R-MODE FACTOR ANALYSIS OF STREAM SEDIMENT DATA IN THE FAIRBANKS MINING DISTRICT, EAST-CENTRAL ALASKA

by

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A thesis submitted to the faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science Geology

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ABSTRACT

The Fairbanks Mining District is located within east-central Alaska and is highly prospective for gold mineralization. Previously identified gold-bearing quartz veins are broadly classified as orogenic style gold mineralization and these are the source for the prolific placer gold resources that has been actively worked in the Fairbanks district since the late 1800s. The only major mineral deposit (>2 Moz) in the district that is actively being mined is the Fort Knox gold deposit (>8 Moz). Fort Knox is classified as a reduced intrusion-related gold deposit, and this style of mineralization is minor in the district compared to orogenic style mineralization.

Exploration for both styles of mineralization was carried out using a stream sediment geochemical dataset collected in the district in 1982 and reanalyzed in 1995. The first ever multivariate statistical analysis of this geochemical survey is presented here. R-mode factor analysis with varimax rotation was performed on log transformed multi-element stream sediment data. This resulted in one factor related to gold mineralization with an As-Sb-Au geochemical association. This factor is strongly associated with orogenic gold veins but is not associated with reduced intrusion-related mineralization, like Fort Knox. High positive scoring samples for this factor are used to define prospective areas for orogenic style gold mineralization. Potential host rocks for reduced intrusion-related mineralization were identified and those areas that have anomalous concentrations of gold are used to define prospective areas for this mineralization style.
## TABLE OF CONTENTS

ABSTRACT................................................................................................................................... iii
LIST OF FIGURES........................................................................................................................ viii
LIST OF TABLES.......................................................................................................................... x
LIST OF EQUATIONS.................................................................................................................. xi
LIST OF ABBREVIATIONS....................................................................................................... xii
ACKNOWLEDGEMENTS........................................................................................................... xv

CHAPTER 1 INTRODUCTION AND LITERATURE REVIEW.................................................... 1
  1.1 Introduction.................................................................................................................... 1
  1.2 Thesis Organization....................................................................................................... 3
  1.3 Literature Review........................................................................................................... 3
    1.3.1 Regional Geology....................................................................................................... 3
      1.3.1.1 Paleozoic Passive Continental Margin............................................................. 4
      1.3.1.2 Devonian Yukon-Tanana Arc........................................................................... 7
      1.3.1.3 Back-arc Rifting.................................................................................................. 7
      1.3.1.4 Subduction Polarity Reversals.......................................................................... 8
      1.3.1.5 Terrane Collision............................................................................................. 9
      1.3.1.6 Syn- and Post-Collisional Tectonics and Plutonism.......................................... 10
      1.3.1.7 Eocene to Present Clastic Sedimentation and Volcanism............................... 11
    1.3.2 Gold Deposits in Metamorphic............................................................................ 12
    1.3.3 Regional Geochemical Survey............................................................................ 12
      1.3.3.1 Stream Sediment Sampling Method............................................................... 12
        1.3.3.1.1 Planning...................................................................................................... 13
        1.3.3.1.2 Sample Collection and Handling.............................................................. 14
        1.3.3.1.3 Geochemical Analysis.............................................................................. 14
        1.3.3.1.4 Quality Control........................................................................................ 15
      1.3.4 Factor Analysis....................................................................................................... 15
    1.4 References Cited............................................................................................................ 15
CHAPTER 2 PROSPECTING FOR GOLD MINERALIZATION IN THE FAIRBANKS MINING DISTRICT, ALASKA USING R-MODE FACTOR ANALYSIS OF STREAM SEDIMENT DATA

2.1 Abstract........................................................................................................................22
2.2 Introduction..................................................................................................................23
2.3 Regional Geology and Gold Mineralization................................................................24
  2.3.1 Gold Mineralization........................................................................................24
2.4 Fairbanks Mining District Geology and Gold Mineralization.....................................26
  2.4.1 Parautochthonous Yukon-Tanana Terrane.....................................................27
  2.4.2 Yukon-Tanana Arc.........................................................................................28
  2.4.3 Seventymile Oceanic Terrane........................................................................28
  2.4.4 Mid-Cretaceous Volcanic and Plutonic Rocks...............................................28
  2.4.5 Tertiary Volcanic and Sedimentary Rocks.......................................................29
  2.4.6 Structural Geology.........................................................................................29
  2.4.7 Gold Mineralization......................................................................................30
    2.4.7.1 Orogenic Gold Deposits.................................................................31
    2.4.7.2 Reduced Intrusion-Related Gold Deposits.....................................32
    2.4.7.3 Gold-Bearing Skarn Deposits........................................................33
2.5 Materials......................................................................................................................34
  2.5.1 Fairbanks Mining District Stream Sediment Geochemical Survey....................34
2.6 Methods.......................................................................................................................35
  2.6.1 Statistical Analysis of Geochemical Data.......................................................36
  2.6.2 Factor Analysis.............................................................................................47
    2.6.2.1 Preparing a Geochemical Dataset for Factor Analysis..........................48
    2.6.2.2 Censored Data....................................................................................48
    2.6.2.3 Normal Distribution............................................................................50
    2.6.2.4 Summary Statistics.............................................................................50
    2.6.2.5 Selecting the Number of Factors.....................................................51
    2.6.2.6 Calculate the Factor Loadings.......................................................52
2.6.2.7 Determine Geochemical Relationships ................................................. 53
2.6.2.8 Calculate the Factor Scores ............................................................... 54
2.6.2.9 Create Factor Scores Maps .............................................................. 55

2.7 Results of Factor Analysis .............................................................................. 55

2.8 Discussion of Factor Scores ............................................................................ 55

2.8.1 Factor One .................................................................................................. 56
2.8.2 Factor Two ................................................................................................ 61
2.8.3 Factor Three .............................................................................................. 70
2.8.4 Factor Four ............................................................................................... 70
2.8.5 Factor Five ................................................................................................. 75
2.8.6 Factor Six ................................................................................................. 87
2.8.7 Factor Seven ............................................................................................. 92
2.8.8 Factor Eight ............................................................................................ 99
2.8.9 Geochemical Associations Related to Gold Mineralization ................. 99
2.8.10 Geochemical Association Related to Other Mineralization Styles ....... 104

2.9 Prospectivity Mapping for Gold Deposits ...................................................... 104

2.9.1 The Cleary Summit – Pedro Dome Area ................................................. 105
2.9.2 The Gilmore Dome Area ......................................................................... 115
2.9.3 The Vault – Treasure Creek Area ........................................................... 111
2.9.4 The Ester Dome Area ............................................................................. 111

2.10 Discussion of Prospectivity Mapping .......................................................... 111

2.11 Conclusions ................................................................................................. 120

2.12 Acknowledgements ...................................................................................... 121

2.13 References Cited ........................................................................................ 121

CHAPTER 3 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK ................................................................. 129

3.1 Major Conclusions of the Study .................................................................. 129

3.2 General Considerations for R-mode Factor Analysis .................................. 132

3.3 Prioritizing Exploration at Prospective Sites Identified in this Study .......... 133

3.3.1 Future Exploration Efforts Using These Maps ........................................ 134
LIST OF FIGURES

Figure 1.1 Map showing the location of the Fairbanks Mining District within east-central Alaska.................................................................2
Figure 1.2a Schematic diagram illustrating the Paleozoic to mid-Permian tectonic evolution of east-central Alaska...........................................5
Figure 1.2b Schematic diagram illustrating the Late Triassic to late Cretaceous tectonic evolution of east-central Alaska.................................6
Figure 2.1 Location, geology, and mineral occurrences of the Fairbanks Mining District.......................................................................................25
Figure 2.2 Geology and mineral occurrences of the Cleary Summit – Pedro Dome area....................................................................................37
Figure 2.3 Geology and mineral occurrences of the Gilmore Dome area...........................................................................................................38
Figure 2.4 Geology and mineral occurrences of the Vault – Treasure Creek area..............................................................................................49
Figure 2.5 Geology and mineral occurrences of the Ester Dome area..............................................................................................................40
Figure 2.6 Sample locations for the Fairbanks Mining District stream sediment geochemical dataset.................................................................45
Figure 2.7 Map showing the concentration of As and Au in the Fairbanks Mining District..................................................................................46
Figure 2.8 Chart showing the factor analysis workflow.................................................................................................................................49
Figure 2.9 Maps showing the distribution of factor scores 1 through 4..............................................................................................................58
Figure 2.10 Maps showing the distribution of factor scores 5 through 8.............................................................................................................59
Figure 2.11 Map A of factor scores for factor one..................................................................................................................................................63
Figure 2.12 Map B of factor scores for factor one..................................................................................................................................................65
Figure 2.13 Map A of factor scores for factor two..................................................................................................................................................67
Figure 2.14 Map B of factor scores for factor two..................................................................................................................................................69
Figure 2.15 Map A of factor scores for factor three..................................................................................................................................................72
Figure 2.16 Map B of factor scores for factor three..................................................................................................................................................74
Figure 2.17 Map A of factor scores for factor four..................................................................................................................................................77
Figure 2.18 Map B of factor scores for factor four..................................................................................................................................................79
Figure 2.19 Map C of factor scores for factor four..................................................................................................................................................81
Figure 2.20 Map A of factor scores for factor five..................................................................................................................................................84
Figure 2.21 Map B of factor scores for factor five..................................................................................................................................................86
Figure 2.22  Map A of factor scores for factor six.................................................................89
Figure 2.23  Map B of factor scores for factor six.................................................................91
Figure 2.24  Map A of factor scores for factor seven...............................................................94
Figure 2.25  Map B of factor scores for factor seven...............................................................96
Figure 2.26  Map C of factor scores for factor seven...............................................................98
Figure 2.27  Map A of factor scores for factor eight.................................................................101
Figure 2.28  Map B of factor scores for factor eight.................................................................103
Figure 2.29  Map showing the location of the prospective areas for lode-gold mineralization..........................................................................................106
Figure 2.30  Prospective areas for gold mineralization in the western part of the Cleary Summit – Pedro Dome area.................................................................108
Figure 2.31  Prospective areas for gold mineralization in the eastern part of the Cleary Summit – Pedro Dome area.................................................................110
Figure 2.32  Prospective areas for gold mineralization in the Gilmore Dome area.................................................................113
Figure 2.33  Prospective areas for gold mineralization east of the Gilmore Dome area.................................................................115
Figure 2.34  Prospective areas for gold mineralization in the Vault – Treasure Creek area.................................................................117
Figure 2.35  Prospective areas for gold mineralization in the Ester Dome area.................................119
Figure 3.1  Map showing the location of prospective areas for lode-gold Mineralization..........................................................................................130
# LIST OF TABLES

| Table 2.1a | Mineral deposits and prospects in the Cleary Summit – Pedro Dome area (#1-7) | 42 |
| Table 2.1b | Mineral deposits and prospects in the Cleary Summit – Pedro Dome (#8-13) | 42 |
| Table 2.1c | Mineral deposits and prospects in the Gilmore Dome Area and the Vault – Treasure Creek area (#14-20) | 42 |
| Table 2.1d | Mineral deposits and prospects in the Ester Dome area and other areas of the Fairbanks Mining District | 42 |
| Table 2.2 | Equations used to determine the symbol levels for the factor score maps | 56 |
| Table 2.3 | Factor loadings from r-mode factor analysis | 57 |
| Table 2.4 | The high loading elements for each factor and the interpreted geology they represent | 60 |
| Table 3.1 | Areas identified in the present study as prospective for the specified mineralization style | 131 |
## LIST OF EQUATIONS

<table>
<thead>
<tr>
<th>Equation 2.1</th>
<th>Calculate the maximum-likelihood factor loadings by linear combination</th>
<th>52</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation 2.2</td>
<td>Calculate the maximum-likelihood factor loadings by summation</td>
<td>52</td>
</tr>
<tr>
<td>Equation 2.3</td>
<td>Calculate the factor scores</td>
<td>53</td>
</tr>
<tr>
<td>Equation 2.4</td>
<td>Calculate Communality</td>
<td>54</td>
</tr>
</tbody>
</table>
LIST OF ABBREVIATIONS

> .................................................................Greater Than
< .................................................................Less Than
% .....................................................................Percent
AA .............................................................................................. Atomic Absorption
AEC ........................................................................................ Atomic Energy Commission
AES ...................................................................................... Inductively Coupled Plasma Atomic Emission Spectroscopy
As ............................................................................................. Arsenic
Apy .......................................................................................... Arsenopyrite
Au .............................................................................................. Gold
Bi .............................................................................................. Bismuth
Bio .......................................................................................... Biotite
Bit .......................................................................................... Bismuthinite
Ca ............................................................................................. Calcium
cm .......................................................................................... Centimeter
CM .......................................................................................... Coulometry
Co .............................................................................................. Cobalt
CO$_2$ .................................................................................. Carbon Dioxide
Cpy .......................................................................................... Chalcopyrite
Cu ............................................................................................. Copper
CV .......................................................................................... Atomic Absorption by Cold-Vapor
DC .......................................................................................... Direct Current
DMpYT ................................................................................ Parautochthonous Yukon-Tanana Terrane
DNC ........................................................................................ Delayed Neutron Counting
DOE ........................................................................................ United States Department of Energy
Dol .......................................................................................... Dolomite
E .............................................................................................. East
Fe .............................................................................................. Iron
ft. .............................................................................................. Foot
Fuc .......................................................................................... Fuchsite
Ga ............................................................................................................................... Billion Years
Gal ........................................................................................................................................ Galena
HSSR .......................................................... Hydrogeochemical Stream Sediment Reconnaissance
H$_2$O............................................................................................... Dihydrogen monoxide aka water
in. .............................................................................................................................................. Inch
INAA ............................................................................ Instrumental Neutron Activation Analysis
km ........................................................................................................................................... Kilometers
km$^2$ ....................................................................................................................................... Squared Kilometers
K$_2$O ............................................................................................................. Dipotassium monoxide
lKg ................................................................................................................... late Cretaceous Plutonic rocks
lKv ................................................................................................................... late Cretaceous volcanic rocks
m .............................................................................................................................................. Meter
Ma .............................................................................................................................. Million Years
mKg ................................................................................................................... middle Cretaceous Plutonic rocks
mKv ................................................................................................................... middle Cretaceous volcanic rocks
mm ..................................................................................................................................... Millimeter
Mo ...................................................................................................................................... Molybdenum
Mol .................................................................................................................................... Molybdenite
Moz ................................................................................................................................ Million Ounces
MPaYT .................................................................................................... Allochthonous Yukon-Tanana Terrane
MTrsv .................................................................................................. Seventymile Ocean Terrane
Musc ................................................................................................................................ Muscovite
N .......................................................................................................................................... Oxygen
NAD-27 ............................................................................................. North American Datum 1927
NNW...................................................................................................................... North Northwest
NW .................................................................................................................. Northwest
O .......................................................................................................................... Osmium
Os ................................................................................................................................ Pyrite
Pb ...................................................................................................................................... Lead
Py ...................................................................................................................................... Pyrite
ACKNOWLEDGEMENTS

I would like to acknowledge the guidance of my advisor Dr. Elizabeth Holley and my committee members Dr. Richard Goldfarb and Dr. Wendy Zhou. I would also like to acknowledge financial support from the Colorado School of Mines, the Society of Economic Geologists, and the United States Geological Survey. This contribution benefitted from informal editing by Ashley Quigley, Marion Nicco, and John Meyer. I would also like to acknowledge the technical support and advice of Dr. Jeffery Jaacks.
CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The Tintina Gold Province (TGP) is a highly prospective area for placer and lode-gold mineralization that spans central Alaska and western Canada (Figure 1.1). Numerous gold prospects have been identified in this region, however, few large lode deposits (> 2 Moz) have been developed. East-central Alaska is located within the TGP and has seen periods of extensive gold exploration. The Fort Knox gold mine (> 8.7 Moz Au (Sims, 2015)) and the Pogo gold mine (> 5 Moz Au (Dilworth et al., 2007)) represent the only two large mineral deposits currently being mined in east-central Alaska. Detailed studies of these mineral deposits reveal different mineralization styles and they are, therefore, classified as different deposit types. Pogo is classified as an orogenic gold deposit and Fort Knox is classified as a reduced intrusion-related gold deposit (Goldfarb and Miller, 1997; Hart et al., 2002). These deposits were discovered using a variety of exploration methods, of which regional geochemistry is regarded as among the most important (Allan et al., 2013). The similarities between these two deposit styles creates a challenge in mineral exploration. The Fairbanks Mining District, located within east-central Alaska, hosts the Fort Knox reduced intrusion-related gold deposit along with numerous orogenic style gold deposits and occurrences (Figure 1.1).

The Fairbanks Mining District was chosen for this study because it contains both orogenic and reduced intrusion-related gold occurrences as well as the world-class Fort Knox gold deposit (Figure 1.1). Data are publically available for a detailed multi-element stream sediment geochemical survey of the Fairbanks Mining District (Jozwik, 2007). The data were collected in 1981 and the samples were reanalyzed in 1995 (Jozwik, 2007). This study employed factor analysis of the reanalyzed data to elucidate geochemical correlations and define a geochemical signature related to gold mineralization in the Fairbanks Mining District. These results enabled the identification of prospective areas for gold mineralization in the Fairbanks Mining District.
Figure 1.1: Map showing the location of the Fairbanks Mining District within east-central Alaska and the Tintina Gold Province (TGP). Geology of east-central Alaska simplified from Dusel-Bacon et al. (2015). Location of the TGP taken from Gough and Day (2010). The mineral occurrences are from the Alaska Resource Data File (ARDF) (U.S. Geological Survey, 2016).
1.2 Thesis Organization

The remainder of this chapter comprises a literature review, which provides background information to support more detailed information in the following chapters. Chapter 2 is structured as a publication. It contains specific information about the background, materials, methods, results and discussion. The final chapter, Chapter 3, contains broad conclusions and a discussion of potential future work.

1.3 Literature Review

The following literature review is meant to provide a general background to support the concepts that are discussed in detail in Chapter 2 and Chapter 3.

1.3.1 Regional Geology

The country rocks of east-central Alaska are greenschist to amphibolite facies metamorphic rocks of continental margin, island-arc, or rift-ocean affinities that have been complexly rifted-from, accreted to, subducted under, and collided with one another between the middle Paleozoic and the Late Cretaceous (Nokleberg et al., 1998; Nelson and Colpron, 2007; Nelson et al., 2013). The three dominant rock assemblages include: (1) the metamorphosed Devonian to Mississippian continental margin-related sedimentary and volcanic rocks of the parautochthonous Yukon-Tanana terrane (DMpYT in Figure 1.1); (2) the metamorphosed Mississippian to Permian island arc and back-arc-related sedimentary and volcanic rocks of the allochthonous Yukon-Tanana terrane (MPaYT in Figure 1.1); and (3) metamorphosed Mississippian to Triassic rift ocean-related sedimentary and volcanic rocks (MTrsv in Figure 1.1). The evolution of these terranes has been well documented for the middle to late Paleozoic (Nelson et al., 2006) and the Mesozoic (Dusel-Bacon et al., 2015).

These country rocks have been intruded by felsic to mafic plutonic rocks in four main stages: (1) during arc-related plutonism due to the westward subduction of Seventymile oceanic crust below the MPaYT in the Late Triassic between 216 – 208 Ma, (2) arc-related plutonism due to the eastward subduction of oceanic crust below the MPaYT and the DMpYT in the Early Jurassic between 191 – 181 Ma, (3) extension-related plutonism within the MPaYT and the DMpYT during the mid-Cretaceous between 112 – 94 Ma, and (4) arc-related plutonism caused...
by the eastward subduction of oceanic crust below the MPaYT and the DMpYT during the Late Cretaceous 68 – 65 Ma (Rubin et al., 1990; Hart et al., 2004; Dusel-Bacon et al., 2015).

Collision of various terranes has been accommodated by folding and thrust faults and many rock packages are in complex faulted contracts with each other (Plafker and Berg, 1994). Dextral strike-slip movement along the Tintina and Denali faults has caused widespread deformation of the rocks syn- and post-regional plutonic events in the Paleozoic and Mesozoic (Plafker and Berg, 1994; Sánchez et al., 2014). Northeast trending faults and less prominent northwest trending faults are also major structural features in east-central Alaska (Gabrielse et al., 2006; Burns et al., 2008; Day et al., 2014). These northeast trending faults are truncated by the Tintina and Denali fault systems and are likely accommodating block rotation related to the movement along these larger dextral systems (Sánchez et al., 2014).

A detailed description of all rock units found in east-central Alaska is beyond the scope of this research. The following sections outline the geologic history of east-central Alaska and provide context for the discussion of the geology of the Fairbanks Mining District in Chapter 2. For a comprehensive explanation of the geology and geologic evolution of the greater circum-pacific region, and specific characteristics of the rock units found in these and other similar metamorphic belts in Alaska and Canada, refer to Foster et al. (1994), Nokleberg et al. (1998), Nelson et al. (2013), and the references therein.

**1.3.1.1 Paleozoic Passive Continental Margin**

During the end of the Precambrian (?) and into the early Paleozoic, the western side of the Laurentian craton (i.e. proto-North America) was a passive continental margin and a shallow water near-shore depositional environment (Figure 1.2a) (Coney et al., 1980). Clastic sediments eroded from the continental craton were deposited with minor carbonates during the late Proterozoic through the early Paleozoic (Foster et al., 1976; Gilbert and Bundtzen, 1979; Aleinikoff et al., 1986; Foster et al., 1994). These rocks represent the parent rocks for the metamorphosed sedimentary and volcanic rocks of the parautochthonous Yukon-Tanana assemblage (DMpYT in Figure 1.1).
Figure 1.2a: Schematic diagram illustrating the Paleozoic to mid-Permian tectonic evolution of east-central Alaska. Time periods A and B are modeled after diagrams from Nelson et al. (2002) and Dusel-Bacon et al. (2015). Time period C is modified from Nelson et al. (2002). Time period D is modified from Dusel-Bacon et al. (2015). Lithologic codes are available in Figure 1.1.
Figure 1.2b: Schematic diagram illustrating the Late Triassic to Late Cretaceous tectonic evolution of east-central Alaska. Time period E – H are modified from Dusel-Bacon et al. (2015). Lithologic codes are available in Figure 1.1.
1.3.1.2 Devonian Yukon-Tanana Arc

In the middle to late Devonian, eastward subduction of oceanic crust initiated arc volcanism along the western margin of the Laurentian continent (Figure 1.2a) (Nelson et al., 2006; Nelson et al., 2013). As a result, granitic plutons were emplaced within the crust on the margin of the continent (Aleinikoff et al., 1986; Davis et al., 2009) between the late Devonian to the Mississippian between 370 and 340 Ma (Dusel-Bacon and Aleinikoff, 1985; Nokleberg and Aleinikoff, 1985; Rubin et al., 1990). Sedimentary and volcanic rocks associated with this Yukon-Tanana arc were deposited along the flanks of active volcanoes beginning in the Silurian(?) and this continued through the Devonian into the Mississippian (Tempelman-Kluit, 1976; Nokleberg and Aleinikoff, 1985; Nelson and Colpron, 2007). Volcanic and volcaniclastic rocks associated with active volcanism were deposited simultaneously with continentally derived clastic sediments (Gilbert and Redman, 1977; Gilbert and Bundtzen, 1979; Bundtzen, 1981; Dusel-Bacon and Aleinikoff, 1985; Foster et al., 1994). The plutonic rocks emplaced during this time represent the parent rocks of the now metamorphosed units classified as augen gneiss and orthogneiss (DMg in Figure 1.1). These rocks intruded the oldest (now metamorphosed) sedimentary and volcanic rocks in east-central Alaska that formed prior to rifting and these packages are found within both the parautochthonous Yukon-Tanana (DMpYT in Figure 1.1), and the allochthonous Yukon-Tanana terranes (MPaYT in Figure 1.1) (Dusel-Bacon and Aleinikoff, 1985; Foster et al., 1994; Dusel-Bacon et al., 2015).

1.3.1.3 Back-arc Rifting

Extension in the back-arc basin of the Yukon-Tanana Arc, possibly driven by slab rollback (Nelson et al., 2013), led to rifting of the arc and the formation of the Seventymile Ocean (Figure 1.2a). This created a divide between a rifted micro-continent terrane termed the allochthonous Yukon-Tanana terrane (MPaYT in Figure 1.1) and the remnant continental margin region termed the parautochthonous Yukon-Tanana terrane (DMpYT; Figure 1.1) (Nelson et al., 2006). Yukon-Tanana arc plutonism was prolonged within the ocean-ward side of the rifted arc relative to the continent-ward side (Nelson et al., 2013) and this magmatism began to fade around 360 Ma and was finished by 350 Ma (Nelson et al., 2006). This rift event importantly marks the change from one to three separate tectonic realms that persisted as separate entities
between the Mississippian and the Late Triassic (Figure 1.2a and 1.2b) (Dusel-Bacon et al., 2015).

This significant sea-floor spreading event occurred between the Late Pennsylvanian to Early Permian (Nelson et al., 2006) and displaced the rifted micro-continent 2000 – 3000 km west of the continental margin by the Early Permian (Belaskey et al 2002; Belaskey and Stevens 2006). Dominantly basaltic volcanic rocks were deposited with minor clastic and carbonaceous sedimentary rocks, which represent the parent rocks of the metamorphosed volcanic and sedimentary rocks of the Seventymile Oceanic terrane (MTrsv in Figure 1.1) (Nelson et al., 2006).

1.3.1.4 Subduction Polarity Reversals

In the Early Permian, there was a switch to northward movement of the proto-Pacific Oceanic plate relative to proto-North America (Nelson and Colpron, 2007). After this change in relative plate motions, there was a radical adjustment in the subduction zone polarity. The eastward dipping subduction zone along the western margin of the allochthonous Yukon-Tanana terrane was replaced by a southwest dipping subduction zone along the eastern margin of this allochthonous micro-continent (Figure 1.2a) (Nelson et al., 2013; Dusel-Bacon et al., 2015). The subduction of Seventymile Oceanic crust below the autochthonous Yukon-Tanana terrane resulted in the emplacement of arc-related dominantly felsic plutonic rocks between 269 – 253 Ma (Nelson et al., 2006; Beranek and Mortensen, 2011). This magmatic event is referred to as the Klondike arc and these rocks cut older rocks of the Yukon-Tanana arc (Nelson et al., 2006). Also during this period, part of the Seventymile Oceanic crust and basin sediments were obducted onto the fore-arc of the eastern margin of the allochthonous Yukon-Tanana terrane (Tempelman-Kluit, 1976; Nelson et al., 2006).

Rocks of the allochthonous Yukon-Tanana terrane were translated northward relative to the margin of the North American continent, and this alienated piece of the continental margin, now semi-entrenched within the oceanic plate, was moving northward with the oceanic crust (Nokleberg et al., 2000). This movement also resulted in the shortening of the elongated micro-continent, which was either accommodated by sinistral strike-slip imbrication along a margin parallel fault (Hansen, 1990), or by margin parallel oroclinal folding (Mihalynuk et al., 1999; Johnston, 2001). Regardless, the rocks of the autochthonous Yukon-Tanana Terrane migrated to
the northeast and collided with the North American continent in the Triassic (Figure 1.2b) (Nokleberg et al., 2000).

The west dipping subduction zone persisted until the Late Triassic, at which point the extinct subduction zone along the western margin of the allochthonous Yukon-Tanana terrane was reactivated (Figure 1.2b) (Dusel-Bacon et al., 2015). It is unclear precisely how much of the Seventymile Ocean was subducted below the allochthonous Yukon-Tanana terrane prior to the subduction zone polarity reversal. It has been argued by Nokleberg et al. (2000) that complete closure of the ocean occurred prior to or coincident with the switch, however, Nelson and Colpron (2007) suggest that there was only a partial closure. Sediments deposited along the ancestral North American margin at this time contain detrital zircons from both the allochthonous and parautochthonous assemblages, indicating that these two terranes were at least proximal to each other by the Late Triassic (Beranek and Mortensen, 2011).

1.3.1.5 Terrane Collision

The estranged allochthonous Yukon-Tanana terrane was translated back to the western margin of the North American continent after the closing of the Seventymile Oceanic realm (Figure 1.2b) (Nokleberg et al., 2000). This initiated the collision of the three tectonic regions and renewed the eastward subduction of oceanic crust below the western margin of the continent, now west of the allochthonous Yukon-Tanana rocks (Nelson et al., 2006). This major collision event was initiated in the Late Triassic and continued into the Cretaceous (Figure 1.2b) (Nelson et al., 2013). Rocks of the allochthonous Yukon-Tanana terrane and the obducted Seventymile Oceanic rocks were thrust above the parautochthonous Yukon-Tanana assemblage (Nelson et al., 2013). This thrusting event was initiated in the Early Jurassic (Figure 1.2b) (Foster et al., 1994), and had ceased by the Late Cretaceous (Figure 1.2b) (Nokleberg et al., 2000). This newly agglomerated region is referred to here as the Yukon-Tanana collisional terrane.

Plutons related to the major collisional event in the Mesozoic were emplaced within the Yukon-Tanana collisional terrane in the Early Jurassic between 197 and 181 Ma (Figure 1.2b) (Day et al., 2002; Davis et al., 2009; Beranek and Mortensen, 2011; Dusel-Bacon et al., 2013; Dusel-Bacon et al., 2015). These silica-undersaturated granitoids are weakly foliated (Dusel-Bacon et al., 2015); kinematic, metamorphic, and geochronologic studies (Dusel–Bacon et al., 1995; Hansen and Dusel-Bacon, 1998; Davis et al., 2009) indicate they were emplaced during a
time of northwest-verging contraction and collision (Dusel-Bacon et al., 2013). Regional metamorphism of the sedimentary, volcanic, and plutonic rocks of the Yukon-Tanana collisional terrane reached amphibolite facies in some areas (Dusel–Bacon et al., 1995; Hansen and Dusel-Bacon, 1998; Davis et al., 2009). Metamorphic grade within this broad region varies between very low-grade diagenesis to amphibolite facies, and these variations are generally abrupt along structurally controlled lithologic contacts (Foster et al., 1994). These structural contacts between rock types with either similar or different metamorphic grades are sometimes low angle thrusts that probably formed during the collisional event between the Late Triassic and Late Cretaceous but they could be high angle sinistral strike-slip faults that were initiated in the mid-Cretaceous (Engebretson et al., 1985; Plafker and Berg, 1994; Nokleberg et al., 2000).

1.3.1.6 Syn- and Post-Collisional Tectonics and Plutonism

East-northeast subduction of oceanic crust below the agglomerated Yukon-Tanana collisional terrane in the Early Jurassic continued into the Late Cretaceous (Figure 1.2b) (Allan et al., 2013; Nelson et al., 2013). The associated granitic intrusions were emplaced during two periods of plutonism: middle Cretaceous plutonism and related volcanism occurring between 135 – 110 Ma (Wilson et al 1985, Newberry et al 1998) or 112 – 95 (Dusel-Bacon et al., 2015), (mKg and mKv in Figure 1.1 and Figure 1.2b); and Late Cretaceous plutonism and volcanism occurring between 68 – 66 Ma (lKg and lKv in Figure 1.1 and Figure 1.2b) (Dusel-Bacon et al., 2015).

In the middle Cretaceous, an oceanic spreading center roughly perpendicular to the North American continental margin interacted with the subduction zone south of the Yukon-Tanana collisional terrane causing counterclockwise rotation of the oceanic plate (Plafker and Berg, 1994). This change in plate motion initiated large-scale, margin-parallel sinistral strike slip faults, such as the Tintina Fault and the Denali Fault, and top-to-the-southeast extensional ductile deformation (Lonsdale, 1988; Plafker and Berg, 1994; Gabrielse et al., 2006), asthenospheric upwelling, and the emplacement of middle Cretaceous granitic intrusions (Hansen and Dusel-Bacon, 1998).

The magnitude and timing of dextral displacement along these faults is contentious within the scientific community (Gabrielse et al., 2006). However, lateral displacement along these faults is estimated to be at least 400 km along the Tintina fault system (Gabrielse et al.,
2006) and 300 – 400 km along the Denali fault system (Lowery, 1998), but estimates have been as high as several thousand km (Marquis and Globerman, 1998; Johnson et al 1996; Wynn et al 1998). There is also a series of northeast trending sinistral faults within the boundaries of the Tintina and Denali fault system, including the Shaw Creek fault (Figure 1.1) (O’Neill et al., 2010). Some of these northeast trending structures were important controls on the emplacement of the Cretaceous plutonic rocks (O’Neill et al., 2010).

As eastward subduction of the oceanic plate continued into the Late Cretaceous, intrusions were emplaced along northeast trending faults forming a continental arc within the Yukon-Tanana collisional terrane (IKg in Figure 1.1 and Figure 1.2b) (Dusel-Bacon et al., 2015). Most of the intrusions emplaced during the Cretaceous are quartz-rich and granitic to granodioritic in composition, however, some gabbro and diabase dikes were also emplaced during this time (Foster et al., 1994; Dusel-Bacon et al., 2015). Eruptive volcanism associated with Late Cretaceous arc magmatism occurred at 93.6 ± 2 Ma and 90 ± 2.8 Ma (Bacon et al., 1985). Sedimentary rocks were also deposited in association with the Late Cretaceous volcanic complexes near Mount Fairplay and Sixtymile Butte (Foster, 1967).

Another phase of plutonism initiated around 65 Ma and terminated around 50 Ma (Tg in Figure 1.1) (Foster et al., 1994; Dusel-Bacon et al., 2015). These intrusions are mainly small bodies, 3 km2 or less, and granitic in composition (Foster et al., 1994). Extrusive volcanic rocks erupted at 61 ± 2 Ma (K-Ar) and 57.8 ± 2 Ma (K-Ar) and 56.4 ± 2 Ma (K-Ar) in the associated with this magmatic activity (Tertiary Volcanic in Figure 1.1) (Foster et al., 1979).

1.3.1.7 Eocene to Present Clastic Sedimentation and Volcanism

Terrestrial sedimentary rocks were deposited in east-central Alaska from the late Cretaceous to the present (Foster et al., 1976). These rocks are un-metamorphosed and vary in composition, including basalt, volcanic tuff, gravel, conglomerate, and sandstone (TQsv in Figure 1.1) (Foster and Clark, 1970; Foster et al., 1994). These Cenozoic sediments unconformably overlie deeply weathered metamorphic rocks (Foster and Clark, 1970).

Glacial moraines and other local sedimentary and erosional features have been linked to the Miocene glacial period, however, these are limited to those of the Alaska Range located along the Denali Fault (Foster et al., 1994). Volcanic rocks were deposited during recent volcanic activity at the Prindle volcano no more than 1,900 years ago but these are very minor
(Foster et al., 1976; Keith et al., 1981). Large areas of east-central Alaska are now covered by unconsolidated but frozen, quaternary aged sediments (Foster et al., 1994). The largest area with these young fluvial sediments is the Tanana river valley, with unconsolidated aeolian sediments in the surrounding uplands (Foster et al., 1994).

1.3.2 Gold Deposits in Metamorphic Rocks

The dominant style of gold mineralization found in metamorphic terranes is shear zone and breccia hosted quartz – gold ± sulfide veins, classified as orogenic gold deposits. The characteristics and classification criteria for this mineralization style are provided in Goldfarb et al. (2005). A less prominent style of gold mineralization can also be found in metamorphic terranes. Sheeted quartz – gold – bismuth veins hosted in reduced felsic intrusions are also found in metamorphic terranes. This second style of gold mineralization is classified as reduced intrusion-related gold deposits (RIRG) (Goldfarb et al., 2005; Hart, 2007). The differences between these deposits is best defined by field observations. Such observations have been catalogued in the Alaska Resource Data File (ARDF) (U.S. Geological Survey, 2016). Although the ARDF provides a preliminary classification of deposits and occurrences in the area, in many cases the data are too limiting to truly determine whether an occurrence is orogenic, RIRG, or another deposit style. In the present study, provisional classifications were assigned for deposits in the ARDF containing sufficient descriptive information to do so. Chapter 2 includes a table and maps detailing the gold occurrences and deposits that were classified and used in the present study.

1.3.3 Regional Geochemical Survey

A regional geochemical survey (RGS) is a method of cataloguing the geochemistry of a given area in a cohesive and consistent manner. A survey can be performed at a wide range of scales (e.g. 1 sample / 1 km2 to 1 sample / 20 km2) and for a wide range of applications including but not limited to regional mineral exploration, geochemical baseline studies, and environmental assessments (Levinson, 1974). Although the acronym RGS includes the word regional, the expression will be used here to describe a geochemical survey collected at a district scale (i.e. one sample / 1 – 5 km2).
The important elements of an RGS are as follows: (1) the sample medium collected; (2) the spatial resolution; (3) the analytical method used; and (4) the elements analyzed. Commonly, research is conducted using data that were collected by prior studies and other considerations specifically applicable to the analysis of historic datasets are: (1) the date of collection and analysis; (2) the name(s) of the original sampler(s); (3) the analytical laboratory used to conduct the analysis; and (4) sample transportation and storage history (if applicable). A standard workflow for the collection and analysis of stream sediment geochemical data is provided in the following section. The important information on points 1 – 4 for the RGS of the Fairbanks Mining District is presented in Chapter 2.

1.3.3.1 Stream Sediment Sampling Method

The following sections outline the standard method for conducting a stream sediment geochemical survey. The geochemical survey data used for this research was conducted following this procedure.

1.3.3.1.1 Planning

The goal of this step is to plan the survey sampling density to fit the needs of your particular project. For a regional study, a scale of about 1 sample per 20 km2 is appropriate and a detailed survey of a smaller area for more thorough investigations of an area, a scale of about 1 sample per 5 km2 is appropriate. This might require a literature search to verify the sample spacing you have chosen will be effective for your purpose.

Part of this step usually includes the creation of maps showing the ideal locations of the samples. The sample locations will be based on the chosen sampling density and will represent the ideal sample locations. The sample locations need to be accessible for the sampling team and it might be necessary to organize 4-wheel drive, helicopter, or fixed-wing transportation to and from the sites, and/or to arrange for access to privately held land. These special accommodations must be made prior to the initiation of the field season.
1.3.3.1.2 Sample Collection and Handling

The goal of this step is to collect a representative sample of material from the stream. The ideal collection location is from an area of lower flow, behind a large rock, or in another slow-moving area of the stream. Sometimes this material is sieved at the sample site to reduce the amount of material to be transported back to the office. This is typically done with a larger screen mesh size (e.g. minus-20, or minus-10 mesh).

Part of this step usually includes recording the sampling location and assigning a sample number. It is advantageous to record a sample number and location in the field as well as any other pertinent information that is desired such as weather, time of day, water temperature or pH, lithology of the rocks that are outcropping nearby, or potential sources of contamination such as roads or buildings.

The sampled material is dried and sieved to a uniform size. This step may happen in the field or after transportation at the office or laboratory. Sometimes the material is sieved at the collection site and then dried and sieved to a smaller size later. This is to reduce the amount of material to be transported from the field. The sample material can be air-dried or oven dried and then sieved to a uniform size for chemical analysis. Because the minus-80 mesh sieve was historically the most available to prospectors, this is most commonly used size in RGS stream sediment studies. The size fraction that is kept for analysis may have a large impact on the results of the survey and it is advisable to perform an orientation survey to determine the most appropriate size fraction to use for your specific purpose. A description of how to execute an orientation survey is available in Levinson (1974) and the references therein.

1.3.3.1.3 Geochemical Analysis

The goal of this step is to select an analytical method that is appropriate for your project goals and budget. Prior to sending the samples to the lab, it is important to consider what the goal of the project is, what elements you are interested in getting results for, and if the method is appropriate for your sample media and the rock types in your project area.

Rocks and minerals have different physical properties to one another that make them more or less amenable to specific types of laboratory analysis, consequently, the details of any analytical method, including the grinding, splitting, or digestion procedures can have a significant influence on the accuracy and/or precision of the analysis. In other words, some
analytical methods are appropriate for specific rocks and others are not. Similarly, the physical structure and chemical bonds of some elements are more or less amenable to specific analytical parameters. Although the sample media for this research is not rock hand samples, the stream sediments are a collection of eroded rock and mineral fragments. The representative sample is sent to the lab following chain of custody procedures. The remaining material is labeled, stored, and protected from contamination.

The analytical methods used in the analysis of the Fairbanks Mining District stream sediment samples include: inductively coupled atomic emission spectroscopy (AES), instrumental neutron activation analysis (INAA), atomic absorption spectroscopy (AA), x-ray fluorescence (XRF), emission spectroscopy (ES), delayed neutron counting (DNC), and coulometry (CM). Details of these analytical procedures are provided in detail in Appendix A. The appropriateness of each method with respect to the elements analyzed is briefly discussed in Chapter 2.

1.3.3.4 Quality Control

It is generally recommended to send control samples into the lab to track their accuracy and precision. These control samples include duplicates, standards, and blanks. The results of the control samples are used to verify the laboratory methods. It is also recommended to compare the results obtained by different laboratories. Sending control material or samples to multiple laboratories is used to test the accuracy and precision of different laboratories. This is done to verify the reported results from the chosen lab and this should be done periodically. If there are issues with the analysis of the control samples, or the results compared to other labs are unsatisfactory, it is necessary to reanalyze sample material or adjust the reported concentrations.

1.3.4 Factor Analysis

Multivariate statistical techniques provide an efficient way to perform statistical analysis on multi-element geochemical datasets to identify element associations related to lithology, alteration, and mineralization (e.g., Grunsky, 2010). Factor analysis is a multivariate statistical method that has been applied to the field of exploration geochemistry since the 1960s (Garrett and Nichol, 1969; Nichol et al., 1969; Closs and Nichol, 1975). In exploration geochemistry, the utility of this method is to group elements based on their common correlations so that the
interdependent relationships between elements are revealed and the total number of variables to be interpreted is reduced (Lawley and Maxwell, 1962; Yong and Pearce, 2013). This method can be used as-is to map areas of mineral prospectivity of the project area in question, or it can be used as a layer with other evidence to support mineral prospectivity mapping (Bonham-Carter et al., 1987; Grunsky and Smee, 1999; Grunsky et al., 2014). The term factor analysis has been used to describe a number of similar mathematical manipulations and it is out of the scope of this work to discuss them all. This work utilized an r-mode factor analysis with a varimix rotation using log-transformed data. For a complete guide on different methods of factor analysis and the mathematics that support them please refer to Yong and Pearce (2013) and the references therein. In Chapter 2, the steps taken to prepare the geochemical dataset for factor analysis, and to perform factor analysis are presented in detail.

1.4 References Cited


CHAPTER 2
PROSPECTING FOR GOLD MINERALIZATION IN THE FAIRBANKS MINING DISTRICT, ALASKA USING R-MODE FACTOR ANALYSIS OF STREAM SEDIMENT DATA

A paper to be submitted to The Journal of Geochemical Exploration
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2.1 Abstract

In the Fairbanks Mining District, lode-gold mineralization occurs in two deposit styles: (1) shear zone and breccia hosted quartz – gold ± sulfide veins cutting metamorphic country rocks; and (2) sheeted quartz – gold – bismuth veins hosted in reduced felsic intrusions. The only large-scale mining operation in the district is developed on a deposit classified as the second style, even though the first style of mineralization is more widespread. Exploration for both styles of lode-gold mineralization has been ongoing in the district, and there is potential for undiscovered deposits. Geochemical surveys are one of the chief methods used in exploration worldwide, and the present study uses stream sediments geochemistry to prospect for gold mineralization in the district. An r-mode factor analysis with varimax rotation was performed on a log transformed stream sediment geochemical dataset, yielding eight factors that explain roughly 70% of the total variance. This method identified one factor associated with gold having an As – Sb – Au geochemical association. The high positive scores for samples for this factor drain areas with known shear zone and breccia hosted quartz – gold ± sulfide veins cutting metamorphic country rocks. However, this factor fails to identify the Fort Knox gold deposit and other prospects of the less dominant mineralization style. In this analysis, the communality for Au is very low (0.45). Therefore, this model poorly explains Au variability in the dataset. In order to explore for deposits with similar geochemistry to Fort Knox, it is possible to combine single-element Au data with the factor analysis, focusing on the factor that identifies reduced felsic intrusions having a Li – Cs – Rb association. This analysis suggests that samples with moderate to high positive scores for factor four that also have significant gold concentrations are...
derived from areas prospective for sheeted quartz – gold – bismuth veins hosted in reduced felsic intrusions, similar to the Fort Knox gold deposit. The combination of factor analysis and single element data resulted in the identification of 25 new areas prospective for different styles of gold mineralization in the district.

2.2 Introduction

Geochemical surveys are one of the chief methods used in the exploration for gold deposits in the Fairbanks Mining District and in adjacent areas of Alaska and Canada, and although there have been many generations of surveys performed, few major deposits have been discovered in Alaska (Allan et al., 2013). This study employs multi-element statistical analyses of historical stream sediment geochemical data in the Fairbanks Mining District in order to (1) define geochemical associations related to the known gold-bearing mineralization styles, and (2) identify new areas of gold prospectivity.

The Fairbanks Mining District is a productive gold placer district in east-central Alaska (Figure 2.1). This district contains a diverse population of gold-bearing lode prospects and deposits including Fort Knox (Hill, 1933; Chapman and Foster, 1969). A detailed stream sediment survey of the Fairbanks Mining District was conducted in the 1980s (Albanese, 1982a, b, c). Statistical analysis of this 11-element dataset was used by Metz (1984) to define areas of mineral prospectivity using single-element anomaly mapping methods. These samples were reanalyzed for 50 elements (Jozwik, 2007) and the present study is the first application of multivariate statistical methods to this new dataset.

Although generalized geologic models of mineral deposits help identify pathfinder elements which can be used in prospectivity mapping (Carranza, 2011), these models do not take into account local variations that may have a significant influence on locations and concentrations of pathfinder elements (Grunsky, 2010). In addition, a project area may contain different mineralization styles that have similar element associations. Therefore, it is important to study pathfinders in the chosen project area in order to maximize the exploration potential for the specific deposit styles in the area of interest. Multivariate statistical techniques provide an efficient way to perform such statistical analysis on large multi-element datasets, in order to identify element associations related to lithology, alteration, and mineralization (e.g., Grunsky, 2010). Factor analysis is one of the most commonly used multivariate techniques because it
extracts correlations between elements that are otherwise hidden, exposing geochemical anomalies related to mineralization (Tripathi, 1979). This method also reduces the total number of variables that need to be interpreted but retains a large percent of the original variance (Tripathi, 1979). Factor analysis can be used as-is to map areas of mineral prospectivity of the project area, or it can provide evidence in targeted approaches using only pathfinder element associations (Bonham-Carter et al., 1987; Grunsky and Smee, 1999; Grunsky, 2010). Through r-mode factor analysis using 38 elements of the 50-element stream sediment geochemical survey data in the Fairbanks Mining District, this study identifies two geochemical signatures associated with lode-gold mineralization, as well as 25 new areas that are prospective for one or both of these mineralization styles.

2.3 Regional Geology and Gold Mineralization

The Fairbanks Mining District is located within east-central Alaska in and around the town of Fairbanks, Alaska (Figure 2.1). The geology of east-central Alaska comprises highly deformed terranes of continental margin, ocean-arc, or rift-ocean affinities that have been complexly rifted from, accreted to, subducted under, and collided with one another between the middle Paleozoic and the Late Cretaceous (Nokleberg et al., 1998; Nelson and Colpron, 2007; Nelson et al., 2013). Felsic to mafic plutonic rocks were emplaced during three main stages of plutonism between the Late Triassic and the Tertiary (Rubin et al., 1990; Hart et al., 2004; Dusel-Bacon et al., 2015). Large dextral strike-slip faults have caused widespread deformation of the country rocks resulting in northeast-southwest trending structures that dissect east-central Alaska (Gabrielse et al., 2006). These faults controlled the emplacement of intrusions during the Mesozoic and were the main fluid conduits for much of the gold mineralization in the region (Gabrielse et al., 2006; Dusel-Bacon et al., 2015). For a detailed geologic history of this region refer to Chapter 1.

2.3.1 Gold Mineralization

Epigenetic gold mineralization has been attributed to regional metamorphic events as well as plutonic emplacement syn- and post-metamorphism (Goldfarb et al., 2016). The source of the gold is unknown but is speculated to have originated from gold-bearing diagenetic pyrite
Figure 2.1: Location, geology, and mineral occurrences of the Fairbanks Mining District in east-central Alaska. The geology of the Fairbanks Mining District is from Newberry et al. (1996) with terminology used in Dusel-Bacon et al. (2015). The location of the Cleary Antiform is from Chapman and Foster (1969). Mineral occurrences are from the Alaska Resource Data File (U.S. Geological Survey, 2016). The mineral occurrences are classified as reduced intrusion-related (RIRG), orogenic (OROG), or skarn style mineralization and the details of this classification are provided in the text. The mineral occurrences are numbered and the names and details are provided in Table 2.1. Streams are from the National Hydrography Dataset (U.S. Geological Survey (USGS) et al., 2018).
from underthrusted ocean basin-related flysch. Most of the lode-gold deposits in east-central Alaska are broadly characterized as gold- and sulfide-bearing quartz veins. These prospects and deposits are hosted in a variety of lithologies including meta-sedimentary, meta-volcanic, and unmetamorphosed plutonic rocks. The gold mineralization has been divided into two broad classifications based on detailed studies (Goldfarb and Miller, 1997; Hart et al., 2002). The most dominant style is shear zone and breccia hosted quartz – gold ± sulfide veins cutting metamorphic rocks, classified as orogenic gold deposits (Selby et al., 2002). The less dominant style is sheeted quartz – gold – bismuth veins hosted in reduced felsic plutonic rocks, commonly classified as reduced intrusion – related gold deposits (Hart, 2007).

2.4 Fairbanks Mining District Geology and Gold Mineralization

The geology of the Fairbanks Mining District has been mapped and described most recently by Newberry et al. (1996), who compiled new and historic findings from the following reports: Forbes et al. (1982); Aleinikoff and Nokleberg (1989); Robinson et al. (1990); Metz (1991); Weber et al. (1992). Other petrologic investigations and lithogeochemical analyses of the mapped geologic units of the district have been conducted by Brown (1962), Chapman and Foster (1969), Swainbank and Forbes (1975), Blum (1983), Foster et al. (1994), Joy et al. (1996), and Douglas et al. (2002). The bedrock geology of the Fairbanks Mining District is illustrated in (Figure 2.1).

The dominant rock types in the Fairbanks Mining District are mica schist and quartzite of the Fairbanks Schist. There are also significant exposures of phyllite of the Birch Hill sequence, metarhyolite of the Muscox sequences, and minor augen gneiss (Figure 2.1) (Forbes et al., 1982; Dusel-Bacon and Aleinikoff, 1985; Newberry et al., 1996). These metamorphosed sedimentary, volcanic, and plutonic units are classified as part of the continental margin-related rocks of the parautochthonous Yukon-Tanana assemblage (Newberry et al., 1996; Davis et al., 2009). The augen gneiss is a metamorphosed granitic sequence that is correlative with other meta-igneous bodies in east-central Alaska, and these rocks intruded the margin of the continent in the Devonian as part of the Yukon-Tanana arc (Dusel-Bacon and Aleinikoff, 1985; Aleinikoff et al., 1986). The Chatanika Terrane forms a conspicuous block of metamorphosed sedimentary and volcanic rocks located in the northeastern part of the district (Swainbank and Forbes, 1975). This metamorphosed sequence is dominated by marble but also contains garnet-bearing eclogitic
metapelite and metabasalt, and is classified as part of the Seventymile Oceanic terrane
(Swainbank and Forbes, 1975; Newberry et al., 1996). Un-metamorphosed, mid-Cretaceous
felsic plutonic rocks are scattered throughout the district and form small dikes and plugs as well
as prominent domes (Blum, 1983; Newberry et al., 1996). The structural fabric of the district is
dominated by northeast trending faults that cut and overprint complexly folded and faulted rocks
(Newberry et al., 1996). The folds were generated by ductile deformation along early northwest
trending and later northeast trending axes (Hall, 1985; Newberry et al., 1996).

2.4.1 Parautochthonous Yukon-Tanana Terrane

Metamorphosed sedimentary and volcanic rocks of the parautochthonous Yukon-Tanana
terrane are the dominant rock type in the Fairbanks Mining District. These metamorphosed
sedimentary and volcanic rocks with continental margin affinities were all subjected to a peak
metamorphic grade of amphibolite facies followed by retrograde metamorphism to greenschist
facies (Joy et al., 1996). They have been divided into three assemblages from oldest to youngest:
(1) The Fairbanks Schist; (2) the Birch Hill sequence; and (3) the Muskox sequence. These three
sequences were originally deposited along the passive continental margin of the Laurentian (i.e.
proto North American) continent in the Proterozoic (Robinson et al., 1990; Foster et al., 1994;
Newberry et al., 1996).

The greenschist to amphibolite facies metamorphic rocks of the Fairbanks Schist terrane
are divided into two members: (1) Quartz muscovite schist, quartzite and chlorite-quartzose
schist, and (2) amphibolite, magnetite-rich biotite schist, quartzose schist, and marble (Newberry
et al., 1996). The Cleary Sequence is a package of meta-volcanic rocks identified by Robinson et
al. (1990). This unit has locally elevated metal concentrations with a distal volcanogenic origin
and it is the possible source rock for the metals contained in the quartz-gold and quartz-gold-
sulfide epigenetic vein prospects (Robinson et al., 1990; Nokleberg et al., 1994). However, this is
unlikely because these rocks were metamorphosed in the Jurassic and gold was deposited in the
Cretaceous (Heffernan, 2004; Dusel-Bacon et al., 2015). This unit has been grouped with the
second member of the Fairbanks Schist (Newberry et al., 1996). Clastic sedimentary and
volcanic protoliths of the Fairbanks Schist terrane are broadly Proterozoic in age (Newberry et
al., 1996). Phyllite, slate, metarhyolite tuff, quartzite, calcareous quartzite schist and impure
marble characterize the Birch Hill sequence and these rocks have an inferred deposition age of
Middle to Upper Devonian (Newberry et al., 1996). The Muskox sequence consists of metamorphosed Upper Devonian aged sandstone and calc-alkaline island arc andesite, basalt and rhyolite (Newberry et al., 1996).

2.4.2 Yukon-Tanana Arc

Coarse grained, foliated, porphyroblastic granodiorite orthogneiss forms two, narrow and elongated bodies in the central part of the Fairbanks Mining District (Newberry et al., 1996). This orthogneiss is similar in mineralogy and character to other metamorphosed granitic rocks found across east-central Alaska and likely crystallized around 350 Ma (Figure 2.1) (Dusel-Bacon and Aleinikoff, 1985; Aleinikoff et al., 1986; Day et al., 2003).

2.4.3 Seventymile Oceanic Terrane

In the Fairbanks Mining District, rocks of the Seventymile Oceanic Terrane are characterized by amphibolite grade interbedded metapelite, metabasalt, metamarl, and marble and are locally classified as the Chatanika Terrane (Figure 2.1) (Newberry et al., 1996; Dusel-Bacon et al., 2015). Protoliths of the Chatanika Terrane are basaltic, calcareous and pelitic sedimentary and volcanic rocks that were deposited in the Seventymile ocean (Swainbank and Forbes, 1975) and subsequently obducted onto the continent during the Triassic along low angle thrust faults (Douglas et al., 2002). These thrust faults, which act as the contact between the Chatanika terrane and the Fairbanks schist, were active between 140 and 115 Ma, with evidence of hydrothermal fluid flow along these faults during this time (Douglas et al., 2002). The exposed block of these rocks in the Fairbanks Mining District is a structural klippe above the rocks of the Fairbanks Schist (Swainbank and Forbes, 1975; Newberry et al., 1996).

2.4.4 Mid-Cretaceous Volcanic and Plutonic Rocks

Un-metamorphosed plutonic rocks intruded the district in two pulses: (1) Quartz-poor, extension-related intrusions at 110 Ma, such as the O'Connorr Creek nepheline syenite (Newberry et al., 1996; Douglas et al., 2002); and (2) Quartz-rich, subduction zone arc-related intrusions, such as the Fort Knox pluton, emplaced between 94 – 88 Ma (Blum, 1983; Newberry et al., 1996) (Figure 2.1). Aplite to pegmatite dikes crosscut porphyritic granodiorite and porphyritic quartz monzonite at the Gilmore Dome pluton (Blum, 1983). These dikes or small plutons vary
in width from 2 to 20 m and generally occur along the edge of the pluton (Blum, 1983). Locally, metamorphic country rocks have been affected by hornfels and calc-silicate metamorphism adjacent to the felsic intrusions (Newberry et al., 1996). Most notably, calcite-epidote and calcite-diopside hornfels found on the western side of the Gilmore Dome pluton are associated with minor tungsten-bearing skarn mineralization (Chapman and Foster, 1969; Blum, 1983). These intrusions formed during crustal thickening related to continental collision in the Cretaceous (Blum, 1983; Dusel-Bacon et al., 2015).

2.4.5 Tertiary Volcanic and Sedimentary Rocks

Tertiary volcanic rocks and associated volcaniclastic sedimentary rocks are exposed in the eastern parts of the Fairbanks Mining District (Newberry et al., 1996). Basalt outcrops have distinct columnar jointing in some places indicating subaerial flows; local pillow and palagonite breccias may indicate lacustrine subaqueous deposition (Forbes et al., 1982; Newberry et al., 1996). Although the basalt units are not widely distributed across the district, the older regional metamorphism was overprinted by a Tertiary thermal event, suggesting the basalt was more extensive but has since been eroded (Newberry et al., 1996).

2.4.6 Structural Geology

The structural fabric of the district is overwhelmingly dominated by northeast trending faults, folds and shear zones (Forbes et al., 1982; Newberry et al., 1996). However, the metamorphic country rocks have been deformed by at least two different events (Hall, 1985). The first deformation event is of an uncertain age and it is associated with northwest trending isoclinal recumbent folding (Forbes et al., 1982). These rocks were refolded by a northeast trending folding event that occurred between 120 – 90 Ma (Forbes et al., 1982; Hall, 1985). The Cleary antiform is the most prominent fold in the district and formed in the second event (Forbes et al., 1982). The axis of the Cleary antiform strikes northeast and is parallel to the trend of mineralization in the Cleary Summit – Pedro Dome area. This structure may be a major control on the mineralized shear zones and faults in along this trend (Hall, 1985). Thrust faults in the district are effectively contacts between different terranes, and the most prominent are the thrust faults that place rocks of Chatanika Terrane above those rocks of the Fairbanks Schist (Douglas et al., 2002).
2.4.7 Gold Mineralization

There are two different styles of gold mineralization in the Fairbanks Mining District: (1) shear zone and breccia hosted quartz – gold ± sulfide veins cutting metamorphic country rocks, and (2) sheeted quartz – gold – bismuth veins hosted in reduced felsic intrusions. The first style is more widespread in the district. These are generally classified as orogenic gold deposits and are the source of much of the giant alluvial gold resource. The second style of mineralization is local in extent but is also an important lode ore style in the district. The world-class Fort Knox gold deposit is the best example of this second style of mineralization and is classified as a reduced intrusion-related gold deposit.

The numerous mineral prospects in the Fairbanks district were first described by Prindle et al. (1913). Prospects in the district have been subsequently studied by Smith (1913), Chapin (1914; 1919), Mertie (1918), Hill (1933), Byers (1957), Allegro (1987), Chapman and Foster (1969), Metz (1991), and Bakke (1995). The Alaska Resource Data File (ARDF) mineral deposit database is currently the most complete compilation of all relevant references for mineral deposits in the state (U.S. Geological Survey, 2016).

A detailed description of all known mineral deposits in the Fairbanks district is out of the scope of this research. However, the mineralogy of these deposits is important for this study, because these data are used to support the interpretations of the r-mode factor analysis. The names and geologic descriptions from the ARDF mineral deposit database are provided for known prospects in the Fairbanks Mining District in Table 2.1. These deposits are located in four main areas: (1) the Cleary Summit – Pedro Dome area (Figure 2.2); the Gilmore Dome area (Figure 2.3); the Vault – Treasure Creek area (Figure 2.4); and the Ester Dome area (Figure 2.5). The deposits listed in Table 2.1 represent those with sufficient descriptive information to be classified in the present study as one of the following deposit styles: orogenic gold, reduced intrusion-related gold, or skarn. The provisional classifications assigned in the present study are solely based on characteristics as catalogued in the ARDF, and it is important to note that field and laboratory work may be required to ground truth these interpretations.
2.4.7.1 Orogenic Gold Deposits

In the Fairbanks Mining District, orogenic style gold deposits are shear zone and breccia
hosted quartz – gold ± sulfide veins and veinlets cutting metamorphic and plutonic rocks. The
known prospects of this style are located in three main areas: (1) the Cleary Summit – Pedro
Dome area (Figure 2.2); (2) the Vault – Treasure Creek area (Figure 2.4); and (3) the Ester Dome
area (Figure 2.5).

The veins at these known prospects vary in width (7.5 cm – 9 m) and mineralogy (quartz
– gold to quartz – gold – sulfide) (Chapman and Foster, 1969). Gold is structurally controlled,
occurring within shears and brecciated zones adjacent to northeast trending faults and shears
(Chapman and Foster, 1969). Gold occurs as free gold in quartz or as small inclusions within
arsenopyrite (Metz, 1991). The gangue minerals are dominantly sulfides and the following have
been reported: arsenopyrite (FeAsS), pyrite (FeS₂), chalcopyrite (CuFeS₂), stibnite (Sb₂S₃),
galena (PbS), sphalerite ((Zn,Fe)S), tetrahedrite (Cu₁₂Sb₄S₁₃), jamesonite (Pb₄FeSb₄S₁₄),
scheelite (CaWO₄), pyrrhotite (Fe, Ni, Co)₁₋ₓS, and molybdenite (MoS₂) (Chapman and Foster,
1969). The host rocks for this style of mineralization in the Fairbanks district include mica and
feldspar-rich low to high grade metamorphosed sedimentary rocks (Chapman and Foster, 1969).

The gold-mineralizing fluids are generally in pressure-temperature equilibrium with the
wall rocks, therefore, these deposits lack a well-developed alteration halo common in other styles
of mineralization (Goldfarb et al., 2005). Although cryptic, alteration assemblages have been
identified at many deposits and detailed study of these indicate an addition of S, H₂O, CO₂, and
K₂O to the wall rock (Goldfarb et al., 2005). The alteration assemblage commonly identified in
greenschist facies metamorphic rocks may include the following carbonate, sulfide, and silicate
minerals: ankerite (Ca(FeMgMn)CO₃), dolomite (CaMg(CO₃)₂), ferroan dolomite, pyrite (FeS₂),
pyrrhotite (Fe₁₋ₓS), arsenopyrite (FeAsS), sericite (KA₁₂(AlSi₃O₁₀)(OH)₂), biotite (approx.
K(Mg,Fe)₃AlSi₃O₁₀(F,OH)₂), albite (Na(AlSi₃O₈)), and chlorite (approx. Mg,Fe)₃(Si,Al)₄O₁₀
(OH)₂•(Mg,Fe)₃(OH)₆). Silicification is also a common alteration style found in association with
orogenic gold deposits, including minor local remobilization of silica, although most silica has
been added from the mineralizing fluid (Goldfarb et al., 2005).
2.4.7.2 Reduced Intrusion-Related Gold Deposits

The one economic example of this style of mineralization in the district is the Fort Knox gold deposit located in the central part of the district (Figure 2.1) (Bakke, 1995). Similar to Fort Knox, other known reduced intrusion-related gold occurrences in the Fairbanks district occur as sheeted quartz – gold ± bismuth veins hosted in reduced intrusive rocks. This style of mineralization is much more localized than the orogenic gold deposits (Chapman and Foster, 1969; Bakke, 1995). Small prospects with this style of mineralization are located in all four of the known prospective areas: (1) the Cleary Summit – Pedro Dome area (Figure 2.2); the Gilmore Dome area (Figure 2.3); the Vault – Treasure Creek area (Figure 2.4); and the Ester Dome area (Figure 2.5). The deposits of this style exhibit the same characteristics as Fort Knox as described below.

The Fort Knox gold deposit is located 20 km northeast of the town of Fairbanks (Figure 2.1 and Figure 2.3). Gold at the Fort Knox deposit occurs in sheeted veins and stockwork zones within and adjacent-to northwest-trending, moderately southwest-dipping shear zones that cut the Fort Knox pluton (Bakke, 1995). Gold also occurs along the margins of east–west trending pegmatites and grey quartz veins that are genetically associated with the felsic intrusions (Bakke, 1995). The hosting Fort Knox pluton intrudes both muscovite-quartz schist and micaceous quartzite of the Fairbanks Schist (Bakke, 1995; Newberry et al., 1996). The host rocks for this style of mineralization are reduced felsic intrusive rocks. The rocks hosting the Fort Knox gold deposit are coarse- to fine-grained granite to granodiorite with minor aplite and pegmatite dikes (Bakke, 1995; McCoy et al., 1997). These rocks are dominantly feldspar, orthoclase, and quartz with accessory zircon and titanite (Bakke, 1995).

Several vein styles are present at the Fort Knox deposit, which are thought to represent different hydrothermal fluid conduits active during plutonic activity and mineralization (Bakke, 1995). The main structures controlling gold mineralization in the Fort Knox deposit comprises east-west striking, steeply south dipping faults. These faults were conduits for pegmatite bodies that transition upward into grey quartz veins averaging about 0.6 g/t Au (Goldfarb, 2018 Pers. Comm., Bakke, 1995). These structures pre-date northwest-southeast striking, gently southwest dipping shear zones, which contain sheeted milky white quartz veins and veinlets that commonly have slightly higher gold grades (Bakke, 1995). The shear zones also contain white quartz fracture-filling veins and thin quartz veinlets which cut the pluton adjacent to the shear zones,
with veinlet densities decreasing away from the major structures (Bakke, 1995). It is proposed that the shear zones were active during the pluton emplacement and gold mineralization (Bakke, 1995). Although the auriferous veins have different morphologies, they are all characteristically low in total sulfide content (<1%) and have a strong Au-Bi-Te geochemical association with a minor enrichment in Mo and W (Bakke, 1995). The reported metallic mineral species in the deposit include native bismuth (Bi), maldonite (AuBi), bismuthenite (Bi₂S₃), telurobismuthite (Bi₂Te₃), bismite (Bi₂O₃), tetradymite (Bi₂Te₂S), eulytite (Bi₄(SiO₄)₃), molybdenite (MoS₂), and scheelite (CaWO₄) (Bakke, 1995; McCoy et al., 1997). Gold is thought to have been deposited contemporaneously with molybdenite, which crystallized at 92.4 Ma (Re – Os of molybdenite from Selby et al., 2002). Atypical of many other style of magmatic-related mineralization styles, the hydrothermal alteration of intrusion-related gold mineralization is typically very minor and only forms narrow (0.5 – 3cm) wide selvages along the edges of the sheeted veins (Hart, 2007). Within these alteration selvages the mafic minerals are replaced by either K-feldspar (KAlSi₃O₈) or carbonate (Hart, 2007). Plagioclase and mafic minerals within the hosting intrusion are altered to sericite (KA₁₂(AlSi₃O₁₀)(OH)₂) with the possible addition of pyrite (FeS₂) and or carbonate minerals outboard of the main alteration selvages (Hart, 2007). The Fort Knox pluton was emplaced 92.5 ± 0.2 Ma (U-Pb of zircon from J.K Mortensen, unpublished data). This pluton is likely part of the Klondike arc that was active during the Late Cretaceous across east-central Alaska (Bakke, 1995; Dusel-Bacon et al., 2015). The close age relationship between the gold mineralization and pluton emplacement is strong evidence to support their coeval development and the classification of Fort Knox as a reduced intrusion-related gold deposit (Selby et al., 2002).

2.4.7.3 Gold-Bearing Skarn Deposits

A few deposits have been classified as gold-bearing skarn occurrences. In general, these deposits exhibit similar characteristics to the orogenic style gold deposits; however, they contain elevated levels of tungsten and calc-silicate gangue minerals and occur as massive lenses and massive replacement bodies within calcareous rock units of the Fairbanks Schist adjacent to plutonic rocks. These occurrences are predominantly located in two of the main mineralized areas: (1) the Cleary Summit – Pedro Dome area (Figure 2.2); and (2) the Gilmore Dome area (Figure 2.3).
2.5 Materials

The details of the sample collection and geochemical survey are provided in the following section. The statistical analyses conducted in the present study are described in the subsequent Methods section.

2.5.1 Fairbanks Mining District Stream Sediment Geochemical Survey

A stream sediment geochemical survey of the Fairbanks Mining District was conducted in 1981 with funding from the State of Alaska as part of a geological and mineralogical investigation of the Fairbank Mining District (Bundtzen, 1982; Metz, 1982; Robinson, 1982) and the results are published in Albanese (1982a, b, c). Stream sediment samples were collected between May and July of 1981 by members of the Alaska Division of Geological and Geophysical Surveys (ADGGS), the University of Alaska's Mineral Industry Research Laboratory, and the Department of Geology and Geophysics at the University of Alaska Fairbanks (Jozwik, 2007). The samples were collected from streams of different catchment sizes and stream orders. A large number of duplicates were collected, although it is unclear if these were field duplicates or laboratory duplicates. The sampling approach taken is not reported but it is assumed here that a sample of the sediment in the stream was collected from a slow-moving section and the location was marked on a topographic map. If the sampling followed standard protocol, the material was likely sieved to minus-20-mesh in the field. Eventually, the samples were air-dried and sieved to minus-80-mesh for subsequent chemical analysis (Jozwik, 2007). A general workflow for the planning, collection, and analysis of stream sediments is provided in Chapter 1.

The stream sediment samples were analyzed in 1981 for 11 elements. The ADGGS laboratory analyzed the samples for Cu, Pb, Zn, Au, Ag, and Mo by atomic-absorption spectrophotometry (AA) (Albanese, 1982a, b, c). The laboratory of Bondar-Clegg and Co. in Vancouver, B.C. analyzed the samples for W and As by coulometry (CM), Hg by cold-vapor atomic-absorption spectrophotometry (CV), and Sn by x-ray fluorescence (XRF) (Albanese, 1982a, b, c). Analysis for Sb is given in the tables of Albanese (1982a, b, c), however the analytical method used to obtain the results is unknown. Nearly all of the 1013 stream sediment samples were analyzed for Cu, Pb, and Zn. Arsenic was analyzed in a majority of the samples.
Only selected samples were analyzed for Au, Ag, Hg, Mo, Sn, Sb, and/or W. For an overview of the AA, CM, CV, and XRF analytical methods please refer to Appendix A.

Pulps from these analyses were stored at the ADGGS warehouse under a tarp until 1995 when they were re-analyzed as part of the 1995 Fairbanks STATEMAP geologic mapping project (Jozwik, 2007). During the re-analyses, the pulp samples were analyzed by Bondar-Clegg and Co. in Vancouver B.C. for a suite of 34 major and trace elements by instrumental neutron activation analysis (INAA), and a suite of 33 major and trace elements by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) (Jozwik, 2007). The pulps were also analyzed for Bi by AA after hydride generation (Jozwik, 2007). Analytical interferences during INAA resulted in unreliable measured values for Ba, Tb, Yb, Zn, and Zr (Baedecker and McKown, 1987). The ICP-AES was performed after a four-acid near total digestion (Hf-HNO3-HClO4 acid digestion with HCl leach) and this digestion method might be incomplete for the following elements: Ba, Cr, Ti, Sn, Al, and rare-earth elements (Jozwik, 2007). For the present study, a stream sediment geochemical dataset consisting of 1,014 samples analyzed for 50 elements was generated by merging the two generations of laboratory analyses. There is one more sample in the combined dataset compared to the old dataset because there is one extra duplicate sample in the more recent reanalysis that had not been analyzed in the original survey. Each element was analyzed by at least one method, and many were analyzed using multiple methods. Stream sediment sample sites are shown in Figure 2.6. Table 1.5 summarizes the analytical method used, the year of analysis, and the appropriate analytical limits of detection for each element. Data tables for both the 1981 and 1995 datasets are available in digital form as supplementary materials (Appendix B).

2.6 Methods

Statistical methods are commonly used in the manipulation of geochemical survey data for the purpose of mineral exploration. Multivariate methods were employed here to prospect for gold mineralization in the Fairbanks Mining District, east-central Alaska.
2.6.1 Statistical Analysis of Geochemical Data

In statistical nomenclature, the term "sample" implies a selection of observations taken from a larger “population”, and many statistical methods assume that the "sample" is sufficient enough to represent an entire "population". However, in the geochemistry vernacular, a "sample" refers to a single specimen of earth material, and each "sample" will have geochemical concentration results for one or many elements. This report uses the geochemical definition and the term "sample" is referring to the stream sediment material that was collected from a single site. Each sample has a reported value for each of the elements analyzed. The elements that were measured are the "variables" to be used in the factor analysis, and the terms "elements" and "variables" are used interchangeably.

The use of regional geochemical survey data in mineral exploration relies on the following hypotheses: (1) the concentration of an element in the sampled material is controlled by geologic factors; and (2) the observed variance in a geochemical dataset is a reflection of this geologic control (Levinson, 1974). These assumptions are accepted in this research, and the geochemical data are used as a tool to strengthen the geologic understanding of the project areas and aid in mineral exploration.

The concentrations of single elements analyzed in a geochemical survey are commonly studied individually (i.e. by univariate statistical methods). As a result, single element maps are commonly produced to illustrate the spatial distribution of these concentrations (Figure 2.7). These can be visually compared to each other to estimate correlation with known geology. Figure 2.7 comprises two single-element maps which are used to show the spatial relationships among Au, As and areas of known mineralization. Useful information can also be gathered by comparing multiple elements to each other. For example, visual assessment of the linear relationship between two elements can be accomplished using maps showing the concentration of multiple elements together or bivariate x-y scatter (Grunsky, 2010). This can be expanded into a correlation matrix of x-y scatter plots for all variables (Grunsky, 2010). If, however, the geochemical dataset contains a large number of variables, it may prove too difficult to effectively and efficiently interpret those results by univariate and bivariate methods (Carranza, 2009; Grunsky, 2010). That difficulty provides the motivation for factor analysis, the goal of which is to reduce the total number of variables and facilitate easier interpretation, while maintaining the majority of the observed variance (Carranza, 2009; Grunsky, 2010).
Figure 2.2: The geology and mineral occurrences of the Cleary Summit – Pedro Dome area, Fairbanks Mining District. The geology is from Newberry et al. (1996) with terminology used in Dusel-Bacon et al. (2015). The location of the Cleary Antiform is from Chapman and Foster (1969). Mineral occurrences are from the Alaska Resource Data File (U.S. Geological Survey, 2016). The mineral occurrences are classified as reduced intrusion-related (RIRG), orogenic (OROG), skarn style mineralization, or lode occurrences. The classified mineral occurrences are numbered and the names and details are provided in Table 2.1a and 2.1b. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.3: The geology and mineral deposits of the Gilmore Dome area. The geology is from Newberry et al. (1996) with terminology used in Dusel-Bacon et al. (2015). The location of the Cleary Antiform is from Chapman and Foster (1969). Mineral occurrences are from the Alaska Resource Data File (U.S. Geological Survey, 2016). The mineral occurrences are classified as reduced intrusion-related (RIRG), orogenic (OROG), skarn style mineralization, or lode occurrences. The classified mineral occurrences are numbered and the names and details are provided in Table 2.1c. Streams are from the National Hydrography Dataset (U.S. Geological Survey (USGS) et al., 2018).
Figure 2.4: The geology and mineral deposits of the Vault – Treasure Creek area, Fairbanks Mining District. The location of the Cleary Antiform is from Chapman and Foster (1969). Mineral occurrences are from the Alaska Resource Data File (U.S. Geological Survey, 2016). The mineral occurrences are classified as reduced intrusion-related (RIRG), orogenic (OROG), skarn style mineralization, or lode occurrences. The classified mineral occurrences are numbered and the names and details are provided in Table 2.1c. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.5: The geology and mineral deposits of the Ester Dome area, Fairbanks Mining District. Figure 2.4: The geology and mineral deposits of the Vault – Treasure Creek area, Fairbanks Mining District. The location of the Cleary Antiform is from Chapman and Foster (1969). Mineral occurrences are from the Alaska Resource Data File (U.S. Geological Survey, 2016). The mineral occurrences are classified as reduced intrusion-related (RIRG), orogenic (OROG), skarn style mineralization, or lode occurrences. The classified mineral occurrences are numbered and the names and details are provided in Table 2.1d. Streams are from the National Hydrography Dataset (U.S. Geological Survey (USGS) et al., 2018).
Table 2.1a: Mineral deposits and prospects in the Fairbanks Mining District. The contained geologic information is from the Alaska Resource Data File mineral deposit database and the ARDF number (ARDF No.) is provided for cross referencing (U.S. Geological Survey, 2016). The map number (Map No.) references the location of these deposits in Figures 2.2, 2.3, 2.4, and 2.5. Based on the limited data on deposit characteristics available in the ARDF, the present study defines the deposit classification (Deposit Class.) for each deposit and prospect as one of the following: orogenic gold, (OROG), reduced intrusion – related gold, (RIRG), or skarn style mineralization.

<table>
<thead>
<tr>
<th>Map No.</th>
<th>Name</th>
<th>Deposit Class.</th>
<th>ARDF No.</th>
<th>Metals</th>
<th>Lat</th>
<th>Lon</th>
<th>Ore</th>
<th>Gangue</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silver Fox</td>
<td>RIRG</td>
<td>LG062</td>
<td>Ag, Au, Cu, Mo, Pb, Sb, W, Zn</td>
<td>65.0085</td>
<td>-147.566</td>
<td>Argentiferous galena, cerussite, chalcopyrite, gold, jamesonite, molybdenite, powellite, sphalerite, stibnite, tetrahedrite</td>
<td>Complex polymetallic vein system contains pyrite, chalcopyrite, argentiferous galena, molybdenite, sphalerite, and some gold.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Nightingale</td>
<td>RIRG</td>
<td>LG067</td>
<td>Ag, Pb, Sb</td>
<td>65.015</td>
<td>-147.522</td>
<td>Argentiferous galena, stibnite</td>
<td></td>
<td>Argentiferous galena and stibnite occur in stockworks and veins within an altered quartz diorite.</td>
</tr>
<tr>
<td>3</td>
<td>True North</td>
<td>OROG</td>
<td>LG055</td>
<td>Au, Sb</td>
<td>65.0459</td>
<td>-147.562</td>
<td>Gold, stibnite</td>
<td>Carbonates, quartz</td>
<td>Thin quartz-carbonate veins contain gold commonly containing stibnite cut high grade metamorphic rocks within gently dipping shear zones and along faulted contacts, confined to a broad northeast-trending zone.</td>
</tr>
<tr>
<td>4</td>
<td>North Star Extension</td>
<td>RIRG</td>
<td>LG081</td>
<td>Au</td>
<td>65.034</td>
<td>-147.478</td>
<td>Gold</td>
<td></td>
<td>Gold occurs in a quartz porphyry dike.</td>
</tr>
<tr>
<td>5</td>
<td>Cheyenne</td>
<td>OROG</td>
<td>LG092</td>
<td>Au, Ag, Sb</td>
<td>65.049</td>
<td>-147.442</td>
<td>Arsenopyrite, stibnite, tetrahedrite</td>
<td></td>
<td>8-inch-wide, mineralized shear zone. The shear zone was hosted in an iron oxide stained schist cut by numerous quartz stringers.</td>
</tr>
<tr>
<td>6</td>
<td>Newsboy</td>
<td>OROG</td>
<td>LG100</td>
<td>Ag, Au, Cu, Pb, Sb, Zn</td>
<td>65.0561</td>
<td>-147.4737</td>
<td>Arsenopyrite, chalcopyrite, gold, pyrite, sphalerite, stibnite</td>
<td>Quartz</td>
<td>Shear zones and stockworks with abundant white quartz are 2 to 14 feet wide and average 4 to 5 feet wide.</td>
</tr>
<tr>
<td>7</td>
<td>Tolovana</td>
<td>OROG</td>
<td>LG110</td>
<td>Au, Ag, As, Pb, Sb, W</td>
<td>65.0626</td>
<td>-147.4518</td>
<td>Arsenopyrite, galena, gold, pyrite, sphalerite, stibnite, tetrahedrite</td>
<td>Quartz</td>
<td>Ribbon-texture quartz stringers to massive quartz veins which vary from a few inches to 3 feet in width. The main shear strikes N30-65E and dips 30-60SE. Ore in the Tolovana Mine varies from ribbon-texture quartz stringers to massive quartz veins which vary from a few inches to 3 feet in width.</td>
</tr>
</tbody>
</table>
Table 2.1b: Mineral deposits and prospects in the Fairbanks Mining District. The contained geologic information is from the Alaska Resource Data File mineral deposit database and the ARDF number (ARDF No.) is provided for cross referencing (U.S. Geological Survey, 2016). The map number (Map No.) references the location of these deposits in Figures 2.2, 2.3, 2.4, and 2.5. Based on the limited data on deposit characteristics available in the ARDF, the present study defines the deposit classification (Deposit Class.) for each deposit and prospect as one of the following: orogenic gold, (OROG), reduced intrusion – related gold, (RIRG), or skarn style mineralization.

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<th>Metals</th>
<th>Lat</th>
<th>Lon</th>
<th>Ore</th>
<th>Gangue</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Dolphin</td>
<td>RIRG</td>
<td>LG112</td>
<td>Au, Ag, Bi, Pb, Sb, Te, Zn</td>
<td>65.0617</td>
<td>-147.4466</td>
<td>Arsénoprite, bismuthinite, boulangerite, chalcopryite, galena, gold, jamesonite, maldonite, marcasite, native bismuth, pentlandite, pyrite, pyrrhotite, sphalerite, stibnite, tetradymite, tetrahedrite</td>
<td>Calcite, feldspar, sericite</td>
<td>The gold content is chiefly in quartz veinlets, typically less than 1 mm wide, that cut the stock. Vein orientations vary with no apparent preferred orientation.</td>
</tr>
<tr>
<td>9</td>
<td>Cleary Hill</td>
<td>OROG</td>
<td>LG205</td>
<td>Ag, Au, Ag, As, Au, Cu, Sb, Pb, Zn</td>
<td>65.065</td>
<td>-147.4387</td>
<td>Arsénoprite, boulangerite, jamesonite, pyrite, stibnite, tetrahedrite</td>
<td>Quartz</td>
<td>The mineralization consists of quartz veins that cut interbedded Paleozoic volcanic rocks, quartzite, and quartz mica schists on the north flank of the Cleary antiform. Most mineralization is found in the Cleary Hill vein system that strikes about N70-80W and dips about 45-70 degrees south.</td>
</tr>
<tr>
<td>10</td>
<td>Christina</td>
<td>OROG</td>
<td>LG146</td>
<td>Au, Ag, Sb</td>
<td>65.069</td>
<td>-147.378</td>
<td>Gold, stibnite</td>
<td></td>
<td>Mineralization is characterized as N 70-80 W, 75 S schist-hosted auriferous shear systems with discrete and/or crushed veins and skarn. Sulfide and oxide alteration typically form envelopes paralleling the shear.</td>
</tr>
<tr>
<td>11</td>
<td>Goose Creek</td>
<td>OROG</td>
<td>LG161</td>
<td>Au, Ag, As, Bi, Pb, Sb, Zn</td>
<td>65.077</td>
<td>-147.36</td>
<td>Arsénoprite, pyrite, sphalerite, stibnite, tetrahedrite</td>
<td>Sericite</td>
<td>Mineralization is characterized as intrusion and schist-hosted, gold bearing stockwork veins, shears and disseminations. mineralization is controlled by an 85 degree south dipping structure.</td>
</tr>
<tr>
<td>12</td>
<td>Too Much Gold</td>
<td>OROG</td>
<td>LG178</td>
<td>Au</td>
<td>65.074</td>
<td>-147.324</td>
<td>Gold</td>
<td></td>
<td>Disseminated sulfides and stibnite is hosted by highly oxidized metarhyolite tuff, iron-oxide stained chloritic schist, and quartzite.</td>
</tr>
<tr>
<td>13</td>
<td>Hi Yu</td>
<td>OROG</td>
<td>LG182</td>
<td>Au, Ag, Pb, Sh, Zn</td>
<td>65.0753</td>
<td>-147.2818</td>
<td>Argentiferous galena, arsenopyrite, boulangerite, gold, pyrite, sphalerite, stibnite</td>
<td>Quartz</td>
<td>Several quartz veins along a prominent shear zone, and most offset by faults. The northwest-trending, south-dipping shear zone and associated veins was known to be over 3,000 feet long on the surface and contained several ore shoots. The northern branch, trends N75W and dips steeply south.</td>
</tr>
</tbody>
</table>
Table 2.1c: Mineral deposits and prospects in the Fairbanks Mining District. The contained geologic information is from the Alaska Resource Data File mineral deposit database and the ARDF number (ARDF No.) is provided for cross referencing (U.S. Geological Survey, 2016). The map number (Map No.) references the location of these deposits in Figures 2.2, 2.3, 2.4, and 2.5. Based on the limited data on deposit characteristics available in the ARDF, the present study defines the deposit classification (Deposit Class.) for each deposit and prospect as one of the following: orogenic gold, (OROG), reduced intrusion – related gold, (RIRG), or skarn style mineralization.

<table>
<thead>
<tr>
<th>Map No.</th>
<th>Name</th>
<th>Deposit Class.</th>
<th>ARDF No.</th>
<th>Metals</th>
<th>Lat</th>
<th>Lon</th>
<th>Ore</th>
<th>Gangue</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Fort Knox</td>
<td>RIRG</td>
<td>FB115</td>
<td>Au, As, Bi, Mo, Te, W</td>
<td>64.992</td>
<td>-147.361</td>
<td>Arsenopyrite, bismite, bismuth, bismuthinite, eulytite, gold, maldonite, molybdenite, scheelite, tellurobismuthite, tetradyinite</td>
<td>Quartz</td>
<td>Gold occurs along margins of stockwork quartz veins and veinlets, quartz-filled shear zones, and along fractures within a granite.</td>
</tr>
<tr>
<td>15</td>
<td>Stepovich</td>
<td>Skarn</td>
<td>FB119</td>
<td>Au, W</td>
<td>64.979</td>
<td>-147.327</td>
<td>Gold</td>
<td>Quartz, diopside, hornblende</td>
<td>Irregular lenses of granular scheelite replacing limestone adjacent to intrusion. Quartz-pegmatite veinlets with minor scheelite strike N 40-60 W and dip 60 NE.</td>
</tr>
<tr>
<td>16</td>
<td>Yellow Pup</td>
<td>Skarn</td>
<td>FB118</td>
<td>W</td>
<td>64.981</td>
<td>-147.348</td>
<td>Scheelite</td>
<td>Apatite, diopside, garnet, hornblende</td>
<td>Scheelite is found with other minerals replacing beds of quartzite and pelitic schists. The mineralization is found along the eastern limb of a small, north plunging asymmetrical antiform that flattens and is truncated to the south by a fault.</td>
</tr>
<tr>
<td>17</td>
<td>Schubert</td>
<td>Skarn</td>
<td>FB111</td>
<td>W</td>
<td>64.975</td>
<td>-147.392</td>
<td>Scheelite</td>
<td></td>
<td>Scheelite occurs as disseminated grains in bands within silicified limestone adjacent to porphyritic granite.</td>
</tr>
<tr>
<td>18</td>
<td>Tungsten Hill</td>
<td>Skarn</td>
<td>FB097</td>
<td>W, Au</td>
<td>64.949</td>
<td>-147.533</td>
<td>Gold, scheelite</td>
<td>Quartz</td>
<td>Scheelite occurs disseminated within the country rocks and within veinlets along the periphery of a large granitic body. Quartz-gold veins cut scheelite.</td>
</tr>
</tbody>
</table>

Vault-Treasure Creek Area

<table>
<thead>
<tr>
<th>Map No.</th>
<th>Name</th>
<th>Deposit Class.</th>
<th>ARDF No.</th>
<th>Metals</th>
<th>Lat</th>
<th>Lon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Treasure Creek</td>
<td>OROG</td>
<td>LG039</td>
<td>Au</td>
<td>65.007</td>
<td>-147.763</td>
<td>Quartz vein with gold.</td>
</tr>
<tr>
<td>20</td>
<td>Bunker Hill</td>
<td>OROG</td>
<td>FB082</td>
<td>Au</td>
<td>64.994</td>
<td>-147.699</td>
<td>Quartz vein with gold.</td>
</tr>
</tbody>
</table>

43
Table 2.1d: Mineral deposits and prospects in the Fairbanks Mining District. The contained geologic information is from the Alaska Resource Data File mineral deposit database and the ARDF number (ARDF No.) is provided for cross referencing (U.S. Geological Survey, 2016). The map number (Map No.) references the location of these deposits in Figures 2.2, 2.3, 2.4, and 2.5. Based on the limited data on deposit characteristics available in the ARDF, the present study defines the deposit classification (Deposit Class.) for each deposit and prospect as one of the following: orogenic gold, (OROG), reduced intrusion – related gold, (RIRG), or skarn style mineralization.

<table>
<thead>
<tr>
<th>Map No.</th>
<th>Name</th>
<th>Deposit Class.</th>
<th>ARDF No.</th>
<th>Metals</th>
<th>Lat</th>
<th>Lon</th>
<th>Ore</th>
<th>Gangue</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ester Dome Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Ryan Lode</td>
<td>OROG</td>
<td>FB065</td>
<td>Ag, Au, Sb</td>
<td>64.863</td>
<td>-147.99</td>
<td>Arsenopyrite, gold, jamesonite, stibnite</td>
<td>Quartz</td>
<td>Quartz veins in shear zones contain gold, arsenopyrite, and minor pyrite and stibnite.</td>
</tr>
<tr>
<td>22</td>
<td>Last Chance</td>
<td>OROG</td>
<td>FB060</td>
<td>Au, Sb</td>
<td>64.875</td>
<td>-147.992</td>
<td>Arsenopyrite, gold, stibnite</td>
<td>Quartz</td>
<td>Quartz vein contains arsenopyrite, stibnite and gold.</td>
</tr>
<tr>
<td>23</td>
<td>Grant</td>
<td>OROG</td>
<td>FB058</td>
<td>Au, Ag, Pb, Sb, W</td>
<td>64.882</td>
<td>-147.957</td>
<td>Arsenic and antimony oxides, arsenopyrite, galena, gold, scheelite</td>
<td>Goethite, muscovite</td>
<td>Brecciated zone presumed to be a vein, contains quartz fragments cemented by oxides of iron, arsenic, and antimony. Contains gold.</td>
</tr>
<tr>
<td>24</td>
<td>Michley</td>
<td>OROG</td>
<td>FB012</td>
<td>Au</td>
<td>64.881</td>
<td>-148.026</td>
<td>Gold</td>
<td>Quartz</td>
<td>Milky white quartz veins are exposed in mine workings. Little to no sulfides.</td>
</tr>
<tr>
<td>25</td>
<td>Sanford</td>
<td>OROG</td>
<td>FB008</td>
<td>Au</td>
<td>64.892</td>
<td>-148.01</td>
<td>Gold</td>
<td>Quartz</td>
<td>Quartz vein near contact between two schist units</td>
</tr>
<tr>
<td>26</td>
<td>McQueen</td>
<td>OROG</td>
<td>FB016</td>
<td>Au</td>
<td>64.873</td>
<td>-148.083</td>
<td>Gold</td>
<td>Quartz</td>
<td>Quartz vein associated with high angle NE trending fault.</td>
</tr>
<tr>
<td>27</td>
<td>Unnamed</td>
<td>OROG</td>
<td>FB156</td>
<td>Au, As, Sb</td>
<td>64.8897</td>
<td>-148.0675</td>
<td>Arsenopyrite, gold, stibnite, pyrite</td>
<td>Quartz, sericite</td>
<td>Quartz-sulfide veinlets with quartz-sericite-pyrite alteration selvages. Mineralization associated with cluster of granitic bodes.</td>
</tr>
<tr>
<td>28</td>
<td>Lepsoe</td>
<td>OROG</td>
<td>FB005</td>
<td>Au</td>
<td>64.897</td>
<td>-148.08</td>
<td>Gold</td>
<td>Quartz</td>
<td>Quartz vein with gold, may be associated with nearby intrusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Gil</td>
<td>Skarn</td>
<td>LG200</td>
<td>Au, Bi, Te, Ag, Mo, W</td>
<td>65.0258</td>
<td>-147.1084</td>
<td>Arsenopyrite, pyrite</td>
<td>Calcite, quartz</td>
<td>The mineralization is stratabound in calc-silicate hornfels and it consists mainly of auriferous quartz and quartz-calcite veins in shear zones and in limonite-stained fractures.</td>
</tr>
<tr>
<td>30</td>
<td>Hattie</td>
<td>RIRG</td>
<td>FB071</td>
<td>Au</td>
<td>64.984</td>
<td>-147.879</td>
<td>Gold</td>
<td></td>
<td>A gold bearing intrusive rock was found to also be elevated in thorium, niobium, tantalum, and REE.</td>
</tr>
</tbody>
</table>
Figure 2.6: Sample locations for the Fairbanks Mining District stream sediment geochemical dataset. Sample locations modified from Albanese (1982a, b, c). Mineral occurrences from the Alaska Resource Data File (U.S. Geological Survey, 2016). The mineral occurrences are classified as reduced intrusion-related (RIRG), orogenic (OROG), or skarn style mineralization and the details of this classification are provided in the text. The mineral occurrences are numbered and the names and details are provided in Tables 2.1a – 2.1d. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.7: Map showing the concentration of As, and Au in the Fairbanks Mining District. Data are from Jozwik (2007). Mineral occurrences from the Alaska Resource Data File (U.S. Geological Survey, 2016). The mineral occurrences are classified as reduced intrusion-related (RIRG), orogenic (OROG), or skarn style mineralization and the details of this classification are provided in the text. The mineral occurrences are numbered and the names and details are provided in Tables 2.1a – 2.1d. Streams are from the National Hydrography Dataset (U.S. Geological Survey (USGS) et al., 2018).
2.6.2 Factor analysis

Factor analysis is a term that has been used to describe a number of similar mathematical manipulations used for multivariate statistical analyses. Although it is out of the scope of this work to discuss all of the possible methods to which this term has been applied, Yong and Pearce (2013) and the references therein provide a complete guide on methods of factor analysis and the supporting mathematics. Factor analysis has been applied to exploration geochemistry since the 1960s (Garrett and Nichol, 1969; Nichol et al., 1969; Closs and Nichol, 1975). In exploration geochemistry, the utility of this method is to group elements based on their common correlations so that the interdependent relationships between elements are revealed and the total number of variables to be interpreted is reduced (Lawley and Maxwell, 1971; Yong and Pearce, 2013). This method can be used as-is to map areas of mineral prospectivity of the project area in question, or it can be used as a layer with other evidence to support mineral prospectivity mapping (Bonham-Carter et al., 1987; Grunsky and Smee, 1999; Grunsky et al., 2014).

The necessary considerations for utilizing factor analysis with geochemical data have been discussed in detail by Grunsky (2010) and Reimann et al. (2002), and these recommendations have been used to guide the data preparation methods outlined here. The topics addressed by these researchers are briefly discussed here to give background information in support of the data manipulations that were performed on each dataset prior to factor analysis in the present study.

This research uses a maximum likelihood r-mode factor analysis modeled after (Lawley, 1940) with varimax rotation of the factor loadings and the factor scores derived using the methods of Kaiser (1958). These analyses are applied to a stream sediment geochemical dataset in the Fairbanks Mining District to: (1) define geochemical signatures associated with lode-gold mineralization; and (2) prospect for lode-gold mineralization in the district. The workflow to complete the factor analysis is illustrated in Figure 2.8.

The results of factor analysis comprise two parts: (1) the factor loadings table, which reveals the geochemical associations; and (2) the factor scores, which are new variables that can be mapped to spatially illustrate geochemical trends (Tripathi, 1979). Both the factor loadings and the factor scores are used here to define the geochemical signatures associated with lode-gold mineralization in the Fairbanks Mining District. The factor scores are used to identify prospective areas for gold mineralization in the district. In the present study, two scripts were
written for MATLAB® to make the data manipulation more efficient, and they are both available as supplementary files (Appendix B). The first script was written to statistically evaluate the geochemical data prior to factor analysis and was modeled after recommendations published by Reimann et al. (2002) and Grunsky (2010). The second script was written to perform a maximum likelihood r-mode factor analysis with varimax rotation modeled after Lawley (1940) and Kaiser (1958). Single element maps and factor scores were plotted using ArcGIS™ following recommendations by Reimann et al. (2005). Single element maps for all the elements used in this study are available in Appendix B.

2.6.2.1 Preparing a Geochemical Dataset for Factor Analysis

It is highly recommended that a thorough evaluation of the dataset be employed prior to attempting factor analysis (e.g., Grunsky, 2010), including the three most important considerations: (1) censored data; (2) normal distribution; and (3) summary statistics. An overview of these topics and how they were addressed here is presented below.

2.6.2.2 Censored Data

Censored data are elements that are detected outside of the limits of detection (below the lower limit of detection (LLD), or above the upper limit of detection (ULD)) in a significant percentage of the total number of samples (Grunsky, 2010). These variables are unlikely to ever be normally distributed and are therefore problematic for factor analysis (Reimann and Filzmoser, 2000; Reimann et al., 2002). A similar problem exists with samples that are only removed prior to factor analysis (Grunsky, 2010). The samples in the Fairbanks dataset that were not re-analyzed in 1995 are, therefore, highly censored and were not used in the factor analysis. An element that has been detected within the limit of detection (LLD < value < ULD) for all samples is 0% censored and a variable that was not detected within the limits of detection for any of the samples is 100% censored (LLD > value > ULD). There is some disagreement about what threshold value is the most appropriate (1% from Grunsky (2010); 20% from Reimann et al. (2002)), however, Reimann et al. (2002) concludes that even highly censored variables can contribute interesting information to the results of factor analysis. Variables that are less than 32% censored are considered "un-censored" for this research. This threshold was chosen to
include the analyses for Au because it is the element of interest for this study. The variables that are included in factor analysis are shown in Table 2.2. Samples with concentrations below the limit of detection were assigned 0.7 times the lower limit of detection for that element and samples that were not analyzed for an element were assigned the mean value for that element. Typically, samples with concentrations above the upper limit of detection are assigned 1.5 times the upper limit of detection for that element, however, no samples in this dataset required this.
2.6.2.3 Normal Distribution

Normally distributed variables contain a range of values that are symmetrical around the mean value (e.g. Davis, 2002). Commonly, geochemical data are not normally distributed, and are skewed by anomalously high values. This can be caused by highly censored datasets as described above. It is often assumed that geochemical data are log-normally distributed and that a log-transformation will restructure the data such that it is normal enough for multivariate analysis (Reimann and Filzmoser, 2000). However, those authors found that this issue is more complex than is usually considered, and most geochemical data are neither normal or log-normally distributed. For simplicity and to follow methods used in past factor analysis studies (e.g., Harraz et al., 2012) the method developed here includes evaluating the data for normality before and after a log-transformation; these results are reported with the summary statistics in Table 2.2. For more information about these and other transformation methods please refer to statistical texts such as Davis (2002).

In exploration geochemistry, the anomalously high values (i.e. outliers) are commonly used individually to explore for mineralization, and statistical manipulation is utilized to more easily recognize geochemical anomalies (Levinson, 1974). However, geochemical anomalies cause the data to be highly skewed and therefore not normally or log-normally distributed (Reimann and Filzmoser, 2000). When utilizing multivariate statistical techniques, the results can be heavily biased towards these outlier values and this generally invalidates the results of factor analysis (Grunsky, 2010). Therefore, it is sometimes advisable to remove samples with anomalous values prior to the application of multivariate techniques (Grunsky, 2010). However, it is assumed here that this bias towards outliers is aiding the identification of gold related elements and, therefore, highly anomalous values were kept in the datasets.

2.6.2.4 Summary Statistics

A summary statistics table was prepared to include the following observations: minimum, maximum, mean, and median values; standard deviation and median absolute deviation; and p values for Kolmogorov-Smirnov (Smirnov, 1948), Shapiro-Wilk (Shapiro and Wilk, 1965), and Chi Square (Garrett, 1989) tests for normality of the original raw dataset and log-transformed dataset (Table 2.2). Histograms, box-plots, and quantile-quantile plots are graphical representations of summary statistical values and they are used as a visual aid in the evaluation
of the data as recommended by Grunsky (2010). These plots are available for each variable as supplementary files in Appendix B.

The summary statistics tables and univariate plots were used to guide the creation of single element concentration maps for each element following recommendations by Reimann et al. (2005). This step served three purposes: (1) to quality control the data; (2) to check the results of factor analysis against raw data; and (3) to visually estimate the correlation of elements not used in factor analysis with the prospective areas identified through factor scores analysis. Single element concentration maps for gold-related elements Au and As are given in Figure 2.7. The concentration maps of all the elements used in the factor analysis are provided as supplementary files in Appendix B.

2.6.2.5 Selecting the Number of Factors

Applications of factor analysis to geochemical data rely on the assumption that there are underlying factors controlling the measured concentrations of the elements (Lawley and Maxwell, 1971). This assumption can be tested by the application of a correlation matrix, which calculates the degree of correlation between each element (Pearson, 1912). If this assumption is accepted, a potential next step is to identify and define these factors, which leads to the question of how many factors should be chosen. The three most common procedures used to estimate the "ideal" number of factors for a dataset are: (1) calculate the eigenvalues following Hoffman and Kunze (1971) and select the number of factors with an eigenvalue greater than one (e.g., Yousefi et al., 2014); (2) calculate the explained variance for each eigenvalue and then select enough factors to meet a pre-determined cumulative variance threshold (e.g. > 70%); and (3) create a scree plot after Cattell (1966) and plot the number of factors against the explained variance, where the number of factors are chosen based on the location where the regression line starts to flatten (i.e. the change in slope). The number of factors to be extracted in factor has an impact on the results of this method and these procedures are considered "rules of thumb" (Reimann et al., 2002). Reimann et al. (2002) recommend testing the results of factor analysis using different numbers of factors for the same dataset, and also performing factor analysis with different combinations of variables. This study calculated the number of factors with eigenvalues greater than one but also calculated the cumulative percent variance for reference.
2.6.2.6 Calculate the Factor Loadings

In the present study, factor loadings were calculated using a maximum likelihood r-mode factor analysis shown in Equation 2.1, whereby, $X$ denotes a variable and $p$ denotes the number of variables ($X_1$, $X_2$, ... $X_p$), $F$ denotes a factor and $m$ denotes the number of underlying factors ($F_1$, $F_2$, ... $F_m$), and $\alpha$ denotes the factor loading value (Lawley, 1940). This equation states that every underlying factor can be explained by the linear combination of all variables multiplied by a factor loading value with the addition of a residual value $e$. The residual value is unique to each variable.

$$X_j = \alpha_{j1}F_1 + \alpha_{j2}F_2 + ... + \alpha_{jp}F_p + e_j$$

(2.1)

Where $j = 1, 2, ... p$

Equation 2.1 can also be written as a summation and this is shown in Equation 2.2. This illustrates, in a different way to Equation 2.1, that factor analysis is a sum of calculations. Loading values are calculated for all variables for all factors by the maximization of the linear correlations with the addition of a residual value $e$.

$$X_j = \sum_{b=1}^{m} a_{jb}F_b + e_j$$

(2.2)

Where $j = 1, 2, ... p$

Essentially, the loading value gives an approximation of how much a specific variable controls an underlying factor, and these values can be displayed in a table. In this way, factor analysis groups elements together that are controlled by the same underlying factor (Reimann et al., 2002). These groups, for the purpose of exploration geochemistry, are used to determine the geochemical signatures as they relate to geology (Tripathi, 1979). The identification of the important elements is discussed in the following section.

Rotation of the factor loadings can make interpretation of the results easier and more intuitive (Yong and Pearce, 2013). The most common method is a varimax rotation (Kaiser, 1958). This method works to minimize the number of variables that load highly to each factor.
and reduce the loading values of low scoring variables (Yong and Pearce, 2013). The details of this mathematical manipulation are discussed in detail in Kaiser (1958).

The communality is a measure of how well the variance in a variable is explained by the entire factor model (comprising all the factors). The communality is calculated for each of the elemental variables ($C_X$) and reported in the factor loading table. Equation 2.3 shows how this value is calculated using the sum of the squared factor loadings ($\alpha$) for each of the underlying factors ($m$).

$$C_X = (\alpha_{F1})^2 + (\alpha_{F2})^2 + ... (\alpha_{Fk})^2$$

(2.3)

Where $m = 1, 2, ... k$

### 2.6.2.7 Determine Geochemical Relationships

A distinct geochemical association generally characterizes lithologic units, alteration, and mineralization (Levinson, 1974). As discussed in the previous section, factor analysis produces groups of elements based on their linear correlations (Lawley, 1940). The concentrations of these elements are controlled by geology (e.g. lithology, alteration, mineralization) and therefore each factor (i.e. group of elements) can be linked to the geology using geochemistry (Tripathi, 1979). For stream sediment data, the concentrations of elements may also be partially controlled by processes in the secondary environment (e.g. adsorption) (Jenne, 1968). In order to pick out the elements that are within a group from the factor loadings table, there must be a decision about what loading values are important.

In most factor analyses, the high positive loading values are given the most attention (e.g. Yousefi et al., 2014), however, Reimann et al. (2002) shows that high negative loading values can also be important. Also, the largest loading values are generally considered the most important (e.g. $> 0.6$) however, some elements that have weak loading values (e.g. 0.3) that load onto more than one factor may also be important (Reimann et al., 2002). Some elements do not load highly onto any factor and some elements load onto multiple factors. For these elements, it is then useful to think about their relevance to the corresponding factor even if that variable does not have a significant loading value for that factor (Filzmoser, 1999). In other words, discussions
that only include the elements with the largest loading values may be ignoring important element relationships (Reimann et al., 2002).

There is no universally accepted threshold value in determining the significant loading values and, therefore, the significant elements for each factor. Commonly researchers will only display the loadings that are greater than 0.2 or less than -0.2 and discuss the significance of any variables with loadings that fall within the absolute value of 0.6 and 1 for each factor (e.g. Marsh et al., 1998; Reimann et al., 2002; Kumru and Bakaç, 2003). This research uses a threshold of 0.6 to determine the most important elements for each factor. Other elements that do not load highly to any factor, and those elements that have moderately high scores for more than one factor are also considered and discussed briefly.

2.6.2.8 Calculate the Factor Scores

A factor score can be assigned to each sample in the dataset for each of the extracted factors and these can be considered new variables (Yong and Pearce, 2013). The present study used the Bartlett method (i.e. regression approach) (Bartlett, 1937). This method was chosen because it produces unbiased scores and it is one of the two most common methods to calculate factor scores (Yong and Pearce, 2013). The method utilizes the factor loading values to assign a factor score to each sample for each of the factors. This calculation is shown in Equation 2.4 and calculates fi which denotes factor score, for the data (i.e. factor) of interest, which is denoted by Fi (Estabrook and Neale, 2013). This calculation uses A, which denotes the matrix of factor loadings, C, which denotes the factor covariance matrix, E, which denotes the residual covariance matrix, and m denotes the total number of factors (Estabrook and Neale, 2013).

\[
f_i = (A' C^{-1} A)^{-1} A' E^{-1} F_i
\]

(2.4)

Where \( i = 1, 2, \ldots, m \)

A high positive factor score indicates that the sample has measured values that reflect the geochemical signature of that factor, whereas a high negative score indicates a disassociation with a particular factor and could indicate a specific lack in a certain geochemical signature (e.g. Tripathi, 1979). A sample can have a high score for more than one factor; for example, a
mineralized sample is expected to score high for a mineralization factor but may score high for a lithologic factor or alteration factor as well (Reimann et al., 2002). As previously mentioned, these factor scores can be considered new variables, and as such, they can be manipulated using similar techniques as were used for the single element variables (Tripathi, 1979).

2.6.2.9 Create Factor Scores Maps

Once geochemical correlations have been identified using the factor loadings, and the factor scores have been calculated, it is possible to map these new variables (i.e. factor scores) to aid in the interpretations of the results (Reimann et al., 2002; Grunsky, 2010). The factor scores can be mapped in the same way that a single element concentration map is created. In the present study, maps were created following recommendations by Reimann et al. (2005) using map symbols that relate to the distribution of values (Table 2.2). In the present study, the moderate to high positive scoring samples for the factors related to gold mineralization are used to define prospective areas for gold mineralization in the Fairbanks Mining District.

2.7 Results of Factor Analysis

R-mode factor analysis of the 38-element log transformed stream sediment geochemical dataset in the Fairbanks Mining District generated an eight-factor model that explains 70% of the total variance (Table 2.3). Factor scores were calculated using the factor loadings, and the scores for each of the eight factors were plotted on a map using ArcGIS™ (Figure 2.9 and 2.10). The symbols and levels used to plot the factor scores are based on the statistical distribution of the factor scores following recommendations made by Reimann et al. (2005). Each factor is discussed below in terms of the associated elements and the spatial distribution of the factor scores with respect to geologic units and features. The results are also available as supplementary files in Appendix B.

2.8 Discussion of Factor Scores

Table 2.4 provides a list of the factors, their associated elements and the interpreted geology controlling the factor. Each of the eight factors are discussed below in terms of the elements with high loadings and the location of the high positive and negative scoring samples.
Table 2.2: Equations used to determine the symbol levels for the factor score maps. These symbol levels identify outliers using a box-plot and this method follows the recommendations by Reimann et al. (2005). The equations use the following notation: $Q_{75}$ is the 75th percentile, and $Q_{25}$ is the 25th percentile. The high positive and moderately high positive symbol levels are used to determine prospective areas for gold mineralization. This method and the results are described in more detail in the text.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Symbol</th>
<th>Schematic Box-Plot</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Positive</td>
<td>![High Positive Symbol]</td>
<td>![High Positive Box-Plot]</td>
<td>$&gt; Q_{75} + (1.5 \times (Q_{75} - Q_{25}))$</td>
</tr>
<tr>
<td>Moderately High Positive</td>
<td>![Moderately High Positive Symbol]</td>
<td>![Moderately High Positive Box-Plot]</td>
<td>$&gt; Q_{75}$</td>
</tr>
<tr>
<td>Interquartile Range</td>
<td>![Interquartile Range Symbol]</td>
<td>![Interquartile Range Box-Plot]</td>
<td>$&gt; Q_{25}$ and $&lt; Q_{75}$</td>
</tr>
<tr>
<td>Moderately High Negative</td>
<td>![Moderately High Negative Symbol]</td>
<td>![Moderately High Negative Box-Plot]</td>
<td>$&lt; Q_{25}$</td>
</tr>
<tr>
<td>High Negative</td>
<td>![High Negative Symbol]</td>
<td>![High Negative Box-Plot]</td>
<td>$&lt; Q_{25} - (1.5 \times (Q_{75} - Q_{25}))$</td>
</tr>
</tbody>
</table>

The average communality for the dataset is 0.62 and some elements have very high individual communality (e.g. Ca 1.0) where some elements have strikingly low communality (e.g. Mo 0.08). The elements with high communality (>0.5) are well explained by the factor model and the variance strongly controls the variance in the dataset (Reimann et al., 2002). The elements with low communality (<0.5) are poorly explained by the factor model, and the observed variance in those elements does not have a significant control on the variance in the dataset.

2.8.1 Factor One

Factor one is associated with Fe, Mg, Ni, and V, and it accounts for 18.2% of the total variance. The high positive scoring samples for this factor are scattered around the district, and there is a notable cluster of high positive values within the Chatanika Terrane north of the Pedro...
Table 2.3: Factor loadings from r-mode factor analysis of the 38-element stream sediment geochemical dataset of the Fairbanks Mining District. Loading values that are above the threshold of 0.6 are considered important and are emphasized in bold. The communality (Comm.) is calculated for each element and an average (Avg.) is calculated for the dataset.

<table>
<thead>
<tr>
<th></th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
<th>F7</th>
<th>F8</th>
<th>Comm.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eigenvalue</strong></td>
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<td>5.34</td>
<td>4.14</td>
<td>3.71</td>
<td>1.96</td>
<td>1.80</td>
<td>1.43</td>
<td>1.27</td>
<td></td>
</tr>
<tr>
<td><strong>% of Total Variance</strong></td>
<td>18.2</td>
<td>14.1</td>
<td>10.9</td>
<td>9.8</td>
<td>5.2</td>
<td>4.7</td>
<td>3.8</td>
<td>3.3</td>
<td>Avg. 0.62</td>
</tr>
<tr>
<td><strong>Cumulative Variance</strong></td>
<td>18.2</td>
<td>32.2</td>
<td>43.1</td>
<td>52.9</td>
<td>58.0</td>
<td>62.7</td>
<td>66.5</td>
<td>69.8</td>
<td></td>
</tr>
<tr>
<td>Al_{ppt AES}</td>
<td>0.30</td>
<td>0.61</td>
<td>-0.01</td>
<td>0.14</td>
<td>0.05</td>
<td>0.12</td>
<td>-0.01</td>
<td>0.02</td>
<td>0.51</td>
</tr>
<tr>
<td>As_{ppm INAA}</td>
<td>0.15</td>
<td>-0.13</td>
<td>-0.06</td>
<td>0.14</td>
<td>0.86</td>
<td>0.08</td>
<td>0.07</td>
<td>0.00</td>
<td>0.81</td>
</tr>
<tr>
<td>Au_{ppb INAA}</td>
<td>-0.04</td>
<td>-0.02</td>
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<td>0.14</td>
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<td>0.05</td>
<td>0.00</td>
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</tr>
<tr>
<td>Ba_{ppm AES}</td>
<td>0.51</td>
<td>0.66</td>
<td>-0.05</td>
<td>0.08</td>
<td>-0.14</td>
<td>0.11</td>
<td>-0.05</td>
<td>-0.18</td>
<td>0.77</td>
</tr>
<tr>
<td>Bi_{ppm AA}</td>
<td>-0.05</td>
<td>0.08</td>
<td>-0.14</td>
<td>0.39</td>
<td>0.28</td>
<td>0.17</td>
<td>0.04</td>
<td>0.03</td>
<td>0.29</td>
</tr>
<tr>
<td>Br_{ppm INAA}</td>
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<td>-0.02</td>
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<td>-0.09</td>
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<tr>
<td>Ca_{ppt AES}</td>
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<td>0.66</td>
<td>-0.02</td>
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</tr>
<tr>
<td>Ce_{ppm INAA}</td>
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<td>0.01</td>
<td>0.00</td>
<td>-0.16</td>
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<td>Co_{ppm AES}</td>
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<td>-0.01</td>
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<td>-0.03</td>
<td>-0.08</td>
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</tr>
<tr>
<td>Cr_{ppm INAA}</td>
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<td>Cs_{ppm INAA}</td>
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<td>-0.02</td>
<td>0.16</td>
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<td>0.02</td>
<td>0.03</td>
<td>0.00</td>
<td>-0.02</td>
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</tr>
<tr>
<td>Cu_{ppm AES}</td>
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<td>-0.15</td>
<td>-0.08</td>
<td>0.04</td>
<td>0.88</td>
<td>-0.07</td>
<td>-0.02</td>
<td>0.89</td>
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<tr>
<td>Fe_{ppt AES}</td>
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<td>0.09</td>
<td>-0.02</td>
<td>-0.02</td>
<td>0.18</td>
<td>0.06</td>
<td>0.04</td>
<td>0.18</td>
<td>0.52</td>
</tr>
<tr>
<td>Ga_{ppm AES}</td>
<td>0.27</td>
<td>0.50</td>
<td>-0.07</td>
<td>0.20</td>
<td>0.08</td>
<td>0.09</td>
<td>0.00</td>
<td>0.33</td>
<td>0.50</td>
</tr>
<tr>
<td>Hf_{ppm INAA}</td>
<td>-0.21</td>
<td>-0.04</td>
<td>0.67</td>
<td>-0.21</td>
<td>-0.14</td>
<td>-0.15</td>
<td>0.05</td>
<td>0.31</td>
<td>0.68</td>
</tr>
<tr>
<td>K_{ppt AES}</td>
<td>0.19</td>
<td>0.47</td>
<td>-0.02</td>
<td>0.25</td>
<td>0.04</td>
<td>0.02</td>
<td>-0.24</td>
<td>-0.01</td>
<td>0.38</td>
</tr>
<tr>
<td>La_{ppm AES}</td>
<td>0.23</td>
<td>0.16</td>
<td>0.42</td>
<td>0.01</td>
<td>-0.04</td>
<td>0.67</td>
<td>0.01</td>
<td>-0.06</td>
<td>0.71</td>
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<tr>
<td>Li_{ppm AES}</td>
<td>0.18</td>
<td>-0.12</td>
<td>0.21</td>
<td>0.71</td>
<td>0.04</td>
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<td>-0.04</td>
<td>0.06</td>
<td>0.62</td>
</tr>
<tr>
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<td>0.09</td>
<td>0.12</td>
<td>0.01</td>
<td>0.88</td>
</tr>
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<td>Mn_{ppm AES}</td>
<td>0.42</td>
<td>-0.08</td>
<td>0.03</td>
<td>0.22</td>
<td>0.18</td>
<td>-0.04</td>
<td>0.22</td>
<td>0.05</td>
<td>0.31</td>
</tr>
<tr>
<td>Mo_{ppm AES}</td>
<td>-0.03</td>
<td>-0.01</td>
<td>-0.02</td>
<td>0.07</td>
<td>0.02</td>
<td>0.26</td>
<td>0.06</td>
<td>0.01</td>
<td>0.08</td>
</tr>
<tr>
<td>Na_{ppt AES}</td>
<td>-0.07</td>
<td>0.85</td>
<td>-0.05</td>
<td>-0.24</td>
<td>-0.15</td>
<td>-0.03</td>
<td>0.12</td>
<td>0.19</td>
<td>0.85</td>
</tr>
<tr>
<td>Nb_{ppm AES}</td>
<td>0.30</td>
<td>0.34</td>
<td>0.26</td>
<td>0.18</td>
<td>-0.01</td>
<td>0.02</td>
<td>0.12</td>
<td>0.46</td>
<td>0.53</td>
</tr>
<tr>
<td>Ni_{ppm AES}</td>
<td>0.64</td>
<td>0.06</td>
<td>-0.05</td>
<td>0.00</td>
<td>0.01</td>
<td>0.58</td>
<td>-0.01</td>
<td>0.04</td>
<td>0.75</td>
</tr>
<tr>
<td>Pb_{ppm AES}</td>
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<td>0.05</td>
<td>-0.01</td>
<td>0.21</td>
<td>0.42</td>
<td>0.67</td>
<td>-0.02</td>
<td>0.06</td>
<td>0.68</td>
</tr>
<tr>
<td>Rh_{ppm INAA}</td>
<td>-0.18</td>
<td>0.13</td>
<td>0.20</td>
<td>0.65</td>
<td>0.02</td>
<td>0.06</td>
<td>-0.13</td>
<td>-0.03</td>
<td>0.53</td>
</tr>
<tr>
<td>Sb_{ppm AES}</td>
<td>0.24</td>
<td>-0.10</td>
<td>-0.11</td>
<td>-0.13</td>
<td>0.81</td>
<td>0.04</td>
<td>-0.10</td>
<td>-0.13</td>
<td>0.79</td>
</tr>
<tr>
<td>Sc_{ppm AES}</td>
<td>0.52</td>
<td>-0.22</td>
<td>0.35</td>
<td>-0.38</td>
<td>0.00</td>
<td>-0.06</td>
<td>0.08</td>
<td>-0.01</td>
<td>0.59</td>
</tr>
<tr>
<td>Sm_{ppm INAA}</td>
<td>0.09</td>
<td>-0.02</td>
<td>0.81</td>
<td>0.26</td>
<td>0.06</td>
<td>0.08</td>
<td>0.14</td>
<td>-0.05</td>
<td>0.78</td>
</tr>
<tr>
<td>Sr_{ppm AES}</td>
<td>0.03</td>
<td>0.81</td>
<td>0.06</td>
<td>-0.16</td>
<td>-0.22</td>
<td>0.08</td>
<td>0.34</td>
<td>-0.01</td>
<td>0.86</td>
</tr>
<tr>
<td>Ta_{ppm INAA}</td>
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<td>-0.07</td>
<td>0.56</td>
<td>0.18</td>
<td>-0.07</td>
<td>-0.09</td>
<td>0.19</td>
<td>0.19</td>
<td>0.44</td>
</tr>
<tr>
<td>Th_{ppm AES}</td>
<td>-0.20</td>
<td>0.05</td>
<td>0.85</td>
<td>0.32</td>
<td>0.07</td>
<td>0.01</td>
<td>-0.05</td>
<td>0.04</td>
<td>0.87</td>
</tr>
<tr>
<td>Ti_{ppt AES}</td>
<td>0.57</td>
<td>0.20</td>
<td>0.31</td>
<td>-0.33</td>
<td>0.00</td>
<td>0.02</td>
<td>-0.11</td>
<td>0.55</td>
<td>0.87</td>
</tr>
<tr>
<td>U_{ppm AES}</td>
<td>-0.33</td>
<td>0.16</td>
<td>0.34</td>
<td>0.59</td>
<td>0.14</td>
<td>-0.01</td>
<td>0.40</td>
<td>0.09</td>
<td>0.79</td>
</tr>
<tr>
<td>V_{ppm AES}</td>
<td>0.60</td>
<td>0.36</td>
<td>-0.12</td>
<td>-0.33</td>
<td>-0.05</td>
<td>0.28</td>
<td>0.02</td>
<td>0.23</td>
<td>0.75</td>
</tr>
<tr>
<td>Y_{ppm AES}</td>
<td>0.11</td>
<td>0.16</td>
<td>0.42</td>
<td>0.20</td>
<td>0.05</td>
<td>0.30</td>
<td>0.51</td>
<td>0.05</td>
<td>0.61</td>
</tr>
<tr>
<td>Zn_{ppm AES}</td>
<td>0.43</td>
<td>0.18</td>
<td>-0.06</td>
<td>0.13</td>
<td>0.29</td>
<td>0.29</td>
<td>-0.08</td>
<td>-0.04</td>
<td>0.42</td>
</tr>
<tr>
<td>Zr_{ppm AES}</td>
<td>-0.32</td>
<td>0.71</td>
<td>-0.13</td>
<td>-0.06</td>
<td>0.00</td>
<td>0.08</td>
<td>0.06</td>
<td>0.03</td>
<td>0.63</td>
</tr>
</tbody>
</table>
Figure 2.9: Maps showing the distribution of factor scores for factors 1 through 4. Factor loadings for these factors are given in Table 2.3 and the associated elements and their interpreted geologic context are provided in Table 2.4. Larger-scale maps that emphasize the highest and lowest scoring samples for each factor with respect to the geology and mineral occurrences are available as Figures 2.11 through 2.18. Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.10: Maps showing the distribution of factor scores for factors 5 through 8. Factor loadings for these factors are given in Table 2.3 and the associated elements and their interpreted geologic context are provided in Table 2.4. Larger-scale maps that emphasize the highest and lowest scoring samples for each factor with respect to the geology and mineral occurrences are available as Figures 2.11 through 2.18. Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Table 2.4: The high loading elements for each factor and the interpreted geology they represent. These interpretations are discussed in more detail in the text.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Associated Elements</th>
<th>Geology Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mg – Fe – Ni – V</td>
<td>High positive scores associated with mafic lithologies &lt;br&gt; High negative scores associated with felsic lithologies</td>
</tr>
<tr>
<td>2</td>
<td>Na – Sr – Ba – Al</td>
<td>High negative scores associated with mafic lithologies</td>
</tr>
<tr>
<td>3</td>
<td>Th – Sm – Ce – Hf</td>
<td>High positive scores associated with felsic rocks</td>
</tr>
<tr>
<td>4</td>
<td>Li – Cs – Rb</td>
<td>High positive scores associated with granitic intrusions</td>
</tr>
<tr>
<td>5</td>
<td>As – Sb – Au</td>
<td>High positive scores associated with shear-hosted gold mineralization</td>
</tr>
<tr>
<td>6</td>
<td>Cu – La – Pb</td>
<td>High positive scores associated with base-metal mineralization</td>
</tr>
<tr>
<td>7</td>
<td>Ca</td>
<td>High positive scores associated with calcite-rich rocks marble and calc-silicate hornfels</td>
</tr>
<tr>
<td>8</td>
<td>Ti – Nb</td>
<td>High positive scores associated with mafic rocks in the Fairbanks Schist</td>
</tr>
</tbody>
</table>
Dome (Figure 2.11). The high negative scoring samples cluster around the Gilmore Dome (Figure 2.12).

The association of Mg, Fe, Ni, and V suggests the samples with high positive scores are derived from drainages with mafic rocks. Mafic rocks such as metabasalt are prevalent in the Chatanika Terrane, and clusters of high positive scores in this area are consistent with the geology (Figure 2.11). There are other areas with high positive scores throughout the district and suggest mafic rock units in the Fairbanks Schist terrane as well (Figures 2.11 and 2.12). The high negative scoring samples are therefore derived from drainages of highly non-mafic rock units. The highest negative scoring samples were collected in drainages with material derived from the Gilmore Dome pluton, which is characterized as dominantly granite in composition and, therefore, the highly negative scoring samples are derived from areas with highly non-mafic or highly felsic rock units. Other high negative scores in the district are either derived from strongly felsic rock units such as quartzite or granitic plutons.

2.8.2 Factor Two

Factor two is associated with Na, Sr, Zr, Ba, and Al, and it accounts for 14.1% of the total variance. There are only two high positive scoring samples, one is derived from the Gilmore pluton (Figure 2.13) and the other is derived from metamorphic rocks of the Fairbanks Schist (Figure 2.13). There are many high negative scoring samples and these dominantly cluster in the northeastern part of the district within the Chatanika Terrane (Figure 2.14).

The lack of abundant high positive scores and the skew of the factor score distribution towards high negative values suggests this factor is controlled by the significant lack in the associated elements Na, Sr, Zr, Ba, and Al. The grouping of these elements commonly suggests felsic Na-, and/or Al-bearing minerals such as feldspar. Unsurprisingly, the highest positive scoring sample is derived from the granitic rocks of the Gilmore Dome pluton (Figure 2.13). The second highest scoring sample is derived from felsic mica schist of the Fairbanks Schist (Figure 2.13). However, this factor appears to be dominantly controlled by highly negative scoring samples and these, therefore, areas that are strongly lacking in felsic minerals. The high negative scoring samples were collected in streams that drain areas of the Chatanika Terrane in the northeastern part of the district (Figure 2.14) and the Fairbanks Schist (Figures 2.13 and 2.13). The high negative scoring samples derived from the Chatanika Terrane are characterizing mafic rocks such as metabasalt or
Figure 2.11: Map A of factor scores for factor one. This map highlights the highest positive and negative scores for factor one. This shows that the dominant high positive scoring samples are located in the Chatanika Terrane and are associated with mafic rock units. The few high negative scores are derived from drainages with non-mafic lithologies such as quartzite or granitic plutons. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.12: Map B of factor scores for factor 1. This map highlights the highest positive and negative scores for factor 1. This shows that the dominant high negative scoring samples are derived from drainages with dominantly felsic granitic rocks of the Gilmore Dome. The other high negative scoring samples are likely derived from areas with other non-mafic lithologies such as quartzite. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.13: Map A of factor scores for factor two. These maps highlight the highest positive and negative scores for factor two. Top: This shows that the highest positive scoring sample is derived from the Gilmore Dome pluton. Bottom: This shows that the second highest positive scoring sample is derived from a felsic lithologic unit of the Fairbanks Schist such as mica schist. Some of the highest negative scoring samples are derived from rocks of the Fairbanks Schist and this suggests there are mafic lithologic units in these drainages. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.14: Map B of factor scores for factor two. This map highlights the highest negative scores for factor two. This shows that the high negative scoring samples are derived from drainages in both the Chatanika Terrane and the Fairbanks Schist. The drainages in the Chatanika Terrane are dominantly mafic rocks such as metabasalt or felsic-mineral poor rocks such as marble. The drainages in the Fairbanks Schist are derived from the mafic amphibolite unit. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
monomineralic rocks such as marble that lack minerals with Na, Sr, Zr, Ba, or Al. High negative scoring samples that are derived from areas of the Fairbanks Schist are either dominated by quartzite or amphibolite (Figures 2.13 and 2.14). Contrary to other factors, factor two is more useful when the highly negative scoring samples are used to identify areas of particularly mafic lithologies.

2.8.3 Factor Three

Factor three is associated with Th, Sm, Ce, and Hf, and it accounts for 10.9% of the total variance. The high positive scoring samples drain the eastern part of the district (Figure 2.15), whereas the anomalously low scoring samples drain the western part of the district (Figures 2.15 and 2.16). The moderately high positive and negative scoring samples generally follow the same segregation but there are some moderately high scoring samples in the western part of the district and vise-versa.

Both high positive and negative scores are derived from drainages dominated by rocks of the Fairbanks Schist (Figure 2.15). The high positive scoring samples are in some cases derived from areas closely associated with the amphibolite unit, however high negative scores also appear to be associated with this unit (Figure 2.16). One of the high positive samples is derived from granite at the Gilmore Dome pluton (Figure 2.15). The areas with high positive samples are likely dominated by felsic rock lithologies similar to granite of the Gilmore Dome or mica-schist units of the Fairbanks Schist. The high negative scoring samples are derived from drainages that are dominated by mafic rocks, specifically the amphibolite of the Fairbanks Schist terrane.

2.8.4 Factor Four

Factor four is associated with the alkali metals Li, Cs, and Rb, and it accounts for 9.8% of the total variance. The high positive scoring samples for this factor are tightly clustered around the Gilmore Dome pluton (Figure 2.17). There is one high negative scoring sample, derived from rocks of the Chatanika Terrane near the contact with the Fairbanks Schist in the northeastern part of the district (Figure 2.18).

The lack of high negative scores suggests that the variance of Li, Cs, and Rb is most strongly controlled by the samples with the high positive scores for this factor. The spatial
Figure 2.15: Map A of factor scores for factor 3. These maps highlight the highest positive and negative scores for factor 3. A: This map shows the high positive scoring samples being derived from both granitic and metamorphic rocks. B: This map shows the high and low scoring samples are both derived from rocks of the Fairbanks Schist and are spatially associated with the amphibolite unit. C: This map shows high positive scoring samples draining rocks of the Fairbanks Schist spatially associated with the amphibolite unit. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Table 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.16: Map B of factor scores for factor three. These maps highlight the highest negative scores for factor three. A: This map shows a high negative scoring sample derived from a drainage dominated by rocks of the Fairbanks Schist. B-C: These maps show high negative scoring samples spatially associated with the amphibolite unit of the Fairbanks Schist. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
association between high positive scoring samples and the Gilmore Dome pluton suggests that this factor characterizes the granitic plutonic rocks of the district (Figure 2.17). The only high negative scoring sample is derived from mafic rocks of the Chatanika Terrane (Figure 2.18). The high positive scoring samples are derived from drainages are exclusively comprised of granitic rocks of the Gilmore Dome pluton. Samples that score within the top 5% are either derived from drainages with a mixture of intrusive and metamorphic country rocks or they are derived from solely metamorphic country rocks (Figure 2.19A-D). This suggests that the samples strongly anomalous in Li, Cs, and Rb (i.e. those derived from Gilmore Dome) are biasing the factor scores because these drainages are solely granitic rocks. The samples that have moderate positive scores are derived from drainages with granitic rocks that are diluted by other lithologies that are also present.

The samples derived from reduced intrusion-related gold mineralized sites in the Fairbanks district have moderate positive scores for this factor (#1, 2, and #14 in Figure 2.17). The samples derived from the Fort Knox gold deposit score in the top 5% for this factor. However, there are samples with moderate positive scores that are derived from drainages dominated by rocks of the Fairbanks Schist (Figure 19A-D). These units are not considered to be prospective for reduced intrusion-related gold mineralization. The moderate positive scores, in this case, are either influenced by (1) rocks of the Fairbanks Schist that are geochemically similar to the granitic intrusions of Gilmore Dome, or (2) unmapped intrusions within these drainages (Figure 2.17, 2.18, and 2.19). It is proposed that the areas with moderate and high positive scores for factor four are areas prospective for intrusions with a similar geochemistry to those of the Fort Knox gold deposit and are, therefore, of importance as a host rock. At this stage in exploration it is considered more useful to include, rather than exclude potentially prospective drainages.

2.8.5 Factor Five

Factor five is associated with As, Sb, and Au, and it accounts for 5.2% of the total variance in the dataset. The distribution of factor scores is strongly skewed to the high positive values. This suggests that the variance of these elements is strongly controlled by the samples with the high positive scores. The high positive scoring samples cluster in three main areas around the known gold-bearing mineral occurrences in the district: (1) Cleary Summit – Pedro
Figure 2.17: Map A of factor scores for factor four. These maps highlight the highest positive scores for factor four. This map shows the high positive scoring samples being derived from the granitic rocks of the Gilmore Dome pluton. This map also shows the moderate positive scoring samples being derived from drainages with other felsic plutons. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.18: Map B of factor scores for factor four. These maps highlight the highest negative scores for factor four. This map shows the one high negative scoring sample is derived from the rocks of the Chatanika Terrane. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.19: Map C of factor scores for factor four. These maps highlight some of the moderate positive scoring samples that score in the top 5% of samples for factor four. A and D: This map shows that some moderate scores within the top 5% are derived from areas dominated by rocks of the Fairbanks Schist. B and C: These maps show that some of the moderate scores within the top 5% are derived from felsic intrusive rocks such as the Gilmore Dome (B) and Fort Knox (C) plutons. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Dome trend, (2) Vault-Treasure Creek area, and (3) Ester Dome area (Figures 2.20 and 2.21). The moderately high positive scoring samples drain the areas adjacent to the high positive scoring samples forming a broad northeast-trending zone. There are two high negative scoring samples, derived from rocks of the Chatanika Terrane and the Fairbanks Schist (Figure 2.20).

This grouping of elements matches the sulfide mineralogy of the shear-hosted gold veins in the district (Chapman and Foster, 1969). This style of mineralization has been classified in the present study as orogenic. The high positive scoring samples are dominantly derived from orogenic mineral occurrences in the Cleary Summit – Pedro Dome area (#5-7 and #9-13 in Figure 2.20). High positive scoring samples are also derived from drainages with reduced intrusion-related mineralization (#4 and #8 in Figure 2.20). Other high positive scoring samples are derived from orogenic mineralization in the Vault-Treasure Creek and Ester Dome areas (#19 and #21 in Figure 2.21). Thus, it is clear that the high positive scoring samples are derived from orogenic style vein material and that the drainages with high positive scores are prospective for this style of mineralization.

Although there is a strong spatial correlation between the gold mineralization and high positive scores, some of the drainages with orogenic mineral occurrences do not have high positive scores (#3 in Figure 2.20; #20 and #24-28 in Figure 2.21). These mineral occurrences are characterized by moderately high positive scores. Likewise, moderately high positive scores are in some cases derived from drainages containing reduced intrusion-related mineralization (#1-2 in Figure 2.20; #30 in Figure 2.21).

However, this factor fails to identify the drainage containing the large Fort Knox reduced intrusion-related deposit. It is troubling that the only geochemical association that is clearly related to gold mineralization is unable to identify the drainages with material derived from the only gold mine in the district, and thus additional consideration was given to this issue. There are significantly more orogenic mineral occurrences than reduced intrusion-related occurrences in the district, and the correlation between those occurrences the high scoring samples is unclear. This is because the two occurrences that are spatially related to a high scoring sample share those drainages with orogenic gold veins as well. The moderately high scorings samples that are derived from drainages containing reduced-intrusion-related may not share that drainage with an orogenic mineral occurrence. However, it is also possible that some of the mineral occurrences that have been classified as reduced intrusion-related are actually orogenic.
Figure 2.20: Map A of factor scores for factor five. This map highlights the highest positive and negative scores for factor five. This map shows the high positive scoring samples are derived from areas with dominantly orogenic gold occurrences. The lack of high negative scores suggests the variance of the elements is strongly controlled by the high positive scoring samples. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.21: Map B of factor scores for factor five. These maps highlight the highest positive scores for factor five. A: This map shows that high positive scoring samples are derived from areas of orogenic style gold mineralization in the southern part of the Ester Dome area. This also shows that moderately positive scoring samples are also derived from areas with orogenic mineralization. B: This map shows moderately high scoring samples being derived from an area with reduced intrusion-related mineral occurrence. C: This map shows moderately high scoring samples can be derived from areas with orogenic style mineralization. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
veins that are hosted within intrusions. Because of the ambiguity of mineral occurrence classification, it is impossible to establish the significance of factor 5 scores with respect to the reduced intrusion-related style of mineralization.

2.8.6 Factor Six

Factor six is associated with Cu, La, and Pb, and it accounts for 4.7% of the total variance in the dataset. The high positive scoring samples are dispersed throughout the district and are generally derived from drainages dominated by rocks of the Fairbanks Schist (Figures 2.22 and 2.23). These high positive scoring drainages are in some instances adjacent to mineralized areas such as the Cleary Summit – Pedro Dome area and the Ester Dome area (Figures 2.22 and 2.23). The high negative scoring samples are dominantly derived from one drainage located in the Chatanika Terrane (Figure 2.23). Other high negative scoring samples are derived from other areas of the district including rocks of the Fairbanks Schist (Figures 2.22 and 2.23).

The grouping of these metals onto factor six suggests the presence of a base-metal rich rock or base-metal bearing mineralization. Orogenic gold occurrences can contain Cu-, and/or Pb-bearing sulfide minerals, and at least one of the high scoring samples is derived from a drainage with an occurrence that reportedly has this geochemistry (#1 in Figure 2.22; #11 in Figure 2.23). Moderately high positive scoring samples may also be derived from drainages with Cu- and/or Pb-bearing sulfide gold mineralization (#13 in Figure 2.23).

The high positive scoring samples appear to follow a northeast trend that roughly corresponds to the location of the Cleary Sequence as mapped by Robinson et al. (1990). This unit is described as a base-metal rich unit of volcanic origin. The factor analysis results may provide evidence that this unit is distinguishable from the rest of the Fairbanks Schist and should be broken into its own unit. Alternatively, the factor analysis results could also suggest the presence of mineralization that is lacking in gold but rich in other Cu- and Pb-bearing sulfide minerals.

The highest negative scoring samples are derived from rocks of the Chatanika Terrane and a few drainages in the Fairbanks Schist (Figure 2.23). Mafic rocks located in both of these areas are likely elevated in Cu and Pb. The high negative scores may be derived from rock units
Figure 2.22: Map A of factor scores for factor six. These maps highlight the highest positive and negative scores for factor six. A and D: The high positive scoring samples are derived from metamorphic rocks of the Fairbanks Schist. B-C: The high positive scoring samples can be derived from drainages with either orogenic and reduced intrusion-related occurrences. High negative scoring samples are sometimes associated with felsic intrusions. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.23: Map B of factor scores for factor six. This map highlights the highest positive and negative scores for factor six. The high positive scoring samples can sometimes be derived from drainages that contain gold mineralization. The high negative scoring samples are derived from areas with felsic lithologic units. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
such as marble from the Chatanika Terrane and quartzite or mica-schist from the Fairbanks Schist.

2.8.7 Factor Seven

Factor seven is associated with Ca, and it accounts for 3.8% of the total variance. High positive scoring samples are tightly clustered around the Gilmore Dome pluton and an area adjacent to the Gilmore Dome pluton in the northern part of the district within the Chatanika Terrane, (Figure 2.24 and 2.25). There are high scoring samples derived from the Fairbanks Schist in a few less prominent areas (Figure 2.26). High negative scoring samples are located in the central part of the district and cluster in the Cleary Summit area, the Vault-Treasure Creek area, and a few other areas north of the Gilmore Dome within the Fairbanks Schist (Figures 2.24, 2.25, and 2.256).

This factor is only associated with one element, Ca, and the factor scores therefore reflect the variance of Ca in the dataset. Generally, factors with only one associated element are difficult to interpret. Both U and Y have moderate loading values on this factor. Because these elements have very low communality values, they are poorly represented by this factor model. However, the weak correlation with Ca here suggests that the high positive scoring samples are also elevated in U and Y.

The location of the high positive scoring samples leads to the interpretation that these samples are derived from rocks that have abundant calcite. The cluster of high positive scores are located in the Chatanika Terrane which contains marble (Robinson et al., 1990) (Figure 2.24). It is possible that metabasalt of the Chatanika Terrane that has Ca-rich pyroxenes and/or plagioclase are also contributing to the variance of this element, although the singular correlation of only Ca suggests a monomineralic rock such as marble. The tightness of the clusters in the Chatanika Terrane suggests that these drainages are dominated by the Ca-rich rock.

The cluster of high positive scores located near the Gilmore dome is spatially associated with the calcite-epidote and calcite-diopside skarns that are located within the metamorphic country rocks adjacent to the pluton (Robinson and Metz, 1979) (Figure 2.25). However, these skarns are not spatially extensive and it is difficult to justify a significant control on the variance of Ca in the district. There are also samples derived from the interior parts of the pluton and this suggests the presence of Ca-rich feldspar, however this is poorly constrained because there is
Figure 2.24: Map A of factor scores for factor seven. These maps highlight the highest positive and negative scores for factor seven. High positive scores are derived from areas with calcite rich rocks such as marble. High negative scoring samples are derived from areas are scattered throughout the district and have an unknown geologic control. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.25: Map B of factor scores for factor seven. These maps highlight the highest positive and negative scores for factor seven. High positive scores are derived from areas with calcite rich rocks such as marble and calc-silicate hornfels skarn. High negative scoring samples are derived from areas of Fairbanks Schist but they have an unknown geologic control. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.26: Map C of factor scores for factor seven. These maps highlight the highest positive and negative scores for factor seven. High positive scores are derived from areas with calcite rich rocks such as marble. High negative scoring samples are derived from areas of Fairbanks Schist but they have an unknown geologic control. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Legend

- Streams
- Cities
- Mineral Occurrences
  - RIRG
  - OROG
  - Skarn
  - Lode
- Fault
- Inferred Fault
- Thrust Fault
- Anticline
- Quaternary Cover
- Tertiary
- Volcanic and Sedimentary Rocks
- Eocene Rocks
- Volcanic and Plutonic Rocks
- mid-Cretaceous
  - Altered Dike
  - Granite
  - Tonalite
  - Granodiorite
  - Syenite
- Seventymile Oceanic Terrane
  - Chathanika Terrane
  - Metapelitic, metabasalt, and marble
- Yukon-Tanana Arc
  - Orthogneiss
- Parautochthonous Yukon-Tanana Terrane
  - Muskox Sequence
  - Metabasalt and metahydrate
  - Birch Hill Sequence
  - Phyllite and slate
  - Fairbanks Schist
  - Mica Schist and quartzite
  - Amphibolite

Factor 7
- 2.15 - 4.67
- 0.52 -2.14
- -0.60 - 0.51
- -2.18 - -0.61
- -4.22 - -2.19

Scale: 0 - 4 Km
WGS 1984 UTM Zone 6N
only one sample (Figure 2.24). Some of the samples with high positive scores are derived from the Fairbanks Schist and may be associated with drainages with amphibolite (Figures 2.25 and 2.26). The amphibolite unit of the Fairbanks Schist is known to have minor to significant marble and therefore high Ca is consistent with this mineralogy (Newberry et al., 1996).

2.8.8 Factor Eight

Factor eight does not have any elements with a loading value greater than 0.6. The highest loading values are those for Ti (0.55) and Nb (0.46), and this factor accounts for 3.3% of the total variance in the dataset. The high positive scoring samples are dominantly derived from one stream in the area between the Cleary Summit area and the Gilmore Dome pluton (Figure 2.27). The high negative scoring samples are scattered throughout the district, the largest cluster is to the west of the Ester Dome area in the southern part of the district (Figure 2.27 and 2.28).

The area with the highest positive scoring samples is along trend with an exposure of amphibolite. Some of the rocks grouped within this unit are strongly elevated in TiO$_2$. The high positive samples are likely derived from drainages dominated by these and other similar mafic rocks throughout the district. The high negative samples are, therefore, likely derived from drainages dominated by felsic rocks.

2.8.9 Geochemical Associations Related to Gold Mineralization

Analysis of the stream sediment geochemical dataset for the Fairbanks Mining District identified two factors that are likely indicative of gold mineralization. (1) The As – Sb – Au signature from factor five reflects the mineralogy of the shear-zone and breccia hosted gold veins cutting metamorphic country rock. The samples with the moderate to high positive scores have the closest association with the majority of the known gold mineralization in the district (Figures 2.20 and 2.21). The samples that have moderate to high positive scores for factor five are, therefore, derived from areas prospective for gold mineralization. (2) The Li – Cs – Rb signature from factor four is spatially associated with the Fort Knox gold deposit and other areas hosting reduced intrusion-related gold mineralization (Figures 2.17 and 2.19). However, the high positive scoring samples for this factor only show areas prospective for the intrusions, which may serve as host rocks for this mineralization style. The samples that are derived from the Fort Knox gold deposit have elevated levels of Au. The combination of elevated Au concentration
Figure 2.27: Map A of factor scores for factor eight. These maps highlight the highest positive and negative scores for factor eight. A and B: High positive scores are derived from the mafic basaltic rocks in the amphibolite. B and C: High negative scoring samples are derived from areas of felsic rocks in the Fairbanks Schist. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.28: Map B of factor scores for factor 8. These maps highlight the highest positive and negative scores for factor 8. A-C: High negative scoring samples are derived from felsic rocks in the Fairbanks Schist. D: High positive scoring samples are derived from areas of mafic rocks in the Fairbanks Schist. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
and positive scores for factor four are used to explore for this style of mineralization in the
district.

2.8.10 Geochemical Associations Related to Other Mineralization Styles

Factor six (Cu – La – Pb) is controlled by the presence of a base-metal rich rock and/or
base-metal mineralization (Figure 2.22 and 2.23). Some of the Cu and Pb enrichment indicated
by high scoring samples is derived from gold-bearing occurrences in the district. High positive
scoring samples are also derived from base-metal enriched shears that do not contain significant
amounts of Au or Sb.

The analytical results for W are highly censored and this element was therefore excluded
from the factor analysis. Unsurprisingly, the elevated levels of W are closely associated with
areas of known skarn style mineralization in Gilmore Dome and Pedro Dome areas. Areas that
are scoring high for factor five overlap with these areas. This suggests that the skarn
mineralization has a similar As and Sb concentration with the orogenic style of mineralization
and has a similar geochemical signature in the stream sediment geochemistry. It is likely,
however, that if other elements, such as W, were utilized in the factor analysis, that these
mineralization styles would be differentiated from each other.

2.9 Prospectivity Mapping for Gold Deposits

Twenty-five new areas prospective for one or both styles of gold mineralization have
been identified in the Fairbanks Mining District by incorporating the results of factor analysis
with the areas of elevated Au concentration (Figure 2.29). The maps show catchments scoring
high and moderately high for both factors 4 and 5. Catchments containing samples with > 18 ppb
gold were also delineated on the maps as areas of anomalous gold concentration. Areas that score
highly for factor 5 are considered to be prospective for orogenic style gold mineralization. Areas
that contain anomalous gold and score highly for factor 4 are considered to be prospective for
reduced intrusion-related style gold mineralization. Areas that contain anomalous gold and score
highly for factors 4 and 5 are generally considered to be prospective for both styles of
mineralization. The areas with abundant known mineral prospects and deposits are not included
in the list of prospective areas although they do fit the same criteria used to define the new areas.
The new areas were drawn based on the drainages of prospective samples. The prospective areas
are labeled based on their relative spatial association with one of the four main areas of known gold mineralization. These prospective areas are discussed in more detail in the following sections.

2.9.1 The Cleary Summit – Pedro Dome Area

The Cleary Summit – Pedro Dome trend has the largest number of known mineral occurrences in the Fairbanks Mining District. It is well characterized in the stream sediments by high positive scoring samples for factor five, moderately positive scoring samples for factors four and five, and overlapping areas of anomalous Au concentration (Figure 2.30, 2.31, and 2.32). This trend is prospective for both styles of gold mineralization. Exploration potential for orogenic gold deposits exists off this trend to the southwest (CSa, Figure 2.32), to the south (CSb, Figure 2.30), and to the northeast (CSc, CSd, and CSe, Figure 2.31). Exploration potential for reduced intrusion-related gold deposits exists off this trend to the north (CSf, Figure 2.30), to the east (CSg, Figure 2.31) and to the northeast (CSh, CSi, and CSj Figure 2.31). Areas CSi and CSj are located within the prospective areas for orogenic gold mineralization CSc and CSe respectively. There are no known reduced intrusion-related gold deposits cutting the Chatanika Terrane in the Fairbanks district, however, the prospectivity maps suggest this could be possible in areas CSe and CSh (Figure 2.31). The True North deposit is hosted within the rocks of the Chatanika Terrane and some have suggested that it is reduced intrusion-related (#3 in Figure 2.30) (Campbell, 2006). However, the results presented here are inconclusive: the samples collected from drainages derived from True North, according to the criteria used here, are (1) elevated in factor five, suggesting an orogenic style deposit, and (2) elevated in factor four with anomalous gold, suggesting a reduced intrusion-related style deposit (Figure 2.30).

2.9.2 The Gilmore Dome Area

The Gilmore Dome area notably contains the large Fort Knox deposit, which is a world-class example of a reduced intrusion-related gold deposit. The Fort Knox gold mineralization is well characterized by the samples that have moderately high positive scores for factor four and have elevated Au concentrations (Figure 2.32). This area of known gold prospectivity for reduced intrusion-related gold mineralization is extended to the north (GDa, Figure 2.32), northwest (GDb, Figure 2.32), east (GDa, Figure 2.33), and to the south (GDb, Figure 2.32). The
Figure 2.29: Map showing the locations of the prospective areas for lode-gold mineralization; for explanation see text. Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.30: Prospective areas for gold mineralization in the western part of the Cleary Summit – Pedro Dome area. Areas CSb, CSc, and CSD are prospective or orogenic gold mineralization (OROG). Areas CSf, and CSh are prospective for reduced intrusion-related gold mineralization (RIRG). Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.31: Prospective areas for gold mineralization in the eastern part of the Cleary Summit – Pedro Dome area. Areas CSc, CSD, and CSe are prospective or orogenic gold mineralization (OROG). Areas CSg, CSr, CSI, and CSj are prospective for reduced intrusion-related gold mineralization (RIRG). Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
skarns style of mineralization in the western part of the Gilmore Dome area is well characterized by moderately high scores for factor five (Figure 2.32). This area of known prospectivity is extended to the south (GDf and GDg, Figure 2.32). The area GDd, that is prospective for reduced intrusion-related gold mineralization, is within the larger area GDf that is prospective for orogenic gold mineralization. An area to the northeast of the Gilmore Dome is characterized by one skarn style prospect and is prospective for reduced intrusion-related gold mineralization (GDh, Figure 2.33) and orogenic gold mineralization (DGi, Figure 2.33).

2.9.3 The Vault-Treasure Creek Area

The Vault-Treasure Creek area is well characterized by the moderately high scoring samples for factor five, suggesting most of the known mineral prospects could be classified as orogenic. This prospective trend may extend to the west (VTa, Figure 2.34) and to the east (VTb, Figure 2.34). These two areas are prospective for orogenic gold deposits. There are small areas with high scores for factor four that also contain anomalous gold in the same drainage (VTc, Figure 2.34), or in an adjacent drainage (VTd, Figure 2.34). These two areas are prospective for reduced intrusion-related gold mineralization.

2.9.4 The Ester Dome Area

The Ester Dome area is prospective for both styles of gold mineralization. The known mineralization in the southeastern part of this area is well correlated with anomalously high scores for factor five, and the results of this study extend this prospective region to the west and to the north (EDa, Figure 2.35). The northern part of the area contains some known orogenic gold deposits and has moderately positive scoring samples for factor four and overlapping anomalous Au (Figure 2.35). Area EDb is a prospective area for orogenic gold deposits that is situated within the prospective area defined by EDa.

2.10 Discussion of Prospectivity Mapping

Factor analysis is an exploratory method and seeks to understand trends in the data rather than produce quantitative results. For this reason, the areas presented here are in need of further detailed work to verify their value. When highly skewed data are used in factor analysis there is a bias towards the outliers within the dataset (Filzmoser, 1999). Regardless, interesting trends can
Figure 2.32: Prospective areas for gold mineralization in the Gilmore Dome area. Areas GDa, GDb, GDe, and GDe are prospective for reduced intrusion-related gold mineralization (RIRG). Areas GDe, GDe, and GDe are prospective for skarn style mineralization and/or orogenic gold mineralization (OROG). Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.33: Prospective areas for gold mineralization east of the Gilmore Dome area. Areas GDa, GDe, and GDi are prospective for reduced intrusion-related gold mineralization (RIRG). Areas GDe, and GDh are prospective for orogenic gold mineralization (OROG). Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.34: Prospective areas for gold mineralization in the Vault – Treasure Creek area. Areas VTa, and VTb are prospective for orogenic gold mineralization (OROG). Areas VTc, and VTd are prospective for reduced intrusion-related gold mineralization (RIRG). Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
Figure 2.35: Prospective areas for gold mineralization in the Ester Dome area. Area EDa is prospective for orogenic style gold mineralization (OROG). Area EDb is prospective for reduced intrusion-related gold mineralization (RIRG). Some mineral occurrences were classified and these are labeled with a number that corresponds to an entry in Tables 2.1a – 2.1d. Geology is simplified from Newberry et al. (1996). Individual maps of these scores overlaying the geology of the Fairbanks Mining District are provided as supplementary files in Appendix B. Streams are from the National Hydrography Dataset (U. S. Geological Survey (USGS) et al., 2018).
still be observed and these results can aid in characterizing elements that are related to the lithology and mineralization of the Fairbanks Mining District. The consequence of using the outliers may statistically invalidate the results. However, the maps presented here outline the known mineralization very well and are, therefore, useful in this context of identifying areas that are potentially prospective for gold mineralization.

In general, the highest and lowest scoring samples for each factor are the best examples of the geologic feature that factor represents. However, similar to anomaly identification using single elements, factor scores are not always normally distributed and using absolute values can be deceiving. The distribution of factor scores is used here to understand which values may be potentially most important and whether the high positive or high negative scoring samples. A catchment basin that contains a mixture of lithologies will have diluted factor scores for the factors related to those units. For this reason, sometimes moderately positive scoring samples also show areas with geology similar to the areas with high positive scores. The samples that have moderately high positive scores for both factor four and factor five are interpreted here as identifying drainages that are either prospective for potential host rocks, or for mineralization, respectively.

2.11 Conclusions

Factor analysis of stream sediment geochemical data was used to characterize lithology and mineralization in the Fairbanks Mining District. R-mode factor analysis of stream sediment geochemistry identified two groups of elements that are associated with gold mineralization: (1) As – Sb – Au is associated with shear zone and breccia hosted quartz – gold ± sulfide veins cutting metamorphic country rocks (i.e. orogenic gold deposits); and (2) Li – Cs – Rb + raw Au concentrations is associated with sheeted quartz – gold – bismuth veins hosted in reduced felsic intrusions (i.e. reduced intrusion-related gold deposits). The factor scores that were calculated in the process of factor analysis provide the basis for mineral prospectivity mapping and identified 25 areas prospective for either of these two styles of gold mineralization.
2.12 Acknowledgements

The authors acknowledge financial support from the Colorado School of Mines, the Society of Economic Geologists, and the United States Geological Survey. This contribution benefitted from informal editing by Ashley Quigley, Marion Nicco, John Meyer, and Neil Grumbley. I would also like to acknowledge the technical support and advice of Dr. Jeffery Jaacks.

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CHAPTER 3
CONCLUSIONS AND RECOMMENDATIONS
FOR FUTURE WORK

3.1 Major Conclusions of this Study

The results of this study confirm that factor analysis is a useful method in the identification of geochemical relationships associated with lithology and mineralization. The factor scores for the factors related to gold mineralization were successfully used to identify 25 areas prospective for gold mineralization in the Fairbanks Mining District (Figure 3.1). These prospective areas are outlined in Table 3.1. The factor most closely associated with gold mineralization is factor five, which has an As-Sb-Au association. Those samples with a moderate to high positive score for this factor are derived from drainages that contain known orogenic style gold mineralization, as well as drainages that are prospective for this style of mineralization (Figure 3.1). The Fort Knox reduced intrusion-related gold deposit was not identified using the factor scores for factor five. In order to identify prospective areas for mineralization similar to Fort Knox, factor four was utilized. This factor has a Li-Cs-Rb association, and the samples with high positive scores are derived from drainages that contain, or are prospective for, felsic intrusions. These intrusions may host reduced intrusion-related style gold mineralization. Those samples that have a moderate to high positive score for factor four and also contain elevated gold concentrations (Au > 18 ppb) are considered prospective for reduced intrusion-related gold mineralization.

The following section outlines general limitations that should be taken into consideration when applying r-mode factor analysis to stream sediment geochemical datasets. That information is followed by a guide to prioritizing the prospective areas identified in this study, as well as general recommendations for future exploration efforts within those areas. The final section of this chapter comprises a discussion of other statistical methods that could be used with the Fairbanks Mining District stream sediment data, to verify the results presented here or to potentially identify other prospective areas in the district.
Figure 3.1: Map showing the locations of the prospective areas for lode-gold mineralization, for explanation see Chapter 2. Prospective areas are labeled on the map and tabulated in Table 3.1. Geology is simplified from Newberry et al. (1996). Streams are from the National Hydrography Dataset (U. S. Geological Survey et al., 2018).
Table 3.1: Areas identified in the present study as prospective for the specified mineralization style.\(^1\) This area is within another area.

<table>
<thead>
<tr>
<th>Prospective Area</th>
<th>Style of Mineralization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cleary Summit - Pedro Dome Area</strong></td>
<td></td>
</tr>
<tr>
<td>Csa</td>
<td>Orogenic</td>
</tr>
<tr>
<td>CSb</td>
<td>Orogenic</td>
</tr>
<tr>
<td>CSb</td>
<td>Orogenic</td>
</tr>
<tr>
<td>CSd</td>
<td>Orogenic</td>
</tr>
<tr>
<td>CSe</td>
<td>Orogenic</td>
</tr>
<tr>
<td>CSf</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td>CSg</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td>CS(^1)h</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td>CSi</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td>CSj(^1)</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td><strong>Gilmore Dome Area</strong></td>
<td></td>
</tr>
<tr>
<td>GDa</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td>GDb</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td>GDc</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td>GD(^1)d</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td>GDe</td>
<td>Orogenic</td>
</tr>
<tr>
<td>GDF</td>
<td>Orogenic</td>
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<tr>
<td>GDg</td>
<td>Orogenic</td>
</tr>
<tr>
<td>GDh</td>
<td>Orogenic</td>
</tr>
<tr>
<td>GDi</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td><strong>Vault - Treasure Creek Area</strong></td>
<td></td>
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<tr>
<td>Vta</td>
<td>Orogenic</td>
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<tr>
<td>VTb</td>
<td>Orogenic</td>
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<tr>
<td>VT(^1)c</td>
<td>Reduced intrusion-related</td>
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<tr>
<td>VTd</td>
<td>Reduced intrusion-related</td>
</tr>
<tr>
<td><strong>Ester Dome Area</strong></td>
<td></td>
</tr>
<tr>
<td>Eda</td>
<td>Orogenic</td>
</tr>
<tr>
<td>Ed(^1)b</td>
<td>Reduced intrusion-related</td>
</tr>
</tbody>
</table>
3.2 General Considerations for R-mode Factor Analysis

In general, highly skewed data invalidates factor analysis. However, the results of the present study show that factor analysis of highly skewed data can still provide insight into the geochemistry of a region. The following paragraphs briefly highlight some potential issues that may introduce uncertainty in the analyses presented in this study.

The variance of the elements in the dataset used here appear to be dominantly controlled by geology and mineralization. However, the variance of some elements is likely also controlled by other factors such as adsorption onto Fe- and Mn-oxides (e.g. Co), pH and temperature of the stream water, the size of the drainage that was sampled, and analytical limitations. In some factor analyses, the results reveal a distinct factor with elements associated directly to Fe and Mn. This suggests those, and other elements with a high loading value with that factor, are strongly controlled by adsorption (e.g. Tripathi, 1979). Although this was not obvious in the results of this factor analysis, it is likely Fe and Mn are controlled by these processes as well as other elements that commonly adsorb onto oxides, such as Co, Ni, Cu, and Zn (Jenne, 1968).

The pH and temperature of the stream water at the sample sites was not reported for the geochemical survey used here (Jozwik, 2007). These parameters influence the ability of elements to mobilize into solution and, therefore, the concentration of elements within the stream’s sediments are controlled to some extent by this variance (Levinson, 1979). It is unknown if the pH or water temperature had a significant effect on the results presented here, because these data are not available. However, if the pH and temperature varied extensively in the project area, this would potentially influence the overall variance of the elements and affect the results of factor analysis.

The size of the catchment basin that is sampled influences the variance of elements because of dispersion and dilution. In general, factor analysis should be performed on stream sediment samples collected from drainages that are of relatively the same size. The exact size is unknown for the drainages examined in this analysis, but it is certain that their sizes are not uniform and this variance likely influenced the correlation of elements. Early in the process of this study there was an attempt to assign drainages to each sample, however, there is a level of uncertainty in the sample locations due to the historic nature of the dataset. This made the detailed creation of sample drainages generally invalid. Catchment basins were created for the samples that are considered to be derived from prospective rocks for gold mineralization, to the
best of the author’s abilities. However, previously sampled sites should be ground-truthed, and new sampling of rocks and soils within these catchments is highly recommended.

There are always analytical limitations in geochemical analysis. The precision of an analytical method can influence the variance of elemental concentration. Factor analysis examines this variance, and as such can be affected by it. The degree to which precision influenced the variance of the data is evaluated using control samples such as standards, blanks and duplicates. Standards evaluate the precision and accuracy of the analytical method against a standard sample with a known value for specific elements. Blank samples are those with a negligible concentration of an element of interest, this is used to evaluate potential laboratory contamination that may influence the accuracy and precision of that element. Duplicate samples evaluate the variance of analysis from the same sampled material. Duplicate samples should be: (1) collected in the field to evaluate variance from field sampling, and (2) a select number of samples should be split and sent for duplicate analysis to test the variance of the laboratory analysis. Duplicates are the most important control samples when evaluating variance because it is a direct measure of how the concentrations of the same material can vary due to sampling or analytical limitations.

3.3 Prioritizing Exploration at Prospective Sites Identified in this Study

All of the 25 prospective sites identified in the present study should be examined in more detail in desktop studies using historic data prior to conducting relatively expensive and time-consuming field work. This would likely eliminate some of the targets due to land access issues, lack of success by previous explorers, and/or land status. The remaining areas should be ranked according to the priorities of the company. For example, a particular company may be interested in targeting either: (1) large low-grade deposits such as those classified as reduced intrusion-related gold mineralization, or (2) small high-grade deposits such as those classified as orogenic gold mineralization. The following section presents a brief overview of some considerations that should be made when using the prospectivity data in the present study to explore for gold mineralization in the Fairbanks Mining District.
3.3.1 Future Exploration Efforts Using These Maps

For the verification of mineralization in any drainage prospective for orogenic and/or intrusion related gold mineralization, the following general recommendations are made: (1) review of detailed government studies and company reports that are freely available online, (2) detailed geological mapping, and (3) stream sediment and rock geochemical sampling. These recommendations are discussed in more detail below.

The Alaska Resource Data File (ARDF) is the most comprehensive list of known mineral occurrences in the district (U.S. Geological Survey, 2016). One of the main utilities of this database is that it cites many of the original studies that mapped and sampled the mineralization and rocks of this district. This database should be used as a guide to identify other sources for more detailed geological information that is available. A physical verification of the location and characteristics of the occurrences in the areas of interest is highly recommended. The mineral occurrence locations listed on the map are accurate to as little as a few meters but as much as 400 m. The geological map of the Fairbanks district presented here represents the best publicly available compilation of the current data. However, it has been created at a large scale and, for the purpose of detailed exploration at the scale of these proposed areas, more detailed geological mapping should be conducted.

The historic dataset provided here is useful in aiding the identification of prospective trends, and has indeed produced new prospective areas for mineralization. Both the known prospective areas and those presented here as new, should be resampled to verify the original analytical results. Samples should be collected at similar locations to those already sampled to verify the historic results. New samples should also be collected of other nearby streams to determine target mineralization more precisely. The sediments in each drainage may be affected by Quaternary geomorphology, which will in turn affect the analytical results of samples from any such area. Therefore, it is advisable to determine whether the sample collected is derived from material from upstream or if the dominant material is from somewhere else, such as a landslide area or colluvium.

In the areas that are prospective for shear zone hosted gold mineralization, structural mapping should be conducted as an important component of the geological mapping. These deposits are strongly structurally controlled, typically on second- or third-order splays of major fault systems (Goldfarb et al., 2005). Because the alteration halo of this style of mineralization is
subtler than that of many other mineralization styles (e.g. porphyry), detailed mapping efforts of the prospective areas should give special attention to cryptic alteration that may serve as a vector for mineralization. The alteration assemblage commonly identified in greenschist facies metamorphic rocks associated with orogenic style gold mineralization, may include the following carbonate, sulfide, and silicate minerals: ankerite, dolomite, ferroan dolomite, pyrite, pyrrhotite, arsenopyrite, sericite, biotite, albite, and chlorite. Silicification is also a common alteration style found in association with orogenic gold deposits (Goldfarb et al., 2005).

The areas that are prospective for reduced intrusion-related gold mineralization should be mapped with a focus on identifying felsic intrusive rocks, typically with granitic to granodioritic compositions, that have a reduced oxidation state (Hart, 2007). Some of the prospective samples of this study are derived from areas that have known intrusions, however, the detailed geology of these intrusions is not well constrained by existing geological maps. Prospective samples that are derived from areas that do not currently have a mapped intrusion should be examined to identify if there is indeed an unmapped intrusion, as the factor analysis suggests. If there is not an exposed intrusion, it is important to examine why the geochemical signature of this drainage was favorable, in order to determine whether the drainage can be disregarded as a prospective target and to weed out false positives. Where there are intrusions, determining the general fertility of the plutonic system is important via geochemical analyses to assess their potential to host gold mineralization. Where such intrusions are identified to contain gold, it is important to conduct detailed mapping of the alteration related to such mineralization. Typical alteration is very minor and generally forms narrow selvages (0.5 – 3 cm) around sheeted veins within the intrusions (Hart, 2007). Within these alteration selvages the mafic minerals are replaced by either K-feldspar or carbonate, while plagioclase and mafic minerals within the hosting intrusion are altered to sericite, with the possible addition of pyrite and or carbonate minerals outboard of the main alteration selvages (Hart, 2007).

3.4 Recommendations for Additional Statistical Analyses

Major and trace element lithogeochemistry of rock units in the Fairbanks district (e.g. Robinson et al. 1990) could be used in a factor analysis, similar to the study in the Yukon by Marsh et al. (1998). The methods of that study included the detailed sampling and geochemical analysis of mineralized rocks as well as unmineralized rocks adjacent to gold-bearing veins, in
order to determine the elements associated with gold mineralization. That study was conducted on rocks and mineralization in the Tungsten gold belt, which analogous to those found in the Fairbanks Mining District. A similar study of rocks and veins in the Fairbanks District would help to constrain the element correlations between the different known rock types. The results could then be compared to the results of the factor analysis of the stream sediment data presented here to help validate the results and provide more insight into the geochemical associations related to gold mineralization in the district. In particular, it would be interesting to compare the geochemistry of orogenic gold veins to the geochemistry of reduced-intrusion related gold veins. Such a comparison could reveal why the stream sediment geochemistry favors the orogenic style rather than the reduced intrusion-related style.

Previous authors have reported success in performing "staged factor analysis" on geochemical data, a technique employing a series of factor analyses (e.g. Yousefi et al., 2014; Hoseinpoor and Aryafar, 2016). The first "stage" uses all of the available elements, and each following "stage" uses only those elements that had a high loading value in the previous factor analysis. This method is used to strengthen the factor scores related to mineralized areas (Yousefi et al., 2014; Hoseinpoor and Aryafar, 2016). This method could be performed on the data presented here and is another method to determine prospective drainages for gold mineralization.

There are different ways to perform a factor analysis, and the two dominant methods are referred to as r-mode and q-mode. Conventional methods of statistical analysis focus on the variability of element concentrations. Due to this, r-mode factor analysis is the more popular method among exploration geochemists because it determines factors using the variance of elements, thereby defining factors related to lithology, alteration, and mineralization (Tripathi, 1979). Q-mode factor analysis is not commonly used in the analysis of exploration geochemistry data because it defines factors based on the variance between samples (rather than the variance between the variables in an r-mode factor analysis). Hypothetically, q-mode factor analysis would highlight areas with similar sample geochemistry and what these samples have in common geochemically. In this way, a q-mode factor analysis would focus on the combination of host rock and mineralization, and the identification of areas that are prospective for a particular host rock-mineralization combination, rather than the identification of geochemical associations related to specific rocks or mineralization styles separately.
Discriminant analysis could be used with these stream sediment data to identify areas of gold prospectivity in the Fairbanks Mining District. Samples that are derived from areas of known gold mineralization would be used as the dependent variable, and these samples would be used to identify other samples that have similar characteristics and classify them as mineralized or not. A discriminant analysis of the Fairbanks Mining District dataset would be useful to classify samples that may or may not be prospective for gold mineralization and thus further evaluate the prospective areas that were identified in this study.

3.5 References Cited


This section provides an overview of the analytical methods used to obtain the concentrations of elements from the stream sediments collected in the Fairbanks Mining District and east-central Alaska.

A.1 Inductively Coupled Atomic Emissions Spectroscopy

Inductively coupled atomic emission spectroscopy (AES) geochemical analysis relies on the principle that every element has a unique light emission spectra that can be distinguished from other elements. Prior to analysis the sample is dissolved into an acid solution after which, the sample solution is passed through the AES apparatus (Lichte et al., 1987). The sample solution becomes nebulized into an aerosol, and then passes through the plasma flame of the apparatus (Lichte et al., 1987). The energy of the plasma excites the electrons in the outer shell of the atoms and, as this excitement dissipates, the atom emits energy as light (Lichte et al., 1987). Each element has a signature spectral fingerprint and this is used to differentiate elements from each other, and the intensity of the emitted light is proportional to the concentration of that element in the sample (Lichte et al., 1987).

The accuracy of this method relies on the correct application of standards during analysis to ensure the apparatus is correctly verified, but when properly applied this method can have an accuracy of ± 5 – 10 percent relative to the standard deviation (Lichte et al., 1987). This method is considered be very precise and it is only limited by the sample preparation methods (Lichte et al., 1987). The sample needs to be ground and mixed thoroughly prior to digestion, and the digestion effectiveness depends on the presence of resistant minerals, that may only be partially dissolved by the acidic solution (Lichte et al., 1987).

This method is suitable to estimate the concentration of 44 elements from rocks with silicate and carbonate minerals (Lichte et al., 1987). However, this method is not suitable for the dissolution of refractory minerals such as zircon, tourmaline, cassiterite, rutile, and chromite (Lichte et al., 1987). This method is not suitable for the estimation of S or B because these
elements are vaporized in the plasma, or H, C, N, O, F, Cl, Br because these elements are present in air and the acidic dissolution solutions (Lichte et al., 1987). The digestion chosen for this particular study is possibly incomplete for elements that occur in refractory or resistant minerals such as Ba in barite, Cr in chromite, Ti in rutile, and there are possibly others (Lichte et al., 1987; Jozwik, 2007). Elements that are normally found in trace amounts need to be diluted if they actually occur in concentrations that exceed their normal working range, including but not limited to: Mg in dolomite, Pb in galena, Zn in sphalerite, Cu in chalcopyrite (Briggs, 2002) The rest of naturally occurring elements can be measured as long as the mineral they are found in is completely dissolved.

A.2 Instrumental Neutron Activation Analysis

The instrumental neutron activation analysis (INAA) method uses a powdered rock sample and has no chemical pretreatment. Neutrons irradiate the sample, which causes a nuclear reaction to occur in naturally occurring isotopes (Baedecker and McKown, 1987). The newly formed radioactive isotopes begin to decay and in the process, they emit gamma-ray radiation, the spectrum of which is characteristic to each element and can be quantified using special detection instrumentation (Baedecker and McKown, 1987). The concentration of an element in the sample is proportional to the activity measured by the radioactive ion produced during this process (Baedecker and McKown, 1987). Both, the amount of time the sample is irradiated and, how long the ions are allowed to decay after the irradiation, have implications for the elements that can be measured (Baedecker and McKown, 1987). Up to 31 elements can be measured using a long irradiation time (> 8 hours) with a high neutron flux (~ 3 x 10^12 neutrons per cm^2 s) and multiple spectral counts during a long period of decay (7 days to 2 months) following the irradiation (Baedecker and McKown, 1987). Another seven elements can be measured using a shorter irradiation time (< 1 hour) with a lower neutron flux, and spectral counts during a short period of decay (< 10 min but some up to 3 hours) (Baedecker and McKown, 1987).

The method is free of error caused by laboratory contamination because it is the direct analysis of the sample without pre- or post- analysis chemical treatment. However, there can be error introduced during the sample preparation because the fineness of grind required to obtain a homogenous powder varies between rock types, thus, if widely variable rocks types within a set of samples are all ground to the same fineness, this may cause bias towards one of the rock types
(Baedecker and McKown, 1987). The lower detection limit of a given element using this method is dependent on the sample concentration of the other elements in the sample, particularly the concentrations of Na, Sc, Fe, Co, and La. This is because the radionuclide activation products of these elements produce spectral interferences (Baedecker and McKown, 1987). Samples with abnormally high or low concentrations of certain elements can also have an effect on the detection limits for many elements (Budahn and Wandless, 2002). Overall, the INAA method may have problems measuring the concentrations of the following elements, which are generally attributed to spectral interferences or a weak spectral line: Zn, Zr, Ba, Gd, Tb, Tm, and Yb (Baedecker and McKown, 1987).

A.3 Atomic Absorption Spectroscopy

Due to the unique atomic structure of each element, they will absorb or emit a specific wavelength of light (Aruscavage and Crock, 1987). This characteristic is exploited in the atomic absorption spectroscopy (AA) method, whereby a geologic sample is atomized, and then exposed to a light source of a certain wavelength (Aruscavage and Crock, 1987). The intensity and wavelengths of the light emitted from the sample is measured (Aruscavage and Crock, 1987). The light source is uniquely absorbed by each element present in the sample, and each sample will then reflect a unique intensity for each wavelength of light, which can be measured by a detector (Aruscavage and Crock, 1987). The difference between the intensity of the source light and the emitted sample light is used to identify which elements are present in the sample, and at what concentrations (Aruscavage and Crock, 1987).

It is generally advantageous to have a chemical decomposition of the sample prior to analysis (Aruscavage and Crock, 1987). The acids or chemicals to choose from vary and are generally chosen based on the geologic sample medium and the elements desired (Aruscavage and Crock, 1987). For example, some elements will become volatile during the process of chemical treatment and therefore a different treatment for those elements would be ideal (Aruscavage and Crock, 1987). It is also possible, and sometimes necessary, to instead use a fusion to decompose the sample to avoid loss of some elements (Aruscavage and Crock, 1987).

There are a number of different interferences that can create error using an AA method (Aruscavage and Crock, 1987). Some elements absorb and emit light in a wide wavelength range and some will reflect light, interacting and interfering with other elements (Aruscavage and
Crock, 1987). For our purposes, it is useful to know that, depending on the sample chemistry and the elements of interest, there are three main types of AA analysis to choose from: (1) flame atomic absorption spectroscopy (FAAS); (2) graphite furnace atomic absorption spectroscopy (GFAAS); and (3) hydride-generation atomic absorption spectroscopy (HGAAS). Very few of the RGS studies specified exactly what kind of analysis the AA was used and so it is simply assumed for the purpose of this research that all the necessary precautions were taken prior to, and during analysis, to correct for any potential interferences or other analytical problems.

A.4 X-Ray Fluorescence

X-ray fluorescence (XRF) is a geochemical analytical method that relies on the emission of energy in the form of x-rays from atoms in the sample as a result of the induced excitation of low-level neutrons in the structure those atoms (Johnson, 1977). The excitation is usually accomplished by using an x-ray tube, which emits polychromatic x-radiation that can be directed at the sample material (Johnson, 1977). Polychromatic x-radiation has the capability of exciting a wide range of elements, allowing for the detection of a wide variety of elemental concentrations at once and, because of that, is usually associated with higher detection limits (Johnson, 1977). The polychromatic method is useful in obtaining the concentrations of major elements, when the detection limits are less critical (Johnson, 1977). To lower the detection limit of the XRF method for the purpose of analyzing trace elements, the sample material should be irradiated by monochromatic light (Johnson, 1977). In order to produce a monochromatic light source, the polychromatic x-radiation is used to irradiate a secondary target, such as gadolinium, which will produce monochromatic x-radiation (Johnson, 1977). The monochromatic radiation from the secondary source can be directed at the sample material, affecting the lower level neutrons, resulting in the release of energetic x-rays (Johnson, 1977). The monochromatic x-radiation method is suitable for a smaller range of elements but it has a lower detection limit for those elements (Johnson, 1977). For this reason, the monochromatic x-radiation method is used for trace element analysis where the detection limit is important (Johnson, 1977). The x-ray emissions from the excited atoms in the sample either using poly- or mono- chromatic light are detected using special equipment, which converts the energy into electronic pulses (Johnson, 1977). The amplitude of the electronic pulses is characteristic to each element and the number of x-rays detected and their amplitudes are collected and reported using specialized equipment.
(Johnson, 1977). Unlike the spectral images from other geochemical techniques, the spectral read-out from an XRF machine is a histogram of x-ray amplitude data after they have been sorted into one of 1,024 amplitude channels (Johnson, 1977). The number of x-rays counted at a given amplitude is proportional to the concentration of that element in the sample material (Johnson, 1977).

The x-rays that are measured by the detector may have been disrupted during analysis resulting in a lower or higher reading for a given element (Johnson, 1977). Some elements will absorb the x-rays being emitted from an element before that energy is detected, resulting in a lower estimated concentration (Johnson, 1977). Alternatively, the x-rays generated by other atom in the sample may excite a nearby atom, resulting in a higher estimated concentration for that second element (Johnson, 1977). Both of these problems affect the accuracy and precision of this analytical method and a mathematical correction of the intensities may need to be done in order to have the most accurate concentration estimate possible (Johnson, 1977).

A.5 Emission Spectroscopy

The emission spectroscopy (ES) method of determining elemental concentrations in geologic materials was designed as a field-ready geochemical method (Grimes and Marranzino, 1968). The ES method relies on the principle that elements emit light in a certain spectrum and that spectrum can be captured and examined (Grimes and Marranzino, 1968). There are a few different ways to set up an ES analytical system and for this research the semi-quantitative direct-current arc method is the only relevant method. For a more in-depth discussion of qualitative ES methods, or alternating-current arc ES methods, please review the references herein. The ES technique involves the arrangement of two electrodes, anode and cathode, situated such that a high temperature and energy plasma is produced in the space between them (Grimes and Marranzino, 1968). The temperature created by the direct-current arc plasma is capable of atomizing and ionizing the sample material such that the atoms will become excited into a new electronic state, and the subsequent transition of the ions back to their relaxed state releases photons of light at a specific wavelength (Grimes and Marranzino, 1968). The emitted light from this process is collected on film and, after processing, the spectral signature of each sample is visually evaluated (Grimes and Marranzino, 1968). Each element present in the sample will have a distinct spectral signature and the visual assessment of the results allows for a semi-
quantitative estimate of the concentration of each element within the sample material (Grimes and Marranzino, 1968).

Standards are a very important part of this method and the correct assembly and analysis of standards has a very important impact on the accuracy of this method. It is important to analyze a standard that is similar in composition to that of the material in question in order to have reliable spectral lines to compare with (Golightly et al., 1987). A detailed description of how standards are prepared and different considerations as to their constituents is described in Grimes and Marranzino (1968) and Golightly et al. (1987). Sample homogeneity also plays a very important role in the accuracy and precision of this method and it is important to have a fully representative sample of the parent material for analysis (Golightly et al., 1987). The ES method in particular requires an experienced analyst to ensure the use of adequate standards and proper preparation and analytical methods, as well as experience working with the resulting spectral data to ensure the most accurate and precise results (Golightly et al., 1987)

A.6 Delayed Neutron Counting

Delayed neutron counting (DNC) is a geochemical analytical method that is used to measure U and Th concentrations in geologic materials (McKown and Millard Jr, 1987). This method is similar in concept to the broader method of INAA, in which the atoms in the sample material are irradiated and subsequently transform into radioactive nuclides (McKown and Millard Jr, 1987). The radioactive nuclides that are produced during the irradiation process decay, releasing radioactive beta and gamma radiation (McKown and Millard Jr, 1987). The DNC, although similar in concept, differs from INAA in practice because it is detecting what happens to the elemental nuclei of U and Th during the irradiation process, which differs from other elements detected using INAA (McKown and Millard Jr, 1987). The atoms of U and Th capture a neutron during the irradiation of the sample, which destabilized the nucleus of the atom to such a degree that it instantaneously split (i.e. it induces a fission reaction) into two lighter elements (McKown and Millard Jr, 1987). Each fission event is also accompanied by the release of one or more neutrons, termed prompt fission neutrons (McKown and Millard Jr, 1987). The two lighter elements created after the fission can be the radioactive isotopes of various elements (McKown and Millard Jr, 1987). These isotopes decay to a stable isotope by a delayed series of beta emissions, and depending on the isotope may be accompanied by the release of a neutron
The neutrons released as the fission-product isotopes are decaying, are termed delayed neutrons and can be detected and counted during DNC analysis (McKown and Millard Jr, 1987). Elaborate detection systems are required to discern the individual delayed neutrons because the energy level and timing of their release are not characteristic enough using basic detector technologies, and for practical uses the overall delayed neutron count is measured (McKown and Millard Jr, 1987). For this reason, the DNC method cannot directly measure the concentrations of the fission species, which would allow for the estimation of Th and U in the sample material (McKown and Millard Jr, 1987). In order to estimate these concentrations, the DNC method uses two separate periods of irradiation and different levels of radiation and applies the known natural isotopic ratio of 238U/235U (McKown and Millard Jr, 1987). This combination of methods results in the estimation of the concentrations of 232Th, 238U, and 235U in the sample medium (McKown and Millard Jr, 1987).

The accuracy and precision of the DNC method for the analysis of U is considered to be very good (McKown and Millard Jr, 1987). The lower detection limit for U is dependent on the concentration in the sample, such that higher concentrations have a better analytical precision and lower concentrations are less precise (McKown and Millard Jr, 1987). At levels above 1 ppm, the analytical precision for U is ± 5 percent, and at levels down to about 0.2 ppm the analytical precision for U is ± 30 percent. The ratio of Th/U in the sample material must be greater than 3 for the DNC analysis to produce precise results for Th (McKown and Millard Jr, 1987). This rule has been determined experimentally and is discussed in more detail in McKown and Millard Jr (1987). In general, for samples with a Th/U ratio greater than 3, a ± 10 percent analytical precision for Th can be expected (McKown and Millard Jr, 1987). For example, a sample with U and Th concentrations on the order of 1 ppm, and 10 ppm respectively, the analytical precision for U and Th is about ± 5 percent and about ± 10 percent respectively (McKown and Millard Jr, 1987). There are negative effects on accuracy when a sample less than 10 grams is used, this is attributed to an inadequately homogeneous sample (McKown and Millard Jr, 1987). Interferences from the gamma radiation from samples anomalously high in elements Be, F, Bi, B, Cd, and Gd, will have a serious impact on the accuracy of the DNC method (McKown and Millard Jr, 1987). Special accommodations can be made in order to correct for these errors but these methods are not routinely used and, in general, samples with
elevated levels of these elements are not suitable for DNC analysis (McKown and Millard Jr, 1987).

A.7 Coulometry

Coulometry (CM) is a geochemical analytical method that is used to measure the concentrations of elements in a geologic sample (Jackson et al., 1987). In general, this method is a titration, by which, the electrical conductivity of the titration product is measured and used as the basis for the concentration estimation (Jackson et al., 1987). The only detailed descriptions of the CM method that were found, describe the CM method of analyzing carbon from carbonate rocks (Brown et al., 2002). Carbon was not analyzed in any of the RGS databases for this research and therefore, the method to analyze for carbon will not be discussed here.

A.8 References Cited


APPENDIX B
SUPPLEMENTARY FILES

The supplementary files included as part of this work are the tables, graphs, and maps used in the data preparation and execution of factor analysis.

<table>
<thead>
<tr>
<th>File Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairbanks Geochemistry</td>
<td>This spreadsheet contains geochemical results for the 1981 and the 1995 analyses of the stream sediments collected in the Fairbanks Mining District. This includes the raw data for both analytical years, the dataset after these were combined, the data after the duplicates were removed, the data after the highly censored samples were removed, a list of the duplicates that were removed, a list of the censored samples that were removed, the data after both duplicates and censored samples were removed and concentrations below the lower limit of detection were replaced (0.7xLLD), an overview table of the elements analyzed with their percent censored and replacement values.</td>
</tr>
<tr>
<td>sumstat</td>
<td>This is a script that is written for MATLAB®. The purpose of this script is to perform summary statistical analysis on the geochemical data. This follows the methods discussed in the text.</td>
</tr>
<tr>
<td>rmode</td>
<td>This is a script that is written for MATLAB®. The purpose of this script is to perform r-mode factor analysis with varimax rotation using log transformed data. This follows the methods discussed in the text.</td>
</tr>
<tr>
<td>Fairbanks Single Element Maps</td>
<td>This folder contains the single element concentration maps for each element in the geochemical dataset. The maps were created using ArcGIS mapping software.</td>
</tr>
<tr>
<td>Fairbanks Summary Statistics Plots</td>
<td>This folder contains the summary statistical plots for each element in the geochemical dataset. The sumstat MATLAB® script was used to create these plots.</td>
</tr>
<tr>
<td>Fairbanks Factor Scores</td>
<td>This folder contains maps showing the distribution of factor scores within the Fairbanks district.</td>
</tr>
<tr>
<td>Fairbanks Factor Analysis Results</td>
<td>This spreadsheet contains the results of the factor analysis including the factor loadings and the factor scores.</td>
</tr>
</tbody>
</table>