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A REVISED GEOLOGIC MODEL FOR THE NORTH STAR GOLD BELT, INTERIOR ALASKA: PROGRESS REPORT

By

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INTRODUCTION

The North Star Gold Belt project (Fig. 1) was conceived with the idea of finding the best geologic analogies for the Belt and using these to estimate resources in the belt. Our initial model was based on Archean volcanogenic gold deposits, such as Homestake, S.D. and Agnico-Eagle, Quebec. The resource ramifications of such a model are major, because these deposits are some of the largest lode gold deposits in the world. However, as described in this report, this model has not stood up to our field work and analytical studies. Based on our work to date, we are proposing two major modifications of our initial model: (1) late PreCambrian-early Paleozoic PVMS deposits of the Southeast USA as models for stratigraphic gold in interior Alaska and (2) variable igneous input into the total gold endowment. In this report, we will (1) describe our reasons for adopting a mixed plutonic-stratigraphic gold endowment model, (2) describe our revised PVMS model, (3) describe a model for gold-related plutons and (4) describe our intended means to run a revised ROCKVAL model for interior Alaska gold.

I. NEED FOR A MIXED STRATIGRAPHIC-PLUTONIC MODEL

A. Geologic evidence

Investigations in the Table Mountain area, (Fig. 1), revealed that veinlet-controlled vein mineralization was not hosted by 'Cleary sequence' lithologies and was associated with sub-alkalic dike swarms. Fluid inclusion and geochemical evidence, summarized in Newberry (1987), indicated this mineralization was similar to sub-alkalic pluton/dike related gold mineralization seen in other parts of the world. Tourmalines present with this mineralization are significantly different (unzoned) from tourmalines associated with volcanogenic deposits (zoned) both in the Cleary Sequence belt and in other parts of the world. Subsequent research indicated that some, but not all, plutons intrusive into 'Cleary sequence'-like lithologies were spatially associated with identified gold resources. Our conclusion was that the plutons had more than a 'remobilizing' role and that some were contributing new gold into the endowment.

B. Evidence from Tellurium anomalies, North Star Gold belt

Examination of the geochemical data acquired for the North Star Gold project (Clautice, 1987) indicates that gold anomalies can be broken into two subsets: those occurring with significant (>.12 ppm) tellurium (Te) and those with insignificant (<.02 ppm) Te. The former group are present near granites and are commonly veined; the latter group are present far from granites and are entirely stratiform in character. An example of the high Au-high Te association is in the Cleary summit area (Fig. 1), where some samples high in gold contain at least .12 ppm Te, approximately 50 times crustal background. Another location is near Miller House (Fig. 1), on the Steese highway, where samples located about 1000 feet from a mapped granite body contain .5-1 ppm Te. D. Menzie (pers. comm., 1987) indicates that altered felsic dike material and quartz-tourmaline veins, presumably derived from igneous rocks, are present in this outcrop. He also reports that veins at this outcrop have fluid inclusions "identical" to the felsite-related veins on Table Mountain. High Au-Te rocks are also present on middle Porcupine Creek (Circle) and in the Healy area: some dike rocks are near both prospect areas. A few vein deposits in the Fairbanks area (Melba deposit, Grant Mine) also contain identified tellurium minerals.

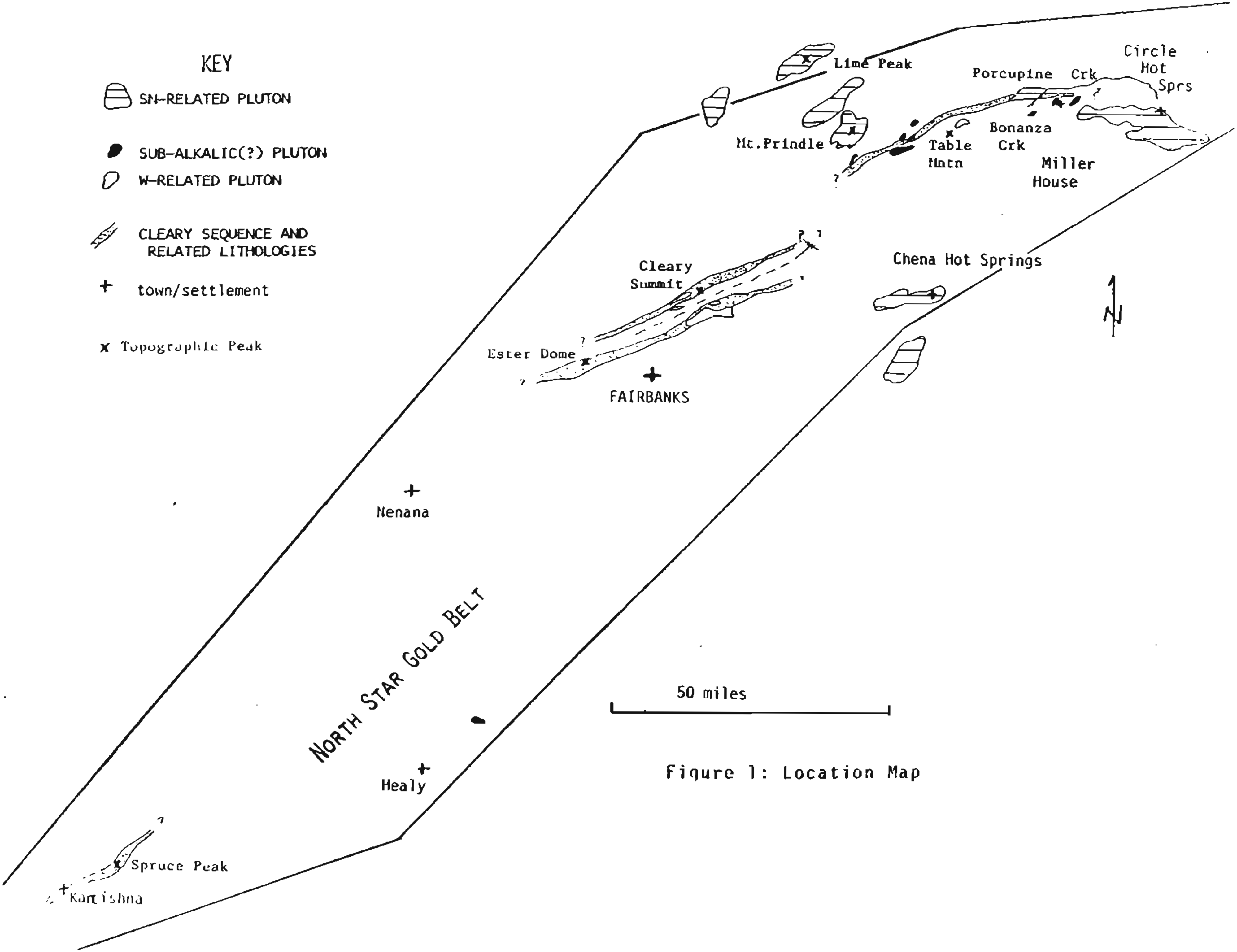


Figure 1: Location Map

In contrast, occurrences clearly related to stratiform sources --far from igneous activity, and lacking veining--contain low Te and high gold values. The most notable example is the Spruce Creek sequence in the Spruce Peak area, where samples containing one to several ppm Au contain less than 25 ppb Te. Also notable are samples from stratabound occurrences on Bonanza Creek, upper Porcupine Creek, and on Ester Dome (Fig. 1), all which contain very low Te and appreciable Au.

Based on world-wide occurrences, Te appears to be an element diagnostic of felsic plutonic-related, hydrothermal ore deposits. Although notably abundant in alkalic-related deposits, it is also present in anomalous levels in non-alkalic porphyry Cu deposits (e.g., Ely, Nevada). In contrast, Te is not known to be present in anomalous concentrations in VMS or PVMS deposits (R. Leveille, writ. comm., 1987). Based on this data and the North Star geochemical data, prospects in the neighborhood of some Cretaceous-Tertiary plutons appear to have a partly plutonic signature, whereas those far from plutonic activity appear to be entirely of volcanogenic origins.

C. Other compositional evidence

Two other elements of probable plutonic origin which occur with veins and placers near plutonic exposures in the area are tungsten and tin. Megascopic scheelite [$CaWO_4$] is common with gold in veins in and near plutonic rocks in the gold belt (Chapman and Foster, 1969; Bundtzen, 1981; Allegro, 1987). Tin anomalies are common in veins near plutons in the Fairbanks area (Chapman and Foster, 1969) and cassiterite is common with gold placers near tourmaline granites in the gold belt. Our sampling has shown that W and Sn rarely (if ever) occur above 50 ppm in Cleary sequence lithologies far from granitic rocks and that significant anomalies in both elements are common in Cleary sequence lithologies near plutons. Most notably, W anomalies are common in veins near plutons with other W mineralization (scheelite skarns) whereas Sn anomalies are most common in veins near plutons with other Sn mineralization (greisens). The implication is that some mineralization in the veins is plutonic-derived, hence the gold is partly plutonic-derived, as well.

D. Pb isotopic evidence

Review of recent literature on lead isotopes in the Yukon-Tanana terrane and in bi-modal associated sulfide deposits yields some surprising results, which are shown on Fig. 2 (a,b). Data from about 30 bi-modal VMS/VPMS districts indicates that such leads generally plot as fields near the "orogene" curve of Doe and Zartman (1979), that generally intersect the "orogene" curve at an age $\pm$ 100 my of the geologic age of the deposit. Work on Kuroko deposits suggests this spread in data results from mixing of sediment- and volcanic-derived leads during oceanic water circulation and/or mixing of magmatic-derived and sediment-derived leads during VMS formation (Fehn et al., 1983). In general, galenas are isolated from changes in lead isotope ratios after their initial deposition, hence, the older the galena, the less radiogenic it is.

Although data for North Star stratiform VPMS deposits is not yet available, data for Devonian bi-modal associated massive sulfides in interior Alaska is available (Church et al., 1987). These sulfides have lead isotopic ratios which plot in the expected place on a Pb 204-206 diagram (Fig. 2a). The expected position for stratabound North Star VPMS deposits is with the early Paleozoic volcanogenic VMS/VPMS deposits or to the left of the early Paleozoic deposits (Fig. 2), depending on the exact age of the original North Star deposits. Notably, the Mineral deposit, from the Virginia gold-pyrite belt [a likely analogy for the Cleary Sequence belt; see next section] falls within this world-wide early Paleozoic field. Consequently, one would expect galenas from truly volcanogenic occurrences in the Fairbanks-Circle area to also plot in this field.

Unfortunately, all galenas tested for Pb isotopes to date are either from veins (generally in or near granitic rocks) or from altered Cleary Sequence outcrops generally within 300 feet of outcrops composed of granitic rocks. Lead isotopes from these samples fall within a restricted area (Fig. 2b) well to the right of the Devonian bi-modal associated massive sulfide leads. This has been previously suggested as showing a rift-related origin for the veins, due to the fact that galenas from modern-day rifts have overlapping lead isotopic values. However, this spatial overlap appears to be coincidental, as--out of some several hundred lead analyses from dozens of ancient rift-related (i.e., bimodal) districts, only the North Star belt galenas fall into the field of modern-day rift deposits.

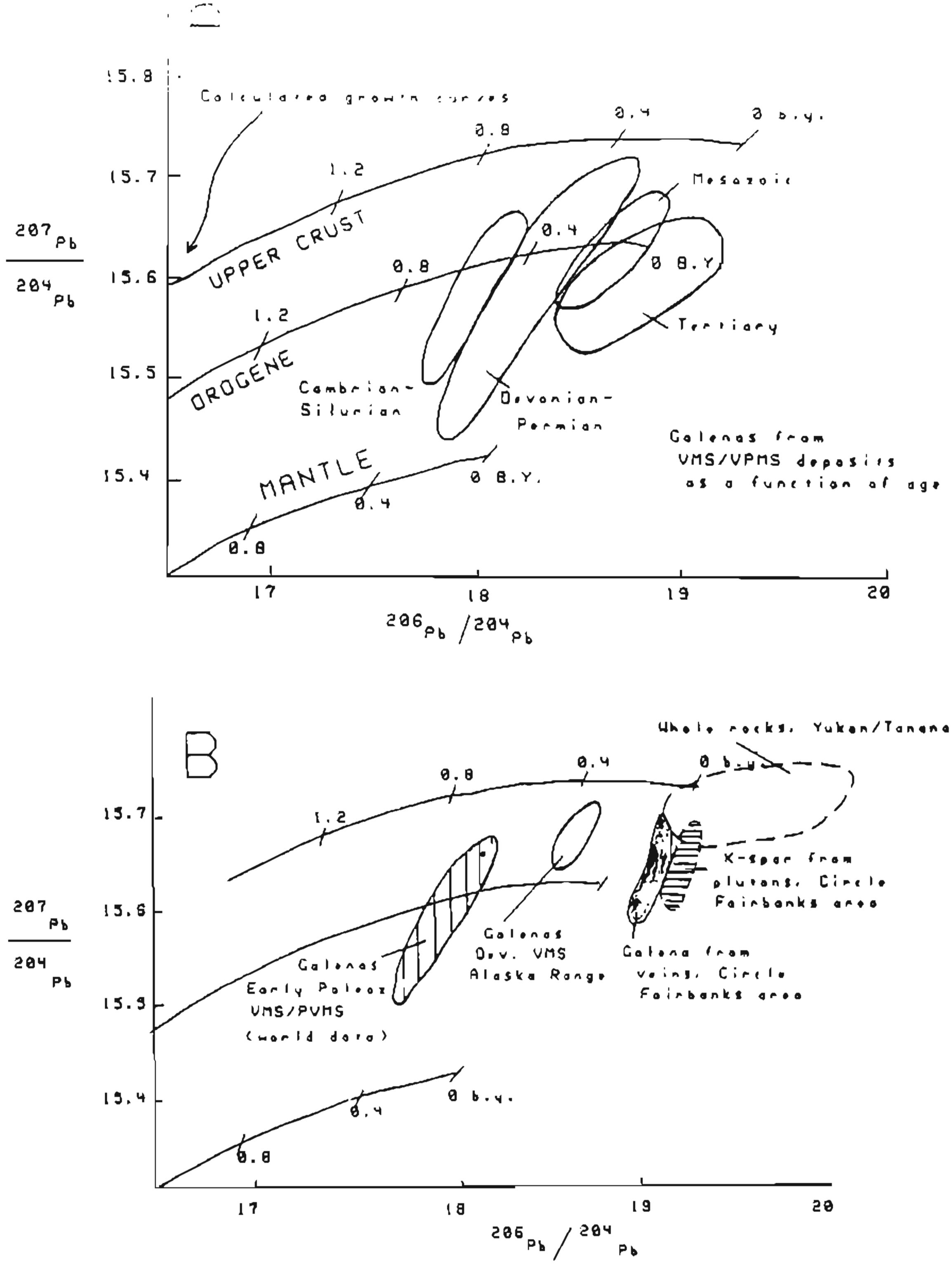


Fig. 2: Pb isotope ratio fields for ores (solid) and silicate rocks (dashed) from worldwide (A) and North Star area (B) sources. Fig. 2a shows progressive changes in ratios with age of VMS/VPMS deposits. Fig. 2b shows that Pb from veins in the Fairbanks-Circle area (shaded) can best be modeled as a misture of plutonic-derived (horizontal ruling) and VPMS-derived (vertical ruling) leads. Pb from the Mineral district ("Mineral") of the VA py belt is the best analog to date for stratabound leads from the North Star belt. Data from: Doe and Zartman (1979), Gulson (1986), Church et al. (1987), and Aleinikoff et al. (1987).

Recent work on lead isotopes from feldspars of plutonic and metamorphic rocks in the Yukon-Tanana region (Aleinikoff et al., 1987) indicates that Cretaceous-Tertiary plutons in this belt have lead isotopic compositions almost identical to the vein/altered stratabound galenas from the Fairbanks-Kantishna-Circle area (Fig. 2b). The lead isotopic characteristic of the plutons cannot be caused by melting or assimilation of Cleary Sequence rocks, as the plutons show no evidence for migmitization around their contacts and were derived from at least several kilometers depth below the present surface. Further, the plutons sampled came from a five-quadrangle area (Circle, Tanacross, Mt. Hayes, Big Delta, and Eagle) well away from the presently known outcrop belt of Cleary sequence lithologies. Lead isotopic signatures of the plutons also does not reflect assimilation of other Yukon-Tanana terrane lithologies as these rocks plot in a generally non-overlapping isotopic field.

The close correlation between vein leads and plutonic leads in the Yukon-Tanana area instead strongly implies that the vein leads were at least partly derived from the plutons. The fact that vein leads lie between the field for plutonic leads and the field for early Paleozoic, bi-modal associated, volcanogenic leads, suggests that the lead isotopic composition of the veins represents a mixture of plutonic-derived and volcanogenic-derived lead. Based on the degree of spatial separation of the three fields, the amount of plutonic component varies from about 80-100 percent, averaging about 85 percent. This is not meant to imply that all lead in the Yukon-Tanana region is largely igneous-derived, but rather that leads in deposits/prospects in plutons or in the near vicinity of plutons are largely igneous-derived.

E. Sulfur isotopic evidence

Sulfur isotope data acquired by T. Bundtzen (writ. comm., 1987) also show good evidence for a major magmatic component to the North Star Gold belt ores. Figure 3 shows ranges in sulfur isotopic data for Fairbanks and Kantishna district ores compared to VMS and plutonic related ores. Plutonic-related ores have sulfur isotopic compositions ranging from about -5 to +5 per mil, whereas VMS sulfides have isotopic compositions which vary with age of the deposit. Sangster (1976) has shown that world-wide, VMS sulfides average 17 per mil lighter than the corresponding seawater sulfur (Fig. 3a). Hence, for a Cambrian or late Proterozoic aged VMS, a sulfur isotopic value of about +10-17 is expected.

Comparison of data from the Fairbanks/Kantishna area with plutonic and VMS reference data (Ohmoto and Rye, 1979) indicates that all deposits in the Fairbanks area (including stratabound prospects) have plutonic sulfur signatures, whereas only stratabound prospects in the Kantishna have the expected signature of VMS sulfur. All vein deposits in the Kantishna area have plutonic sulfur signatures.

F. Summary and Implications for North Star gold belt resource assessments

Based on isotopic and geochemical data, gold prospects/deposits in the North Star gold belt appear to represent a continuum between strictly plutonic-related (e.g., the high Te, tourmaline gold on Table Mountain) and strictly volcanogenic-related (e.g., the Spruce Creek sequence in the Kantishna Hills). Plutonic involvement appears to have caused not only gold remobilization, but also variable addition of new gold, to form the large-tonnage and high-grade gold veins of the North Star Gold belt. Lead isotopic data indicates that a clearly plutonic component is present in vein ores: how much of the gold present is due to plutonic sources is difficult to specify--gold does not behave exactly like lead, after all--but it is likely to be significant. Present data suggests that of the various types of plutons present, those with alkalic affinities and those related to tungsten skarns make the greatest gold contribution. The plutons related to tin deposits make a smaller gold contribution. An important inference is that interior Alaska has a very large gold resource base due to the action of two independently-operating gold concentration mechanisms: volcanogenic and plutonic. U.S.B.M. geologists have also suggested that a third type of mineralization which produced epithermal gold deposits may be present in the Healy area. Especially significant gold resources appear to result where the different mineralization types overlap.

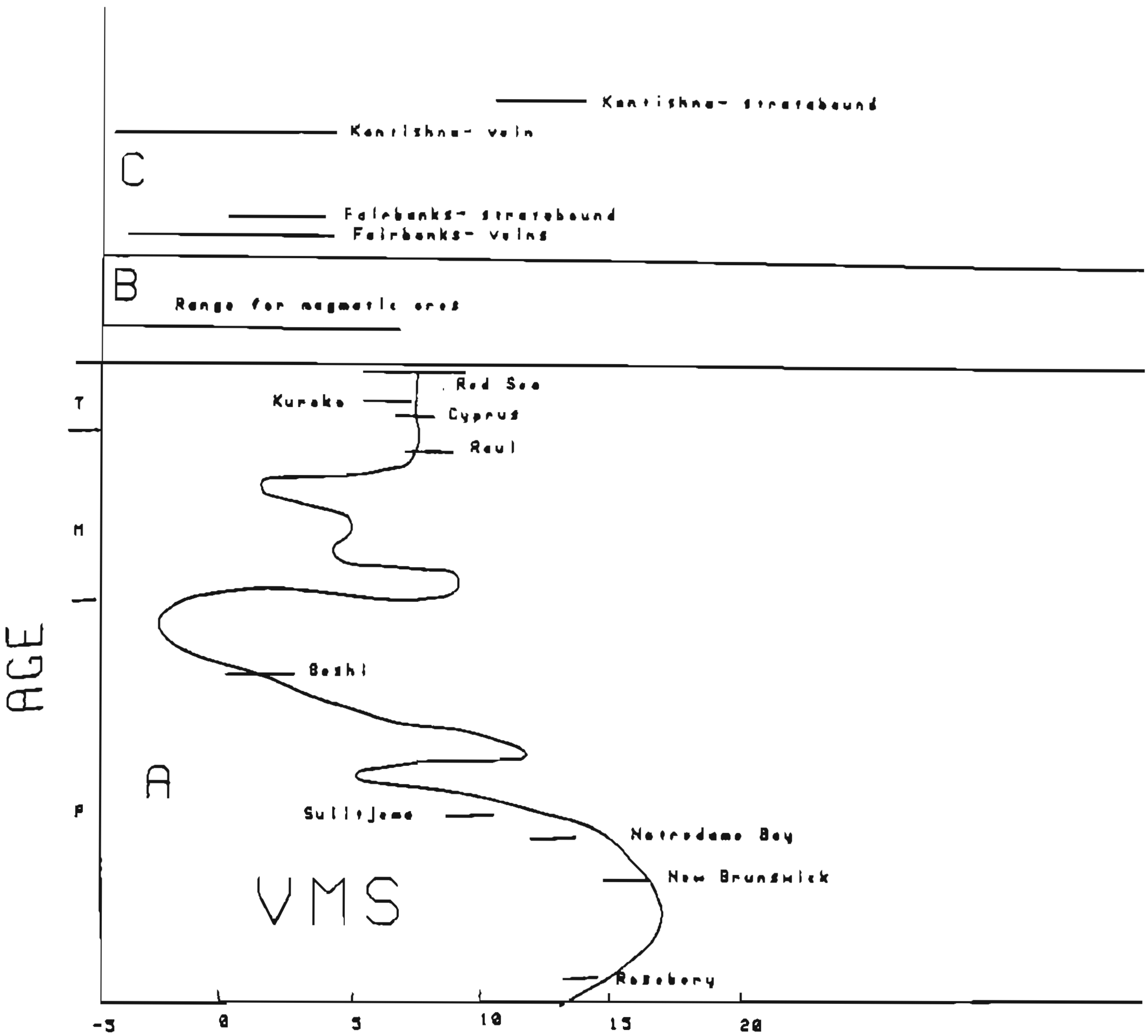


Figure 3: Sulfur isotopic data for world-wide (A,B) and North Star gold belt (C) sulfide occurrences. 3A = Volcanogenic Massive Sulfide (VMS) deposit sulfides, as a function of geologic age, after Sangster (1976). 3B = plutonic-related deposits (from Ohmoto, 1979). 3C = North Star occurrences (Buntzen, unpbl. data).

II. AN EARLY PALEOZOIC VPMS MODEL FOR STRATABOUND NORTH STAR GOLD

Introduction

Our original model for stratabound North Star gold was based on the early Proterozoic VPMS deposits of Canada and the northern U.S. These deposits are characterized by (1) an association with felsic and not mafic metavolcanic rocks, (2) abundant stratabound ankerite with gold-pyrite, (3) very low base metals, and (4) gold restricted to exhalative horizons. Our subsequent work in the North Star belt has shown (1) gold is associated with both felsic and mafic metavolcanic rocks (e.g., Circle area), (2) stratabound ankerite is not present anywhere, (3) base metal values are generally greater than or equal to gold values, (4) only a few clear-cut examples of appreciable stratabound gold anomalies exist, and (5) most gold is in altered felsic rock rather than in obviously exhalitive (cherty) rocks. An obvious possibility is that we need a better model, and such a model, based on occurrences in Cambrian to Eocambrian bimodal volcanic-sedimentary sequences, is outlined below.

A. Southern Appalachian gold belts of Cambrian-Eocambrian age

Five belts of gold deposits (Fig. 4) are currently recognized in the SE Piedmont region, U.S.A. These 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 (e.g., Whitney et al., 1978; Butler, 1981; Bell, 1982; Feiss, 1982; Pavlides et al., 1982; Abrams and McConnell, 1984; Neathery and Hollister, 1984). Each belt consists of late Proterozoic to Cambrian rocks, as indicated by Pb-U dating of zircons in metafelsites (e.g., 550 m.y. for the Virginia pyrite belt) and by fossil and stratigraphic evidence. Ranges in Pb-U ages are 620-520 m.y. Although several of the belts appear to be en echelon segments, differences in lithologic and trace element characteristics of the volcanic rocks have led most workers to conclude that they represent originally separate volcanic entities.

The lithologies present in each belt are dominated by pelitic schists (or higher grade equivalents) with bimodal felsic and mafic metavolcanic rocks. Notably absent or very rare are intermediate composition metavolcanic rock. Despite the bimodality, most authors (e.g., Pavlides, 1981) consider the assemblage to represent immature island arcs. Most workers have noted calc-alkalic affinities for the volcanic rocks, based on immobile trace element abundances. The Chopawamsic Formation in the Virginia pyrite belt is a typical example, with 2000-3000 meters thickness. Commonly it consists of about 1/2 felsic (pelitic?) schist, 1/4 mafic and 1/4 felsic (metavolcanic) schist. Metavolcanic rocks have very limited strike continuity; the formation is characterized by erratic changes in lithology along strike. Small amounts of carbonate rock are also present.

All the SE Piedmont gold belts contain some small (.1-5 million tons) volcanogenic massive sulfide deposits, most of which are subequally enriched in Cu, Pb, and Zn. Pyrite-pyrrhotite-gold rich massive sulfides (lacking appreciable base metals) are also present in the Virginia pyrite belt, the Carolina slate belt, and the Dahlonega gold belt. Stratabound tourmaline is present with some of these deposits. More notably, the Carolina slate belt and Kings Mt. belt contain stratabound gold in sericitically altered felsic metavolcanic/metaplutonic(?) rocks, which are thought by some to represent hot-springs altered felsic rocks and not exhalites *per se*.

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. 5), the distribution of the Au deposits is complicated. Firstly, the belt of gold vein deposits is not entirely restricted to the belt of volcanic rocks and VMS deposits (Fig. 5). Secondly, even where located in the belt of volcanic rocks, gold veins occur in plutonic rocks as well as volcanic rocks. For example, the largest deposit in the Ashland-Wedowee belt, the Hog Mountain deposit, is entirely within a "quartz diorite" body. Thirdly, galena from the veins is distinctly radiogenic (like those from the Fairbanks district) and is distinct from galena from the associated stratabound VMS deposits. 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 rare.

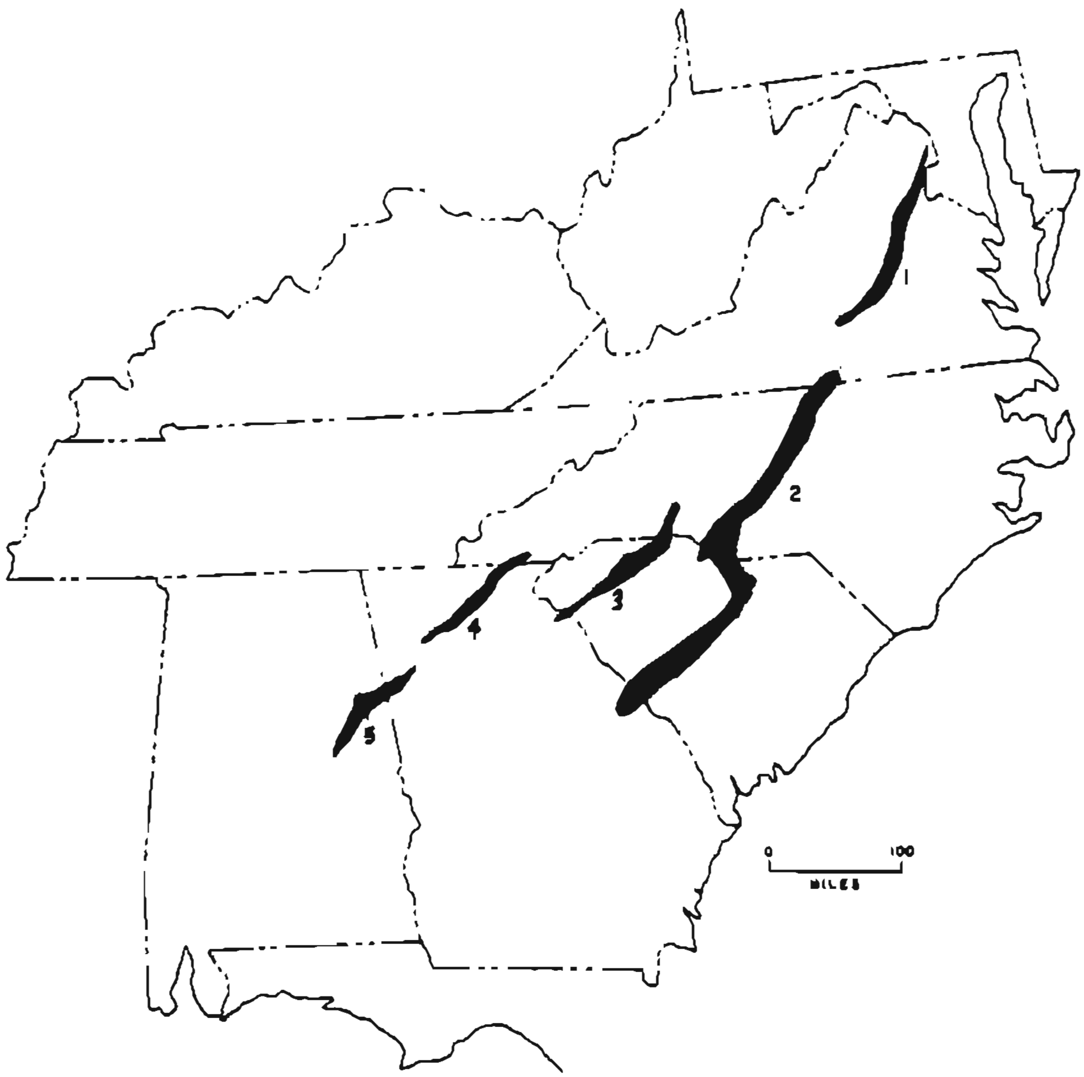


Fig. 4 EoCambrian-Cambrian volcanogenic(?) gold belts of the SE US Piedmont. 1 = Virginia Py belt, 2 = Carolina slate belt, 3 = Kings Mtn belt, 4 = Dahlongea district, 5 = Ashland-Wedawee belt

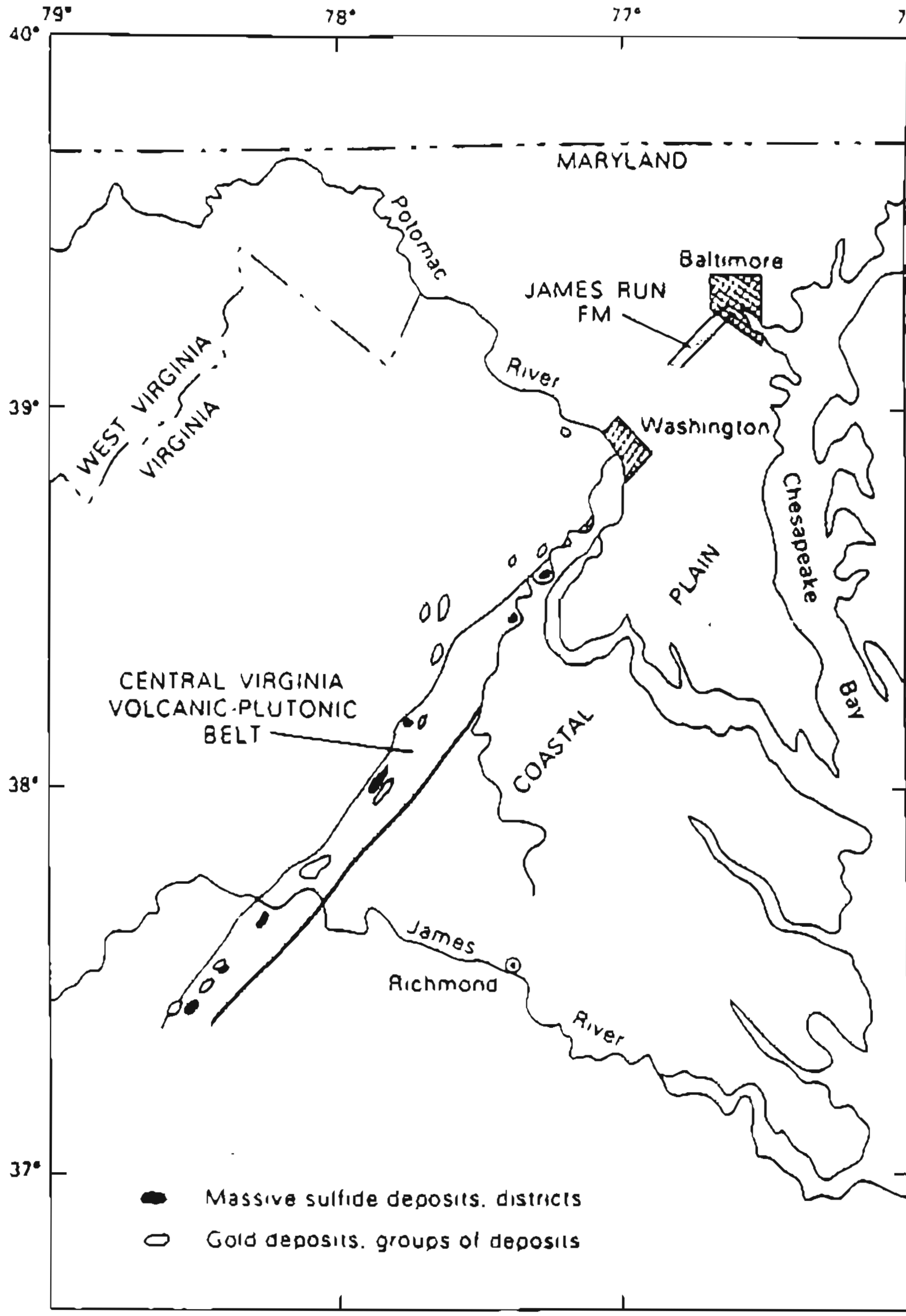


FIG. 5 . Generalized map showing the trend of the central Virginia volcanic plutonic belt and the distribution of deposits and groups of deposits of massive sulfides and gold. Taken from Pavlides et al. (1982).

B. Other potentially analogous districts/belts

Districts of late Proterozoic to Cambrian ages with bimodal volcanic and sedimentary rocks and gold veins include the Westland and Nelson Province goldfields, South Island, New Zealand; Dolgellan Au belt, North Wales; Bindalen area, Norway; and Kraslice-Klingenthal area, Czechoslovakia. Laznicka (1985) suggests that some gold vein deposits in the Tasman geosyncline, Australia and the Ural Mountains, USSR have similar ages and affinities. Perhaps more importantly, although Caledonian and other Phanerozoic bimodal-associated VMS districts are quite common, documented examples of associated gold veins are rare. It may be that a given bi-modal volcanic belt cannot produce both major VMS and significant gold veins. Perhaps, for example, stratabound gold precursors to gold vein deposits represent a variety of "failed" VMS deposits. Certain special metamorphic conditions and/or plutonic intrusions may be needed to properly mobilize gold into the veins, conditions which are not realized in most bimodal volcanic fields.

C. Applicability of the SE US Piedmont to the North Star belt

The major reason for applicability of the SE US model is the similarity in rock types and ages in the two areas. The 'bimodal' character of the Cleary Sequence has been described by many workers, e.g. Pessel et al. (1987) and Allegro (1987). An early Cambrian age for the belt is indicated by Oldhamia (a Cambrian trace fossil) in rocks depositionally overlying the Cleary Sequence (Pessel et al., 1987). Other similarities are mineralogical, i.e., the presence of stratabound, zoned tourmaline and the virtual absence of stratabound ankerite in both belts. Vein mineralogies are also similar.

D. Resource implications of the SE US Piedmont model to the North Star gold belt

One obvious and important implication is that we can find enough grade-tonnage data from the Piedmont belts to construct relatively tight probability distributions. Furthermore, study of the belts could lead to models of district size and spacing (c.f., Fig. 5, with sizes and spacings of gold districts in the Virginia pyrite belt). This could enormously simplify our problem of estimating the resource potential of the North Star gold belt. On the other hand, these deposits do not normally appear to be very large: gold production from the entire SE Piedmont region has been on the order of 3 million oz, and although a fair amount of gold is still in the ground, the gold resources are probably about an order of magnitude smaller than that represented by Archean volcanogenic deposits. The exception to this rule is the recently discovered Ridgeway deposit in the Carolina slate belt (S. Carolina), with published reserves of 55 m.t. at .035 opt Au, indicating that significant, if not enormous, resources are present in these belts.

Relative to the 10 million oz of gold produced in the Kantishna-Fairbanks-Circle area, however, a SE U.S. model alone seriously under-predicts gold endowment for the North Star belt. Use of this model underscores the need for an additional (plutonic) gold source in the model and for additional study.

III. PLUTONIC ROCKS ASSOCIATED WITH GOLD IN THE NORTH STAR GOLD BELT

Introduction

Major types of plutonic rocks associated with gold deposits seem to have crystallized at low-oxidation state (Keith and Swan, 1987) and/or from alkalic to sub-alkalic magma (Mutschler et al., in press). The Steese-White Mountains project has shown that both of these types of plutonic rocks crop out in the North Star gold belt (Burns et al., 1987). Preliminary investigations suggest the sub- alkalic and the low-oxidation state plutonic rocks continue in a southwestward trending discontinuous belt along or near the North Star gold belt (Fig. 1). The sub-alkalic-related gold deposits in particular appear to have a high potential to be associated with gold deposits and are not generally recognized in Alaska.

A. Chemical characteristics of plutons associated with gold deposits

Background

A pluton is considered alkalic if it contains a high amount of $Na_2O + K_2O$ relative to SiO_2, and the greater the amount of alkali (for given amount of silica), the more alkalic. An "alkalic index" -- essentially a modification of Mutschler et al. (in press) is

$$A.I. = wt.\% \, Na_20 + wt.\% \, K_20 + 16 - (0.372) \, wt.\% \, Si_20.$$

A simple (though not rigorous) measure of oxidation state is simply the ratio $Fe_20_3/Fe0$.

Characteristics

Plotting the alkalinity index vs. oxidation state index for Alaskan plutons associated with gold prospects/deposits (Fig. 6) shows that all the plutons associated with gold possess (a) high alkalinity or (b) very low oxidation state or (c) some combination of moderate alkalinity and low oxidation state. Highlighted points are those from plutons spatially associated with gold deposits in the North Star gold belt.

For contrast, some representative plutons associated with "low gold" porphyry and skarn deposits are shown on Fig. 1; these plot to the right and below the gold-bearing plutons. Also shown are alkalic plutonic rocks not known to be associated with gold deposits. At this preliminary stage, combined alkalinity and oxidation state parameters appear to usefully discriminate gold-related plutons. Preliminary data, presented below, suggests that the abundance of plutonic magnetite may be a critical part of the story.

B. Proposed petrologic-chemical model for gold-related plutons

(1) plutonic derived gold

Studies of mineral separates from major plutonic rocks from many places in the world indicate that magnetite is an important gold sink (Fig. 7). The data shows that magnetite has the highest gold concentrations of common rock-forming plutonic minerals, with concentrations commonly in the 10-300 ppb range (Fig. 7). Gold concentrations in other mafic minerals are typically in the 1-3 ppb range, and are less than 1 ppb in the felsic minerals. Tilling et al. (1973) showed that for rocks of the Marysville pluton, more than 70 percent of the contained gold is in magnetite. They also suggested that some or much of the gold in mafic minerals is from magnetite inclusions in those minerals.

If gold is strongly partitioned towards magnetite during magmatic fractionation, then magnetite abundance in a rock should greatly influence the ability for gold to concentrate in the residual magma. Figure 8 for example, shows gold abundance data for some magnetite-bearing and magnetite-absent plutonic rocks of Japan. The two groups have opposite trends, magnetite-absent plutons showing a general increase in Au with fractionation and magnetite-bearing plutons showing a decrease in gold abundance with fractionation. These contrasting trends presumably develop because gold is depleted from the residual melt during crystallization of magnetite-rich rocks. Clearly, low-oxidation state plutons are more likely to concentrate gold.

Plutonic chemistry also influences gold partitioning because it influences magnetite crystallization, through the mineral reaction:

K-feldspar + magnetite + H_2O + quartz = biotite + $1/2 \, O_2$
$KAlSi_3O_8$ Fe_3O_4 $2SiO_2$ $KFe_3Si_3AlO_{10}(OH)_2$

Although increasing oxidation state forces magnetite crystallization, increasing the alkali abundance (at quartz saturation) forces biotite crystallization at the expense of magnetite. Hence, the abundance of crystallized magnetite is a product of both the alkalinity and the oxidation state.

Gold abundance trends for typical calc-alkalic and alkalic rocks clearly illustrate the effect of magma chemistry (Fig. 9). Calc-alkaline plutons have higher overall gold abundances but show a trend of decreasing gold content with increasing fractionation, whereas alkalic plutons often have lower overall gold contents, but show increasing gold content with increasing fractionation.

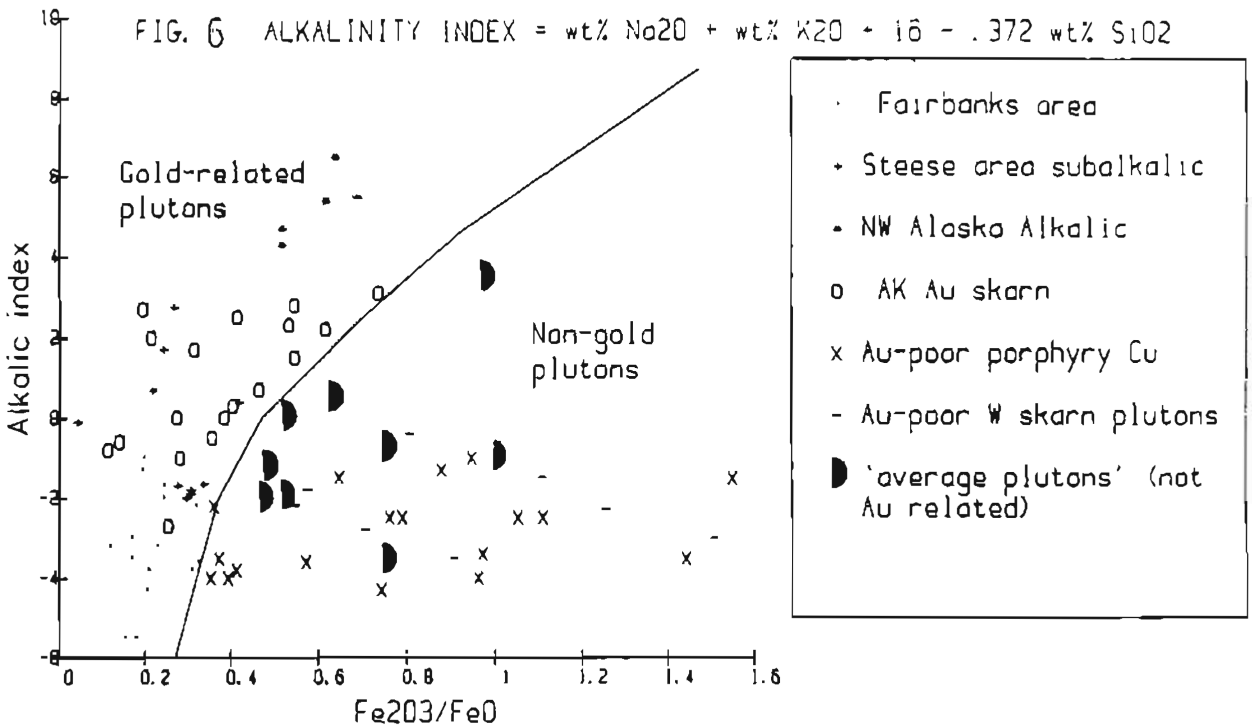


Fig. 6: Alkalinity index vs. oxidation state index for gold-associated and non-gold associated plutons. Data from: Miller and Ferrians (1968), Miller and Elliot (1969), Newberry (1986), Newberry and Swanson (1986), Allegro (1987), and Burns et al. (1987)

Fig. 7 : Average gold contents of major plutonic minerals

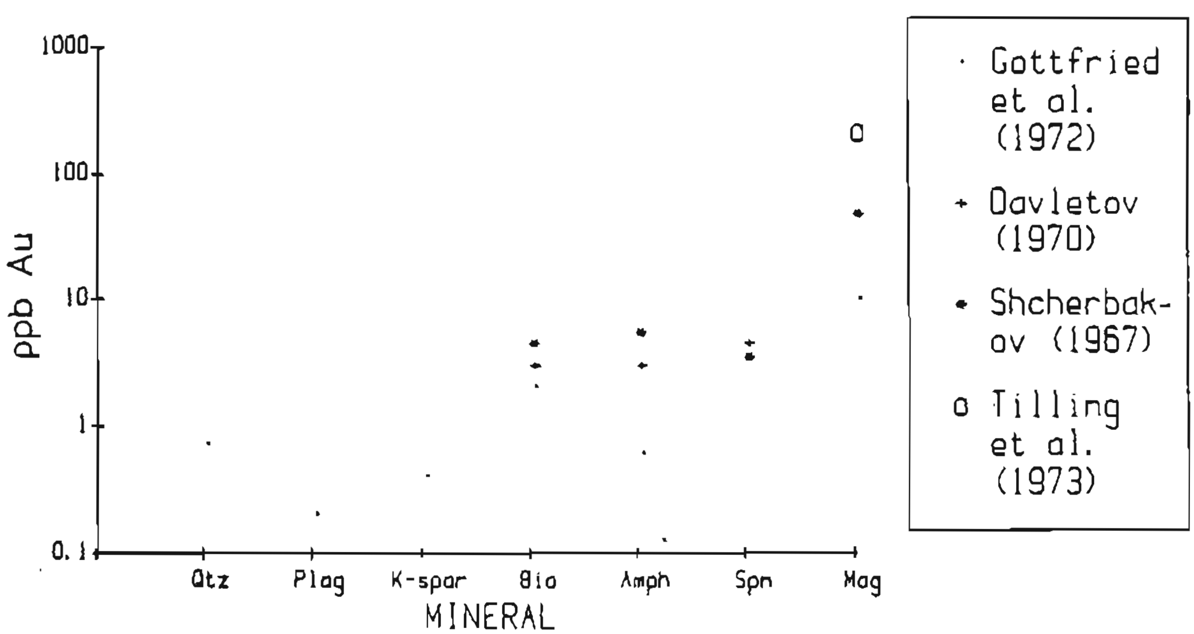


Fig. 3 Gold abundance vs. fractionation for several plutonic suites

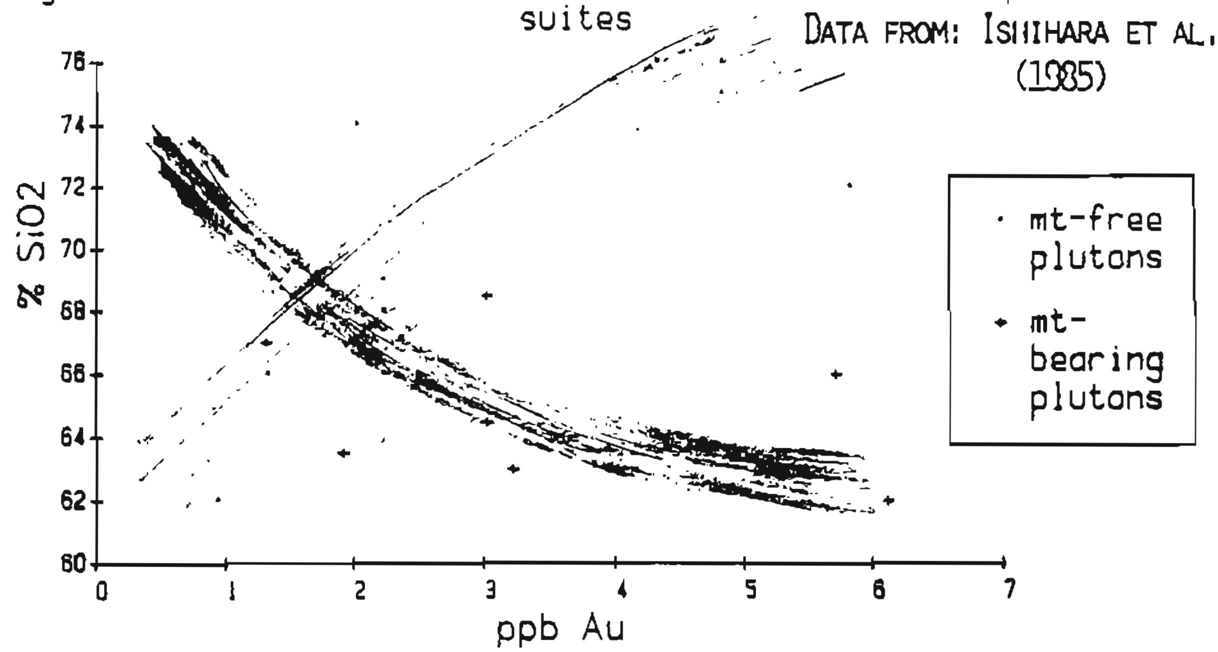
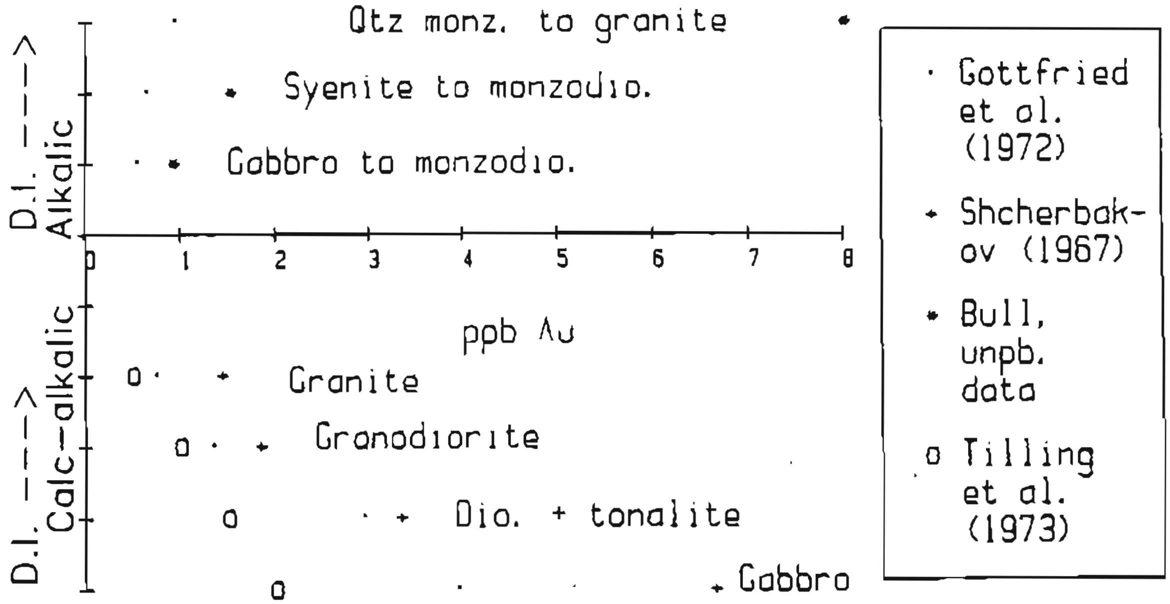


Fig. 9 Gold abundance vs. fractionation for several plutonic suites



An exception to this 'rule' is for plutons which have undergone liquid-liquid fractionation in addition to crystal-liquid (the case above) fractionation. The former type are characterized by high Rb, Li, B, Si (etc.) abundances and commonly associated with Sn deposits. During liquid-liquid fractionation, gold is preferentially depleted in the more fractionated part of the melt (Hildreth, 1981); hence, such fractionation will decrease the amount of gold available for hydrothermal mineralization. Plutons which have undergone liquid-liquid fractionation will not be good targets for plutonic derived gold deposits. Rb or B could make good analytical indicators of such liquid-liquid fractionation, as they are strongly concentrated during such fractionation.

In summary, the mineral-chemical evidence at hand suggests that plutonic systems which crystallize abundant magnetite fail to concentrate gold, and those which do not crystallize much magnetite can at least potentially concentrate gold. The data also suggest that compositional parameters can predict magnetite abundance in quartz saturated rocks.

(2) Remobilization of wall-rock gold

Studies of gold solubility show that at low (<300C) temperatures, gold mobility is entirely as a bisulfide complex (Fig. 10), which means that if magmatic/meteoric/metamorphic fluids are to transport gold, they must be buffered to an oxidation state-pH region compatible with gold- bisulfide stability. Plutons which contain abundant magnetite and/or hematite buffer fluids to a pH/oxidation state outside of the gold bisulfide stability maxima. Fluids which emanate from, or travel through such plutons will consequently not be able to effectively mobilize the gold in stratabound sources into veins.

Note that plutons which have undergone liquid-liquid fractionation (see above) and have no propensity for plutonic-sourced gold deposits will still have the ability to cause gold remobilization if they possess the required low oxidation state.

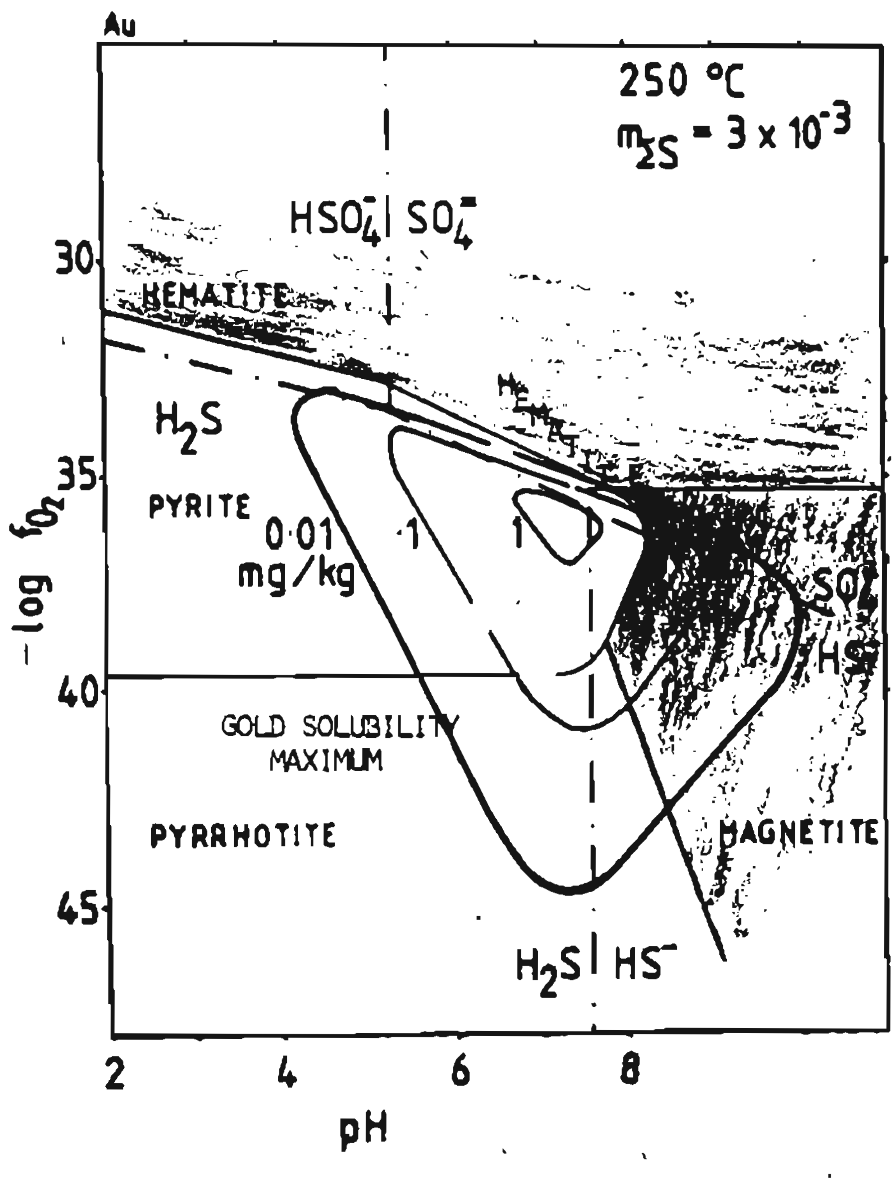
B. Other chemical tests for gold-related plutons

This study and other studies of gold-bearing hydrothermal systems suggest that such systems have several geochemical indicators. Because background levels for gold in 'normal' plutonic rocks are close to analytical sensitivity (about 2-5 ppb), merely testing for gold is not a very adequate means of assessing the gold potential of a pluton. Further, as outlined below, the characteristic of gold-related plutons is that gold is concentrated in the most fractionated units--thus, high gold concentrations in the least-evolved units may actually be detrimental for gold deposits. The way around these problems is to look at 1) metal contents in the most fractionated units of a pluton, and 2) elements with higher background levels (relative to detection). Two such elements are tellurium (Te) and thallium (Tl). Background values for Te are about 5 ppb, however, gold-associated plutonic/volcanic rocks commonly have Te contents of 100-1000 ppb. Values of >100 ppb Te have been found in some plutonic rocks associated with gold deposits in the Hope Creek area (Steese Conservation district). Thallium has not been measured in rocks of the North Star belt, but background value for granitic rocks (1.2 ppm) is significantly higher than the detection limit (.2 ppm), making it a potentially useful indicator element.

D. Implications for gold resource analysis

If further work holds up the alkalinity-oxidation state (Fig.6) discriminant, it should be possible to quickly determine the potential for plutonic related gold deposits given some plutonic rock data. This would be particularly valuable for areas which have little exposure or little geologic data. Because telluride gold (characteristic of many alkalic systems) does not form significant placer deposits, the presence of a favorable plutonic index may be of more importance than the presence of gold placers. In addition, because there appears to be a correlation between low-magnetite plutons and gold deposits, it may be possible to check rock chemistry with aeromagnetic studies in determining gold favorability.

FIGURE 10: GOLD SOLUBILITY CONTOURS FOR GOLD AS A BISULFIDE COMPLEX



IV: PROPOSED WORK TO REFINE NORTH STAR GOLD BELT MODELS AND PRODUCE A VIABLE ROCKVAL FOR INTERIOR ALASKA GOLD

We propose three lines of investigation, discussed in greater detail below: (1) more tests for the applicability of SE US Piedmont model to the NS gold belt, (2) more tests for applicability of the alkalinity-oxidation state model for plutonic gold favorability, and (3) means to quantify gold resources associated with each deposit type.

A. Testing the applicability of the SE US Piedmont model to the North Star gold belt

Our confidence in applying SE Piedmont grade-tonnage models to the Cleary Sequence would be appreciably increased if it can be shown that the SE US Piedmont lithologies closely resemble those of the Cleary Sequence. Hence, the model can be tested in several ways:

(1) Age dating of the volcanic rocks. Zircon dates are being pursued.

(2) Major, minor, and trace element data is available for metavolcanic rocks from the Virginia pyrite belt, the Carolina slate belt and the Dahlonega gold belt. Data for the other belts can presumably be found as well (?). Existing data suggests that these belts represent a restricted tectonic environment, as indicated by immobile trace element plots. For example, the basaltic rocks are appreciably different from normal mid-ocean ridge basalts. Immobile trace element data on metavolcanic rocks from the Cleary Sequence will quantify the resemblance of the Cleary Sequence to the SE Piedmont rocks.

(3) Samples of stratabound tourmalines from the SE Piedmont can be analyzed and compared to our Cleary sequence tourmalines. [John Slack, USGS Reston, has agreed to send some samples.] Previous work has shown that tourmalines from different types of ore deposits have appreciably different compositions.

(4) Sample truly stratabound lead from Cleary sequence rocks for Pb isotopic work. Determine if these leads yield values similar to those seen in the stratabound deposits of the SE Piedmont.

Analytical work described above would require some re-mapping and re-sampling of key areas to be undertaken in June 1988.

B. Testing a plutonic-derived gold model for the gold belt

(1) Acquire more data for plutons known to be associated with gold deposits. This would include Fe_2O_3/FeO--alkalinity data and B/Rb/Te/Tl data and include data from both literature searches and new analyses from plutons not in the belt.

(2) Acquire data from previously unsampled plutons in the gold belt (e.g., Kantishna area) and Rb/B/Te/Tl data for all plutons in the gold belt and from several examples of veins in the area.

(3) Set up a discriminant analysis based on the literature search and analytical results and apply it to this study.

Analytical work would require some re-mapping and sampling of key areas.

C. Rockval modeling of gold endowment in the North Star belt

The model would consist of both volcanogenic and plutonic-derived gold, each run separately and the total aggregated. Favorability for volcanogenic gold would be based on proximity to the key bi-modal volcanogenic units [meta-basalt and meta-felsite]. Grade, tonnage, and prospect distribution models would be based on SE US VPMS deposits/belts, assuming that this model continues to hold up to our additional analytical work. Favorability for plutonic-related gold would be based on results of compositionally-derived discriminant analyses and proximity to the appropriate plutons. Grade, tonnage, and prospect distribution models would be based on world wide data for pluton-related deposits. We anticipate that the proposed sampling and analytical work would be completed by August 1988 and the Rockval analysis and preliminary report be completed by September 30 1988.

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