DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PRELIMINARY MINERAL RESOURCE ASSESSMENT OF THE ELK CITY 1°X2° QUADRANGLE, IDAHO AND MONTANA:

Compilation of geologic, geochemical, geophysical, and mineral deposits information

By

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Part I: Text and Plate A

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EXECUTIVE SUMMARY

The Elk City 1°x2° quadrangle covers a mountainous area of limited access in a strategic geologic setting. The quadrangle extends from the suture zone between island arc and continental rocks (the Salmon River suture) on the west into the foreland fold and thrust belt on the east. Most of the area is underlain by terrigenous metasedimentary rocks of unknown correlation or depositional basin setting. These continental metasedimentary rocks had a complex metamorphic and plutonic history: they underwent metamorphism of both Middle Proterozoic and Cretaceous age and were intruded during four magmatic episodes of Middle Proterozoic, Cambrian-Ordovician, Late Cretaceous, and Eocene age. The structural and magmatic complexity produced many different types of mineral deposits (sediment hosted, stratabound, vein, disseminated, and placer) and perhaps facilitated concentration of metals through time by means of remobilization.

Potential for precious metal, base metal, and rare earth element mineral resources of the six most significant mineral deposit types and of at least 50 other metal (or nonmetal) deposit types can be recognized from the preliminary data. Analysis of mining history, district studies and compiled geologic mapping from many sources, geochemistry from the NURE program, USGS and NURE geophysical surveys, and available remote sensing data provide enough information to indicate several target areas for the primary types of deposits, but much information is lacking in some parts of the quadrangle or for some types of deposits.

Gold, silver, and a polymetallic association (primarily antimony, arsenic, tungsten, bismuth, and, in some cases, mercury or copper) have been mined throughout large areas in the quadrangle, particularly on the western side (fig. 1). Deposits are primarily Cretaceous mineralized quartz veins but also include Cretaceous disseminated deposits and historically important local Oligocene and modern placer gold deposits. Available geologic, geochemical, and geophysical characteristics of the known deposits indicate that potential for unknown deposits may exist in surrounding areas. A major outcome of this preliminary study is that the most interesting target areas occur in the southcentral and eastern parts of the quadrangle in areas that are not part of well-known gold mining districts and are not obviously in the same geologic environment as the better known mining districts. The most outstanding geochemical anomalies of this association in the quadrangle are coincident with outstandingly high aeromagnetic anomalies but are unexplained by the known geology or by previous mining history. The source of the gold and base metal mineralization is unknown but could have come from any of the four magmatic episodes present in the area or from the country rock Yellowjacket Formation or could have been recycled through several events. Detailed study of these areas and comparison with known deposits is needed.

Cobalt, copper, and associated gold mineralization are important in the Elk City quadrangle. The Blackbird cobalt mine in the southeastern corner of the quadrangle is a sediment-hosted deposit in the Middle Proterozoic Yellowjacket Formation. Large parts of the quadrangle are underlain by the Yellowjacket Formation or by metasedimentary rocks that may be correlative. These areas of suspected Yellowjacket Formation are coincident with areas having anomalously high values for copper and cobalt in stream sediment samples. High aeromagnetic values near areas of geochemical interest may reflect sources for the Middle Proterozoic mineralization or some younger, unrelated magnetic bodies.

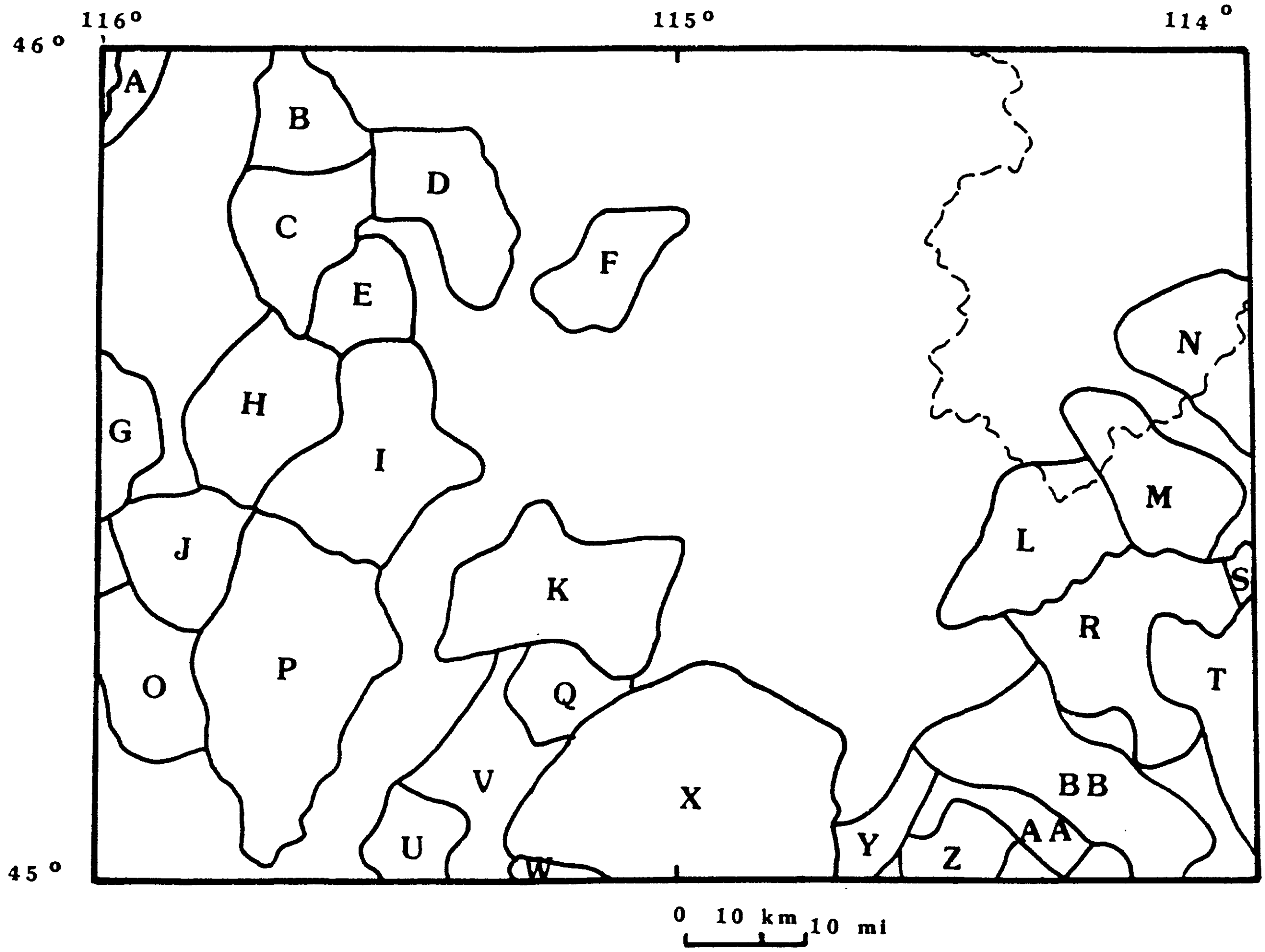

Figure 1. Index map of mining districts in the Elk City 1°x2° quadrangle, Idaho and Montana, after Mitchell and others (1981).

A	Harpster	O	Resort
B	Newsome	P	Warren
C	Tenmile	Q	Ramey Ridge
D	Elk City	R	Mackinaw
E	Orogrande	S	Aurora
F	Green Mountain	T	Eureka
G	Florence	U	Profile Gap
H	Buffalo Hump	V	Edwardsburg
I	Dixie	W	Thunder Mountain
J	Marshall Lake	X	Big Creek
K	Chamberlain Basin	Y	Wilson Creek
L	Mineral Hill	Z	Yellow Jacket
M	Indian Creek	AA	Musgrove
N	Gibbonsville	BB	Blackbird

Regional east-west linear trends in these areas of interest may reflect old structures in the host rocks. Detailed stratigraphic, cobalt-copper±gold deposits in the quadrangle are needed in order to evaluate the origin of these deposits and the potential for resource occurrence in other parts of the quadrangle.

The roof zones and margins of particular phases of Eocene granite plutons have anomalously high values for the association of beryllium-uranium-molybdenum-tin and anomalous thorium/potassium ratios. There is a weaker correlation between this association and Middle Proterozoic and Cambrian-Ordovician plutons; Cretaceous plutons have anomalously low values for the association. Beryl prospects occur in vugs along the contacts of the Eocene Bighorn Crags pluton. However, no production of uranium, molybdenum, or tin from this setting is reported in the quadrangle. In light of the favorable geochemical information, more work along these pluton margins is necessary to evaluate the beryllium, uranium, molybdenum, tin potential.

Strong silver anomalies, which are independent of gold or arsenic anomalies but are in close association with some beryllium-uranium-molybdenum-tin anomalies, occur in the northcentral part of the quadrangle. The geochemical anomalies are not correlated with geophysical anomalies or particular linear features but are localized along roof zones or margins of Eocene granites. Only one known silver occurrence, which has had no production, is associated with these anomalies. Further work is necessary to delimit the resource potential.

Small areas of tungsten-bearing skarn mineralization occur in the western part of the quadrangle in possible Late Proterozoic to Paleozoic metasedimentary roof pendants. The geochemical data available for this preliminary study indicated that moderate tungsten values are ubiquitous in areas with anomalously high gold and silver values, however, the available geochemical data do not provide any guidelines for targeting this type of tungsten deposit. Thirty-six occurrences are reported. There has been no known production from the Elk City quadrangle, but tungsten has been mined from skarns in similar rocks in the Yellow Pine district in the northwest part of the Challis quadrangle. More work is necessary on the stratigraphy and structure of the hosting metasedimentary rocks and on the reported occurrences in order to evaluate the potential for tungsten resources.

Niobium, columbium, and rare earth element deposits with small amounts of reported production occur in carbonatic veins and lenses on the eastern side of the quadrangle. These veins and lenses are associated with Middle Proterozoic amphibolite, augen gneiss, and a variety of metasedimentary rocks and may be carbonatite-related. The area around these deposits has not been mapped in detail and the structural and metamorphic settings as well as the age and origin of the carbonate veins, whether "carbonatite magma" or metamorphic differentiation of calcareous sedimentary layers, must be evaluated. The resource potential cannot be estimated without further geologic, geochronologic, and geochemical work.

Too little information on geologic setting, timing, geochemistry, or mining history is available to evaluate the potential for a large variety of other possible resources in the quadrangle. There are many examples in the quadrangle of (1) geologic environment indicative of a particular mineral deposit model with no known occurrences or geochemical anomalies, (2) known occurrences in areas that are poorly understood geologically, and (3) otherwise unexplained geochemical anomalies. Further work is necessary to estimate the appropriateness of some mineral deposit models for evaluating resource potential.

Problems

The Elk City quadrangle occupies a critical position relative to the tectonic framework of the northern Cordillera. This area warrants a comprehensive, multi-disciplinary study which would bear on our better understanding the diverse mineral deposits and the potential for additional mineral resources.

Stratigraphy, Metamorphism, and Structure in Metasedimentary Rocks

Much of the quadrangle is underlain by metasedimentary rocks that are probably Middle Proterozoic, but Early Proterozoic, Late Proterozoic, and Paleozoic rocks may also occur. The reconnaissance mapping in most of these rocks is insufficient to allow regional correlation, to provide understanding of the basin in which they were deposited, to project the potential for the occurrence of unknown resources such as those that occur in nearby unmetamorphosed Middle Proterozoic strata, or to evaluate the origin of mineral deposits that are known to occur in them. Study of these rocks would provide:

* Information for regional correlation of sedimentary units;
* A model for the basin in which these sediments were deposited and the relationship of this basin to that of the Belt Supergroup;
* A regional basin model for deposition of the strata at the Blackbird cobalt deposit;
* More information for mineral deposit models for Blackbird-type cobalt-copper deposit and possibly for Spar Lake-type copper-silver, for Sullivan-type lead-zinc, and for tungsten skarn mineralization like that at the Yellow Pine mine;
* Information on the timing and geometry of thrusting across the quadrangle from the suture zone on the west to the fold and thrust belt on the east;
* Information on the amount of thrust transport; and
* Criteria for recognition and tracing of stratigraphic horizons related to sediment-hosted cobalt-copper deposits.

Discrimination of Magmatic Suites

Plutonic rocks of four different magmatic episodes are now recognized in the quadrangle; none have been mapped and described in detail. Vast areas underlain by rocks as diverse as Middle Proterozoic deformed granite and Eocene granophyre have been lumped as a single unit. Much mapping, geochemical, isotopic, and geophysical research is necessary to identify and describe these systems. Topical study of the plutons will result in:

* Detailed maps, petrologic descriptions, and geochemical data of lasting value to subsequent workers;
* Models for the tectonic setting and petrogenesis of the Middle Proterozoic porphyritic granite and amphibolite suite(?) and of the Cambrian-Ordovician alkali syenite plutons;
* Assessment of the age, geochemical, and structural differences between phases of the Late Cretaceous Idaho batholith;
* Evaluation of the different tectonic and crustal processes which produced the magma types of different ages;
* Information from dating studies that will genetically relate plutons and hydrothermal mineral deposits; and

* Information on the origin of the metals in hydrothermal mineral deposits and the possible recycling of the metals through several plutonic hydrothermal episodes.

Regional Tectonics

The tectonic setting has direct bearing on the genesis of mineral deposits in the quadrangle. Study of stratigraphy, metamorphism, deformation, and magmatism help define the tectonic history of the quadrangle. In addition, direct study of the crustal geometry of the Salmon River suture zone and effects related to its formation will provide important controls on:

* Geometry of accretion;
* Present-day geometry of the truncated west side of ancient sedimentary basins;
* Timing of metamorphism and deformation in relation to origin of the Late Cretaceous magmas;
* Petrogenesis of Late Cretaceous magmas in terms of depth of formation and chemistry of rocks in the probable source region (i.e., subducted oceanic slab?, overthickened crust?, etc.);
* Details of Late Cretaceous to present block faulting, uplift, and extension (including study of the southwest continuation of the extensional mylonite that defines the Bitterroot dome and the possible northwest-trending fault south of Chamberlain Basin that seems to have controlled unroofing of Late Cretaceous granite and possibly emplacement of Cambrian-Ordovician plutons; and
* Genesis of hydrothermal mineral deposits and relation to specific magmatic events.

Mineral Deposits

Many types of topical studies of mineral deposits and processes of mineralization are important aspects of the proposed study. Modern methods of study applied to deposits in the quadrangle will result in:

* Models for the origin and age of niobium, columbium, rare earth element deposits and the possibility that they are part of a carbonatite province;
* Direct dating of hydrothermal gold, silver, and associated base metal deposits that will provide better understanding of the genetic relationship between the deposits and Late Cretaceous magmas;
* Information on the depth and temperature of formation of the gold-bearing quartz vein deposits and associated disseminated gold deposits;
* Additional information on the setting of sediment-hosted cobalt-copper deposits.

The Elk City quadrangle has a history of extensive mining and prospecting activity for a wide variety of mineral deposits and commodities (fig. 1). The preliminary mineral resource evaluation indicates a high potential for undiscovered resources of both previously exploited mineral deposit types and of presently undiscovered types. These preliminary data also result in identification of specific target areas for further research and exploration. A complete assessment of the quadrangle would result in more target areas and additional industry interest in the area. Topical studies on origin and controls of mineral deposits in the area will result in research on unique mineral deposit settings, development of new deposit models, and formulation of better exploration criteria in the region.

Recommendations

Although the general geologic framework of the Elk City quadrangle is established, much of the specific geology is poorly understood. The purposes of undertaking the mineral resource assessment of the quadrangle are to provide better overall geological data for the region and to pursue topical studies that bear directly on evaluation of mineral deposits. Detailed recommendations are in following sections.

Geologic Studies

Geologic mapping of about half of the quadrangle must be updated to provide more details. Topics of study in these less well known and in recently studied areas should include (1) detailed stratigraphy of metamorphosed layered units; (2) metamorphism and deformation of the stratified rocks and of plutons that intruded them; (3) igneous petrology of the four major plutonic suites; (4) controls of mineralization for known deposit types; and (5) geochronology of metamorphism, plutonism, and mineralization.

Geochemical Studies

Additional geochemical data are required to produce a complete mineral resource assessment. In a more protracted study, further sampling and/or addition of data from previous wilderness mineral assessment surveys would be important. Topical studies on several target areas is proposed: (1) study of the broad gold and related element geochemical halo that surrounds the Blackbird cobalt deposit and the Mackinaw-Mineral Hill gold mining districts (fig. 1); (2) study of a similar association of anomalously high values in the southcentral part of the quadrangle in the Big Creek mining district (fig. 1); (3) study of enigmatic silver anomalies possibly associated with margins of several Eocene granite plutons for which there is no appropriate mineral deposit model.

Geophysical Studies

Additional aeromagnetic data should be acquired to provide details of aeromagnetic highs associated with geochemical anomalies and to fill in gaps in the present data set. Present gravity data are for specific areas and new sites must be located to provide more even coverage. Topical studies of deep crustal features (by seismic refraction and possibly reflection) are proposed to provide three-dimensional views of basement tectonics that bear on regional tectonic setting, origin of silicic magmas, and genesis of hydrothermal mineral deposits.

Remote Sensing Studies

Remote sensing studies that can identify hydrothermally altered areas should be attempted in the mineral assessment studies. In addition, topical studies of linear features in specific areas both in known mining districts and in designated target areas must be attempted.

INTRODUCTION

Topography

The Elk City 1°x2° quadrangle (lat. 45°00'N to 46°00'N by long. 114°00'W to 116°00'W) covers a forested area of subdued mountainous terrain (plate 1). The most prominent topographic feature is the canyon cut by the west-flowing Salmon River that transects the middle of the quadrangle. Although the Salmon River is the major drainage, the northeastern part of the quadrangle is drained by the Bitterroot River system and the central and northwestern parts are drained by the Clearwater River system. Elevations in the quadrangle range from Trapper Peak at 10,211 ft in the Bitterroot Mountains in the northeastern corner to the base of the Salmon River canyon at about 1,900 ft on the western boundary. Much of the central and western parts of the quadrangle are a high basin (between 5,000 and 5,700 ft) that has been deeply dissected to form three separate subbasins (the Elk City-Dixie basin, Chamberlain Basin, and the Burgdorf-Warren basin). Most of the quadrangle is densely forested; however, slopes in the Salmon River canyon are rocky and grass covered and vegetative cover is minor above treeline at about 7,500 ft.

Land Status

Only about 5% of the land in the quadrangle is private. The remaining 95% is federal land managed by the U.S. Forest Service. About 50% of the federal land is in the wilderness system. The quadrangle includes the Gospel-Hump Wilderness and large parts of the Selway-Bitterroot and Frank Church-River of No Return Wildernesses.

Access

Access is moderate to poor. No major highways cross the quadrangle, but well-maintained county and U.S. Forest Service roads make access to eastern and western parts of the area fairly easy. Access to the center of the quadrangle is limited to one east-west road (through the Magruder Corridor), to boat traffic along the Middle Fork and main Salmon Rivers, and to small public and private airstrips.

Base Materials

With the exception of eight 15' quadrangles in the southeast and southwest parts of the Elk City 1°x2° sheet, the entire quadrangle is available in finished 7-1/2' quadrangles at 1:24,000 scale. For areas covered by the 15' quadrangles, maps at 1:24,000 scale are available as advance 7-1/2' or orthophoto quadrangles.

Aerial photos are available for the entire quadrangle through several government agencies. The most complete coverage is available through the U.S. Forest Service which manages most of the land. Black and white photo coverage is complete, and color photos are available for much of the area. Several scales are available and mixing of scales may be required to get complete coverage of the quadrangle. Because of the heavy vegetation in much of the area, large-scale photos or color photos would only be useful in selected well-exposed areas. Direct geologic mapping on aerial photos is impractical in most cases.

SECTION A

GEOLOGY

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Previous Geologic Investigations

The previous geologic mapping of the Idaho portion of the quadrangle (fig. A1) was compiled by the Idaho Bureau of Mines and Geology (Mitchell and Bennett, 1979). Most of the Montana portion of the quadrangle was recently remapped by the Montana Bureau of Mines and Geology (fig. A2; Fisk, 1969; Berg, 1977). Between 1979 and 1987, about 50% of the quadrangle was remapped by the USGS through the program for mineral resource evaluation of wilderness lands and as part of the strategic and critical minerals program (fig. A2). Less than 5% of the quadrangle is completely unmapped.

Geologic mapping of wilderness lands by the USGS and the Idaho Bureau of Mines and Geology provides most of the data base for the quadrangle (plate A). About 60% of the quadrangle was mapped before 1978 at scales of 1:250,000 or 1:125,000. The generalized lithologic maps that resulted from these studies are incomplete. Mapping done by the Montana Bureau of Mines and Geology covers another 15% of the quadrangle and provides fairly complete information at a moderately detailed scale (about 1:50,000). Recent USGS mapping (mostly at 1:50,000 scale) has superseded much of the early mapping by the Idaho Bureau of Mines and Geology, the Montana Bureau of Mines and Geology, and the USGS, and has included much additional area.

Because many large and important mining districts occur in the quadrangle, mapping in areas of mining activity constitutes the second major source of geologic mapping. These studies cover limited areas but are invaluable sources of geologic mapping because they are commonly detailed and provide integrated information on metamorphic, structural, plutonic, and mineralization history. Unfortunately, almost all of these studies are old; most date from 1900 to 1940. Nonetheless, many are good basic studies of ore deposits and will serve as excellent background for studies using modern methods of determining temperature and pressure of formation, origin of fluids, age of mineralization, and origin of metals.

Thesis maps comprise a third source of geologic data and in several areas provide the only available or most detailed information. The theses commonly provide much detail but, because of the topical nature of most of these studies, the mapping may be somewhat incomplete. In some cases, these topical studies are most important for information on specific geologic problems or for providing more information on the geologic history than is available through some of the regional mapping studies.

Published topical studies are almost entirely lacking in the Elk City quadrangle. The only study that combines a problematic approach with geologic mapping is the ongoing USGS study of the "Idaho cobalt belt." Other than thesis projects, which are not commonly of a regional scale, none but the most recent mapping has addressed specific geologic problems of stratigraphy, metamorphism, structural history, origin of plutons, age and origin of the several mineral deposit types, etc.

Setting

The Elk City quadrangle is on the western edge of the pre-Late Cretaceous North American continent; the northwestern corner of the quadrangle straddles the Salmon River suture zone between allochthonous oceanic terranes and para-autochthonous continental rocks. Oceanic rocks on the west are metamorphosed and deformed volcanic, plutonic, and sedimentary components of an

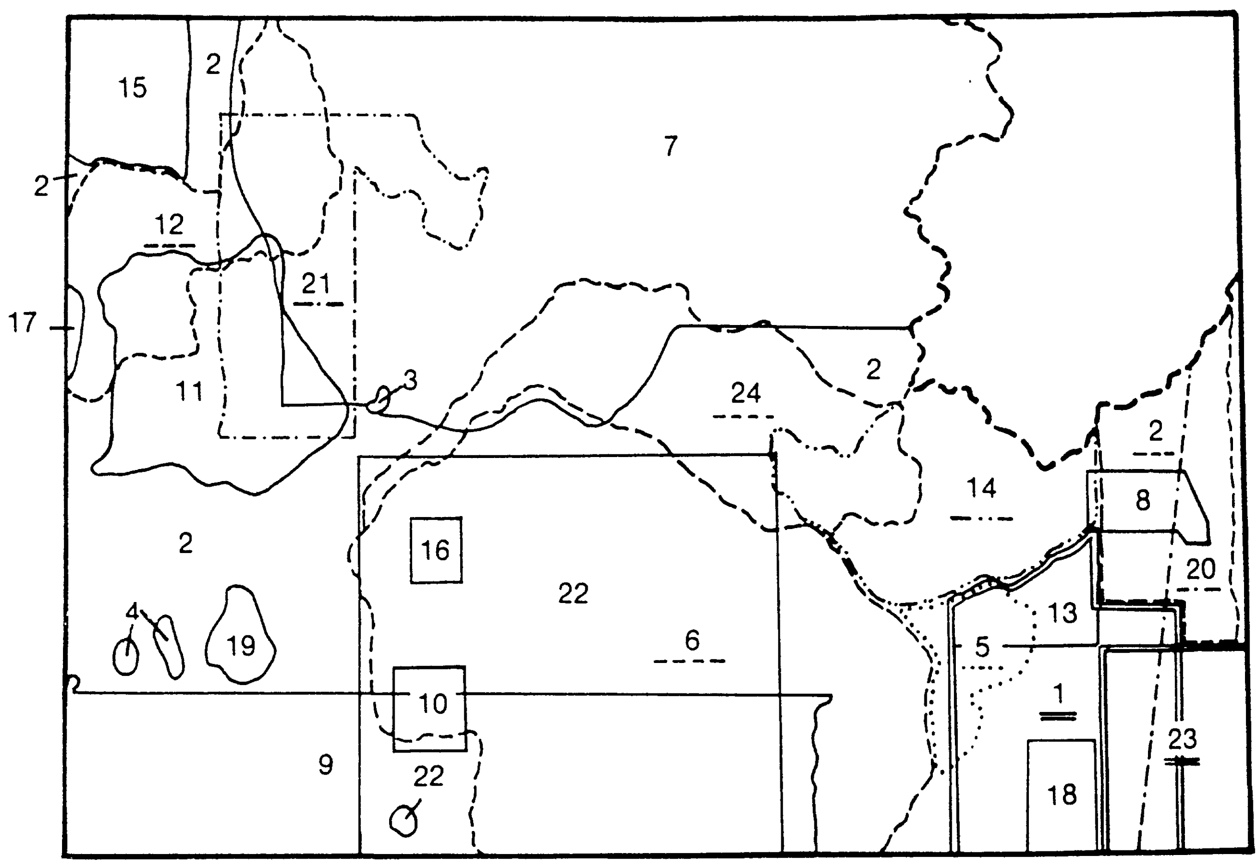

Figure A1. Index to geologic mapping in Idaho available before 1979 (Mitchel and Bennett, 1979).

1. Bennett, 1977
2. Bond, 1978
3. Capps, 1939
4. Capps, 1940
5. Cater and others, 1975
6. Cater and others, 1973
7. Greenwood and Morrison, 1973
8. Kaiser, 1956
9. Kiilsgaard, T.H., USGS, unpublished map
10. Kirkpatrick, 1974
11. Knowles and Bennett, 1978
12. Kuhns and Cox, 1974
13. Maley, 1974
14. Miller, 1979
15. Myers, 1968
16. Otto, 1978
17. Price, E.H., unpublished mapping
18. Purdue, 1975
19. Reed, 1937
20. Ross, 1963
21. Shenon and Reed, 1934
22. Shenon and Ross, 1935
23. Shockley, 1957
24. Weiss and others, 1972

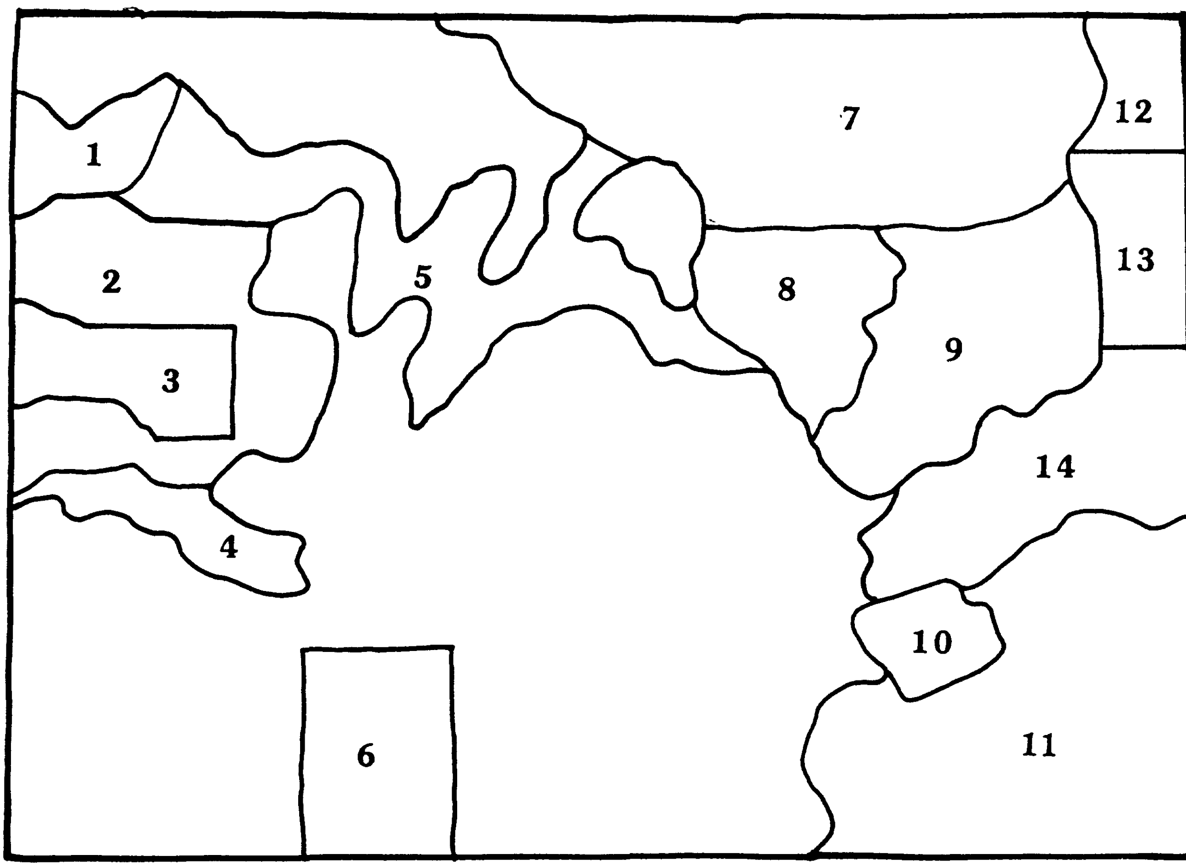

Figure A2. Index to geologic mapping in Montana and to mapping in Idaho available after 1979.

1. Hoover, 1986
2. Lund and Esparza, 1990; K. Lund and K.V. Evans, USGS, unpublished data
3. Lund, 1984; Lund and Snee, 1988
4. K.V. Evans, USGS, unpublished data
5. K. Lund, USGS, unpublished data
6. B.F.Leonard, USGS, unpublished data
7. Toth, 1983
8. K. Lund, F. Mutschler, M. Pawlowski, USGS, unpublished data
9. Lund and others, 1983b
10. Lund and others, 1983c
11. Connor and Evans, 1986; J. Connor and K.V. Evans, USGS, unpublished data
12. Ross and others, 1955
13. Fisk, 1969
14. Berg, 1977

Unnumbered areas: work finished before 1979, see figure A1.

island arc. Continental units on the east include probable Middle Proterozoic to lower Paleozoic terrigenous metasedimentary rocks. Most of these rocks accumulated in one or more Middle Proterozoic sedimentary basin(s), and some may have formed in the Late Proterozoic to Paleozoic miogeocline. During the Jurassic(?) to Cretaceous, the edge of North America was truncated and the island arc rocks were accreted along a compressive transcurrent fault. Final accretion occurred between 120 and 90 Ma. The continental rocks were intruded by four major magmatic suites of Middle Proterozoic, Cambrian-Ordovician, Late Cretaceous, and Eocene age. Late Cretaceous plutons intruded across the suture zone. Basin and Range extension of post-Eocene age has been found in the eastern part of the quadrangle.

Several types of mineral deposits are known in the quadrangle. Sediment-hosted cobalt-copper-gold deposits occur at and near the Blackbird mine in Middle Proterozoic metasedimentary rocks. Depending on correlation, other higher grade metamorphic rocks in the quadrangle are potential hosts for cobalt-copper deposits of this type, copper deposits as found in the Belt Supergroup, lead-zinc deposits as found in rocks that are correlative with the Belt Supergroup, or tungsten skarn deposits as found in miogeoclinal rocks. The best known deposits in the quadrangle are gold- and silver-bearing quartz veins temporally associated with Late Cretaceous granite. Antimony, arsenic, tungsten, and mercury are associated in some environments. A few, Late Cretaceous disseminated gold deposits are found in some districts. Disseminated gold deposits are also found in Cambrian-Ordovician plutons and in Eocene rhyolitic volcanic rocks. Gold in quartz veins may also be related to Middle Proterozoic granite. With a few significant exceptions, it is difficult to document the relationship of mineral deposits to specific plutonic suites. In addition, it is possible that metals introduced early have been remobilized during subsequent magmatic events.

Although the general geologic setting of the Elk City quadrangle is known, the details are largely unknown. Much of the quadrangle is inadequately studied to give information on stratigraphy, structure, geologic history, and age of rocks or timing of events. There is evidence of multiple episodes of plutonism, but the genetic relationship between these and mineral deposits is largely undocumented although hypotheses linking mineral deposits and the youngest (Eocene) period of plutonism abound in the literature. Understanding the age and genesis of these magmatic hydrothermal deposits is crucial to further exploration. Correlations of most metasedimentary rocks are gross generalizations and are conflicting. The importance in this region of stratabound mineral deposits of several ages and types makes a better understanding of sedimentary processes, geometry of sedimentary basins, and regional correlation imperative.

The unsatisfactory level of geologic mapping in the Elk City quadrangle is shown on the compiled geologic map (plate A): 1) where original map unit designations are listed first with query followed by suggested map unit with query (eg. Yi? or Ygn?) and 2) where contacts are left hanging. No attempt was made during this compilation to interpret continuation of contacts or to rename units based on the pre-existing information. In most cases, these map units contain too many undivided units (eg. plutonic rocks of Middle Proterozoic to Eocene age were previously combined) or the published descriptions are too incomplete to make conclusive changes.

Rock Units

Terrigenous Sedimentary and Metasedimentary Rocks

<u>Yellowjacket Formation and Lemhi Group</u>. Middle Proterozoic sedimentary and low-grade metasedimentary rocks crop out in the southeastern and southcentral parts of the quadrangle. Dark, fine-grained, micaceous, feldspathic quartzites, siltites, and argillites of the Yellowjacket Formation are overlain by light, fine-grained, feldspathic quartzite and argillitic siltite of the Lemhi Group. Together, these rocks are at least 30,000 ft thick (Ruppel, 1975). The Yellowjacket Formation has been subdivided into three lithostratigraphic subunits (Connor and others, 1985); in addition the Hoodoo Quartzite (Ross, 1834) is probably a facies of part of the Yellowjacket (Ekren, 1988). The Blackbird cobalt mine is a sediment-hosted deposit associated with mafic tuffaceous rocks located in the middle subunit of the Yellowjacket Formation (Connor and others, 1985; Nash and Hahn, 1986). The Yellowjacket Formation was deformed and in places metamorphosed prior to being intruded by 1,370±10 Ma porphyritic granite plutons and mafic dikes (U/Pb zircon ages; Evans, 1986), which were, in places, subsequently metamorphosed and deformed to become augen gneiss and amphibolite.

The Yellowjacket Formation, Lemhi Group, and related rocks may have formed outboard of the Belt basin at least partly in the miogeocline (Ruppel, 1975), may have been deposited by turbidity currents in a deep marine setting (Lopez, 1981), or may have formed in a rift basin at the continental margin (Hahn and Hughes, 1984; Nash and Hahn, 1986).

Correlation between units of the Yellowjacket Formation and Lemhi Group and the Belt Supergroup, which crops out to the north and east, have been alternately proposed and refuted. Ruppel (1975) suggested possible correlations. Whereas Armstrong (1975), based on Rb-Sr model ages of greater than 1,500 Ma on the cross-cutting porphyritic granite, suggested that these same metasedimentary rocks are older than the Belt Supergroup. Based on the younger dates (about 1,370 Ma) for cross-cutting plutons (Evans and Zartman, 1981a; Evans, 1986), a Middle Proterozoic age and equivalency to the Belt Supergroup seems likely. However, a maximum age of the Yellowjacket Formation and the relationship of these rocks to the Belt Supergroup have not been established.

Metasedimentary rocks in the southcentral part of the quadrangle were mapped as Yellowjacket Formation and Hoodoo Quartzite (Shenon and Ross, 1936; Cater and others, 1973). These outcrops are probably traceable from presently accepted outcrops of Yellowjacket Formation to the south and northeast. However, more detail is needed in this part of the area in light of studies detailing the internal stratigraphy of the Yellowjacket Formation (Connor and Evans, 1986), the importance of related cobalt mineralization, and the need for tracing stratigraphy into less known and high-grade metamorphic rocks.

<u>Other metasedimentary rocks</u>. Elsewhere in the quadrangle, terrigenous rocks are metamorphosed to medium and high grades, multiply deformed, and occur primarily as isolated roof pendants in igneous rocks. Because of the high metamorphic grade and poor access, the stratigraphy and metamorphic and deformational history of these rocks is poorly understood. The metamorphic rocks across the Elk City quadrangle have been variously correlated with rocks of the Belt Supergroup (Lindgren, 1904; Beckwith, 1926; Shenon and Reed, 1934; Greenwood and Morrison, 1973); with pre-Belt basement forming "Belt Island" (Harrison and others, 1974) or the "Salmon River arch" (Armstrong, 1975); with the Yellowjacket Formation

and related rocks that are on the east side of the quadrangle (Cater and others, 1973; Knowles and Bennett, 1978; B.F. Leonard, USGS, unpublished data); or possibly with Late Proterozoic to Paleozoic rocks (Lund, 1984).

The present level of geologic mapping, stratigraphic studies, and tracing of units from better known areas is insufficient for satisfactory correlation of stratified rocks across the quadrangle. Because sediment-hosted mineral deposits are important in the Belt Supergroup, in the Yellowjacket Formation and related rocks, and in Paleozoic sedimentary rocks to the south near Bayhorse, Idaho, correlation of the stratified rocks is imperative to any study of potential for undiscovered mineral resources.

Five tectonostratigraphic units and many subunits have been mapped in roof pendants in the Gospel-Hump Wilderness Area in the northwestern part of the quadrangle (Lund, 1984). The lower three units are probably Middle Proterozoic. (1) The lowest, including biotite gneiss, calc-silicate gneiss, schist, and quartzite, was intruded by porphyritic granite (now augen gneiss) that has been dated at about 1,370 Ma by the U-Pb method; this granite is thought to be related to similar 1,370 Ma porphyritic granite and augen gneiss that intruded the Yellowjacket Formation in the southeastern part of the area (Evans and Fischer, 1986). This supports the possible stratigraphic tie across the quadrangle that is suggested by lithologic similarities and geochemical anomalies (see Geochemistry, section B). (2) A calc-silicate gneiss unit and a (3) muscovite-bearing quartzite unit, which represent about 3000 m of stratigraphic thickness, structurally overlie the lower unit. Primary sedimentary features such as climbing ripples, ball and pillow structures, flame structures, parallel laminae, possible mud cracks, and current ripples are found in these amphibolite facies rocks (Lund, 1984). Based on composition, primary sedimentary features, and thickness, these are thought to be equivalent to other Middle Proterozoic units in the region, but specific correlations cannot be made (Lund, 1984). The upper two tectonostratigraphic units are markedly different from the underlying probable Middle Proterozoic rocks. (4) The lower of these units consists of a variety of laterally continuous lithologies including muscovite schist, clean quartzite, calc-silicate gneiss, marble, apatite-pyrite quartzite, and quartzite-pebble conglomerates with both quartzite matrix and mafic matrix. (5) The upper of these units is primarily quartzite with minor interbeds of other lithologies. These units total a structural thickness of about 6500 m (Lund, 1984). Skarns in the marble units contain tungsten, silver, lead, copper, and nickel mineralization (Lund and Esparza, in press). The diversity of metasedimentary rocks in the upper two units indicates protoliths and rapid facies changes that are uncharacteristic of Middle Proterozoic rocks in the region. These rocks have been tentatively correlated with Late Proterozoic Windermere Group and Paleozoic miogeoclinal rocks (Lund, 1984; Lund and Esparza, in press). However, no fossils have been found to substantiate these correlations. Tungsten and other base metal occurrences in skarns are common in Paleozoic and possible Paleozoic rocks of the Challis quadrangle (Cookro, 1983; 1985) to the southeast.

Metasedimentary rocks near Big Creek in the southwestern part of the quadrangle are low-grade argillitic siltites and medium-grade marble, calc-silicate gneiss, quartzite, quartz-pebble quartzite (Kirkpatrick, 1974; B.F. Leonard, USGS, unpublished data), and metavolcanic rocks (Leonard, 1962). The low-grade argillitic siltite unit was intruded by the Ramey Ridge alkali syenite pluton (Leonard, 1963) of probable Cambrian-Ordovician age (K.V. Evans, USGS, unpublished data). Tungsten skarns related to intrusion of Cretaceous plutons occur in the marble units (Cook, 1956; Savage, 1970; Cookro and Petersen, 1984). The medium-grade metasedimentary rocks were first correlated in part with the Belt Supergroup and in part with Paleozoic miogeoclinal rocks (Schrader and Ross, 1926; Shenon and Ross, 1936); were later correlated entirely with the Belt Supergroup (Ross, 1962); and were more recently correlated with the Yellowjacket and Hoodoo Formations (Cater and others, 1973; B.F. Leonard, USGS, unpublished mapping). Lithologies, associated mineral deposits, and regional trends suggest possible correlation of parts of the quartzite-marble part of the section with Paleozoic rocks along trend to the southeast near Bayhorse and with possible Late Proterozoic to Paleozoic rocks to the north in the Gospel-Hump Wilderness Area (Lund, 1984). The low-grade argillitic siltite unit is probably part of the Yellowjacket Formation (K.V. Evans, USGS, personal communication).

Metasedimentary rocks in the central and northcentral parts of the quadrangle include thick quartzite units, calc-silicate gneiss, feldspathic gneiss, and schist. Augen gneiss (i.e., deformed Middle Proterozoic porphyritic granite) is common in the feldspathic gneiss and schistose units (Greenwood and Morrison, 1973; K. Lund, USGS, unpublished data). These metasedimentary units were mapped in reconnaissance studies and correlated with units of the Belt Supergroup on the basis of dominant lithology (Weiss and others, 1972; Cater and others, 1973; Greenwood and Morrison, 1973). Details of the stratigraphy and structure of these areas are almost completely unknown and subsequent mapping of parts of these study areas has shown that more work is needed.

Island Arc Metamorphic Rocks

Low- to high-grade metamorphosed island arc rocks crop out in the northwestern part of the quadrangle (plate A). Low-grade spilitic and keratophyric volcanic rocks with relict plagioclase phenocrysts are intercalated with volcaniclastic conglomerate. Medium- to high-grade mafic gneiss, calc-silicate gneiss, and marble are thrust westward over the lower grade metavolcanic rocks (Myers, 1982). Volcanogenic massive sulfide deposits and pure marble deposits are associated with these rocks. The low-grade metavolcanic rocks probably correlate with the Seven Devils Group (Myers, 1982) as described by Vallier (1977) along the Snake River about 30 mi to the southwest. The medium- to high-grade rocks are probably equivalent to the part of the Riggins Group (Hamilton, 1963; Myers, 1982; Lund, 1984; Hoover, 1986), which may be a more highly metamorphosed equivalent of the Permian-Triassic volcanic, volcanogenic, and calcareous rocks of the Seven Devils Group and gradationally overlying rocks in the Grangeville 1°x2° quadrangle to the west (Lund and others, 1983a).

Igneous Rocks

Although it is now known that there are four major magmatic episodes in the quadrangle, much of the mapping on plate A preceded dating of most plutons. In the oldest mapping, all plutonic rocks are represented as one age, usually Cretaceous. Eocene plutons were first recognized by Ross (1928), Middle Proterozoic plutons were not dated until the 1970's (Reid and others, 1973; Armstrong, 1975), and Cambrian-Ordovician plutons were first identified in 1981 (Evans, 1981). The many hanging contacts and queried ages on plate A illustrate these problems.

Middle Proterozoic plutons. Porphyritic granite to augen gneiss and associated amphibolite dikes intruded rocks of the Yellowjacket Formation and gneissic terrigenous metasedimentary rocks of unknown correlation throughout the quadrangle. Examples of these plutonic rocks have been mapped in the southeastern part of the quadrangle near Salmon, Idaho (Evans, 1981; Lund and others, 1983c); in the northeastern part of the quadrangle in western Montana (Berg, 1977; Lund and others, 1983b); in the east-central part of the quadrangle between areas of the above studies (K. Lund, USGS, unpublished mapping); in the center of the quadrangle (Weiss and others, 1972; Cater and others, 1973; Greenwood and Morrison, 1973; K. Lund, USGS, unpublished mapping); and in the northwestern part of the quadrangle near Elk City and Red River (Greenwood, 1967; K. Lund, USGS, unpublished mapping). Least deformed rocks in the southeastern part of the quadrangle have been dated by U-Pb on zircons at 1,370±10 Ma (Evans, 1981; Evans and Zartman, 1981a). Augen gneiss also from southeastern areas (near Shoup, Idaho) and from northwestern areas (Red River area) are of the same age (Evans and Fischer, 1986).

The occurrence of these plutons has been important to the understanding of the tectonic framework of central Idaho. These rocks were first thought to be deformed parts of the Idaho batholith (Shockey, 1957). When first dated, Rb-Sr model ages on these granitic rocks were greater than 1,500 Ma (Armstrong, 1975). This data suggested that most of the area of the Elk City quadrangle and parts of nearby quadrangles was a pre-Middle Proterozoic (pre-Belt) basement terrain called the Salmon River arch (Armstrong, 1975). This idea corroborated that of Harrison and others (1974) who suggested that this area was a Middle Proterozoic high (Belt Island) that shed sediments north and east into the Belt Basin. The U-Pb zircon dates of 1,370 Ma on these granitic rocks, although a minimum age for the host rocks, makes it permissible that the Yellowjacket Formation and Lemhi Group rocks are correlative with the Belt Supergroup. The equivalent ages on several augen gneiss bodies throughout the quadrangle suggest a possible correlation or at least a tectonic connection between the Yellowjacket Formation and the other metasedimentary rocks that were intruded by these granitic rocks.

Although not well documented, there are indications that a variety of mineral deposits are related to these rocks. Areas in the eastern part of the quadrangle, which are underlain by or thought to be underlain by the augen gneiss, host gold-bearing quartz veins, molybdenum prospects of unknown origin, and have anomalously high values for incompatible element associations (see Geochemistry section). Because the genesis of these occurrences, prospects, and anomalies is unknown, more study is necessary. In the same area, niobium-columbium-rare earth element deposits occur in possible carbonatite lenses and veins in and near the augen gneiss and amphibolite (Anderson, 1960; Crowley, 1960; Heinrich and Levinson, 1961). The occurrence of these deposits, whether of magmatic origin or formed by metamorphic differentiation, is not established by the previous work.

Cambrian-Ordovician plutons. Several hornblende- and biotite-bearing alkali syenite to quartz alkali syenite plutons crop out in the southern part of the Elk City quadrangle (plate A; as well as in the western part of the Dillon quadrangle and in the northern part of the Challis quadrangle). Two of these plutons (Arnett Creek and Deep Creek) crop out in the southeastern part of the quadrangle (Evans, 1981) and another (Ramey Ridge) crops out in the southcentral part of the quadrangle (Leonard, 1963). These plutons intruded rocks of the

Yellowjacket Formation. Cambrian to Ordovician U-Pb zircon dates of 481 to 541 Ma are reported (Evans, 1981; Evans and Zartman, 1981b). Two undated plutons near Rush Creek Point and Acorn Butte (plate A) were originally thought to be Middle Proterozoic (Cater and others, 1973) but are probably also Cambrian to Ordovician (K.V. Evans, USGS, personal communication). The plutons at Ramey Ridge, Acorn Butte, Rush Creek Point, and Middle Fork Peak (in the Challis quadrangle) form a northwest trend that coincides with a major aeromagnetic high (see Geophysics section) and anomalously high metal values in stream sediments (see Geochemistry section). Although the age of mineralization is not established, gold has been mined from the Ordovician Arnett Creek pluton (Umpleby, 1913b). The tectonic setting of these plutons is unknown but is probably related to high-angle faulting that affected sedimentary basins of the same age elsewhere in east-central Idaho (Garmezy and Scholten, 1981).

<u>Possible island arc mafic plutons</u>. Deformed and metamorphosed plutonic rocks of unknown age occur in the northwestern corner of the quadrangle (Myers, 1982) but are too minor to appear as separate units on plate A. These rocks are mostly hornblende- and biotite-bearing tonalitic to quartz dioritic plutons. Secondary muscovite and epidote are common (Myers, 1982; Hoover, 1986). These plutons cut island arc metavolcanic and volcanic-derived metasedimentary rocks. The plutons may be allochthonous, having intruded prior to accretion of the island arc rocks to North America (as is the case for some metamorphosed or altered plutons mapped along trend to the south (Hamilton, 1963; Lund, 1984). Without further study, the age of the plutons can only be bracketed between Triassic and Late Cretaceous, and the origin remains questionable.

<u>Late Cretaceous Idaho batholith plutons</u>. Late Cretaceous plutons crop out over almost half of the quadrangle (plate A). In the northern part of the quadrangle they are part of the Bitterroot lobe of the Idaho batholith whereas plutonic rocks to the south are part of the Atlanta lobe (Armstrong, 1975). The Atlanta lobe is thought to be older than the Bitterroot lobe (Armstrong and others, 1977) but uplift and cooling effects complicate interpretation of available isotopic data (Snee and others, 1987). The metamorphic rocks that occur through the central part of the quadrangle have been interpreted to be the floor of the Idaho batholith (Hamilton, 1978; Hyndman, 1979; Wiswall, 1979; Wiswall and Hyndman, 1987), but other mapping in these rocks suggests that, in the main, the metamorphic rocks are roof pendants and septa whose outcrop pattern is controlled by high-angle faulting (Lund, 1984; and interpreted from mapping by Cater and others, 1973; Myers, 1982; Lund and others, 1983b; Lund and Esparza, in press; B.F. Leonard, USGS, unpublished data; K. Lund, USGS, unpublished data).

The earliest recognized plutons of the Idaho batholith are 94 to 88 Ma epidote-bearing hornblende-biotite tonalite and granodiorite that most commonly transect the suture between island arc and continental rocks (Lund, 1984; Snee and others, in press). Initial strontium isotope ratios of tonalite samples increase abruptly along a 5 km transect from oceanic (less than 0.704) to continental (greater than 0.706) terranes (Armstrong and others, 1977; Fleck and Criss, 1985). Deformational fabrics in the tonalite and granodiorite are strongest near the suture zone but decrease to a weak foliation away from the suture zone.

Younger, more voluminous, and more widespread muscovite-biotite granite intruded the tonalite and granodiorite plutons and continental rocks east of the suture zone. The granite plutons are about 78 to 68 Ma (Snee and others, in press). Toth (1983, 1985) reports several granite and quartz monzonite plutons in the northeastern part of the area. Granite is undeformed except along the margins of the Bitterroot Dome in the northeast part of the quadrangle (Hyndman, 1980; Toth, 1983, 1985; Garmezy and Sutter, 1983). Individual plutons and the sequence, style, and timing of intrusion have been determined in only a few areas in the quadrangle. Much mapping work on these rocks remains to be done.

The presence of primary epidote in the tonalite and granodiorite indicates that these plutons were emplacement at depths of about 18 km (Zen, 1985). Based on presence of primary muscovite in the granite plutons, Hyndman (1980) concluded that these plutons were also emplaced at depths of around 17 km. However, cooling curves generated from $^{40}Ar/^{39}Ar$ data indicate that rapid uplift occurred after deep emplacement of the early tonalitic plutons and that the younger granitic plutons were emplaced at shallow depths of less than 9 km (Lund and others, 1986; Snee and others, in press), in agreement with depth estimates from chemical data on the muscovite composition (Toth, 1987).

The origin of the Idaho batholith magmas is unknown. Although most workers have suggested that the magma was generated by subduction along the suture zone on the west side of the quadrangle (Hyndman and Talbot, 1976; Onasch, 1977; Hamilton, 1976; Myers, 1982), the fact that the magma intruded the suture zone itself and that new work suggests that the suture zone formed by compressive strike-slip faulting rather than subduction (Lund, 1984; Lund and Snee, 1988) leaves these hypotheses in doubt. Chemical data to address this question are lacking across the quadrangle and other nearby areas.

For many years, the plutons of the Idaho batholith were thought to have been the cause of metamorphism of the country rocks in the region (Reid, 1959; Hietanen, 1962; Hamilton, 1963; Onasch, 1977; Myers, 1982). However, recent work has shown that in the westcentral part of the quadrangle, the plutonic rocks intruded previously regionally metamorphosed and deformed country rocks and caused only minor localized contact metamorphic effects and the onset of voluminous plutonism lagged metamorphism by at least 25 Ma (Lund, 1984; Lund and Snee, 1988).

In the mining districts on the west side of the quadrangle, quartz-vein gold mineralization has been dated at 78 to 71 Ma by $^{40}Ar/^{39}Ar$ studies and is therefore related to the muscovite-biotite granite plutons (Snee and others, 1984; Gammons and others, 1985; Lund and others, 1986). This finding significantly changes deposit models for this type of mineralization in the region (compare with Ross, 1931; Anderson, 1951; Bennett, 1980; Criss and Taylor, 1983 who all concluded that these quartz-vein gold deposits were Tertiary).

<u>Eocene plutons and volcanic rocks</u>. Eocene epizonal hornblende-biotite syenogranite and biotite monzogranite plutons and cross-cutting hypabyssal rhyolite to dacite dikes occur in many places in the eastern and central parts of the quadrangle (plate A). In general the plutons become more granophyric and miarolitic towards the top of the bodies (Lund and others, 1983b). Detailed descriptions are available for the Painted Rocks (Lund and others, 1983b; K. Lund, F. Mutschler, and M. Pawlowsky, USGS, unpublished mapping) and Running Creek (Toth, 1983) plutons in the northern part and the Bighorn Crags (Cater and others, 1973) and Casto (Ross, 1934) plutons in the southern part. Other large, but undescribed and mostly unmapped, masses of this rock type crop out in the central part of the quadrangle north of the Salmon River (K. Lund, USGS, unpublished mapping) in areas previously mapped as Cretaceous intrusive rocks (Weiss and others, 1972; Cater and others, 1973). Hypabyssal dikes and small

elongate plutons occur in the Big Creek area in the southcentral part of the quadrangle (Cater and others, 1973; B.F. Leonard, USGS, unpublished mapping). The dikes commonly trend north-northeast and are most concentrated in areas where larger plutons are exposed. The origin of the Eocene magma is unknown, but may have had a deeper source than much of the Cretaceous magma (Rehn and Lund, 1981). The plutons were emplaced at shallow crustal levels (4-6 km) near the top of Cretaceous plutons after much post-metamorphic uplift and erosion had taken place. The magma seems to have caused no contact metamorphism of the country rocks into which it was emplaced (Lund and others, 1983b; Lund and others, 1986).

Eocene rhyolitic to dacitic volcanic rocks of the Challis Volcanics crop out in the southeastern part of the area (plate A). Equivalent volcanic rocks occur locally above the Eocene Painted Rocks pluton in the northeastern part (Fisk, 1969; Berg, 1977; Lund and others, 1983b) and associated with the Thunder Mountain caldera in the southcentral part of the area (Shenon and Ross, 1936; Cater and others, 1973; B.F. Leonard, USGS, unpublished data). Disseminated gold is present in these rocks, especially in the Thunder Mountain caldera south of the Elk City quadrangle (Shenon and Ross, 1936).

Columbia River Basalt Group. A few small outcrops of Miocene Columbia River Basalt Group occur along the northwestern edge of the quadrangle (plate A). These basalts are part of the easternmost extent of what is known as the Clearwater Embayment of the Columbia Plateau (Bond, 1963). Units included in this area are primarily Lower Miocene Grande Ronde Basalt, Imnaha Basalt, and minor amounts of the Middle Miocene Priest Rapids Member of the Wanapum Basalt (Swanson and others, 1979).

Unconsolidated Deposits

Unconsolidated, alluvial sand and gravel deposits, commonly not in active stream channels, occur near Elk City in the northwestern part of the quadrangle (Ta on plate A). Cobbles in the deposits include metasedimentary, Cretaceous plutonic, and Eocene volcanic and hypabyssal lithologies (K. Lund, USGS, unpublished data). These unconsolidated sediments contain large, rich placer gold deposits (Thomson and Ballard, 1924; Shenon and Reed, 1934). Because of the somewhat exotic nature of the cobbles (Eocene igneous rocks are not found cropping out in the general drainage basin) and because these unconsolidated sediments seem to be older than the present stream systems, these deposits may correlate with Tertiary gravels that are capped by Miocene basalt in the northwestern corner of the quadrangle (Myers, 1982).

Quaternary alluvium (Qu on plate A) is common along active streams throughout the quadrangle. Alpine glacial deposits occur in nearly all areas that attain elevations above 7,000 to 8,000 ft. Placer gold deposits are common in the active or recent alluvial deposits in the Elk City, Red River, Dixie, and Florence mining districts in the northwestern part of the area (Livingston and Stewart, 1914; Thomson and Ballard, 1924; Shenon and Reed, 1934; Lorrain and Metzger, 1938; Reed, 1939), in the Marshall Lake and Warren mining districts (fig. 1) in the southwestern part (Capps, 1940), in the Hughes Creek mining district in the northeastern part (Sahinen, 1957), and in the Mackinaw mining district (fig. 1) in the southeastern part (Umpleby, 1913b). In addition, gold has been recovered from small placer deposits along the Salmon River (Weiss and others, 1972; Cater and other, 1973).

Geologic History

The oldest known rocks in the quadrangle are metasedimentary strata which are probably Middle Proterozoic; although an older age can not be disproven, it seems unsupported by present information. The best control is the minimum age provided by cross-cutting Middle Proterozoic plutons (Evans, 1981; Evans and Fischer, 1986). Although not conclusive, the available data suggest the Proterozoic metasedimentary rocks across the quadrangle are probably correlative with parts of the Yellowjacket Formation and related rocks and with the Belt Supergroup. In spite of the scanty stratigraphic information, it is probable that during Middle Proterozoic time the area of the Elk City quadrangle (if the rocks were not subsequently transported great distances) was part of one or more depositional basins (Evans, 1981; Evans and Lund, 1981). Without further stratigraphic and structural work, it is impossible to know whether these rocks were deposited in the Belt Basin, the basin into which the Yellowjacket Formation was deposited, or an intervening sedimentary basin. Because the area of the known Belt Basin received detritus from the south and southwest (Harrison, 1972), it is possible that the area of the Elk City quadrangle was intermittently emergent and provided a source for detritus accumulating in other Middle Proterozoic sedimentary basins (Evans, 1981). The basinal setting must be better understood before an appropriate mineral deposit model for stratabound deposits can be developed for mineral exploration in this area.

A Middle Proterozoic metamorphic and deformational event occurred after deposition of the Yellowjacket Formation but before intrusion of the 1,370 Ma granitic plutons. Surrounding the dated plutons, low-grade regional metamorphic fabric in the Yellowjacket Formation is overprinted by contact metamorphic effects, and the plutons cut previously formed metamorphic fabric (Berg, 1977; Evans, 1981, 1986).

Although not dated and only correlated by means of incomplete compositional, thickness, and facies data, it seems likely that metasedimentary rocks along a band from the southcentral to northwestern part of the quadrangle are part of the Late Proterozoic to Paleozoic miogeocline (Lund, 1984). Rocks of the miogeocline were thought to be absent in this part of Idaho (Ross, 1962; Harrison and others, 1974; Armstrong, 1975; Burchfiel and Davis, 1975; Hamilton, 1978; Dickinson, 1981) because of nondeposition or subsequent tectonic dismemberment of the pre-Cretaceous margin of North America. Investigating the possible presence of these rocks in the quadrangle will require more detailed work and will bear on stratigraphic and tectonic interpretations as well as on models for the occurrence of several types of sediment-hosted and stratabound mineral deposits.

A little known Cambrian-Ordovician tectonic event produced alkalic magmas that resulted in a band of poorly understood alkali syenite plutons across the southern edge of the quadrangle. These may be related to early Paleozoic continental extension that has not yet been widely recognized (Evans, 1981).

During the Permian to Triassic, island arc volcanic, volcanogenic sedimentary, calcareous, and conglomeratic rocks were being deposited in the Wallowa terrane (Silberling and Jones, 1984). The island arc that makes up this terrane is thought to have formed near the equator, southwest of its present position with respect to North America (Hillhouse and others, 1982).

During the Early Cretaceous (about 120 Ma), the island arc and associated rocks of the Wallowa terrane were accreted to North America along the Salmon River suture zone (Lund and Snee, 1988). Although previous models called for accretion at a subduction zone (Hamilton, 1876; Hyndman and Talbot, 1976; Onasch, 1977; Dickinson and Thayer, 1978), a newer interpretation, based on mapping on both sides of the suture zone (Lund, 1984) and on geochemistry along the zone (Armstrong and others, 1977; Fleck and Criss, 1985), is that the suture zone is a right-lateral transpressive fault (Lund, 1984; Lund and Snee, 1988).

Regional metamorphism and deformation, which was consanguinous with accretion from about 120 to 93 Ma, produced greenschist to upper amphibolite facies metamorphism in both oceanic and continental rocks. Structures indicate diverging lateral transport outward from the suture zone and vertical transport near the juncture. The deformation resulted in inverted metamorphic sequences; in both terranes, metamorphic grade decreases structurally downward and spatially away from the suture zone. The metamorphic and deformational effects are more widespread in continental rocks east of the suture zone. Metamorphic fabrics across most of the Elk City quadrangle may have formed during this event, and related deformation is continuous (but progressively younger eastward) to the Montana fold and thrust belt (Snee, 1982). Although Skipp (1987) draws regional thrust faults through metasedimentary inliers in the quadrangle, these faults are completely unsubstantiated by available mapping (compare with plate A). Thrust faults have been mapped in the Gospel-Hump Wilderness Area (Lund, 1984; Lund and Esparza, in press), in the southeastern part of the quadrangle (Evans, 1981; Lund and others, 1983c), and in the northeastern part of the quadrangle (Berg, 1977; Lund and others, 1983b). Greenwood (1967) mapped a large fold in Proterozoic granite and gneiss in the northwestern part of the quadrangle. No other mapping of macroscopic structures (thrust faults or folds) has been done.

The island arc was stitched to the continent at 93 Ma by intrusion of the earliest plutons of the Idaho batholith. A final dynamothermal event along the suture zone occurred from 93 to about 88 Ma and was accompanied by emplacement of tonalitic plutons. Schistosity related to this event is parallel to the suture zone and is superimposed on the plutons and on previously deformed roof pendant rocks. Chemically similar but not pervasively deformed tonalite was intruded across the quadrangle until about 86 Ma (Lund and Snee, 1988; Snee and others, in press).

At or before 88 Ma, rapid uplift and erosion of continental rocks occurred by means of north-northeast trending faults along the suture zone and to the east. Over 15 km of uplift is documented in some areas (Lund and Snee, 1988), but elsewhere local rates and amounts have not been determined.

Uplift preceded emplacement of 78 to 68 Ma muscovite-biotite granite plutons at depths of less than 9 km (Lund and others, 1986; Snee and others, in press). From 78 to 68 Ma, mineralized quartz veins filled fractures in roof pendants and upper parts of the coeval granite plutons (Snee and others, 1984; Gammons and others, 1985; Lund and others, 1986; Chauvot, 1986). By 55 Ma, a large portion of the presently exposed Late Cretaceous plutons of the Idaho batholith were at a crustal depth of 5 km or less (Snee and others, in press).

After most of the uplift was complete, between 52 and 48 Ma, Eocene epizonal granite plutons were emplaced (Lund and others, 1983b; Toth, 1983) at or near the roof of the Cretaceous plutons (depths of 4 to 6 km). Coeval volcanic rocks are preserved in the northeastern, southeastern, and southcentral parts of the quadrangle. The plutons are localized along north-northeast trending high-angle structures or at the juncture between these and earlier west-northwest structures (see Remote Sensing, section D). The plutons are cut by north-northeast trending high-angle faults and coeval or slightly younger hypabyssal dikes were emplaced in the fractures. Larger scale, north-northeast trending normal faults produced a block faulted terrain through the northeast and northcentral part of the quadrangle (plate A). These faults rotated blocks of Eocene plutonic and volcanic rocks and of older roof rocks (Rehn and Lund, 1981; Lund and others, 1983b; K. Lund, USGS, unpublished data) and may be related to Eocene or younger extension. Eocene plutonic rocks were also cut by the extensional fault that formed the mylonite along the east and south sides of the Bitterroot dome (Garmezy and Sutter, 1983). These events may be related to Basin and Range extension previously unrecognized in this complex metamorphic and plutonic terrain.

Continued erosion of the area occurred from the Eocene to Miocene. Early workers disputed the maximum age of the "old erosion surface in Idaho" but agreed that it formed before extrusion of the Columbia River Basalt Group (Lindgren, 1904; Umpleby, 1912; Blackwelder, 1912; Rich, 1918). Remnants of probable Oligocene debris occur as the gold-bearing gravels below Columbia River basalt and outside of present drainages in the western part of the quadrangle.

The Columbia River Basalt Group was extruded during the Miocene in the region west of the Elk City quadrangle. Basalt flowed into the western part of this area but was probably prevented from flowing farther east because of relief caused by uplift along high-angle faults parallel to the suture zone (Lund, 1984; Zen, 1985).

During Miocene to Recent time, minor normal faulting offset and rotated the basalt. Erosion produced the cirques and incised stream valleys of the present drainage systems.

SECTION B

GEOCHEMISTRY

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Introduction

The preliminary geochemical evaluation of the Elk City, Idaho-Montana 1°x2° quadrangle is based on stream sediment and spring sediment samples collected at 1,711 sites throughout the area as part of the National Uranium Resources Evaluation (NURE) program (Broxton and Beyth, 1980). The great majority of the samples are stream sediments collected in second-order streams. The sample material was sieved through a 100-mesh sieve and the fine fraction (<100 mesh) was analyzed by the following techniques (Broxton and Beyth, 1980):

1. <u>X-ray fluorescence</u>
   Ag, Bi, Cd, Cu, Nb, Ni, Pb, Sn, W, As, Se, Sr
2. <u>Emission spectrography</u>
   Be, Li
3. <u>Neutron activation</u>
   Al, Au, Ba, Ca, Ce, Cl, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mg, Mn, Na, Rb, Sb, Sc, Sm, Sz, Ta, Tb, Th, Ti, V, Yb, Zn.

Geochemical Data Presentation

The geochemical data in this report are presented in the form of plots of geochemical associations rather than individual element plots. Three major associations were looked at in some detail:

A. A Au-related association (Au, Cl, Cu, Pb, W, Sb, As, Bi)
B. A Co-related association (Co, Cu, Cr, Mg, V, Sc, Fe)
C. A Be-related association (Be, Cr, Dy, Li, Nb, Rb, Sn, Ta, U, Zn)

These associations were derived on the basis of mathematical correlations as well as regional associations relative to the three lead elements (Au, Co, and Be, respectively). The values of elements within a given association were normalized to individual threshold values and combined by addition.

Anomalous areas delineated by these associations were looked at on a window rather than individual-site basis using the relative element magnitude (REM) program (Van Trump and Alminas, 1978).

The REM program calculations are performed on the basis of two parameters for each of the elements within the selected elemental suite. The first of these, the intensity factor, is derived by dividing the mean of all anomalous values of a given element within the defined area by its respective threshold value. The second, the area factor, is derived by dividing the number of sample locations within the defined area that contain anomalous levels of this element by the total number of sample locations within this area. These two values are multiplied for each element and the product is the individual element magnitude (E.M.). All individual element magnitudes are added to give the total anomaly magnitude of the cell. In addition, each individual element magnitude is divided by the anomaly magnitude of the cell and the quotient is expressed in percent. This is the relative element magnitude (REM).

The E.M. values for each individual element within the association for all window areas are given in table format in the respective association description. In addition, the inter-window association intensity and lead element contents are indicated.

Au-association

The Au geochemical association used in this report incorporates eight elements. In addition to Au these are As, Bi, Cl, Cu, Pb, Sb, and W.

Areas delineated by this geochemical association within the Elk City quadrangle are shown on plate B1 using two contour levels for moderate and high intensity. Data windows labeled Au-1 through Au-7 are superimposed on these areas to permit the calculation of intra-window associational relationships as well as inter-window anomaly intensities. Henceforth in this report, the anomalous areas will be referred to by their window designations. In addition to the Au-association anomalies this map shows stream-sediment sites (black dots) at which the gold content was >_ .2 ppm and those at which the silver content is >_ 5.0 ppm (open triangles). Individual prospects or mines at which lode gold has been reported are shown by an X; areas containing such mines and prospects are shown by stipple.

Au-association Anomaly Delineation

The Au-related geochemical association delineates seven major areas in the Elk City quadrangle. Area Au-1 is located in the northwestern corner of the quadrangle and encompasses approximately 576 mi^2. This area incorporates the Newsome, Tenmile, Elk City, and Orogrande, as well as the northern portions of the Buffalo Hump and Dixie mining districts (fig. 1; Mitchell and others, 1981).

The Au-2 area, located to the southwest of Au-1, encompasses approximately 60 mi^2 and incorporates the southern portion of the Dixie and Buffalo Hump districts as well as portions of the Florence and Marshall Lake (fig. 1) districts. Area Au-3, immediately to the south of Au-2, incorporates approximately 160 mi^2 and occurs in the central portions of the Warren and Resort (fig. 1) districts.

Area Au-4 is a complex curvilinear zone in the south central portion of the Elk City quadrangle. It is approximately 300 mi^2 in areal extent and incorporates the Profile, Edwardsburg, and Ramsey Ridge districts (fig. 1) as well as a portion of the Big Creek district and the southern tip of the Wilson Creek district (fig. 1).

Area Au-5 incorporates the whole southeastern corner of the Elk City quadrangle and extends into the Dillon, Montana 1°x2° quadrangle to the east and the Challis, Idaho 1°x2° quadrangle to the south. The portion of this area within the Elk City quadrangle encompasses approximately 640 mi^2 and incorporates the Mineral Hill, Indian Creek, Mackinaw, Aurora, Eureka, and Blackbird mining districts as well as the southern tip of the Gibbonsville district (fig. 1).

Area Au-6 is in the central portion of the quadrangle and encompasses the northwest-trending Salmon River canyon. No mining district delineations are shown by Mitchell and others (1981), although numerous placer sites are indicated. This area encompasses approximately 130 mi^2.

Au-7 is the smallest area by far and is located in the extreme northeastern corner of the quadrangle. This area encompasses approximately 24 mi^2 and cannot be related to any known mineralization.

Au-association Anomaly Description

Area Au-1 is the second largest in extent in the Elk City quadrangle but ranks only sixth in overall anomaly intensity. Element magnitude (E.M.) calculations (table 1) indicate the following relative values for associated components: Au>Bi>Pb>W>As>Sb>Cl>Cu. This is the only area in which gold is the predominant component within the association although it still ranks third in overall Au content. Geologically this is a complex area. It is underlain predominantly by Middle Proterozoic metasedimentary rocks and intrusions. Much of the area is underlain by Cretaceous rocks of the Idaho batholith and a small portion of the Eocene Bargamin Creek pluton. The area is characterized by numerous gold lodes and placers. The lode gold occurs primarily in fissure veins coincident with the Idaho batholith. An extensive but low-level aeromagnetic high occurs in the southern portion of the area.

Area Au-2 is the second smallest in extent within the quadrangle, but ranks second in overall anomaly intensity and gold content. The relative values of associated components (Sb>Au>W>As>Bi>Pb>Cu>Cl) are quite dissimilar to that in area Au-1. The association in this area, as well as the other two anomalies located in the southwestern quarter of the quadrangle (Au-3, Au-4), is characterized by a high antimony content. This area is underlain almost exclusively by rocks of the Idaho batholith with minor outcrops of Late Proterozoic to Paleozoic metasedimentary rocks and Middle Proterozoic gneiss. Gold lodes and placers occur in this area (plate E). The lode gold occurs primarily in quartz-sulfide veins. No aeromagnetic anomaly is present.

Area Au-3 is located immediately south of Au-2. This anomaly is intermediate in areal extent and ranks fourth in overall anomaly intensity. The geochemical association (Sb>As>Au>Pb>Bi>W>Cu>Cl>) is similar to that of Au-2. Antimony is again the predominant component but with a high arsenic input. Widespread arsenopyrite has been reported from the Warren district. This area occurs exclusively within rocks of the Idaho batholith. As in Au-2 (also dominated by the Idaho batholith), the aeromagnetic image does not show any pronounced expression in this area.

Area Au-4 is the third largest in extent and overall anomaly intensity. The Au-association (Sb>As>Au>Pb>Bi>W>Cu>Cl>) is identical to that in area Au-3 and very similar to that in area Au-2. The predominance of antimony is supported by the numerous Sb prospects (Mitchell and others, 1981). These prospects occur primarily in the western end of the anomaly and tend to be rich in arsenic as well. The geology in this area is extremely complex and nearly all rock types found within the Elk City quadrangle are present in this subarea. This belt-like geochemical anomaly shows a striking spatial correlation with a belt of strong high and low aeromagnetic anomalies. The geochemical as well as aeromagnetic patterns extend to the south toward the Yellow Pine district.

By far the most interesting anomaly in the Elk City quadrangle is Au-5 in the southeastern corner of the sheet. This area is underlain primarily by Middle Proterozoic rocks with minor exposures of Cambrian-Ordovician, Late Cretaceous, and Eocene plutons. The Yellowjacket Formation and Middle Proterozoic intrusions constitute some 90% of the area. Area Au-5 is spatially the largest of the seven anomalies within the quadrangle and extends eastward into the Dillon, Montana, and southward into the Challis, Idaho, 1°x2° quadrangles. This area is characterized by the highest overall anomaly intensity as well as the highest contents in Au, Cu, As, Bi, and Cl. The Au-association (Cu>As>Au>Bi>Cl>Pb>W>Sb) indicates a clear predominance of copper in this area, reflecting the Cu-rich

Table B1. Au-association E.M. calculations

Element	Intra-window	Au-1	Intra-area rank	Au-2	Intra-area rank	Au-3	Intra-area rank	Au-4	Intra-area rank	Au-5	Intra-area rank	Au-6	Intra-area rank	Au-7
As	5	42.0	4	68.8	2	96.0	1	208.1	2	360.4	2	86.9	6	10.6
Au	1	132.9	2	133.2	3	94.9	6	46.4	3	137.5	3	58.9	3	22.6
Bi	2	56.7	5	54.5	5	47.0	8	1.5	4	125.5	6	29.5	1	48.3
Cl	7	12.8	8	3.2	8	6.2	4	63.3	5	87.7	7	9.3	7	0.0
Cu	8	12.6	7	15.7	7	10.2	5	49.6	1	640.3	1	202.6	5	15.3
Pb	3	56.4	6	47.0	4	65.8	3	75.3	6	36.3	5	32.3	2	23.2
Sb	6	17.8	1	187.8	1	137.0	2	120.8	8	14.2	8	0.0	8	0.0
W	4	46.6	3	96.7	6	31.4	7	38.7	7	22.9	4	35.1	4	16.4
Total		377.9		606.9		488.6		603.7		1423.2		454.7		140.8
Inter window rank		6		2		4		3		1		5		7

copper in this area, reflecting the Cu-rich Blackbird district in the southwest and the Mineral Hill-Indian Creek districts in the north-northeastern portion of the area. Arsenic and antimony show a very similar distribution to that of copper whereas bismuth occurs primarily in the Blackbird district. Gold and silver occur along northwest- and northeast-trending zones centered around the Copper Mountain-Haystack Mountain area. The chlorine occurs as a large doughnut-shaped halo also centered on the Copper Mountain-Haystack Mountain area.

A striking spatial relationship can be seen between the geochemical and aeromagnetic patterns in this area (plates B1 and C1). A 260 gamma aeromagnetic high occurs in the Copper Mountain-Haystack Mountain area. This aeromagnetic high is surrounded by a semi-rectangular 80 gamma aeromagnetic low area consisting of northwest- and northeast-trending components. These aeromagnetic low areas coincide with the intense portions of the Au-association anomaly. Gold occurs exclusively within these zones and silver nearly so. The copper-arsenic-antimony zones occur about equidistant from the aeromagnetic high to the north-northwest and the southwest. Chlorine also forms a doughnut-shaped anomaly centered on the Copper Mountain-Haystack Mountain aeromagnetic high and occurs essentially in the aeromagnetic low zones.

Area Au-6 is located in the central portion of the Elk City quadrangle and encompasses the northwest-trending Salmon River canyon. This area is underlain mainly by the Idaho batholith, more restricted Middle Proterozoic gneiss, schist, and quartzite, and minor Middle Proterozoic intrusives. Au-6 ranks fourth within the quadrangle in areal extent and fifth in overall anomaly intensity. The Au-association (Cu>As>Au>W>Pb>Bi>Cl>Sb) is very similar to that of Au-5 which is located upstream. Gold placers are present in this area (plate E1b). Aeromagnetic highs occur in the eastern and western ends of the area.

Au-7 is located in the northeastern corner of the quadrangle and is smallest in extent and lowest in intensity. This area is underlain predominantly by undifferentiated Middle Proterozoic units, some Cretaceous Idaho batholith, and minor Eocene intrusive rocks. The Au-association relationship (Bi>Pb>Au>W>Cu>As>Cl>Sb) is most similar to area Au-1. There are known mineral occurrences in this area.

Silver is generally included in any Au related geochemical association. It was excluded in this study in that it shows two distinct modes of occurrence. A part of the silver is obviously related to the Au association and occurs within the seven delineated areas. A large cluster of samples with anomalous silver contents, however, is totally unrelated to the gold mineralization. These samples form a north-trending linear cluster in the north-central portion of the quadrangle in the Fire Mountain-Buck Knob area. More isolated sites occur to the north of Buck Knob and a tight cluster to the west of Eagle Point. These silver anomalies generally tend to occur over or near the margins of Eocene felsic intrusives. Chlorine, tungsten, bismuth, and the Be-association elements (see below) are enriched in these silver areas. No specific relationship between aeromagnetic patterns and the Ag-distribution has been noted. There are no known prospects in these areas (Mitchell and others, 1981).

Au-association Anomaly Discussion

Based on existing NURE stream-sediment data, the Au-association used in this report delineates every area of known precious-metal mineralization within the Elk City quadrangle. In addition, some areas are delineated that have no history of past production. The areas delineated by this association transect nearly every rock type mapped within the quadrangle. No clear relationship between the geochemical patterns and structure (mapped or inferred) can be noted. The clearest relationship is that between the geochemical and the aeromagnetic patterns.

The most prominent geochemical-aeromagnetic correlation occurs in the southeastern corner of the quadrangle, in area Au-5. A 260 gamma aeromagnetic high occurring in the Copper Mountain-Haystack Mountain area is bordered by northeast- and northwest-trending linear aeromagnetic lows (plate C1, and see Geophysics section C). The aeromagnetic high is centered on an area mapped as Yellowjacket Formation whereas the aeromagnetic lows transect Middle Proterozoic intrusions, the Yellowjacket Formation, and a range of other rock types. The lower level Au-association contour encompasses the aeromagnetic high and low areas whereas the higher value contour tends to encompass only the aeromagnetic low areas. The Be-association (plate B3) also occurs in the Au-5 area. This association occurs almost exclusively within the aeromagnetic low areas with the highest intensities occurring at lineament intersections.

The Copper Mountain-Haystack Mountain aeromagnetic high might well represent a shallowly buried Tertiary intrusion (plate C1). The Be-association anomalies in the surrounding aeromagnetic low areas indicate the intrusion might be felsic to intermediate in composition. The northwest- and northeast-trending aeromagnetic lows transect all rock types and might be indicative of strong alteration along some preexisting structural trends. It is within these areas that the most intense portions of the Au-association anomaly occur. It is also in these areas that gold and silver occur. Area Au-5 encompasses in excess of 640 mi^2 and the calculated relative intensity of the Au-association anomaly is greater here by a factor of three than that of any other area within this quadrangle. The author believes that area Au-5 has considerable potential for precious- and base-metal deposits. It is considered the area of highest interest within the quadrangle.

A second area that shows a high correlation between geochemical and aeromagnetic patterns in the Elk City quadrangle is Au-4 (compare plates B1 and C1). At this locale, the major aeromagnetic feature is a >500 gamma aeromagnetic high centered on Acorn Butte, an area that is mapped predominantly as Middle Proterozoic granite but is more likely Cambrian-Ordovician syenite (see plate A and Geology section A). The area as a whole is a semicircular, belt-like complex of alternating aeromagnetic highs and lows and transects a great variety of Middle Proterozoic metasedimentary rocks, Cambrian-Ordovician plutons, and Tertiary intrusive and volcanic rocks. The Au-association anomaly follows the aeromagnetic pattern closely. A Be-association anomaly (plate B3) also occurs over and adjacent to the Acorn Butte aeromagnetic high.

Area Au-4 is ranked just below Au-5 in mineral potential. Although this area ranks only third in anomaly intensity, three major factors support the higher evaluation:

1. The high correlation between the geochemical and aeromagnetic patterns in this area.
2. The great similarity in geochemical associations seen here at the West End disseminated gold deposit near Yellow Pine.
3. The similarity of geologic setting (on the rim of the Thunder Mountain caldera) of area Au-4 and the West End mine.

Area Au-2 is characterized by an association dominated by gold and silver. This area is almost totally underlain by Cretaceous rocks of the Idaho batholith which generate no distinctive aeromagnetic pattern (plate C1). The intensity of the geochemical anomaly in this area does not correspond to the amount and type of known mineralization; therefore the area is recommended for further exploratory work.

Area Au-3 incorporates only Cretaceous rocks of the Idaho batholith. There is no aeromagnetic expression associated with the geochemical anomaly here. The most intense portion of the Au-association anomaly centers over the cluster of gold-bearing quartz-sulfide vein prospects. Placers derived from these prospects were the main source of past gold production. The geochemical expression in this area is fully compatible with the known gold sources.

Area Au-6 incorporates the Salmon River canyon in the central portion of the quadrangle. This area is underlain predominantly by Cretaceous rocks of the Idaho batholith although mapping is reconnaissance in nature. The Au-association anomaly occurs in two parts--an east-end portion and a central-west portion. The association seen here is very similar to that in area Au-5, so the east-end anomaly is interpreted to be part of the major hydrothermal system in Au-5. The central-west anomaly lends itself to two interpretations.

The first interpretation hinges on the broad, low-level aeromagnetic high extending from Lodgepole Point in the southwest through Arctic Point in the northeast. The most intense portions of the Au-association anomaly occur in the pronounced aeromagnetic low areas to the northwest and southeast of this high, whereas scattered Au prospects and Au- and Ag-rich sample sites occur over the aeromagnetic high. The aeromagnetic high may indicate a buried intrusion at some depth and the aeromagnetic low areas may indicate adjacent more strongly altered portions of the Idaho batholith. The Au and the Au-association mineral assemblage in the tributaries of the Salmon River would then be very locally derived from fissure fillings at the top of a hydrothermal system.

The alternate interpretation would postulate that the placers in the central-west area are the products of the modern reworking of older gravels perched in the Salmon River tributaries. Based on the associational similarity and lack of other known sources, these gravels would have to be derived from the Au-5 system.

Area Au-1 is characterized by an association strongly dominated by gold with high contents of bismuth, lead, and tungsten. The area incorporates rock types of Middle Proterozoic through Tertiary age. A broad, low-level aeromagnetic high occurs in the Mammoth Mountain-Moore Butte area transecting Middle Proterozoic granites, quartzites, and rocks of the Idaho batholith. Historically, the gold production from this area was mainly from placers although numerous quartz pod and fissure vein lodes are also present. Surficial geochemistry indicates that the lode gold occurs in numerous, widely scattered minor concentrations. There is no detectable focal system in this area and if Au stockwork or disseminated deposit is present, it is at substantial depth.

Interpretation of area Au-7 is plagued by insufficient geologic information and no production data. The silver that is unrelated to the Au-association anomalies occurs predominantly in the northeastern quarter of the quadrangle, generally in the outer margins of Tertiary intrusions or the country rock adjacent to them. The largest silver area, extending between Fire Mountain and Buck Knob, shows a spatial relationship to a north-south trending linear aeromagnetic feature. This silver is associated with bismuth, chlorine and the Be-association anomalies (plate B3) discussed below. These occurrences may be related to pneumatolytic processes in the margins of the Eocene granitic intrusions. It is unknown if the structural controls appropriate for mineralization are present.

Co-association

The Co geochemical association incorporates seven elements: Co, Cr, Cu, Fe, Mg, Sc, and V. Areas delineated by this geochemical association are shown on plate B2. These areas are determined on the basis of moderate Co-association anomaly intensity. Data windows labeled Co-1 through Co-9 are superimposed on these areas to permit the calculation of intra-window associational relationships as well as inter-window anomaly intensities. The anomalous areas are referred to by their window designation. In addition to the Co-association anomalies, this map shows stream-sediment sample sites at which the Co content is >_ 23 ppm. Individual prospects and mines at which Co was reported are shown by a triangle; large groups of such occurrences are shown by stipple.

Co-association Anomaly Delineation

The Co-related geochemical association delineates 9 areas within the quadrangle. Area Co-1 is located in the northeast and encompasses some 40 mi^2. This area falls outside of any known mining districts (fig. 1). Area Co-2 encompasses 138 mi^2 and incorporates most of the Indian Creek mining district and minor portions of the Mineral Hill and Mackinaw districts (fig. 1). Co-3, located in the southeastern corner of the quadrangle, encompasses only about 10 mi^2 and falls within a small portion of the Mackinaw district. Area Co-4 is also located in the southeast and encompasses some 138 mi^2. This area incorporates most of the Blackbird mining district and the western portion of the Mackinaw district (fig. 1). Co-5 is located in the central portion of the quadrangle and encompasses the northwest-trending Salmon River canyon. This is the largest of the anomalies at 220 mi^2 and incorporates no identified mining districts. Area Co-6 is located in the northeastern portion of the quadrangle. This area encompasses only 57 mi^2 and falls outside of any mining districts. Co-7, in the south-central part, is the third largest anomaly encompassing some 163 mi^2. This area incorporates portions of the Edwardsburg, Ramey Ridge, and Big Creek districts. Co-8 is a small area (48 mi^2) located to the west of Co-7 in the west-central portion of the quadrangle. It incorporates the extreme southern tips of the Buffalo Hump and Dixie districts and the northern portion of the Marshall Lake and Warren districts (fig. 1). Co-9 is located in the northwestern portion of the quadrangle and encompasses approximately 104 mi^2. This area incorporates portions of the Tenmile and Elk City districts (fig. 1).

Co-association Anomaly Description

Area Co-1 is a minor Co-association anomaly ranking seventh in areal extent and fifth in anomaly intensity. E.M. calculations (table 2) indicate the following association: Co>Cr>V>Sc>Mg>Cu>Fe. This area is underlain primarily by the Middle Proterozoic Lemhi Group. Eocene Challis volcanics and granitic intrusions also occur here. No cobalt-containing mines or prospects are known in this area.

Co-2 ranks only fifth in areal extent but third in overall anomaly intensity. E.M. calculations (table B2) indicate the following association: Cu>Co>Sc>V>Mg>Fe>Cr. This area is underlain by Middle Proterozoic metasedimentary rocks and the Yellowjacket Formation in decreasing order. A cobalt occurrence has been reported at the East Fork prospect here. This area is located some 7 miles north of the Copper Mountain-Haystack Mountain aeromagnetic high within a generally aeromagnetic low zone.

Table B2. Co-association E.M. calculations

Intra-area rank	Co-1 E.M.	Intra-area rank	Co-2 E.M.	Intra-area rank	Co-3 E.M.	Intra-area rank	Co-4 E.M.	Intra-area rank	Co-5 E.M.	Intra-area rank	Co-6 E.M.	Intra-area rank	Co-7 E.M.	Intra-area rank	Co-8 E.M.	Intra-area rank	Co-9 E.M.	Element
1	138.4	2	120.0	1	183.2	2	563.6	2	144.2	1	19.8	2	152.1	1	112.5	1	66.5	Co
2	107.3	7	32.5	2	45.4	7	4.8	3	96.3	5	12.3	7	0.0	3	33.4	6	9.5	Ca
6	56.8	1	233.3	4	16.9	1	3343.1	1	242.4	4	16.6	1	186.1	2	70.6	2	41.2	Cu
7	54.5	6	48.8	3	17.0	3	52.3	7	18.0	2	17.3	4	106.9	5	11.5	5	20.8	Fe
5	58.7	5	63.4	5	0.0	6	11.0	4	51.6	6	5.6	5	91.0	6	8.9	7	7.0	Mg
4	67.2	3	96.4	6	0.0	4	24.2	6	34.0	3	17.2	6	75.3	7	3.2	4	27.7	Sc
3	83.2	4	85.3	7	0.0	5	13.6	5	37.0	7	0.0	3	140.8	4	12.3	3	37.8	V
	566.1		669.6		262.5		4012.6		623.4		87.8		752.3		252.4		210.5	Total
Inter-window rank	5		3		6		1		4		9		2		7		8	

Co-3 is the smallest Co-association anomaly within the quadrangle. Despite this, it ranks sixth in overall anomaly intensity. E.M. calculations indicate the following individual association relationship within this window: Co>Cr>Fe>Cu>Mg>Sc>V. This area occurs over a minor "low" embayment at the edge of the Copper Mountain-Haystack Mountain aeromagnetic high.

Area Co-4 ranks second in areal extent but has the highest overall anomaly intensity by far. E.M. calculations show an association (Cu>Co>Fe>Sc>V>Mg>Cr) that is very similar to that of area Co-2. This area is underlain by the Middle Proterozoic Yellowjacket Formation and granitic intrusions in nearly equal parts. The cobalt-producing Blackbird district occurs in the area, as do several cobalt-containing prospects to the south and east. The aeromagnetic setting of this area is similar to that of Co-2; i.e., it is located in an aeromagnetic-low zone some 7 miles west-southwest of the Copper Mountain-Haystack Mountain aeromagnetic high.

Area Co-5 is the largest in extent of the Co-association anomalies with 220 mi^2 but ranks only fourth in overall anomaly intensity. This area encompasses a northwest-trending section of the Salmon River canyon, underlain primarily by Cretaceous rocks of the Idaho batholith. Some outcrops of Middle Proterozoic gneiss and intrusions are also present. The Co-association (Cu>Co>Cr>Mg>V>Sc>Fe) is similar to that of area Co-4. One cobalt-bearing prospect is present in the extreme eastern end of the area. Otherwise, the area is characterized by placers. The Co-association anomaly in this area is probably the product of the reworking of older gravels in the Salmon River tributaries. The similarity of the Co-5, Co-2, and Co-4 Co-association indicates that these gravels were probably derived in the latter two areas. The two aeromagnetic highs in this area show little relationship to the geochemical patterns.

Area Co-6 ranks sixth in areal extent and has the lowest overall anomaly intensity. The Co-association (Co>Fe>Sc>Cu>Cr>Mg>V) is unlike that of the areas with known cobalt prospects. This area is underlain primarily by Middle Proterozoic gneiss, some Cretaceous Idaho batholith rocks, and minor Eocene granite. The complex aeromagnetic patterns here are not easily interpreted on the basis of surface mapping.

Co-7 is located in the south-central portion of the quadrangle and ranks third in areal extent and second in overall anomaly intensity. E.M. calculations indicate that this particular association (Cu>Co>V>Fe>Mg>Sc>Cr) is similar to that in areas Co-2 and Co-4. This area is underlain predominantly by rocks of Middle Proterozoic age including the Yellowjacket Formation, the Lemhi Group(?), quartzites of unknown correlation, and granites of four ages. Two prospects with reported cobalt mineralization occur here. The aeromagnetic setting here is similar to that of areas Co-2 and Co-4.

Area Co-8 ranks eighth in areal extent and seventh in overall anomaly intensity. E.M. calculations indicate that the Co-association (Co>Cu>Cr>V>Fe>Mg>Sc) shows no similarity to the cobalt-producing areas. This area is underlain predominantly by Cretaceous rocks of the Idaho batholith with minor Middle Proterozoic gneiss. There is no distinctive aeromagnetic pattern present.

Area Co-9 is the fourth largest anomaly in extent but ranks only eighth in overall anomaly intensity. The individual Co-association found here (Co>Cu>U>Sc>Fe>Cr>Mg>) is relatively similar to that in area Co-8. This area is underlain predominantly by Middle Proterozoic rocks consisting of gneisses, granite, and schist. Minor outcrops of Cretaceous Idaho batholith and Eocene granite also occur. There is no pronounced aeromagnetic expression in this area.

Co-association Anomaly Discussion

On a regional scale, the delineated Co-association anomalies show a striking spatial relationship to areas of Middle Proterozoic rocks. The most intense of these anomalies (Co-4>Co-7>Co-2>Co-5) generally have four characteristics in common:

1. A substantial proportion of the anomalous area is underlain by rocks of the Middle Proterozoic Yellowjacket Formation.
2. There is an aeromagnetic high located close to the anomaly.
3. Copper is dominant within the Co-association.
4. The most intense Co-association anomalies tend to coincide with areas in which the most intense Au-association anomalies occur.

The first characteristic suggests that the Yellowjacket Formation serves as the source for the copper-cobalt. Characteristics 2 and 4 indicate that a hydrothermal system provided the required solution and thermal parameters for the remobilization of the Cu-Co association and its subsequent concentration along stratigraphic and structural traps.

Areas Co-2 and Co-4 fall within the Au-5 Au-association anomaly and occur at an equal distance from the Copper Mountain-Haystack Mountain aeromagnetic high (plate C). Although the overall anomaly intensity of area Co-4 is substantially greater than that at Co-2, the anomaly component relationship is basically identical. The Yellowjacket Formation underlies a large proportion of the Co-4 area. It also occurs in the Co-2 area although to an unknown extent. Cobalt-bearing mines and prospects are present in both areas.

Area Co-7 incorporates the central portion of the Au-association anomaly Au-4. This anomaly occurs over and adjacent to the aeromagnetic high at Acorn Butte. The area ranks second in overall anomaly intensity and the Co-association is similar to that seen in areas Co-2 and Co-4. The Yellowjacket Formation underlies much of this area and two cobalt-bearing prospects are indicated here.

Area Co-5 coincides with the area delineated by Au-association anomaly Au-6. The easternmost portion of this anomaly has a setting identical to that of area Co-4. One cobalt-bearing prospect is present. The western portion of the anomaly occurs over and adjacent to the aeromagnetic high at Lodgepole Point-Arctic Point. The area as a whole ranks fourth in overall anomaly intensity and the association is similar to those of the previous three anomalies. Middle Proterozoic rocks crop out in this area although the Yellowjacket Formation has not been identified. However, this part of the quadrangle is inadequately mapped. This area is estimated to have moderate cobalt potential.

All other Co-association anomalies in the quadrangle have low cobalt potential based on present information.

Be-association

The Be geochemical association used in this report incorporates ten elements. In addition to Be these are Cs, Dy, Li, Nb, Rb, Sn, Ta, U, and Zn. Anomalies delineated by this geochemical association within the Elk City quadrangle are shown on plate B3 using two contour levels for moderate and high anomaly intensity. Data windows labeled Be-1 through Be-5 are superimposed on these areas to permit the calculation of intra-window associational relationship as well as interwindow anomaly intensities. Henceforth in this report, the anomalous areas will be referred to by their respective data window designations.

In addition to the Be-association anomalies, this map shows stream sediment sites (black dots) at which the Be content is ≥5 ppm. Prospects at which beryl has been reported are shown by an X.

Be-association Anomaly Delineation

The Be-related geochemical association delineates five major areas within the quadrangle. All five of the areas are located in the eastern half of the quadrangle.

Be-1 is located in the north central portion and encompasses about 13.5 mi^2. This area does not incorporate any known mining district. Be-2, to the south and east of Be-1 encompasses 24 mi^2. No prospects are indicated in this area (Mitchell and others, 1981). Area Be-3 is located in the northeastern corner of the quadrangle. It encompasses some 40 mi^2. No mine or prospect information is available for this area. Area Be-4 is located in the east-central portion of the quadrangle. This area encompasses some 50 mi^2 and incorporates the northern tip of the Mineral Hill district. The last area, Be-5, is located near the southern quadrangle boundary. This is the largest of the five areas of 50 mi^2 and incorporates portions of the Musgrove, Blackbird, Wilson Creek, and Yellowjacket mining districts (fig. 1).

Be-association Anomaly Description

Area Be-1 is the least extensive of the five delineated Be-association anomalies and is lowest in overall anomaly intensity. E.M. calculations (table B3) indicate the following Be-association: Ta>Be>Zn>Li>U >Rb>Nb>Dy>Sn>Cs. This area is underlain predominantly by Tertiary granite with minor Middle Proterozoic quartzite. Areas Be-1, Be-2, and Be-3 fall into a zone of aeromagnetic patterns that are related to deep-seated structure (see plate C1).

Area Be-2 ranks fourth in areal extent and third in overall anomaly intensity. The Be-association here (Be>Cs>Ta>Rb>U>Zn >Li>Sn>Dy>Nb) is quite different from that of Be-1. This area is underlain predominantly by Eocene granite and more restricted outcrops of Middle Proterozoic Lemhi Group, undifferentiated quartzite, and granite.

Area Be-3, located in the northeastern corner, ranks third in areal extent and second in anomaly intensity. Despite its proximity to Be-2, the Be-association (U>Be>Cs>Li>Rb>Ta>Zn>Dy>Sn>Nb) in Be-3 is quite dissimilar and is dominated by uranium. This area is underlain predominantly by Eocene granite and some Middle Proterozoic undifferentiated metasedimentary rocks and Eocene volcanic rocks.

Area Be-4 ranks second in areal extent but only fourth in anomaly intensity. E.M. calculations of association (U>Ta>Be>Li>Rb>Zn>Sn>Dy>Cs>Nb) are similar to those of Be-3. This area is also underlain predominantly by Eocene granite. Middle Proterozoic granite and Cretaceous rock of the Idaho batholith comprise the remainder of the area. The aeromagnetic anomalies yield a complex and not easily interpreted pattern (plate C1).

Area Be-5 ranks first in areal extent and has, by far, the highest anomaly intensity. The individual Be-association here (Be>Ta>U>Sn>Li>Nb>Dy>Cr>Rb>Zn) indicates Be to be the dominant component. This is confirmed by the presence of beryl-bearing prospects within the area. This area is located immediately adjacent to a substantial aeromagnetic high (plate C1).

Table B3. Be-association E.M. calculations

Element	Intra-area rank	Be-1 E.M.	Intra-area rank	Be-2 E.M.	Intra-area rank	Be-3 E.M.	Intra-area rank	Be-4 E.M.	Intra-area rank	Be-5 E.M.
Be	2	93.2	1	121.7	2	122.2	3	75.8	1	241.7
Cs	10	0.0	2	96.5	3	117.8	9	18.8	8	71.7
Dy	8	20.5	9	7.0	8	31.3	8	25.2	7	72.5
Li	4	36.1	7	48.9	4	103.5	4	69.8	5	86.8
Nb	7	20.6	10	0.0	10	0.0	10	4.1	6	79.1
Rb	6	34.4	4	53.3	5	77.2	5	50.9	9	69.9
Sn	9	20.5	8	23.3	9	11.1	7	31.9	4	128.7
Ta	1	157.6	3	91.1	6	55.6	2	94.8	2	241.1
U	5	36.0	5	64.1	1	137.9	1	138.2	3	225.0
Zn	3	57.5	6	52.9	7	33.0	6	32.8	10	34.8
Total		476.2		576.1		696.3		544.6	1	252.2
Inter-window rank	5		3		2		4		1	

Be-association Anomaly Discussion

On a regional scale, the Be-association anomalies are predominantly related to the marginal portions of Eocene felsic intrusions. This association also occurs, however, in areas previously delineated as Au-association anomalies and especially in those with pronounced aeromagnetic highs (Au-4 and Au-5). In these areas the Be-association is believed to indicate a felsic to intermediate composition for the postulated buried intrusions.

Minerals deposited by pneumatolytic-pegmatitic processes at the margins of Eocene intrusives are believed to be the source for the Be-association anomalies. The silver associated with these anomalies has been discussed in the Au-association section. In addition to the silver, these anomalous areas might hold some potential for rare earth, beryl, uranium, and possibly molybdenum (not analyzed for) mineralization.

SECTION C

GEOPHYSICS

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Introduction

Studies of previous geophysical work were conducted as part of a multi-disciplinary team effort to assess the mineral resource potential of the Elk City 1°x2° quadrangle. The main thrust of the geophysical work was to investigate the geologic implications of the magnetic and gravity anomaly patterns, to define their significance to mineral resource evaluation, and to compile and display appropriate geophysical data for the quadrangle. Wide-spaced reconnaissance NURE gamma-ray spectrometer data provide information about the distribution of the surface concentrations of radioactive uranium, potassium, and thorium, the largest concentration being in the felsic plutonic rocks.

Regional gravity, magnetic anomaly, and radio-element concentration maps plus interpretive maps (plates C-1 and C-2; fig. C-4 to C-9) show spatial relations between the geophysical anomalies and the geology, geochemistry, mineral deposit types, and linear Landsat features. Plates C-1 and C-2 are overlays for comparison of the magnetic and gravity anomalies with the geology and other data.

The aeromagnetic data (plate C-1) when superimposed on the geologic map (Chapter A, plate A) illustrate the correlation of magnetic patterns with various types of geologic features and provide information applicable to prospecting for geologic structures and igneous intrusions in the subsurface that might have associated mineral deposits. Valuable information results from correlation of the magnetic anomaly data with the geochemistry data (section B) and with the Landsat linear features (section D). The isostatic gravity anomaly map (plate C-2) provides valuable insights for regional prospecting, such as information about regional structures and the distribution of low-density igneous intrusions typical of the Eocene felsic intrusions in the quadrangle. A number of mineral deposit types (see section E) appear to be spatially related to granitic intrusions and fault zones.

The magnetic anomaly data generally provide more specific information than the gravity anomaly and radiometric data for use in mineral resource evaluation. Positive magnetic anomalies are often associated with exposed granitic intrusions. A partial correlation may mean that the intrusion in question is not uniformly magnetized. In some cases the configuration of the anomaly may indicate the presence of concealed magnetic intrusions or more subsurface extensions of the exposed plutons. The widespread Cretaceous biotite granodiorites and granites of the Idaho batholith are less magnetic than the Eocene plutons, generally show low magnetic gradients, and exhibit no distinctive expressions that could be used to locate their contacts.

Griscom prepared the first draft of the report on regional interpretations of the gravity and magnetic anomaly data, and the gamma-ray spectrometer data. Kleinkopf compiled the report, prepared the introduction, the recommendations, and worked with the other team members in integrating and cross referencing the data from the various disciplines in order to provide information for the mineral resource assessment.

Interpretation of Regional Gravity Survey

Interpretation of the regional isostatic residual gravity map (fig. C-4) has identified a number of major gravity features. The largest feature is the gravity low that is considered to be the expression of the thick low-density granitic and locally granodioritic rocks of the Cretaceous Idaho batholith. The approximate boundary of these rocks is taken to be the 0 mGal contour line for which a generalized location is shown on the gravity interpretation map (fig. C-5). Major gravity lows are caused by the young basins containing Tertiary and Quaternary sediments (TQ on fig. C-5) and also by the thick low-density pyroclastic deposits, labeled Eocene cauldron complex, at the south edge of the quadrangle. Steep linear gravity gradients locally identify border faults of the sedimentary basins and other steep gradients identify the crescentic caldera faults of the cauldron complexes.

Trending approximately north-south along the west border of the quadrangle at 116°W is the hachured line that separates the higher-density rocks (tonalite, quartz diorite, and plagiogranite) of the western border of the Idaho batholith from the lower density rocks of the main mass of the Atlanta lobe. This high-density western portion is similar in distribution and relative location to the density distributions observed in the Sierra Nevada and Peninsular Ranges batholiths of California (Griscom and Oliver, 1980). Farther to the west the batholith intruded allochthonous terranes of Paleozoic and Mesozoic rocks overlain by Tertiary basalt flows. Local very dense masses of concealed older plutonic or volcanic rocks probably account for the much higher gravity values (most of area A on the interpretive map) although at least one anomaly (labeled Ki on map) at latitude 46°N, longitude 116°W is probably caused by high-density western rocks of the Idaho batholith.

In the northeast corner of the quadrangle is an area of low gravity interpreted to be caused by Idaho batholith, much of which is concealed beneath exposed Proterozoic rocks. This interpretation is in agreement with cross section A-A' of Hyndman (1983), this area being called the Sapphire tectonic block. The block is believed to have been extended down to the east across the east half of the Bitterroot lobe (Hyndman, 1983; Garmezy and Sutter, 1983).

Rocks of the Bitterroot lobe directly west of the Sapphire tectonic block form the north-trending Bitterroot dome, a foliation dome with mylonic rocks along the east contact. This area is gravitationally positive, values being well above the 0 mGal contour (area between the two letters "C"). We interpret the gravity data to indicate that the batholith is probably no more than 2 km thick in this area, is somewhat higher in density than the typical granite, and is underlain by relatively high density Proterozoic rocks.

Trending northwest-southeast across the entire quadrangle is the Salmon River Arch (Armstrong, 1975) within which are exposed highly metamorphosed Proterozoic rocks believed to represent the floor of the Idaho batholith (Hyndman, 1983). Alternatively, other workers have concluded that most of the rocks are exposed as Middle Proterozoic roof pendants in the batholith (K.V. Evans, written commun., 1987). These older rocks now separate the Atlanta lobe of the batholith from the Bitterroot lobe to the north. Relatively high gravity is observed over much of these Proterozoic rocks (three areas marked B). An area of low gravity (area D) connects the low gravity of the Atlanta lobe with that of the Bitterroot lobe, extends northeast completely across the arch, and is substantially underlain by exposed Proterozoic rocks. A major northeast-trending fault zone forms the southeast border of this low gravity connection. Apparently there is yet more plutonic rock beneath the surface in this connecting corridor of area D.

In the center of the east half of the quadrangle is an elongate gravity low (area E). This low is internally complex, perhaps because of locally inaccurate data, but seems at least in part to be associated with an area of Cretaceous granodiorite. Gravity low F is associated with Precambrian rocks of the Salmon River arch which suggests the presence of either low density Tertiary or Cretaceous granitic rocks, which could account for the low gravity values.

The Eocene plutons in general do not appear to significantly affect the gravity field although the Crags pluton appears to produce a slight local gravity low. Perhaps the plutons are generally similar in density to the rocks they intrude. One unusual gravity high (G) is observed just to the south of the quadrangle and may be related to the mafic-felsic complexes of Cambrian-Ordovician age.

The lowest gravity values for the Idaho batholith are generally -15 to -20 mGal with only a few falling below -20 mGal. This result compares with values of -15 to -25 mGal for the Peninsular Ranges batholith and -30 to -40 mGal for the Sierra Nevada batholith. Because measured density values for the Idaho batholith are similar to those measured for the two California batholiths, the Idaho batholith either may be thinner than the others or may have relatively higher density rocks in its lower portions. The band of Middle Proterozoic rocks that separates the Bitterroot and Atlanta lobes is expressed in the gravity anomaly data as a series of interruptions of a northwest trend in a field dominated by linear features and general gravity grain of northeasterly trend.

The principal facts for the gravity data are available on magnetic tape from the Data Service Officer, EROS Data Center, U.S. Geological Survey, Sioux Falls, SD 57198. These data were used to prepare the isostatic residual anomaly maps for this paper (plate C-2; fig. C-4) and for the published Bouguer anomaly map of Idaho (Blankey and others, 1985).

Interpretation of Regional Magnetic Anomaly Map

For the regional interpretation, we have used the published aeromagnetic maps of Idaho (U.S. Geological Survey, 1978) and Montana (U.S. Geological Survey, 1980) and have combined them into one map at a scale of 1:500,000. The area of the Elk City quadrangle and vicinity was isolated as a specific illustration for this report (fig. C-6). The interpretation here is intended to be regional in scope and ignores numerous local magnetic features.

Individual major magnetic features on the interpretation map (fig. C-7) are outlined by solid lines where the inferred causative rock masses are believed to be exposed or at very shallow depth. Concealed subsurface magnetic sources are outlined by dashed lines. The geologic nature of the source rocks for each anomaly is indicated for the most part but sources for some anomalies are uncertain and are discussed below.

Anomalies with Proterozoic Sources

Several magnetic anomalies in the eastern part of the study area are associated with, or inferred to have Precambrian sources. These features trend strongly northwesterly and imply a northwest tectonic grain both predating the Idaho batholith and perhaps also syntectonic with batholith emplacement. Typically these anomalies appear to have sources that are antiformal in shape and that have crests plunging beneath the surface to the northwest and southeast for substantial distances. The symbol of an arrow is used on the interpretation map to portray the direction and subsurface distance of these plunging antiforms.

A most conspicuous feature is the linear magnetic high that extends northwest from the northeast portion of the Elk City quadrangle for a distance of about 150 km. We infer that the source rocks of this feature are not the

Tertiary pluton that crops out, but instead are more mafic rocks in the Proterozoic metamorphic complex beneath the Tertiary pluton. Near the north border of the quadrangle, the source rocks appear to plunge northwest below the surface where both Cretaceous and Eocene plutonic rocks are exposed. The crest of this subsurface antiform is offset left-laterally for a distance of 7-8 km at longitude 115°W (and the northwest side here probably elevated 1-2 km); and then the source rocks apparently reverse their plunge direction and resurface in the Hamilton quadrangle about 33 km northwest of their last exposure in the Elk City quadrangle. Model studies using a 2 ½ -dimensional program have been made on profiles A-A', B-B', and C-C' (figs. C-1 to C-3) across this feature. The profiles are located on the aeromagnetic map (fig. C-6). Results show a large antiformal magnetic mass 40-60 km wide, the two sides dipping outwards at angles of 20°-40°, with a vertical extent of possibly as much as 10 km. If the vertical relief is somewhat less than 10 km, then the calculated dips must be less and the assumed magnetization must be increased for the bodies. Based on regional information from the geologic map of Idaho (Bond, 1978), it is concluded that along the 150-km feature, there are highly magnetic source rocks inferred to be located in the older Precambrian crystalline basement that underlies the Middle Proterozoic metasedimentary rocks.

The crest of the 150-km antiform as described above plunges below the surface and is perhaps deepest where it causes a saddle in the magnetic anomaly at latitude 46°N., longitude 115°W. Profile B-B' (fig. C-2) was modeled near this saddle in an effort to determine the minimum depth extent of the antiform beneath the overlying Tertiary plutonic rocks, which are relatively nonmagnetic. The calculation suggests that the crest is at least 3-4 km below the surface and that the antiform probably has a more gently rounded shape than in the other two calculated sections. Comparison of the gravity interpretation map with this saddle in the magnetic anomaly shows an excellent correlation between the saddle and the northeast-trending gravity low connecting the two lobes of the batholith. The Cretaceous granitic rocks of the batholith and the exposed Tertiary pluton are interpreted to be the major rock units of the saddle and to be at least 3-4 km thick (following model B-B, fig. C-2), here causing a gravity anomaly of -10 mGal. It can be further inferred that the batholith may be 6-8 km thick in those limited areas where it causes gravity values of -20 mGal, a result somewhat less than the values of 10-12 km obtained for the Sierra Nevada and Peninsular Ranges batholith (Griscom and Jachens, unpublished data).

To the north along the Bitterroot dome are two additional areas of substantial magnetic anomalies that are believed also to be caused predominantly by Proterozoic rocks. Although these anomalies occur in areas mapped as Idaho batholith, they (1) are very similar to the 150-km anomaly, striking to the west and northwest, (2) have similar large vertical extent and gentle marginal gradients, and (3) occur in an area of positive isostatic gravity anomalies that includes Proterozoic rocks. These three arguments strongly suggest both a predominantly Proterozoic source with a thin cover overlying Idaho batholith. The magnetic data indicate that the batholithic rocks themselves may also be magnetic in these areas. Of great significance is the fact that these magnetic anomalies and their associated structures trend northwest and west, whereas the geologic units of the Bitterroot dome and the associated mylonite strike north-south and show no signs of these presumably older, deeper structures that cross the surface contacts at large angles.

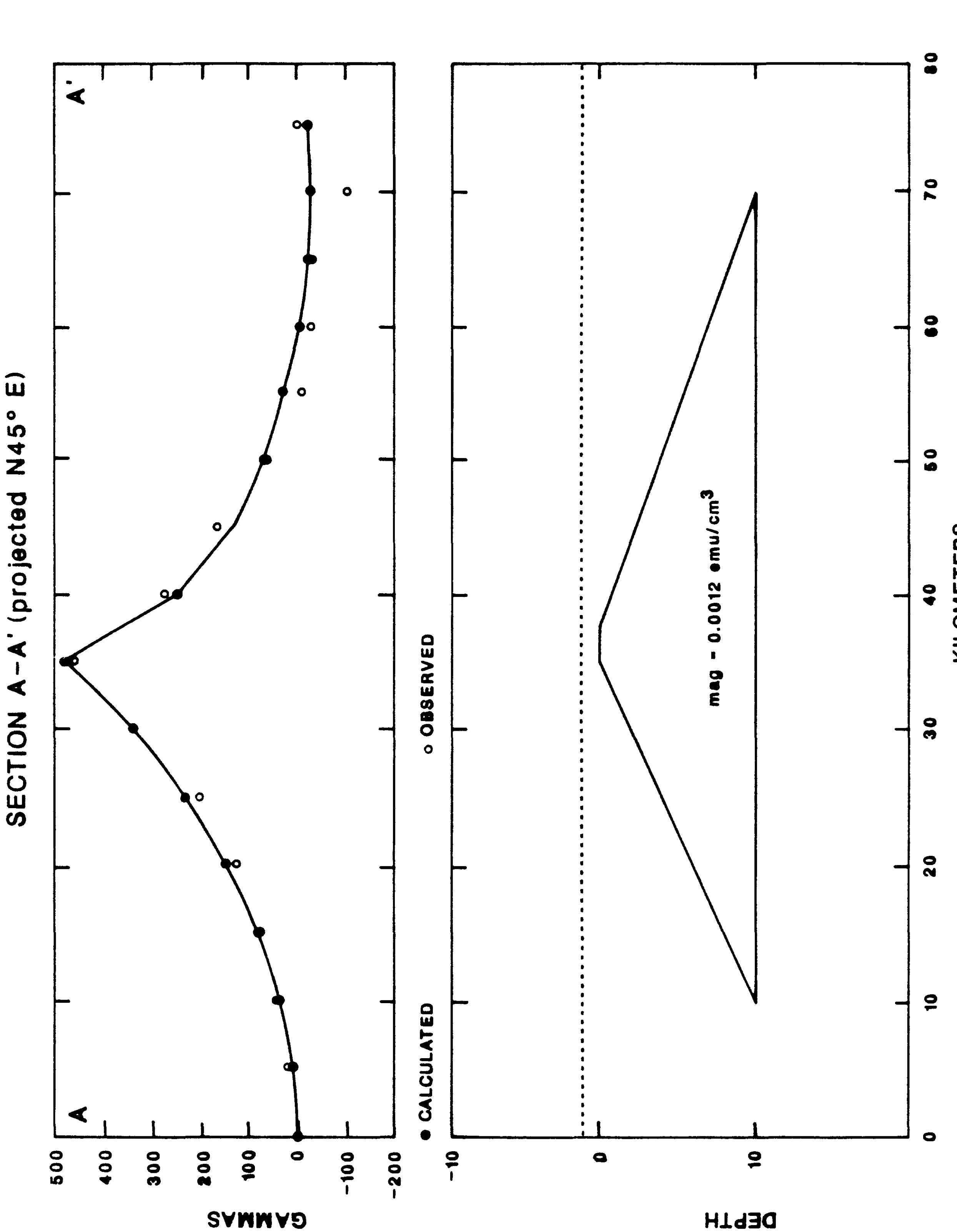

Figure C1. Section A-A'. Magnetic model projected on to a line striking N45°E.

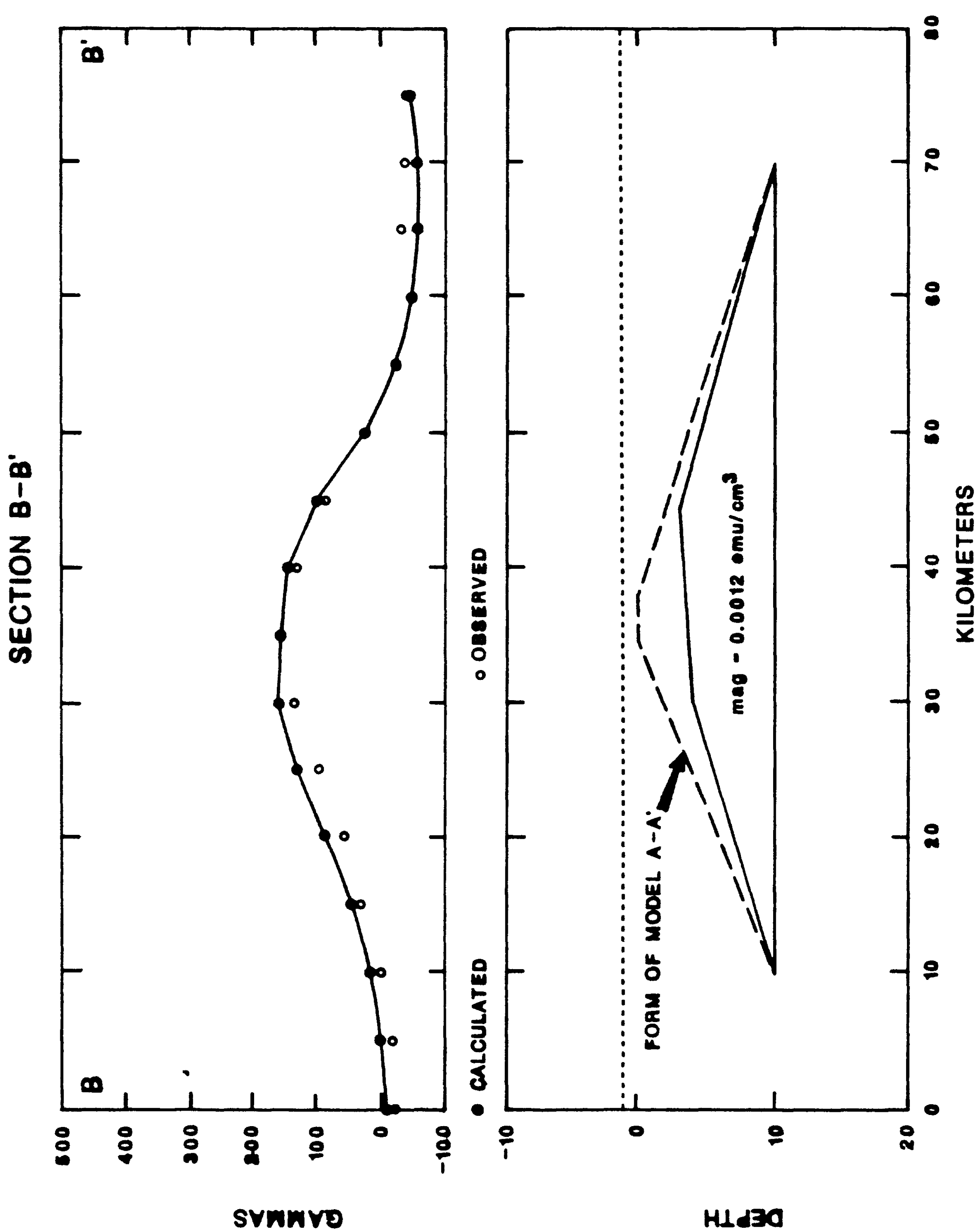

Figure C2. Section B-B'. Magnetic model.

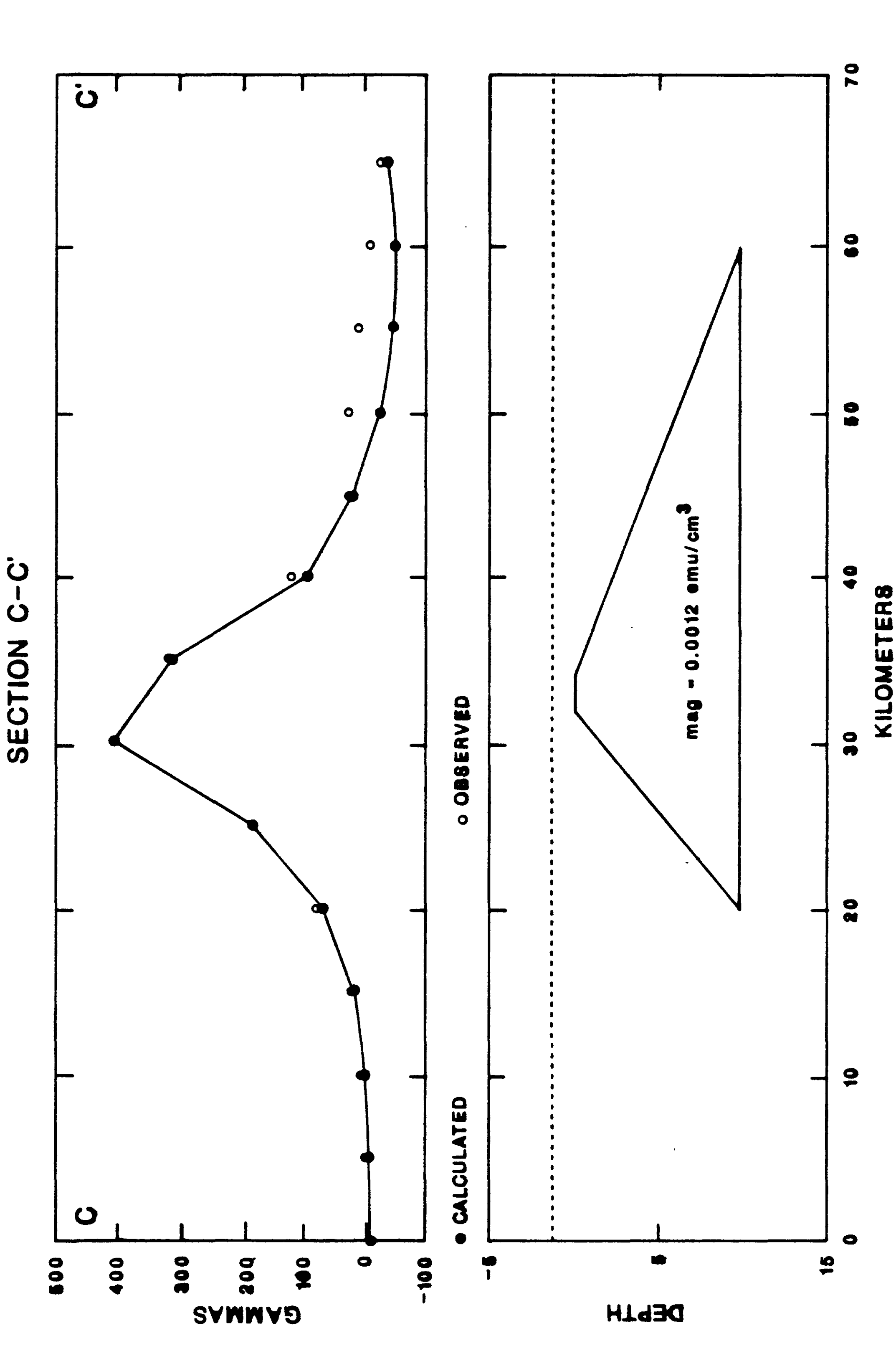

Figure C3. Section C-C'. Magnetic model.

Anomalies West of the Idaho Batholith

Numerous substantial aeromagnetic anomalies occur a short distance west of the Elk City quadrangle (fig. C-6). in the area of allochthonous island arc terrane (section A). The larger features are caused mainly by a complex of volcanic and igneous intrusive rocks of oceanic crust affinity, and possibly by outlying concealed tonalites of the Idaho batholith. The abundant overlying Tertiary basalts cause numerous high-amplitude short-wavelength anomalies. A curved north-south line identifies the approximate eastern limit of this highly magnetic area is drawn on the interpretation map (fig. C-7).

Anomalies of the Idaho Batholith

The rocks of the western border phases of the Idaho batholith are magnetic; such rocks include tonalites and quartz diorites and some granodiorites. The boundary between these western magnetite-bearing rocks and the ilmenite-bearing rocks of the main central portion of the batholith has been described as the magnetite-ilmenite boundary by Piccoli and Hyndman (1985). These two general rock types can also be identified by interpretation of the aeromagnetic map (U.S. Geological Survey, 1978) and especially well by examination of the NURE data, flown east-west at only 122 m above ground. These latter two boundaries between magnetic and non-magnetic rocks are shown on the magnetic interpretation map (fig. C-7) and are in reasonable agreement with the ground investigations of Piccoli and Hyndman (1985). This line may also represent a boundary between I-type plutonic rocks to the west and S-type two-mica granitic rocks to the east.

The central granitic mass of the Atlanta Lobe is predominantly an ilmenite-bearing, two-mica granite which is at most very weakly magnetic and does not display significant aeromagnetic anomalies. There are exceptions to this generalization as indicated by several discrete positive magnetic anomalies. There are four anomalies in the south-central and in the southeastern part of the quadrangle that are inferred to have source rock of alkali syenite of possible Cambrian to Ordovician age, although Precambrian sources may contribute to these anomalies (see section A and plate A). Syenite sources are favored because they crop out in the anomaly area, they are typically moderate to highly magnetic, and the magnetic patterns are more complex than that of the two major Precambrian-sourced anomalies to the north. Other exceptions are some unexplained east-west trending magnetic highs (labeled A) in the Bitterroot lobe north of the Elk City quadrangle. As mentioned previously, the granodiorites and granites of the Bitterroot dome on the east margin of the Bitterroot lobe are magnetic, and tentatively interpreted to be the result of reaction with and assimilation of adjacent underlying magnetic Proterozoic rocks.

The two anomalies labeled B on the interpretation map are puzzling. The features, except for the south third of the southern one are associated with Proterozoic rocks, but their sources may not crop out. Both features are associated with gravity lows (D and F on the gravity interpretation map) and are contained within the main mass of the Idaho batholith according to the gravity interpretation. The form of the anomalies suggests the causative masses have vertical extents of at least several kilometers and very likely the sources of the anomalies are intrusive rocks of Cretaceous or Tertiary age.

In the northeast corner of the Elk City quadrangle, the Idaho batholith is non-magnetic, but as one proceeds further northeast into the Sapphire tectonic block within the Butte quadrangle, it is evident that the individual stocks are magnetic (anomalies labeled Ki on interpretation map). Two alternatives are suggested. The first alternative is that the tectonic block is largely underlain by batholith so that these stocks are merely its exposed high-level intrusions. The material of the stocks has crystallized at shallower depths than the rest of the batholith to the southwest. It has been observed in the Sierra Nevada batholith, that commonly the rocks which crystallized at shallower depths (those near the Sierra Nevada crest), lack muscovite, contain magnetite rather than ilmenite, and are magnetic. The magnetic data suggest a similar situation exists here in Idaho and Montana. The second possibility is that the stocks are older, and not genetically related to an underlying batholith, which raises a question of whether the Idaho batholith underlies the Sapphire block.

Anomalies Produced by Eocene Plutons

The Eocene epizonal granitic plutons at the south of the Elk City quadrangle are magnetic, and become even more so to the south in the Challis quadrangle (Mabey and Webring, 1985). The magnetic anomalies are labeled Ti and are located near the south border of the Elk City quadrangle. The Bighorn Crags pluton produces a strong anomaly and to the northwest has an associated similar magnetic high (labeled Ti?) indicating a possible subsurface extension that may be a source of mineralization. The causative rocks of this queried anomaly, if Tertiary, apparently do not crop out, and because there is no surface exposure, they do not show on the gamma ray spectrometer survey. Additional gravity data may better define this feature. Other Tertiary plutons crop out north and east of the Bighorn Crags pluton and extend to the north beyond the quadrangle edge. However, these Tertiary plutons to the north exhibit no magnetic expression. There appears to be a general northward decrease in magnetic expression of Eocene plutons which seems to correlate with a decrease in the outcrop area of associated Eocene volcanic rocks and suggests the possibility that the plutons may be at deeper erosion levels to the north and that perhaps only the uppermost portions of the plutons are magnetic, the formerly extant upper magnetic levels having been stripped off the northernmost plutons by erosion.

The two largest Tertiary plutons in the Elk City quadrangle lie partly or wholly astride the 150-km linear Proterozoic magnetic anomaly. The source rocks of this magnetic anomaly plunge beneath the northerly Tertiary pluton near latitude 46°N, longitude 115°W and appear otherwise undisturbed by the Tertiary pluton which evidently overlies but does not significantly intrude this deep-seated magnetic feature. According to cross section B-B' (fig. C-2), the depth of the anomaly source is 3-4 km, although the stock is about 16 km wide and thus is markedly tabular, being less than 4 km thick. The only available intrusive source or root that is located below the outcrop area of the pluton may be the small saddle exactly at latitude 46°N, longitude 115°W where the magnetic anomaly is offset. It seems more likely, however, that this pluton has been emplaced laterally from some source well to the side of the 150-km anomaly.

The larger of the two Tertiary plutons crops out along the south flank of the 150-km anomaly. The two northernmost outcrop areas of the pluton actually lie on the crest of the anomaly and are associated with small saddles in the anomaly, implying that the source rocks lie at very shallow depth (<1 km) below the pluton. The pluton otherwise does not disturb the broad magnetic gradient sloping down to the south, a gradient which on model A-A' (fig. C-1) is interpreted to represent a southwest-dipping surface with a slope of about 20°. Thus the pluton is wedge-shaped in cross-section, being no thicker than 10 km

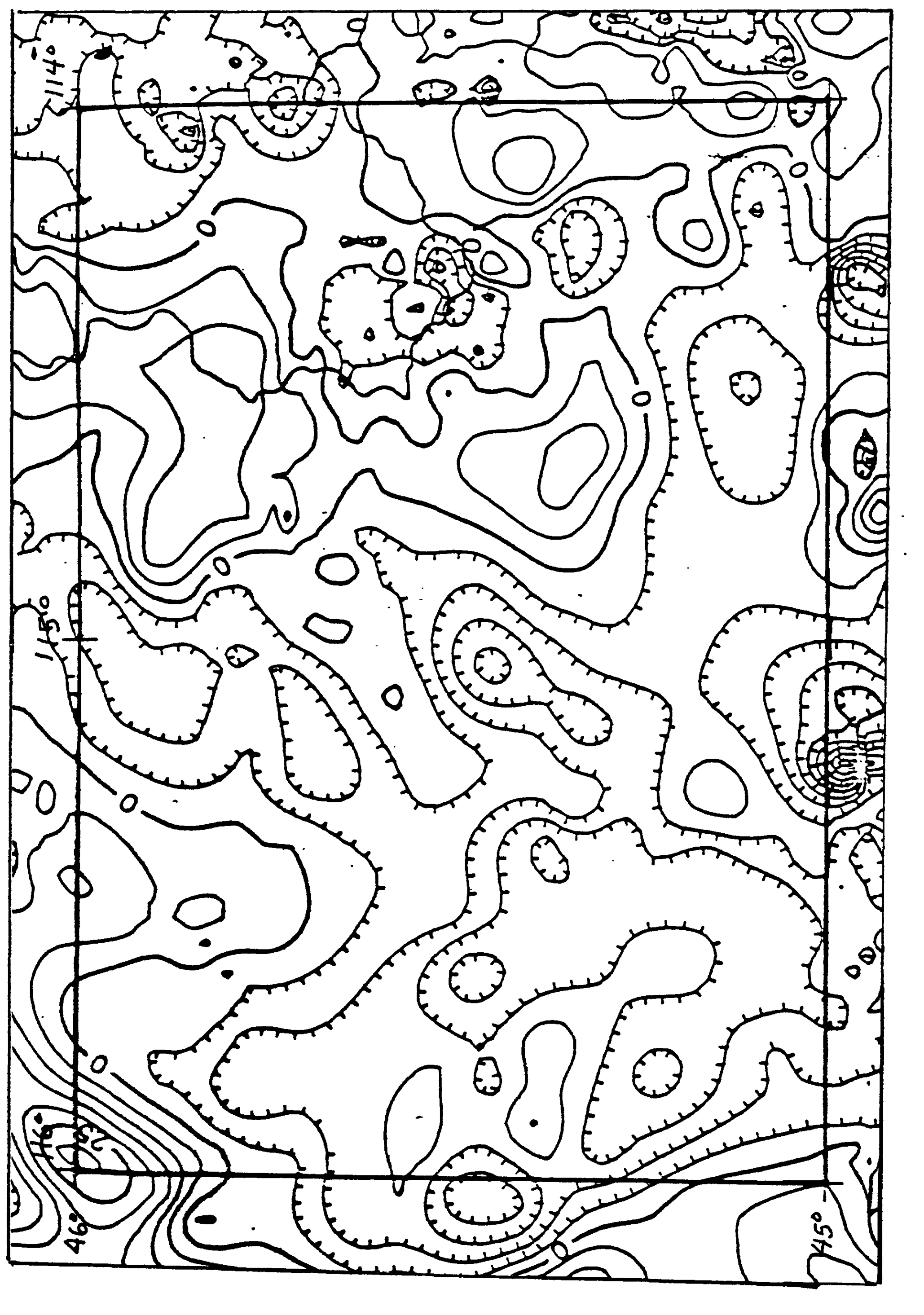

Figure C4. Isostatic residual gravity anomaly map of the Elk City, Idaho region.

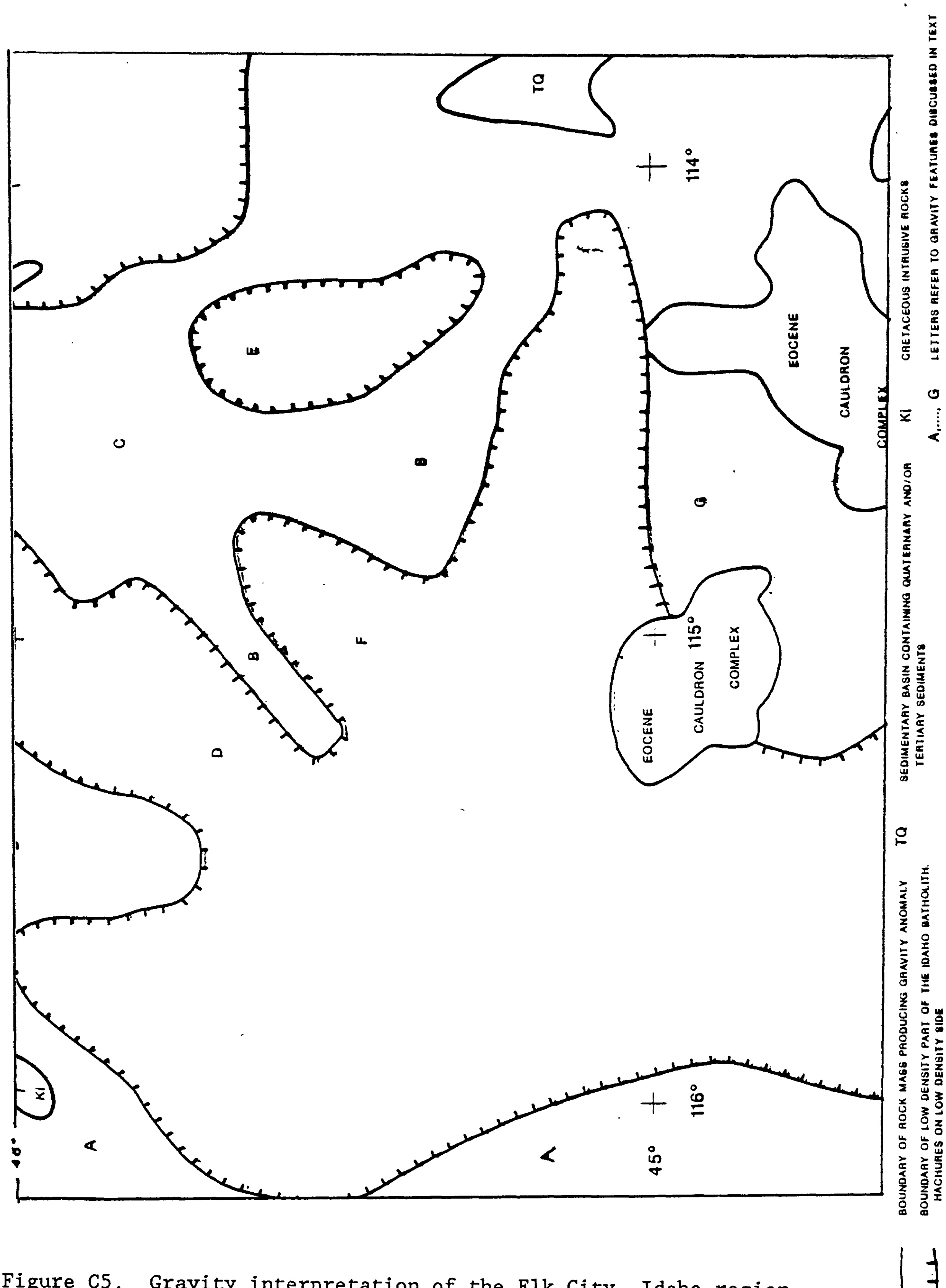

Figure C5. Gravity interpretation of the Elk City, Idaho region.

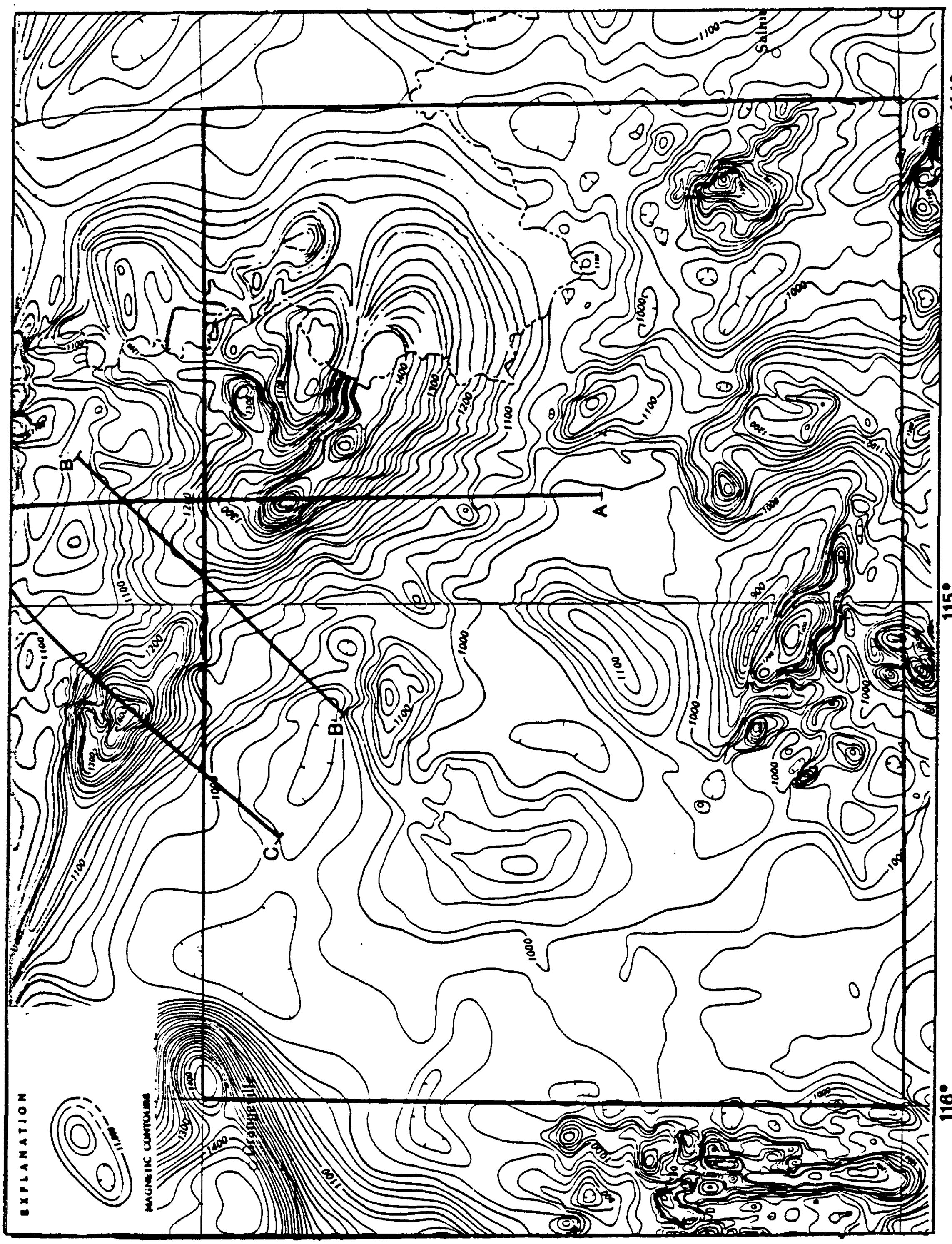

Figure C6. Aeromagnetic anomaly map of the Elk City, Idaho region.

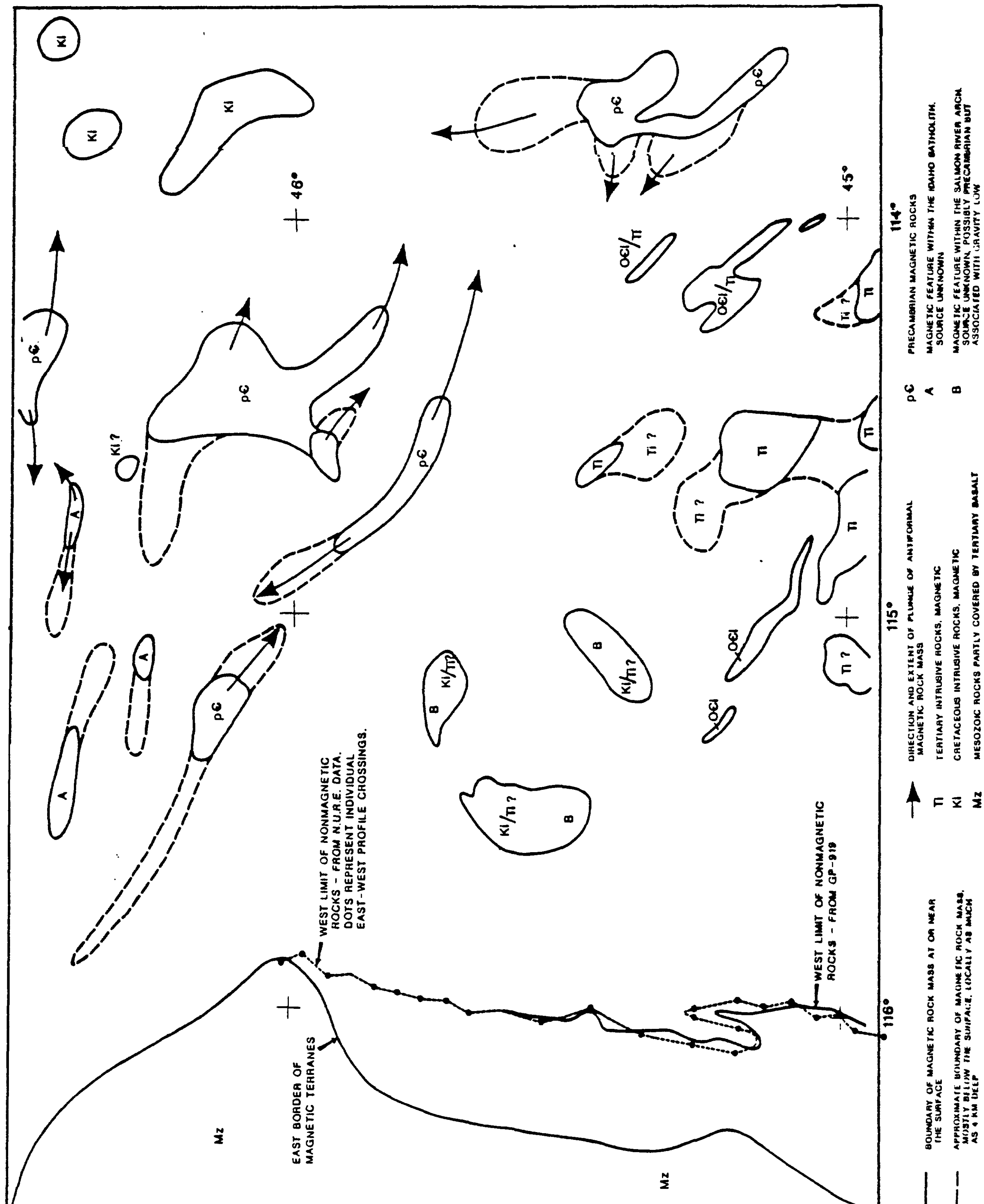

Figure C7. Aeromagnetic interpretation of the Elk City, Idaho region.

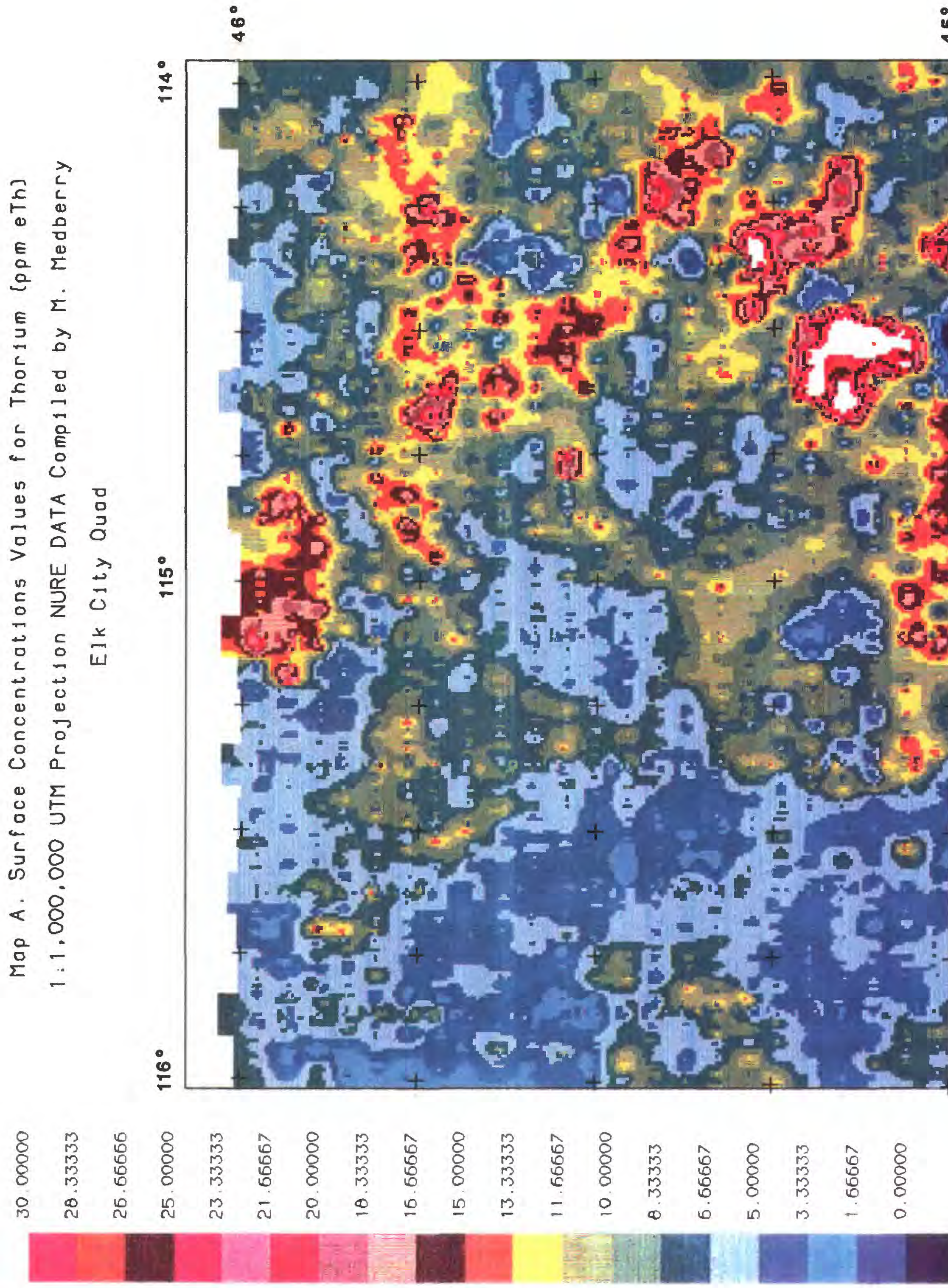

Figure C8. Color contour map showing surface concentration values for thorium (ppm eTh), in the Elk City 1°x2° quadrangle. UTM projection, scale 1:1,000,000, NURE data processed and compiled by M. G. Medberry.

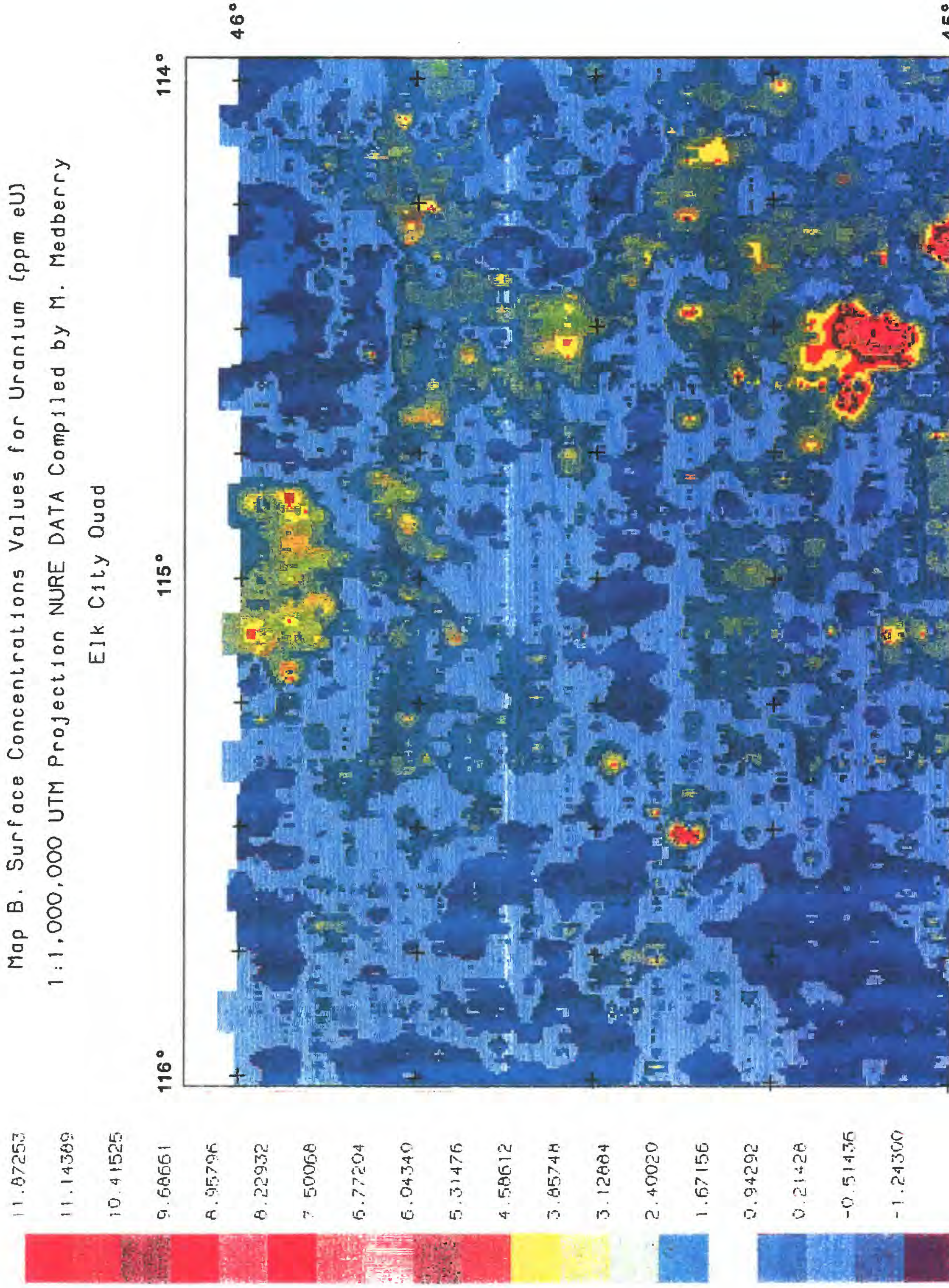

Figure C9. Color contour map showing surface concentration values for uranium (ppm eU). UTM projection, scale 1:1,000,000, NURE data processed and compiled by M. G. Medberry.

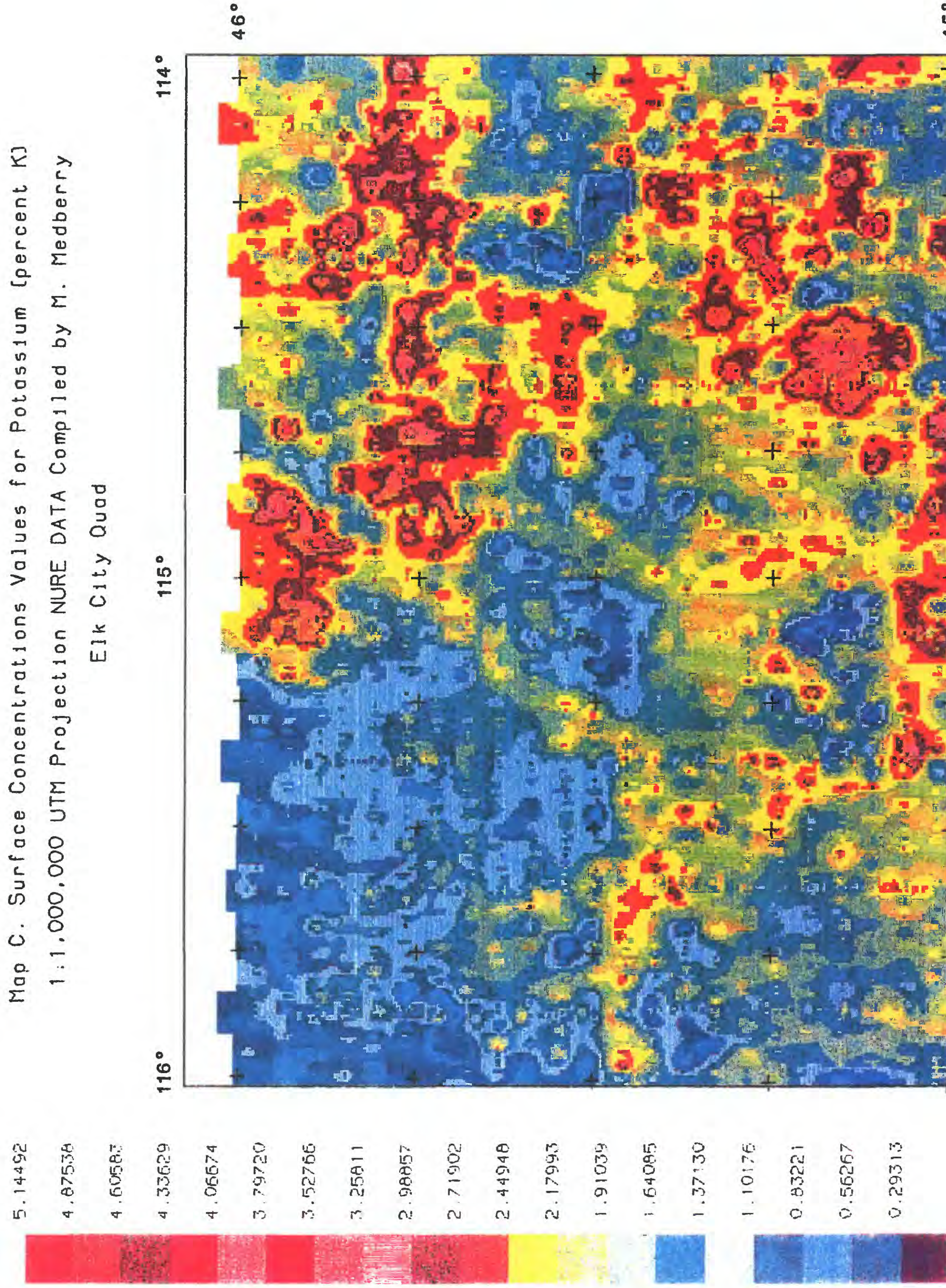

Figure C10. Color contour map showing surface concentration values for percent potassium. UTM projection, scale 1:1,000,000, NURE data processed and compiled by M. G. Medberry.

at its south contact and tapering to a feather edge at the north contact over a lateral distance of 20 km. This pluton is thus also rather tabular and presumably was emplaced laterally from some source southwest of the pluton beyond the magnetic anomaly gradient.

Anomalies over Eocene Volcanic Rocks

Some small subcircular magnetic highs and lows are associated with the Eocene volcanic rocks along the south edge of the Elk City quadrangle. One large, circular magnetic feature, labeled Ti?, may be the expression of a pluton beneath the volcanics or possibly the expression of a caldera because the closely associated surrounding magnetic low implies that the causative mass is shallow and very thin.

Interpretation of Gamma Ray Spectrometer Survey

A gamma ray spectrometer survey was conducted by Geometrics, Inc. in 1979 using a helicopter along east-west flightlines spaced 5 km apart at an average altitude of 122 m above the ground. The data are published by Geometrics, Inc. (1979) for the Department of Energy under the NURE Program and include magnetic profiles as well as pseudocontour maps of the gamma ray data. For purposes of this report, the digital gamma-ray data for Elk City were accessed from high-density magnetic tapes stored in USGS magnetic tape libraries and element surface distribution maps were prepared. Surface concentration values for uranium (U), thorium (Th), potassium (K), and the ratio values for U/TH, TH/K, and U/K are shown by a rainbow color shade scheme ranging from warm colors for highs to blues for low values (figs. C-8 and C-9). The color composite technique is a method for extracting subtle variations in the radioelement distribution. The gamma-ray spectrometer maps provide a different data base than the geochemistry in the examination of the regional distribution of the three elements and are used to compare their combined distributions with the geologic, geochemical, and geophysical maps.

The three elements (K, Th, U) are clearly very highly correlated with each other, the uranium-rich areas being almost invariably located within larger areas containing above average amounts of potassium and thorium. The major anomalous areas are located in the east half of the Elk City quadrangle and tend to avoid those places underlain by Cretaceous rocks of the Idaho batholith. Correlation with Eocene plutonic rocks is excellent (areas A, B, C, and D, and E, as noted on the potassium-map, fig. C-8) and in the case of area C, the contours seem to form a crude ring correlating with the marginal portions of the pluton. This ring may simply be due to the low topography in the center of the pluton. Area G is located near Eocene plutons (C, D) but over Idaho batholith; perhaps some smaller Eocene plutons have been overlooked in this area. Anomalous areas H, I, J, and K appear to be associated with Eocene volcanic rocks, the extrusive equivalents of the Eocene plutons; elsewhere in Idaho these rocks contain minable amounts of uranium. Some areas of Eocene volcanic rocks, however, do not display anomalous amounts of K, Th, or U. It is also possible that areas J and K contain unmapped areas of Eocene plutonic rocks. Anomalous areas L and M are associated with Proterozoic rocks and appear to form broad belts trending northwest in similar fashion as the magnetic anomalies associated with Proterozoic rocks in this location.

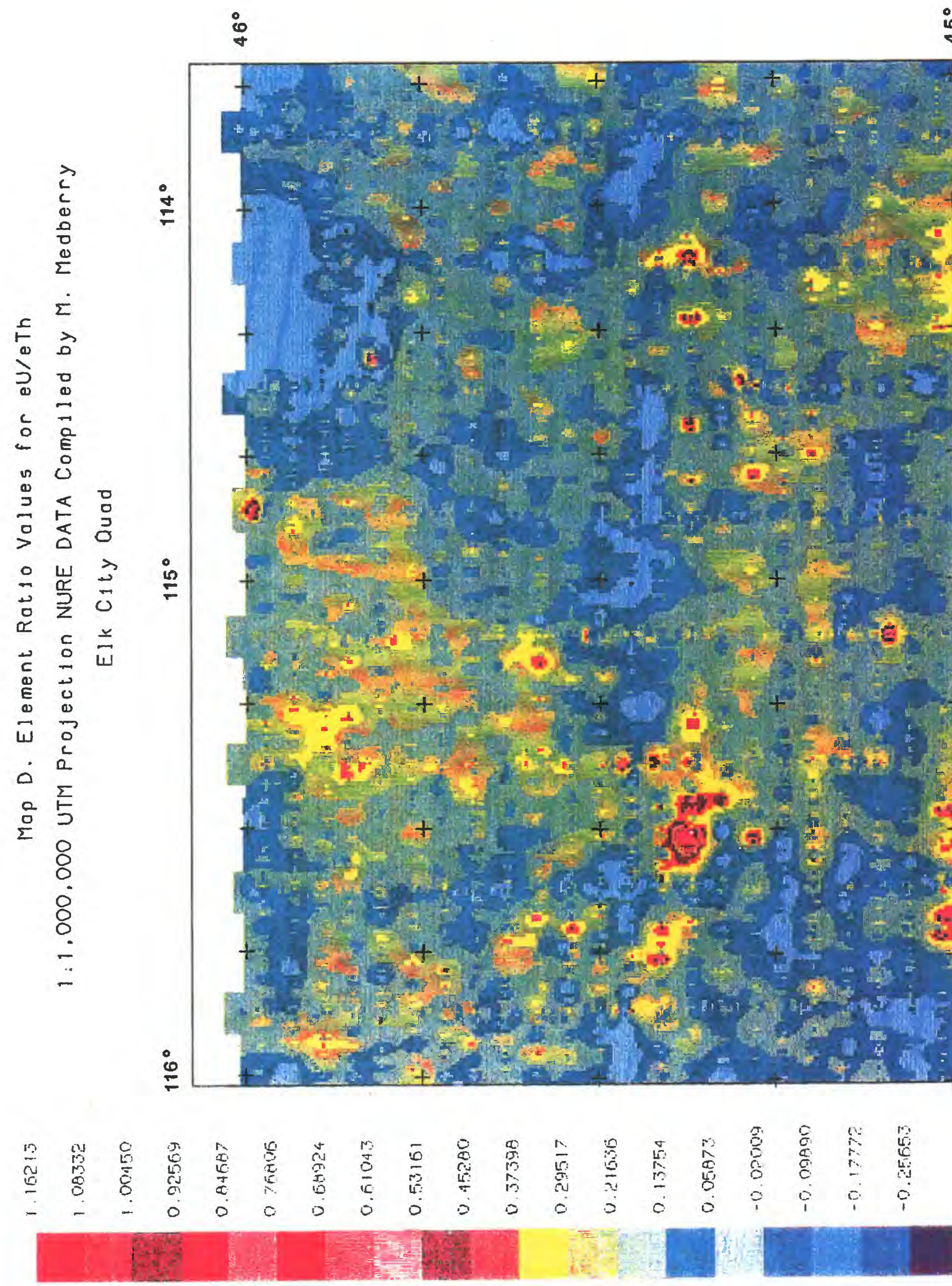

Figure C11. Color contour map showing element ratios for eU/eTh in the Elk City 1°x2° quadrangle. UTM projection, scale 1:1,000,000, NURE data processed and compiled by M. G. Medberry.

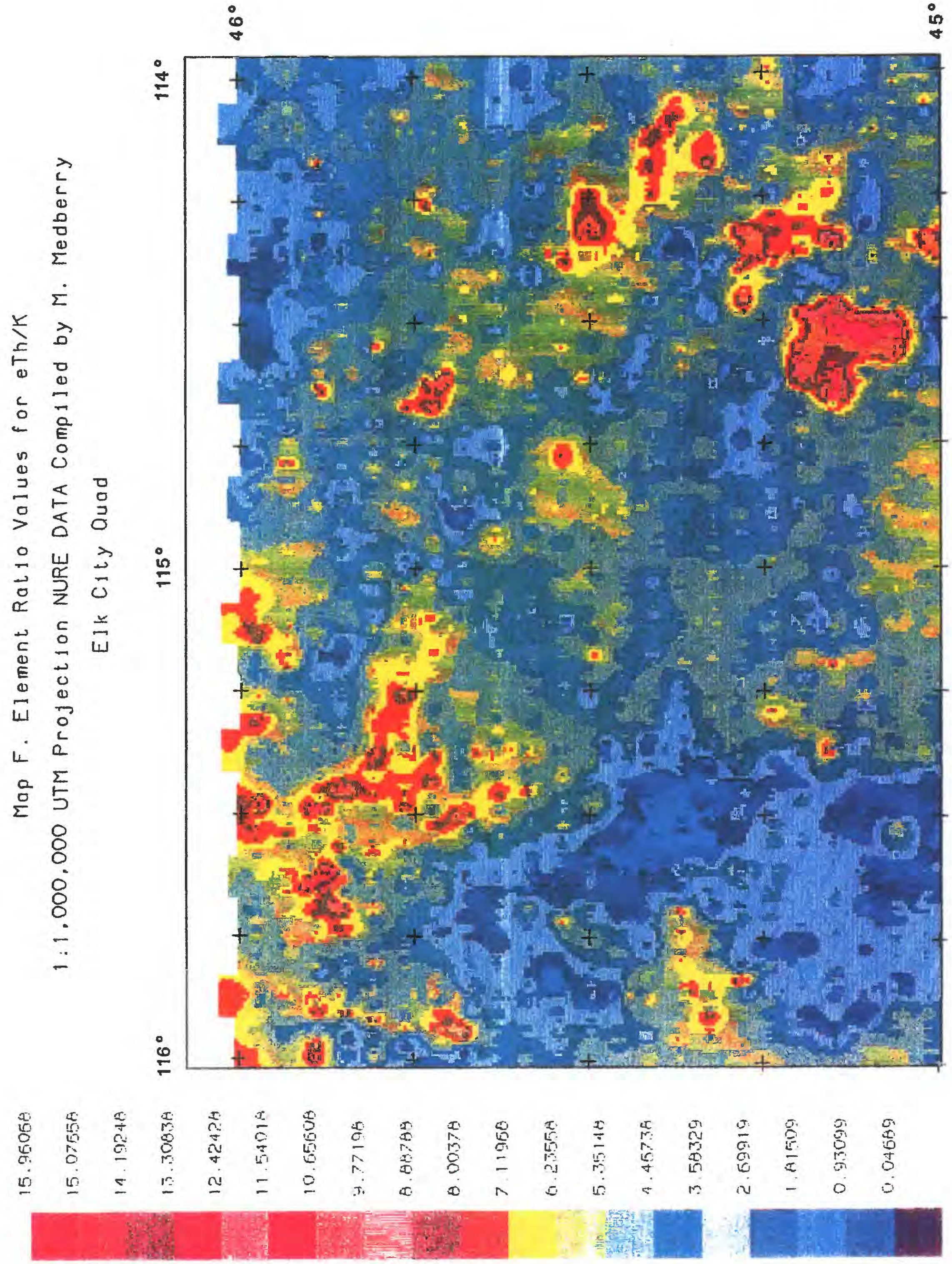

Figure C12. Color contour map showing element ratios for eTh/K. UTM projection, scale 1:1,000,000, NURE data processed and compiled by M. G. Medberry.

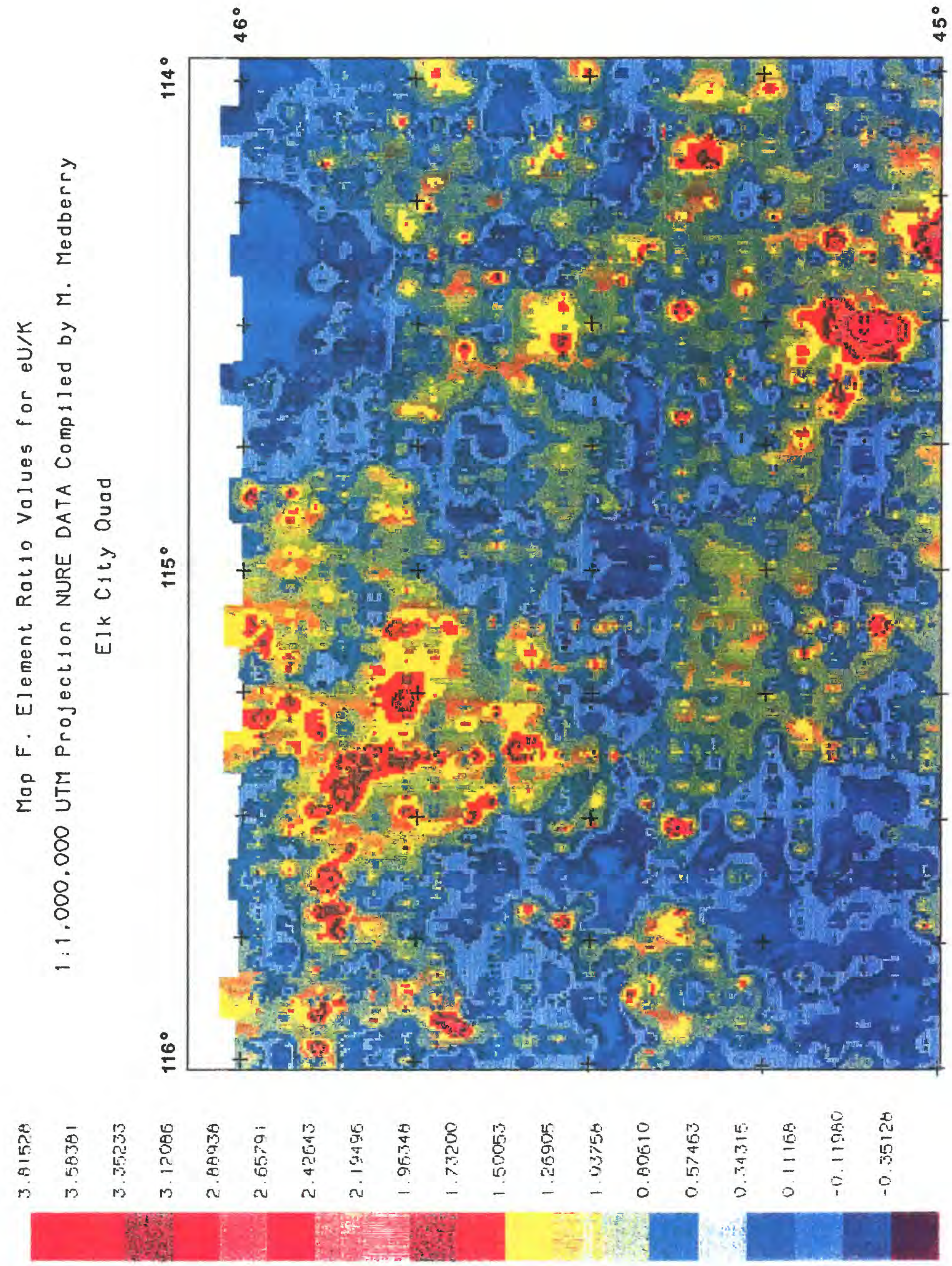

Figure C13. Color contour map showing element ratios for eU/K. UTM projection, scale 1:1,000,000, NURE data processed and compiled by M. G. Medberry.

SECTION D

REMOTE SENSING

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Linear Features Analysis

Introduction

To map linear features in the Elk City Idaho-Montana quadrangle, we acquired a color mosaic of Landsat data from D. Sawatsky and S. Simpson of the U.S. Geological Survey (USGS), Denver, Colorado. The mosaic was digitally prepared from four Multispectral Scanner (MSS) scenes (see fig. D1) and photographically reproduced at 1:1,000,000 scale. The print used included MSS bands 7, 5, and 4 represented as red, green, and blue, respectively, and is commonly referred to as a color-infrared or false-color composite. Linear features were visually identified on the composite and traced on a transparent overlay. Typically, linear features were drawn between areas of sharp tonal differences or along linear segments of drainages. Linear features may include geological/structural elements such as contacts, faults, or dikes. The orientation and density of linear features may relate to specific mineral occurrences (e.g. vein deposits) and to terrains with similar histories. This information can be used to delineate target areas for exploration and assessment work, as demonstrated by linear feature studies elsewhere in Montana (Ehmann, 1985; Rowan, Trautwein, and Purdy, in preparation).

Scene I.D.	Date	Path/Row
1793-17522	9/24/74	45/27
1793-17525	9/24/74	45/28
1792-17464	9/23/73	44/27
1072-17574	10/03/72	44/28

Figure D1. Landsat scene identification number, date of acquisition, and path and row reference numbers for data used in mosaic.

Limitations

There are a number of data limitations in this preliminary study of linear features in the Elk City quadrangle. Firstly, the MSS data used has a spatial resolution of 80 m which results in over-representing longer features on the map at the expense of any shorter features. Secondly, Landsat data is acquired with sun illumination from the southeast. This illumination will tend to enhance recognition of northeast-trending linear features and suppress northwest-trending features. Radar data acquired from other illumination directions and combined with Landsat data would minimize this problem. Radar data would also improve resolution (SLAR data is approximately 10 m). Thirdly, the scale used for mapping in this study (1:1,000,000) was probably too small, again favoring recognition of longer features compared to shorter ones. A more appropriate scale would be 1:250,000 or 1:100,000, especially if using TM and radar data.

Analysis

In order to perform the analysis, the linear features were digitized at 1:250,000 scale and processed using LINANL software developed at the U.S. Geological Survey by Sawatzky and Raines (1981). The linear features were first registered to a standard UTM grid (fig. D2). Note that there are two areas of no data where the mosaic ended along the southern edge of the quadrangle. Linear features are, for the most part, evenly distributed over the map area despite

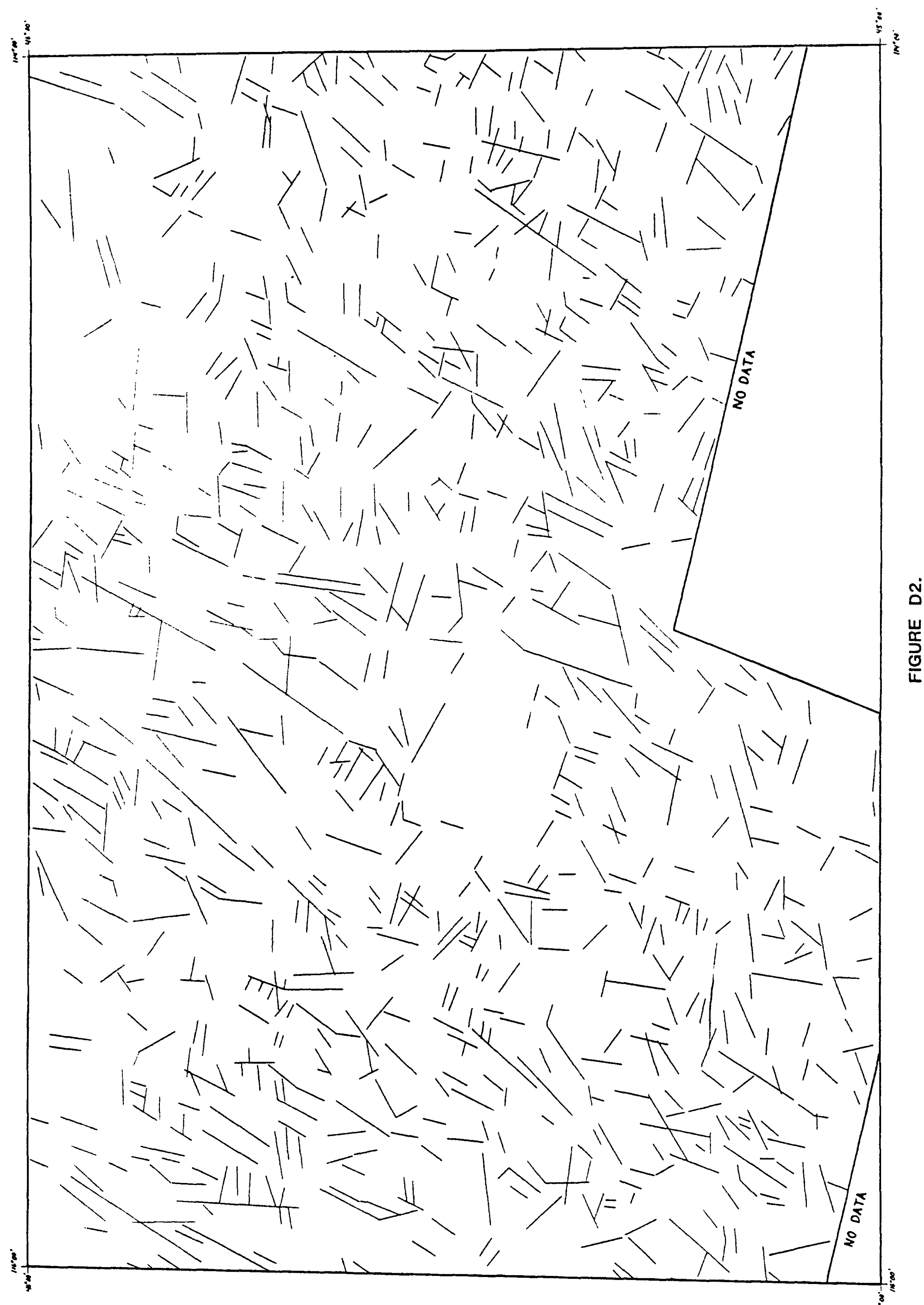

Figure D2.

a variety of geologic terrains (see geologic map, plate A). One conspicuous exception is a 30 km x 20 km area without mapped linear features centered around the Meadow of Doubt, an elevated plateau underlain by rocks of the Late Cretaceous Idaho batholith. Within the quadrangle, linear features do not correspond well to mapped faults. Most of the longer linear features trend northeast, cutting across geologic units. A 20-km-long feature is mapped along the west side of Parachute Ridge and 15-km-long features occur along Bargamin Creek, Whimstick Creek, and through Dutcher Mountain north of the Salmon River. One long north-trending feature extends 15 km along Johns Creek in the northwest corner of the quadrangle.

In order to assess the spatial distribution of linear features in more detail, we constructed a contour plot to show the relative density of linear features (fig. D3). A high density may be associated with variations in lithology, or an abundance of faults, fractures, and/or drainages. Particularly high density values (>50 linear elements/grid cell) occur in 13 areas, five of which are spatially coincident with mines and prospects (Mitchell and others, 1981). Of these five, one density high overlies a cluster of Au, Cu, and Pb mines a few kilometers south of Orogrande. Another lies between Dutcher and Ulysses Mountains, including monazite mines worked for rare earth elements. The other areas of high linear feature density should be evaluated by other geologic, geochemical, and geophysical techniques for similarities to these mining areas.

We also conducted an analysis of trends of the linear features. A strike-frequency plot of the data indicated that there were no azimuth ranges with a particularly high frequency of occurrence. For purposes of discussion, therefore, we arbitrarily divided the data into four major compass directions and set an azimuth range for each. For a reference point, north was assigned values of 0° and 360°. North trends were defined as lines with azimuths from 330° to 30°. Northeast trends were defined for lines from 30° to 60°. East-west trends were defined from 60° to 120°, whereas northwest trends were defined from 120° to 150°.

After each trend was separated, it was contoured using the LINANL software. For each plot, a contour level was chosen to delineate areas of high density (fig. D4, D5, D6, and D7). The high density areas were evaluated for patterns within each trend and for relationships with other trends. For example, there appears to be an alignment of several high density areas of northeast trends in the western part of the quadrangle (fig. D5). Significance was also attached to map areas dominated by only one trend, such as the area around Pyramid Mountain where a high density of only north-trending features occur (fig. D4). Areas such as the southwest quarter of the quadrangle where high density areas of several trends overlap are also apparent.

Our interpretation of these patterns led to a map of regional-scale trends which has been separated into two maps for the sake of clarity (plates D1 and D2). Parts of each regional-scale trend are labelled based on geographic or demographic features they include. Several relationships between the trends can be seen. Two zones of northeast-trending features (Red River Hot Springs and Concord-Warren) are interrupted by a band of northwest-trending features (Dixie) (fig. D8), suggesting different terrains. North-south trends near Pyramid Mountain (fig. D9) also truncate the northeast trends of the Red River Hot Springs area. A band of east-west trends can be traced across the entire quadrangle, a distance of 150 km (fig. D9).

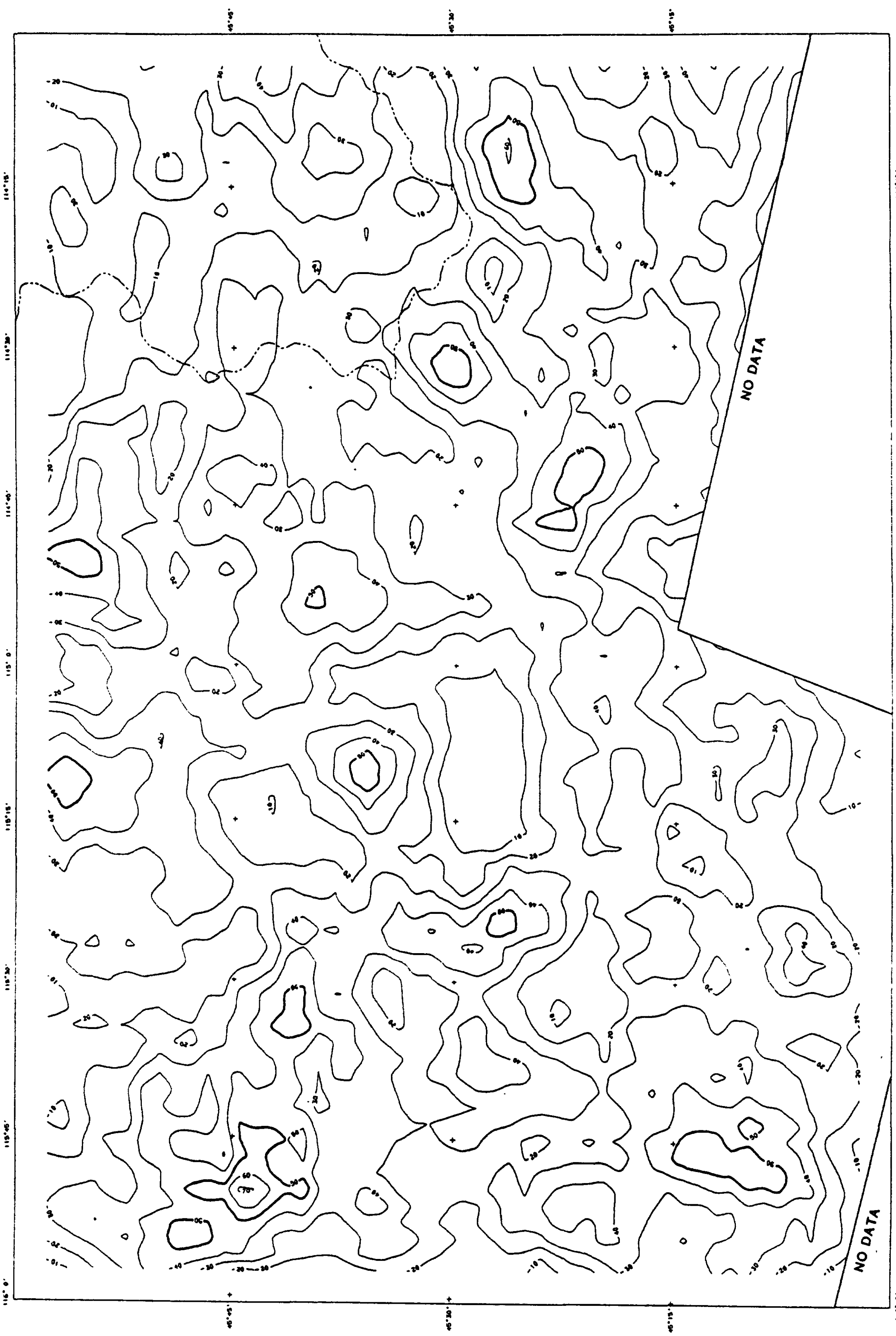

FIGURE D3.

ALL TRENDS
ID1221, DCVAL=10
ELK CITY 1 X 2 QUADRANGLE
MSS CIR LINEAR FEATURES

Figure D3

FIGURE D4.

NORTH TRENDS, IDI 1,4,1
ELK CITY 1 X 2 QUADRANGLE

Figure D4

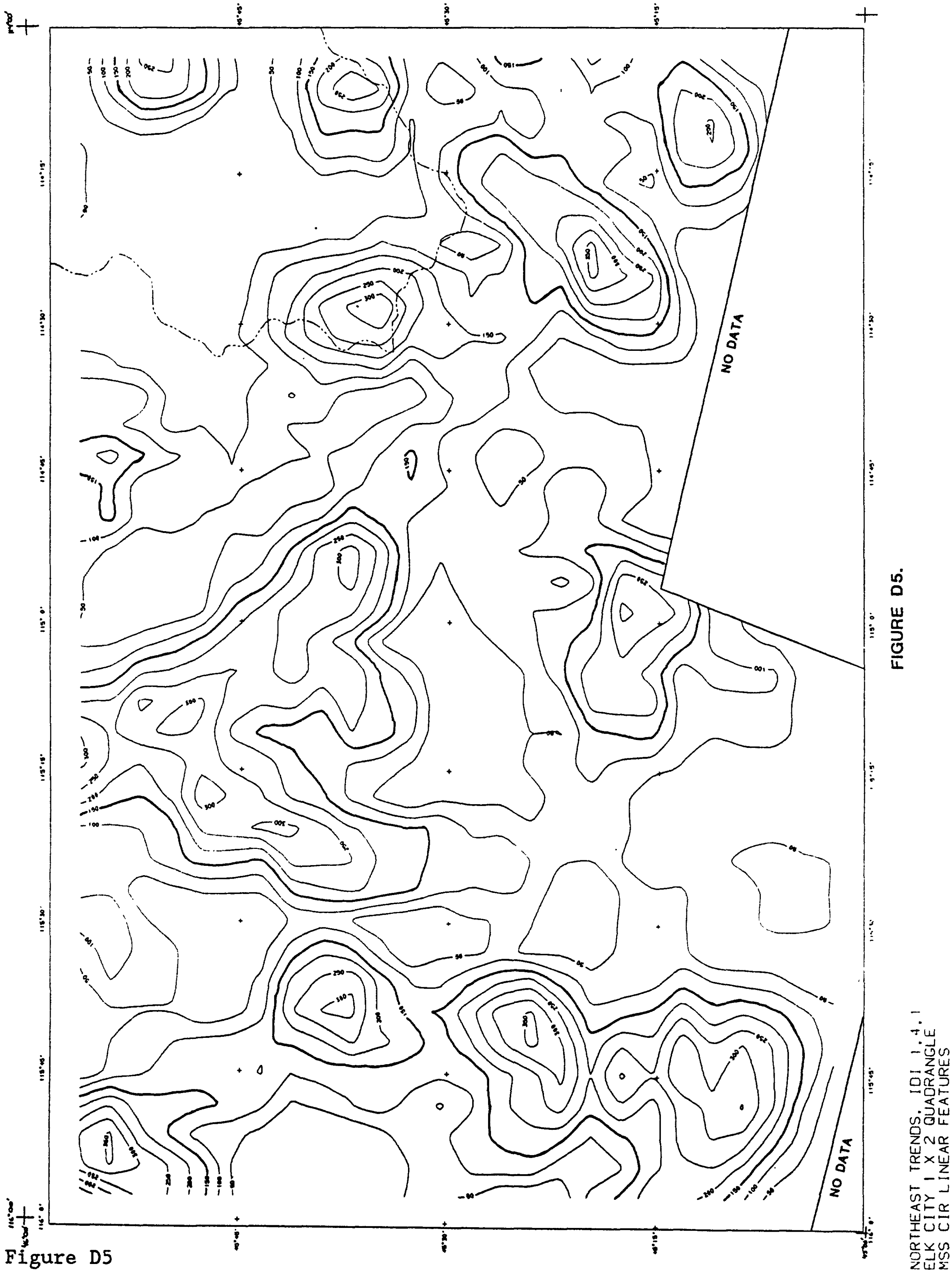
FIGURE D5.
NORTHEAST TRENDS, IDI 1.4.1
ELK CITY 1 X 2 QUADRANGLE
MSS CIR LINEAR FEATURES
NO DATA
NO DATA

Figure D5

FIGURE D6.

EAST-WEST TRENDS, IDI 1.4.1
ELK CITY 1 X 2 QUADRANGLE

Figure D6

FIGURE D7.

NORTHWEST TRENDS, IDI 1.6.1
ELK CITY 1 X 2 QUADRANGLE
MSS CIR LINEAR FEATURES

Figure D7

The significance of these trends depends on integrating them with other geologic data. Our focus was on known mines and prospects, as this data was readily available. Specifically, we have considered deposits of gold, lead/zinc, copper, and cobalt from maps compiled using MRDS files (see Mineral Resources, section E; plates E-1-a, E-1-c, E-1-d, and E-1-e), as these commodities can geologically relate to structural features that we may have mapped. We suggest that the specific areas described below are good candidates for future study using other techniques. We will also consider the trends in terms of their relationship to the permissible tract maps for polymetallic veins, stratiform deposits, skarns, and volcanic-hosted deposits (figs. E1, E2, and E3).

Gold. Three groups of trends have some spatial association with known gold lodes: east-west, northeast, and northwest. We consider a linear feature to be associated with a prospect if it directly overlies the prospect, or is within the estimated error of mapping (0.5 km). The east-west trends are associated with 18 known prospects, at least four of which are known to have some production. The associations occur within the Marble Point-Moose Butte and Big Creek/Edwardsburg areas (plate D2). The producing prospects are (with MRDS record number in parentheses): Coeur D'Alene Mine (W015122), Lone Pine Mine (W015088), Butte and Orogrande Mines (W015134), and Snowbird Mine (W014895), with unknown production from the Petsite Lode (D000483). Northeast trends are associated with 23 known prospects, all in the Concord-Warren area. Five of these are producing mines: American Eagle Mine (W015128), Golden Anchor Mine (W014957), Harris-Holte Mine (W014959), Delaware Mine (W015002), and Knott Mine (W015004). Northwest trends are associated with four deposits and two producing mines within the Dixie Area. The producing mines are Robinson Dike Mine (W015174) and Dixie Comstock (W014948).

Lead/zinc. Three trends are associated with known lead/zinc deposits: east-west, northeast, and northwest. East-west trends intersect 10 prospects and at least four producing mines in the Marble Point-Moose Butte and Big Creek/Edwardsburg areas. The producing mines are Lone Pine Mine (W015088), Coeur D'Alene Mine (W015122), Snowbird Mine (W014895), Red Bluff Mine (W014898), and possibly the Petsite Lode (production unknown, D000483). Northeast trends in the Concord-Warren area are associated with 10 prospects and four producing mines: American Eagle Mine (W015128), Golden Anchor Mine (W014957), Monolith Group (W014859) and Harris-Holte (W014959). Northwest trends are associated with three deposits in the Dixie Area, including two producing mines: Dixie Comstock (W014948) and Skylark Mine (W015164).

Copper. Copper prospects are intersected by three trends (east-west, northeast, and northwest), although east-west trends dominate in the Big Creek/Edwardsburg area. Among the Big Creek/Edwardsburg and Marble Point-Moose Butte areas there are associations with 20 copper prospects. Four of these have produced: Coeur D'Alene Mine (W015122), Butte and Orogrande Mine (W015134), Snowbird Mine (W014895), and Red Bluff Mine (W014898). Production is unknown from the Petsite Lode (D000483) in the Marble Point-Moose Butte area. Northeast trends are associated with 10 prospects and four producing mines. In the Red River Hot Springs area four prospects and one mine (American Eagle, W015128) overlie linear features. The remainder are in the Concord-Warren area, including Harris-Holte (W014959), Golden Anchor Mine (W014957), and Orogrande District (D001479). There are two associations with northwest trends, both in the Dixie Area. The mine with production is Skylark Mine (W015164).

Cobalt. East-west trends intersect two cobalt occurrences in the Big Creek/Edwardsburg area; neither has recorded production.

Tract maps. Our regional-scale trends were compared to preliminary tract maps of permissible areas for polymetallic veins, stratiform deposits and skarns, and volcanic-hosted deposits (figs. E1, E2, and E3). There is good correspondence of our mapped areas with favored areas for Au-Ag polymetallic veins and stratiform deposits including Co and Cu in Middle Proterozoic rocks. Only minor associations with skarn and volcanic-hosted deposit models were observed.

Polymetallic veins. Tract GP-1 (fig. E1) is striking in that it includes many of the areas defined by our regional trends of linear features. The GP-1 area includes almost all of the east-west trends of the Big Creek-Edwardsburg area and most of the east-west trends of the Marble Point-Moose Butte area. GP-1 also includes all of the northeast trends of the Concord-Warren area, as well as half the northeast trends of the Red River Hot Springs area. Most of the northwest trends of the Dixie area are also included. GP-2 has less correspondence to our trends, including only some of the north trends of the Pyramid Mountain area and a few northwest trends of the Boulder Point area. Tract GP-3 has a strong association with almost all the northeast trends defined in the Shoup area.

Stratiform deposits. The most apparent correlation of linear trends to the stratiform deposit model occurs in tract ST-1 where most of the east-west trends in the Marble Point-Moose Butte area occur (figs. D6 and E2). East-west trends are also associated with tracts ST-2 (Red River Hot Springs area) and ST-3 (Big Creek-Edwardsburg area) as well as skarn tract SK-2 (Big Creek-Edwardsburg area).

Volcanic hosted deposits. The major regional trends of linear features do not spatially correspond to any of the tracts developed by the model based on deposits hosted in Challis Volcanics (fig. E3).

Conclusions

Linear features mapped in this study, interpreted on a regional scale, have good spatial correspondence to known deposits and suggest several key areas for future assessment work. Thirteen zones of anomalously high linear feature density (fig. D3) are noted. Four areas defined by regional patterns of linear features are considered targets for gold, lead, zinc, and copper deposits (plates D1 and D2): Marble Point-Moose Butte, Big Creek-Edwardsburg, Concord-Warren, and Dixie. In addition, the Red River Hot Springs area is considered an appropriate target for copper exploration. Linear features mapped in this quadrangle are generally not associated with cobalt deposits, except in the Big Creek-Edwardsburg area. Regional trends of linear features coincide especially well with certain tracts (see Resource Assessment, section E). Northeast trends spatially correspond to tracts GP-1 and GP-3 in the Au-Ag polymetallic veins model. For stratiform deposits hosted by Belt Supergroup rocks (including Cu and Co), tracts ST-1, ST-2 and ST-3 have significant concentrations of east-west trending linear features. East-west trends are also associated with a skarn tract, SK-2.

Possible Sites of Hydrothermal Alteration

Background

Digital analysis of Landsat Multispectral Scanner (MSS) images has been used for more than a decade to map hydrothermally altered rocks (Rowan and others, 1974). The technique is based on intense Fe^{3+} absorption in the MSS response range due to the presence of ferric-oxide and hydrous-oxide minerals (fig. D8). Selected ratios of MSS channels are combined to form color-ratio composite images in which areas with anomalously high concentrations of these minerals, collectively termed limonite, are displayed in a specified color. Maps of the anomalously limonitic rocks are compiled by delineating the areas displayed in the color-ratio composite image or plotting the picture elements (pixels) directly using the appropriate digital number (DN) ranges.

Extensive field evaluation is needed for distinguishing the limonitic hydrothermally altered rocks from limonitic-weathering unaltered rocks. Also, non-limonitic hydrothermally altered rocks are not detected using color-ratio composite MSS images (Rowan and others, 1977). In sparsely vegetated regions, such as Nevada, large areas of hydrothermally altered rocks have been mapped using this approach (Rowan and Purdy, 1984). In the Dillon, Montana-Idaho and Butte, Montana 1°x2° quadrangles, smaller areas were mapped because of the more extensive vegetation cover.

Landsat Thematic Mapper (TM) images are more useful for mapping hydrothermally altered rocks than MSS images, because TM images have additional spectral channels in the near-infrared wavelength region (fig. D8) and higher spatial resolution (30m vs. 79m). Most hydrothermally altered rocks contain OH-bearing minerals, such as kaolinite, alunite, pyrophyllite, K-mica, and montmorillonite. Molecular vibrations in these minerals cause OH-absorption features in the TM response range, although the fundamental absorption features occur at longer wavelengths (Goetz and others, 1983). The most intense OH-absorption features within the TM response range are centered near 2.20 μm for Al-OH minerals (fig. D8) and 2.35 μm for Mg-OH minerals. Carbonate minerals exhibit an absorption feature in the 2.30 to 2.35 μm region, and zeolites have decreased reflectance in the 2.0 to 2.5 μm region due to H_2O absorption. OH-bearing minerals are also common in certain unaltered rocks and, hence, their reflectance spectra are similar to the hydrothermally altered rock spectra. Discrimination, therefore, requires field evaluation. Field evaluation has not been conducted in this study.

Digital Image Processing

Evaluation of TM imagery for mapping potentially hydrothermally altered rocks in the study area was conducted by processing the appropriate portion of TM scene number 50505-17552, located in the southwestern part of the quadrangle. The Elk City quadrangle is challenging for image processing because of the extensive vegetation cover, high topographic relief, and presence of unaltered OH-bearing rock units (Mitchell and Bennett, 1979). Although outcrops are abundant in the quadrangle, TM measurements of their spectral radiance are uncommon due to abundant vegetation cover. Shadows on north-facing slopes also obscure large areas. In addition, parts of the canyons of the Salmon River and South Fork of the Salmon River are obscured by fog in this image.

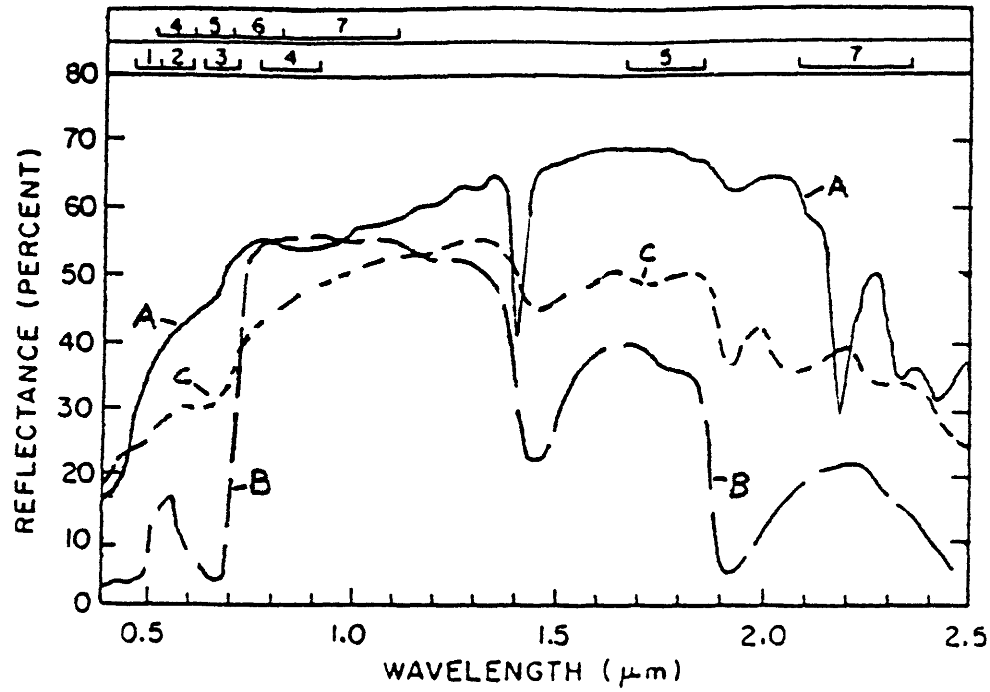

Figure D8. Reflectance spectra of A, limonitic muscovite-bearing hydrothermally altered rock showing Al-OH absorption feature at 2.20 μm and Fe^{3+} absorption features near 0.90 μm and shorter wavelengths; B, pine tree exhibiting chlorophyll absorption at 0.68 μm, high 0.7-1.2 μm reflectance and HOH absorption at 1.4 μm, 1.9 μm and longer wavelengths; and C, lichen showing features of B, but lower intensity. At top, Landsat MSS channels on top line and TM channels on lower line.

The digital processing of TM data was designed to identify pixels that have high TM5/TM7 ratio values because OH absorption causes low TM7 reflectance relative to TM5 (fig. D8). However, vegetation also has moderately high TM5/TM7 ratios owing to water absorption (Knipling, 1969). Therefore, pixels consisting of vegetation were deleted from the image by using its diagnostic spectral reflectance in TM channels 3 and 4 (fig. D8). All pixels with a TM4/TM3 DN larger than 32 were deleted from the image; these pixels consist mainly of vegetation, such as trees, grass, and lichen.

The remaining pixels in the 0-32 DN range were analyzed for OH, CO_3, and H_2O absorption intensity by subdividing the TM5/TM7 DN range. Pixels with DN's larger than 119 were plotted at 1:250,000-scale, and concentrations of these pixels are outlined in the attached map (plate D3). Pixels with slightly lower DN's are commonly coincident with slopes along streams where lichens are extensive on outcrops and talus. Lichen exhibits water absorption and, hence, high TM5/TM7 ratio values (Rowan and others, 1987). Because of their slight chlorophyll absorption in TM3, the low TM4/TM3 DN range (0-32) was selected to exclude these areas.

Results

The concentrations of mapped pixels (plate D3) may be related to OH absorption in hydrothermally altered rocks or in unaltered rocks, such as muscovite-bearing schist, quartzite, and granite. High TM5/TM7 values may also be due to carbonate absorption. Field studies are needed to determine the cause of the high values and to map the hydrothermally altered rocks.

Geobotanical Studies

Spectral reflectance of forest canopy trees was measured in the Idaho Cobalt Belt of the Salmon River Mountains, Idaho (Purdy and others, 1986). Copper and cobalt mineralization are associated with the Middle Proterozoic Yellowjacket Formation. The terrain is rugged, ranging in elevation from 1150 m to 2750 m. The forest is composed of Douglas fir (Pseudotsuga menziesii), lodgepole pine (Pinus contorta), and less abundant Engelmann spruce (Picea engelmannii), and subalpine fir (Abies lasiocarpa). The pine and spruce are found growing in soils with both high and low copper and cobalt values. Subalpine fir is growing only on sites with high to intermediate copper and cobalt values, although it is distributed more widely elsewhere in the northern Rocky Mountains. Douglas fir is more common on sites with low to intermediate copper and cobalt values, although it occurs occasionally at anomalous sites.

Reflectance was measured with a field-portable spectroradiometer. Reflectance in the green through red portion of the spectrum (0.50 to 0.68 μm) tends to be higher for Englemann spruce and lodgepole pine growing in anomalous soils than for these species growing in background soils. In this spectral region, however, the reflectance of Douglas fir growing in anomalous soils is slightly lower than of those growing in soils with background values. The sample size for Douglas fir on anomalous sites, however, is low. The reflectance values of all three species growing in anomalous soils is higher in the spectral region where reflectance is controlled by cell structure (0.76 to 1.10 μm). Reflectance of all three in anomalous soils is lower in the spectral region influenced by water absorption in the vegetation (1.35 to 2.50 μm).

These spectral variations were not detected in enhanced Landsat TM data, probably due to noise from density variations in the tree canopy and the strong influence of topography on the data. That is, minor spectral changes related to mineralization may be overwhelmed by larger changes due to density and topographically controlled vegetation patterns. The spectral variations seen in this study, however, may be within the detection limits of some currently available airborne sensors. With higher spatial and spectral resolution, the problems of thinning canopy and topography can possibly be overcome.

SECTION E

PRELIMINARY MINERAL RESOURCE ASSESSMENT

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Over 1,000 properties have been identified in the Elk City quadrangle (Mitchell and others, 1981; see below). About 75 of the lodes can be considered major (workings greater than 200 ft, ore production greater than 100 short tons (st), or, when appropriate, gold production greater than 100 troy ounces (toz)). Data on these properties and appropriate ones outside the quadrangle, together with geologic, geochemical, and geophysical characteristics of the quadrangle, led to the identification of about 50 deposit types which are present or permissible in the quadrangle (following the general classification scheme of Cox and Singer, 1986). Deposit types are identified and catalogued by (1) the degree of certainty that a given deposit type was present and (2) the level of quantifiable information useful in a mineral resource assessment (table E1). Grade and tonnage models were present for many of the deposit types. Two new grade and tonnage models were developed: one for the numerous gold vein deposits found in the western half of the quadrangle (tentatively identified as Au-Ag polymetallic veins; see below) and one for Blackbird Co-Cu deposits (see below). The gold vein deposits are generally small (less than 100,000 metric tons (mt)) but can be associated with disseminated Au bodies which have been historically recognized (e.g., Oro-grande) and are of current exploration interest (see below). The grade and tonnage model for the Blackbird Co-Cu also includes a discussion which compares its likely contained Co with other Co-bearing deposit types. One possible conclusion is that an undiscovered sediment-hosted Cu deposit can contain several hundred times more Co than a Blackbird Co-Cu deposit. This, of course, needs to be tempered by the fact that Blackbird-type deposits are present in the quadrangle; this is not clearly the case for sediment-hosted Cu.

Most deposits considered are found in one of the following geological settings:

1. Stratiform deposits in rocks of the Belt Supergroup and suspected equivalents in the quadrangle (Blackbird Co-Cu, sedimentary exhalative Zn-Pb, bedded barite, sediment-hosted Cu).
2. Deposits associated with the plutonic rocks (Au-Ag polymetallic veins, simple Sb both vein and disseminated, Cu veins, W skarns).
3. Deposits associated with the Eocene Challis volcanic rocks (sedimentary U, epithermal Au). Mineralization related to Eocene calderas is possible in Tract V-1 and adjacent areas; however, dating suggests deposits in this tract are Cretaceous, not Eocene.
4. Deposits associated with Eocene intrusions in the eastern half of quadrangle (porphyry Cu, Climax Mo).
5. Deposits in a small part of the extreme northwest corner of the quadrangle are hosted by accreted island arc rocks (serpentine asbestos, marble). Also permissive are volcanogenic massive sulfides as deposits of this type are known to occur in these rocks.
6. Surficial deposits including a broad range of fluvial and glacial placer deposits (Au, Ti, REE, garnet), sand and gravel deposits, and peat deposits.
7. Some deposits (U and/or Th veins, carbonatites, pegmatites) are associated with Middle Proterozoic rocks and are of an unknown age. These deposits are not part of the felsic assemblage as defined by stream geochemistry (also see Geochemistry, section B).

Given the possibility of pre-Belt Supergroup rocks in the quadrangle, particularly if marine felsic to mafic volcanics are identified, several additional types of massive sulfide deposits would be permissible (table E1, part C).

The only fuels recognized are adjacent to the quadrangle on the east and consist of lacustrine lignite deposits. Oil and gas deposits are unlikely given the rock types and the level of metamorphism present in much of the quadrangle. About 12 hot springs are listed in the quadrangle.

A total of 13 tracts are delineated; the general criteria for the five recognized tract types are given below:

1. Tracts GP-1 to GP-3 (fig. E1) delineate areas on the presence of two-mica granites together with evidence that exposure is in or near the granite-country rock contact, based on the presence of significant numbers and/or size of roof pendants. Areas with northeast linear trends seem to be particularly useful in target definition.
2. Tracts ST-1 to ST-4 (fig. E2) delineate areas in which bedrock is believed to be part of, or equivalent to, the Belt Supergroup. In some areas the permissible rocks are in roof pendants within the delineated tracts (ST-1, ST-2).
3. Tracts SK-1 and SK-2 (fig. E2) are defined by the presence of calcareous rocks at or near the contact with Late Cretaceous plutonic rocks.
4. Tract IA (fig. E2) delineates an accreted island arc volcanic assemblage.
5. Tracts (V-1 to V-3) (fig. E3) is delineated on the presence of the Challis volcanic rocks. Part of a caldera is suspected to be present in or adjacent to Tract V-1.

Information was insufficient to attempt to make estimates of the number of undiscovered deposits of the types considered in the preassessment.

Table E1. Deposit type known or suspected to occur in the Elk City 1°x2° quadrangle, Idaho, Montana. Table is divided into three parts; part A identifies deposit types known to be in, or adjacent to the quadrangle, and part B identifies deposit types which could occur, but are not known in, or adjacent to the quadrangle, but permissive geology is present. Part C identifies deposit-types, some of which might be present, given the possibility of pre-Belt Supergroup rocks in the quadrangle. Deposit-types identified in this section should be excluded or included during full assessment. Each part is farther broken down into sections based on level of knowledge useful in mineral resource assessment. (Footnotes are at end of table)

PART A: DEPOSIT TYPE KNOWN IN OR ADJACENT TO QUADRANGLE

Deposit-types in this section have (1) grade and tonnage models, and (2) delineated tracts (see figs. 1-3, maps 1-3)

DEPOSIT-TYPE NAME[1]	COX-SINGER NUMBER[2]	NAME OF DEPOSIT(S) OF THIS DEPOSIT TYPE[3]	COMMENTS[4]
W skarn	14a	36 records in MRDS[5] for quadrange are likely W skarn or a related deposit type; includes Antimony Rainbow; Yellow Pine (Challis quadrangle).	These deposits are classified as W skarn but it is controversial, an issue a full assessment will need to address; permissible in tracts SK-1, SK-2, figure E2.
Au-Ag polymetallic veins[6]	22d[7]	American Eagle, Buster, Grome, Hinkson-Bishop, Jumbo-Venture, Little Sheep Eater	Delineation based on presence of two-mica granite and evidence that area is near batholith-country rock contact (e.g. numerous roof pendants); geochemistry useful in target identification (also see); tracts GP-1, GP-2, GP-3, figure E1.
Simple Sb (veins)	27d	Red River Stibnite Wells Prospect; Chalfant Antimony,	Suspected to be part of mineralizing event leading to Au-Ag polymetallic veins; tracts GP-1, GP-2, GP-3, figure E1.
Simple Sb (disseminated)	27e	Mulligan Group	Do.
Polymetallic veins	22c	Copper Glance; Ramshorn, Hall-Interstate (Challis quadrangle)	Do.
Bedded barite	31b	Woods Creek, Barite Prospect (?)	Delineation based on presence of rocks suspected to be Middle Proterozoic tracts ST-1, ST-2, ST-3, ST-4, figure E2.
Blackbird Co-Cu	24d[8]	Blackbird; about 50 records on properties with Co found in MRDS; most in or adjacent to Blackbird district.	Do. also see Lund and others, 1983, for additional details on geochemistry of Yellowjacket Formation; geochemistry suggests two target areas in tract. See map overlay E-1-a.
Sandstone U	30c	--	Occurrences are known at base of Challis volcanics in paleosol in the Challis quadrangle; Tracts V-1, V-2, V-3, figure E3.
Serpentine-hosted asbestos	8d	Blacktail Asbestos prospect	Hosted by serpentine and talc schist, part of island arc; Tracts AI figure E2.
Sado epithermal veins	25d	Sunnyside, Lucky Boy Parker Mt (all in Challis quadrangle)	Tracts V-1 to V-3, figure E3.

Deposits in this section have (1) grade and tonnage model, and (2) lack delineation tracts

Placer Au-PGE	39a	250 records describing properties in MRDS for deposit-type	NURE geochemistry does not delineate gold placers; future Au production by large-volume mining from those worked by small-volume mining can be predicted using method in Bliss and others (1987) and should be made in formal assessment.

Superior	34a	McConn Creek, McComas	--
W veins	15a	Baldy Mountain	--
Cu skarn	18b	Mayflower Group	--
Porphyry Cu-Mo	21a	Bobcat Gulch	Drilling occurred on deposit in eastern part of quadrangle. Geophysics should be useful in delineation.
Upwelling phosphate	34c	Hailley Creek	The SE corner of the quadrangle identified as part of the western phosphate field (U.S. Geological Survey and others, 1964, fig. 35)
Carbonatites	10	Mineral Hill, Lee Buck No. 3 Iron Creek, Woods Creek	Deposit descriptions suggest deposits in quadrangle smaller than used in Cox and Singer (1986); some may be vein deposits--needs to be resolved during assessment.
Climax Mo	16	--	Delineation may be possible using aeromagnetics.
Deposits in this section lack (1) grade and tonnage models but (2) have delineated tracts.			
Marble and limestone	N/A	Switchback marble quarry	Carbonates in island-arc rocks; Tract AI, figure E2.
Pumice, scoria	N/A	--	Challis volcanics; Tracts V-1, V-2, V-3, figure E3.
Deposits in this section lack (1) grade and tonnage models and (2) delineated tracts.			
Cu veins	N/A	Blue Bluff prospect, Copper Cliff, Missouri Creek Group, Wild Horse Copper	Some deposits appear to be part of mineralization system associated with Au-Ag polymetallic veins.
Barite veins	N/A	Several deposits in Missoula Co., MT (not in quadrangle)	Known to occur in Sheep Creek deposits (Heinrich and Levinson, 1961); need more work.
Uranium veins (± thorium)	N/A	Garm-Lamoreaux, Surprise, Moon, Great Western, Salmon River Uranium; Lucky Joe	Some deposits are in carbonatites and may be part of mineralization associated in that deposit type (Cox and Singer, 1986, No. 10)
Th-REE veins (± uranium)	N/A	Sheep Creek, Radiant Group, Lemhi Pass (E of quadrangle)	Do.
Ti-REE (heavy sands) placers (±uranium)	N/A[9]	106 records describe placer properties in quadrangle from MRDS for this deposit type.	--
Fluorspar veins	N/A	Meyers Cove (Challis quadrangle); Crystal Mt.; Big Squaw Creek, Smothers Fluorspar; Fluorite deposit, MT (not in quadrangle)	Significant reserves identified at Big Squaw Creek deposit; volcanics may be key to tract delineation and needs to be examined during full assessment.
Quartz crystals	N/A	Be Van Quartz Crystal prospect	--
Silica	N/A	Deposits near-Salmon, ID (E of quadrangle)	--

Pb-Ag veins	N/A	Ringbone Cayuse; Blue Jay	--
Pegmatites			
with significant U-Th	N/A	Snowdrift Claim;	--
with significant Si	N/A	Jersey Creek	--
with significant mica	N/A	Snowdrift Claim; Glenan prospect	--
with significant Be	N/A	Rainbow Claim; Cathedral Rock-Sula district (NE of quadrangle)	Includes pegmatitic veins and in granite.
Garnet placers	N/A	Thorpe placers, over 20 placer properties identified with garnet as secondary commodity in MRDS	--
Bentonite	N/A	Pits S of Salmon, ID (E of quadrangle)	Thin beds in Kirtley Fm.
Lignite[10]	N/A	Produced in pioneer days in the West Fork of the Bitterroot River area and in the Salmon, ID area (E of quadrangle)	Deposits occur in middle Tertiary lake sediments containing U in upper part.
Peat	N/A	Florence, Newsome, Secesh Basin, Dixie, Elk City Districts.	Reed-sedges and shrub and tree peat in boggy meadows at high altitudes in glaciated areas.
Sand and gravel	N/A	--	Glacial, residual, and fluvial deposits are present.

PART B: DEPOSIT TYPES ARE NOT KNOWN IN OR ADJACENT TO QUADRANGLE BUT PERMISSIVE GEOLOGY IS PRESENT

Deposit-types in this section have (1) grade and tonnage models, and (2) delineated tracts.

DEPOSIT-TYPE NAME	COX-SINGER NUMBER	COMMENTS
Sedimentary exhalative Zn-Pb	31a	Permissible rocks include these suspected to be part of the Belt Supergroup; tracts ST-1 to ST-4, figure E2; Bedded barite deposits are commonly associated and have been identified in quadrangle (i.e. Woods Creek).
Sediment-hosted Cu	30b	Permissible rocks include those suspected to be part of the Belt Supergroup; Tracts ST-1 to ST-4, figure E2; Spar Lake in MT member of deposit type; Tracts ST-1 to ST-4, figure E2.
Hot Springs Au-Ag	25a	Rhyolite domes, etc. in Challis quadrangle and present with epithermal vein deposits, Tracts CV-1 to CV-3, figure E3, appropriate.

Deposit-types in this section lack (1) grade and tonnage models but (2) have delineated tracts.

Zeolites	--	Possibly present in Columbia River Basalt Group in western part, Tract IA, figure E2.

Deposit-types in this section lack (1) grade and tonnage models and (2) delineated tracts.

Gold on flat faults	37b	Core complex present in northeast section of quadrangle; gold geochemistry along mylonite zone (see area Au-7, Map B1).
Stratabound Cu-Au	--	--

PART C: DEPOSIT TYPES WHOSE PRESENCE HIGHLY UNCERTAIN

DEPOSIT-TYPE NAME	COX-SINGER NUMBER	COMMENTS
Kuroko massive sulfides	28a	Dependent on recognition of marine felsic to mafic extrusive rocks, particularly in Tract ST-1, figure E2.
Cyprus massive sulfides[11]	24a	Rocks associated with island arc volcanic rocks in Tract ST-1, figure E2.
Besshi massive sulfides[11]	24b	Do.
Volcanogenic Mn[11]	24c	Do.
Podiform chromite	8a	Possible ultramafic assemblage in accreted terranes, possible in Tract IA, figure E2.
Pegmatites with significant feldspar	--	Pegmatites have been identified in and adjacent to the quadrangle but not described as containing significant feldspars.
Cu skarns	18b	Found in association with porphyry Cu; possible tracts SK-1, SK-2 figure E2, and tract developed for porphyry Cu.
Zn-Pb skarns	18c	Associated with Cu skarns, tracts SK-1, SK-2, figure E2, and tract developed for Cu skarn.
Au skarns	--	Do.
Talc	--	Associated with serpentine-hosted asbestos, possibly tract AI in figure E2.

[1]Names are from Cox and Singer, 1986, when available.
[2]Also from Cox and Singer, 1986.
[3]Deposits outside the Elk City quadrangle are identified.
[4]Delineation criteria, including geological, geochemical, and geophysical evidence; also may give resource assessment issues; also suggested work to be addressed in full assessment as well as opportunities for other research.
[5]MRDS--Mineral Resources Data System, a computerized database on mineral deposits, prospects, and occurrences.
[6]Not in Cox and Singer, but suspected to be a Au-Ag end member of the polymetallic vein (Cox and Singer, 1986, No. 22c), grade and tonnage model developed from deposits in this quadrangle, a disseminated subtype is associated (see below).
[7]Number not in Cox and Singer (1986) but consistent with deposit types herein.
[8]Descriptive model in Cox and Singer (1986) provisional grade and tonnage model developed for preassessment (see below).
[9]Descriptive and grade-tonnage models are present for Shoreline placer Ti (Cox and Singer, 1986, No. 39c) but likely not applicable to fluvial deposits.
[10]Oil and gas are not likely present based on currently recognized genetic models; see below for hot springs.
[11]These deposit types were identified as potentially associated with Blackbird Co-Cu (Cox and Singer, 1986) but are not in the same environment in this quadrangle.

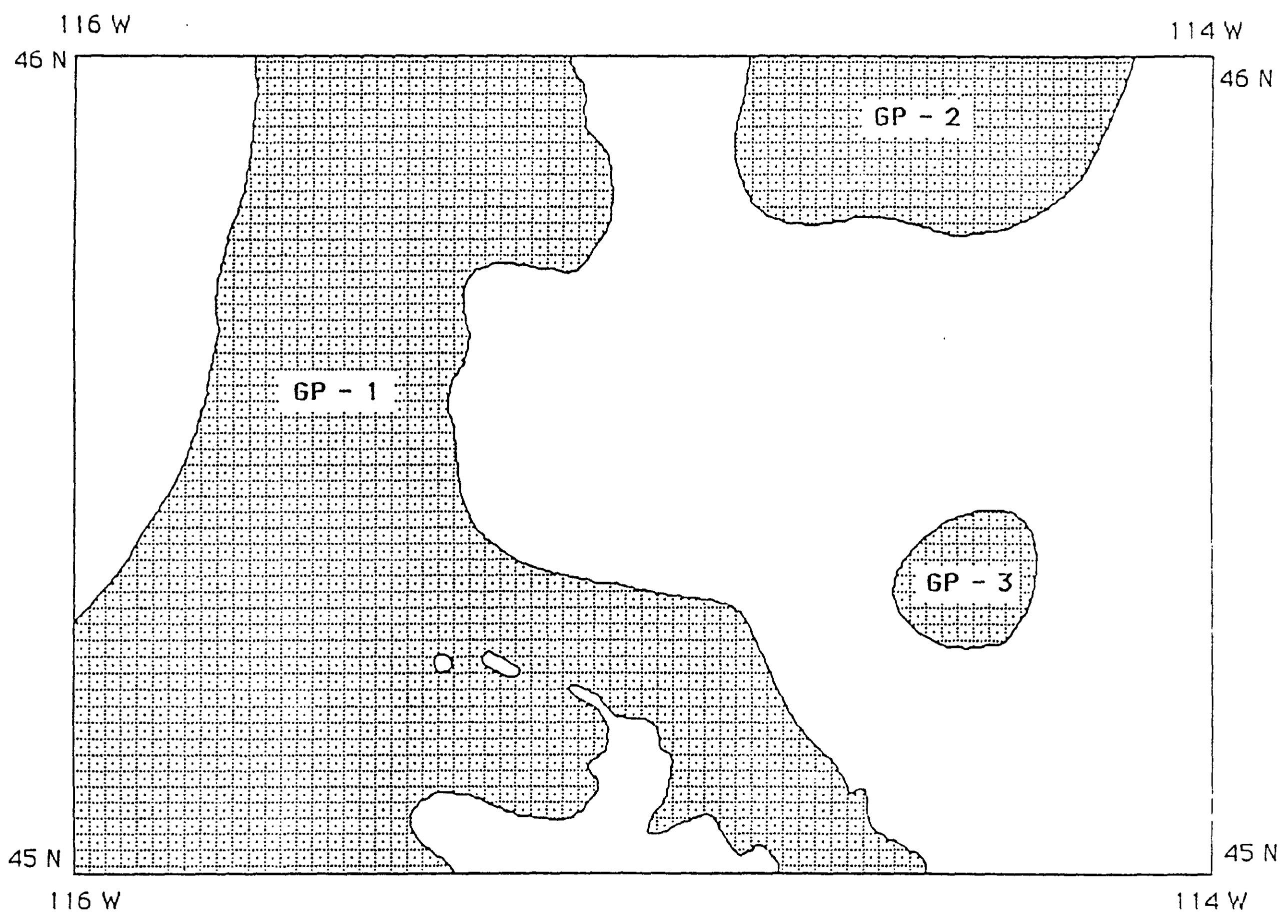

Figure E1. Map showing tracts (GP-1 to GP-3) that are primarily of interest for Au-Ag polymetallic veins and related deposit types identified in table E1. Elk City 1°x2° quadrangle, Idaho-Montana, scale approximately 1:1,000,000.

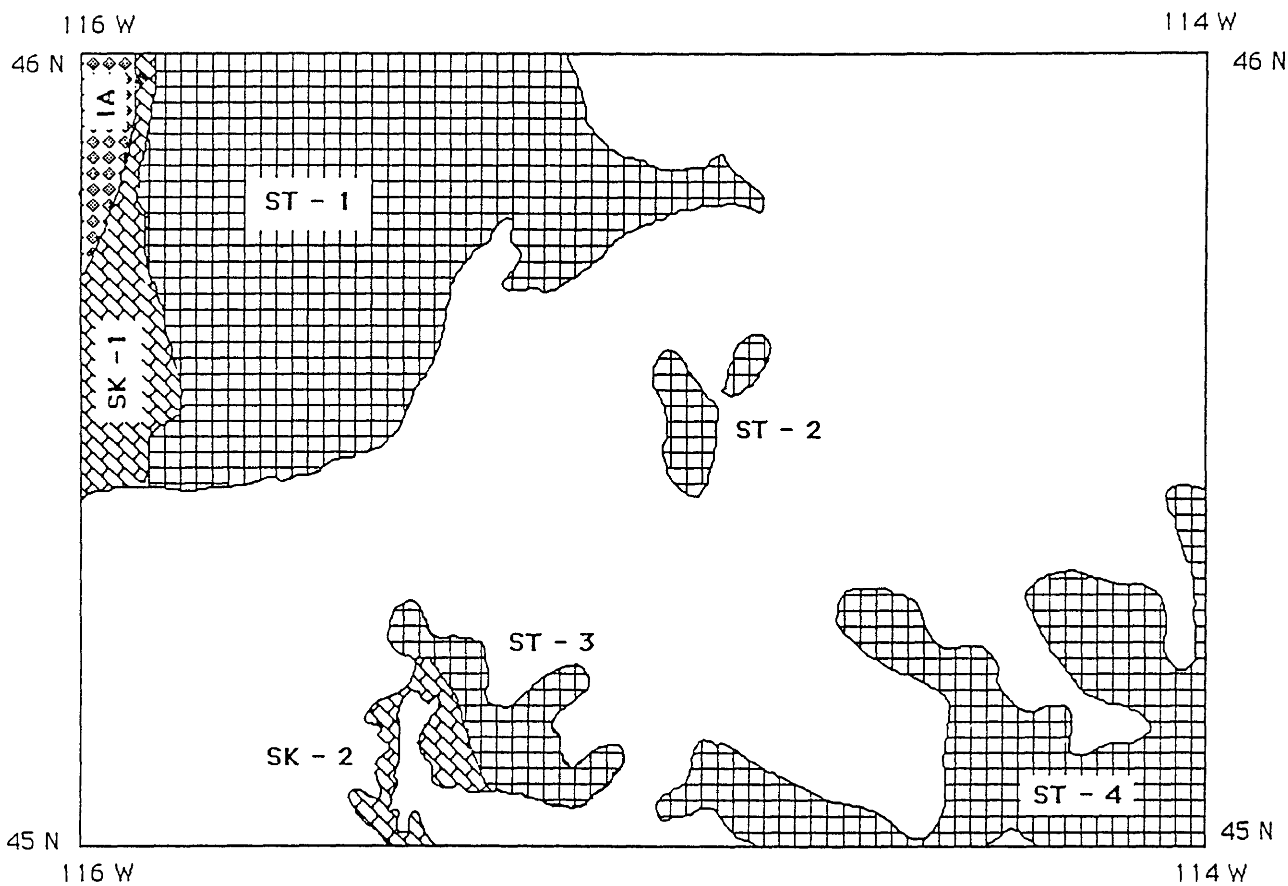

Figure E2. Map showing tracts ST-1 to ST-4 for various stratiform deposits (see text) and tracts SK-1 and SK-2 for W skarns and possibly other skarn types as well. Tract AI is for deposits hosted in island arc accreted rocks. Elk City 1°x2° quadrangle, Idaho-Montana, scale approximately 1:1,000,000.

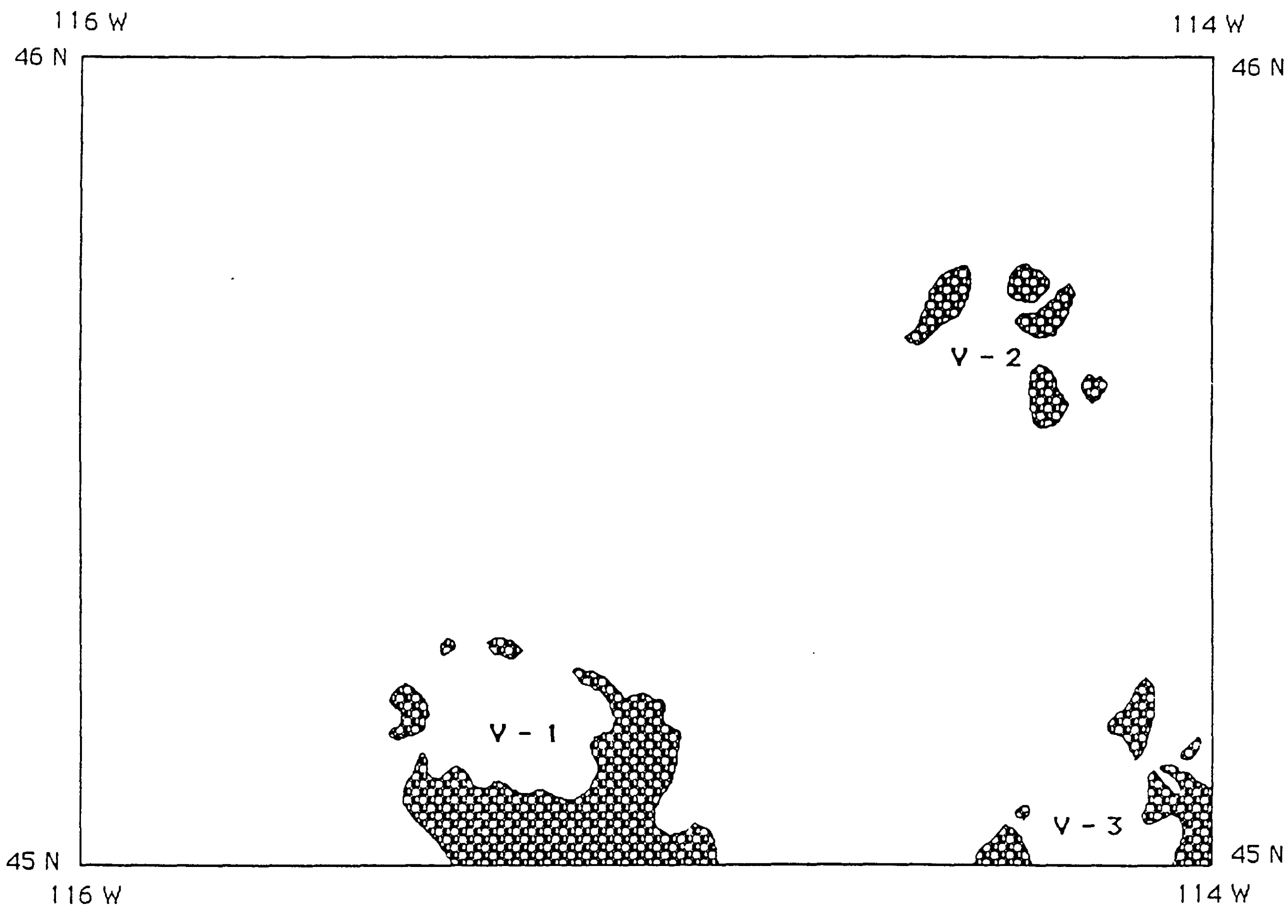

Figure E3. Map showing tracts V-1 to V-3 for epithermal deposits as well as other deposits hosted by the Challis volcanics. Elk City 1°x2° quadrangle, Idaho-Montana, scale approximately 1:1,000,000.

Mineral Occurrences, Prospects, and Mines

Mineral occurrences, prospects, and mines were extracted from the Mineral Resources Data System (MRDS) and plotted by selected commodities on a series of mylar overlays (see plates E-1 through E-5). Sites plotted on these overlays have not been checked for locational accuracy or completeness. Some points are for two or more properties. The following commodity-oriented overlays for the Elk City quadrangle are provided:

1. Au-bearing Lodes (± Ag)

A total of about 380 records describing Au (± Ag) properties were identified (plate E-1). Of this number, 78 percent of properties had Au or Ag identified as the primary commodity. In those cases where gold is identified as a secondary commodity, Cu is identified as the primary commodity in 40 percent of the cases. This group, in which Cu is primary, is made up of properties where mineralization is (a) Au-Ag polymetallic deposits where Cu is significant (see fig. E7), (b) occurrences of Cu associated with Au with and without Au-Ag polymetallic deposits, (c) Blackbird Co-Cu deposits in which about a third of the deposits have reported Au (see fig. E14; including 8 properties where Co is identified as the primary commodity), and (d) Cu vein deposits with Au. Au as a secondary commodity was also found with properties where the primary commodity was identified as Pb, Sb (vein and disseminated types), W, and Zn among others.

2. Au-bearing placers

A total of about 260 records describe Au placers (plate E-2); of this number, only 3 percent had some other commodity besides Au identified as primary. In the case of the Gold Queen placer, production was identified as medium (Au between 25 and 5,000 metric tons (mt)); all other properties had small (less than 25 mt Au), unknown, or no production. Secondary commodities were commonly found in these placer properties: about 40 percent contain Ti (± Fe), 14 percent REE (includes Zn, Nb, monazite), and 10 percent garnet. Other commodities noted include Ag, Pb, Zn, PGE (Elkhorn Bar), Sn, U, and Hg.

3. Cu-bearing lodes

A total of about 240 records describe properties with lode Cu (plate E-3). Those with Cu as the primary commodity had small (less than 50,000 mt Cu), unknown, or no production. Most of the Cu properties are associated with Au lodes (see section on Au-Ag polymetallic veins, Blackbird Co-Cu deposits or associated occurrences; see section on Blackbird Co-Cu deposits below) or Cu vein deposits.

4. Co-bearing lodes

A total of 51 records describe properties with Co as a commodity (plate E-4). Of this number, over 20 percent describe properties with some production. Most of the properties are deposits or associated occurrences of the Blackbird Co-Cu deposit type (see below). Some occurrences may also be related to sediment-hosted Cu deposits of which 18 percent of those in the grade and tonnage model have reported Co grades (see table E4).

5. Lead- and Zinc-bearing lodes

A total of 150 records describe properties with Pb and/or Zn as a commodity (plate E-5). Of this number, 14 properties had Pb and/or Zn identified as the primary commodity. In all but one case, Pb was identified as "superior to" Zn, although this may be due to standard usage rather then actual superiority in abundance. Production from these properties was either small or absent. Pb and Zn were most commonly found as a secondary commodity to Au, usually as part of the Au-Ag polymetallic deposits or occurrences around them (see figs. E8 and E9). Pb or Zn were also reported as a secondary commodity to Ag, W, Cu, Mo, F, and Hg on a few properties.

Provisional Grade and Tonnage Model of Au-Ag Polymetallic Veins, Model 22d

The model developed for Au-Ag polymetallic veins is based on properties from the areas delineated as permissible for this deposit-type (fig. El, Tracts GP-1 to GP-3) in the Elk City quadrangle. Both grade and tonnage data were estimated from properties with significant workings ($\geq$200 ft) and deposits are defined as all workings within 1 km of each other. Lead grade is significantly correlated with zinc grade (r = 97, n= 4). Table E2 summarizes values found on figures E4 to E7. A detailed descriptive model is not available but a general discussion of the genetic model is given in Lund and others (1986). A disseminated subtype is possibly present and discussed below.

Provisional Grade and Tonnage Model of Blackbird Co-Cu, Model 24d

The Co-Cu deposits of the Blackbird district in the southeast quarter of the Elk City quadrangle represent one of few domestic sources of the strategic and critical mineral Co. How Blackbird-type deposits are classified has important ramifications in terms of evaluating the amount of undiscovered Co in the quadrangle. Cox and Singer (1986) classified these deposits as a separate deposit type, called Blackbird Co-Cu, with its own descriptive model by Earhart (1986). The deposit types with Co grades that they include among their deposit models are komatiitic Ni-Cu, dunitic Ni-Cu, synorogenic-synvolcanic Ni-Cu, sediment-hosted Cu, and lateritic Ni. Not included by Cox and Singer (1986) was a grade and tonnage model for Blackbird Co-Cu, nor descriptive and grade-and-tonnage models for alternative types of Co such as hydrothermal (Crockett and others, 1987) or plutonogenic hydrothermal (Smirnov and others, 1983); these additional types include Bou Azzer, Morocco, and deposits in the Timiskaming district, Ontario. Deposits of the Blackbird district have, in the past, been genetically classified as hydrothermal deposits (Anderson, 1947; Roberts, 1953; Purdue, 1975). More recently they have been recognized as synorogenic, stratabound deposits related to mafic tuffs (Nash and Hahn, 1986), although modified slightly by subsequent recrystallization, differentiation, and remobilization (Modreski, 1985).

In order to examine how Blackbird deposits compare as a source of Co relative to other deposits with models, a grade and tonnage model was devised for the preliminary assessment of the Elk City quadrangle. The model developed here is based on properties in and adjacent to the Blackbird district where deposit tonnage is estimated using properties within 1 km of each other. Grade data was from properties with significant workings (total length $\geq$ 200 ft). Failure to handle grade and tonnage data in a consistent fashion and not in accordance with standard grade and tonnage modeling techniques makes this model a crude proxy for a formal assessment. The model is also provincial, which is appropriate to a mineral resource assessment of the Elk City quadrangle, but may not be applicable elsewhere. Table E3 is based on figures E11 to E14.

Table E2. Estimate of the percentage of Au-Ag polymetallic vein deposits that equal or exceed a given grade or tonnage as taken from figures E4 to E7

Variable	Cutoff[1]	Percentage		
		90	50	10
Ore (mt)	10	100	630	16,000
Gold (g/mt)	4	12	25	63
Silver (g/mt)[2]	5.1	-	-	100
Copper (%)[3]	0.0025	-	-	0.15
Lead (%)[3]	0.01	-	-	0.36
Zinc (%)[4]	0.032	-	-	0.13
Gold (kg)	0.6	8.3	63	630

[1]Cutoff is value of variable less than any value used to construct grade and tonnage curves.

[2]At least 35 percent of the deposits contain reported silver.

[3]At least 20 percent of the deposits contain copper and/or lead.

[4]At least 10 percent of the deposits contain reported zinc.

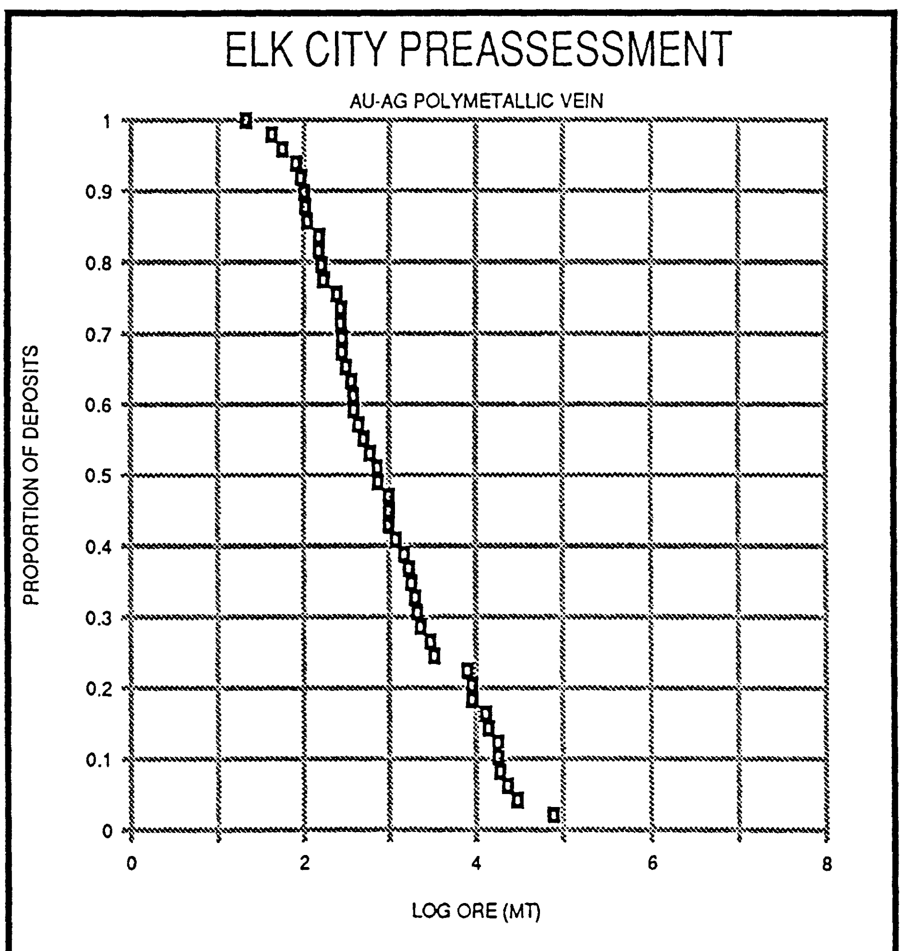

Figure E4. Tonnage of Au-Ag polymetallic vein deposits.

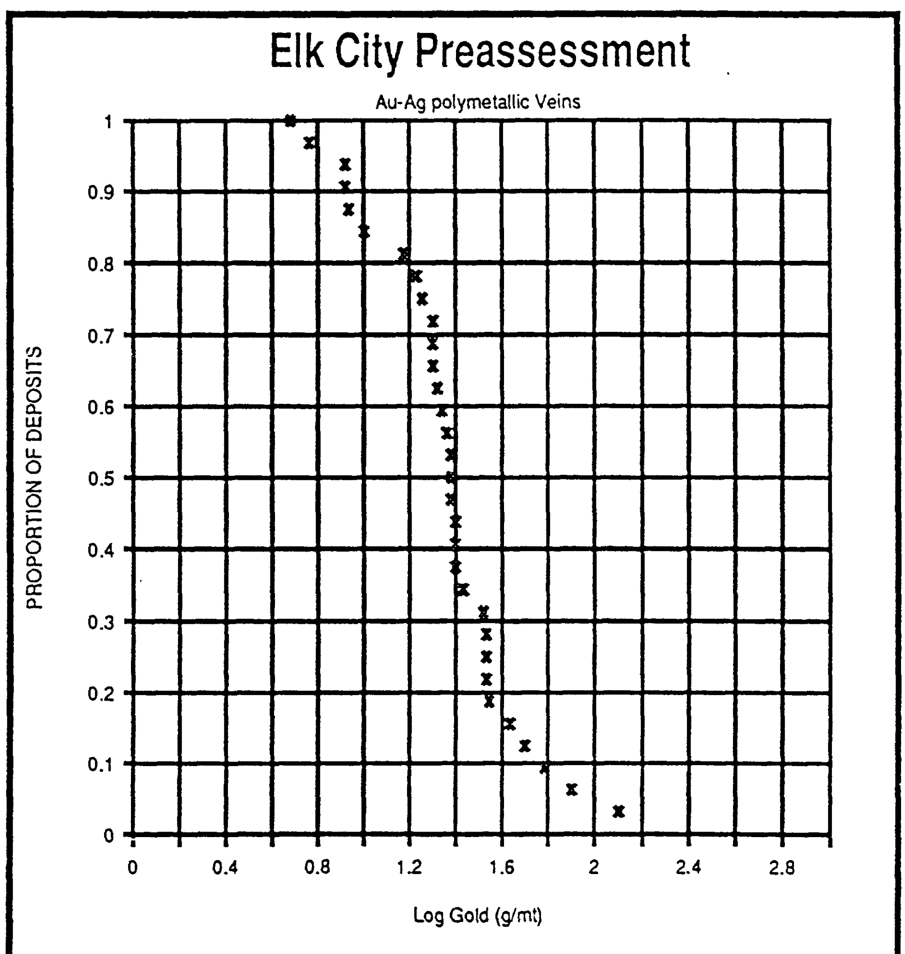

Figure E5. Gold grades of Au-Ag polymetallic vein deposits.

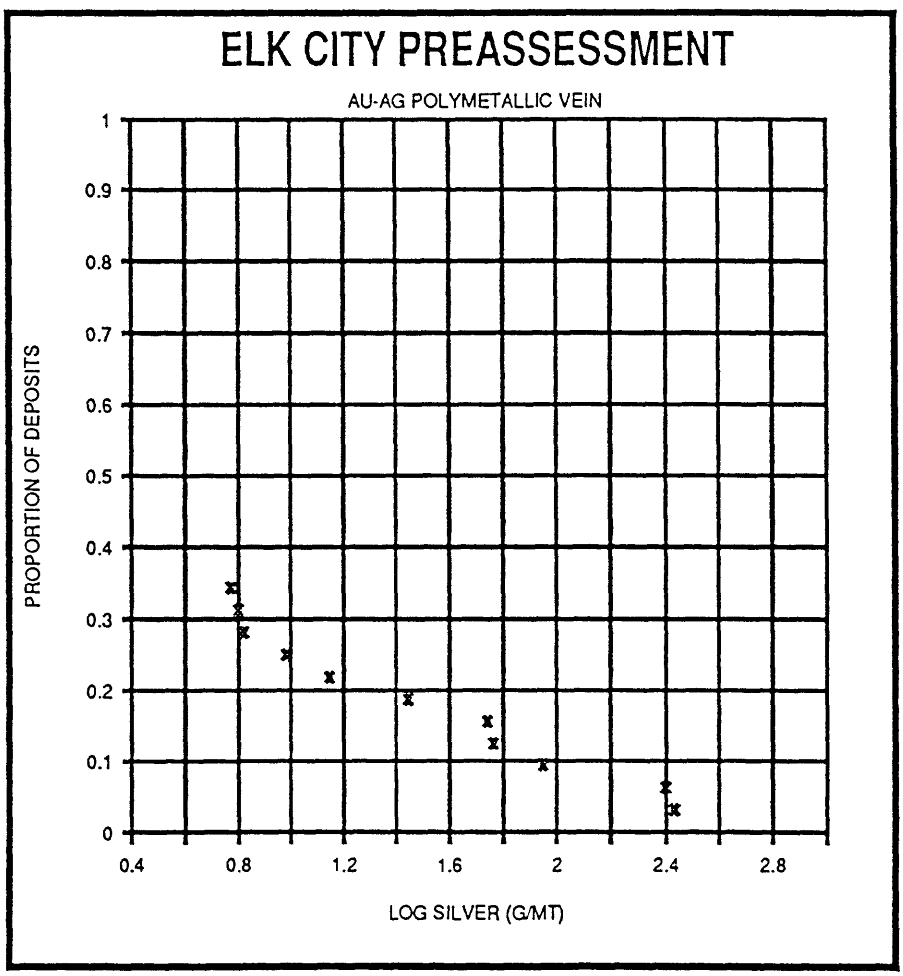

Figure E6. Silver grades of Au-Ag polymetallic vein deposits.

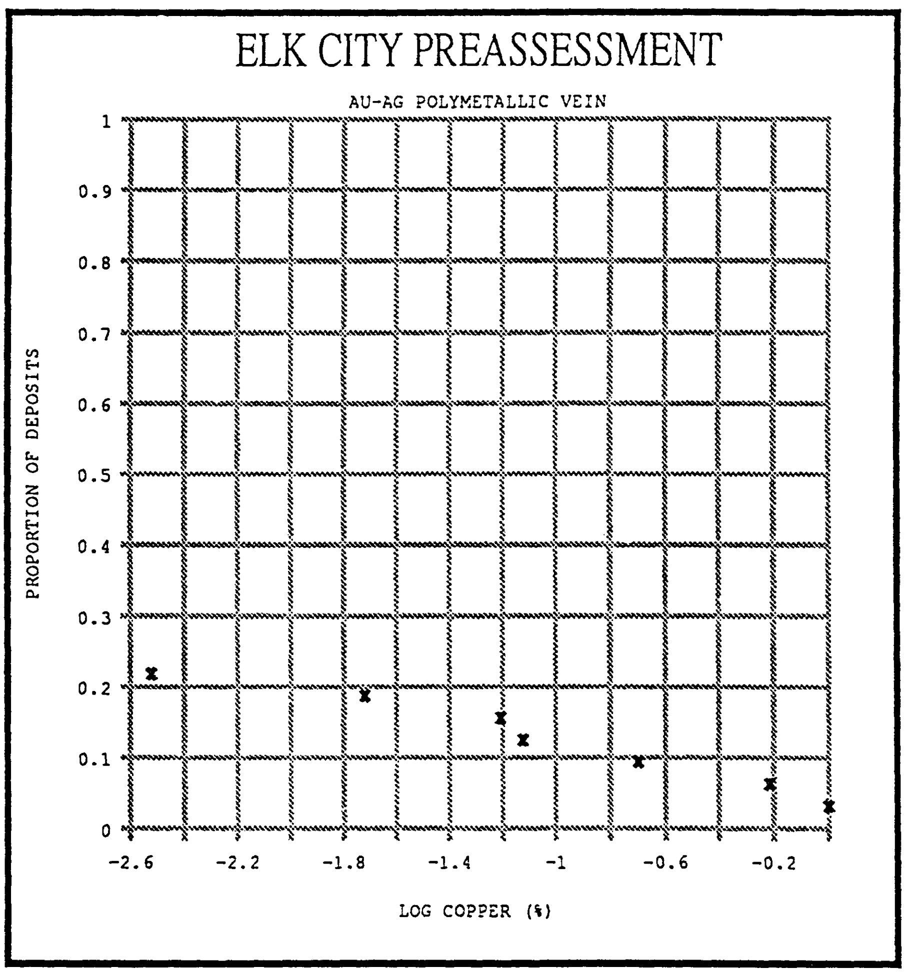

Figure E7. Copper grades of Au-Ag polymetallic vein deposits.

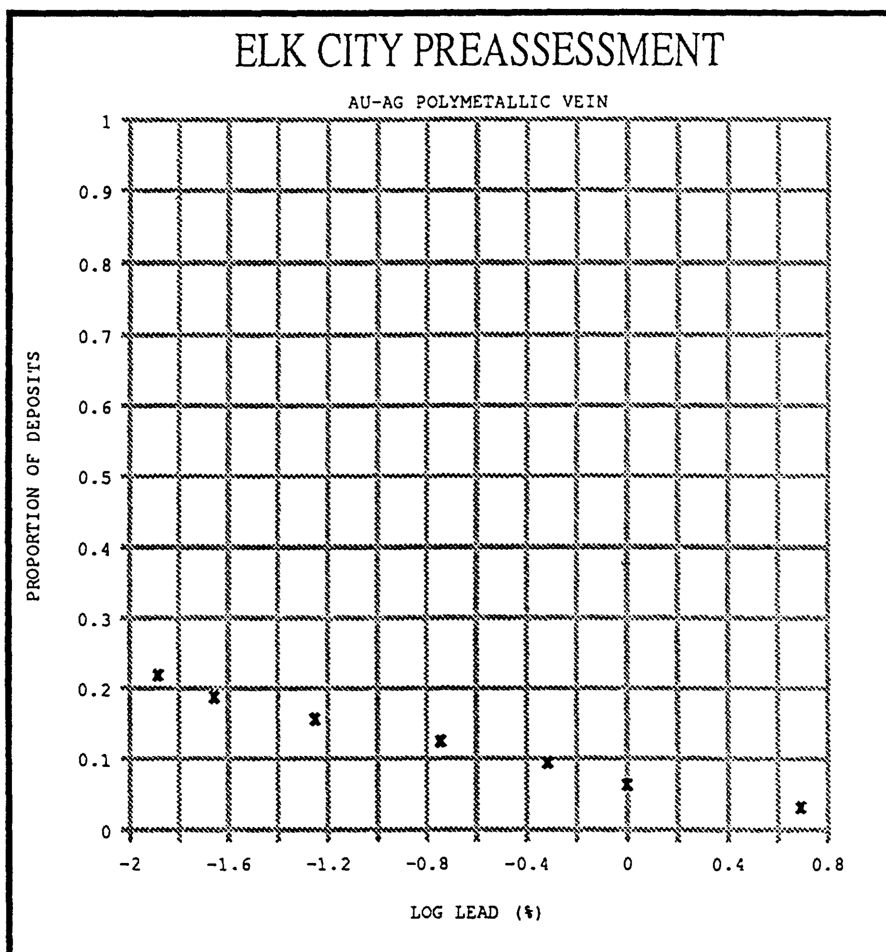

Figure E8. Lead grades of Au-Ag polymetallic vein deposits.

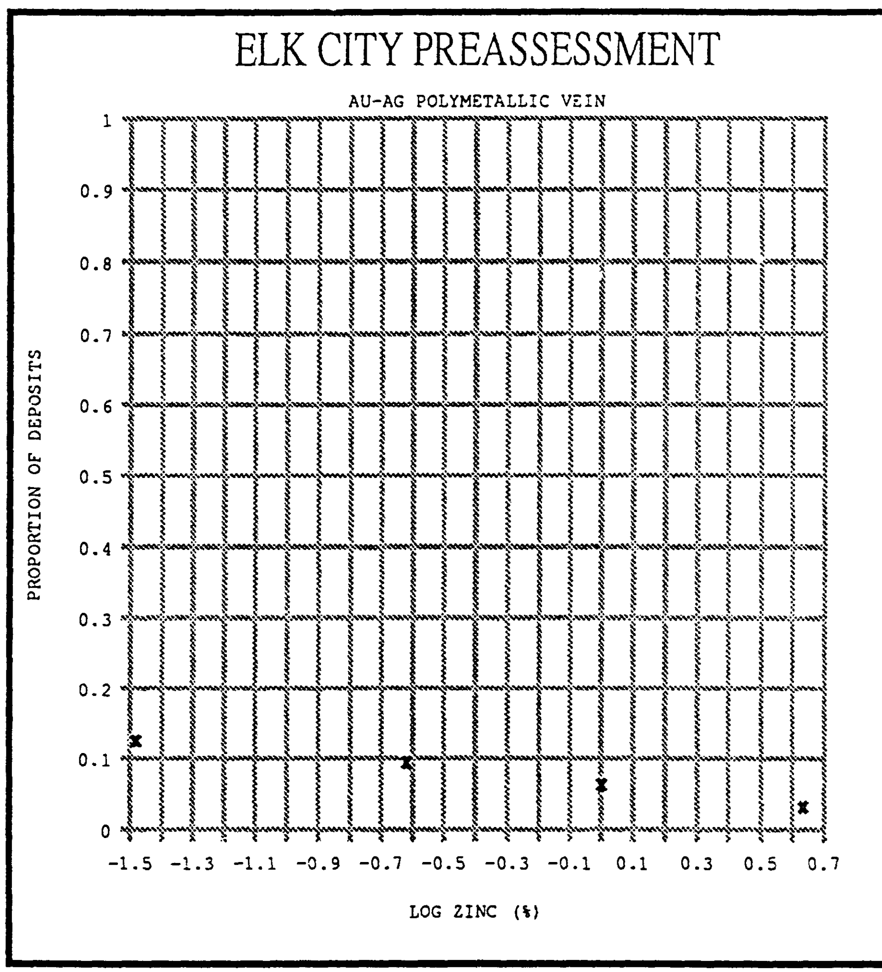

Figure E9. Zinc grades of Au-Ag polymetallic vein deposits.

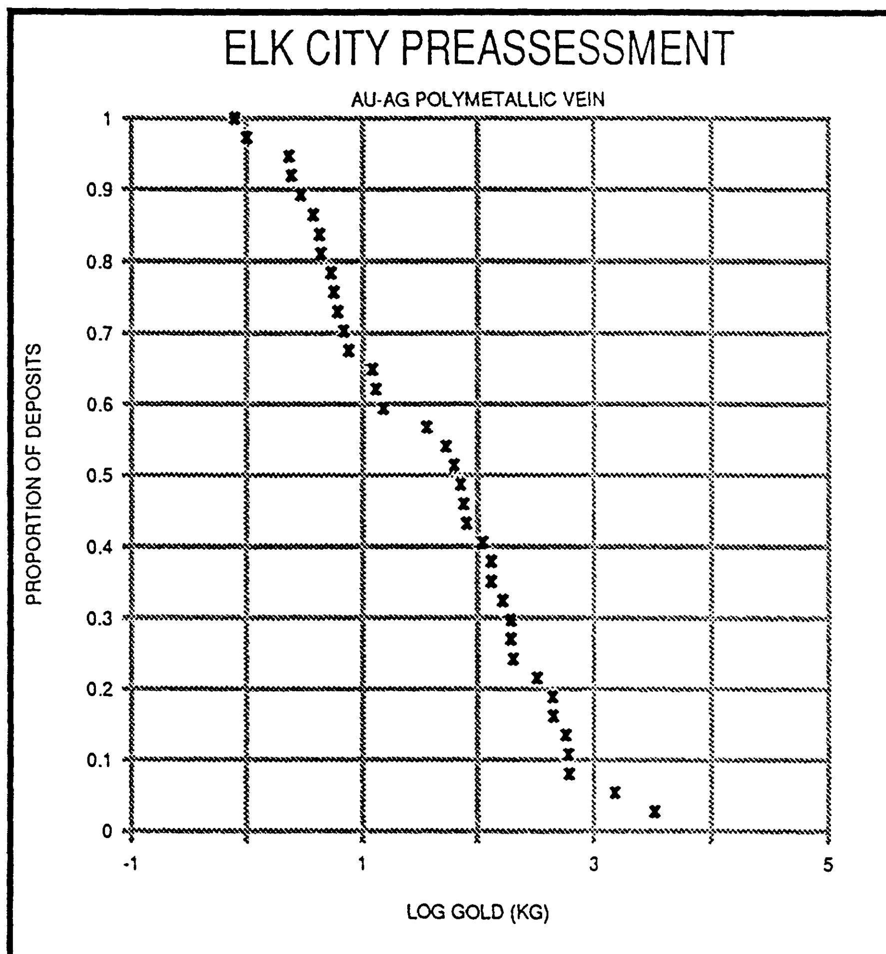

Figure E10. Contained gold of Au-Ag polymetallic vein deposits.

techniques makes this model a crude proxy for a formal assessment. The model is also provincial, which is appropriate to a mineral resource assessment of the Elk City quadrangle, but may not be applicable elsewhere. Table E3 is based on figures E11 to E14.

A typical Blackbird deposit will contain 20,000 tonnes of ore with 0.54 percent Co and 1.1 percent Cu; about a half of the deposits will contain Cu grades as described by the grade and tonnage model (figs. E11 to E14) and about a third of the deposits will contain gold. The median Cu grade given as typical is probably low because Cu was either selectively avoided during mining, discarded during milling, or simply not reported. Gold grades are between 0.32 ppm and 4 ppm (table E3).

It is unclear whether the Blackbird deposits should be treated as unique or as a member of an existing population with a grade and tonnage model. If it is part of an existing group, the sediment-hosted Cu deposits seem a likely candidate. In terms of tonnage, the Blackbird deposits appear to be comparably small, but deposits in the sediment-hosted Cu model (Cox and Singer, 1986) represent deposits which are probably size-biased; only the largest ones in a district are reported, or they represent deposits with ore bodies of unknown spacing or are composite of all mineralized bodies in a district. If treated similarly and including reserves reported in the district (Modreski, 1985; Nash and Hahn, 1986), the largest deposit size would be on the order of millions of metric tons. Deposits of this size are compatible with tonnages of the sediment-hosted Cu deposit type (Mosier and others, 1986, fig. 154); Cu grades are also comparable (Mosier and others, 1986, fig. 155). Cobalt grades are higher than for the sediment-host Cu deposits but fit nicely on the end of the Co grade curve (Mosier and others, 1986, fig. 156 B). However, that is the end of any similarities. Ag is reported in over 20 percent of the sediment-hosted Cu deposits (Mosier and others, 1986, fig. 156 A), although none is reported for the Blackbird deposits (fig. E11). These deposits near Blackbird are unique in terms of gold grades; none of the sediment-hosted Cu deposits have reported gold. It is not likely to be just an absence of reporting, as Ag grades have been reported as low as 1 gram per metric ton (g/mt). To date, only one deposit, Mount Cobalt, Queensland, seems similar in terms of a grade and tonnage model to those in the Blackbird district.

If the Blackbird deposits represent a separate population and the grade and tonnage model developed herein is applicable and generally comparable to grade and tonnage models for other deposit types, comparisons can also be made between deposit types on the basis of Co content. Using the median grade and tonnage, a typical undiscovered Blackbird deposit will contain 108 mt of cobalt. A typical Blackbird deposit contains the least Co (table E4) in comparison to five other deposit types with reported Co grades (Cox and Singer, 1986, appendix B). However, Co is <u>not</u> present in all occurrences of the five other deposit types. The percentage of deposits with reported Co grades varies from 9.4 percent for synorogenic-synvolcanic Ni-Cu to 26 percent for komatiitic Ni-Cu (table E4). For those deposits with reported Co, the amount of Co likely will vary from 6.8 (dunitic Ni-Cu) to 2,800 times (lateritic Ni) the amount in a typical Blackbird deposit (table E4). Although sediment-hosted Cu deposits have not been recognized in the Elk City quadrangle, geology permissible for their occurrence has been recognized and delineated; this deposit type may also have significant Co. The chances that a sediment-hosted Cu deposit will contain Co grades similar to those in the grade and tonnage model (Mosier and others, 1986) are between one out of five or six. If the deposit contains these grades, it will have 480 times the Co usually found in a Blackbird type deposit (table E4).

Table E3. Estimate of the percentage of Blackbird Co-Cu deposits that equal or exceed a given grade or tonnage as taken from figures E11, E12, and E13

Variable	Cutoff[1]	Percentage		
		90	50	10
Ore (mt)	100	320	20,000	3,400,000
Cobalt (%)	0.09	0.25	0.54	1.6
Copper (%)[2]	1.0	-	1.1	4.8
Gold (g/mt)[3]	0.32	-	-	3.9

[1]Cutoff is a value less than any value used to construct the grade and tonnage models.

[2]About 50 percent of the deposits contain copper reported at grades greater than the cutoff.

[3]About a third of the deposits contain gold at grades reported greater than the cutoff.

Table E4. Comparison of Blackbird deposit with other deposit-types with reported Co grades (Cox and Singer, 1986, appendix B)

Deposit type	Cox & Singer No.	Percentage of deposit with reported Co grades	Mean Co Grade	Mean contained Co (mt)	Ratio to median of Blackbird deposit type
Blackbird Co-Cu	24d	100	0.54[1]	108[1]	1
Komatiitic Ni-Cu	6a	26	.056	960	8.9
Dunitic Ni-Cu	6b	14	.026	730	6.8
Synorogenic-synvolcanic Ni-Cu	7a	9.4	.047	930	8.6
Sediment-hosted Cu	30b	18	.24	52,000	480
Lateritic Ni	38a	17	.069	300,000	2,800

[1]Grade and tonnage either reported or used in calculations are medians not means for the case of Blackbird Co-Cu type deposits.

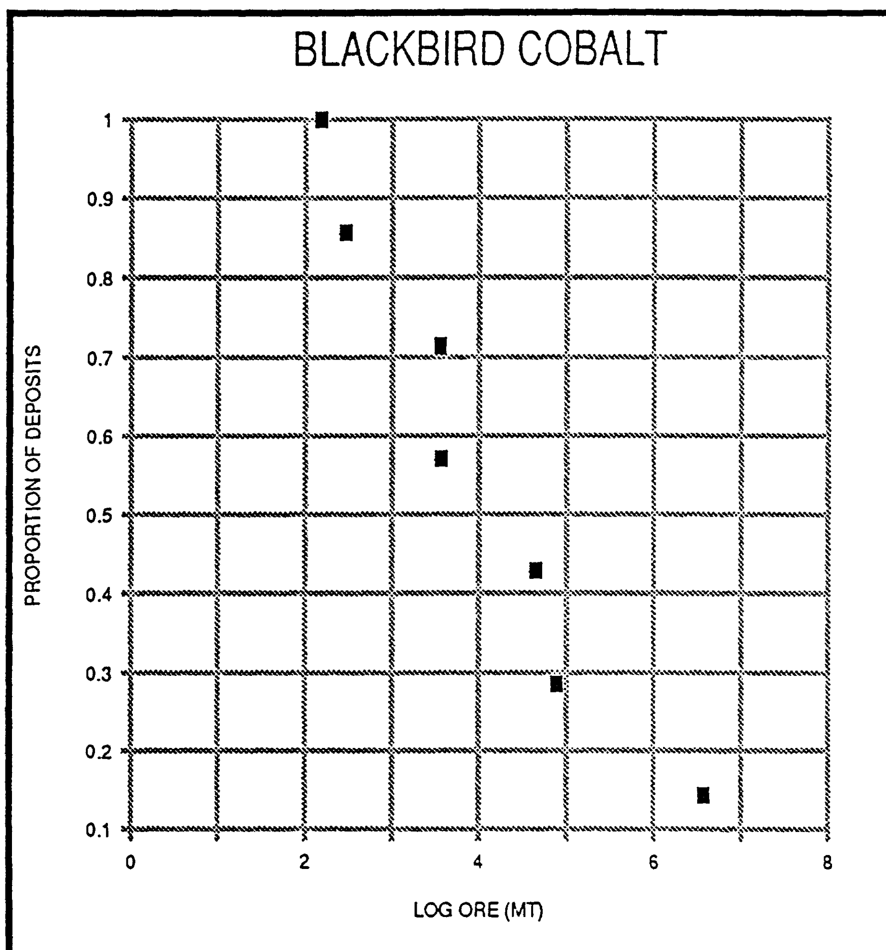

Figure E11. Tonnage of Blackbird Co-Cu deposits.

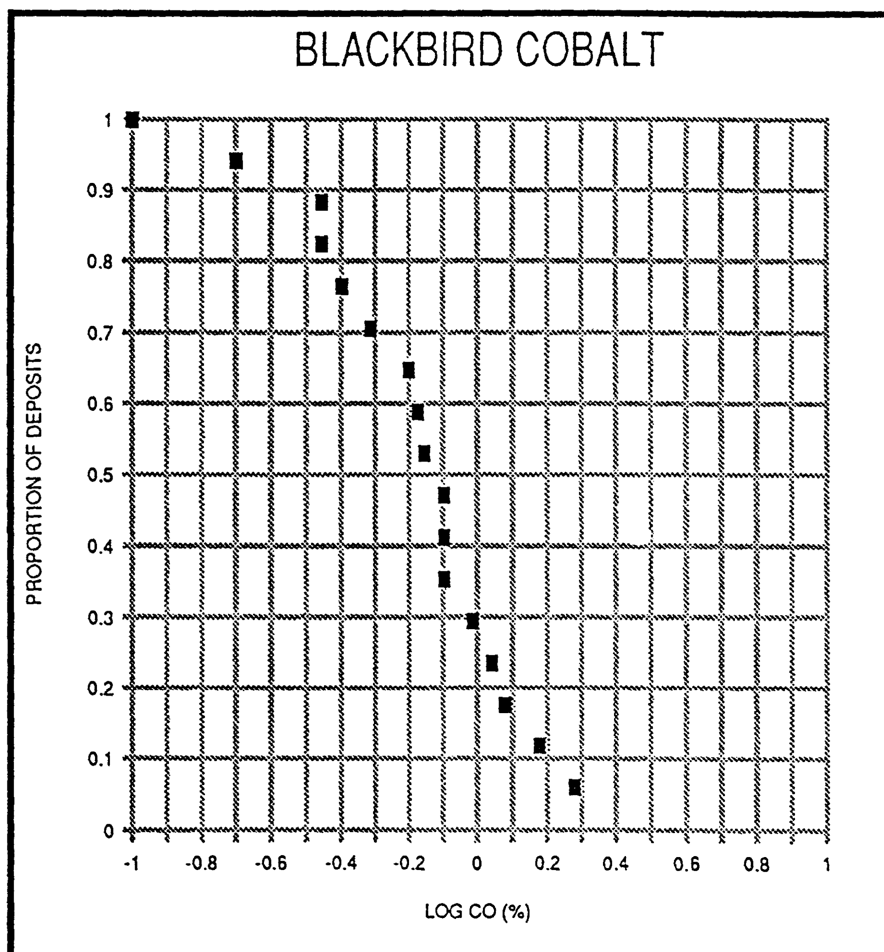

Figure E12. Cobalt grades of Blackbird Co-Cu deposits.

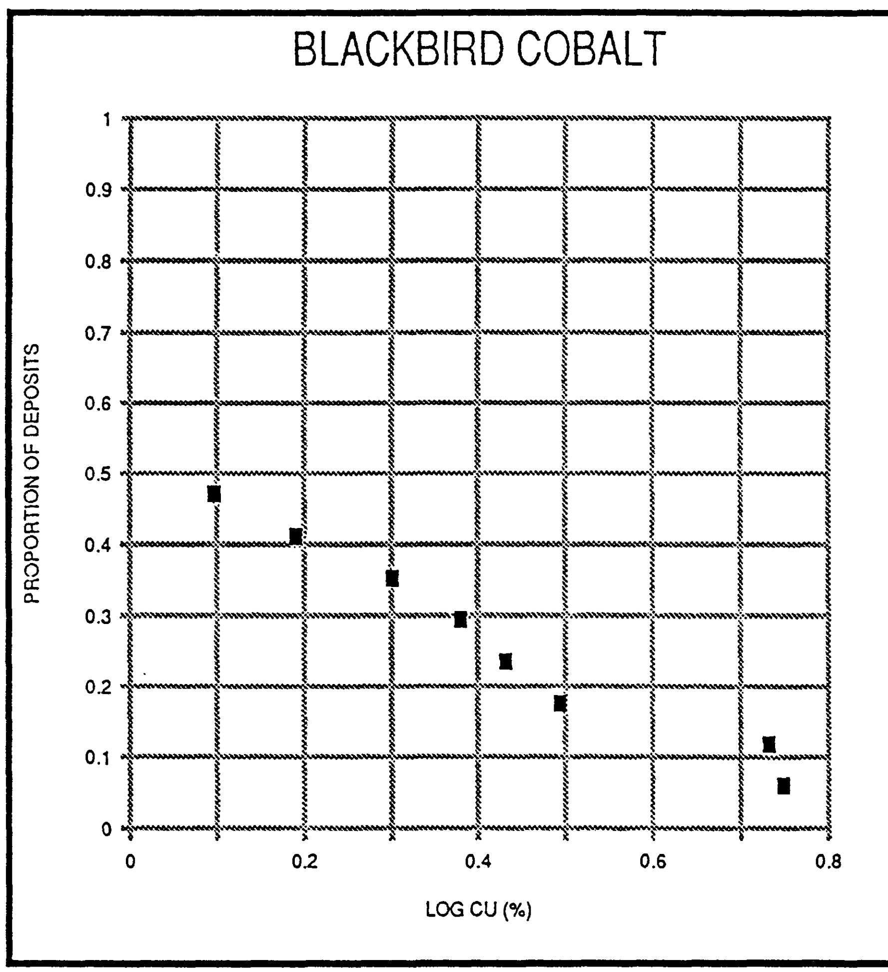

Figure E13. Copper grades of Blackbird Co-Cu deposits.

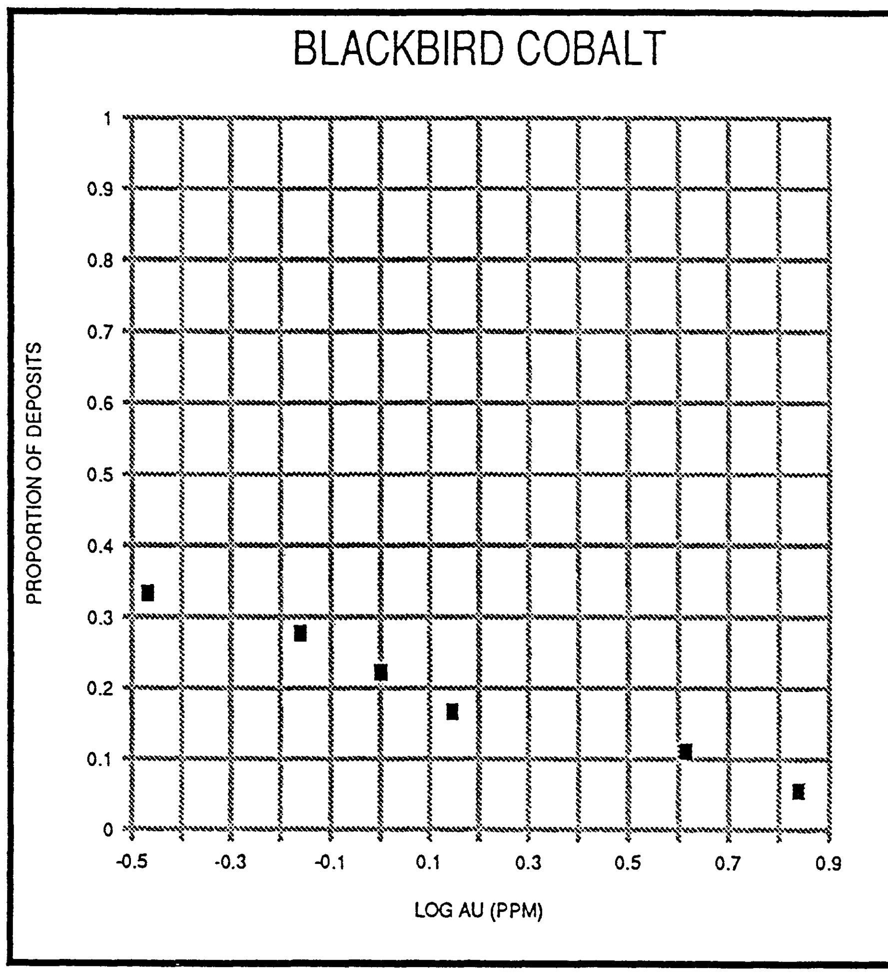

Figure E14. Contained gold of Blackbird Co-Cu deposits.

If the Blackbird Co-Cu deposits are actually a part of the sediment-hosted Cu deposit population, undiscovered deposits should be better described by the grade and tonnage model for that deposit type. If the general conclusions reached based on table E4 are correct, an undiscovered deposit of that type in the Elk City quadrangle could contain significant Co.

Au-Ag Polymetallic Deposits, Disseminated Subtype

Disseminated gold bodies on the Butte and Orogrande and Alice properties (Tract GP-1, fig. E2) in the Elk City mining district were described as occurring in a shear zone as much as a half mile wide (Shenon and Reed, 1934). Scatter plots of grade and tonnage data from Au-Ag polymetallic veins and disseminated deposits found in this area and elsewhere in Tracts GP-1 to GP-3 show that the two types form two distinct groups (fig. E15). The vein deposits are described by a grade and tonnage model (see above). The disseminated deposits identified to date occur both near and somewhat distant from the the vein occurrences. In all cases, disseminated Au deposits are usually associated with Cu, Pb, Zn, Sb, and Mo. However, these secondary commodities do not usually occur in sufficient concentration to justify recovery. Historically, disseminated deposits have been identified as being between 10,000 mt and 1,000,000 mt in size; recent exploration has found larger deposits. The Friday property (near Oro-grande) is reported to contain 12 million mt with 1.2 g/mt to 1.7 g/mt Au (Mining Engineer, 1987, v. 39, no. 5, p. 332), whereas historical Au grades are between 0.6 g/mt to 2.5 g/mt Au (fig. E15). This deposit type is one of the more attractive exploration targets in the quadrangle.

Geothermal Springs in the Elk City Quadrangle

Several hot springs or groupings of hot springs are reported in this quadrangle in GEOTHERM, a computerized database once operated by the Survey and now off-line. Additions to this data were made from Young (1981) and from Berry and others (1980). GEOTHERM records may contain data on location, sample description, analysis type, collection conditions, flow rates, and the chemical and physical properties of the fluid. The complete record can be found in a published compilation of data for Idaho, U.S. Geological Survey Open-File Report 83-431B, which is issued as microfiche only (Bliss, 1983b). The listing given here is taken, in part, from U.S. Geological Survey Open-File Report 83-431A (Bliss, 1983a) which contains a set of indices for the Idaho data. Several records may be present for a given hot spring:

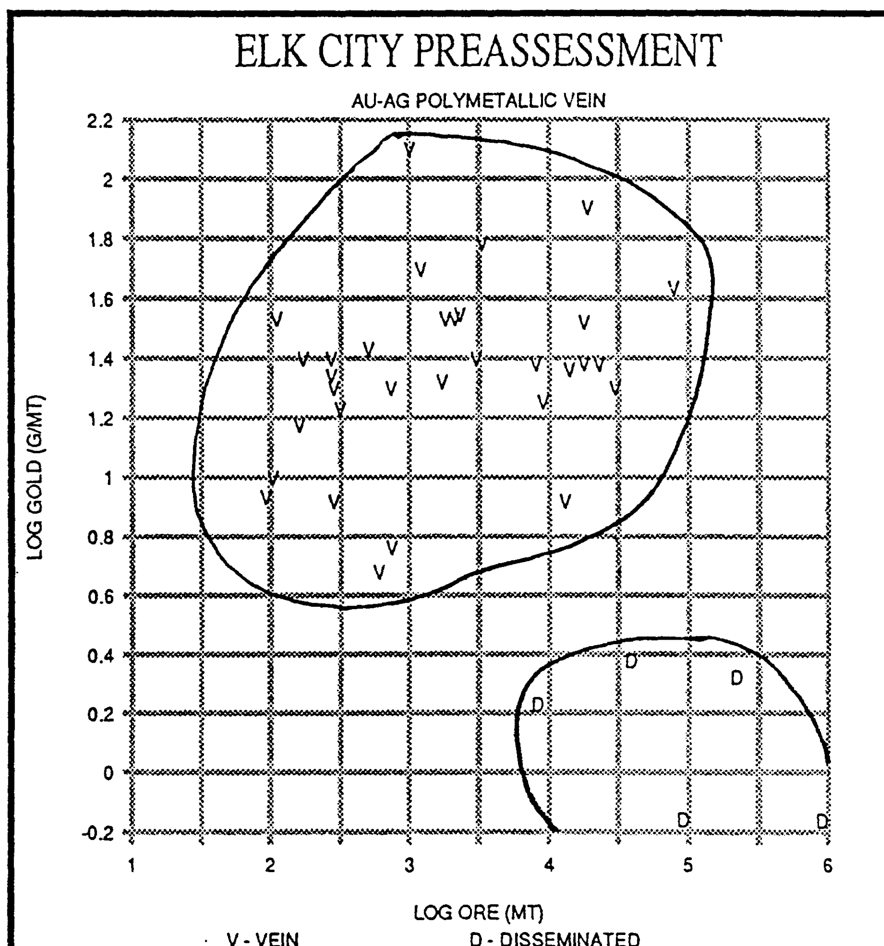

Figure E15. Scatter plot showing the separate groupings of vein and disseminated subtypes, Au-Ag polymetallic deposits.

Table E5. Geothermal springs in the Elk City quadrangle

Name	Latitude	Longitude	Temp. (°C)	Geotherm Record No.
Barth	45-30.75N	115-02.56W	61	81162
Do	45-30.75N	115-02.56W	60	25317
Big Creek	45-18.42N	114-20.27W	93	81169
Burgdorf	45-16.61N	115-54.74W	45	81159
Horse Creek	45-30.18N	114-27.78W	43	-----([1])
Lick Creek	45-04.20N	115-49.56W	33	-----([2])
Owl Creek	45-20.64N	114-27.78W	50	-----([2])
Red River	45-47.26N	115-11.86W	55	81161
Running Warm	45-51.12N	114-56.22W	41	-----([2])
Secesh	45-10.20N	115-48.42W	--([3])	-----([2])
Sheep Creek	45-02.12N	115.33.64W	Q 45([4])	25118
Snowshoe Johnson	45-02.52N	114-36.96W	42	-----([2])
Unnamed	45-52.00N	115-45.00W	46	15275

[1]See Young (1981).

[2]See Berry and others (1980).

[3]Identified as hot (Berry and others, 1980).

[4]Temperature is qualified in a fashion given in the full GEOTHERM record.

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