen in other arc-related volcanic belts.

In summary, trace element parameters indicate a close similarity between the NSGB and the VA-CA belts, and combined with the apparent bi-modality of major oxide compositions, implies some variation(s) on primitive calc- alkalic arc, fore-arc, and/or rifted arc for the overall setting(s). Major oxide compositions of schists and quartzites surrounding the Cleary sequence, plotted on an AFM diagram (Fig. 21) mostly fall in the greywacke field or intermediate between greywacke and shale, suggesting an arc-derived provenance for these meta-sedimentary rocks. Such a provenance would be most compatible with a fore-arc setting for most of the known Cleary sequence.



Fields are A, comendite and pantellerite; B, rhyolite; C,rhyodacite and dacite; D, andesite; E, andesite and basalt; F, subalkaline basalt; G, alkali basalt; H, trachyandesite; I, trachyte; and J, phonolite.

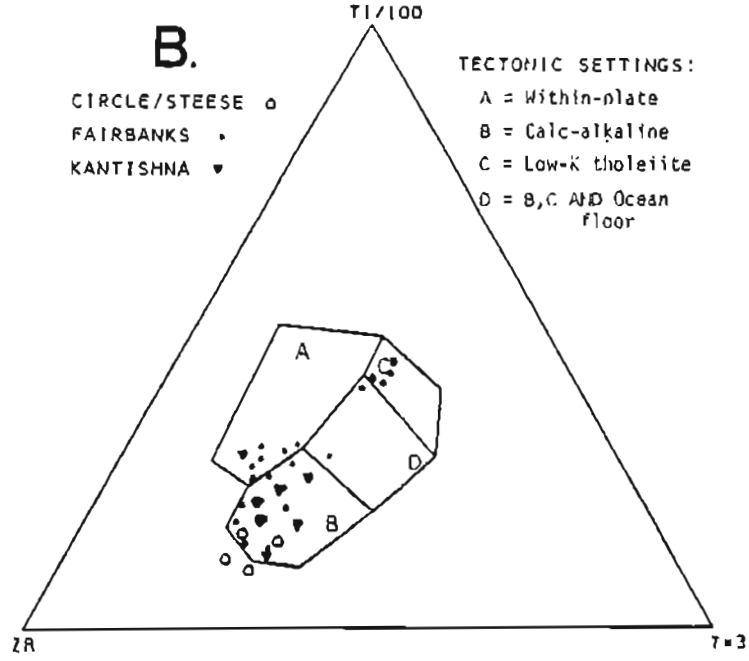


FIGURE 17: Trace element diagrams for North Star Gold Belt metavolcanic rocks 17A: Nb/Y vs. Zr/Ti diagram, showing presence of both basaltic and andesitic compositions. 17B: Ti-Zr-Y diagram, showing mixture of calc-alkalic and within-plate tectonic affinities for the metabasaltic rocks (similar to the Carolina slate belt).

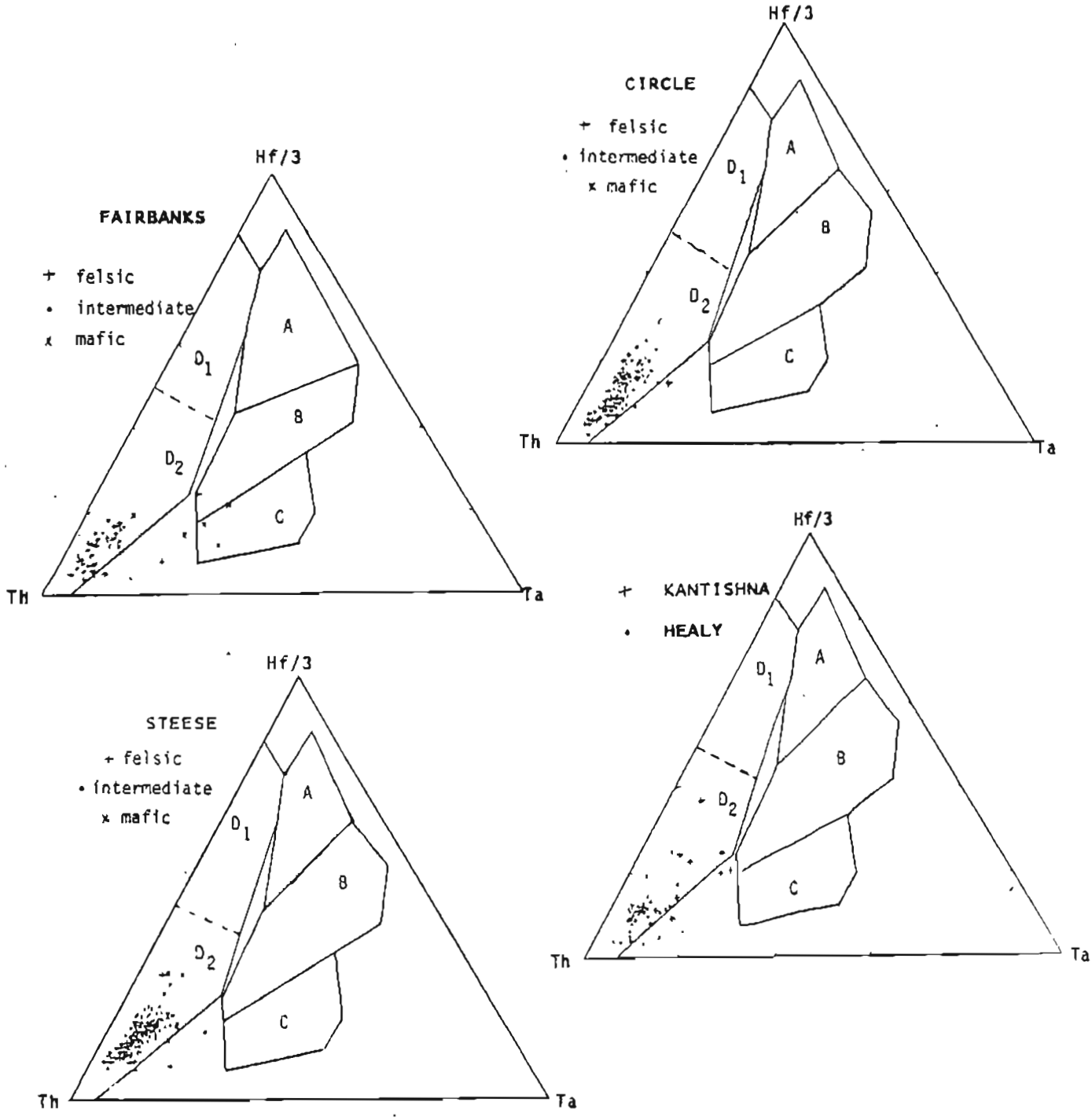


FIGURE 18: Th-Hf-Ta diagrams for metavolcanic rocks of the North Star Gold Belt, showing mostly calc-alkalic affinities, with some alkalic-affinity mafic rocks. Key to fields: A = N-type MORB (mid-ocean ridge basalt), B = E-type MORB + tholeiitic within-plate basalt & differentiates, C = alkaline within-plate basalt and differentiates, D = destructive plate margin basalts & differentiates, D_1=calc-alkaline, D_2=primitive arc tholeiite.

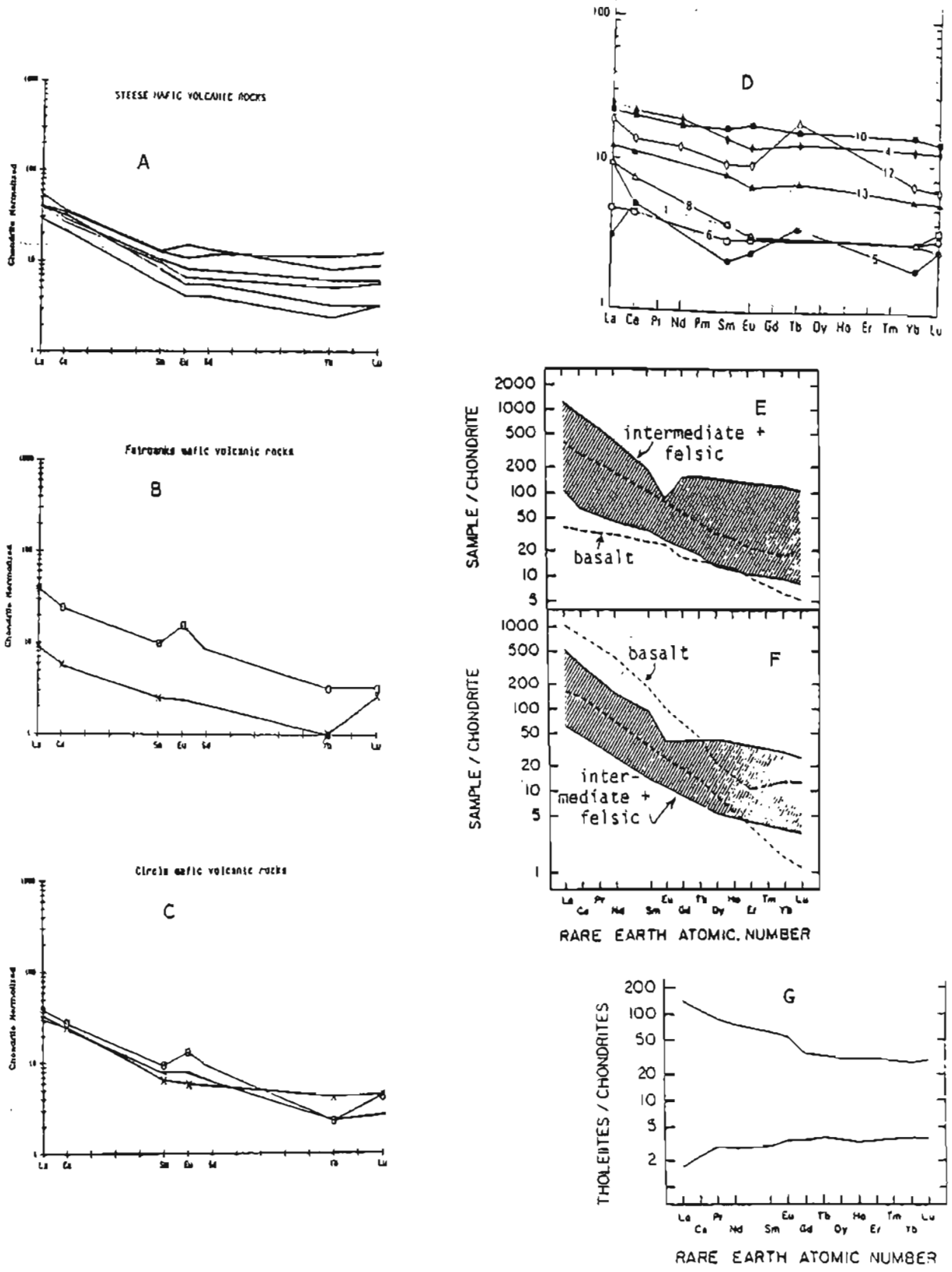


FIGURE 19: REE diagrams for representative mafic metavolcanics from the NSGB area (A,B,C), compared to: (D) representative mafic metavolcanics from the Va py belt, and ranges of values for (E) alkalic basalts, (F) K-rich basalts, and (G) island arc tholeiites. Note lack of alkalic affinities for NSGB and Va py belt mafic rocks.

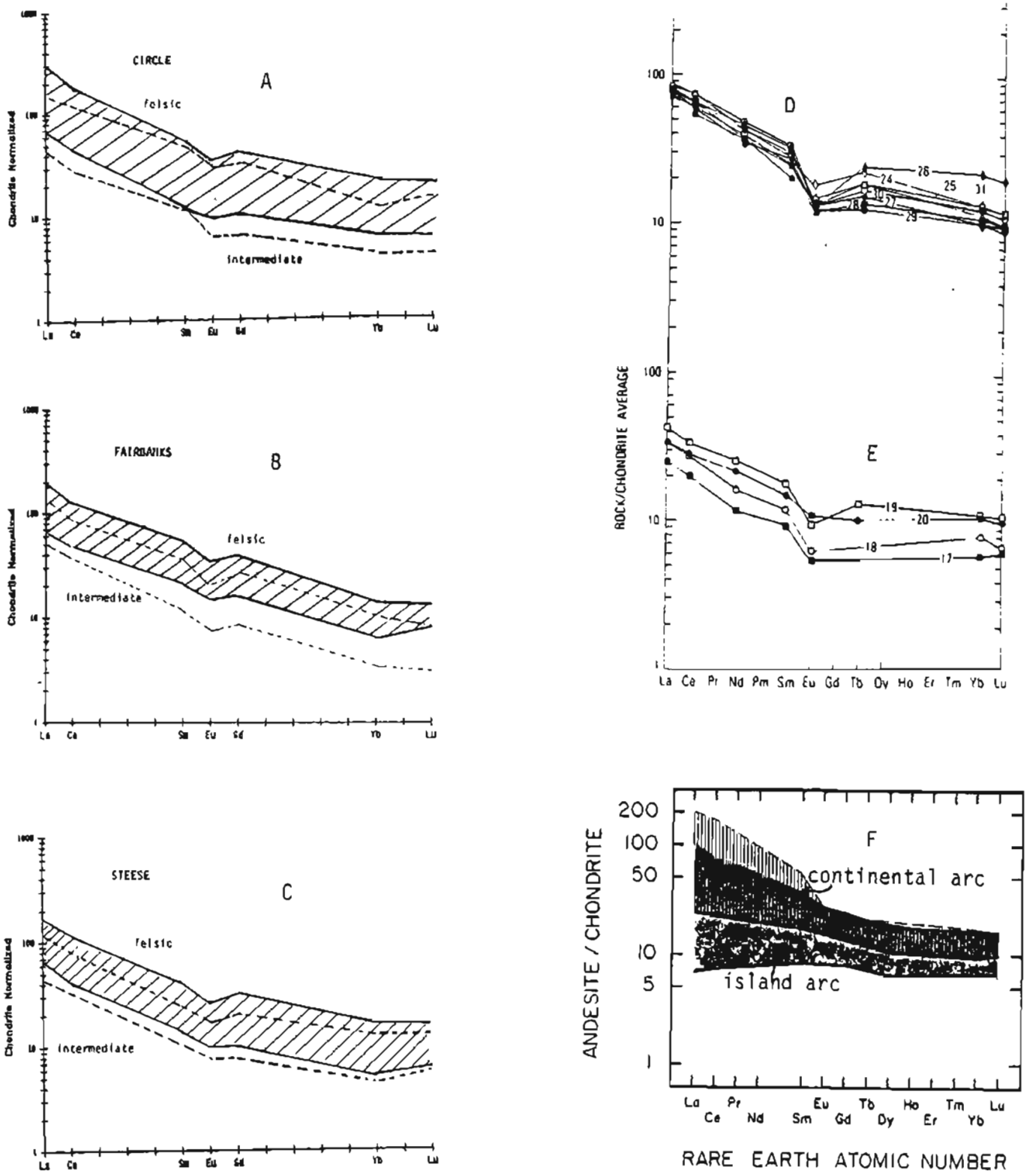


FIGURE 20: Ranges in chondrite-normalized REE abundances for felsic and intermediate composition metavolcanic rocks from the MSGB area (A,B,C) compared to: (D) felsic and (E) intermediate-composition metavolcanic rocks from the Virginia pyrite belt and (F) ranges for continental, subduction-related andesites (ruled) and island arc andesites (shaded). MSGB intermediate metavolcanic rocks most resemble continental arc andesites, and the MSGB metavolcanic rocks show a simple, fractionation relation between mafic (Fig. 19A,B,C), intermediate and felsic rocks.

end-members (all in molecular percents):

$A = Al_2O_3 + Fe_2O_3 - (Na_2O + K_2O)$

$C = CaO - 3.3P_2O_5$

$F = MgO + FeO + MnO$

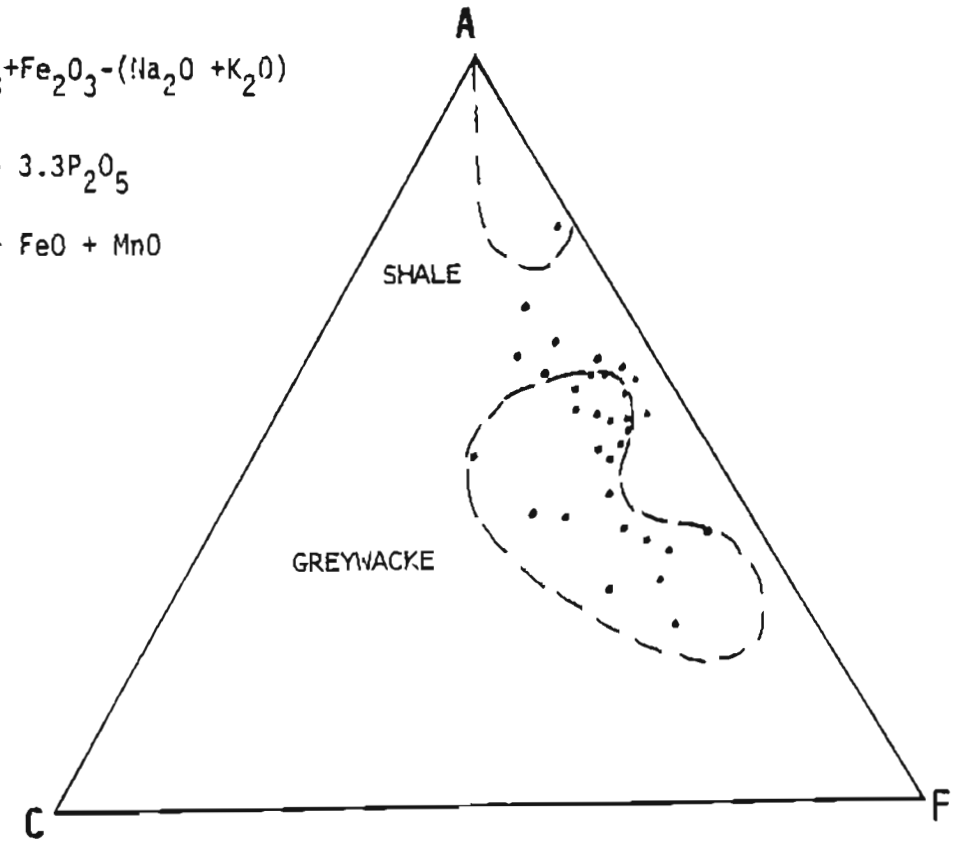


FIGURE 21: A-C-F projection for non-volcanic (i.e., sedimentary)-protolith schists and quartzites in the Fairbanks area, showing mostly greywacke or greywacke-shale bulk compositions. This data implies a subduction-related source for most rocks in the Fairbanks area and is compatible with a subduction-related tectonic setting for the Cleary Sequence.

Resource implications of the Va-Ca belt model to the NS gold belt

We propose using grade/tonnage/district spacing data from the Va-Ca belts. Stratabound/volcanogenic Au districts represent the pre-eminent gold production/reserves in the area. Au production from vein deposits--of metamorphic/remobilized origin?-- outside of granites has been very small (< 50,000 ounces for the entire SE Piedmont), and will be neglected for this study. The stratabound/volcanogenic districts occur at a spacing of about 1/ 25 miles of CA-VA belt and districts commonly contain only one major deposit. Compiled grade and tonnage data for these districts will be employed in constructing the necessary grade and tonnage models. Total contained gold resources from such districts varies from < 10,000 oz to about 2 million oz and these resources will presumably make up an appreciable part of the Rockval resource estimates.

III. PLUTONIC-HYDROTHERMAL RELATED GOLD DEPOSITS: ANALOGS TO SOME NORTH STAR GOLD BELT DEPOSITS

Consideration of world-wide occurrences of gold in and adjacent to plutonic rocks suggests at least two major groupings - (1) porphyry/epithermal and (2) "mesothermal" veins. Both types can be associated with gold-bearing skarns/replacement bodies if carbonates are nearby. The former type is characterized by 1) disseminated/veinlet mineralization in the plutonic/dike rocks, 2) large, pervasive alteration halos, 3) evidence for shallow plutonic/dike emplacement, and 4) generally mid-Tertiary or younger ages. The latter type is characterized by lesser pervasive alteration, deeper levels of plutonic emplacement, and generally early Tertiary or older ages. Distinction between the two groups is important, as the pervasive alteration characteristic of the shallower group causes the plutonic rocks to be chemically different from the deeper group.

Because there is (1) no existing evidence for major, pervasive hydrothermal systems in the NSGB area,(2) evidence for mostly mid-to late-Cretaceous plutonic ages, and (3) evidence for 4.5- 1 km plutonic emplacement depths, we are considering only the deeper model for plutonic gold-related deposits in the NSGB. This model, and its applicability to the NSGB are described below.

Table I lists some districts which appear to contain "mesothermal" plutonic-related gold deposits. The gold occurs as quartz-sulfide veins, found in plutonic and country rocks, with lesser gold-bearing skarns

TABLE I: PLUTONIC-RELATED GOLD DISTRICTS

NAME, LOCATION	PRODUCTION	TYPE	DISTINCTIVE MINERALOGY	IGNEOUS
Flat, Ak.	1.3M oz	VNS	asp,stb,sch,tour,ank	alk, re
Black Hornet, Id	21T oz	VNS	asp, stb	red
Boise Basin, Id.	2.3M oz	VNS	asp, stb	red
Pioneer, Id.	25T oz	VNS	asp, bis mins	red
Quartzburg, Id.	.4M oz	VNS	asp, bis mins	red
Pierce, Id.	.4M oz	VNS	asp	red
Atlanta, Id.	.4M oz	VNS	sulfosalts	red
Neal, Id.	.1M oz	VNS	asp	red, al
Pine Grove, Id.	30T oz	VNS	asp	red, al
Westview, Id.	20T oz	VNS	asp, sulfo, stb, ank	red, al
Buffalo Hump, Id.	27T oz	VNS	asp, stb, mo, Te	red
Dixie, Id.	40T oz	VNS		red
Orogrande, Id.	32T oz	VNS	asp, mo, Te, sch	red
Tenmile, Id.	.1M oz	VNS	asp	red
Warren-Marshall, Id.	.9M oz	VNS	asp, stb, ank, sch	red, al
Mineral Hill, Id.	23T oz	VNS	asp	?
Silver City, Id.	1M oz	VNS	asp, stb, sulfo, carb	red, al
Yellow Pine, Id.	.3M oz	VNS	asp, stb, sch, tour,Te	red, al
Park, Mt.	80T oz	VNS	asp	red, al
Radersburg, Mt.	.3M oz	VNS,sk	asp, ank, sch	red, al
Georgetown, Mt.	.5M oz	vns,rpl,sk	asp, Te, tour, sch, stb	red, al
N. Moccasin, Mt.	.5M oz	vns,rpl	Te	alk
First Chance, Mt.	.4M oz	VNS	mo, Te	?
Elkhorn, Mt.	70T oz	vns,rpl	tour, asp, Te, bis	red
Wickes, Mt.	.3M oz	VNS	tour, asp, sulf,	red
Helena, Mt.	.4 M oz	VNS	tour	red
Marysville, Mt.	1.3M oz	VNS	Mn-carbonates	red
Rimini, Mt.	.2M oz	VNS	tour,asp	red
Pony, Mt.	.4M oz	VNS	mo,sch	red
Renova, Mt.	.2M oz	vns,rpl	ank, Te, asp	red
Sheridan, Mt.	40T oz	vns,rpl	asp, ank, Te	red
Virginia City, Mt.	2.5M oz	vns	Te, stb	red
White Oaks, N.M.	.2M oz	VNS	tour, sch	alk
Ortiz, N.M.	.5M oz	vns,sk	asp, tour, sch, Te	alk
Central City, Colo.	3.8M oz	VNS	Te, sch, sulf, ank	alk
Rossland, B.C.	3M oz	vns,rpl	asp, tour, Mo,carb	alk,red
Premier, B.C.	2M oz	VNS	sulfo, sch	red
Hedley,B.C.	1.6M oz	sk,vns	asp,sch,Te,tour,bis	alk,red
Bridge River, B.C.	4M oz	VNS	asp, sch	red
Kochkar, U.S.S.R.	4M oz	VNS	asp,tour,bis,sulf,Te,ank	alk, re
Berezovo, U.S.S.R.		VNS	asp,tour,sch,ank,sulf	alk
Darasun, U.S.S.R.	2.2M oz	VNS	asp,tour,sch,ank,Te,sulf, bis, Mo, stb	alk, re
Muruntau, U.S.S.R.	7.5M oz	VNS	asp,tour,ank,bis,sulf,sch	alk
Bereszovsk, U.S.S.R.	9M oz	VNS	asp, tour, sch	?
Charters Towers, Aust.	6M oz	VNS	asp,sulf,Te,bis	red

key: T=thousand, M=million, VNS=veins, rpl=replacement bodies, sk=skarn, Te=tellurides, bis = bismuth minerals, asp=arsenopyrite, sul sch=scheelite, stb=stibnite, Mo=molybdenite, tour=tourmaline, alk=alkalic, red=reduced

and replacement bodies in the country rocks. Arsenopyrite and pyrite are present in virtually all cases. Other minerals common in small amounts include scheelite, tourmaline, tellurium minerals, sulfosalts, stibnite, molybdenite, bismuth minerals, and ankerite. Anomalous levels of tin are present in a few of the deposits.

Major deposits are present in plutonic rocks, and more commonly, in country rocks near dikes/plugs and within 1-5 miles of the main pluton contact. The mineralization in the Tobacco Roots batholith area, Montana (Fig. 22) is an example of the distribution of such mineralization around an intrusive complex.

Qualitative consideration of the compositions of plutons associated with mesothermal gold veins shows that most are either reduced (low Fe_2O_3/FeO) or alkalic (high Na + K/Si) or both (Table I). These chemical differences appear independent of other major element characteristics, as plutonic rocks varying from diorite to granite are both associated with and not associated with gold veins. To attempt quantification of this apparent relationship, a discriminant analysis was performed on 665 analyses of gold and non-gold related plutonic rocks.

Discriminant analysis & results

Major oxide compositions of 665 plutonic rocks were collected into a database from about 150 geographic locations. The rocks span a wide range of compositions (Fig. 23a,b); rocks containing nepheline in the norm, normative corundum > 3 %, or rocks that were noticeably altered (such as containing high CO_2 or F) were the only rocks not acceptable for inclusion in the database. About 40 percent of the rocks in the database are known to be related to lode gold or placer gold deposits. The plutonic rocks were analyzed by discriminant analysis in an attempt to determine 1) what characteristics yield gold-producing plutonic rocks and 2) to predict which plutonic rocks in the NSGB would be likely to be associated with gold.

The data was randomly divided into a classifying group, composed of 60 percent of the data, and a test group, composed of the remaining 40 percent, every time the discriminant functions were computed. The ratio of gold to non-gold in both the classifying and test groups were kept the same as in the total database. With this method, one can judge whether the discriminant function formed on the

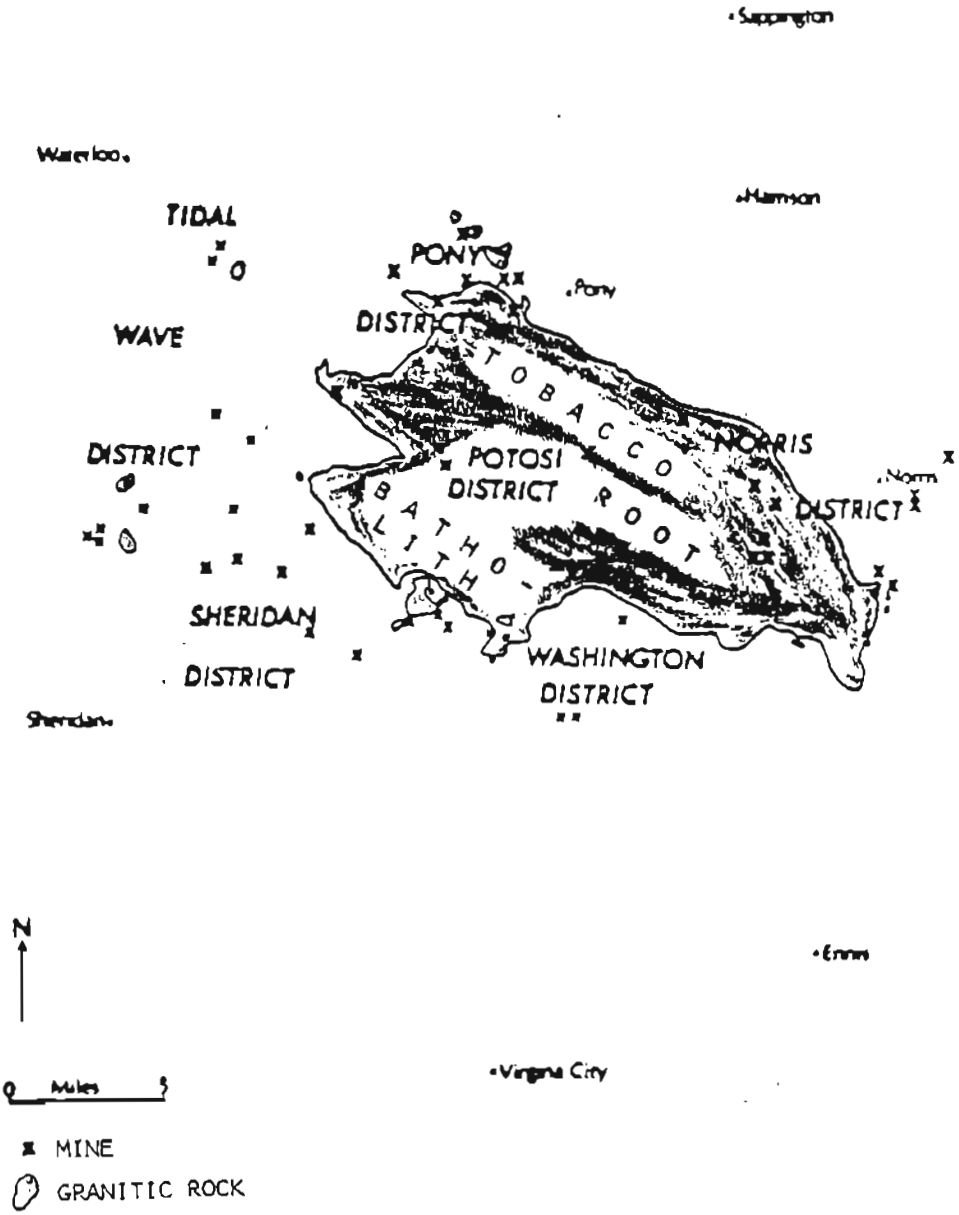


FIGURE 22: Map showing distribution of gold veins within and around plutonic rocks in the Tobacco Root Mountains area, SW Montana. This distribution is typical of plutonic-related gold districts.

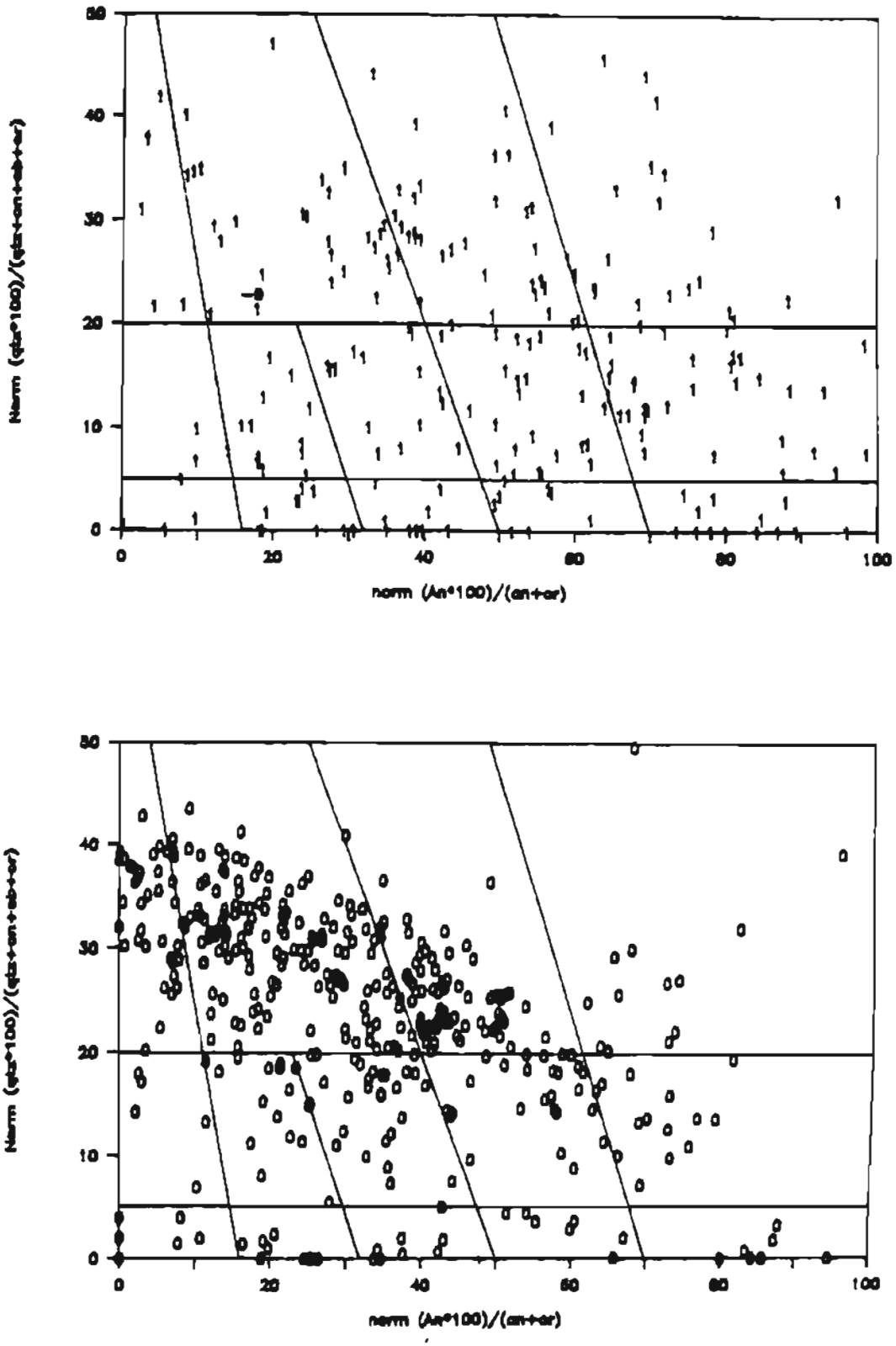


Fig. 23: Plot showing the distribution of plutonic rocks in the database. The classification scheme used categorizes plutonic rocks based on their CIPW normative mineralogy (Streckeisen and LaMaitre, 1979). Gold-related plutonic rocks are shown by '1'; non-gold plutonic rocks by '0'.

classification group worked well on the test group. The process was repeated for a total of five times to get a more accurate estimate of the results.

The five discriminant functions on randomized data sets averaged a 10 percent APER rate (a measure of the total accuracy of the discriminant function, see appendix IV) with a standard deviation of about 1.5. The discriminant functions also had a 5 percent average TYPE II error rate, the percent of gold-related rocks misclassified as non-gold related rocks, with a standard deviation of about 1.1. The major variables in the discriminant are the ratio Fe_2O_3/FeO and, less importantly, the alkalinity index ($Na_2O + K_2O + 16 - (.372 * SiO_2)$). Although these variables are functions of major oxide variables, the oxide ratio and alkalinity index are not highly correlated with the measured variables. The gold-related rocks have very low Fe_2O_3/FeO, or low oxidation state.

Because the discriminant functions classified the known test groups reasonably well, the analyses of the plutonic rocks of the NSGB were run for classification. Analyses of plutonic rocks from the Circle, Steese, Fairbanks, and Kantishna areas were input as a test group. Preliminary runs classified the rocks much as to be expected. Steese area lamprophyres, the Pinnell Trail monzogranite, the Circle area Two-Bit pluton, Gilmore Dome plutons, and many of the plutonic rocks in the Kantishna area classified strongly as gold-related. The Circle Hot Springs pluton and rocks from the Hope granite suite (Steese area) classify as non-gold related.

Application to the North Star Gold Belt

Using the grade, tonnage, and prospect distribution data from the obetter-known districts of Table I, we have devised grade, tonnage, and prospect density distributions for plutonic-related mesothermal veins. We propose to use firstly use discriminant analysis to assign favorabilities for vein deposits in the Circle, Steese, Fairbanks, and Kantishna areas, based on the chemical character of the plutonic and dike rocks in those areas. We will then determine the area in which the favorable plutonic rocks occur, and use this area times the prospect density distribution to yield a prospect distribution for each major area. Finally, we propose to use the grade and tonnage distributions derived from the districts in Table I to generate grade and tonnage distributions for the pluton-related veins in the NSGB area.

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APPENDICES

I. Maps showing Te, Au anomalies in Cleary sequence and locations of igneous rocks

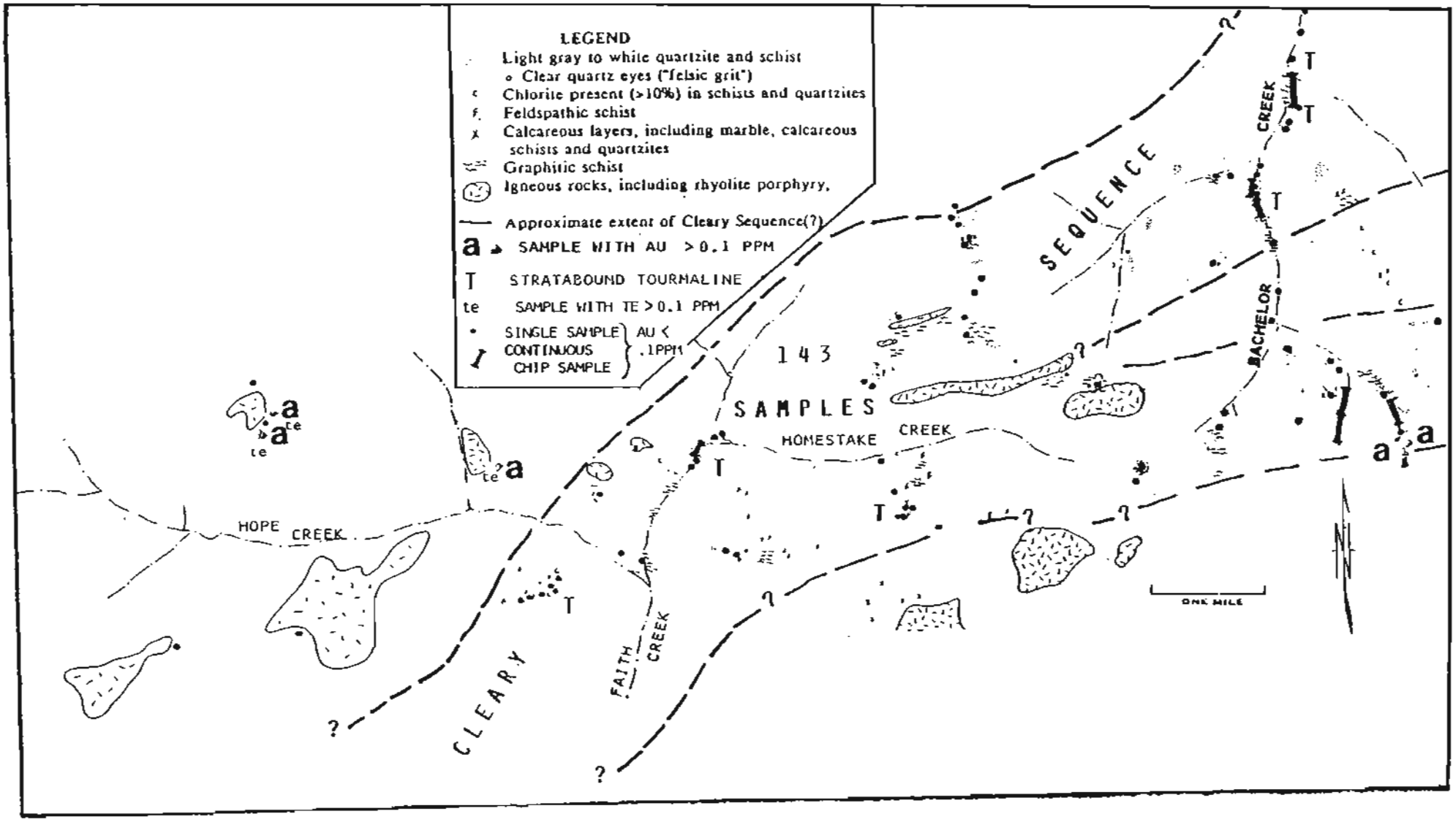
II. Map showing locations of W-rich veins and plutonic rocks, Ester Dome area

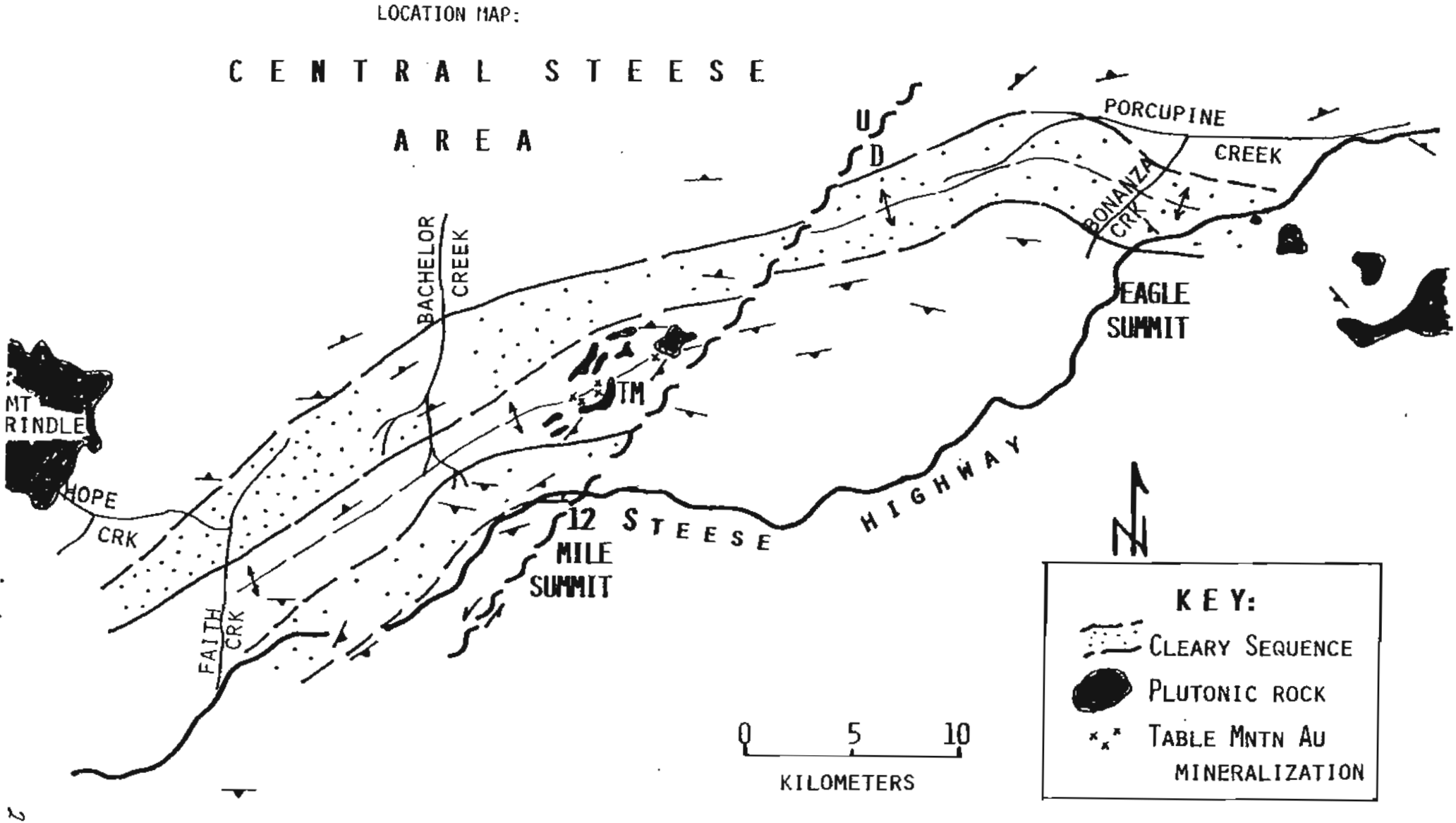
III. Summary of field observations from the NSGB area from the 1987 field season.

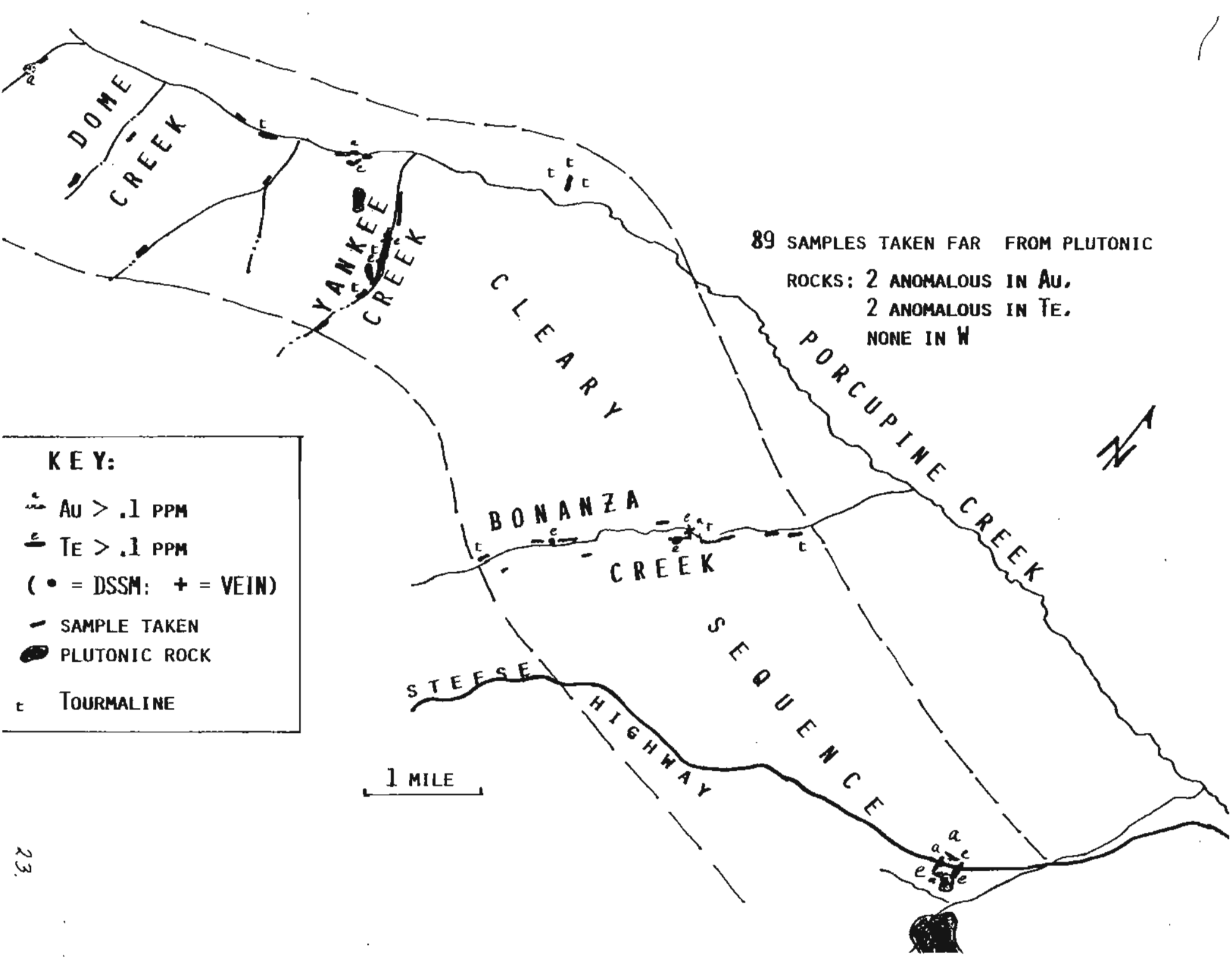
IV. Summary of discriminant analysis for gold-related vs. non-gold plutons

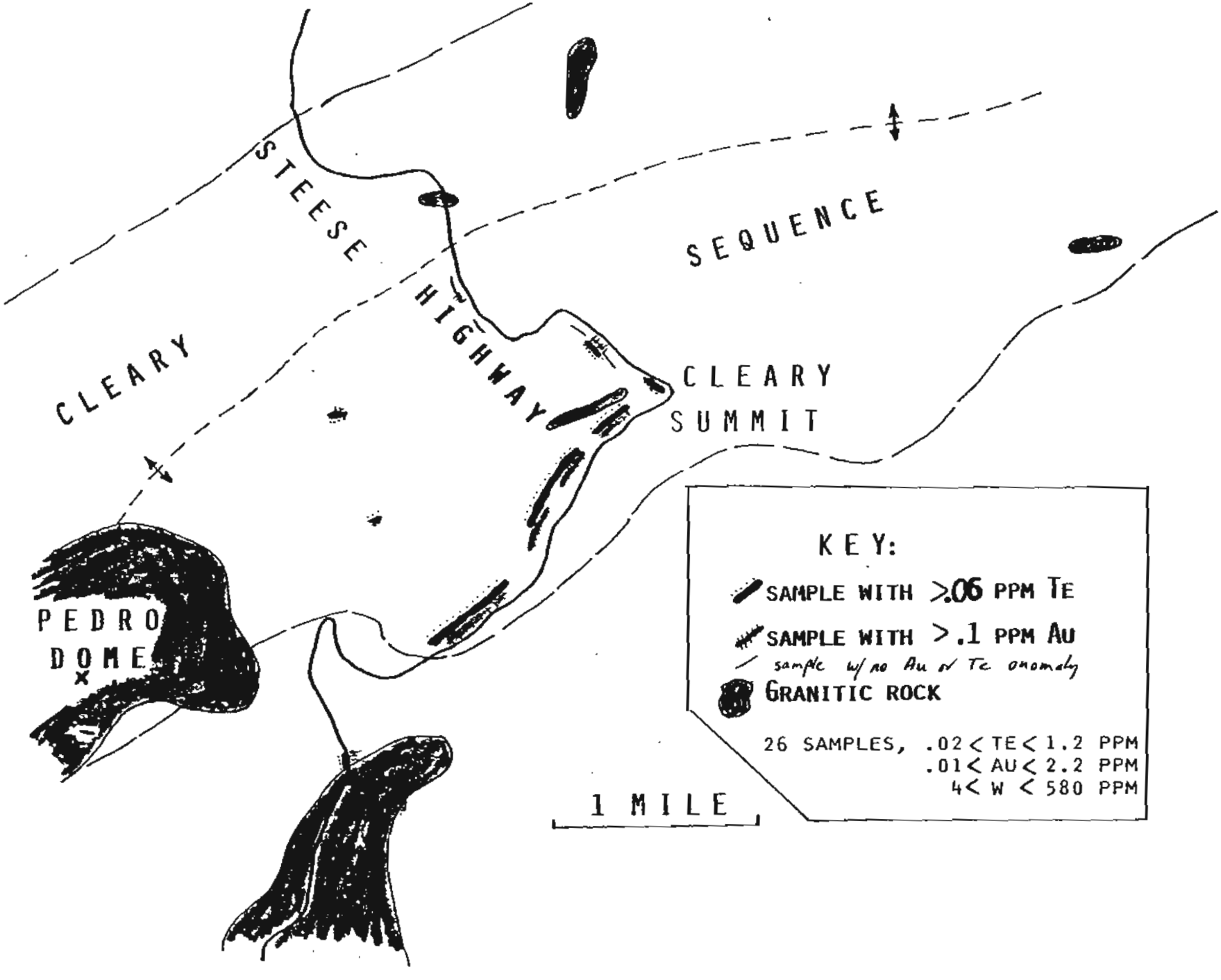
APPENDIX I:

Maps showing sample locations, gold and tellurium anomalies, and locations of plutonic rocks for the North Star Gold belt

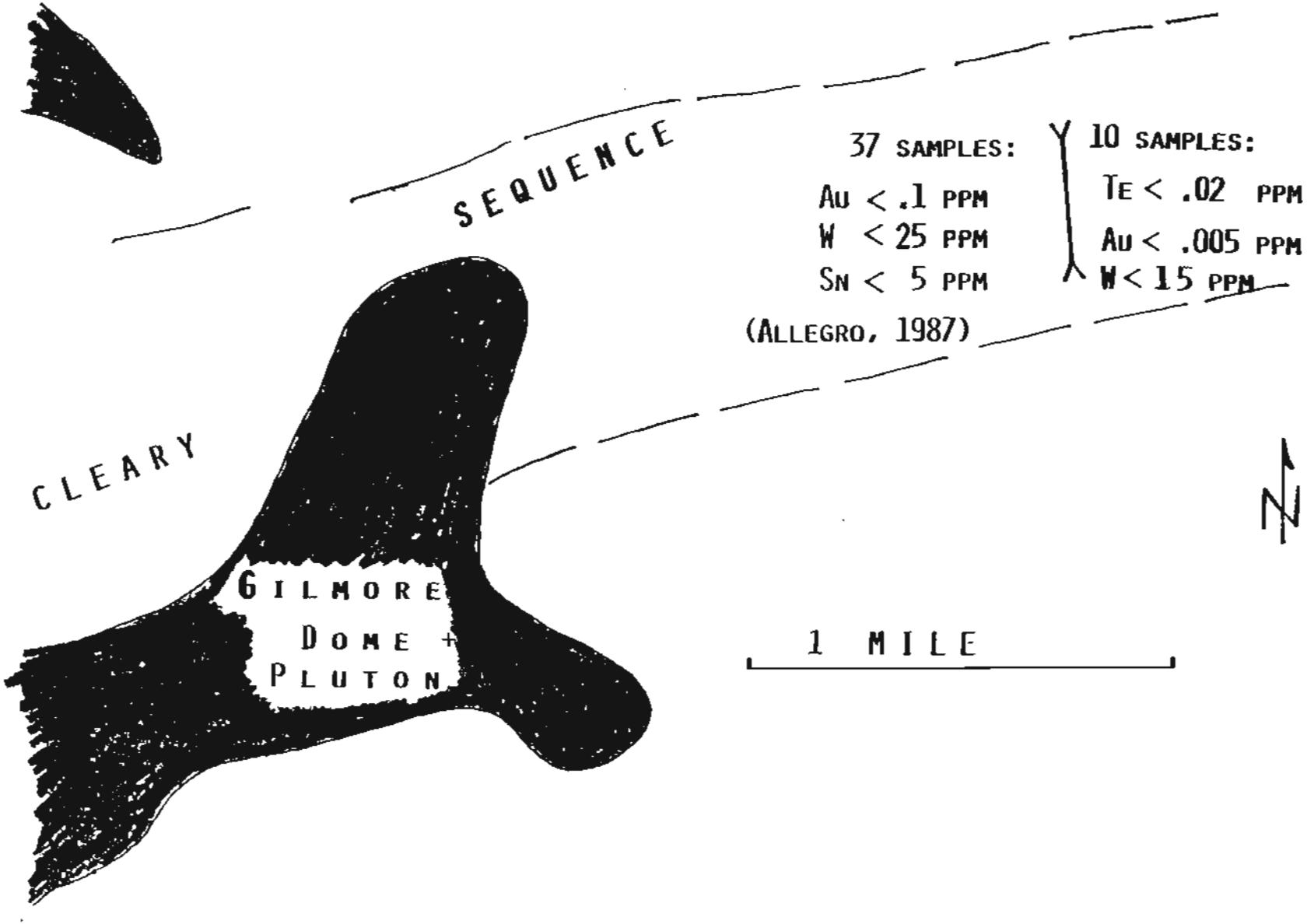

LEGEND
Light gray to white quartzite and schist
Clear quartz eyes ("felsic grit")
Chlorite present (>10%) in schists and quartzites
Feldspathic schist
Calcareous layers, including marble, calcareous schists and quartzites
Graphitic schist
Igneous rocks, including rhyolite porphyry,
Approximate extent of Cleary Sequence(?)
SAMPLE WITH AU >0.1 PPM
STRATABOUND TOURMALINE
SAMPLE WITH TE >0.1 PPM
SINGLE SAMPLE
CONTINUOUS CHIP SAMPLE
AU < .1PPM
143 SAMPLES
HOMESTAKE CREEK
HOPE CREEK
CLEARY
FAITH CREEK
BACHELOR CREEK
SEQUENCE
ONE MILE

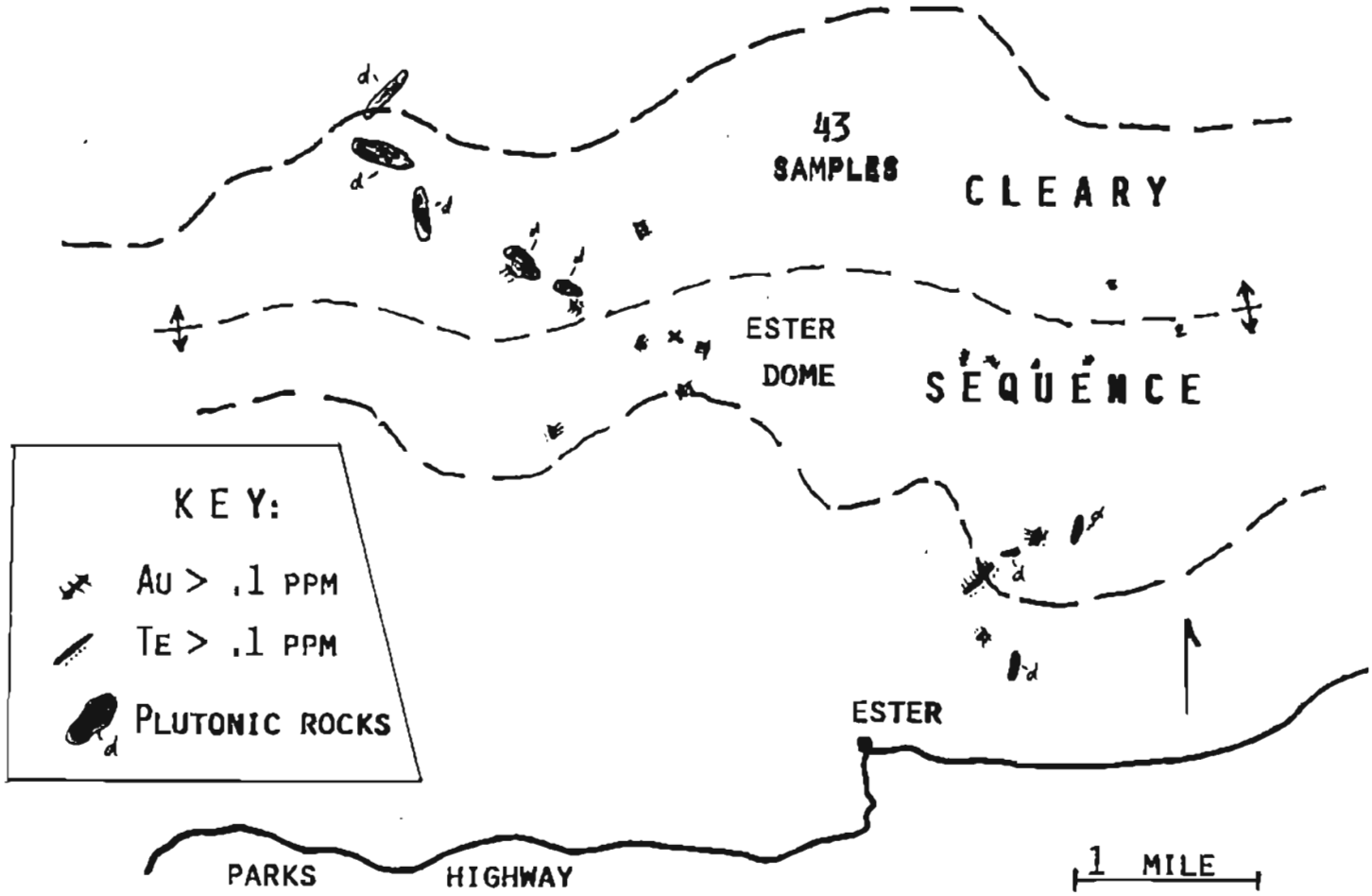

LOCATION MAP:
CENTRAL STEESE
AREA
U
D
PORCUPINE
CREEK
BONANZA
CRK
BACHELOR
CREEK
EAGLE
SUMMIT
TM
MT
RINDLE
HOPE
CRK
FAITH
CRK
12
MILE
SUMMIT
STEESE
HIGHWAY
N
KEY:
CLEARY SEQUENCE
PLUTONIC ROCK
TABLE MNTN AU
MINERALIZATION
0
5
10
KILOMETERS

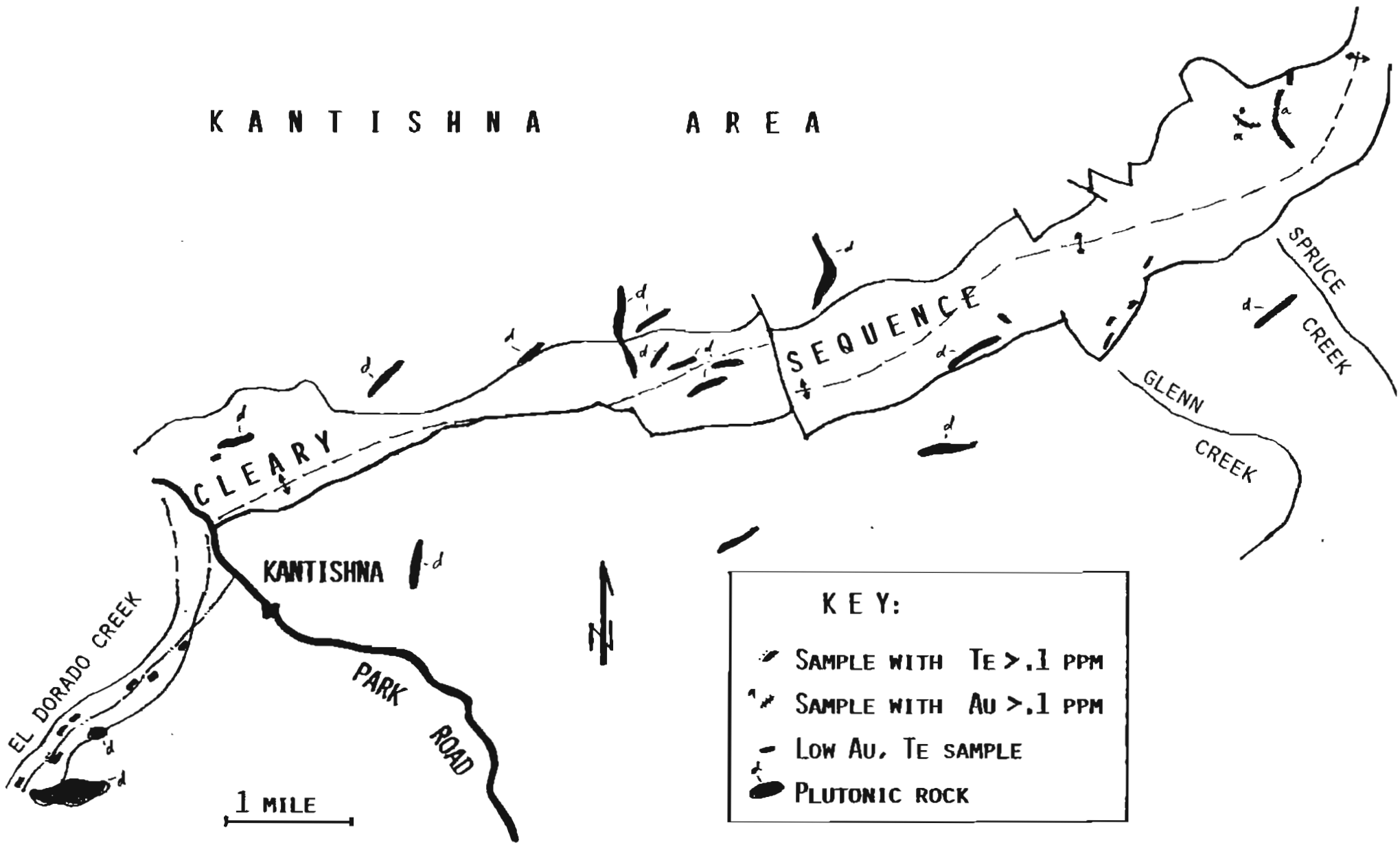

DOME CREEK
YANKEE CREEK
CLEARY
BONANZA CREEK
PORCUPINE CREEK
SEQUENCE
STEESE HIGHWAY
1 MILE
N
89 SAMPLES TAKEN FAR FROM PLUTONIC ROCKS: 2 ANOMALOUS IN Au, 2 ANOMALOUS IN Te, NONE IN W
KEY:
Au > .1 PPM
Te > .1 PPM
(• = DSSM: + = VEIN)
SAMPLE TAKEN
PLUTONIC ROCK
t TOURMALINE


STEESE HIGHWAY
SEQUENCE
CLEARY
CLEARY SUMMIT
PEDRO DOME
KEY:
SAMPLE WITH ≥.06 PPM TE
SAMPLE WITH > .1 PPM AU
sample w/ no Au or Te anomaly
GRANITIC ROCK
26 SAMPLES, .02 < TE < 1.2 PPM
.01 < AU < 2.2 PPM
4 < W < 580 PPM
1 MILE

"GIL" AREA

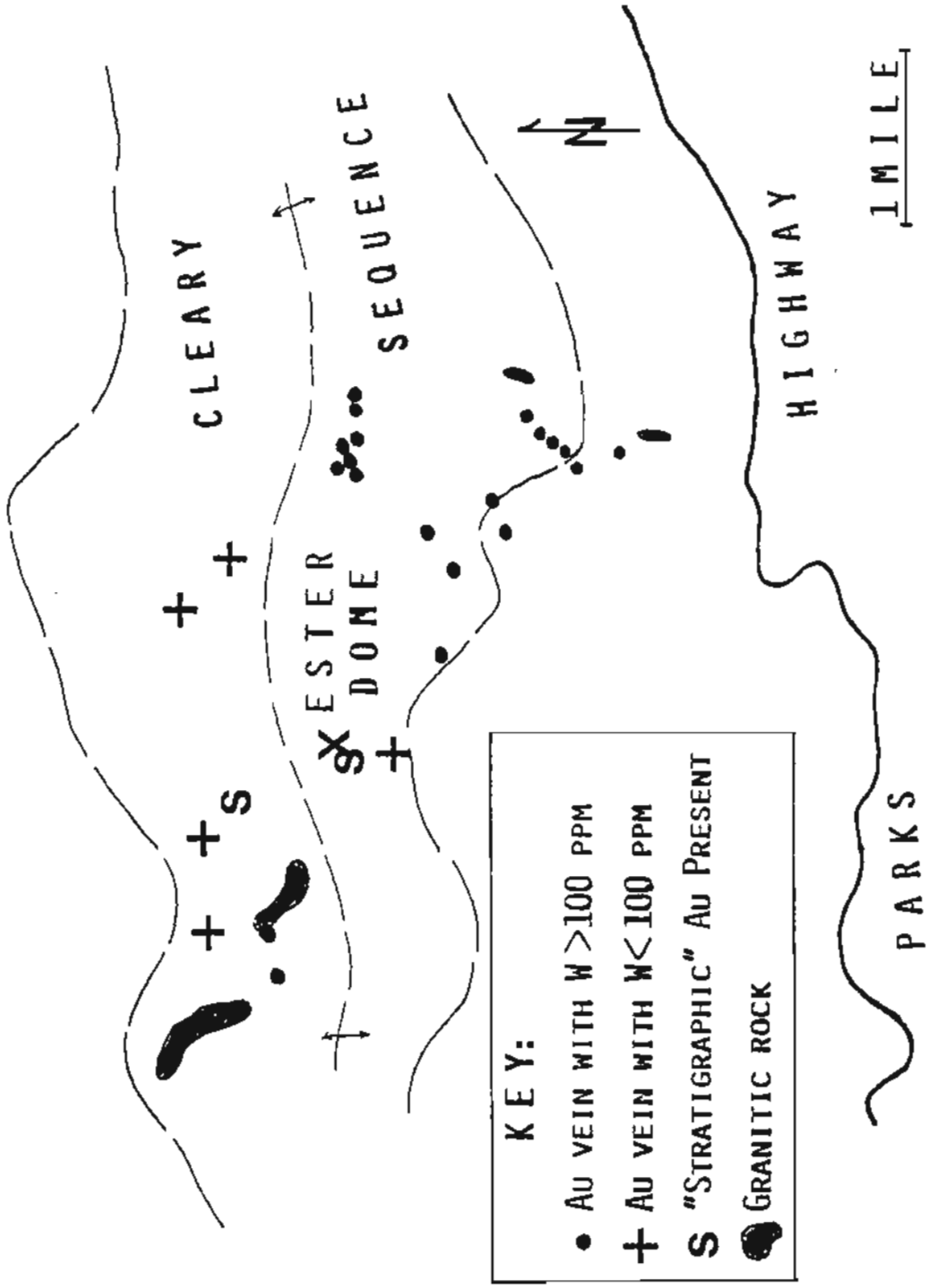

SEQUENCE
CLEARY
GILMORE
DOME +
PLUTON
37 SAMPLES:
Au < .1 PPM
W < 25 PPM
Sn < 5 PPM
(ALLEGRO, 1987)
10 SAMPLES:
Te < .02 PPM
Au < .005 PPM
W < 15 PPM
N
1 MILE


43
SAMPLES
CLEARY
ESTER
DOME
SEQUENCE
KEY:
Au > .1 PPM
Te > .1 PPM
PLUTONIC ROCKS
ESTER
PARKS
HIGHWAY
1 MILE


KANTISHNA AREA
CLEARY
SEQUENCE
SPRUCE CREEK
GLENN CREEK
KANTISHNA
EL DORADO CREEK
PARK ROAD
1 MILE
N
KEY:
SAMPLE WITH TE >.1 PPM
SAMPLE WITH AU >.1 PPM
LOW AU, TE SAMPLE
PLUTONIC ROCK

APPENDIX II:

MAP SHOWING LOCATIONS OF HIGH- AND LOW- W VEINS, STRATIGRAPHIC GOLD, AND PLUTONIC ROCKS, ESTER DOME AREA



APPENDIX III:

North Star Gold Belt, Interior Alaska

Summary of field work and observations, 1987
Diana Nelson Solie

The stratigraphic package which in the Fairbanks and Steese-White Mountain areas includes what is called the Cleary sequence is thought to extend across Interior Alaska from the Yukon-Alaska border, through the Circle and Fairbanks mining districts, to the Kantishna district. In view of the model that the Cleary sequence is, at least in part, a metamorphosed submarine volcanic deposit including gold-bearing exhalative layers, we sought to test the correlation of these stratigraphic packages across the Interior, and to identify potential auriferous units. Our 1987 target areas were chosen in order to augment existing data, to cover in reconnaissance fashion a wide area, and on the basis of accessibility. These areas were:

A. Circle area (Circle C-3, C-4 quads)
   1. Porcupine Creek
   2. Bonanza Creek
   3. Yankee Creek
   4. "Peplar's" (sp?) outcrop, Steese Highway (sect.14,T8N,R12E,Circle C-3)
B. Fairbanks area
   1. Gil trenches (E. of Gilmore Dome, sect.24,T2N,R2E,Fairbanks D-1)
   2. Cleary Summit (Livengood A-1)
   3. Ester dome (Fairbanks D-3)
      a. Blue Bonanza trenches (sect.25,T1N,R3W)
C. Healy area (Healy D-3)
   1. Mount Lathrop area
   2. Keevy Peak area
D. Kantishna area (Mt. McKinley)
   1. Spruce Peak
   2. Lloyd prospect (near Wheeler brothers camp)
   3. Wheeler property (along Quigley Ridge road)

Selected sections were measured in an attempt to document rock types, and their relative abundances and stratigraphic relations, with an eye to possible correlations between target areas. Detailed geochemical sampling of these sections was done to determine which, if any, strata may be anomalous in gold. The following is a list of sections which were measured, and their corresponding geochemical sample numbers:

a) Warner's "conveyor belt pit", Porcupine Ck: 100'
   (Circle C-3, sect.33,T9N,R11E)
   30667,30633-46,30685-89.
b) Gil trenches: 1100'. Used section from G.L.Allegro, (PDF 85-53, sheet 7 of 7).
   30543,30574-81.
c) Cleary Summit, on south side, from Milepost 19 toward the top of the hill: 320'
   30558-72.

d) Cleary Summit, on north side, used section measured by T.E.Smith and M.A.Albanese, from top of hill, northward: Their sample nos. 1776-1784.
e) Ester Dome, Blue Bonanza prospect, southernmost trench: 27', northernmost trench: 15'.
30468-72,30548-52; 30553-57.
f) Spruce Peak sequence, Kantishna area:
30611-22.

Due to incomplete exposure in most areas, structural complexities, the lack of a definitive widespread marker unit(s), and the probable lateral change in lithologies over such a wide area, absolute correlations between measured sections is not possible. There are, however, broad similarities among all the target areas. These include the presumed preCambrian/Paleozoic age, the overall regional metamorphic grade (+/- greenschist facies), the presence within the package, to variable degree, of volcanogenically derived rocks, and the predominance of what is typically referred to as 'Birch Creek schist', (ie, brown to tan quartz mica schists and brown, tan or grey micaceous quartzites). The presence of carbonates indicates a marine depositional environment for at least parts of all target areas. Tertiary (possibly Cretaceous?) intrusives are known to be present in all of the areas. The relationship between gold and these intrusives has not yet been fully investigated.

The following is a summary of notes and observations written by DNS on 8/28/87 with additions on 7/10/88, incorporating minor comments by K.Clautice:

I. Circle area

1. Lithologies in Porcupine drainage are very similar to those of Bachelor Ck. and Faith Ck. in the Steese-White Mtn. area.
2. Chlorite-rich rocks are common, with rocks ranging from light green to dark green ('mafic schists'). No definitive biotite observed in the area.
3. Phyllitic textures, though present, are not the norm.
4. One strong foliation is ubiquitous, the beginnings of another foliation are not uncommon.
5. Sulfides are present in both the dark grey graphitic schists, and in the light grey/white schists.
6. Exposure of white schist is very limited.
7. No rhyolites observed in area.
8. Evidence of igneous and/or hydrothermal activity present in "Peplar's outcrop" on Steese highway. High Au values are associated with this occurrence. No intrusives were verified in the Porcupine Ck drainage.
9. Tourmaline and quartz vein float in upper Bonanza Ck are similar in appearance to the veins of Table Mtn.
10. Marbles are common, especially in Yankee Ck. They are light grey, with dark brown weathering rinds.
11. Minor calcareous quartz chlorite schists are present, and also weather with a brown rind.

II. Fairbanks area

1. Intrusive activity in the Fairbanks district is widespread, and its effects are difficult to separate from other possible modes of mineralization.

2. White schist and white quartzite are sparse, and often are demonstrably alteration effects near veins and/or intrusives (eg, at the top of Cleary Summit, white schist is in contact with an intrusive body).

3. An apparent stratigraphic relationship between white schist and graphitic schist elsewhere on Cleary Summit (see measured section) suggests that white schist is not an alteration effect in all cases, but can be a distinct lithologic unit.

4. Carbonates are present, though not prevalent.

5. The only magnetite-bearing rocks noted were in the Gil trenches. According to G.L.Allegro (pers.comm, 1987), these magnetic strata are associated with anomalous Au values.

6. A small, weathered rubblecrop of lamprophyre was observed on Cleary Summit.

7. The 'normal' rocks in the district, accompanying the lithologies discussed above, are brown-weathering, tan or grey biotite-muscovite +/- chlorite quartz schists and quartzites.

8. 'Felsic grits' are present rarely.

9. One strong foliation is present, which has isoclinally folded any previous foliation. Development of second (or is it third?) schistocity is rare in Cleary sequence. Crenulations and kinks are not uncommon.

10. Metamafic rocks were most noteable in the Gil trenches, though also present on Cleary Summit to a lesser degree.

11. Sulfides are not common or abundant in stratigraphic layers.

12. Volcanogenic-looking rocks are much less abundant than in other areas.

13. A strong Fe-Mn staining is commonly associated with 'white schists'.

14. Tourmaline was found in the Cleary Summit white schist.

III. Healy area

1. Overall metamorphic grade seems a little lower than in Fairbanks and Circle areas, with more prevalent phyllitic textures.

2. Chlorite-bearing rocks are common. No biotite seen.

3. White schists are well-exposed and thick. They can be argued to be either stratigraphic white layers, or layers which have been preferentially altered to whiteness. They are associated with high pyrite contents.

4. Sulfides (pyrite, +/- arsenopyrite) are associated mostly with the white schists, as well as nearly ubiquitous small amounts of disseminated pyrite.

5. Sulfides are concentrated particularly in the fold noses and along foliations of white schists.

6. Abundant black phyllitic schists, shales, with pyrite commonly disseminated. Some have yellow stain.

7. Carbonates are present in the section.

IV. Kantishna area

1. Overall metamorphic grade somewhat lower that in Fairbanks and Circle districts, with phyllitic textures and abundant chlorite.

2. More sulfides seen than elsewhere, most in non-metavolcanogenic settings (eg, Wheeler property, and Bunnell Mine - west of the Roadhouse), though sulfides were also observed in schists of probable volcanic origin.

3. There appear to be lots of volcanogenic schists, both felsic and mafic.

4. Abundant 'graphitic' schists present.

5. Dark grey marbles are part of the sequence.

6. Some of the white schists can be argued to be alteration products, where they are patchy, non-stratigraphic zones.

7. There is one strong foliation, with some crenulations and kinks, and evidence of isoclinal folding. No second foliation development observed.

8. Cross-cutting quartz-carbonate veins common.

APPENDIX IV: Summary of discriminant analysis for

gold-related vs. non-gold plutons

The discriminant functions were computed using a SAS program (DISCRIM). Both linear and quadratic equations were constructed. As the quadratic equations yielded a much lower error rate, only the results for the quadratic discriminants will be discussed here.

The success of the discriminant function can be evaluated by several ways. An estimate of the overall effectiveness of the discriminant functions is the apparent error rate (APER) which is defined as

$$APER = \frac{n_{1m} + n_{2m} + \ldots + n_{im}}{n_1 + n_2 + \ldots + n_i}$$

where n_i = total # of observations in each group 1 - i

n_{im} = # of misclassified observations in each group.

For exploration purposes, however, the APER may not be the best number to minimize. Instead, the TYPE II error, which is the number of gold-plutons misclassified as non-gold plutons, should be kept low so that gold deposits are not overlooked. A discriminant function which yields a relatively low overall rate with a particularly low TYPE II error rate, particularly for the test group, would seem the most desirable. We have reached that point in forming our discriminant function, and thus feel justified in classifying data from the NSGB. The APER and TYPE II error rates for five computer runs are summarized in table IV.1.

TABLE IV.1: SUMMARY RESULTS OF QUADRATIC DISCRIMINANT FUNCTION FOR PREDICTING GOLD-RELATED PLUTONS VS. NON-GOLD PLUTONS:

	Classification Group		Test Group	
	APER (%)	TYPE II error (%)	APER (%)	TYPE II error (%)
Run 1)	7.4	3.8	9.5	4.6
Run 2)	8.4	4.4	9.9	3.7
Run 3)	9.5	1.9	12.5	5.6
Run 4)	9.7	6.3	7.6	7.4
Run 5)	8.7	1.9	9.9	4.6
Average:	8.7	3.7	9.9	5.2