DETERMINATION OF GEOLOGICAL SOURCES FOR PREHISTORIC CHERT ARTIFACTS, NORTHWESTERN ALASKA

by

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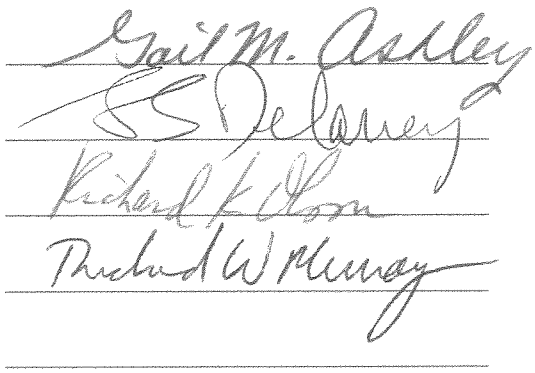
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ABSTRACT OF THE DISSERTATION

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The determination of the prehistoric human routes in northwestern Alaska is important for studying the peopling of North America. However, archaeological data do not provide sufficient information for reconstruction of prehistoric migration networks. Most sites in this area are surficial and chert artifacts are often the only surviving prehistoric relics. Therefore, chert sourcing in northwestern Alaska is crucial as it provides a unique opportunity for tracing inter-group contacts.

The research involved a regional geological-geochemical approach to "sourcing" of prehistoric chert artifacts using petrology, mineralogy and geochemistry. Artifact-outcrop correlation is based on the idea that both the artifact and outcrop have an identical geologic history that is recorded by unique petrological, mineralogical and geochemical signatures. Developing a regional database of signatures that distinguish each chert outcrop variety is fundamental to the approach. Artifacts are compared with the database using statistics to determine artifact source.

Twelve chert varieties from nine chert outcrops in the western Brooks Range were studied. Analytical data are obtained by instrumental neutron activation analysis, electron

microprobe analysis, X-ray diffraction, inductively coupled plasma source mass spectrometry, optical microscopy and hand specimen study. Outcrop data was compared with 289 chert artifacts from 57 prehistoric sites in northwestern Alaska by the superposition of artifact data on geochemical fields obtained for each outcrop at one, two and three standard deviations from the means of signature values.

The research revealed important geological implications regarding depositional environment, provenance and diagenesis of Paleozoic-Mesozoic chert deposits in the western Brooks Range. Four outcrops were identified as prehistoric chert quarries based on their statistically significant correlation with 51 artifacts from 29 prehistoric sites. Results are summarized in maps that show the geographic and cultural distribution of cherts from each quarry throughout prehistoric time. The geographic distribution shows wide distribution of chert from quarry area to Bering Strait coast, Chukchi Sea and to the Kobuk valley, as well as the possible expansion across the Bering Strait, to the Arctic Ocean, and to the northeast. Four quarries were used by many prehistoric groups from the American Paleo-Arctic tradition (~10,000 B.P.) to the Arctic Woodland Eskimo (1000 to Recent). Results of chert sourcing provide critical information for the reconstruction of prehistoric migration routes in the western part of eastern Beringia. The geological-geochemical approach to prehistoric chert sourcing is applicable to any region.

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TABLE OF CONTENTS

TITLE PAGE i

ABSTRACT OF THE DISSERTATION ii

ACKNOWLEDGMENTS iii

TABLE OF CONTENTS vii

LIST OF TABLES xi

LIST OF FIGURES xii

CHAPTER ONE: INTRODUCTION 1
- 1.1. Statement of the Problem 1
  - 1.1.1. Need for Chert Sourcing in Northwestern Alaska 1
  - 1.1.2. Possible Quarry Areas 9
- 1.2. Regional Geology 11
  - 1.2.1. Bedrock Geology and Tectonics 11
  - 1.2.2. Glaciation During Prehistoric Time 12
- 1.3. Chert Sourcing 12
  - 1.3.1. Visual Correlations 12
  - 1.3.2. Geological-Geochemical Approach 14
- 1.4. Objectives 16

CHAPTER TWO: GEOCHEMISTRY OF PALEOZOIC-MESOZOIC CHERT DEPOSITS IN THE WESTERN BROOKS RANGE, ALASKA: IMPLICATIONS FOR DEPOSITIONAL ENVIRONMENT 19
- 2.1. Abstract 20
- 2.2. Introduction 20
- 2.3. Geologic Framework 23
- 2.4. Methods 26
  - 2.4.1. Sampling 26
  - 2.4.2. Analytical Methods 27
  - 2.4.3. Problems in INAA of cherts 29
- 2.5. Results 32
  - 2.5.1. Mineralogy 33
  - 2.5.2. Geochemistry 36
    - 2.5.2.1. Major and Trace Elements 36
    - 2.5.2.2. Rare Earth Elements 42
- 2.6. Discussion: Depositional Environment 45
  - 2.6.1. Geochemical Model 45

2.6.2. Depositional Environment 47
2.6.2.1. Lisburne Group 47
2.6.2.2. Etivluk Group 53
2.6.2.3. Redox Conditions 56
2.7. Conclusions 58

CHAPTER THREE: GEOLOGICAL-GEOCHEMICAL APPROACH TO SOURCING OF PREHISTORIC CHERT ARTIFACTS, NORTHWESTERN Alaska 61
3.1. Abstract 61
3.2. Introduction 62
3.3. Archaeological Background 66
3.4. Geologic Framework 67
3.5. The Geological-Geochemical Approach to Chert Sourcing 69
3.5.1. Sampling 69
3.5.1.1. Outcrops 69
3.5.1.2. Prehistoric Artifacts 71
3.5.2. Analysis 73
3.5.3. Data Processing 73
3.5.3.1. Computer 73
3.5.3.2 Distinguishing Chert Outcrops 74
3.5.3.3. Correlation of Chert Artifacts with Chert Outcrops 74
3.6. Results 77
3.6.1. Distinguishing Outcrop Chert Varieties 77
3.6.1.1. Mineralogical Signatures 77
3.6.1.2. Geochemical Signatures 78
3.6.2. Quarry Geochemical Fields 84
3.6.3. Correlation of Artifacts with Outcrops 87
3.6.3.1. Black Artifacts 87
3.6.3.2. Gray Artifacts 90
3.6.3.3. Red Artifacts 90
3.7. Discussion: Geological-Geochemical Approach 93
3.7.1. Outcrop Sampling 94
3.7.2. Regional Database 94
3.7.2.1. Selection of Discriminative/correlative Signatures 95
3.7.3. Correlation Process 100
3.7.3.1. Statistics 100
3.7.3.2. Selection of the Geochemical Fields 103
3.7.4. Variability Within Prehistoric Chert Quarries 103
3.7.5. Maps of Chert Distribution 104
3.8. Conclusions 106

CHATPER FOUR: DISTRIBUTION PATTERNS OF PREHISTORIC CHERT QUARRIES IN THE WESTERN BROOKS RANGE 108
4.1. Abstract 108
4.2. Introduction 109
4.3. Chert Sourcing in Northwestern Alaska 113
4.3.1. Background 113
4.3.2. Analytical Methods 114
4.3.3. Data Processing 116
4.4. Geological Setting of Quarries 116
4.4.1. Wrench Creek Quarry 116
4.4.2. Upper Kelly River Quarry 118
4.4.3. Upper Kugururok River Quarry 121
4.4.4. Anisak Quarry 121
4.5. Mineralogy and Geochemistry of Quarries 126
4.6. Correlation of Artifacts with Quarries 133
4.6.1. Geological-Geochemical Approach 128
4.6.2. Wrench Creek Quarry 133
4.6.3. Upper Kelly River and Upper Kugururok River Quarries 134
4.6.4. Anisak Quarry 136
4.7. Distribution Patterns 139
4.7.1. Wrench Creek Chert 139
4.7.2. Gray Cherts from Upper Kelly River and Upper Kugururok River Quarries 143
4.7.3. Red Cherts from Upper Kelly River and Upper Kugururok River Quarries 145
4.7.4. Gray Anisak Chert 155
4.8. Discussion 148
4.8.2. Reliability of Chert Sourcing 148
4.8.1. Problems in Interpretation 149
4.9. Synthesis 151
4.9.1. Geographic Distribution 151
4.9.2. Cultural Distribution 151
4.10. Conclusions 157

CHAPTER FIVE: SYNTHESIS AND CONCLUSIONS 160
5.1. Geological-Geochemical Approach 161
5.2. A Regional Study of Chert Deposits 162
5.2.1. Analysis of Samples 163
5.2.2. Discrimination of Chert Outcrops 164
5.2.3. Geological Results 164
5.3. Regional Database 165
5.4. Comparison of Artifacts with the Database of Chert Outcrops 166
5.4.1. Results of Artifact-Quarry Correlation 169
5.5. Archaeological Implications 169

APPENDICES: 172
Appendix I. Database of geochemical signatures of twelve chert varieties from nine chert outcrops in the western Brooks Range, Alaska 173
Appendix I.1. Geological description of nine chert outcrops 174
Appendix I.2. INAA data on 12 chert varieties from nine outcrops 185
A. Major, minor and trace element composition 186
B. REE composition 192
C. Elemental ratios 198
Appendix I.3. Discrimination diagrams 203
A. Error bars at one standard deviation 208
B. Bivariate diagrams with geochemical fields at one, two and three standard deviations 214
Appendix I.4. Quarry geochemical fields 221
Appendix I.5. Mineralogical composition of inclusions 226
Appendix II. Database of geochemical signatures for 289 chert artifacts from 57 prehistoric sites located in northwestern Alaska 228
Appendix II.1. List of 289 chert artifacts from 57 prehistoric sites 229
Appendix II.2. INAA data on 289 chert artifacts from 57 prehistoric sites located in northwestern Alaska 238
A. Major, minor and trace elements 239
B. REEs 249
C. Elemental ratios 258
Appendix III. Diagrams illustrating artifact-outcrop correlations 270

REFERENCES CITED 283

LIST OF TABLES

Table 1.I	Synopsis of Cultural Sequences in Northwestern Alaska (From Giddings and Anderson, 1986)	6
Table 2. I	Summary of INAA Data for Outcrops for 12 Chert Varieties, Western Brooks Range (ppm)	30
Table 2.II	Analytical Accuracy, Precision and Detection Limits	32
Table 2.III	Correlation Coefficient (R) Values	38
Table 3.I	Elements and Elemental Ratios Used for Correlation of Chert Artifacts with Outcrops	89
Table 4.I	Summary of INAA for Prehistoric Chert Quarries In the Western Brooks Range (ppm)	129
Table 4.II	Black Chert Artifacts Correlated with Wrench Creek Quarry	135
Table 4.III	Gray Chert Artifacts Correlated with Upper Kelly River and Upper Kugururok River Quarries	137
Table 4.IV	Red Chert Artifacts Correlated with Upper Kelly River and Upper Kugururok River Quarries	139
Table 4.V	Gray Chert Artifacts Correlated with Anisak Quarry	139

LIST OF FIGURES

Figure 1.1. Beringia during glacial maximum isotope stage....2
Figure 1.2. Study Area. Northwestern Alaska archaeological sties and Area of chert outcrop sampling....4
Figure 1.3. Location of bedrock exposure of chert-bearing deposits in northwestern Alaska....10
Figure 1.4. Paleogeographic map of Alaska during maximum extent of late Wisconsinan glaciation....13
Figure 1.5. Research plan....17
Figure 2.1. Models of depositional environment for Paleozoic-Mesozoic chert-bearing formations in the western Broks Range....21
Figure 2.2. Location of Chert Outcrops Analyzed in this Study....24
Figure 2.3. Summary of chert-bearing formations in the western Brooks Range, Alaska....25
Figure 2.4. Mineralogical Composition and Diagenetic Patterns Of 12 chert varieties from Lisburne and Etivluk groups, western Brooks Range, Alaska....34
Figure 2.5. Microquartz-filled radiolarians in Kuna Formation....37
Figure 2.6. Elemental ratios for 12 Lisburne and Etivluk chert varieties (based on INAA data)....40
Figure 2.7. PAAS-normalized REE abundance patterns of the 12 chert varieties....43
Figure 2.8. Elemental ratios of REEs normalized to PAAS in 12 western Brooks Range chert varieties based on INAA data....44
Figure 2.9 . Mean concentrations of 12 western Brooks Range chert varieties plotted on Murray's discrimination diagram La_n/Ce_n vs. Al_2O_3 / (Al_2O_3+Fe_2O_3)....50
Figure 2.10. Mean concentrations of Etivluk Chertsr plotted on the La_n/Ce_n vs. Eu_n/Sm_n diagram....54
Figure 2.11. Mean concentrations of chert varieties plotted on the Ce_n/Ce_n* vs. Ba/Fe diagram....57
Figure 2.13. Summary of main geochemical and mineralogical signatures and depositional environment of late early Mississippian to Jurassic chert deposits in the western Brooks Range, Alaska....59
Figure 3.1. Map of study area and prehistoric sites....63
Figure 3.2. Summary of stratigraphy, geochemistry and petrology of chert-bearing formations in the western Brooks Range.
Figure 3.3. Research plan....70
Figure 3.4. Map of chert outcrops sampled in Kelly, Kugururok, Anisak and Nimiuktuk River basins, western Brooks Range, Alaska....72
Figure 3.5. An example of geochemical variability within chert varieties (KE12)....75
Figure 3.6. Separation of cherts from stratigraphic groups and formations in

the western Brooks Range by series of diagrams showing intervals of elemental ratio variability at 1σ....79
Figure 3.7. Separation of black chert varieties....81
Figure 3.8. Separation of gray (a,b,c,d,e) and Red (f) chert varieties of Etivluk Group by geochemical fields....85
Figure 3.9. Geochemical fields of Upper Kelly River and Upper Kugururok River quarries (at 3σ) obtained by combining outcrop and artifact Samples from quarries....88
Figure 3.10. Examples of artifacts-outcrop correlations....91
figure 3.11. Artifact-outcrop correlation by key (depositional, provenance, and diagenetic) geochemical signatures....97
Figure 3.12. Correlation of artifacts with quarry/outcrop geochemical fields....101
Figure 3.13. Map of distribution of chert artifacts correlated with Wrench Creek quarry, western Brooks Range, northwestern Alaska....105
Figure 4.1. Map of study area and prehistoric sites....110
Figure 4.2. Map of chert quarries identified in the western Brooks Range....115
Figure 4.3. Summary of stratigraphy, main geochemical and mineralogical characteristics, depositional environment and diagenetic patterns....17
Figure 4.4. Wrench Creek quarry....119
Figure 4.5. Upper Kelly River quarry....120
Figure 4.6. Upper Kugururok River quarry: (a) general view, and (b) detail....122
Figure 4.7. Anisak Quarry: (a) view, and (b) detail....124
Figure 4.8. Mineralogical composition of micro inclusions in quarry cherts....127
Figure 4.9. Illustration of artifacts - quarries correlation: (a) Wrench Creek quarry, (b, a) Upper Kelly River and Upper Kugururok River quarries, gray and red varieties, and (c) Anisak quarry....131
Figure 4.10. Correlation of black chert artifacts with Wrench Creek quarry by Ce_n/Ce_n^* values....135
Figure 4.11. Geographic distribution of Wrench Creek chert....140
Figure 4.12. Cultural distribution of the western Brooks Range quarry cherts....142
Figure 4.13. Geographic distribution of gray cherts from the Upper Kelly River and Upper Kugururok River quarries....144
Figure 4.14. Geographic distribution of red chert from the Upper Kelly River and Upper Kugururok River quarries....146
Figure 4.15. Geographic distribution of gray chert from the Anisak quarry....147
Figure 4.16. Map of general distribution of the prehistoric chert

artifacts correlated with the four western Brooks Range quarries....152
Figure 4.17. Distribution of cherts from the four Western Brooks range quarries in sites of a) American Paleo-Arctic tradition and b) Northern Archaic tradition....154
Figure 4.18. Distribution of cherts from the four western Brooks Range quarries in sites of Arctic Small Tool tradition: a) Denbigh complex, b) Choris and Ipiutak cultures....155
Figure 4.19. Distribution of cherts from the four western Brooks Range quarries in sites containing: a) Old Whaling complex, and b) Western Thule and Arctic Woodland Eskimo....156

CHAPTER ONE: INTRODUCTION

1.1. Statement of the Problem

Chert artifacts comprise an overwhelming majority of cultural remains in most of the prehistoric sites world wide. Often they are the only surviving relics in archaeological sites and the only sources of information about prehistoric cultures. A geological approach to the study of prehistoric chert artifacts provides a unique opportunity to obtain critical information needed to resolve important archaeological questions concerning prehistoric populations. In particular, chert artifact sourcing has proved important in reconstructing interaction networks of prehistoric cultures (Luedtke, 1978, 1987, 1992, 1993a, 1995; Nagle et al., 1980; Lech, 1983; 1984; Selivanova, 1984, 1986; Selivanona and Galibin, 1992). Monitoring of the movement of cherts from quarries to prehistoric sites and correlation of artifacts originating from the same chert source can be used to determine human migration patterns, intergroup contacts, trade and exchange routes, cultural intersections, inter- and intra-tradition variation, and technological class variation.

1.1.1. Need for Chert Sourcing in Northwestern Alaska

The determination of the routes of human migration across northwestern Alaska is extremely important for studying the peopling of North America. This region represents the eastern part of Beringia that provided the only land connection with the Old Word and the most plausible migration route for prehistoric humans (Fig. 1.1.). The deeper penetration into North America through Alaska was likely through intra-continental movement of these early Arctic-adapted peoples (Anderson, 1988). Archaeological research combined with dating of the Bering Land Bridge and key archaeological sites suggests that Beringia has

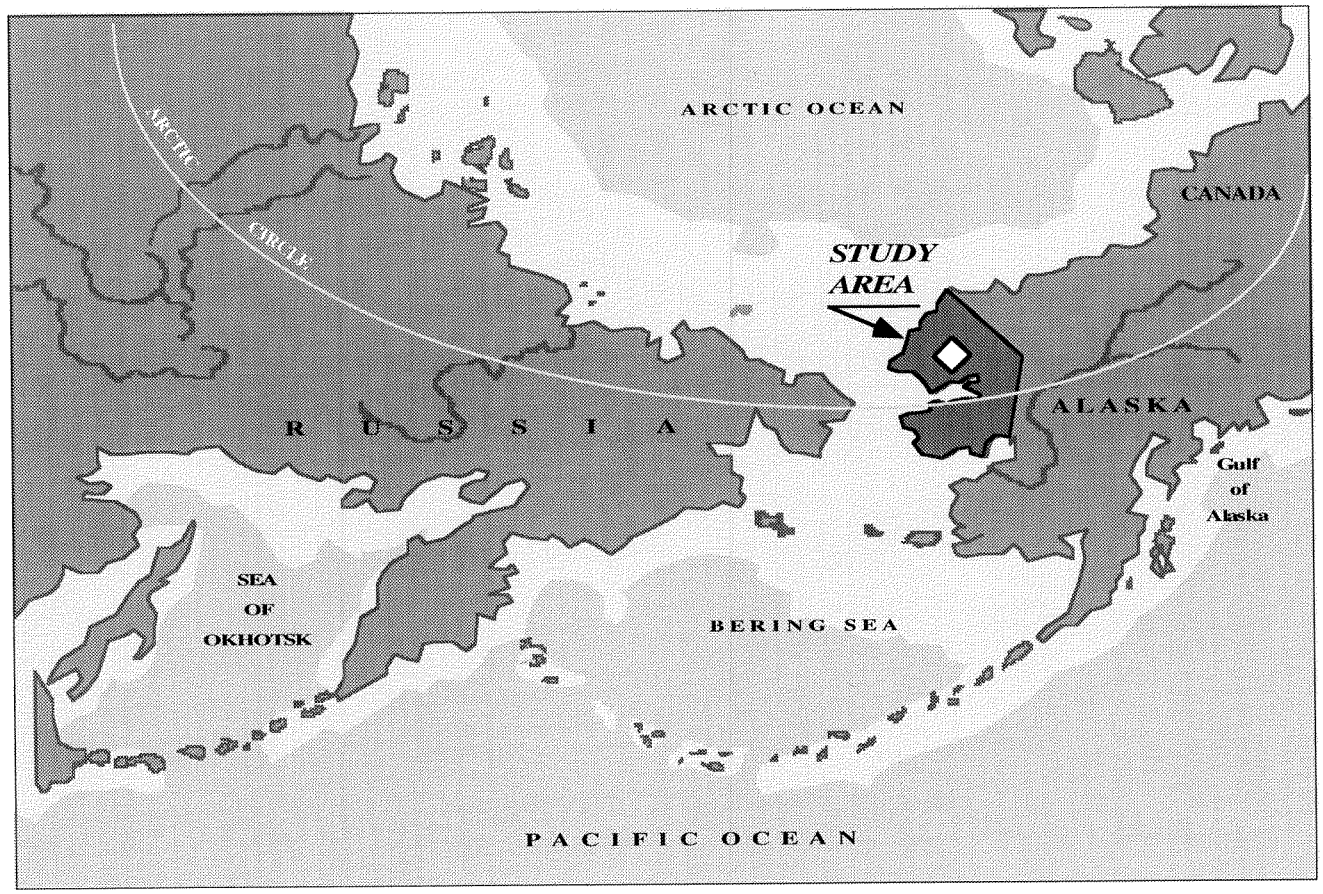


Figure 1.1. The Bering land bridge during glacial maximum (isotope stage 2) . Modified from West, 1981, originaly derived from Hopkins, 1972)

been occupied since 11,600 B.P., or perhaps slightly earlier in marginal areas (Hopkins, 1967; Anderson 1988; Hoffecker et al., 1993). However, determination of the routes of initial migration of humans across Beringia and routes of their rapid expansion into other parts of Alaska and the New World comprise some of the most difficult questions in North America archaeology.

The sea level history indicates that the land bridge connection between two continents existed from 25,000 B. P. to ~14,000 B.P. (Hopkins, 1967; McManus and Creager, 1984). By 14,000 B. P. sea level had risen to 38 meters below present level and severed the land connection between Siberia and Alaska. Two short time episodes in which the land bridge was re-established by eustatic sea level fluctuation (at 13,000 B. P. and 11,000 B. P.) occurred after which the Bering Platform was permanently flooded. Because of the rising sea level between 14,000 B. P. and 4,000 B. P., much evidence of late Pleistocene and lower-to-middle Holocene occupation in Beringia is now under water. Many prehistoric sites have been discovered in the central and eastern parts of Beringia (northwestern Alaska and Chukchi Peninsula) in a variety of environmental settings (coastal, riverine, woodland). They contain remains of many prehistoric cultures encompassing the time period from about 10,000 B.P. to the present. (Giddings, 1960; Anderson, 1970a, 1970b, 1972, 1984, 1988; Hall, 1975; Bockstoce, 1979; Gal, 1982, 1993, 1994; Gerlach and Hall, 1986; Giddings and Anderson, 1986) (Fig. 1.2.). In general these prehistoric cultures are classified into the four following prehistoric periods (from oldest to youngest) (Table 1.I):

1) The American Paleo-Arctic tradition (10,000-8,000 B. P.) was discovered at the Onion Portage site as an Akmak assemblage. It bears resemblance to finds from Siberia and central

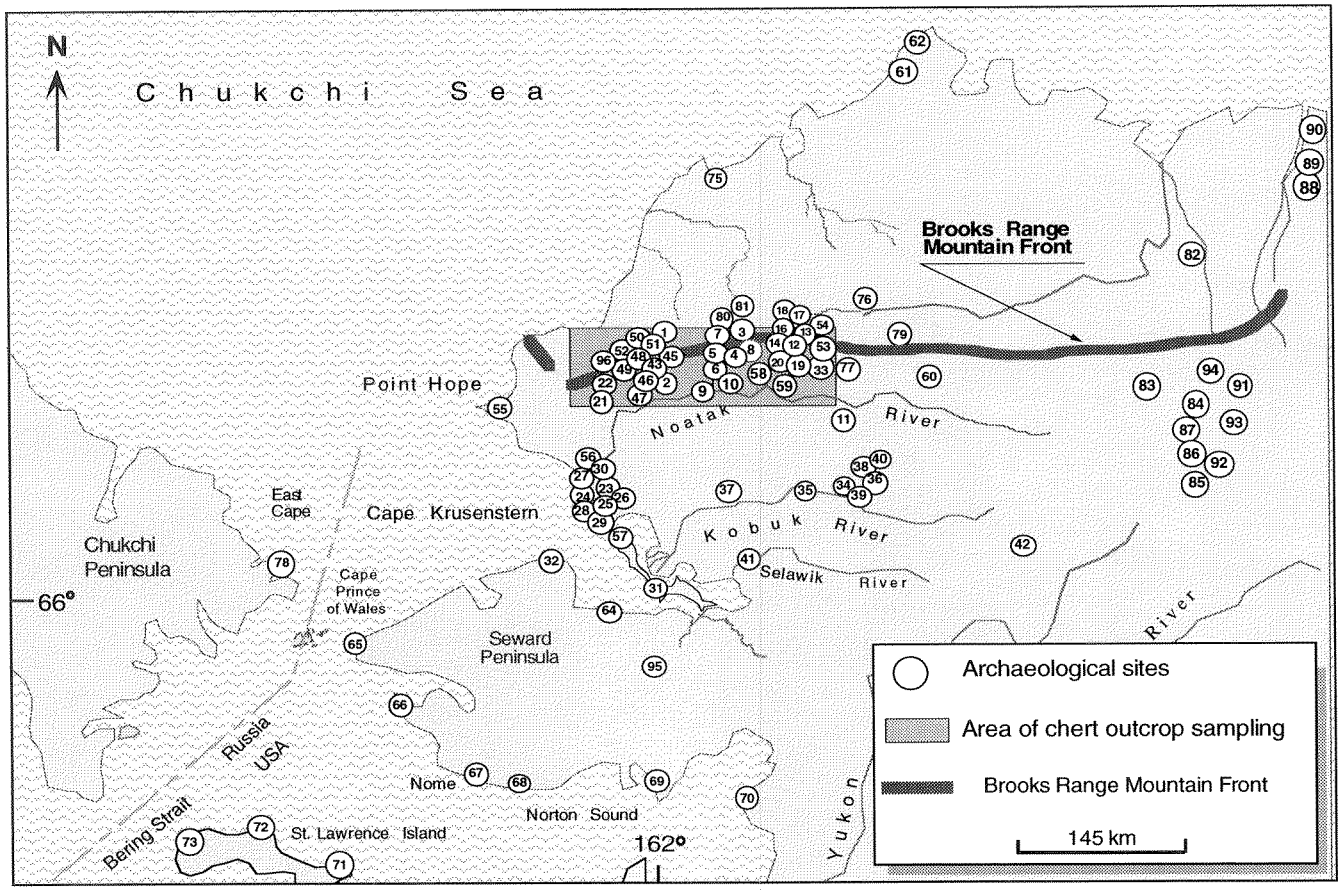
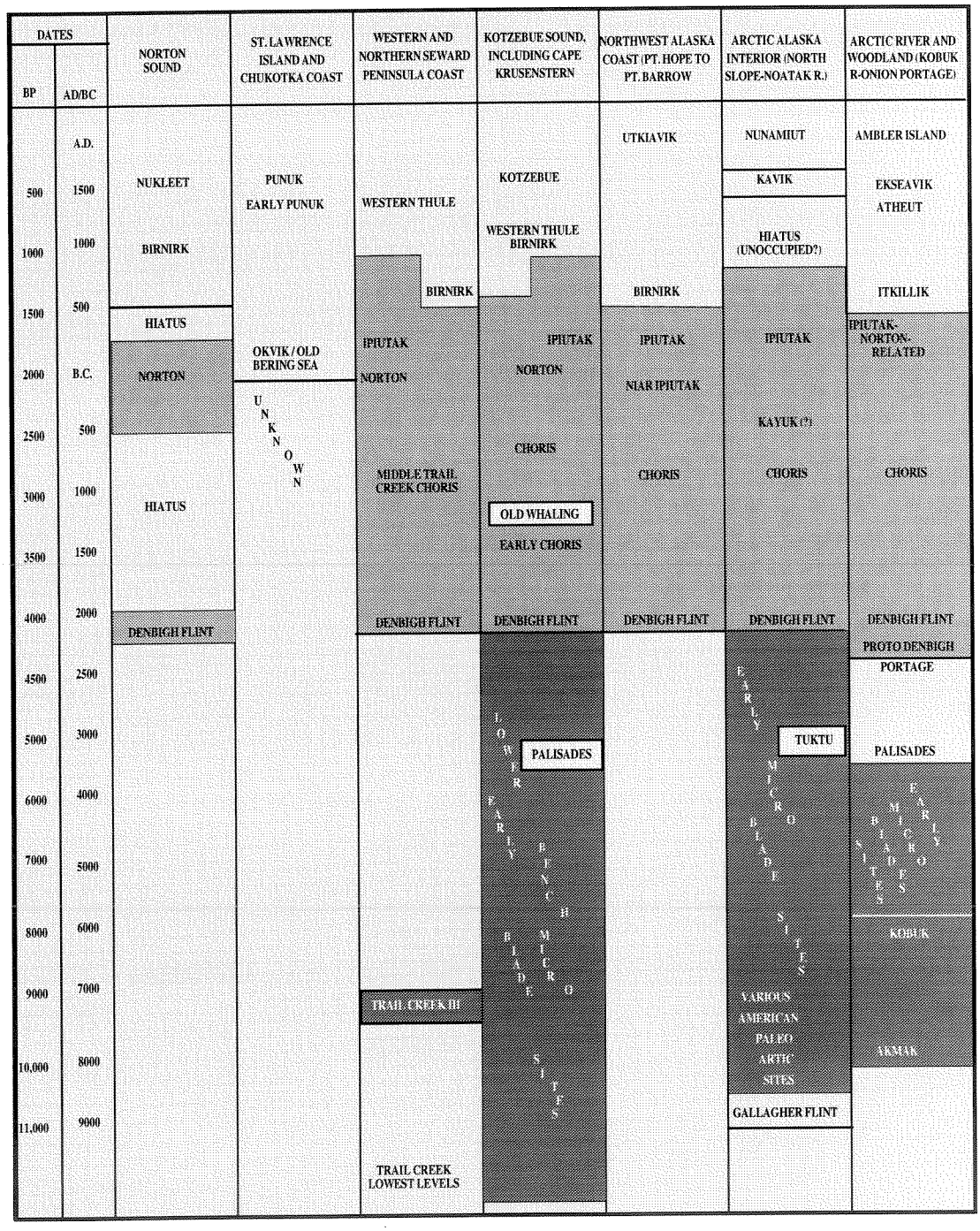


Figure 1.2 Study area. Location of archeological sites is from Solecki, 1951; Giddings, 1960; Anderson, 1970a, 1970b, 1972, 1984; Campbell, 1971; Hall, 1975; Hall and Mull, 1976; Stanford, 1976; Bockstoce, 1979; Giddings and Anderson, 1986; Gerlach and Hall, 1986.

Key to sites: 1) Upper Kelly River quarry, 2) Kelly River chipping stations NKR-1; **Kugururok River sites**: 3) Upper Kugururok River quarry, 4) NKUR-1, 5) KU02, 6) KU03, 7) Kaguik (KO02), 8)NU03 (Noat-3062); **Noatak River sites**: 9) N-5, 10) NR-17, 11) NR-27; **Nimiuktuk River sites**: 12) Nim 5-1, 13) Nim-7, 14) Nim-11, 15) Nim-15, 16) - 94108, 17) -94141, 18) -94127; **Anisak River sites:** 19) Anisak quarry, 20) AN08; 21) Red Dog Del-168, 22) Red Dog Del-166; **Cape Krusenstern sites**: 23) Battle Rock, 24) Palisades, 25) Lower Bench, 26) Sisualik, 27) Birnirk, 28) Ipiutak, 29) Denbigh, 30) Old Whaling; 31) Choris, 32) Cape Espenberg, 33) Burial Lake site; **Kobuk River basin sites**: 34) Onion Portage, 35) Atheut, 36) Lookout site on Knoll, 37) Kiana Bench, 38) High Old Bench, 39) Locality-2, 1963, 40) Ambler River site; 41) Selawik; 42) Lake Norotuk; **Saxsot Creek sites**: 43) Noat.-3006, 44) Noat.-3009, 45) Noat.- 3011; **Wrench Creek sites**: 46) Noat.-3014, 47) Noat.-3015, 48) Noat.-3018, 49) Noat.-3023, 50) Noat.-3024, 51) Noat.-3046, 52) Noat.-3047; **Nimiuktuk River sites**: 53) Picnic Creek site, 54) Setting Sun site; 55) Point Hope site, 56) Rabbit Creek site, 57) Kotzebue; 58) Kugururok River chipping stations Kug-2 through Kug-5, 59) Noatak River chipping stations NR-9, -10, -14, 15, 19-23, 60) Punjik Point, 61) Coffin, 62) Walakpa, 63) Tugulak, 64) Deering, 65) Walles sites, 66) Point Spencer, 67) Cape Nome sites, 68) New Beach sites at Cape Nome, 69) Cape Darby, 70) Cape Denbigh sites, 71) Punic Island sites, 72) Kukulik Mound, 73) Gambell sites, 74) Indian Port, Siberia, 75) Tunalik, 76) Tukuto Lake, 77) Feniak Lake, 78) Uelen sites, 79) Mesa, 80) Kugururok (found by Lechenbruch), 81) Utukok River sites, 82) Itkillik River sites, 83) Natvakrunk Lake , 84) Franklin Bluff, 85) Kayuk, 86) Avingak, 87) Tuluak Lake, 88) Peters Lake, 89) Schreder Lake, 90) Katalaturuk, 91) Utu Lake, 92) Tuktu Lake, 93) Okiotak, 94) Kogruk, 95) Trail Creek caves.

Table 1.I. Synopsis of the cultural sequences in northwestern Alaska (from Giddings and Anderson, 1986)



KEY:
- NORTHERN MARITIME TRADITION
- ARCTIC SMALL TOOL TRADITION
- NORTHERN ARCHAIC TRADITION
- AMERICAN PALEO ARCTIC TRADITION

and southwestern Alaska (Mochanov, 1980; West, 1981; Anderson, 1984, 1988; Dikov and Titov, 1984). The fact that Onion Portage is located on the routes from the Bering Sea coast into inland Alaska has an important bearing on the problem of deciphering the earliest prehistoric routes in Alaska.

2) The Northern Archaic tradition (5,800-4,000 B.P.) was discovered at Cape Krusenstern, Onion Portage, Noatak River sites and in Anaktuvik Pass (Giddings, 1960; Gal, 1982; Gerlach and Hall, 1986; Giddings and Anderson, 1986). The origin of the tradition is not clear. Its assemblages are similar to those from the Alaskan interior and Canadian Yukon, but are strikingly different from those in Arctic coastal and adjacent tundra regions.

3) The Arctic Small Tool tradition (4,000-1,000 B. P.) discovered in coastal sites at Cape Denbigh, Cape Krusenstern, Walakpa, Choris, Cape Espenberg, in Trail Creek, Onion Portage, Noatak River sites and in Punyik Point. This tradition may have originated from Asia, or may also be a derivative of the American Paleo-arctic tradition (Anderson, 1970b, 1972, 1984, 1988).

4) The prehistoric Eskimo cultures (1,000 B.P.-present) appeared as a result of dramatic change in coastal cultures of northwestern Alaska (Anderson, 1984) caused by new populations moving into the region from coastal Alaska or islands fringing the Bering Strait.

A wide variety of sites belonging to all four prehistoric traditions have been identified: dwelling sites, hunting and meat processing campsites, lookout sites, coastal fishing campsites and chipping workshops and stations. Most of sites are surficial or have very thin (5-10 cm) cultural layers because of very low soil accumulation. Subsequently, they are unstratified and undated by radiocarbon. The only multilayered site is Onion

Portage containing a sequence of most of the known prehistoric complexes. However, its stratigraphy is very complicated because of annual frost or permafrost disturbance and bioturbation (Hamilton 1970).

Chert artifacts are often the only archaeological remains. The artifacts are made of variety of cherts: glassy or grainy, mottled, black, gray, blue-gray, light-gray red to maroon, and smokey-gray that came from different sources. In some sites, obsidian artifacts occur. These indicate a great transport distance as the closest available obsidian sources are at least 150-200 km to the south (Patton and Miller, 1970; Clark, 1972).

The typology of artifacts is generally the only source of information about prehistoric cultures and their sequence (Anderson, 1972; Gerlach and Mason, 1992). The origins of four traditions and the location of prehistoric migration routes in this part of Beringia generate many unanswered questions. Therefore, chert artifact sourcing in northwestern Alaska is crucial. It provides a unique opportunity for tracing intergroup contacts and traveling patterns, and leads to improved understanding of the mechanisms of population dynamics from the earliest Americans to recent Alaskan Eskimos. Inclusions of some foreign cherts within archaeological sites of northwestern Alaska will provide evidence of large scale (possibly intercontinental) communication and improve our understanding of the peopling of America. For instance, American Paleo-Arctic and Arctic Small Tool traditions were affiliated with Asian cultures. The Northern Archaic tradition is strikingly different from the Arctic coastal cultures and adjacent Alaskan Interior and Canadian Yukon (Anderson, 1984). Geographic, temporal and socio-cultural juxtaposition of the Northern Archaic and American Paleo-Arctic traditions leave open the problem of the origin of the Northern Archaic tradition (Gal, 1982). The boundaries of geographic distribution of cherts from the

western Brooks Range quarries for each tradition would hopefully highlight the geographic origin of the Northern Archaic tradition.

1.1.2. Possible Quarry Areas

The Seward Peninsula and the Kobuk River drainage basin (with their numerous inland and coastal prehistoric sites) were important routes of travel and migration of prehistoric populations (Burch, 1976, Anderson, 1984). However, no tool quality chert sources are known on the Peninsula nor in the Kobuk River drainage (Sainsbery, 1972; Beikman and Lathram, 1976; Karl et al., 1989) suggesting that chert was mined elsewhere and transported into the region.

The Noatak basin was also the location of many major interior routes across northwestern Alaska from west to east and north to south (Anderson, 1972; Burch, 1976). Tributaries of the Noatak River dissect the Brooks Range permitting easy access to the north slope and shores of the Arctic Ocean. These are the same migration routes used presently by caribou. The Noatak basin is underlain with chert rich Paleozoic-Mesozoic sedimentary deposits cropping out in the Brooks Range (Mull et al., 1982; 1987; Ellersieck et al., 1983, 1990; Mayfield et al., 1983, 1988; Karl, 1989; Karl et al., 1989; Curtis et al., 1990; Moore et al., 1994) (Fig. 1.3.). Many chert chipping stations and a few large workshops, are closely associated with chert outcrops, indicating that the western Brooks Range was a prehistoric mining area for chert raw materials which were transported throughout Beringia (Anderson, 1972; Hall and Mull 1976; Malyk-Selivanova and Ashley, 1994b).

The purpose of this research is to obtain the distribution patterns of the variety of cherts sourced in the western Brooks Range, and subsequently found as artifacts in prehistoric sites located in northwestern Alaska (that are dated from 9,700 B.P. to Recent).

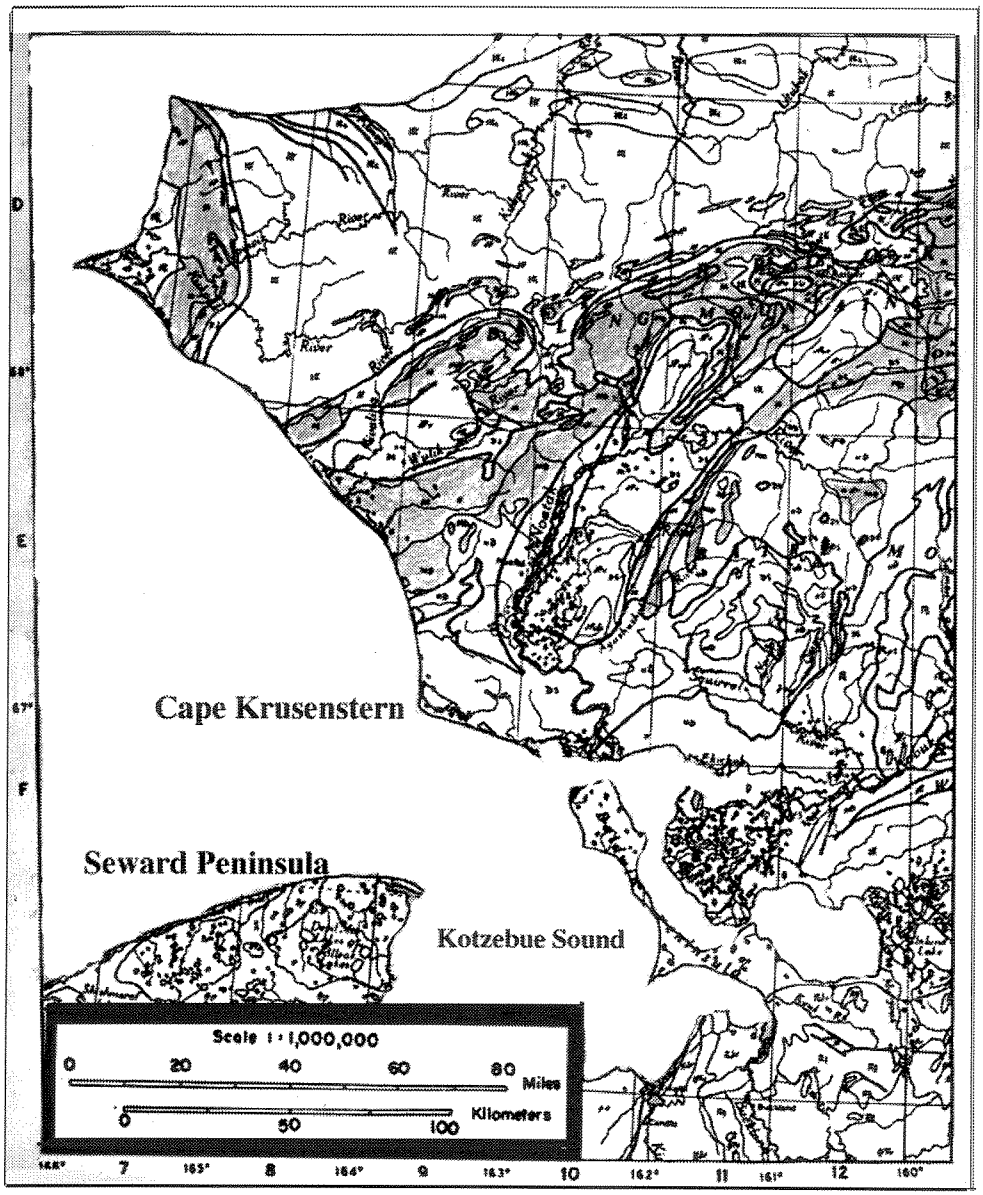


Figure 1.3. Area of chert outcropping in northwestern Alaska. Bedrok exposures of chert -bearing formations are concentrated along the Brooks Range mountain front (modified from Beikman and Lethram, 1976).

More specifically this study aims to correlate cherts from outcrops in the Kelly, Kugururok and Anisak basins (northern tributaries of Noatak River) with chert artifacts in a number of prehistoric sites of northwestern Alaska using geochemistry and petrology in order to identify prehistoric chert quarries in the western Brooks Range.

1.2. Regional Geology

1.2.1. Bedrock Geology and Tectonics.

Bedrock in the western Brooks Range is extremely rich in chert (Mull et al., 1982; Curtis et al., 1984, 1990; Ellersieck et al., 1990). The tool quality cherts are exposed in the northern part of the Noatak basin (Kelly, Kugururok and Anisak Rivers) and are represented by Paleozoic-Mesozoic chert deposits.

The stratigraphy of rocks composing the Brooks Range is complicated because of the complex tectonic history. The Brooks Range was formed during the late Jurassic to early Cretaceous as result of the southward subduction of the Arctic Alaska continental plate beneath the oceanic plate (Mayfield et al., 1983; Moore et al., 1994). The oceanic crust and sediments deposited in a basin located to the south of the present day Brooks Range were broken up and telescoped as numerous allochthon sheets that were juxtaposed northward (older over younger). The orogeny produced numerous thrust faults with up to tens of kilometers of displacement. As a result, the Brooks Range is composed of a mosaic of thrust sheets containing different lithofacies of coeval rock units (Martin 1970; Churkin et al. 1979; Mayfield et al. 1983, 1988; Moore et al., 1994). The late early Mississippian to early Jurassic chert deposits analyzed in this study are from eight map units (Mayfield et al., 1984; Curtis et al., 1984, 1990; Ellersieck et al., 1990) attributed to two stratigraphic groups of formations: Lisburne Group characteristically enriched with black cherts, and Etivluk

Group enriched with gray, bluish-gray, greenish-gray, maroon, and maroon cherts.

1.2.2. Glaciation During Prehistoric Time.

The glaciation history of the region is important in terms of accessibility of chert sources by prehistoric people. The Quaternary history of Alaska indicates that the last glaciation in the Brooks Range during oxygen Isotope Stage 2 was Itkillik II glaciation or Walker Lake glaciation (local name) that lasted from 25,000 to 11,500 B.P. (Hamilton and Porter, 1975; Hamilton, 1982, 1986; Hamilton et al., 1993; Hamilton and Ashley, 1993). There were two ice caps in the region during this time period: the larger one blanketed the central and eastern Brooks Range area and the smaller cap was restricted to the DeLong Mountains (the western Brooks Range), but glacier tongues extended to the main Noatak valley (Fig. 1.4.). The northern tributaries of Noatak River were essentially free of ice and accessible to people (even in the basin headwaters region) by 10,000 B.P., whereas ice remained in the central Brooks Range for several hundred years later. Thus, the western Brooks Range chert sources were available to people from 10,000 B.P. to Recent.

1.3. Chert Sourcing

The identification of geological sources for chert artifacts found in prehistoric sites is a difficult procedure. The challenges are to: 1) distinguish and identify specific geological chert sources and 2) match artifacts to sources (Sieveking et al., 1972; Selivanova, 1984).

1.3.1. Visual Correlation.

Archaeologists often use visual properties of cherts (color, luster, fracture, patina and inclusions) for both correlation of chert artifacts manufactured from the same raw material and for their correlation with specific chert sources. Indeed, cherts from different sources

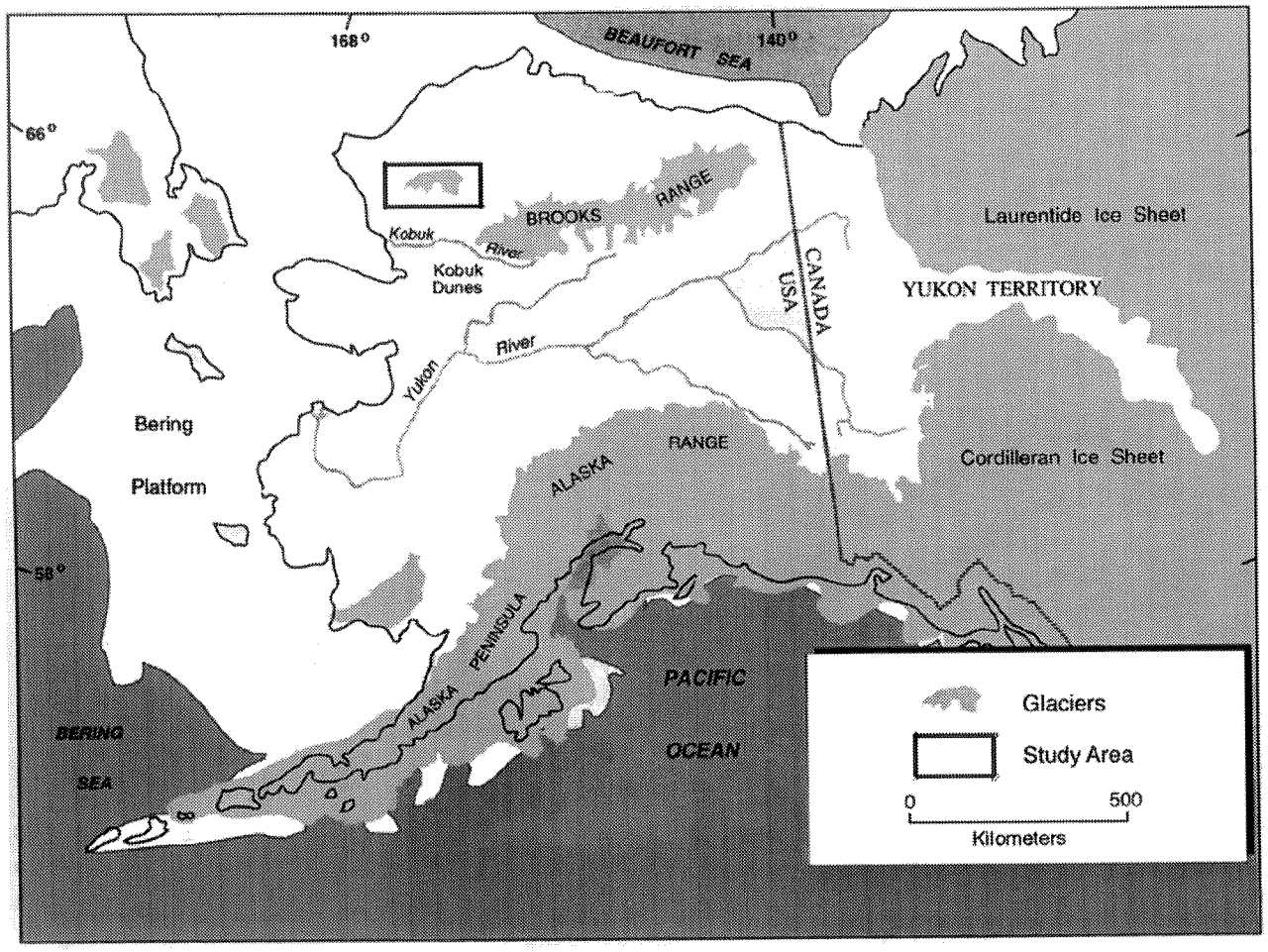


Figure 1.4. Paleogeographic map of Alaska showing areas covered by ice during maximum extent of late Wisconsinan glaciation. Map data are from Ashly and Hamilton, 1993.

are sometimes visually distinctive, and archaeologists working in a particular geographic region quickly become familiar with the specific local source.

However, the geological study of chert outcrops demonstrates that cherts from different geological formations and different geographic areas are often visually identical. In addition, a wide range of physical properties (color, luster, etc.) occur within a single formation or chert layer, lens and even within a single nodule (Luedtke, 1979; Selivanova, 1986). There is no doubt that visual identification alone is inadequate for any rigorous study of chert material types and their correlations. Clearly stated objective (qualitative and quantifiable) criteria must be found.

1.3.2. Geological-Geochemical Approach

Chert sourcing and fingerprinting are complicated geochemical and mineralogical problems. Because cherts have a characteristically uniform composition (up to 99% SiO_2), a monotonous structure (microcrystalline or cryptocrystalline quartz) and submicroscopic (10μ-100μ) mineral inclusions, the application of simple petrographic microscopy to correlation of chert samples does not commonly yield relevant information, except when cherts contain large (>~500μ) exotic mineral inclusions. However, even in such cases petrographic analysis alone rarely provides objective criteria for correlation of chert samples (Sieveking et al., 1970; Selivanova and Galibin, 1982; Selivanova, 1984). Comparison of chert artifacts with chert sources based on trace element composition (instrumental neutron activation analysis) and statistical (multivariate analysis) treatment of analytical data is an established technique in western Europe (Aspinall and Feather, 1972; Sieveking et al., 1972; Matiskainen et al., 1986), in New England and Michigan (Luedtke, 1987, 1992, 1993a), in northern California (Kowalski and Schatzki, 1972) and in the central great plains (Hoard et

al., 1992a, 1992b). These studies revealed methodological problems, however, involved in correlation of artifacts with outcrops and point to the need of rigorous, region-wide study of chert source rocks incorporating a more regional view of the geologic context (Sieveking et al., 1972, Luedtke, 1978, 1979, 1992, 1993b; Selivanova, 1984, 1986). The first regional geological-geochemical prehistoric chert sourcing was performed in central Russia by the author of this thesis (Selivanova and Galibin 1982, 1992; Selivanova, 1984, 1986), but was based on emission spectral analysis not sensitive enough for detection of trace element composition.

This present research applies the geological-geochemical approach to the sourcing of prehistoric chert artifacts in northwestern Alaska. The geological-geochemical approach is based on the assumption that both the prehistoric artifact and its geological source have identical mineralogy, fossils, and bulk trace element chemistry that reflect their identical geological history. Geochemical signatures record specific geological conditions of chert formation (depositional environment, provenance and diagenetic patterns) and are often unique for each chert layer. The cornerstone of the geological approach to chert sourcing is the construction of a regional database of geochemical and mineralogical signatures discriminating stratigraphic groups, formations, units and lithofacies of chert deposits and eventually individual outcrops from each other. Then, any artifact can be compared geochemically with the outcrop database to be assigned to its geological source. Another crucial point for successful sourcing is choosing the proper geochemical and petrological signatures and correlation technique for chert-outcrop correlation.

The research plan included field work (sampling of chert outcrops), and sampling of prehistoric chert artifacts in museums, followed by analysis and correlation of both

artifact and outcrop samples, and finally the application of results to archaeological problems in northwestern Alaska (Figure 1.5.).

This research is the first regional geological chert sourcing study based on an integrated geological-geochemical approach. It utilizes highly sensitive instrumental neutron activation analysis (INAA) for detection of trace element composition in cherts, electron microprobe analysis (EMPA) for detection of mineral micro-inclusions and computer programs for treatment of analytical results, as well as optical microscopy and hand specimen study. This research is also the first of its kind in Alaska.

1.4. Objectives

Objective (1) To construct a database of elemental concentration and mineral composition of chert outcrops in the western Brooks Range (Kelly, Kugururok and Anisak Rivers (Chapter 2).

Objective (2) To determine petrological and geochemical signatures of cherts in order to discriminate between stratigraphic groups, formation, units and lithofacies of cherts represented in each studied chert outcrop (Chapter 2).

Objective (3) To obtain petrological and geochemical signatures of representative chert artifacts from 57 prehistoric sites in northwestern Alaska (Chapter 3).

Objective (4) To correlate chert artifacts with chert outcrops in the western Brooks Range using petrology and geochemistry (Chapter 3).

Objective (5) To apply the prehistoric chert sourcing results to such archaeological problems as:

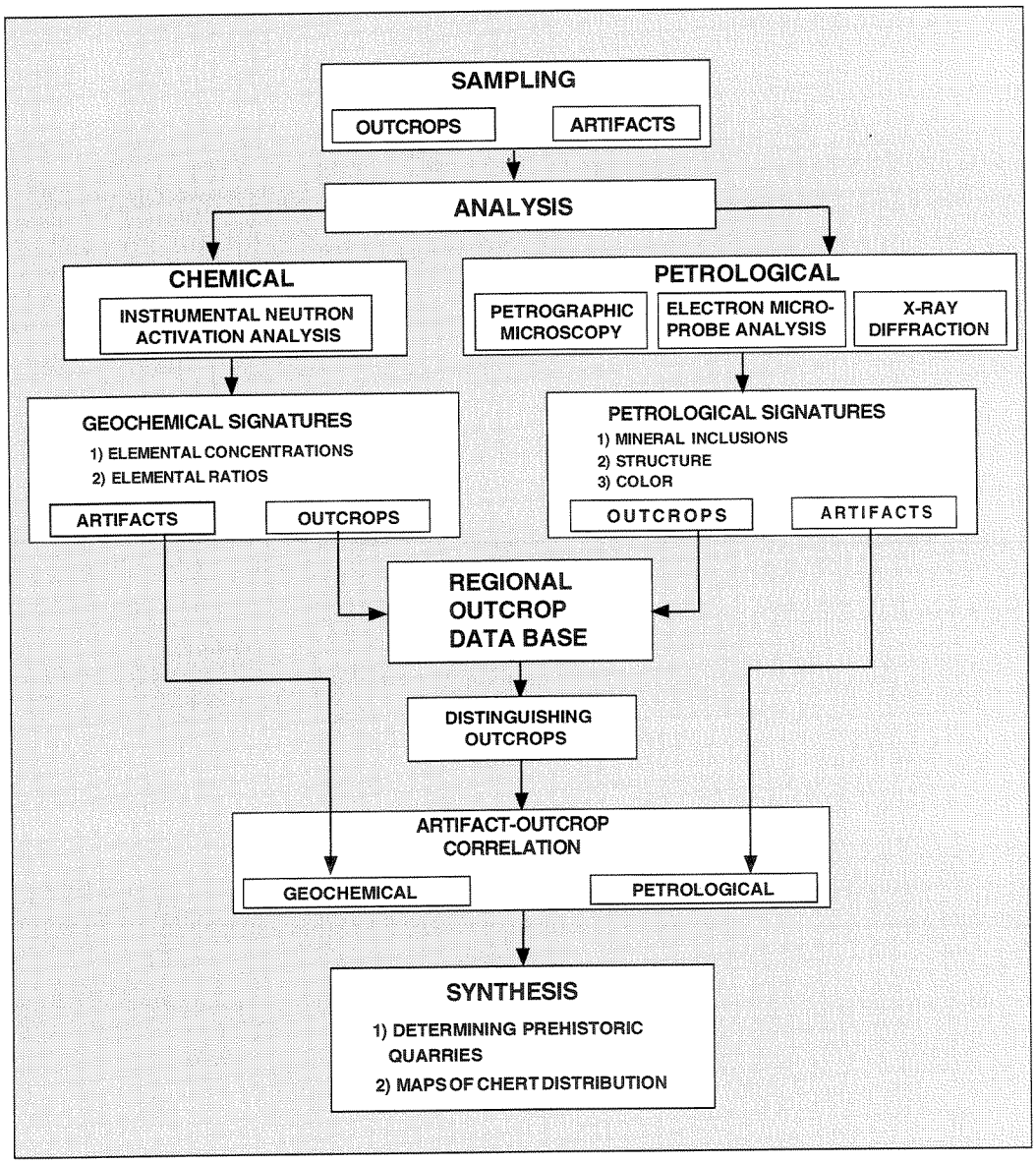


Figure 1.5. Research plan

a) Determination of prehistoric chert quarries in the western Brooks Range,

b) Identification of the geographic limits of distribution of cherts from the western Brooks Range in prehistoric sites of northwestern Alaska,

c) Identification of cultural distribution of cherts from the western Brooks Range quarries in order to determine what quarries were used by which specific prehistoric groups (Chapter 4).

CHAPTER TWO:

GEOCHEMISTRY OF PALEOZOIC-MESOZOIC CHERT DEPOSITS IN THE WESTERN BROOKS RANGE, ALASKA: IMPLICATIONS FOR DEPOSITIONAL ENVIRONMENT

2.1 Abstract.

Mineralogical, petrological and geochemical signatures of twelve chert varieties of upper Mississippian to Jurassic age from the western Brooks Range, Alaska, were determined using optical petrography, electron microprobe analyses, instrumental neutron activation analyses, and X-Ray diffractometry. The twelve chert varieties fall into two types that are correlated with two stratigraphic groups: the Lisburne Group (Mississippian-Pennsylvanian) and the Etivluk Group (Pennsylvanian-Jurassic). Rare-earth elements, Al and Fe concentrations were used to interpret depositional environment. Ce_n/Ce_n^*, and La_n/Ce_n values in cherts are used as indicators of depositional environment such as open ocean and continental margin, Eu_n/Sm_n values are indicators of volcanogenic input. The amount of the terrigenous matter in a sample is calculated based on its Al concentration. Pyrite or barite inclusions and Ba/Fe values are indicators of final oxidizing or reducing diagenetic conditions.

The Tupik, Akmalik and some of Kuna cherts of the Lisburne Group have pronounced negative Ce anomalies (mean $Ce_n/Ce_n^* = 0.25$-0.57) and negligible terrigenous component. The Siksikpuk and Otuk cherts of the Etivluk Group do not have negative Ce anomalies and contain significantly higher terrigenous component. No correlation between Ce_n/Ce_n^* patterns and observed oxidizing-reducing patterns has been found in cherts.

The evolution in depositional setting of Tupik, Akmak and Kuna chert-bearing

Formations (Lisburne Group) evolved from open ocean to continental margin during early late Mississippian-early Pennsylvanian time. During late Pennsylvanian-Jurassic time depositional environment of the Siksikpuk and Otuk Formations (Etivluk Group) was a continental margin with increasing input of volcanogenic material.

2.2 Introduction

Chert deposits comprise an important part of the late Mississippian to Jurassic sedimentary rock record of the western Brooks Range, Alaska. The carbonate-chert and shale-chert interbedded units of the Lisburne and Etivluk Groups were deposited in a basin that was located south of the Arctic Alaska continental plate during late early Mississippian to Jurassic time (Mayfield et al., 1988; Dumolin et al., 1993). Determination of the depositional environment of chert is fundamental for tectonostratigraphic and paleogeographic reconstructions of the south region of the Arctic Alaska terrane prior to the Brooks Range orogeny (late Jurassic - early Cretaceous). However, the depositional environment and tectonic setting of these rocks, and consequently the paleogeographic reconstruction in the western Brooks Range, is still disputed (Churkin et al. 1979; Churkin, 1980, 1981, 1985; Dutro, 1980, 1981; Grane, 1980; Metz, 1980; Mull, 1980; Mayfield, 1980; Nelson, 1980; Warren, 1980; Mayfield et al., 1983; Murchey et al., 1983; Box, 1985; Mull et al., 1987; Moore et al., 1994). Two main contrasting models of depositional environment for these deposits based on the stratigraphic and paleontologic data have emerged: 1) "open" ocean facies deposited on oceanic crust near the passive continental margin for all late Mississippian to early Jurassic deposits (Churkin et al., 1979) (Fig. 2.1a), and 2) "restricted" basin deposits within a two-sided epicontinental sea separating Barovian (Arctic Alaska) and Nukaland plates in pre-Permian time that was followed by a south-

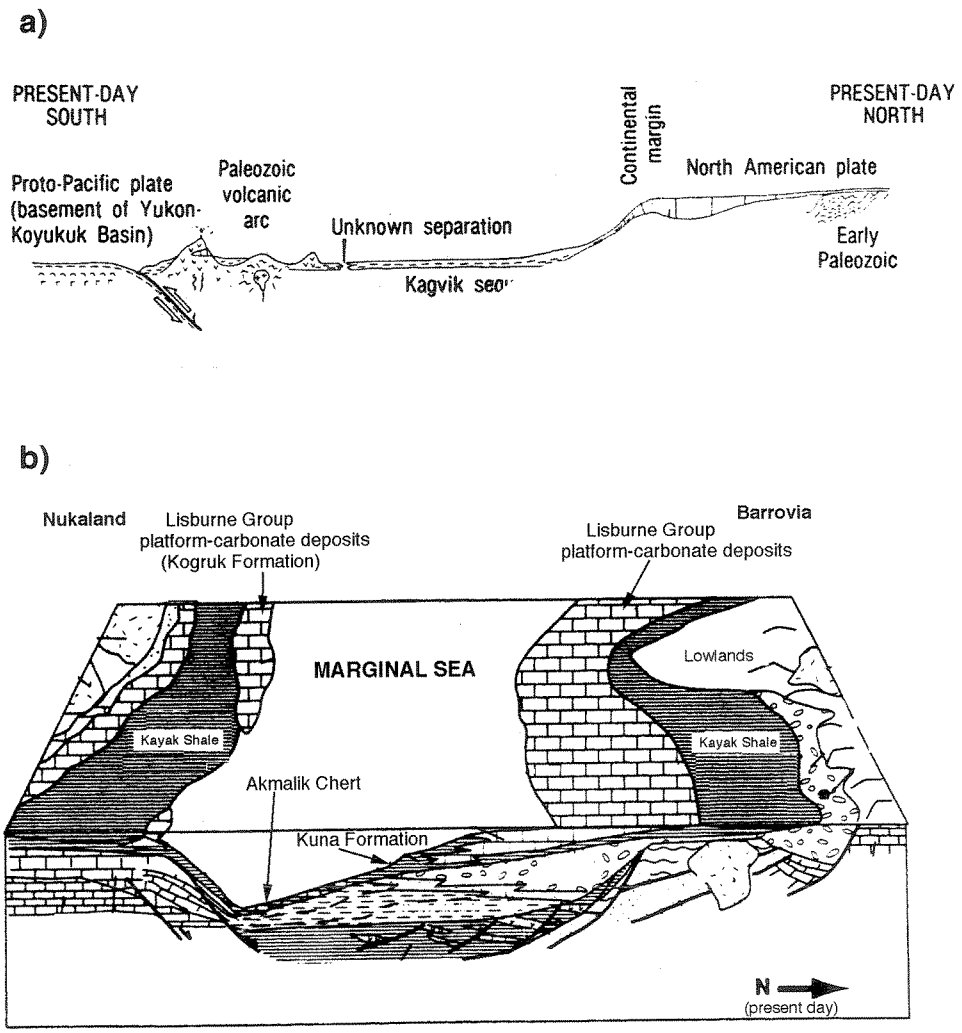


Figure 2.1. Models of depositional environment of the chert-bearing formations of the Mississippian-Pennsylvanian time (modified from Churkin et al., 1979 and Moor et al., 1986).

facing passive margin during Pennsylvanian to early Jurassic (Mayfield et al., 1983, 1988) (Fig. 2.1b). According to Mayfield et al. (1988) the Angayucham Ocean was opened by rifting during Pennsylvanian time. Moore et al. (1994) generalized that all or part of the Upper Devonian to Jurassic stratigraphy of the south part of Arctic Alaska terrane composed a south-facing passive-margin sequence. The Arctic Alaska plate was bordered to the south by the Angayucham Ocean which was opened presumably by rifting during Devonian time along the southern margin of the Arctic Alaska plate (Hitzman et al., 1986; Grantz et al., 1991).

Geochemistry is a powerful tool for the discrimination of different depositional environments and provenance of chert (Shimizu and Masuda, 1977; Steinberg et al., 1983; Karl, 1989; Murray et al., 1990, 1991, 1992a; Huebner et al., 1991; Murray, 1994; Girty et al., 1996). The general criteria used for discrimination of continental margin, open ocean basin depositional settings of chert includes variation of Ce_n/Ce_n^* values (e.g. Murray et al., 1990, 1991, 1992a). The model developed by Murray (1994) for determination of three types of depositional environments of cherts (continental margin, open ocean and mid ocean ridge) is based on the variations of La_n/Ce_n (as a measure of Ce anomaly), Al, Ti, and Fe values. More recent work of Girty et al. (1996) also discusses techniques elucidating terrigenous provenance signals based on trace element distinctions

This chapter presents the first geochemical and mineralogical descriptions for chert deposits of Lisburne Group (Tupik, Akmalik and Kuna cherts) and Etivluk Group (Siksikpuk and Otuk Formations) of Mississippian to early Jurassic age from the western Brooks Range. The cherts represented in this study are comprised of 12 varieties sampled from different thrust sheets exposed in the Kelly, Kugururok and Anisak River basins (Figs. 2.2, 2.3). The

term "chert variety" is used here to refer to a chert layer, or chain of chert lenses and nodules, as well as a unit of chert layers and chains stratigraphically related in the outcrop. The objectives of this study are to obtain the petrological, mineralogical and geochemical characteristics of these deposits in order to determine their depositional environments, provenance and diagenetic patterns based on these characteristics, and the application of published geochemical models (Murray et al., 1990; Murray, 1994; Girty et al, 1996).

2.3. Geologic Framework

The Brooks Range (Figs. 1.2, 1.3) was formed during the late Jurassic to early Cretaceous orogeny (Mayfield et al., 1983, 1988; Box, 1985; Churkin, 1985; Howell, 1989; Worrall, 1991; Moore et al., 1994). The southern part of the Arctic Alaska continental plate was involved in south dipping subduction beneath oceanic crust (Mayfield et al., 1983, 1988; Churkin, 1985; Moore et al., 1994). During the plate collision, the oceanic crust and the stable continental shelf with Devonian to early and middle (?) Jurassic sediments (deposited in a basin south of the present day Brooks Range) were broken up and telescoped as numerous thrust sheets with a combined displacement of the order of hundreds of kilometers (Mayfield et al., 1983). As a result, the Brooks Range is composed of stacks of complexly deformed thrust sheets grouped into seven allochthons (Mull et al., 1982; Mayfield et al., 1983, 1988; Curtis et al., 1990; Ellersieck et al., 1983, 1990; Karl, 1989; Karl et al., 1989). Five allochthons (Brooks Range, Picnic Creek, Kelly River, Ipnavik River and Nuka allochthons) are represented by sedimentary sequences, and three ones (Copter Peak and Misheguk Mountain allochthons) by igneous sequences. The stratigraphy (Fig. 2.3) is complex because of significant facies differences between coeval formations, which are then deformed by numerous tight folds and cut by faults (Martin 1970; Churkin et al. 1979;

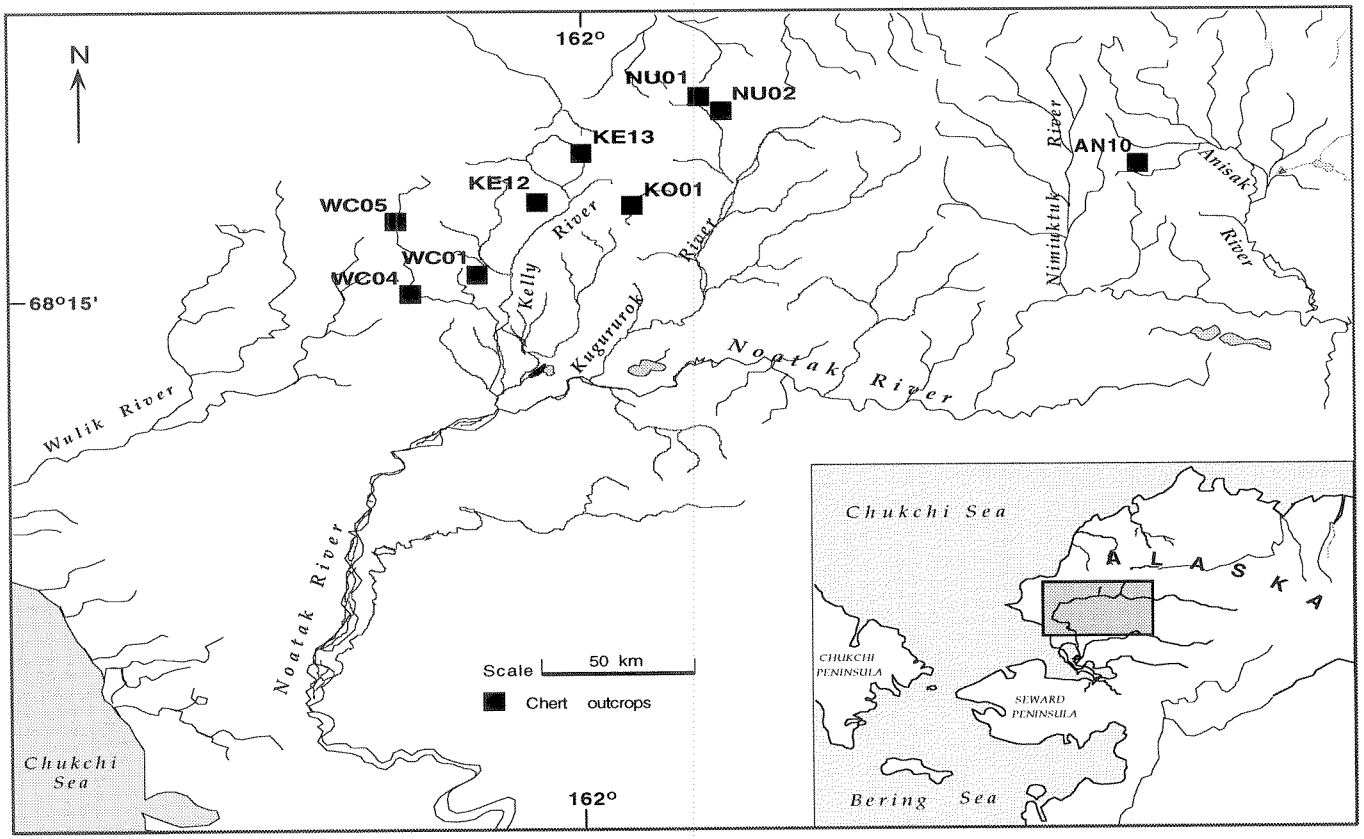


Figure 2.2. Location of chert outcrops analyzed in this study. Inset shows location of larger scale map. Outcrop coordinates: NU01: N68^{0}33'36", W161^{0}27'17"; **WC04:** N68^{0}09'47", W162^{0}32'44"; **KE12:** N68^{0}20'25", W162^{0}02'37"; **WC01**: N60^{0}09'43",W162^{0}20'46"; **WC05**: N68^{0}20'25", W162^{0}02'37"; **KO01**: N68^{0}21'16", W162^{0}23'17"; **KE13:** N68^{0}27'41"; W162^{0}01'41"; **NU02:** N68^{0}33'01", W161^{0}27'08"; **AN10:** N68^{0}22'36", W159^{0}36'22".

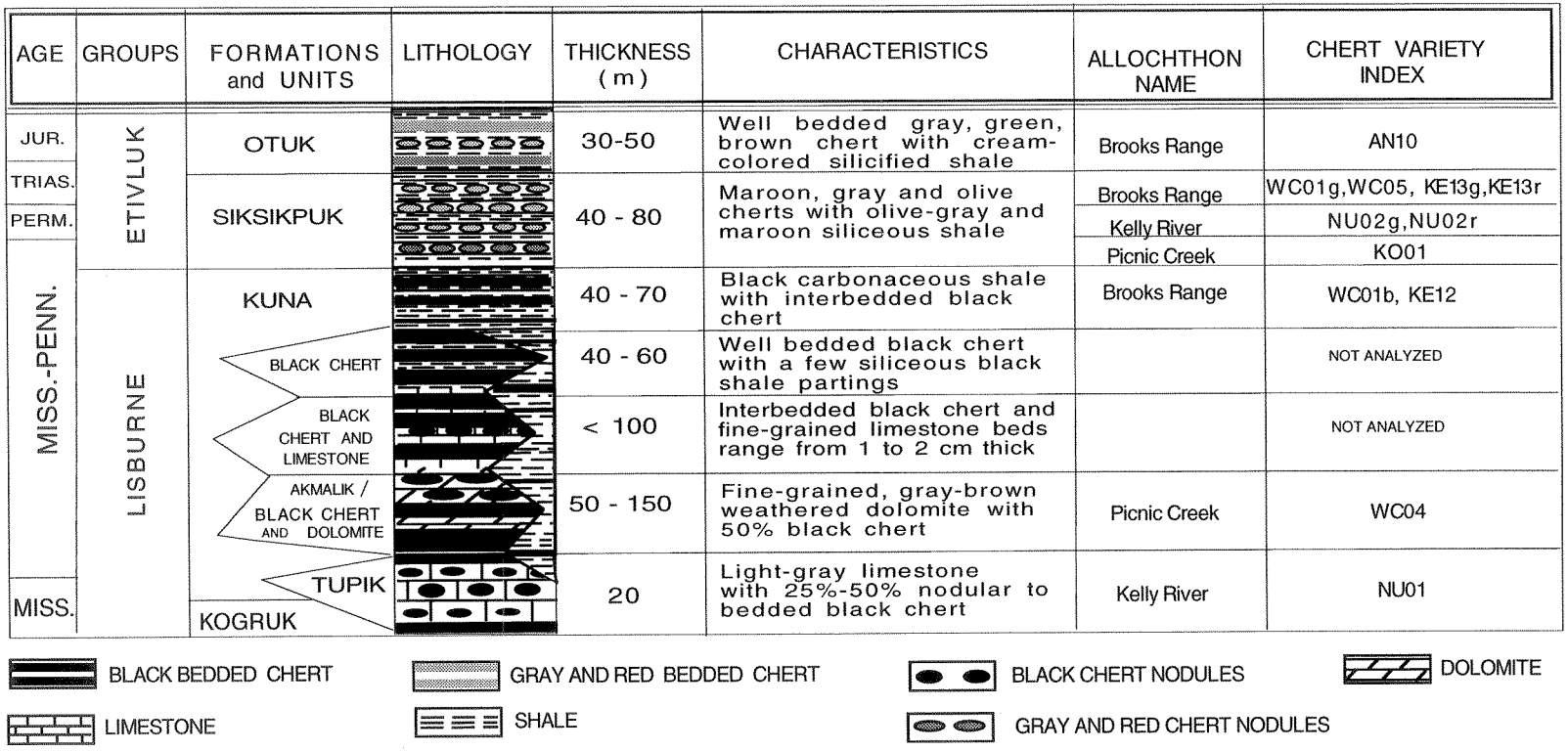


Figure 2.3. Summary of stratigraphy of chert-bearing formations in the western Brooks Range, Alaska (compiled from Mull et al., 1982; Ellersieck et al., 1983; Curtis et al., 1990) and indexes of cherts analyzed in this paper.

Mayfield et al. 1983, 1988). Due to the complex geology, the structural and stratigraphic synthesis of the western Brooks Range remains incomplete (Dumolin et al., 1993; Moore et al., 1994). The nomenclature and dating of deposits are taken from United State Geological Survey (U.S.G.S.) maps and Open File Reports (Mayfield et al., 1983, 1984; Curtis et al., 1983, 1984, 1990; Ellersieck et al., 1983, 1990) with supplements from Mull et al. (1982) and Dumolin et al. (1993).

The late early Mississippian to early Jurassic chert deposits analyzed are from eight map units (Mayfield et al., 1984; Curtis et al.,1984, 1990; Ellersieck et al., 1990). These eight units are probably facies variations of four chert-bearing formations: Tupik and Kuna Formations (including Akmalik chert) belonging to the Lisburne Group (late early Mississippian-Pennsylvanian) and Siksikpuk and Otuk Formations belonging to the Etivluk Group (late Pennsylvanian-early Jurassic) (Fig. 2.3). Lisburne cherts are mostly black, whereas Etivluk cherts are gray, bluish-gray, greenish-gray, maroon, and maroon. The Lisburne chert deposits are intercalated with carbonate and shale; the Etivluk deposits are typically shale-hosted. Two assemblages of mafic rocks are associated with chert-bearing formations in a series of allochthons. The first is identified as oceanic-plateau and seamount basalts of Devonian-early Jurassic age (Moore et al., 1994). The second is younger (middle Jurassic) gabbroic assemblage that is determined as an incomplete ophiolite (Pallister et al., 1989; Moore et al., 1994).

2.4. Methods

2.4.1. Sampling.

Twelve chert varieties representing the Lisburne and Etivluk Groups were sampled from nine outcrops in Kelly, Kugururok and Anisak River basins (Figs. 2.2 and 2.3) and

selected for analysis. Following the U.S.G.S. nomenclature (Curtis et al., 1984, 1990; Mayfield et al., 1984; Ellersieck et al., 1990) four black chert varieties (NU01, WC04, KE12 and WC01b) of the Lisburne Group represent from oldest to youngest: the Tupik Formation (NU01), the Black Chert and Dolomite or Akmalik chert (according to Mull et al., 1982) (WC04) and the Kuna Formation (KE12 and WC01b). The Tupik and Akmalik cherts are carbonate-hosted, and the Kuna cherts are shale-hosted. Eight additional varieties represent Etivluk Group shale-hosted cherts: seven (WC01g, WC05, KO01, KE13g, KE13r, NU02g, NU02r) are from the Siksikpuk Formation and one (AN10) is the Otuk chert.

In three outcrops, color varieties were studied: two Siksikpuk outcrops contained red (KE13r, NU02r) and gray (KE13g, NU02g) varieties, and black WC01b Kuna chert and gray WC01g Siksikpuk chert were sampled in the outcrop where a gradational contact between these two formations (Lisburne and Etivluk Groups) was exposed. All twelve varieties are from allochthons that are lowest in the tectonic stack of Brooks Range thrust sheets: Brooks Range Allochthon 1, Picnic Creek Allochthon 2 and Kelly River Allochthon 3 (Mayfield et al., 1984; Curtis et al., 1984, 1990; Ellersieck et al., 1990). The description of outcrops is given in Appendix I.1.

Because of its sedimentary and diagenetic nature, chert is not homogeneous and often shows high variability even within the same variety. In order to obtain representative characteristics, each variety was sampled with at least 15 samples selected from different parts of a chert layer or nodule chain.

2.4.2. Analytical Methods.

Twenty five polished thin sections of twelve chert varieties were studied under petrographic microscope and with electron microprobe (EMPA), using the JEOL JXA-8600

at the Department of Geological Sciences, Rutgers University using energy dispersive spectroscopy and backscattered electron imaging.

Seven samples were analyzed by X-Ray diffraction. Samples were powdered in a tungsten-carbide mill. The analyses were performed on a Siemens D500 diffractometer using Ni-filtered CuKα radiation, divergent slit of 1 degree and a receiving slit of 0.05 degree. The data were collected by a DACO microprocessor using a step width of 0.05 degree two theta and measuring time of 0.5 seconds. Phases were identified by etching with standard XRD patterns of the JCPDS file.

A total of 201 samples of chert were analyzed by instrumental neutron activation analysis (INAA) at the Missouri University Research Reactor (MURR). The samples were crushed with a Carter Press with high-purity Fe plates that were isolated from samples with styrofoam. They were inspected under magnification to select fragments without inclusions or contaminants (i.e., metallic streaks). Three measurements were made on each sample following two neutron irradiations: 1) short irradiation for the short-lived elements Al, Ca, Dy, K, Mn and V; 2) long irradiation for the medium-lived elements As, Ba, La, Lu, Nd, Sm, U, and Yb by the first measurement and 3) long-lived elements Ce, Co, Cr, Cs, Eu, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Tb, Th, and Zn by the second measurement. Standard Reference Materials of SRM-163a Fly ash, SRM-688 Basalt rock, and SRM-278 Obsidian Rock from the National Institute of Standards and Technology (NIST) were simultaneously irradiated. The results are summarized in Table 2.I. The accuracy of INAA for 24 elements was determined by blind analysis of NIST SRM-278 (Table 2.II). The accuracy of MURR is within the claimed precision of NIST SRM-278 for all elements, except U, Zn and Cr. Analytical precision of MURR was determined by quadruplicate analyses of five samples

selected from five of the twelve analyzed varieties (Table 2.II). The detection limit for each element calculated as 3 times the blank is listed in the Table 2.II.

2.4.3. Problems in INAA of cherts.

Very low elemental concentrations of REEs in cherts cause difficulties in their identification when their analytical photopeaks are close to photopeaks of elements with higher concentration.

For example, Nd-Ba interferences in Ba-rich Siksikpuk cherts were recognized by the appearance of Nd anomalies that are not characteristic of natural samples of any rock type (igneous, metamorphic and sedimentary). Lisburne cherts and Otuk cherts that are depleted in Ba relative to Siksikpuk cherts did not show Nd anomalies. A strong positive correlation between Ba and Nd concentrations was obtained on Ba vs. Nd bivariate diagrams for Siksikpuk chert. ICP-MS analysis of a few Siksikpuk and Lisburne cherts showed regular Nd patterns in both types of cherts and confirmed Ba-Nd interference obtained by INAA. The interference occurred for the following peaks: 91kv for Nd, and 92 kv for Ba. This requires using other peaks available for Nd concentrations.

Light rare earth elements - U interference in U-rich Lisburne cherts was obtained because of neutron fission of U. The interference was recognized from REE patterns showing unexplainable Heavy REE depletion or LREE enrichment. Bivariate plots (U-La, U-Ce, U-Nd and U-Sm) showed the progressive correlation between REEs and U in three of the most U-enriched Lisburne cherts. ICP-MS showed lower concentrations of LREE then those determined by INAA. Corrected La, Ce and Nd concentrations were obtained by calculations: La corrected = 1.012*(La-0.09647*U); Ce corrected = 1.017*(Ce-0.283*U); Nd corrected = 1.035*(Nd-0.23*U) (Glascock et al., 1986, personal communication, 1997).

TABLE 2.I.. SUMMARY OF INAA DATA USED IN THE STUDY
(based on the INAA of 15 samples from each variety)

A. SUMMARY OF MAJOR ELEMENT DATA (ppm).

Variety	Color	Al	Ca	K	Mn	Na	Fe	Ba
Etivluk Group								
AN10	gray	8300 ± 1700	100 ± 190	2200 ± 1100	162 ± 215	700 ± 80	4550 ± 3230	830 ± 87
NU02g	gray	8700 ± 140	490 ± 600	2200 ± 1100	343 ± 41	1150 ± 80	3200 ± 450	7720 ± 4816
NU02r	red	6700 ± 410	2500 ± 960	800 ± 1300	147 ± 62	700 ± 175	3650 ± 1300	1770 ± 380
KE13g	gray	5400 ± 1200	1300 ± 5000	1300 ± 500	23 ± 10	850 ± 152	950 ± 130	1050 ± 640
KE13 r	red	13600 ± 4900	360 ± 920	3800 ± 1900	194 ± 255	2000 ± 580	8100 ± 4000	28750 ± 22440
KO01	gray	9600 ± 110	1200 ± 600	2300 ± 1100	662 ± 345	950 ± 93	4250 ± 1550	12410 ± 5270
WC05	gray	7500 ± 2000	3000 ± 2900	600 ± 800	294 ± 357	1250 ± 450	2150 ± 1300	16310 ± 12790
WC01g	gray	9300 ± 1300	***	2200 ± 800	360 ± 195	800 ± 100	5150 ± 1500	18720 ± 9200
Lisburne Group								
WC01b	black	7800 ± 1700	100 ± 300	1800 ± 700	40 ± 20	700 ± 80	2200 ± 750	890 ± 180
KE12	black	3700 ± 600	2900 ± 2000	800 ± 400	7 ± 2	550 ± 100	1650 ± 300	110 ± 20
WC04	black	3000 ± 600	15300 ± 7800	500 ± 400	10 ± 3	400 ± 100	750 ± 100	80 ± 30
NU01	black	1600 ± 200	14800 ± 1500	200 ± 100	11 ± 1	350 ± 40	400 ± 50	20 ± 3

Note: *** - below detection limit.

B. SUMMARY OF TRACE ELEMENT DATA (ppm).

Variety	Color	Cr	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	Sb	Co
_Etivluk Group												
AN10	gray	8.5 ± 5.2	0.03 ± 0.06	0.85 ± 0.20	3.19 ± 0.74	0.79 ± 0.17	0.66 ± 0.08	12.3 ± 3.2	64 ± 27.2	0.08 ± 0.01	0.82 ± 0.23	5.10 ± 2.40
NU02g	gray	8.5 ± 0.5	0.02 ± 0.08	0.79 ± 0.09	2.71 ± 0.25	0.62 ± 0.08	0.58 ± 0.07	8.9 ± 1.3	314 ± 130.1	0.07 ± 0.01	0.44 ± 0.05	2.00 ± 0.50
NU02r	red	1.8 ± 0.7	0.26 ± 0.20	0.30 ± 0.11	2.03 ± 2.03	0.20 ± 0.20	0.39 ± 0.39	3.1 ± 3.1	70 ± 70.0	0.04 ± 0.04	0.24 ± 0.02	2.60 ± 4.10
KE13g	gray	5.5 ± 0.6	0.13 ± 0.10	0.47 ± 0.08	2.04 ± 0.23	0.34 ± 0.05	0.38 ± 0.09	4.7 ± 1.2	185 ± 90.1	0.05 ± 0.01	0.21 ± 0.03	3.30 ± 1.50
KE13r	red	9.8 ± 3.0	0.04 ± 0.16	1.63 ± 0.53	7.87 ± 3.66	0.92 ± 0.36	1.31 ± 0.47	15.5 ± 6.0	902 ± 666.3	0.16 ± 0.06	0.49 ± 0.05	4.80 ± 3.80
KO01	gray	9.5 ± 2.1	0.32 ± 0.17	0.92 ± 0.15	2.88 ± 0.23	0.86 ± 0.18	0.68 ± 0.14	12.1 ± 2.1	568 ± 310.1	0.08 ± 0.01	0.89 ± 0.39	20.40 ± 14.10
WC05	gray	6.5 ± 2.1	0.17 ± 0.18	0.74 ± 0.34	2.78 ± 0.48	0.41 ± 0.13	0.57 ± 0.23	6.8 ± 2.7	306 ± 191.2	0.07 ± 0.03	0.49 ± 0.17	6.10 ± 2.40
WC01g	gray	6.0 ± 2.7	0.05 ± 0.12	0.91 ± 0.09	4.35 ± 0.55	1.10 ± 0.10	1.10 ± 0.19	11.9 ± 1.3	303 ± 134.2	0.08 ± 0.01	0.30 ± 0.11	2.00 ± 1.30

Lisburne Group												
WC01b	black	8.9 ± 2.6	1.05 ± 0.34	0.57 ± 0.07	3.02 ± 0.73	1.13 ± 0.13	0.69 ± 0.21	8.4 ± 1.9	44 ± 10.6	0.05 ± 0.01	0.63 ± 0.13	4.13 ± 2.83
KE12	black	11.9 ± 4.1	1.18 ± 0.29	0.32 ± 0.09	0.57 ± 0.13	0.32 ± 0.05	0.17 ± 0.02	3.1 ± 1.0	17 ± 3.9	0.03 ± 0.01	0.10 ± 0.02	0.37 ± 0.09
WC04	black	7.0 ± 1.2	2.26 ± 0.44	0.28 ± 0.03	0.29 ± 0.04	0.61 ± 0.03	0.20 ± 0.03	2.4 ± 0.5	9 ± 4.6	0.03 ± 0.00	0.11 ± 0.02	0.23 ± 0.04
NU01	black	6.5 ± 1.2	4.39 ± 0.50	0.16 ± 0.02	0.17 ± 0.02	0.06 ± 0.01	0.11 ± 0.01	0.4 ± 0.1	43 ± 4.3	0.01 ± 0.00	0.08 ± 0.01	0.11 ± 0.01

C. SUMMARY OF REE DATA (ppm)

Variety	Color	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	La_n/Yb_n	Ce_n/Ce_n*	Eu_n/Sm_n
Etivluk Group													
AN10	gray	2.31±0.86	6.42±3.01	2.30±1.28	0.54±0.23	0.15±0.06	0.10±0.03	0.47±0.15	0.34±0.09	0.06±0.02	0.49± 0.10	1.22 ± 0.17	1.48 ± 0.12
NU02g	gray	2.57±0.58	5.86±1.59	2.64±0.91	0.55±0.17	0.13±0.04	0.09±0.03	0.52±0.12	0.30±0.05	0.04±0.01	0.64± 0.08	1.01 ± 0.11	1.25 ± 0.09
NU02r	red	1.80±0.60	4.65±1.73	2.17±0.79	0.56±0.19	0.14±0.05	0.11±0.05	0.70±0.39	0.42±0.10	0.06±0.01	0.31± 0.05	1.07 ± 0.08	1.29 ± 0.07
KE13g	gray	1.36±0.30	2.60±0.75	1.82±0.72	0.31±0.07	0.07±0.02	0.04±0.03	0.27±0.14	0.17±0.04	0.03±0.01	0.61± 0.05	0.77 ± 0.11	1.19 ± 0.06
KE13 r	red	7.26±4.20	15.9 ±9.32	7.89±4.72	1.51±0.81	0.37±0.20	0.27±0.16	1.35±0.71	0.69±0.27	0.11±0.05	0.73± 0.21	0.93 ± 0.08	1.25 ± 0.08
KO01	gray	3.46±0.56	8.09±1.98	4.49±4.14	0.76±0.17	0.18±0.04	0.10±0.04	0.50±0.18	0.36±0.05	0.05±0.01	0.72± 0.09	1.01 ± 0.24	1.22 ± 0.10
WC05	gray	3.82±1.16	9.14±3.57	4.16±1.47	0.83±0.29	0.21±0.07	0.12±0.04	0.70±0.35	0.38±0.10	0.05±0.02	0.74± 0.14	1.01 ± 0.17	1.28 ± 0.09
WC01	gray	6.48± 2.05	7.57±5.56	7.81±2.86	1.84±0.70	0.44±0.18	0.18±0.08	1.05±0.28	0.51±0.08	0.08±0.01	0.93± 0.25	1.13 ± 0.09	1.21 ± 0.06
Lisburn Group													
WC01b	black	3.50±0.50	9.74±1.71	4.11±0.90	0.88±0.16	0.18±0.02	0.11±0.05	0.83±0.18	0.48±0.07	0.08±0.02	0.55± 0.07	1.17 ± 0.14	1.05 ± 0.07
KE12	black	1.27±0.44	1.53±0.37	1.22±0.47	******	0.05±0.02	0.03±0.01	0.21±0.13	0.16±0.06	0.03±0.01	0.60± 0.05	0.57 ± 0.10	******
WC04	black	2.02±0.30	1.66±0.27	1.42±0.34	******	0.05±0.01	0.03±0.01	0.20±0.07	0.12±0.02	0.03±0.00	1.32± 0.30	0.40 ± 0.03	******
NU01	black	1.98±0.32	1.06±0.17	1.88±0.35	******	0.05±0.01	0.03±0.01	0.18±0.05	0.10±0.02	0.04±0.00	1.43± 0.15	0.25± 0.01	******

Note: 1) ****** - data for Sm have been affected by Sm-U interference in U-enriched chert varieties: NU01, WC04, KE12.

2) ± refers to one standard deviation from the mean.

TABLE 2.II. ANALYTICAL ACCURACY, PRECISION AND DETECTION LIMITS

Element	SRM-278 NIST	SRM-278 MURR	SRM-278 MURR Accepted value	Precision** MURR % of measured Accuracy*	Detection limit MURR values
	ppm	ppm	MURR / NIST	%	ppm
Al	74800 ± 800	75200	1.00	8	1000
Ca	7000 ± 10	8200	1.17	76	1000
Fe	14300 ± 100	13800	0.97	14	50
K	34500 ± 170	32800	0.95	21	500
Mn	400 ± 15	420	1.05	35	0.50
Na	35800 ± 400	33900	0.95	7	50
Ni	3.60 ± 0.30			62	4.00
Rb	127.50 ± 0.30	124.	0.97	12	1.00
Sr	63.50 ± 0.10	68.2	1.07	32	2.00
Th	12.40 ± 0.30	11.6	0.94	10	0.05
U	4.58 ± 0.04	6.22	1.36	7	0.20
Ba	1140	880	0.77	34	10
Ce	62.20	61.5	0.99	18	0.06
Co	1.50	1.50	1.00	30	0.10
Cr	6.10	6.80	1.11	8	0.50
Cs	5.50	5.10	0.93	7	0.10
Eu	0.84	0.75	0.90	18	0.005
Hf	8.40	8.20	0.98	10	0.02
Lu	0.73	0.65	0.90	6	0.01
Sb	1.50	1.43	0.95	8	0.05
Sc	5.10	4.98	0.98	11	0.01
Ta	1.20	1.23	1.03	13	0.01
Tb	1.00	1.03	1.03	35	0.01
Yb	4.50	4.32	0.96	16	0.05
Zn	55.	83.	1.52	26	5.00
La		29.83		16	0.05
Nd		24.00		26	1.00
Sm		5.86		18	0.08
Dy		6.09		18	0.01
V		0.00		31	2.00
As		0.00		84	0.50

Notes: SRM-278 - standard obsidian.
NIST - National Institute of Standard and Technology.
MURR - Missouri University Research Reactor.

* Accuracy is shown as the ratio of MURR to NIST data for SRM-278 obsidian standard;

** Precision was calculated by the average % variations of quadruplicate analyses of five chert samples (DU01 - DU05) from five outcrops: WC04, WC01b, KE13r, KE13g and AN10.

Sm-U interference is double. It is a combination of U-fission product -Sm interference with U (106kv) -Sm (103kv) peaks interference. Because of the absence of the appropriate peak, Sm correction is impossible and its concentration in the three Lisburne cherts is left unidentified.

2.5. Results

2.5.1. Mineralogy

The optical microscopic study of thin sections combined with EMPA and X-Ray diffraction analysis indicates that the matrix of all cherts is composed mainly of microcrystalline quartz, although crystoballite is present in trace concentrations. Cherts contain low amount of rare inclusions of a series of translucent minerals and dark dusty particles of clay (?), opaque minerals (hematite and /magnetite (in red cherts) and pyrite) and possibly organic matter (in black cherts). The dust material in three Lisburne cherts is not spread uniformly. Micro-layers and micro-areas (from < 1mm to 10 mm) that differ by the degree of dusty clay contents were observed. In the matrix of Etivluk cherts the dusty material is more heterogeneous.

The silica matrix contains mineral inclusions (10-100μm on average) and microfossils that are replaced mostly with microcrystalline quartz. Mineral inclusions are: pyrite, barite, magnetite, hematite, dolomite (including Fe-dolomite and Mn-dolomite), calcite, kaolinite, illite, smectite, chlorite, glauconite, clinozoisite, rutile, apatite, ilmenite, zircon, quartz and cristobalite (Fig. 2. 4). The mineralogy of the inclusions is consistent within stratigraphic units. All the Lisburne chert varieties, as well as Otuk chert from Etivluk Group are pyrite bearing, whereas the Siksikpuk varieties contain barite and iron oxides. However, some of the Siksikpuk cherts contain small single inclusions of pyrite.

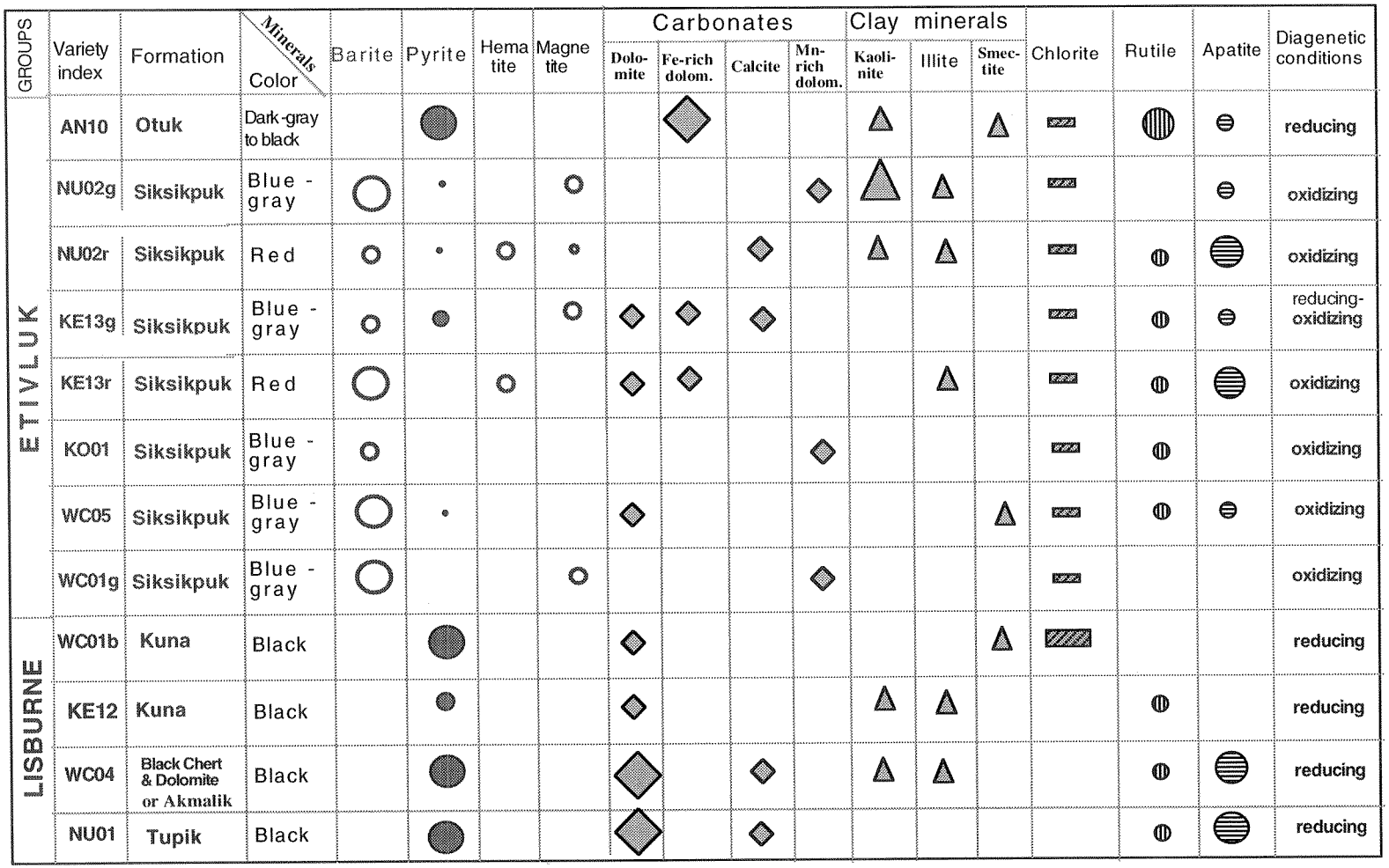


Figure 2.4. Mineralogical composition and diagenetic patterns of 12 chert varieties from Lisburne and Etivluk Groups, western Brooks Range, Alaska. The size of the symbols is proportional to the abundance of minerals.

For instance, in the KE13g variety, pyrite inclusions are dominant relative to barite inclusions. Submicron single inclusions of magnetite were found in both gray and red Siksikpuk varieties, whereas hematite dust inclusions were found just in red Siksikpuk chert varieties. The presence of hematite in red- colored Etivluk cherts and its absence in gray cherts demonstrate the correlation of red color in chert with the hematite inclusions in it. The distribution of chlorite in chert varieties discriminates three chlorite-free Lisburne cherts (NU01, WC04 and KE12) from the fourth Lisburne chert (WC01b) and all the Etivluk cherts that are chlorite-bearing.

The mineral phase assemblages are characteristic and different for pyrite-bearing and barite-bearing chert varieties. In all pyrite-bearing cherts (Lisburne Group and Otuk Formation), dolomite forms well shaped fresh crystals (up to 30% in carbonate-hosted cherts). Some dolomite crystals have zonation indicating more than one dolomitization stages. These crystals often include grains of pyrite and single grains of calcite. In these cherts, apatite and pyrite grains typically show good crystal form, whereas clay minerals (illite and kaolinite) are corroded. On the other hand, in barite-bearing varieties (Siksikpuk Formation), barite is fresh (non-leached) and occurs often as euhedral crystals, whereas dolomite is leached or absent.

Radiolarians are found in all cherts. They are, however, poorly preserved (Fig. 2.5). Microcrystalline quartz-filled radiolarians are free of the clay particles that are spread throughout the matrix. In Lisburne cherts, radiolarians are rare and often replaced with pyrite. Tupik chert contains radiolarians (Burkle, L., personal communication, 1998) that are different from those in all other chert varieties: they are much larger (~1 mm) and are very well preserved. Radiolarians in Etivluk cherts are infilled with microcrystalline quartz, but

some are partly substituted by barite. Sponge spicules (Burkle, L., personal communication, 1998) are found in Kuna cherts of Lisburne Group (WCO4, KE12 and WC01b outcrops). In Akmalik cherts (WC04), spicules have a characteristic crescent shape and are calcite-filled.

2.5.2. Geochemistry

Instrumental neutron activation analyses of 201 chert samples (15 to 19 samples from each of the 12 varieties) detected 31 major, minor, trace and rare earth elements (REEs). The summary data used in the chapter are reported in Table 2.I. The INAA data for each sample are in Appendix I.2. Correlation coefficient (r) values between major and trace elements and some of the REE indices are listed in Table 2.III. High inter-element association is seen between Al, K, Na and Fe (r = 0.72-0.77), as well as between these major elements and Sc, Hf, Ta, Th, Rb (r = 0.70 - 0.82). Strong correlations also occur between Th, Sc, Hf, Ta, Rb (r = 0.86-0.95), Ba and Sr (r = 0.94), and Zn and V (r = 0.81). The correlation coefficient values vary significantly from outcrop to outcrop.

2.5.2.1. Major and Trace Elements. The absolute elemental concentrations in chert are not useful for comparison of chert varieties with each other because of the dilution effect of SiO_2. High SiO_2 concentrations, commonly from the diagenetic formation of cherts (Murray et al., 1992b; Murray, 1994). In order to compensate for the dilution effect, I normalized absolute element concentrations to Al which is thought to be largely immobile during diagenesis of marine sediments (Murray, 1994). Chert varieties are compared with each other using Al-normalized elemental ratios. Al is proven as an excellent indicator of terrigenous input into certain pelagic sediment (Boström and Paterson, 1969; Boström et al., 1973; Taylor and McLennan, 1985). The Al-normalized ratios in cherts therefore can also

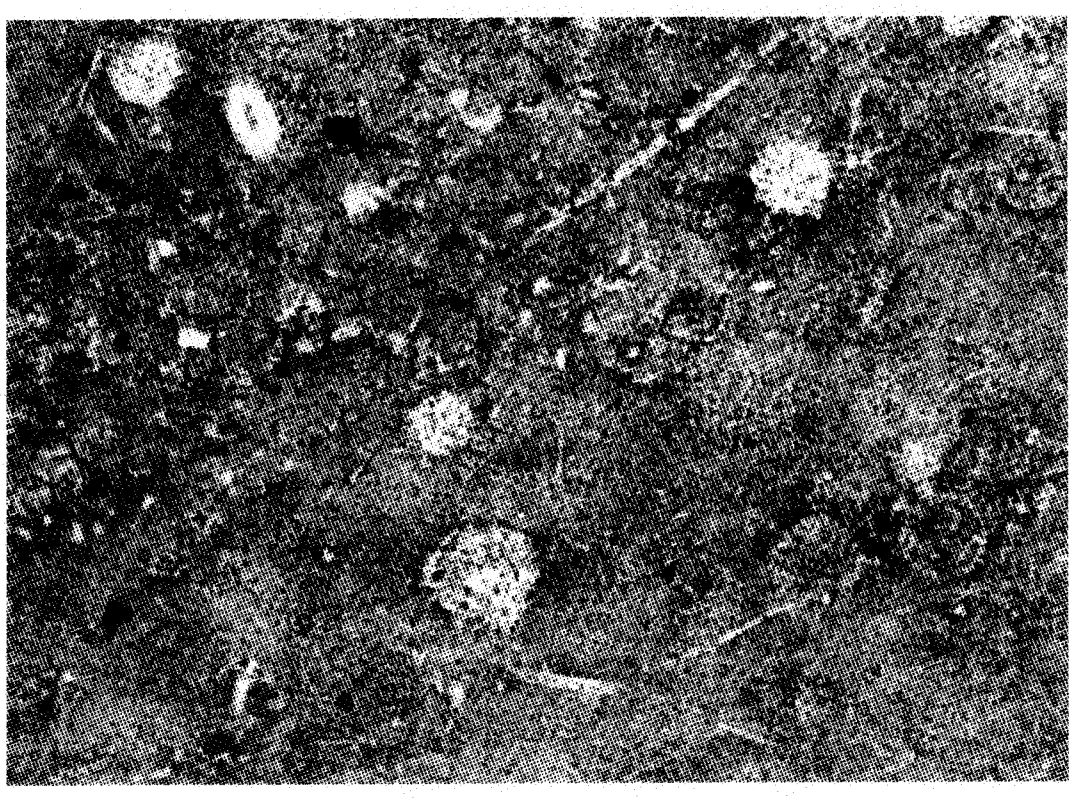


Figure 2.5. Microcrystalline quartz-filled radiolarians in Kuna chert

TABLE 2.III. CORRELATION COEFFICIENT (r) VALUES
ALL SAMPLES FROM TWELVE VARIETIES.

Variables	Al	Ca	K	Mn	Na	Fe	Ba	Ce_n/Ce_n^*	La_nYb_n	Eu_n/Sm_n	Cr	Co	Ni	Zn	Sb	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	As	V
Al	1.00																								
Ca		1.00																							
K	0.77		1.00																						
Mn				1.00																					
Na	0.72		0.56		1.00																				
Fe	0.77		0.50		0.62	1.00																			
Ba	0.60					0.57	1.00																		
Ce_nCe_n								1.00																	
La_nYb_n									1.00																
Eu_nSm_n										1.00															
Cr	0.49		0.45								1.00														
Co				0.52								1.00													
Ni	0.48												1.00												
Zn	0.49										0.49		0.71	1.00											
Sb												0.59			1.00										
U										-0.64				0.45		1.00									
Th	0.78		0.62		0.79	0.79	0.71				0.53						1.00								
Sc	0.79		0.61		0.78	0.80	0.67		0.45		0.49		0.48	0.52			0.87	1.00							
Cs	0.50								0.47		0.67		0.54	0.64		0.47	0.50	0.53	1.00						
Hf	0.71		0.58		0.68	0.72	0.58		0.44		0.46						0.86	0.85	0.59	1.00					
Rb	0.76		0.68		0.58	0.70	0.48		0.44		0.69						0.86	0.79	0.72	0.77	1.00				
Sr	0.60				0.71	0.60	0.94										0.72	0.67		0.57	0.51	1.00			
Ta	0.77		0.61		0.82	0.79	0.74				0.47						0.95	0.89		0.86	0.81	0.73	1.00		
As																								1.00	
V	0.47										0.54		0.58	0.81		0.55			0.65						1.00

Note: - 0.45 < r < 0.45 not shown. (-) indicates negative correlation. Data from the Appendix 2.

be compared with analogous ratios in PAAS (Post Archean Australian Shale) to show the proportion of the terrestrial fraction in the chert. This chapter discusses ratios used for determination of depositional environment, provenance and diagenetic conditions (Figs. 2.6 and 2.8). A series of other elemental ratios that are useful for discrimination of outcrops from each other is given in Appendix I.3.A.

$(Al_{sample}/Al_{PAAS})x100$. The concentrations of the terrigenous matter in each chert sample was calculated using (Al_{sample}/Al_{PAAS}) x 100%. In the three Lisburne cherts (NU01, WC04 and KE12) terrigenous component comprises 2% to 4%, whereas in the youngest WC01b Lisburne chert and Etivluk cherts it ranges from 4% to 20% (Fig. 2.6a).

Fe/Al. The Fe/Al variation does not show well expressed patterns (Fig. 2.6b). Most of the Etivluk cherts have Fe/Al values that are equal to PAAS, whereas most of Lisburne cherts have Fe/Al values a little lower than PAAS.

Ba/Al. Ba/Al discriminates all the Siksikpuk varieties from the rest of the cherts (Fig. 2.6c). The Siksikpuk cherts have Ba/Al values that are higher than PAAS and considerably vary within outcrops. The Otuk chert and all Lisburne varieties have Ba/Al values essentially equal to PAAS with no variability within outcrops (Fig. 2.6c). These data correlate with the mineralogy: all the Siksikpuk cherts contain barite, whereas the Lisburne and Otuk cherts do not. This indicates that barite is the dominant mineral carrying the Ba in these rocks.

U/Al. U/Al values indicate U enrichment of Lisburne cherts relative to PAAS and U equal to PAAS in Etivluk cherts. There is a gradual decrease of the U/Al values from the oldest Lisburne chert to the youngest one. The oldest NU01 Tupik carbonate-hosted chert

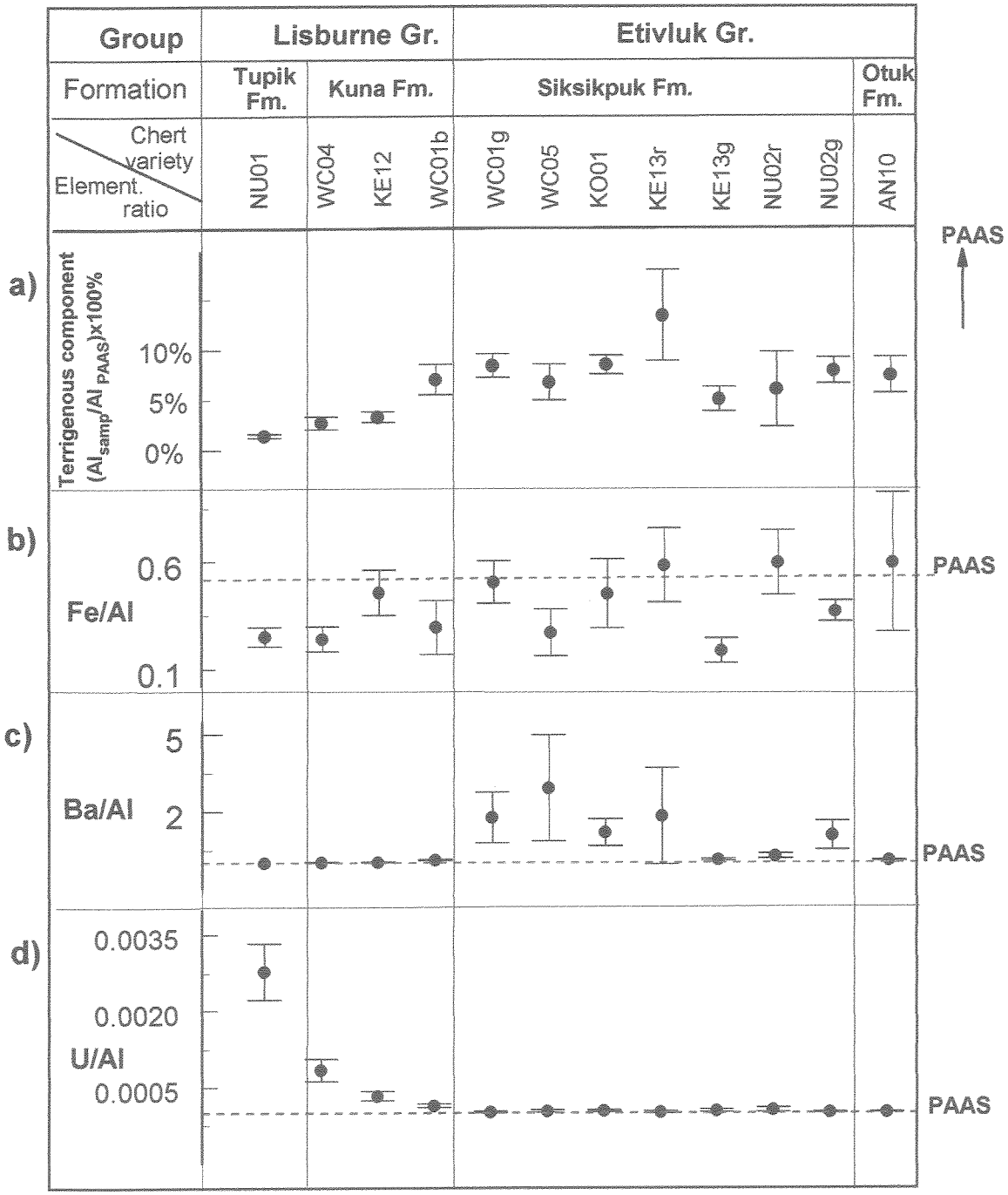

Group
Lisburne Gr.
Etivluk Gr.
Formation
Tupik Fm.
Kuna Fm.
Siksikpuk Fm.
Otuk Fm.
Chert variety
Element. ratio
NU01
WC04
KE12
WC01b
WC01g
WC05
KO01
KE13r
KE13g
NU02r
NU02g
AN10
PAAS
a)
Terrigenous component (Al samp/Al PAAS)x100%
10%
5%
0%
b)
Fe/Al
0.6
0.1
PAAS
c)
Ba/Al
5
2
PAAS
d)
U/Al
0.0035
0.0020
0.0005
PAAS

Figure 2.6.

Figure 2.6. Elemental ratios for 12 Lisburne and Etivluk chert varieties (based on INAA data). (a) $(Al_{sample} / Al_{PAAS})x100\%$ serve as a measure of terrigenous component in cherts; (b) Fe/Al show depletion in Fe for most of Lisburne cherts and a continental source of detrital component for most of Etivluk in all cherts; (c and d) Ba/Al, and U/Al are examples of elemental ratios discriminating Lisburne cherts from Etivluk cherts. Intervals of variability show one standard deviation from the means.

is significantly enriched in U/Al compared to the three other Lisburne cherts (Fig. 2.6d).

2.5.2.2. Rare Earth Elements. REE data are normalized to the average Post Archean Australian Shales (PAAS, Taylor and McLennan, 1985) (Fig. 2.7). The REE patterns show so called negative Ce anomalies (a depletion of Ce relative to its trivalent lanthanide, La, neighbors) in contrast with nonexistent or positive Ce anomalies in WC01b Kuna chert (Lisburne Group) and all the Etivluk Group cherts.

Ce_n/Ce_n^*. Values defining the Ce anomalies were calculated as $Ce_n/Ce_n^* = (Ce_{sample}/Ce_{PAAS})/Ce^* = 3\,(Ce_{sample}/Ce_{PAAS})\,/\{(2La_{sample}/La_{PAAS}) + (Nd_{sample}/Nd_{PAAS})\}$ (e.g. German and Elderfield, 1990, references therein). Three Lisburne outcrops (NU01, WC04 and KE12) have Ce_n/Ce_n^* mean values = 0.25 to 0.57 (Fig. 2.8a), whereas the fourth Lisburne chert (WC01b chert from the Kuna Formation on the contact with Siksikpuk Formation) has $Ce_n/Ce_n^* = 1.17$. The Siksikpuk cherts have Ce_n/Ce_n^* mean values altered from 0.77 to 1.13. The lowest Ce_n/Ce_n^* values = 0.77($\pm$ 0.11) in Siksikpuk cherts (KE13g) are transitional between negative and no Ce anomaly. The Otuk chert (AN10) has $Ce_n/Ce_n^* = 1.22$ (Fig 2.8a).

La_n/Ce_n. La_n/Ce_n values are also reliable indicators of relative behaviour of Ce (Murray, 1994). They are useful to consider because of the higher quality of La and Ce data, compared to Nd used in part of the Ce_n/Ce_n^* calculation. Means of La_n/Ce_n values in three Lisburne cherts range from 1.76 to 3.92 (indicating significant Ce depletion). The fourth Lisburne chert WC01b and all Etivluk cherts have La_n/Ce_n values ranging from 0.76 to 1.00 indicating no Ce depletion (Fig. 2.8b).

Eu_n/Sm_n. REE patterns show positive or no Eu anomalies for both Lisburne and Etivluk cherts (Fig. 2.7). Because of the lack of data for Gd and slightly anomalous

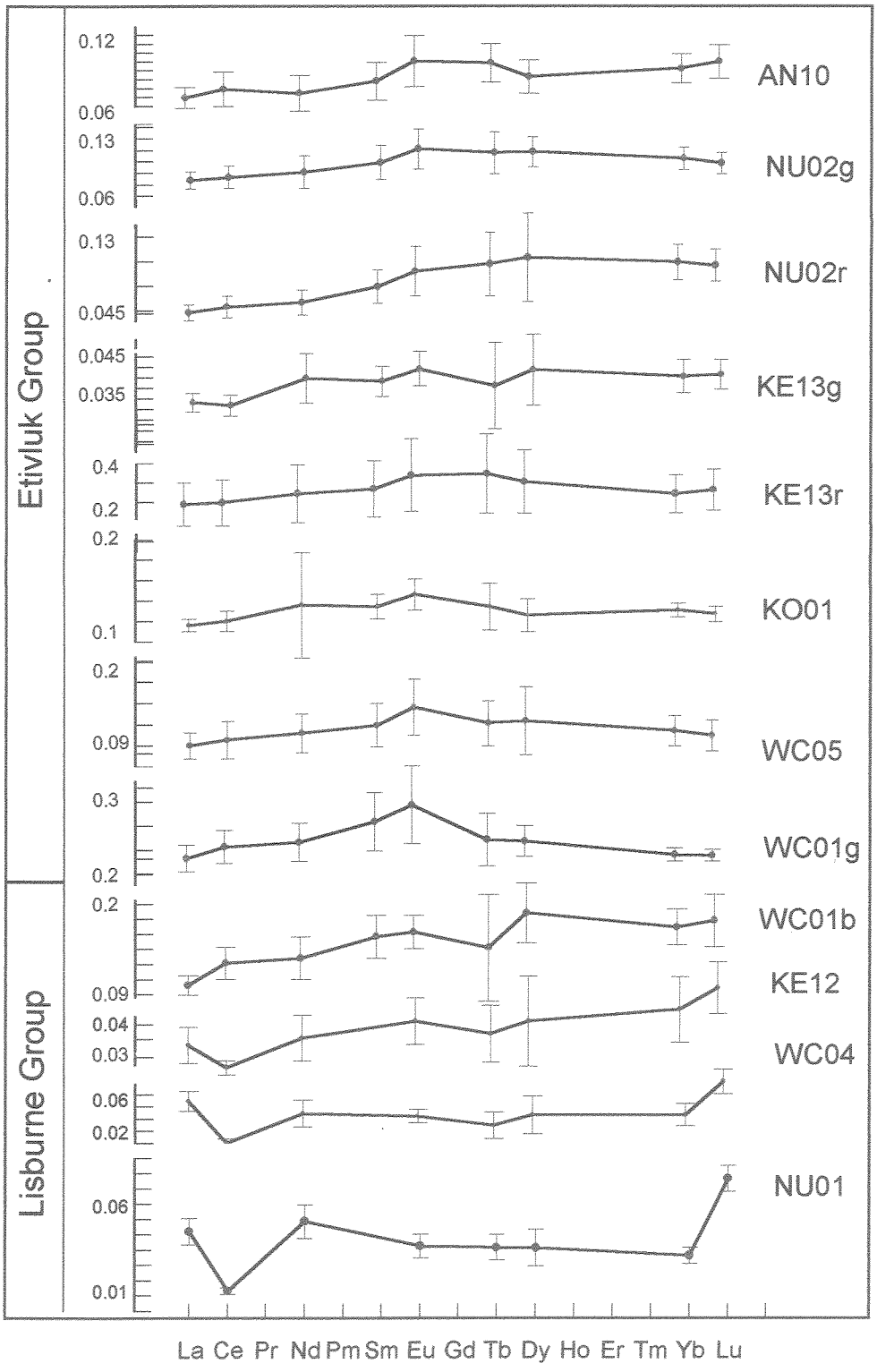


Figure 2.7. PAAS-normalized REE abundance patterns of the 12 chert varieties. Lines connect mean concentrations (based on 15 samples from each variety). Intervals of variability show one standard deviation from the mean.

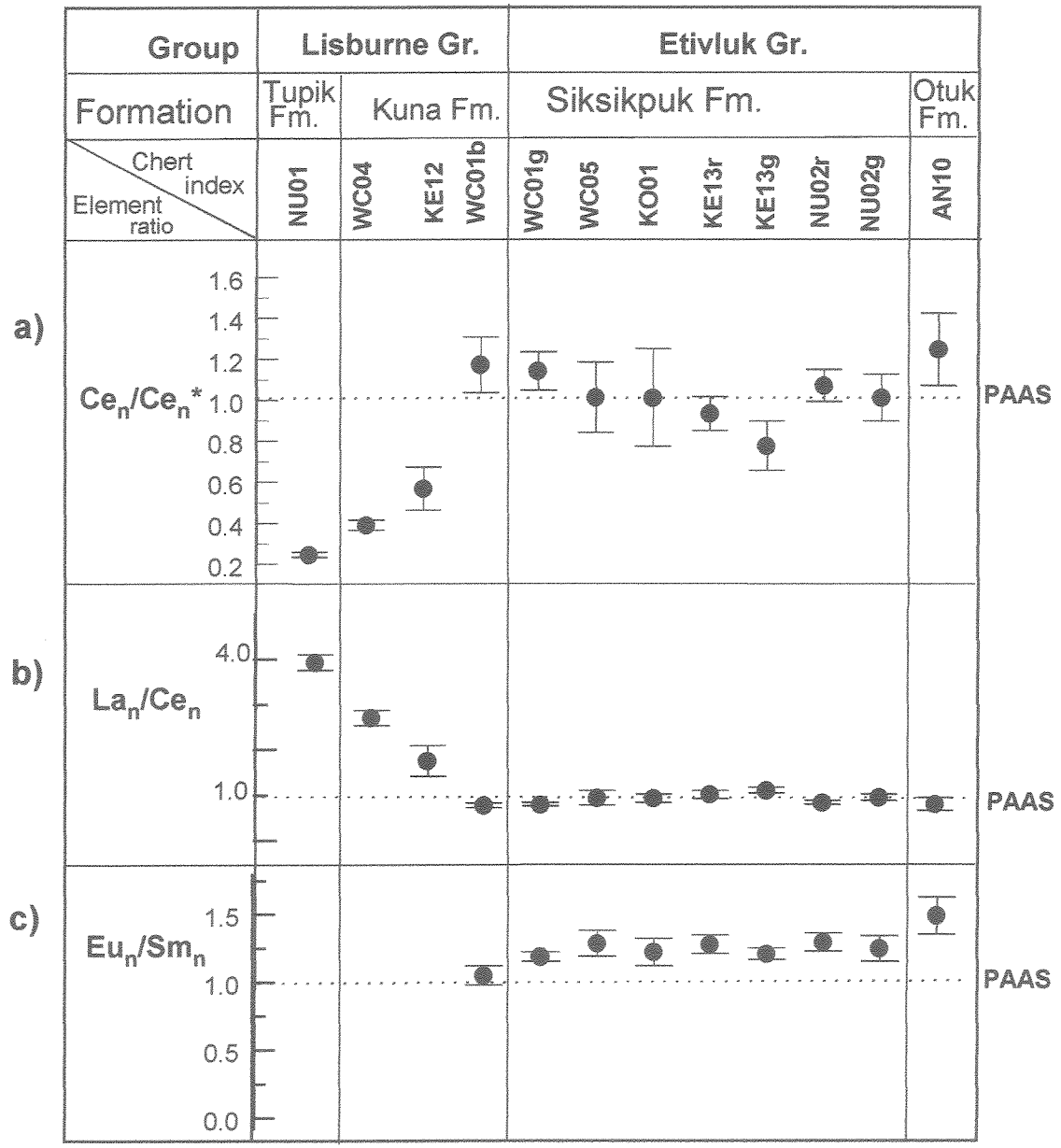


Figure 2.8. Elemental ratios of REEs of 12 chert varieties in the western Brooks Range normalized to PAAS. Intervals of variability show one standard deviation from the mean.

concentrations of Tb, the Eu_n/Sm_n values were determined as = $(Eu_{sample}/Eu_{PAAS}) / (Sm_{sample}/Sm_{PAAS})$ as an indicator of the value of Eu fractionation in REE. The calculation of Eu_n/Sm_n values was not possible for three U-enriched Lisburne chert varieties (NU01, WC04 and KE12) because of interference between U-Sm analytical photopeaks as discussed previously. Eu_n/Sm_n values are almost equal to PAAS in Lisburne outcrop WC01b, are slightly higher than those in PAAS in the Siksikpuk cherts and are significantly higher in Otuk cherts (Fig. 2.8c).

2.6. Discussion: Depositional Environment

2.6.1. Geochemical Model

Identification of depositional environment of cherts must rely on those primary signatures that survive during diagenetic formation of chert and, in particular, during chemical fractionation that accompanied the concentration of SiO_2 into the chert (Murray, 1994, references therein). Of the 31 elements detected by INAA, REEs, Al and Fe can be used as depositional environment indicators because these elements are considered to be the least mobile during the diagenesis of marine sediments (Boström et al., 1973; Taylor and McLennan 1985; McLennan, 1989; Murray et al., 1992c; Murray, 1994).

Ce anomalies in REE patterns have been used successfully as reliable indicators of chert depositional environments (Shimizu and Masuda, 1977; Steinberg, et al., 1983; Murray et al., 1990, 1991, 1992a; Musashino, 1990; Huebner et al., 1992; Murray, 1994; Girty et al., 1996). Ce anomalies are generated because most of REEs are trivalent and soluble in sea water. However, Ce oxidizes from the soluble Ce^{3+} state to the insoluble Ce^{4+} state in seawater. In open ocean water, Ce oxidation leads to depletion of Ce (and hence values of $Ce_n/Ce_n^* < 1.0$). As a result, the open ocean water characteristically shows negative Ce

anomalies (Shimizu and Masuda, 1977; Steinberg et al., 1983; Murray et al., 1991, Byrne and Sholkovitz, 1996). Radiolarian and diatom tests providing silica for chert in open ocean environment inherit the Ce depletion signature and thus, open ocean siliceous deposits are characterized by Ce anomalies. Authigenic minerals incorporated in open ocean cherts also inherit seawater REE patterns with negative Ce anomalies. However, detrital terrigenous material is characterized by Ce_n/Ce_n^* ~1 (Murray et al., 1990; Murray, 1994), and when incorporated into chert tends to smooth out negative Ce anomalies. Sediments deposited rapidly and near continental shelf would have less exposure time to seawater and therefore be less likely to have acquired the characteristic seawater signatures with negative Ce anomaly (Murray, 1990; Huebner et al., 1992). As a result, continental margin cherts show mostly flat (without negative Ce anomalies) REE patterns due to high terrigenous component. Analyses of cherts of known depositional setting indicate that the overwhelming majority of open ocean cherts show negative Ce anomalies, whereas continental margin cherts are characterized with Ce_n/Ce_n^* = or >1 (Shimizu and Masuda, 1977; Murray et al., 1991, Murray, 1994; Girty et al., 1996).

The relative behavior of Ce is usually measured by Ce_n/Ce_n^*, but can also be measured by La_n/Ce_n ratios (Murray , 1994). Murray et al. (1990) and Murray (1994) suggested the following values of Ce_n/Ce_n^* and La_n/Ce_n for different chert depositional environments: 1) $Ce_n/Ce_n^* >\sim 0.8$ and $La_n/Ce_n = 1$ or < 1 for continental margin, 2) $Ce_n/Ce_n^* = \sim 0.55$ and La_n/Ce_n = 1-3 for open ocean and 3) $Ce_n/Ce_n^* = \sim 0.30$ and $La_n/Ce_n > 3$ for oceanic ridge-proximal areas.

Al and Fe occur only in trace amounts in radiolaria (Martin and Knauer, 1973) and thus are representative of the non-biosiliceous fraction of cherts. Moreover, Al

concentrations in cherts are controlled by the terrigenous component in cherts (Steinberg, et al., 1983; Murray, 1994). Relative Al concentrations (such as Al/Fe) are not controlled by amount of diagenetic silica. They are the function of the distance from the continent and may be considered as an indicator of the depositional environment. Fe is more abundant in hydrothermal deposits (Boström, 1976; Steinberg, et al., 1983). Murray (1994) suggested that relative Fe concentrations in cherts are helpful for determining depositional environment because their relative abundances depend on the distance from the ocean ridge sources of hydrothermal Fe. He pointed, however, that the Fe/Ti ratios are required to differentiate ridge-proximal from open-ocean cherts with strongly negative Ce anomalies. Since Ti data are not available I could not use this criterion.

2.6.2. Depositional Environments

2.6.2.1. Lisburne Group. REE patterns (Fig. 2.7) show pronounced negative Ce anomalies in three Lisburne cherts: Tupik, Akmalik/Black Chert and Dolomite and one of Kuna cherts. The other (WC01b) Kuna chert has $Ce_n/Ce_n^* > 1$. It appears that there may be a progressive positive correlation between the stratigraphic age of the chert and Ce_n/Ce_n^* values within the Lisburne Group. The oldest chert from Tupik Formation (late early Mississippian?) has the largest negative Ce anomaly (0.25 ± 0.01) and the two cherts from younger Kuna Formation (Mississippian-Pennsylvanian) have intermediate values (0.4-0.57). The youngest Kuna chert (WC01b, that was exposed on the contact between Kuna and Siksikpuk Formations), and the overlying Etivluk cherts have $Ce_n/Ce_n^* > 0.79$ (Fig. 2.7a). Using Ce_n/Ce_n^* values as indicators of the depositional environment of cherts the depositional setting of the Tupik-Kuna cherts gradually evolved from open ocean to continental margin during late-early Mississippian to Pennsylvanian time.

My results contrast with the widely accepted tectonic model proposing the deposition of Tupik, Akmalik and Kuna cherts in the epicontinental sea to the south of the Arctic Alaska terrane during Devonian - late Mississippian time (Mayfield et al., 1988; Moore et al., 1994). However, the production of such strong negative Ce anomalies (0.24-0.57) in three Lisburne cherts requires a very low energy basin with minimal terrigenous input to avoid inherited $Ce_n/Ce_n^* \geq 1$. Although low clastic input might be possible on a continental margin, such a setting is unlikely to be maintained for approximately 50-60 million years (late early Mississippian - Pennsylvanian) while deposition of Tupik, Akmalik and Kuna cherts occurred. Petrographic and mineralogical data indicate the presence of micro-layers enriched by dusty clay components in silica matrix in four studied Lisburne cherts. If these clays were composed of local terrigenous matter, they would be abundant enough in these samples to cause the bulk rock to have $Ce_n/Ce_n^* \sim 1$. Because the bulk $Ce_n/Ce_n^* = 0.24 - 0.57$, it is reasonable to interpret the depositional environment as distal to a continental source.

It is well known that Ce_n/Ce_n^* values in sediments (even in the open ocean) are commonly much higher than those in the seawater column (Byrne and Sholkovitz, 1996). For example, modern sediments in a number of marginal and continental seas such as the Mediterranean or Sea of Japan show flat or positive REE patterns in sediments despite the negative Ce anomalies in the overlying seawater (Byrne and Sholkovitz, 1996). Chert sediments typically have very low accumulation rate (relative to other types of sediments) (Boström et al., 1973). Ce_n/Ce_n^* values in cherts reflect average Ce concentrations resulted from a combination of different sources during the long accumulation period. Thus, the low Ce_n/Ce_n^* values in the Lisburne cherts might reflect more severe Ce anomalies in the water

column. Based on these combined lines of evidence, the deposition of three Lisburne (Tupik, Akmalik and part of Kuna) cherts in a sediment starved basin on the continental margin is very doubtful.

The Fe data, however, do not support the open ocean depositional environment of Lisburne cherts. Fe/Al values in three Lisburne cherts are less than or close to those in the PAAS (Fig. 2.6b). This might be due to depletion of the system in Fe or enrichment in Al. However, Murray (1994) suggests that relative Fe concentrations increase in open ocean cherts relative to continental margin ones.

The Fe depletion/Al enrichment causes deviation of two of the Lisburne cherts from the geochemical fields on Murray's (1994) diagram La_n/Ce_n vs. AL_2O_3 / (AL_2O_3+Fe_2O_3) discriminating chert depositional environments (Fig. 2.9). On this diagram, mean concentrations of four Lisburne cherts are widely spread between open ocean and continental margin according to La_n/Ce_n values. Two carbonate-hosted cherts occur in the area corresponding to open ocean environments according to La/Ce values, but fall outside of the open ocean pelagic and ridge fields due to the higher AL_2O_3 / (AL_2O_3+Fe_2O_3) values. One of shale-hosted Kuna cherts (KE12) falls on the border of the pelagic field also possibly due to a weak depletion of Fe. The youngest shale-hosted Kuna chert (WC01b) that is characterized with a positive Ce anomaly occurs in the continental margin field.

This discrimination diagram was constructed by Murray (1994) based on cherts of known deposition. However, Murray's (1994) data for the pelagic field was restricted to shale-hosted cherts younger than the Jurassic and thus may not be representative of carbonate-hosted open ocean cherts. This may explain why carbonate-hosted Tupik (NU01) and Akmalik (WC04) cherts fall outside the pelagic field. The assumption that carbonate

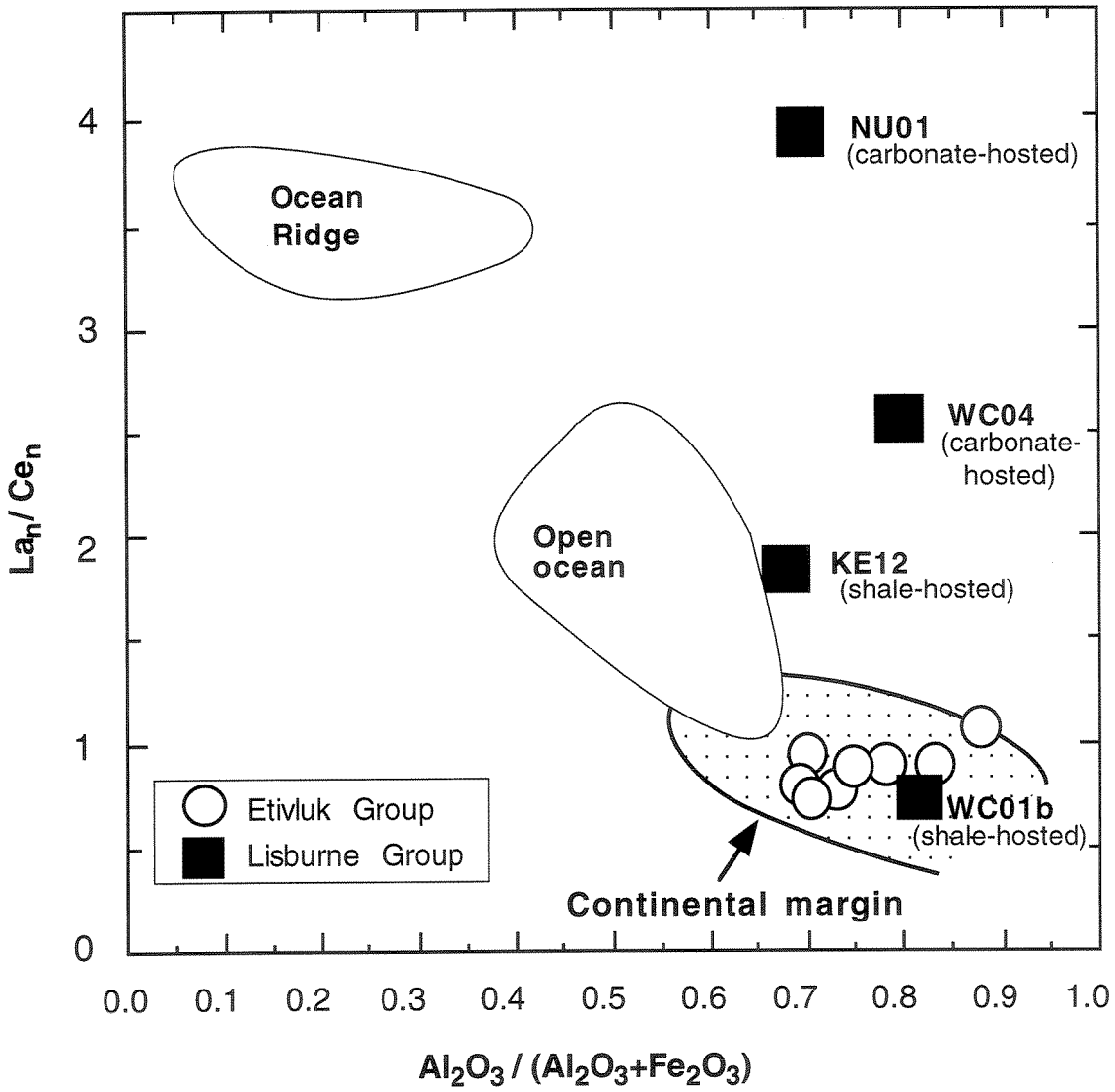


Figure 2.9. Mean concentrations of 12 western Brooks Range chert varieties plotted on the Lan/Cen vs. Al2O3/(Al2O3+Fe2O3) discrimination diagram of Murray (1994). Etivluk cherts are all within the field of the continental margin, whereas Lisburne cherts fall as follows: carbonate-hosted cherts are outside the open ocean field, one of the shale-hosted cherts falls on the border of the open ocean field and another one into the continental margin field.

material originates from the deep ocean calcareous oozes would be in good agreement with the fact that deep ocean pelagic calcareous oozes have characteristically negative Ce anomalies (Toyoda et al., 1990).

The difference in the inferred depositional environment between the two Kuna cherts probably reflects the difference in their stratigraphic position: WC01b Kuna chert is from the well exposed gradational contact with the Siksikpuk formation at the uppermost part of the Kuna Formation. All studied Lisburne cherts have specific signatures (high U/Al and very low Ba/Al) (Fig. 2.6c,d). However, the WC01b Kuna chert differs from the other three by much higher Ce_n/Ce_n^* values (1.17) That may record a transitional environment between open ocean and continental margin.

Geochemical evidence for the open ocean depositional setting of the Tupik and Kuna cherts concurs with paleontological data (Churkin et al., 1979). In the western Brooks Range the oldest part of the Kogvik sequences in the DeLong Mountains (which underlies Permian chert-shale deposits in the western Brooks Range) is characterized by a Nereites trace-fossil assemblage and thus is deep water (Churkin et al., 1979). Because of the presence of limestone turbidites interbedded with these deposits, Churkin et al. interpreted Kogvik sequence as oceanic facies deposited near the continental shelf (Fig. 2.1a). The Tupik and Kuna Formations (according to U.S.G.S. nomenclature) is an equivalent to the oldest part of this sequence.

Additionally, in the west-central Brooks Range, conodont species in the Akmalik chert represent a mixture of shallow-water platform to slope biofacies, as well as some pelagic elements (Dumolin et al., 1993). The poor preservation and species composition (representing mixed environments) of the Akmalik conodonts indicate their basinward

transport by turbidity currents. Kuna cherts from the Brooks Range allochthon as well as Akmalik Chert from the Picnic Creek allochthon were deposited in deep water conditions and are chiefly older than the younger Lisburne platform facies (Dumolin et al., 1993). The paleontological data here indicate also that Akmalik chert was formed in deeper water than the Kuna chert, in a position more distal and (or) restricted from clastic input (Dumoulin et al., 1993). This is consistent with geochemical data indicating a stronger negative Ce anomaly and lower amount of terrigenous component in the Akmalik/Dolomite and Chert Unit WC04 chert than those in KE12 (Kuna) chert (Figs. 2.6a and 2.8a).

The open-ocean depositional environment interpreted for the Lisburne cherts is also corroborated by the association of Lisburne cherts with pillow basalts (Pallister and Carlson, 1988; Pallister et al, 1989). The open-ocean depositional environment of late early Mississippian is consistent with the model of the opening of the Angayucham ocean south of Arctic Alaska plate during Devonian (Grantz et al., 1991) rather than Pennsylvanian time (Mayfield et al., 1988).

The evolution of the depositional environment of late Paleozoic chert deposits in the western Brooks Range is analogous to that of the chert sediments of the Tamba Group (a part of the Japanese Paleozoic-Mesozoic accretionary prism) (Musashino, 1990). Ce_n/Ce_n^* values of the Tamba Group record the change from the open ocean to the continental margin setting during early-middle Permian, whereas in the western Brooks Range the change occurred earlier, during Upper Pennsylvanian age.

Additional geochemical data that would represent the entire range of Lisburne chert stratigraphic units (from Kogruk Formation to the uppermost Kuna Formation) and their lateral facies will provide more information on the depositional environment of Lisburne

cherts. It will show if Ce_n/Ce_n^* variations obtained for three Lisburne cherts indicate open ocean depositional environment or unique sediment starved situation on the continental margin recorded in the lateral lithofacies.

2.6.2.2. Etivluk Group. All Etivluk cherts have Ce_n/Ce_n^* values near 1.0 with exception of KE13g Siksikpuk chert that has low Ce_n/Ce_n^* values (0.77 ± 0.11). A few samples from this outcrop have Ce_n/Ce_n^* ~0.6 suggesting a transitional deposition on the border between open ocean and continental margin. On Murray's La_n/Ce_n vs. AL_2O_3 / $(AL_2O_3+Fe_2O_3)$ discrimination diagram all Etivluk cherts cluster within the field of continental margin cherts (Fig. 2.9). This field, however, does not discriminate cherts deposited in passive margins from those deposited in active margins. The depositional conditions for Etivluk cherts may however be determined using provenance-related Eu_n/Sm_n discriminant.

Eu_n/Sm_n values can be used as indicators of provenance because Eu-enrichment is characteristic for plagioclase rich sediments (Nance and Taylor, 1977; Steiberg et al., 1983; Taylor and McLennan, 1985; McLennan, 1989). Volcanic arcs (ocean and continental) that did not experienced crustal fractionation provide plagioclase rich sediments that are typically Eu-enriched relative to sediments derived from post-Archean upper continental crust (geochemically similar to PAAS) (McLennan, 1989).

Based on the REE data for continental margin cherts (Murray et al., 1991) I developed a continental margin field on the La_n/Ce_n vs. Eu_n/Sm_n diagram and added reference subfields of possible provenance sediments and rocks (Fig. 2.10). Different provenances can be determined for those cherts that fall outside the overlapping subfields. The youngest WC01g Siksikpuk chert (from the gradational contact with underlying WC01b Kuna chert)

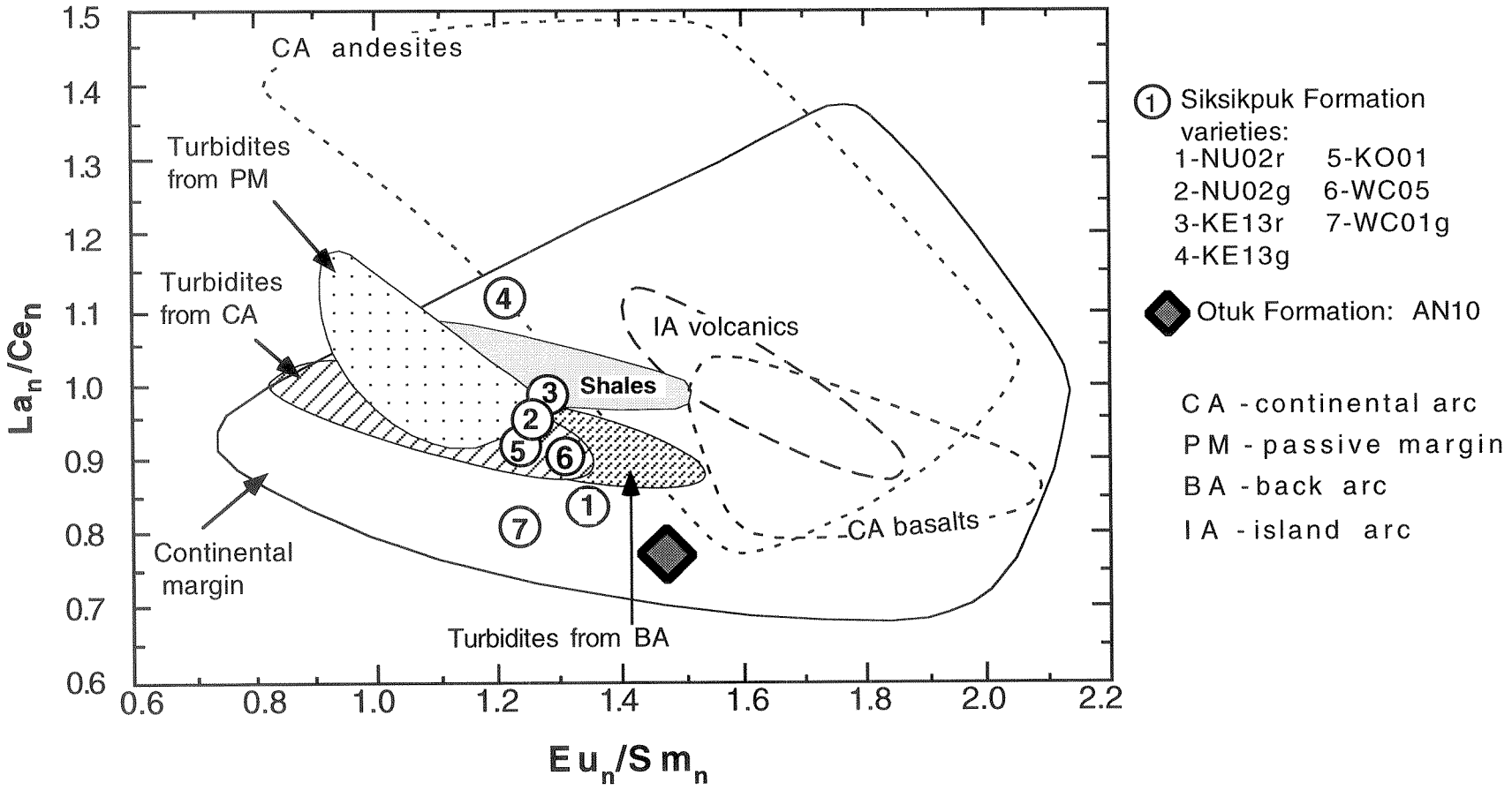

CA andesites
Turbidites from PM
Turbidites from CA
IA volcanics
Shales
CA basalts
Continental margin
Turbidites from BA
1
2
3
4
5
6
7
La$_n$/Ce$_n$
Eu$_n$/Sm$_n$
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
① Siksikpuk Formation varieties:
1-NU02r
2-NU02g
3-KE13r
4-KE13g
5-KO01
6-WC05
7-WC01g
Otuk Formation: AN10
CA - continental arc
PM - passive margin
BA - back arc
IA - island arc

Figure 2.10.

Figure 2.10. Mean concentrations of 12 western Brooks Range chert varieties plotted on the La_n/Ce_n vs. Eu_n/Sm_n diagram. Field of cherts deposited on continental margin is constructed using chemical data taken from Murray et al. (1991). Plotting the reference compositions of possible provenance sediments and sedimentary rocks provided subfields of: turbidites from continental arc basins, turbidites from back arc basins, turbidites from passive margins (McLennan and Taylor, 1990), turbidites from shales (Gromet et al., 1984; Taylor and McLennan, 1985), unaltered volcanic rocks from continental and island arcs (Carr et al., 1982; Taylor and McLennan, 1985; Hickey et al., 1986).

plots far away from all subfields indicating no volcanogenic influence (Fig. 2.10). The mean compositions of most Siksikpuk cherts fall in the area of overlapping subfields of turbidites from continental arc, back arc, passive continental margin and shales suggesting that the depositional environment of Siksikpuk cherts had input of turbidites that may have contained debris of volcanic rocks. The significantly higher Eu_n/Sm_n values in Otuk chert remove it toward the subfields of unaltered continental arc andesites and basalts indicating possible input of intermediate to mafic volcanic rock debris into the depositional environment. In general, the depositional environment of Etivluk cherts during Pennsylvanian to Jurassic times seems to represent a continental margin that evolved from a provenance with no volcanic debris to one with abundant volcanics.

2.6.2.3. Redox Conditions. The potential application of Ce_n/Ce_n^* values as a paleoredox indicator has been widely discussed in the literature (Wright et al., 1984; Banner et al., 1988; Liu et al., 1988; German and Elderfield, 1990). Oxidation of soluble Ce^{+3} to insoluble Ce^{+4} is caused by the oxic conditions in the sea water. Therefore, one might expect that a negative Ce anomaly is a reliable indicator of oxidizing conditions during sediment deposition (Liu et al., 1988). However, attempting to derive a predictable relationship between negative/positive Ce anomalies in solid phase and depositional redox conditions would be an oversimplification (German and Elderfield, 1990).

Geochemical and mineralogical data on chert deposits in the western Brooks Range show no correlation between Ce_n/Ce_n^* values and observed oxidizing-reducing patterns for studied Lisburne and Etivluk cherts. Pyrite-enrichment (with absence of barite and iron oxide inclusions) that indicates reducing diagenetic conditions found in Lisburne chert varieties that are characterized with Ce_n/Ce_n^* values $<<1$, as well as in the youngest Kuna

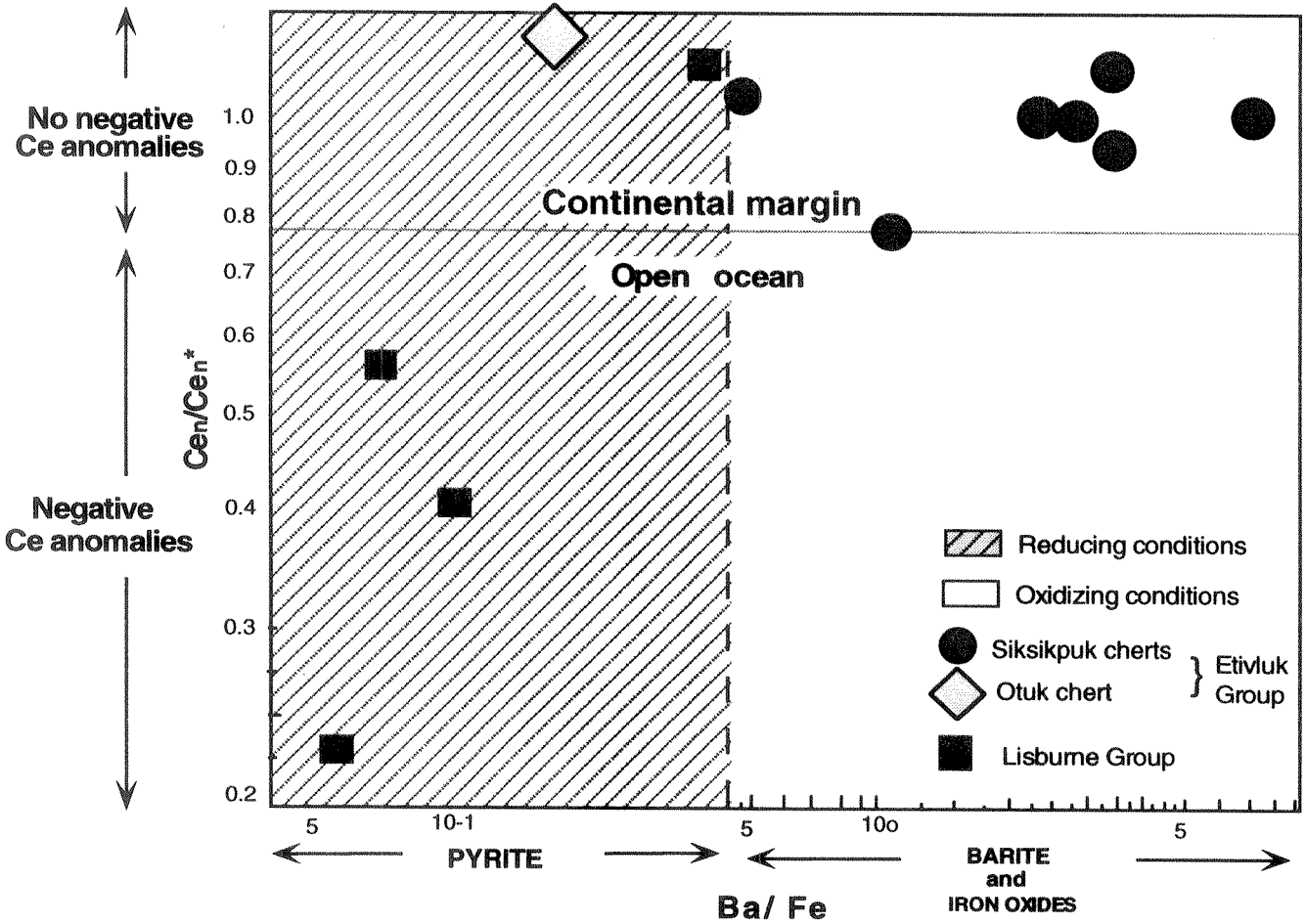


Figure 2.11. Mean concentrations of Ce_n/Ce_n^* and Ba/Fe plotted on bivariate diagram illustrate no correlation between Ce_n/Ce_n^* values and observed oxidizing-reducing patterns in the late early Mississippian to Jurassic cherts.

(Lisburne) chert and Otuk (Etivluk) chert characterized with $Ce_n/Ce_n^* > 1$ (Fig. 2. 11). Mineral phase relationships in pyrite-enriched varieties (Lisburne Group and Otuk Formation) recorded strong late stage of dolomitization and pyritization indicating intensive diagenetic processes. The primary redox conditions more likely were obscured by subsequent diagenetic processes and differed from the recorded oxidizing / reducing conditions in chert. Thus, the recorded oxidizing-reducing patterns reflect final stage in the chain of diagenetic changes in cherts and might not reflect redox conditions during deposition.

2.7. Conclusions

1. Geochemical signatures have divided upper Mississippian - Jurassic chert deposits in the western Brooks Range into two main types that are correlated with two main stratigraphic groups: Lisburne Group (late early Mississippian to early Pennsylvanian) and Etivluk Group (upper Pennsylvanian to Jurassic). Differences in these signatures reflect differences in depositional environment (Fig. 2.12).
2. Ce_n/Ce_n^* values = 0.24-0.63 (negative anomalies) and La_n/Ce_n = 0.76-3.92 in the three of four studied Lisburne cherts (from Tupik, Akmalik and Kuna Formations) suggest open ocean deposition environment, whereas Ce_n/Ce_n^* = 0.79- 1.3 and La/Ce=0.76-1.0 in all Etivluk cherts (Siksikpuk and Otuk Formations) and the youngest Kuna chert indicate continental margin deposition.
3. The gradual increase of Ce_n/Ce_n^* values in Lisburne cherts (from 0.25 in the oldest Tupik, chert to 1.17 in the youngest Kuna chert) may record the gradual change in their depositional environment from the open ocean to the continental margin during the late early Mississippian - Pennsylvanian time.

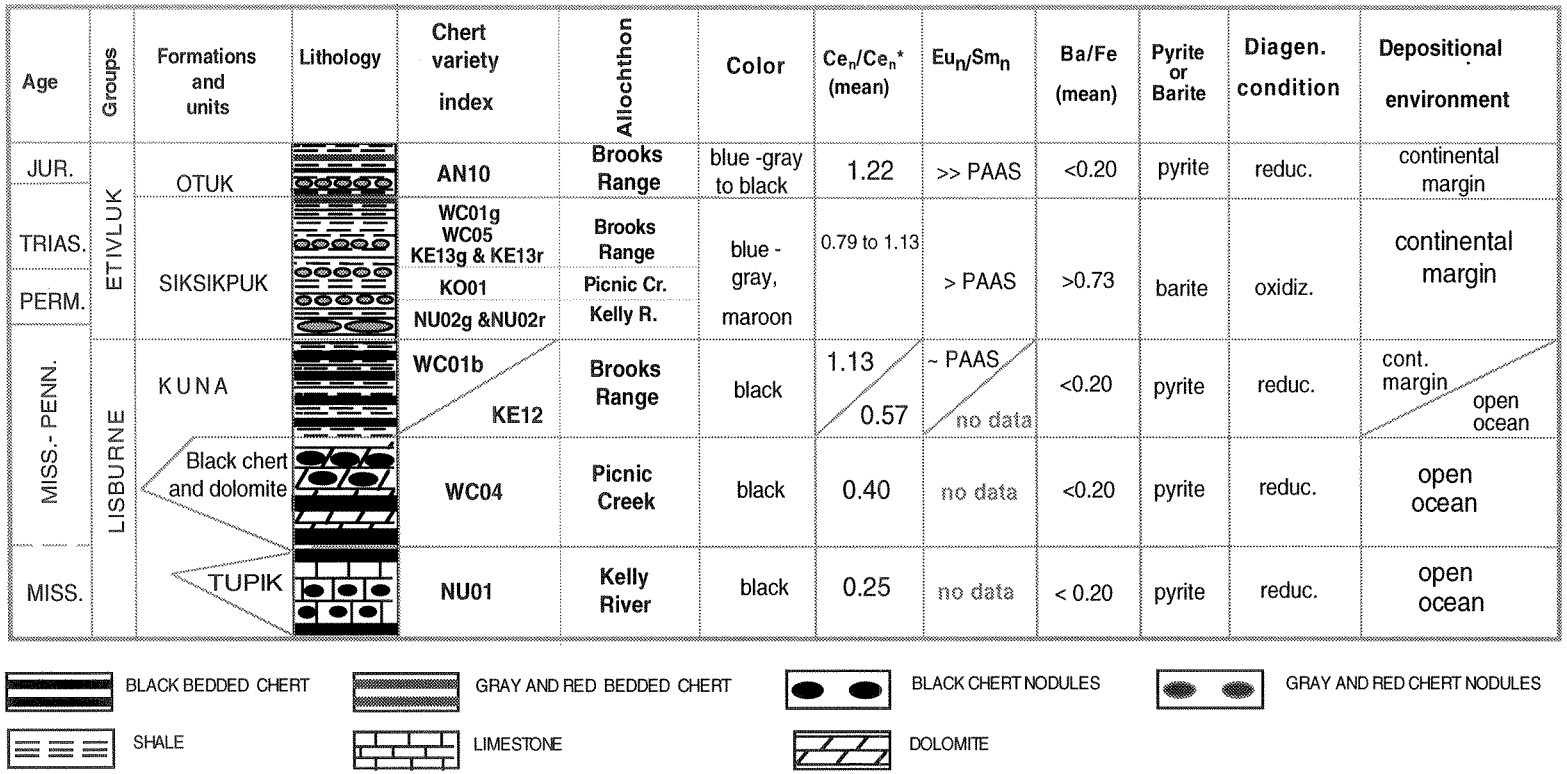


Figure 2. 12. Summary of main geochemical and mineralogical signatures and depositional environment of late early Mississippian -Jurassic chert deposits in the western Brooks Range, Alaska.

4. The significantly higher Eu_n/Sm_n values in Otuk chert relative to Siksikpuk cherts indicate that the continental margin environment of Etivluk cherts evolved from a provenance with no volcanic debris during Pennsylvanian to Triassic time to one with abundant volcanics during Jurassic time .

5. No correlation between Ce/Ce* patterns and diagenetic oxidizing-reducing patterns has been found in the late Paleozoic-middle Mesozoic cherts from the western Brooks Range.

CHAPTER THREE: GEOLOGICAL-GEOCHEMICAL APPROACH TO SOURCING OF PREHISTORIC CHERT ARTIFACTS, NORTHWESTERN ALASKA.

3.1. Abstract

This chapter discusses the geological-geochemical approach to prehistoric chert sourcing illustrated by a study conducted in northwestern Alaska. Two hundred eighty nine artifacts from 57 prehistoric sites were compared with 12 chert varieties sampled from 9 outcrops in the western Brooks Range. Correlation of each chert artifact with its chert source is based on the idea that both the artifact and outcrop have identical geologic history: depositional environment, provenance and diagenesis, that are characterized by unique geochemical and mineralogical signatures.

Data were obtained by instrumental neutron activation analysis, electron microprobe analysis, optical microscopy and hand specimen study. A regional geochemical-petrological database is constructed comprised of the most discriminating geochemical and petrological signatures for each chert outcrop variety. The database can then be used to compare any artifact from prehistoric sites located in the region to determine artifact source. Correlation of artifacts with outcrops is based on the superposition of artifact data on geochemical fields of outcrops obtained by descriptive statistics at one, two, and three standard deviations from the means. Four outcrops in the western Brooks Range were firmly correlated with 51 artifacts and determined as prehistoric chert quarries.

The geological-geochemical approach to prehistoric chert sourcing is applicable to any region.

3.2. Introduction

The sourcing of lithic materials has proved important in reconstructing interaction networks of prehistoric cultures (Luedtke, 1978, 1987, 1992, 1993a, 1995; Nagle et al., 1980; Nagle, 1980, 1984; Lech, 1983; Selivanona, 1984; Takacs-Biro, 1986; Andrefsky, 1994). Chert artifacts comprise an overwhelming majority of most of the prehistoric sites world wide. Correlation of artifacts by chert chemistry (fingerprinting), as well as the determination of the geological source for each artifact, can be crucial in identifying prehistoric inter-and intra-cultural contacts in some areas. In northwestern Alaska where most of the prehistoric sites are surficial, unstratified, and undated, chert artifacts are often the only surviving relics of prehistoric cultures (Fig. 3.1). Determining the distribution patterns of a variety of cherts sourced in the western Brooks Range prehistoric mining area and subsequently found as artifacts in archaeological sites located in Beringia can hopefully be used to decipher intergroup contacts and determine human migration patterns. The recognition of any foreign cherts within the archaeological sites provides evidence of large (possibly intra-continental) scale communication and will improve our understanding of the peopling of America.

Chert sourcing and fingerprinting is a complicated geochemical and mineralogical process. Because cherts have a characteristically uniform composition (up to 99% SiO_2), a monotonous structure (microcrystalline or cryptocrystalline quartz), and submicroscopic (10μ-100μ) mineral inclusions, the application of simple petrographic microscopy to correlation of chert samples does not normally work, except when cherts contain large (>~500μ) exotic mineral inclusions. Comparison of chert artifacts with chert sources based

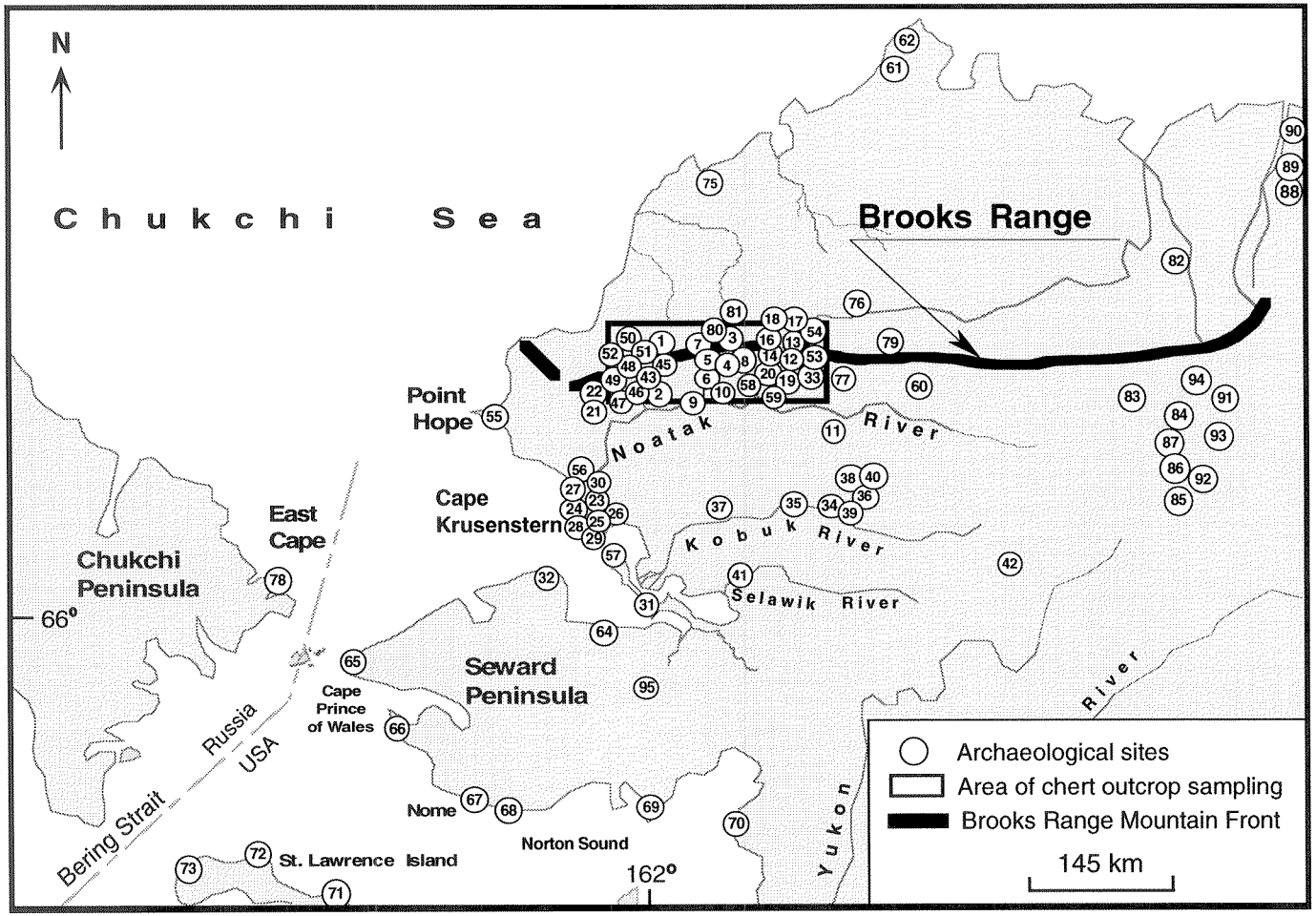

N
Chukchi Sea
Brooks Range
Point Hope
Noatak River
Cape Krusenstern
East Cape
Chukchi Peninsula
66°
Seward Peninsula
Cape Prince of Wales
Russia
USA
Bering Strait
Nome
Norton Sound
St. Lawrence Island
162°
Kobuk River
Selawik River
Yukon River
Archaeological sites
Area of chert outcrop sampling
Brooks Range Mountain Front
145 km

Figure 3.1

Figure 3.1. Map of study area and prehistoric sites (data from Solecki, 1951; Giddings, 1960; Anderson, 1970b, 1972, 1984; Hall and Mull, 1976; Stanford, 1976; Bockstoce, 1979; Giddings and Anderson, 1986, Gal, 1993, 1994).

Archaeological sites from which chert artifacts were analyzed: 1) Upper Kelly River quarry, 2) Kelly River chipping stations NKR-1; **Kugururok River sites**: 3) Upper Kugururok River quarry, 4) NKUR-1, 5) KU02, 6) KU03, 7) Kaguik (KO02), 8)NU03 (Noat-3062); **Noatak River sites**: 9) N-5, 10) NR-17, 11) NR-27; **Nimiuktuk River sites**: 12) Nim 5-1, 13) Nim-7, 14) Nim-11, 15) Nim-15, 16) -94108, 17) -94141, 18) -94127; **Anisak River sites:** 19) Anisak quarry, 20) AN08; 21) Red Dog Del-168, 22) Red Dog Del-166; **Cape Krusenstern sites**: 23) Battle Rock, 24) Palisades, 25) Lower Bench, 26) Sisualik, 27) Birnirk, 28) Ipiutak, 29) Denbigh, 30) Old Whaling; 31) Choris, 32) Cape Espenberg, 33) Burial Lake site; **Kobuk River basin sites**: 34) Onion Portage, 35) Atheut, 36) Lookout site on Knoll, 37) Kiana Bench, 38) High Old Bench, 39) Locality-2, 1963, 40) Ambler River site; 41) Selawik; 42) Lake Norotuk; **Saxsot Creek sites**: 43) Noat.-3006, 44) Noat.-3009, 45) Noat.- 3011; **Wrench Creek sites**: 46) Noat.-3014, 47) Noat.-3015, 48) Noat.-3018, 49) Noat.-3023, 50) Noat.-3024, 51) Noat.-3046, 52) Noat.-3047; **Nimiuktuk River sites**: 53) Picnic Creek site, 54) Setting Sun site; 55) Point Hope site, 56) Rabbit Creek site, 57) Kotzebue.

Archaeological sites from which chert artifacts were not analyzed: 58) Kugururok River chipping stations Kug-2 through Kug-5, 59) Noatak River chipping stations NR-9, -10, -14, 15, 19-23, 60) Punjik Point, 61) Coffin, 62) Walakpa, 63) Tugulak, 64) Deering, 65) Walles sites, 66) Point Spencer, 67) Cape Nome sites, 68) New Beach sites at Cape Nome, 69) Cape Darby, 70) Cape Denbigh sites, 71) Punic Island sites, 72) Kukulik Mound, 73) Gambell sites, 74) Indian Port, Siberia, 75) Tunalik, 76) Tukuto Lake, 77) Feniak Lake, 78) Uelen sites, 79) Mesa, 80) Kugururok (found by Lechenbruch), 81) Utukok River sites, 82) Itkillik River sites, 83) Natvakrunk Lake , 84) Franklin Bluff, 85) Kayuk, 86) Avingak, 87) Tuluak Lake, 88) Peters Lake, 89) Schreder Lake, 90) Katalaturuk, 91) Utu Lake, 92) Tuktu Lake, 93) Okiotak, 94) Kogruk, 95) Trail Creek caves.

on trace element composition and statistical treatment of analytical data is an established technique in western Europe (Aspinall and Feather, 1972; Sieveking et al., 1972), in central Russia (Selivanova and Galibin 1982, 1990; Selivanova, 1984, 1986), in Finland (Matiskainen et al., 1986), in New England, Pennsylvania and Michigan (Luedtke, 1987, 1992, 1993a), in Northern California (Kowalski and Schatzki, 1972) and in the central Great Plains of the United States (Hoard et al., 1992a, 1992b). However, these studies reveal methodological problems involved in correlation of artifacts with outcrops and point to the need of a rigorous, region-wide study of chert source rocks using geological approach (Sieveking et al., 1972, Luedtke, 1978, 1979, 1992, 1993b; Selivanova, 1984, 1986). For example, chemical variability within the chert sources requires proper sampling to characterize a chert source adequately (Selivanova, 1984; Luedtke, 1995). Also, some elements are far more diagnostic than others and assigning artifacts to sources based on equal treatment of all elements can lead to erroneous results (Luedtke, 1979).

This chapter focuses on the development of a geological-geochemical approach for sourcing of prehistoric chert artifact in northwestern Alaska (Fig. 3.1). Four tributaries (Kelly, Kugururok, Nimiuktuk and Anisak) of the Noatak River were chosen for the study because of extensive outcropping of chert and numerous quarrying sites. Construction of a regional geochemical-petrological database of chert outcrops is the corner stone of this approach and the database should be comprised of the most discriminating geochemical and petrological signatures for each chert outcrop variety. These parameters include: absolute element concentrations, elemental ratios including (but not limited to) Ce_n/Ce_n^*, Eu_n/Eu_n^* (or Eu_n/Sm_n) and Ba/Fe, mineral inclusions, such as barite and pyrite, and physical properties such as color. These signatures are truly geochemical (not only chemical) indicating the

affiliation of a particular chert source to a specific stratigraphic unit characterized by a specific provenance, depositional environment and diagenetic conditions. Artifact-outcrop correlation, based on geochemical-mineralogical signatures, implies similar geological conditions of formation for both artifact chert and outcrop chert, and thus, avoids mistaken identity based on a relatively limited comparison using bulk chemistry alone.

The objectives of the chapter are to describe the geological-geochemical approach to the sourcing of prehistoric cherts and to demonstrate the application of the technique to prehistoric chert artifacts in northwestern Alaska. Specifically, I will attempt to determine the prehistoric chert sources in the western Brooks Range (Kelly, Kugururok and Anisak River basins), as well as distribution patterns of mined varieties from several northwestern Alaska prehistoric sites.

3.3. Archaeological Background

Northwestern Alaska represents the easternmost portion of Beringia and is the most plausible migration route for humans from Asia to North America (Fig. 3.1). Many prehistoric sites dated from 10,000 B.P. to Recent occur in this region (Giddings,1960; Anderson, 1970a, 1970b, 1972, 1984, 1988; Hall, 1975; Bockstoce, 1979; Gal, 1982; Gerlach and Hall, 1986; Giddings and Anderson, 1986). Most of sites are surficial and contain mixed prehistoric complexes from the oldest American Paleo-Arctic Tradition to Northern Maritime Tradition and are represented by chert artifacts that vary in color: black, gray, light gray, blue gray, red and maroon. Dating by radiocarbon is seldom possible because of a lack of organic material and the complicated stratigraphy in multilayered sites that are commonly affected by both cryoturbation and bioturbation.

The Seward Peninsula, the Kobuk and Noatak River basins were the locus of major

interior routes across northwestern Alaska and possibly, intra-continental east-west routes (the Seward Peninsula). However, no tool quality chert sources are available on the Peninsula, nor in the Kobuk basin, whereas the Noatak basin (particularly in the northern part of Brooks Range) is rich in chert bearing formations (Fig. 3.1). Many chert chipping stations and a few large workshops are closely associated with chert outcrops indicating that the western Brooks Range was a prehistoric mining area (Anderson, 1972; Hall and Mull 1976; Malyk-Selivanova and Ashley, 1994; Malyk-Selivanova et al., 1996).

3.4. Geologic Framework

Tool-quality chert deposits in northwestern Alaska crop out along the west-east front of the Brooks Range (Fig. 3.1). They are represented in the western Brooks Range by eight map units (Mayfield et al., 1984; Curtis et al., 1984, 1990; Ellersieck et al., 1990) that are likely facies variations of four chert-bearing formations of upper Mississippian to early Jurassic age: the Tupik and Kuna Formations of the Lisburne Group (Mississippian - Pennsylvanian), and the Siksikpuk and Otuk Formations of the Etivluk Group (Pennsylvanian-Jurassic) (Fig. 3.2). These sediments are part of the Devonian to Jurassic age sequences deposited in a basin located to the south of the modern Brooks Range. The basin was formed as a result of the late Jurassic to early Cretaceous collision of North America continental plate with the oceanic plate. During the collision, these sediments were obducted, imbricated and telescoped by numerous thrust sheets with a combined displacement measured in hundreds of kilometers (Churkin et al., 1979; Mull et al., 1982; Mayfield et al., 1983, 1988; Ellersieck et al., 1983, 1990; Box, 1985; Churkin, 1985; Howell, 1989; Mull 1989; Karl, 1989; Karl et al., 1989; Worrall, 1991; Moore et al., 1994; Curtis et al., 1990). Thrusting fortuitously stacked chert-bearing formations that expose sequences

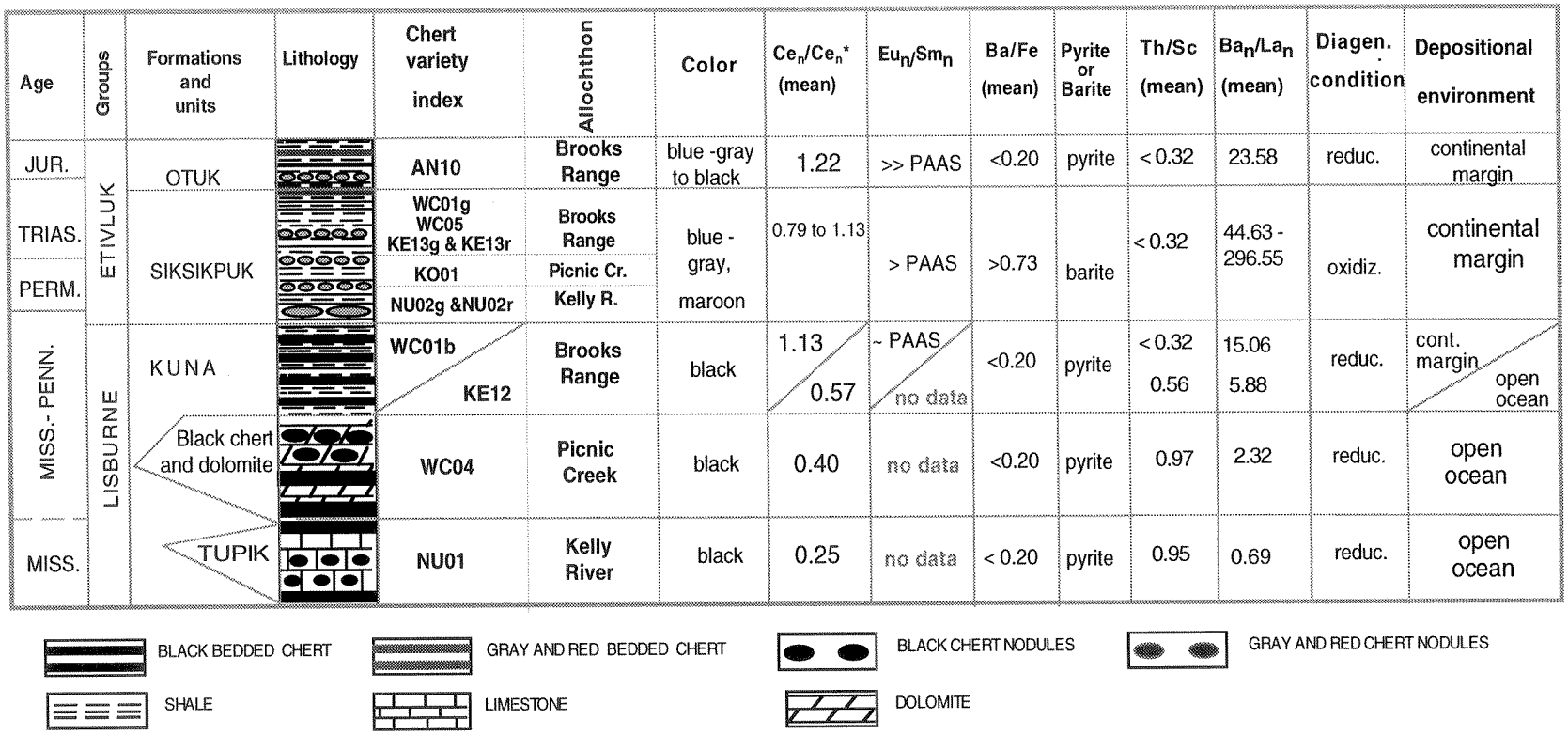


Figure 3.2. Summary of stratigraphy, geochemistry and petrology of late early Mississippian to Jurassic chert deposits in the western Brooks Range. The stratigraphic nomeclature was taken from U.S.G.S. maps and Open file Reports (Mayfield et al., 1983, 1984; Curtis et al., 1983, 1984, 1990; Ellersieck et al., 1983, 1990) Black Chert and Dolomite unit is equivalent to Akmak chert by Mull et al., 1989. PAAS (post -Archean Australian shale) is used as a reference for the average composition of the upper continental crust.

of different ages and lithologies in close proximity to each other. As a result, chert outcrops in the western Brooks Range provide distinctive geochemical signatures and an excellent opportunity for testing the geological-geochemical approach to chert sourcing. Figure 3.2 depicts a summary of stratigraphy, as well as the main geochemical and mineralogical signatures and their implications for chert-bearing deposits in the region.

3.5. The Geological-Geochemical Approach to Chert Sourcing

The research plan (Fig. 3.3) includes: 1) detailed geological sampling of chert outcrops (including chert varieties within outcrops) in the study area, as well as chert artifact sampling in prehistoric collections, 2) analysis of artifact and outcrop samples by instrumental neutron activation analysis (INAA) for detection of trace element concentrations and electron microprobe analysis (EMPA) combined with X-Ray diffraction (XRD) for determination of mineral inclusions, 3) construction of a database of chert outcrops consisting of the most discriminating geochemical and mineralogical characteristics for each variety in order to clearly separate chert varieties from each other, and 4) a comparison of geochemical and mineralogical signatures of each artifact with each chert outcrop variety using diagrams showing intervals of signature variability, bivariate diagrams, and descriptive statistics.

3.5.1. Sampling

3.5.1.1. Outcrops. Based on U.S.G.S. geological maps, northern tributaries of Noatak River were targeted for chert outcrop sampling because of abundant Lisburne and Etivluk chert exposures and many associated prehistoric chipping stations. More than fifty chert outcrops of different chert quality were sampled. Nine of them characterized with tool quality chert were chosen for the detailed analytical study (Fig. 3.4). We use "chert variety" to refer to

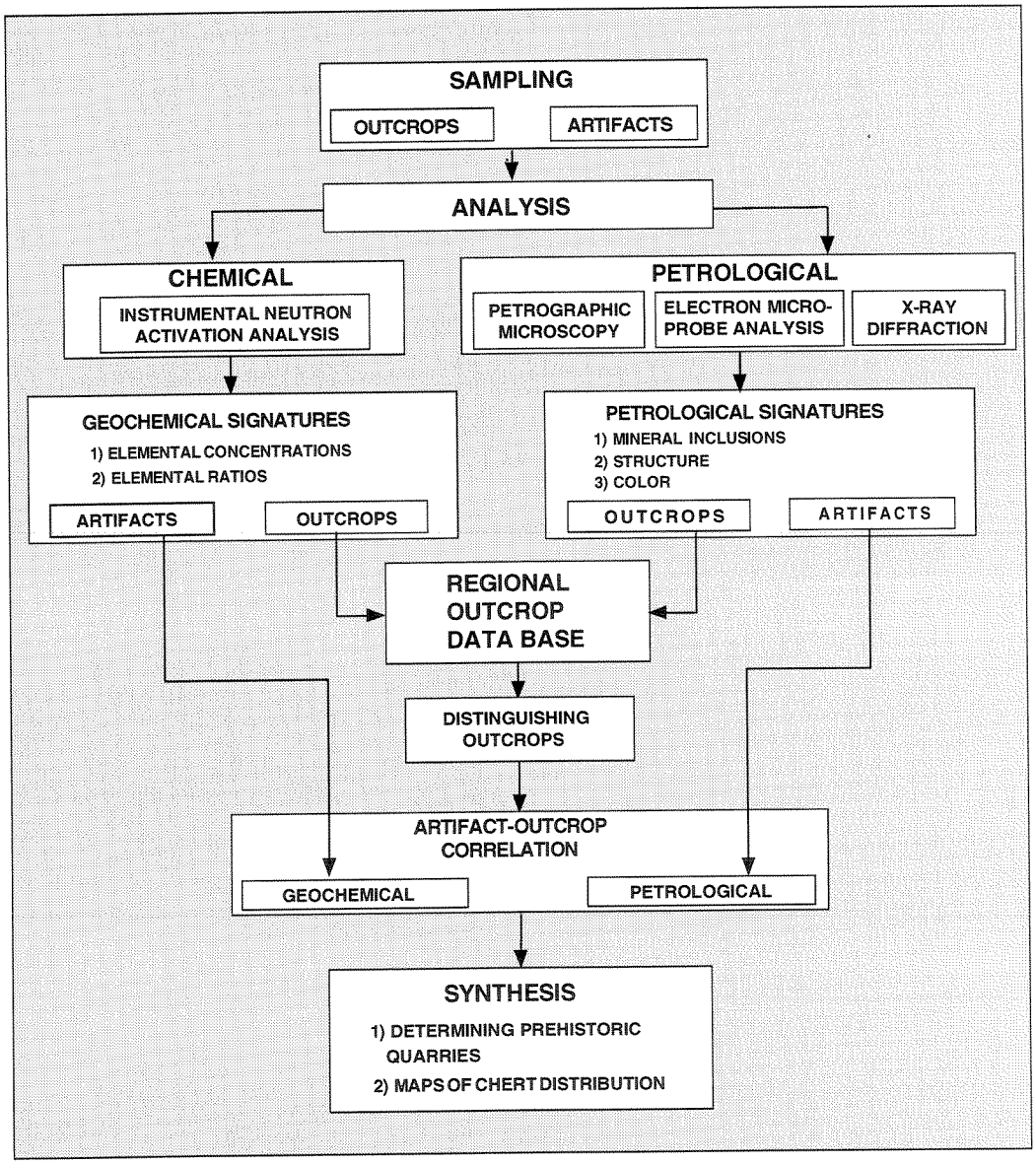


Figure 3.3. Research plan

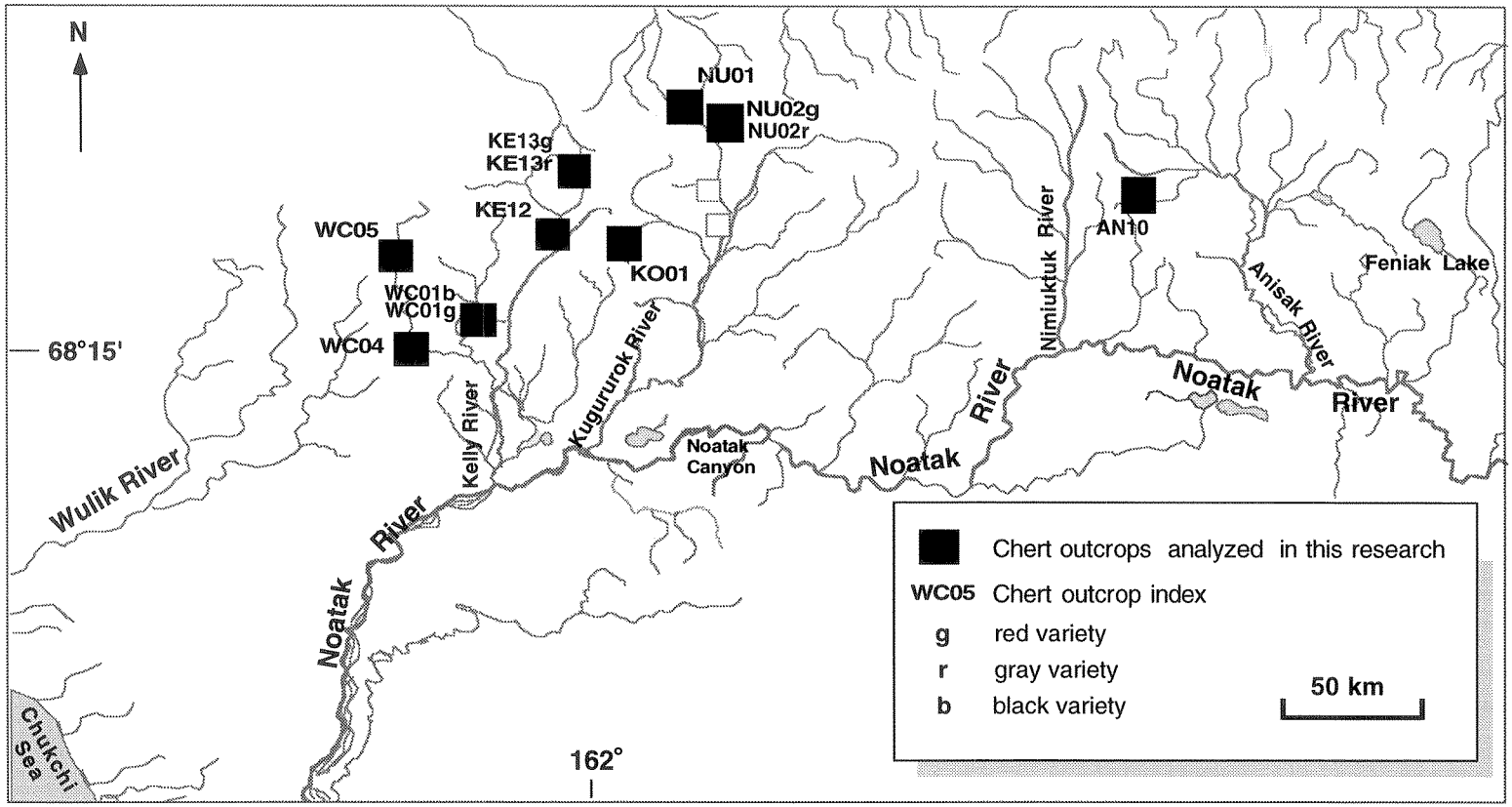


Figure 3. 4 . Map of chert outcrops studied in Kelly, Kugururok and Anisak River basins, western Brooks Range, Alaska.

a chert layer or chain of nodules or lenses. As three outcrops contain two chert varieties each, a total of twelve chert varieties were sampled and analyzed. Four of these varieties (NU01, WC04, KE12 and WC01b) are black vitreous Lisburne cherts, and eight others (WC01g, WC05, KO01, KE13g, KE13r, NU02g and NU02r) are red, maroon, gray and blue-gray Etivluk cherts (Fig. 3.2). Indexes containing letters indicate color chert varieties sampled in the same outcrop (b=black, g=gray, and r=red).

Because of typically high chemical and petrological variability between and within chert layers, nodule chains, and even within a single nodule (Luedtke, 1978, 1979; Selivanova, 1984) fifteen or more samples were collected from each variety along strike in order to obtain representative geochemical-petrological characteristics. A total of 201 samples from twelve chert varieties were collected to create a primary outcrop database. Three outcrops are closely associated with large prehistoric workshops and clearly were prehistoric chert quarries: Upper Kelly River (outcrop KE13, red and gray), Upper Kugururok River (outcrop NU02, red and gray) and Anisak (outcrop AN10).

3.5.1.2. Prehistoric Artifacts. A total of 289 artifacts (mostly flakes) from the 57 northwestern Alaskan prehistoric sites were sampled: 196 from museum collections (Haffenreffer Museum at Brown University and University of Alaska Museum, Fairbanks) and 95 from prehistoric sites in the study area during the archaeological survey conducted simultaneously with outcrop sampling. Of the 289 total artifacts analyzed, 37 prehistoric flakes sampled from three workshops found in close association with KE13 (red and gray), NU02 (red and gray), and AN10 chert outcrops were considered as quarry artifacts.

The selection of chert artifacts for analysis was based on visible differences in color and texture of chert varieties in the assemblage. In unstratified sites, all colored varieties of

cherts were sampled regardless of typology. In the stratified site, Onion Portage, all colored varieties of cherts were sampled from each cultural complex and assemblage. In all cases, the inner, unaltered (unweathered and unpatinized) parts of artifacts were selected for chemical analysis and thin sections.

3.5.2. Analysis.

Outcrop samples from twelve chert varieties and artifacts sampled from 55 prehistoric sites in northwestern Alaska were analyzed by INAA at the Missouri University Research Reactor (MURR) to determine chemical composition. Full details of INAA procedure of chert samples at MURR are given in Chapter 2.

Thirty one thin sections of outcrop samples and 26 thin sections of artifacts (all are splits of INAA samples) were studied by petrographic microscopy and by EMPA. Nine of them (outcrop samples only) were analyzed by XRD at Rutgers University to determine mineralogical inclusions and mineral phase relationships. Seven outcrop samples were analyzed for organic carbon concentrations at LECO Corporation using a CR412 analyzer (820 Commonwealth Drive, Warrendale, PA).

3.5.3. Data processing

3.5.3.1. Computer. The Axum technical graphics and data analysis program (Mathsoft Inc., 101 Main Street, Cambridge, MA) was used for construction of diagrams showing intervals of variability of signatures. The Gauss-386i VM (vers. 3.2.13) program was used for constructing geochemical fields at three, two and one standard deviations for each chert outcrop variety, as well as for the superposition of artifact data on those fields. FoxPro for Windows version 2.5 (1989-1993 Microsoft Corporation) was used as a complimentary database program to the Gauss program. Combining 1, 2 and 3σ geochemical fields on the

same graph was done with Coreldraw graphic program (Corel Corporation, 1600 Carling Avenue, Ontario, Canada) by overlapping binary plots imported from the Gauss program.

3.5.3.2. Distinguishing Chert Outcrops. The procedure of distinguishing chert outcrop varieties from each other included obtaining the intervals of signature variability and bivariate plots that provided maximum separation between chert varieties. The limits of the intervals of variability and the geochemical fields on bivariate plots for each variety were determined by descriptive statistics based on one, two and three standard deviations from the means. Three standard deviation intervals (Fig. 3.5a) and fields (Fig. 3.5b) on diagrams were considered as areas of geochemical variability within chert varieties.

Rare earth element (REE) absolute abundances were normalized to the average Post Archean Australian Shale (PAAS) (Taylor and McLennan, 1985). Ce anomalies were calculated from $Ce_n/Ce_n^* = (Ce_{sample}/Ce_{PAAS}) / Ce_n^* = 3(Ce_{sample}/Ce_{PAAS}) / 2(La_{sample}/La_{PAAS} + Nd_{sample}/Nd_{PAAS})$ (German and Elderfield, 1990 and references therein).

3.5.3.3. Correlation of Chert Artifacts with Chert Outcrops. All artifacts analyzed were divided into three main groups according to their color (black, gray and red) to be compared with outcrops of appropriate color. Within these color groups, artifacts were divided into subgroups to assure legible plots. Subgroups included twenty-two artifacts from the prehistoric sites located in the same part of northwestern Alaska.

The correlation of artifacts with outcrops was done by an iterative process of sequentially plotting each artifact subgroup on both range of variability diagrams and bivariate diagrams that yielded the maximum separation of outcrops. The superposition of the artifact data on geochemical fields of outcrops reveals which artifact and which outcrop have similar compositions. Artifacts falling into the three, two or one standard deviation

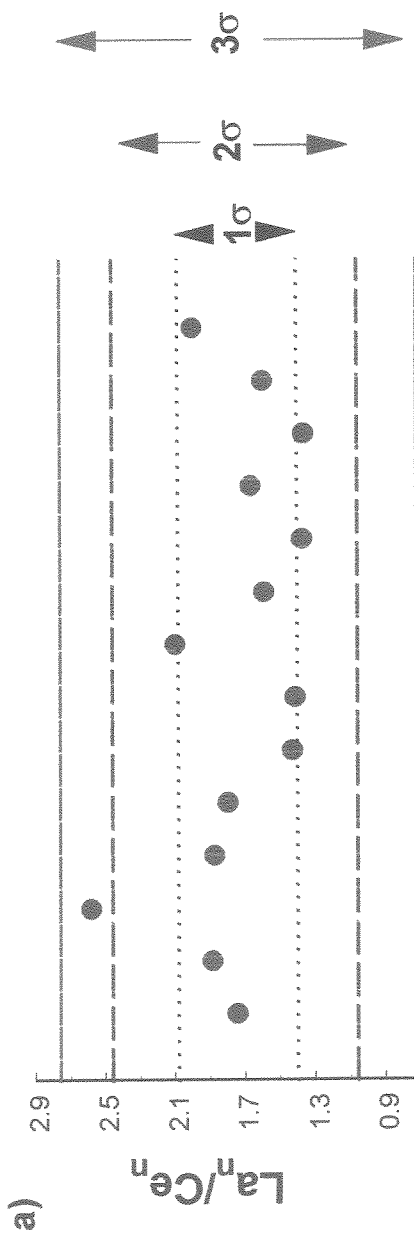


Figure 3.5a. An example of geochemical variability of La_n/Ce_n within chert variety KE12 determined by error bars at one, two and three standard deviations.

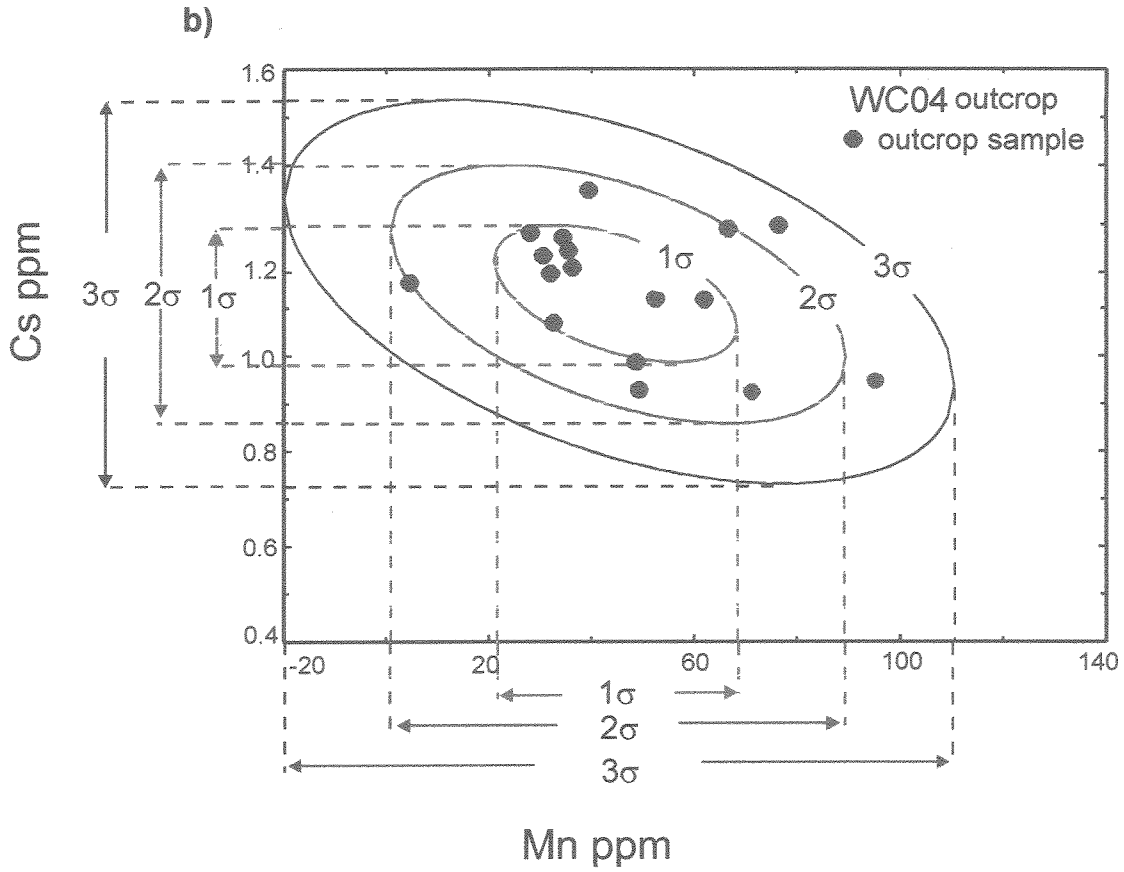


Figure 3. 5b. An example of geochemical variability within chert varieties: geochemical fields at one, two and three standard deviations on Mn vs. Cs bivariate diagram.

fields of the outcrop were considered geochemically identical to this outcrop. If outcrop fields overlap, and an artifact falls into this overlapping area, other combinations of elements were compared until a one-on-one correlation was made (i.e. a perfect match). In some cases it is impossible to avoid the overlapping of fields at three or even at two standard deviations. Two and one standard deviation fields, respectively, were then used for assigning artifacts to an outcrop. No direct correlations can be made for artifacts that consistently occur within 3σ, 2σ and 1σ overlapping areas.

3.6. Results

3.6.1. Distinguishing Outcrop Chert Varieties

The twelve outcrop chert varieties studied can be divided into three main groups by visual petrological characteristics: black glassy cherts (Tupik and Kuna Formations of Lisburne Group and black zones from mottled nodules of Otuk Formation, Etivluk Group), glassy blue-gray to dark-gray cherts (Siksikpuk and Otuk Formations of Etivluk Group), glassy red to maroon cherts (Siksikpuk Formation of Etivluk Group) (Fig. 3.2).

3.6.1.1. Mineralogical signatures. Using mineral composition, all twelve varieties can be placed into two groups: barite-bearing cherts and pyrite-bearing cherts.

Black cherts of all formations of Lisburne Group, as well as dark gray and black mottled cherts of Otuk Formation are pyrite bearing (Fig. 3.2). Both black and gray zones of Otuk (AN10) chert variety contain pyrite inclusions (up to 1-3 mm) that are often visible in hand specimens. Variation in organic carbon concentrations was the only chemical difference that was found between black and gray zones with the black zone being significantly enriched in organic carbon compared to the blue-gray zone. In the black zone $C_{organic}$ %= 0.61, whereas in the gray zone $C_{organic}$ %=0.01.

All gray and red varieties of Siksikpuk Formation are barite-bearing indicating their oxidizing diagenetic conditions (Fig. 2.4). Single pyrite inclusions detected in some of Siksikpuk cherts reflect local reducing conditions. Hematite inclusions are characteristic of red-maroon varieties of Siksikpuk Formation (KE13r and NU02r) and are not characteristic of gray varieties.

3.6.1.2. Geochemical signatures. Geochemical signatures (Appendix I.2 and I.3) clearly separate stratigraphic groups, formations within each group, specific outcrops, and color varieties within the outcrops. Negative Ce anomalies (as well as La_n/Ce_n >1) are characteristic for three (of four) Lisburne chert varieties, NU01, WC04 and KE12, and separate them from the rest of the studied varieties that have either no or positive Ce anomalies (Fig. 3.6a,b). Lisburne chert varieties are distinguishable from Etivluk varieties by higher U/Th values (Fig. 3.6c). High Ba/Al values are characteristic of Siksikpuk Formation (Fig. 3.6d). Eu_n/Sm_n and Rb/Sr values clearly discriminate gray Otuk cherts from Siksikpuk cherts (Fig. 3.6e,f).

Within the Lisburne Group, NU01 , WC04, KE12 and WC01b outcrops are clearly separated from each other by U/Th, Ce_n/Ce_n* and La_n/Ce_n at 1 standard deviation (1σ) (Fig. 3.6 a,b,c), as well as by geochemical fields at 3σ on numerous bivariate plots (Fig. 3.7 a,b). The WC01b Lisburne variety clearly differs from three other Lisburne cherts by a positive Ce anomaly and higher Ba values (Figs 3.6a, 3.7b,c).

Black zones in mottled gray-black nodules of AN10 outcrop, Otuk Formation of Etivluk Group can be unequivocally separated from three black Lisburne cherts (NU01, WC04 and KE12) by positive Ce anomalies (Fig. 3.6a,b) and higher Ba values (Fig. 3.7c). They can be separated from WC01b (the fourth Lisburne chert that has positive a Ce

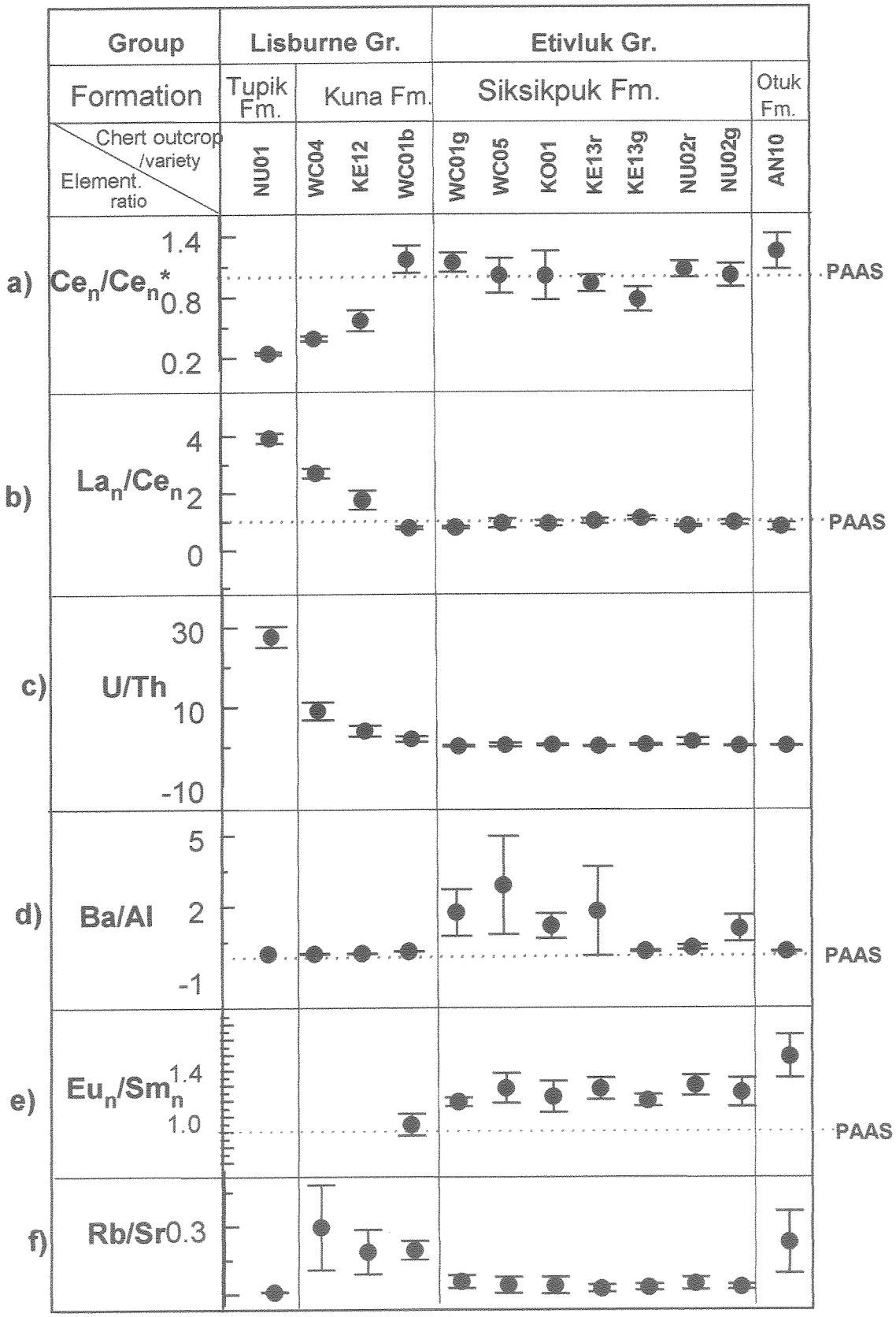

Group
Lisburne Gr.
Etivluk Gr.
Formation
Tupik Fm.
Kuna Fm.
Siksikpuk Fm.
Otuk Fm.
Chert outcrop /variety
Element. ratio
NU01
WC04
KE12
WC01b
WC01g
WC05
KO01
KE13r
KE13g
NU02r
NU02g
AN10
a)
Ce_n/Ce_n*
1.4
0.8
0.2
PAAS
b)
La_n/Ce_n
4
2
0
PAAS
c)
U/Th
30
10
-10
d)
Ba/Al
5
2
-1
PAAS
e)
Eu_n/Sm_n
1.4
1.0
PAAS
f)
Rb/Sr
0.3

Figure 3.6.

Figure 3.6. Separation of cherts from stratigraphic groups and formations in the western Brooks Range by series of diagrams showing intervals of elemental ratio variability at one standard deviation from the mean. "n" symbolizes normalization to PAAS (Taylor and McLennan, 1985).

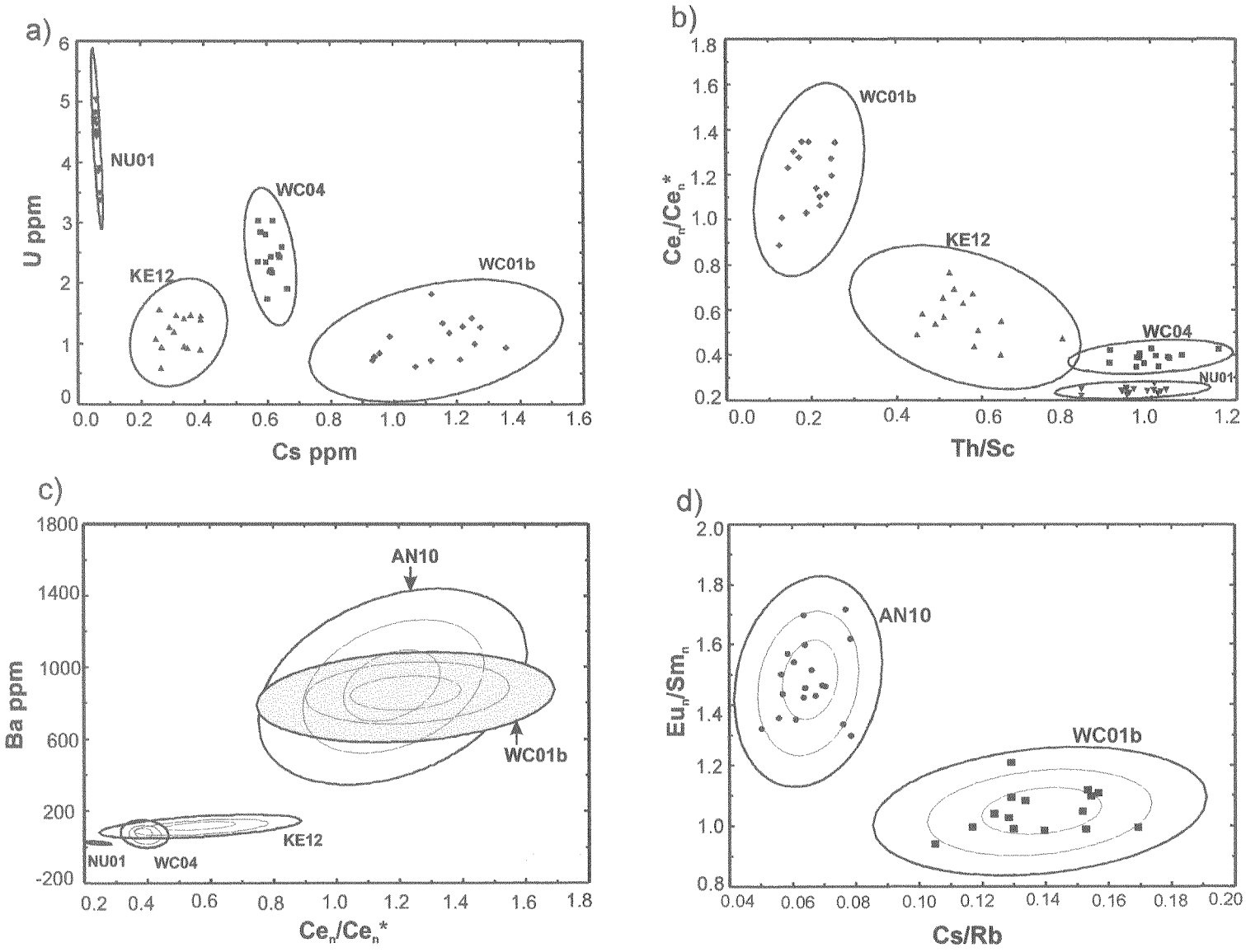


Figure 3. 7a,b,c,d.

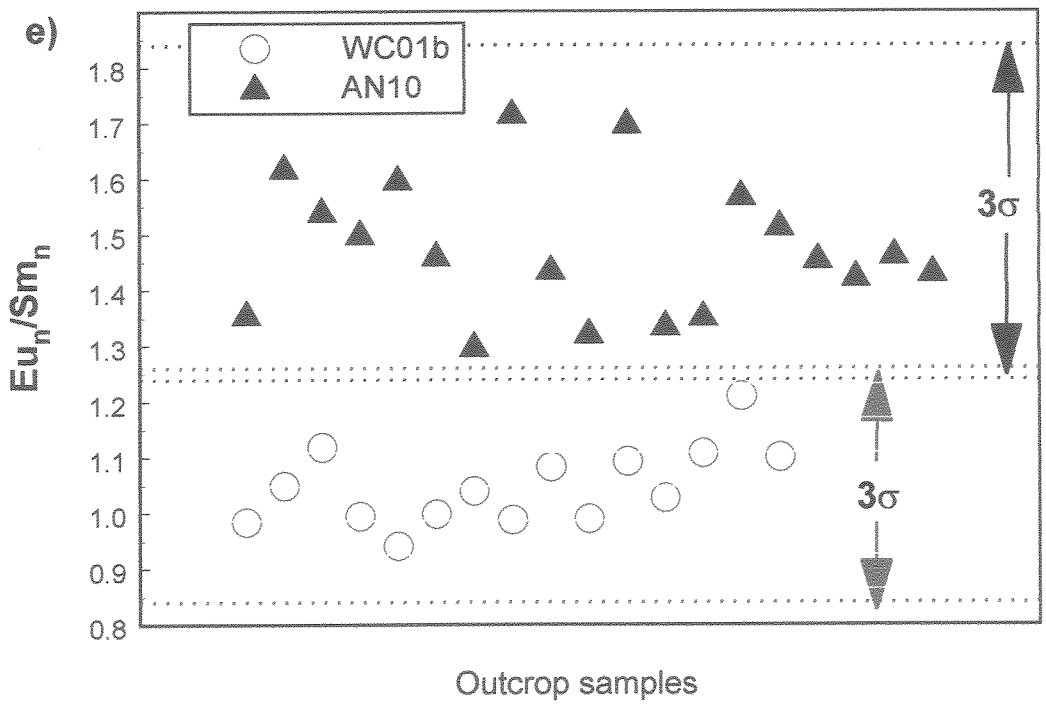

e)
WC01b
AN10
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
Eu$_n$/Sm$_n$
3σ
3σ
Outcrop samples

Figure 3.7e.

Figure 3.7. Separation of black chert varieties: (a) and (b) - discrimination of Lisburne chert varieties; (c) - separation of Otuk and WC01b black cherts from the rest of Lisburne varieties by higher Ce/Ce* (positive Ce anomalies) and Ba values indicating different depositional environment and provenance, respectively; (d) and (e) - distinguishing of WC01b black Lisburne variety from black zones in mottled nodules of AN10 Etivluk variety: the insignificant overlapping of 3σ intervals for Eu_n/Sm_n occurs measured as large as 0.02.

anomaly) by higher Eu_n/Sm_n values (Figs. 3.6e and 3.7d,e).

Gray chert varieties of Siksikpuk Formation (Etivluk Group) are geochemically close to each other, thus producing overlapping geochemical fields. However, the progressive signature-by-signature selection of binary plots made it possible eventually to separate each chert variety from other varieties of Siksikpuk Formation. Some varieties were separated at 3σ, and some ones were discriminated at 2σ (Fig.3.8a,b,c,d).

The gray chert variety of Otuk Formation (AN10) differs from gray Siksikpuk cherts by higher Eu_n/Sm_n values (Fig.3.6e) and by Ba/Fe values: pyrite-bearing Otuk chert has much lower Ba/Fe values than the characteristically barite-bearing Siksikpuk cherts.

Red-maroon chert varieties of Siksikpuk Formation, KE13R and NU02r, can be separated at 3σ by numerous binary diagrams such as one on the Figure 3.8f.

3.6.2. Quarry Geochemical Fields

Those outcrops which were immediately adjacent to prehistoric workshop sites and thus considered as prehistoric quarries provided a unique opportunity to determine chemical and mineralogical variability between prehistoric artifacts and their known sources.

Three outcrops (KE13r,g, NU02r,g and AN10) are associated with large prehistoric workshops containing prehistoric chert flakes that are visually similar to outcrop cherts. Geochemical similarity of some these flakes with the adjacent outcrop chert supports the interpretation that these outcrops were prehistoric chert quarries: Upper Kelly River, Upper Kugururok River and Anisak quarries. To obtain geochemical fields showing the realistic range of the variability of chert mined in each quarry, I combined data of both the chert layers sampled in the quarry and prehistoric flakes found on it. These fields turned out to have a larger spread of data than those obtained for the outcrop layer fields alone. I named

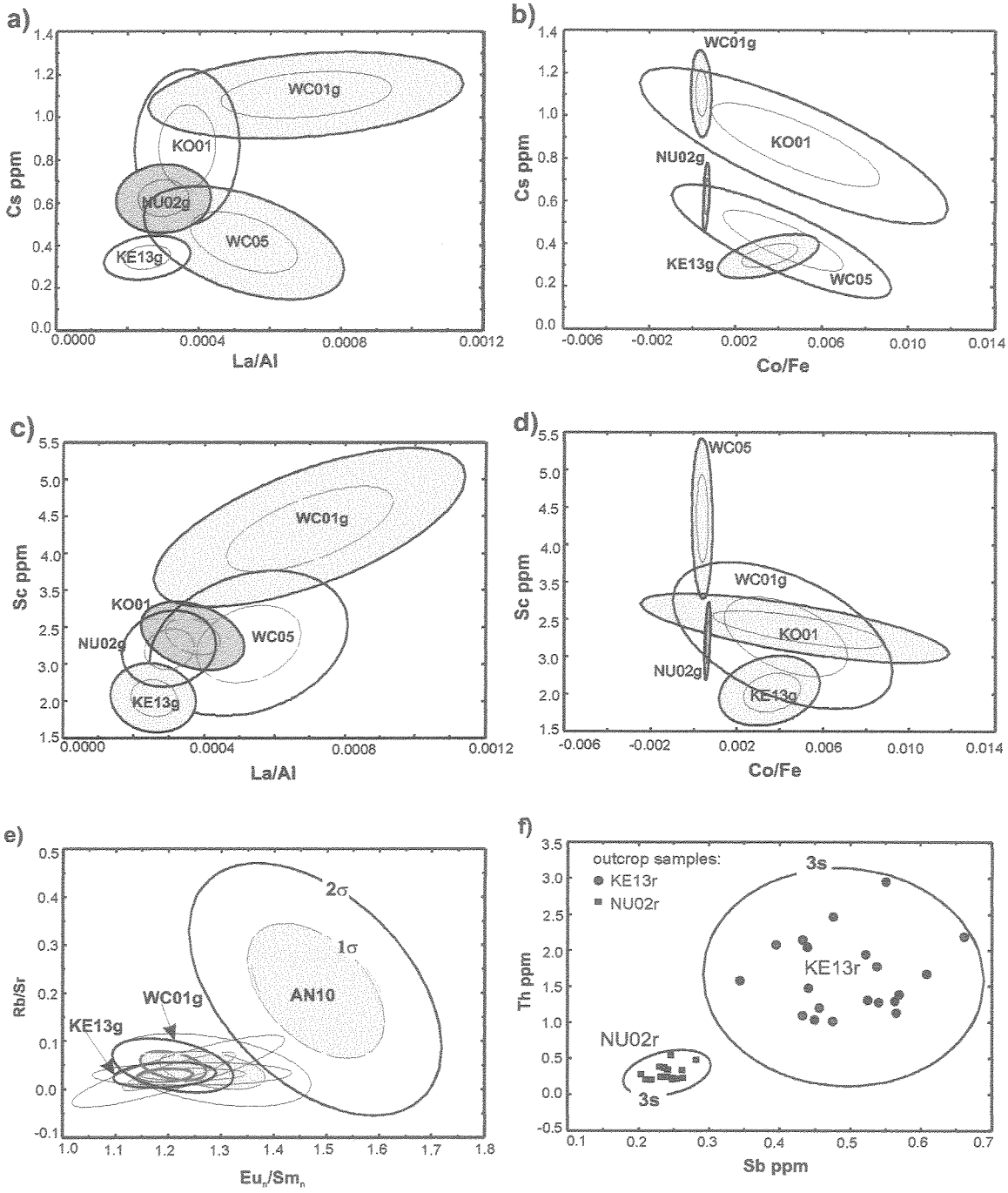

a)
Cs ppm
La/Al
WC01g
KO01
NU02g
WC05
KE13g
b)
Cs ppm
Co/Fe
WC01g
KO01
NU02g
KE13g
WC05
c)
Sc ppm
La/Al
WC01g
KO01
NU02g
WC05
KE13g
d)
Sc ppm
Co/Fe
WC05
WC01g
KO01
NU02g
KE13g
e)
Rb/Sr
Eu$_n$/Sm$_n$
2σ
1σ
AN10
WC01g
KE13g
f)
Th ppm
Sb ppm
outcrop samples:
KE13r
NU02r
3s
KE13r
NU02r
3s

Figure 3.8.

Figure 3.8. Separation of gray (a,b,c,d,e) and red (f) chert varieties of Etivluk Group by geochemical fields. Plots (a), (b), (c), and (d) show step by step discrimination of gray Siksikpuk chert varieties from each other at two standard deviations: (a) - separation of WC01g variety from all varieties but KO01 variety by the Co/Fe vs. Cs bivariate diagram, (b) - discrimination between KO01 and all the varieties but WC01g, as well as separation between KE13g and NU02g, (c) - separation of WC01g from KO01; and (d) - separation of WC05 from both KE13g and NU02g; (e) - separation of AN10 Otuk variety from Siksikpuk varieties at two and one standard deviations. Shaded patterns are used to indicate different fields.

these fields *quarry geochemical fields* and use them for correlation of Upper Kelly River, Upper Kugururok River, and Anisak quarries with those red and gray artifacts mined in unknown sources (Fig. 3.9, Appendix I.4).

3.6.3. Correlation of Artifacts with Outcrops

A total of 289 chert artifacts from 57 prehistoric sites of northwestern Alaska (Appendix I.1) were divided into three main color groups (black, red and gray) and compared with appropriately colored chert varieties from nine outcrops using geochemistry. The artifact signatures were superposed on geochemical outcrop fields on bivariate diagrams. Of 289 artifacts analyzed, 37 artifacts were from quarry workshops. These were used separately to construct the quarry geochemical fields and were excluded from the correlation. Two hundred fifty two artifacts were compared with twelve chert varieties. Chemical compositions and geochemical signatures of 289 artifacts are given in Appendix I.2 and diagrams illustrating the artifact-outcrop correlations are in Appendix III. Twenty percent of the artifacts (51 samples) were identified: 33 artifacts were correlated with certain outcrops at 3σ confidence, and 18 artifacts were correlated with two possible sources. No sources were identified for 201 artifacts. Of nine outcrops studied in the western Brooks Range, four were determined as prehistoric chert quarries: Wrench Creek quarry (WC04 outcrop), Upper Kelly River quarry (KE13 outcrop), Upper Kugururok River quarry (NU02 outcrop) and Anisak quarry (AN10 outcrop).

3.6.3.1. Black Artifacts. All black artifacts were compared with four black Lisburne chert varieties NU01, WC04, KE12 and WC01b by signatures developed by combination of 37 elements and elemental ratios (Table 3.I). Black artifacts were also compared to AN10 chert of the Otuk Formation which has characteristic black zones and thus might be a source

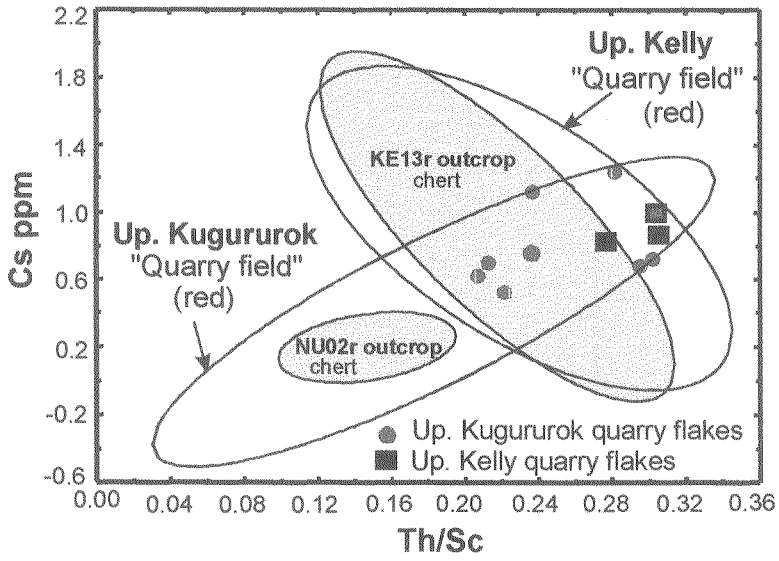


Figure 3.9. Geochemical fields of Upper Kelly River and Upper Kugururok River quarries (at 3σ) obtained by combining outcrop and artifact samples from quarries. These fields are larger than those (shaded) obtained for outcrop samples only.

Table 3.I. Elements and elemental ratios used for correlation of chert artifacts with outcrop chert varieties

1) Elements and elemental ratios used for correlation of black chert artifacts with black cherts of Lisburne Group (NU01, WC04, KE12, WC01b) and Otuk Formation of Etivluk Group (AN10): La, Ce, Nd, Eu, Tb, Dy, Yb, Lu, Ba, U, Co, Cr, Cs, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Th, Zn, Al, Ca, K, Mn, Na, V, Fe/Al, Th/Sc, Ba/Fe, Rb/Sr, La/Al, La/Yb, Ce/Ce*, La/Ce.
2) Elements and elemental ratios used for correlation of gray chert artifacts with gray chert varieties of Etivluk Group (WC01g, WC05, KO01, KE13g, NU02g, AN10): La, Ce, Nd, Eu, Sm, Dy, Yb, Lu, Ba, Co, Cr, Cs, Fe, Hf, Rb, Sb, Sc, Sr, Th, Al,, Mn, V, Ba/Al, Fe/Al, Th/Sc, Ba/Fe, Rb/Sr, Fe/Mn, Mn/Al, Co/Fe, Co/Al, Cs/Mn, Cs/Co, Cs/Rb, La/Al, La/Yb, Eu/Sm, Ce/Ce*, La/Ce.
3) Elements and elemental ratios used for correlation of red chert artifacts with red chert of Siksikpuk Formation (KE13r, NU02g): La, Ce, Nd, Eu, Sm, Dy, Tb, Yb, Lu, Ba, Co, Cr, Cs, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Th, Zn, Al, Ca, K, Mn, Na, V, Ba/Al, Fe/Al, Th/Sc, Ba/Fe, Rb/Sr, Fe/Mn, La/Al, La/Yb, Eu/Sm, Ce/Ce*, La/Ce.

of black artifacts.

Of the 106 artifacts, 14 artifacts are geochemically identical with the WC04 outcrop. The other 92 black artifacts could not be correlated with any studied black Lisburne chert outcrops. The correlation of black artifacts was a relatively easy procedure because clear separation between 3σ geochemical fields was obtained for Lisburne chert varieties (Fig. 3.10 a,b).

3.6.3.2. Gray Artifacts. A total of 120 gray artifacts of unknown geological sources were compared with six gray varieties of Etivluk cherts using geochemical signatures developed by combination of thirty-nine elements and elemental ratios (Table 3.I). Because the fields of Etivluk chert varieties overlap, the procedure of progressive selection of outcrop geochemical fields was applied. Artifacts that systematically fall into the fields of the same outcrops were assigned to those outcrops (Fig. 3.10c). Artifacts that did not occur within the field of the same outcrop consistently (i.e. plot sometimes outside the field or in another field) were termed "unsourced".

Six gray artifacts demonstrate strong correlation with Anisak quarry, seven artifacts with Upper Kelly River quarry and two artifacts with Upper Kugururok River quarry. Ten artifacts were correlated with both Upper Kelly River and Upper Kugururok River quarries at equal confidence because they consistently plotted into overlapping 3σ areas. No artifacts were correlated with KO01, WC01g and WC05 outcrops.

3.6.3.3. Red Artifacts. Comparison of twenty six red-maroon prehistoric artifacts with two red chert varieties from Upper Kelly River and Upper Kugururok River quarries was based on geochemical signatures developed by combination of forty elements and elemental ratios (Table 3.I). Nine artifacts were assigned to a red variety of Upper Kelly River quarry and

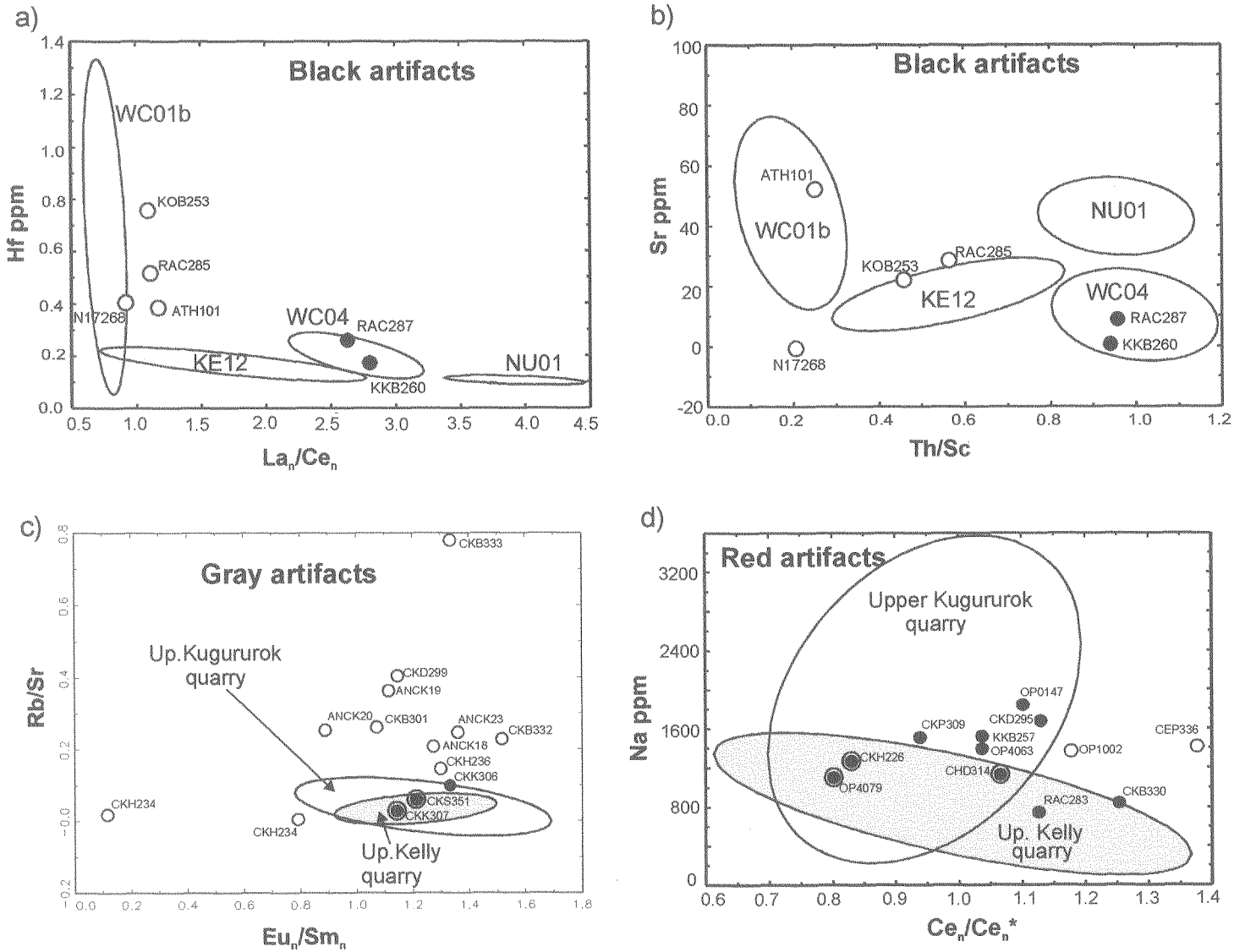

a)
Black artifacts
WC01b
KOB253
RAC285
ATH101
N17268
WC04
RAC287
KE12
KKB260
NU01
Hf ppm
La$_n$/Ce$_n$
b)
Black artifacts
ATH101
WC01b
NU01
KOB253
RAC285
KE12
WC04
RAC287
KKB260
N17268
Sr ppm
Th/Sc
c)
Gray artifacts
CKB333
Up.Kugururok quarry
CKD299
ANCK19
ANCK20
CKB301
ANCK23
CKB332
ANCK18
CKH236
CKK306
CKH234
CKS351
CKK307
CKH234
Up.Kelly quarry
Rb/Sr
Eu$_n$/Sm$_n$
d)
Red artifacts
Upper Kugururok quarry
OP0147
CKP309
CKD295
KKB257
OP4063
OP1002
CEP336
CKH226
CHD314
OP4079
RAC283
CKB330
Up. Kelly quarry
Na ppm
Ce$_n$/Ce$_n$*

Figure 3.10.

Figure 3.10. Examples of artifacts-outcrop correlations: (a) and (b) - one of subgroups of black artifacts with Lisburne cherts outcrops: artifacts RAC287 and KKB260 clearly correlate with WC04 chert variety as they fall consistently into its geochemical field, whereas other artifacts occur within the WC01b and KE12 fields sporadically and thus can not be correlated; (c) and (d) -one of subgroups of gray artifacts (c) and red artifacts (d) with Siksikpuk cherts from Upper Kugururok River and Upper Kelly River quarries. Black circles are artifacts correlate with the certain outcrop. Doubled circles are artifacts that occur in overlapping fields and correlated with both quarries. Blank circles are artifacts that were not correlated with any outcrops.

one to Upper Kugururok River quarry. The source of thirteen artifacts may be either Upper Kelly River or Upper Kugururok River quarry because they fall in the area of overlapping fields. In spite of the geochemical similarity of most signatures, three artifacts are not correlated with Upper Kelly River nor with Upper Kugururok River quarries due to the difference in very diagnostic signatures such as Ce_n/Ce_n^*, La_n/Yb_n and Ba/Fe (Fig. 3.10d).

3.7. Discussion: Geological-Geochemical Approach

The geological-geochemical approach is based on the idea that both the chert artifact and its geological chert source have identical mineralogy, microfossils, and bulk trace element chemistry that reflect their identical geologic history. That history is recorded in geochemical signatures specific for different geological conditions of chert formation and unique for each chert layer.

However, the uniform structures and composition of chert consisting of up to 99% cryptocrystalline and/or microcrystalline quartz (SiO_2), as well as the high trace-element variability within the chert layers make chert varieties very difficult to distinguish or correlate. On the other hand, differences in trace-element composition and micro inclusion mineralogy between chert layers or chert nodule chains reflect variations in depositional, provenance and diagenetic history of cherts.

A chert artifact created from a specific chert layer is identical to that layer inheriting all its geochemical and petrological features that reflect provenance, depositional environment, diagenetic conditions and local geochemical composition. Therefore, artifact sourcing has to be based on the geochemical and petrological signatures that are unique for each source rock. Sourcing based only on bulk chemistry, or mineralogy, or petrographic microscopy may lead to misidentification of chert artifact sources because it does not take

into consideration all the geological factors.

3.7.1. Outcrop Sampling

The success of chert sourcing depends to a great degree on the proper sampling of outcrops. The chemical variability within the chert layers and nodules (including variability of trace elements associated with heterogeneously distributed mineral inclusions) makes it impossible to directly correlate artifact-sample with outcrop-sample using chemistry alone. Sets of samples selected along each chert layer or nodule chain are required in order to obtain the range of variability of each trace element within each layer. Chert layers, lenses, or nodule chains may crop out in vertical cross sections or on slopes where they are well exposed. This type of exposure provides an opportunity to obtain representative geochemical fields for each layer. However, chert cropping out on gentle slopes covered with colluvium often represents the mixture of different chert layers and thus has the potential for generating high variability and diffuse geochemical fields.

3.7.2. Regional Database

Constructing the regional database for chert outcrops is the central point of the method and the basic requirement for the successful determination of geological sources of prehistoric chert artifacts in any region (Fig. 3.3). The regional database of chert outcrop signatures is the set of petrographic (color), geochemical (elemental concentrations and elemental ratios), and mineralogical (mineralogy of inclusions) signatures of each chert variety (15 samples from each). Elemental ratios provide very useful geochemical signatures. They are constant for particular mineral inclusions in cherts. Their values are not affected by irregular distribution of mineral inclusions within the chert (or by difference in their size) and thus they are constant for the particular chert. A series of diagrams (intervals

of variability, elemental variation and elemental ratio variation diagrams) that separate chert varieties based on the most discriminating geochemical signatures are the necessary supplements to the regional database.

Obviously, increasing the number of outcrops involved in the database, and increasing the number of discriminative signatures used will make the sourcing of artifacts more reliable. Once constructed, the database can be used to compare any chert artifact from any archaeological site in the region.

3.7.2.1. Selection of Discriminative/Correlative Signatures. Two main groups of signatures were chosen for discrimination of chert sources from each other and their correlation with chert artifacts: 1) signatures that are key indicators of provenances, depositional environments and diagenetic conditions and thus discriminate cherts from different stratigraphic formations and units, and 2) signatures reflecting geochemical difference between lateral lithofacies within the same formation or unit.

Ce_n/Ce_n^* values provide reliable depositional signatures (Shimizu and Masuda, 1977; Murray et al., 1990; Murray, 1994). $Ce_n/Ce_n^* < \sim 0.8$ are considered as negative Ce anomalies that are characteristic for open ocean depositional environment and $Ce_n/Ce_n^* > 0.8$ indicate continental margin depositional environment (Murray et al., 1990). The significant difference in Ce_n/Ce_n^* values between artifact and outcrop overrides all other similarities, as it strongly infers that artifact chert and outcrop chert were deposited in different environments.

In the western Brooks Range, Ce_n/Ce_n^* values provide a powerful tool for sourcing black artifacts. Negative Ce anomalies characteristic for three black Lisburne chert varieties NU01, WC04, KE12 indicate their open ocean deposition. Black artifacts with no or positive

Ce anomalies can not be correlated with any of these outcrops even if all other signatures indicate their similarity (Fig. 3.11a).

High Eu_n/Sm_n values (e.g. in AN10, Fig. 3.7d,e) are characteristic of plagioclase-rich volcanoclastic material (Nance and Taylor, 1977; Taylor and McLennan, 1985; McLennan, 1989; Girty et al., 1996) and thus may be used as volcanoclastic provenance indicators. The difference in Eu_n/Sm_n values between the artifact and outcrop indicates different provenance and thus different geological sites.

Ba/Al and Ba/Fe are important diagenetic signatures for the Upper Paleozoic and Mesozoic cherts in the western Brooks Range. As Figure 3.6d shows $Ba/Al_{sample} > Ba/Al_{PAAS}$ is characteristic for barite-bearing Siksikpuk cherts and $Ba/Al_{sample} \sim Ba/Al_{PAAS}$ is characteristic for pyrite-bearing Lisburne and Otuk cherts. Correlation of Ba/Al and Ba/Fe values to mineralogical data in 12 chert varieties revealed that $Ba/Al > 0.20$ and $Ba/Fe > 0.73$ are characteristic for barite-bearing cherts and thus indicate oxidizing conditions during late stage diagenesis (Fig. 3.11b), whereas $Ba/Al < 0.10$ and $Ba/Fe < 0.20$ are typical for pyrite-bearing cherts and indicate reducing conditions. Thus, Ba/Fe values and Ba/Al values reveal whether artifact and outcrop have similar diagenetic patterns that are crucial for their correlation (Fig. 3.11b,c). However, in cases when Ba/Al values in the artifact falls between 0.2 and 0.10 and and Ba/Fe between 0.73 and 0.20, the range where both reducing and oxidizing conditions occur (Fig. 3.11b), only the mineralogy (determined by EMPA) can help assign the artifact to the correct pyrite- or barite-bearing chert source.

Outcrops that have similar depositional, provenance, and diagenetic signatures (i.e. Siksikpuk cherts) can be separated from each other and correlated with artifacts by signatures (such as Cs, Sc, Rb/Sr and other) that reflect local geochemistry specific for lithofacies (Fig.

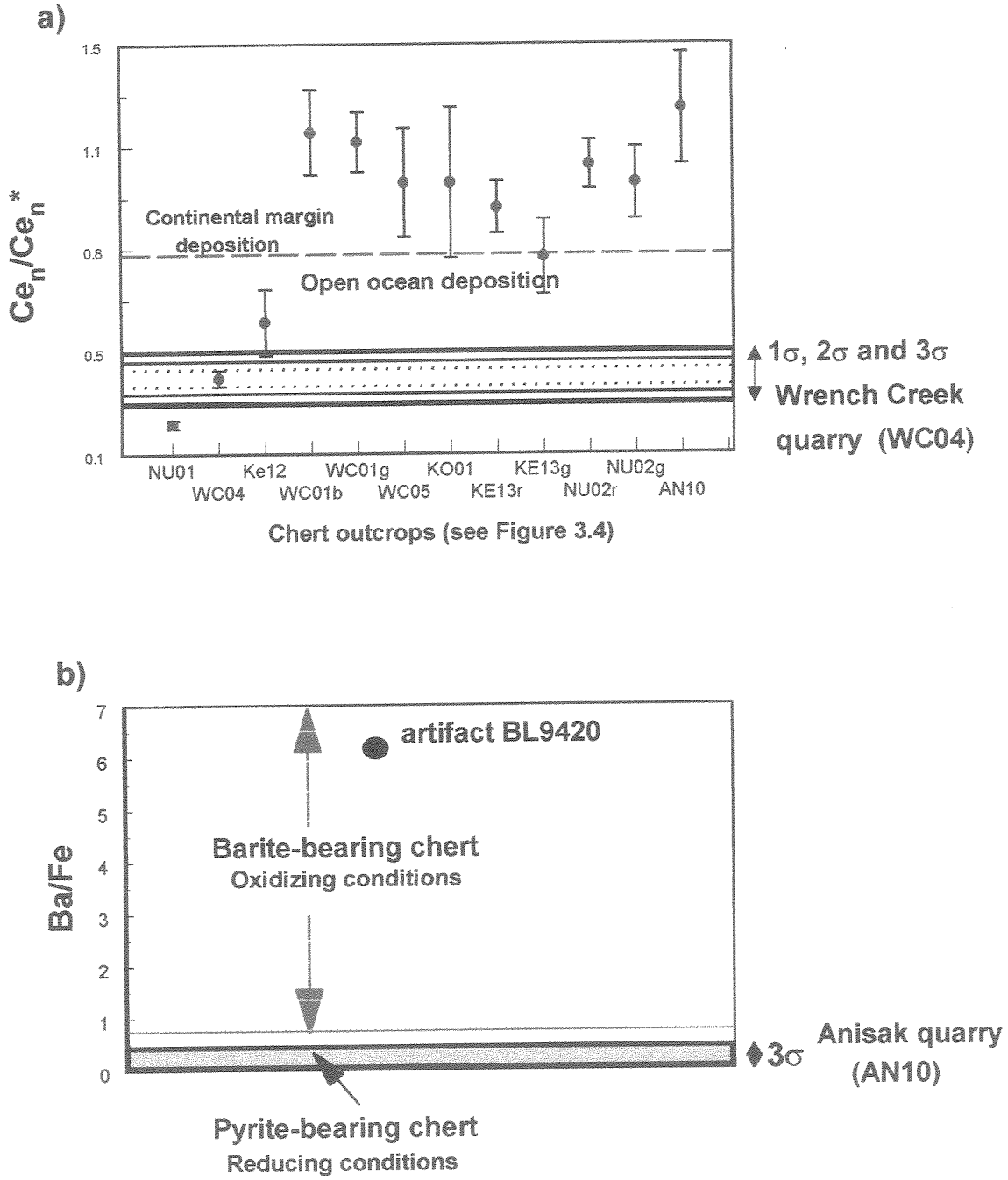


Figure 3.11a,b.

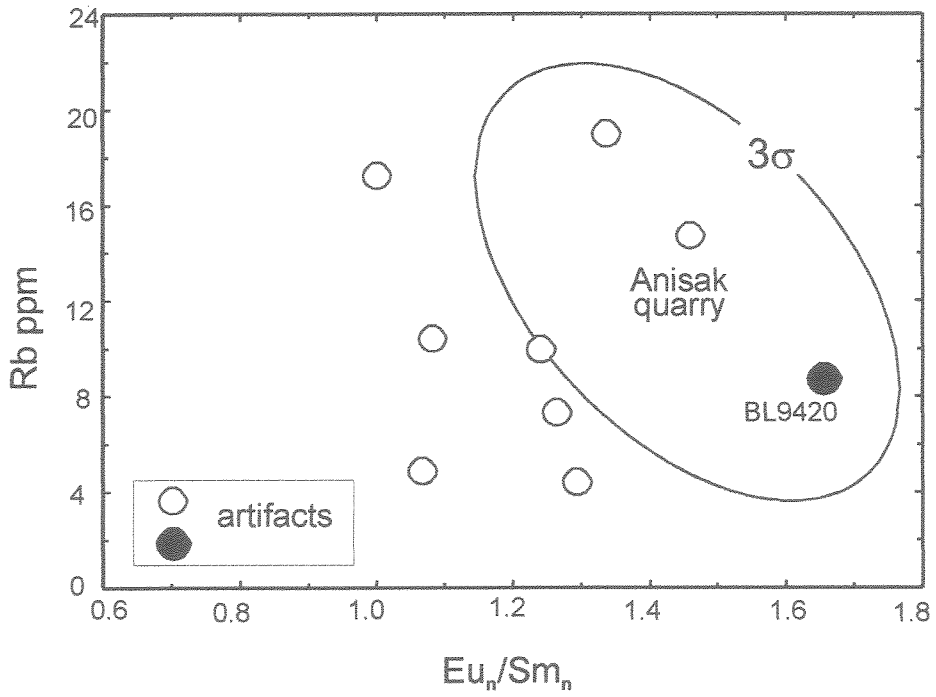

24
20
16
12
8
4
0
Rb ppm
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Eu$_n$/Sm$_n$
3σ
Anisak
quarry
BL9420
artifacts

Figure 3.11c.

Figure 3.11. Discriminating geochemical signatures: (a) Ce/Ce* values divide twelve chert varieties into two groups of different depositional environments: open ocean for three black Lisburne chert varieties with negative Ce anomalies (including WC04 determined as Wrench Creek quarry) and the continental margin for the rest of varieties with positive or no Ce anomalies; (b) - high Be/Fe value in BL9420 artifact indicates oxidizing diagenetic conditions and excludes assigning this gray artifact to Anisak quarry that is characterized by reducing conditions. This diagenetic difference overrides all other similarities of BL9420 artifact with Anisak quarry (c).

3.8a,b,c,d).

3.7.3. Correlation Process.

3.7.3.1. Statistics. Chert artifacts found in archaeological sites present a mixture of cherts that might have been mined in geochemically different chert sources and thus are not expected to form a multivariate normal distribution. Therefore, combining both artifact and outcrop data into one population to apply multivariate discriminant and principal component analysis to artifact-outcrop correlation may lead to misinterpretations.

The set of samples from the chert layer or nodule chain forms the normal distribution and reflects the variability within the chert source that can be shown by confidence intervals (Luedtke, 1979) or intervals of variability (Selivanova, 1984) obtained by three, two, and one standard deviations from the mean for each element. On bivariate diagrams these intervals turn into geochemical fields that indicate that 0.3% of all artifacts made from this chert variety might fall outside of the 3σ field, 5% might fall outside of the 2σ field, and 32% might fall outside of the 1σ field. Fields obtained using 3 standard deviations are most useful for correlation of artifacts with outcrops because they reflect element variability within the outcrops and maximize the correlation of artifacts with chert variety.

However, when fields of outcrops obtained by 3σ overlap, then 2σ or 1σ fields can be used to constrain correlation (e.g. Etivluk cherts discrimination, Fig. 3.8). Those artifacts falling consistently into the overlapping area should be assigned to all the outcrops from overlapping area at equal confidence (Fig. 3.12a). Some artifacts consistently (element by element) occur in the immediate vicinity (just outside the 3σ field) of the geochemical field of the same outcrop. If the difference between the position of artifact and the outcrop field on the bivariate plot is less than the analytical precision, then an artifact can be assigned to

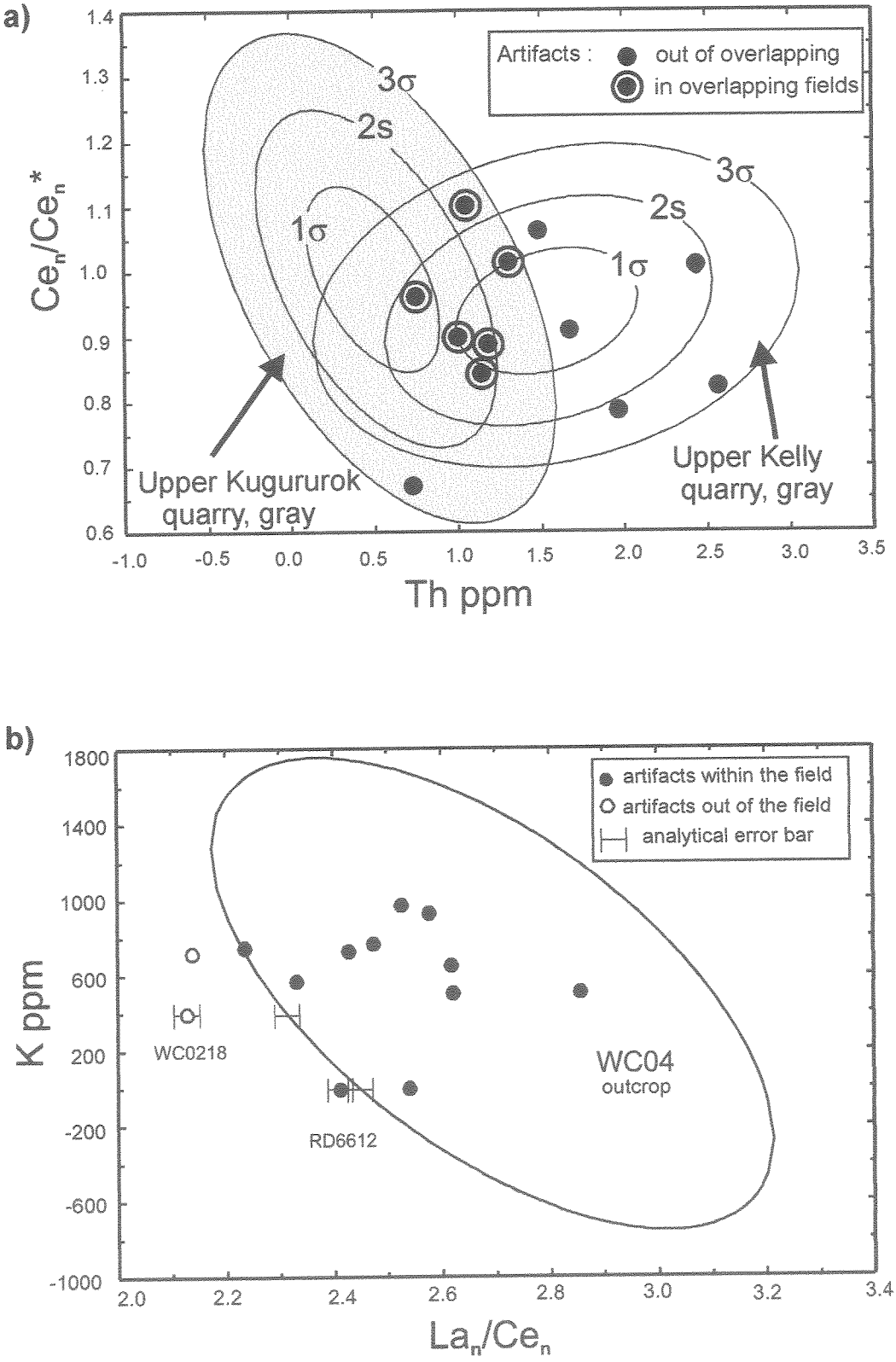

a)
Artifacts :
out of overlapping
in overlapping fields
3σ
2s
1σ
3σ
2s
1σ
Upper Kugururok quarry, gray
Upper Kelly quarry, gray
Ce_n/Ce_n*
Th ppm
b)
artifacts within the field
artifacts out of the field
analytical error bar
WC0218
RD6612
WC04
outcrop
K ppm
La_n/Ce_n

Figure 3.12.

Figure 3.12. Process of correlation of artifacts with quarry / outcrop geochemical fields: (a) - artifacts occurring in overlapping area (doubled circles) must be assigned to both, Upper Kelly River and Upper Kugururok River quarries, (a) - error bars show the range of analytical error/precision for La/Ce values for artifacts and geochemical fields; RD6612 artifact can be assigned to WC04 outcrop, whereas WC0218 can not.

the outcrop (Fig. 3.12b). The artifact that occurs out of the field defined by analytical precision can not be assigned to this field.

3.7.3.2. Selection of the Geochemical Fields. Correlation of artifacts with outcrop involves plotting artifact data on as many discriminating diagrams as possible to see what artifacts fall consistently into specific fields. The example of a relatively simple case is the comparison of black artifacts with black Lisburne chert outcrops. On the Figure 3.10a,b, artifacts RAC287 and KKB260 fall systematically into the field of WC04 outcrop and can be correlated with it. Artifacts N17268 and ATH101 fall into WC01b field occasionally and thus, can not be correlated with the WC04 outcrop.

It is much more complicated to assign an artifact to a particular geochemical field when field overlapping occurs. For instance, gray chert varieties of Etivluk Group are geochemically very close to each other and commonly overlap (Fig. 3.8). An artifact should be assigned to the field where it falls consistently based on all signatures. Those fields where artifact falls only occasionally should be eliminated from consideration.

3.7.4. Variability Within Prehistoric Chert Quarries

Variability between chert layers in the quarry and artifacts found associated with this quarry might be significant. In the Upper Kelly River and Upper Kugururok River quarries, for example, geochemical fields including both chert artifacts and layer samples are much larger than fields that include only layer samples (Fig. 3.9). In the Upper Kelly River quarry, position of flakes clustering within and out of the chert layer field indicates that prehistoric people mined a series of red and gray layers in the quarry including those layers sampled for this research. In the Upper Kugururok River quarry, position of red flakes (all falling out of the layer field) indicates that humans were mining layers in this quarry not sampled in this

study (Fig. 3.9).

3.7.5. Maps of Chert Distribution

The main task of the prehistoric chert sourcing in northwestern Alaska was to obtain the distribution patterns of varieties of cherts mined in the western Brooks Range quarries and found as artifacts in archaeological sites in the region. My goals were to show: 1) which quarry varieties comprise each archaeological site, 2) how far cherts were transported from quarries to the north, south, west and east, 3) the boundaries of distribution of each chert variety as artifacts in northwestern Alaska, and 4) what prehistoric sites contain foreign cherts.

The map of distribution patterns of cherts mined in the Wrench Creek prehistoric quarry (WC04 outcrop on the Figure 3.4) is an example of many maps obtained as a result of chert sourcing. This map (Fig. 3.13) suggests transportation of Wrench Creek chert from the quarry to the Kelly River, then along the Noatak River to the sea coast, and then from the coast to the east up the Kobuk River to the important prehistoric site at Onion Portage. However, the map also demonstrates problems in interpretation of distribution patterns of sourced chert artifacts. The key question is whether or not chert material for all chert artifacts correlated with the Wrench Creek quarry were mined by people in that quarry and then transported to the prehistoric sites? An alternative possibility is that artifacts were made of reworked cherts, such as black chert pebbles or cobbles obtained from Noatak River alluvium or glacial deposits, or from coastal outcrops. A wide spectrum of geological and archaeological aspects have to be considered to adequately answer these questions. For example, the glacial history of the region may be needed in order to determine if a specific outcrop was accessible for prehistoric people of a certain culture at the time of the mining.

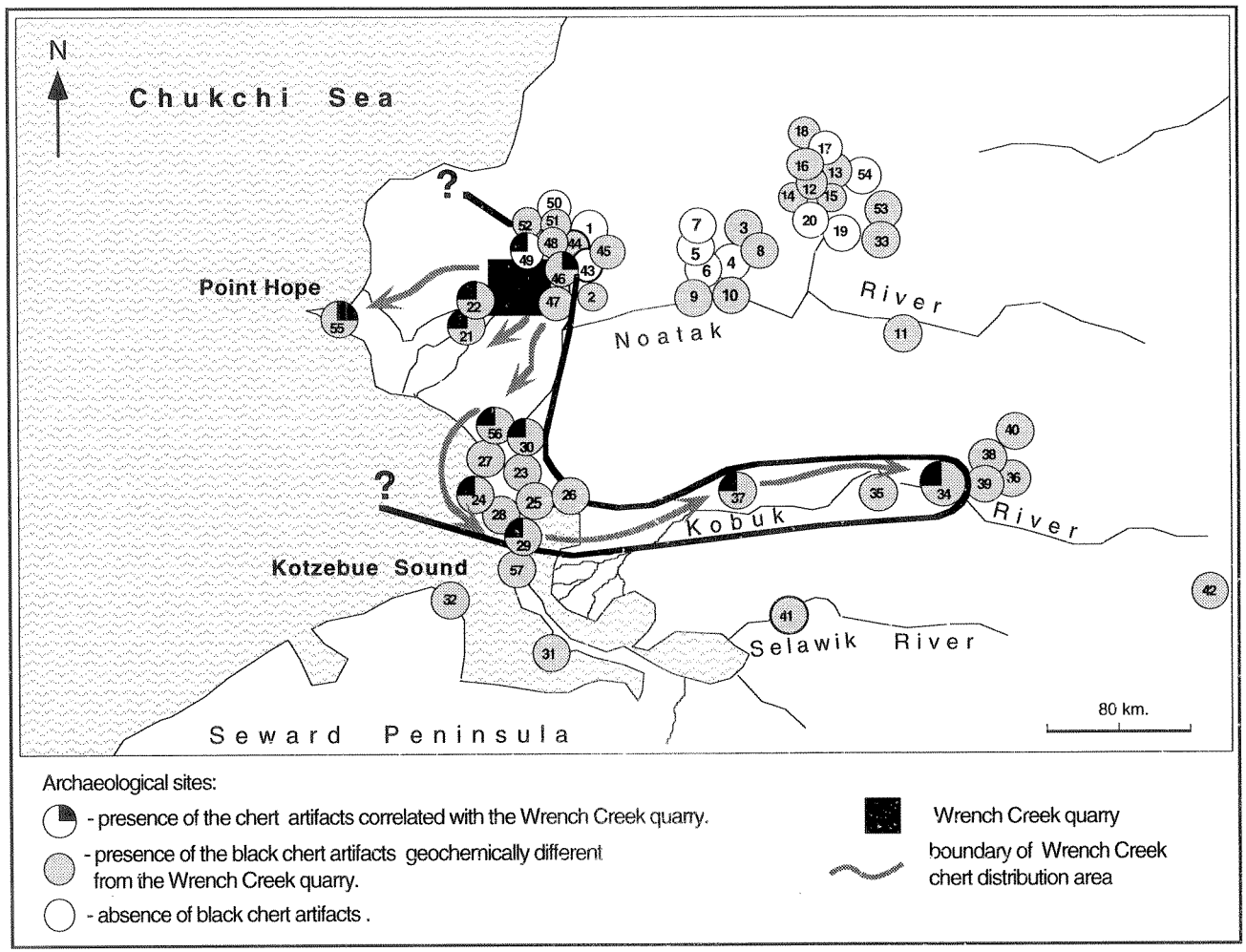


Figure 3.13. Map of distribution of black cherts from the Wrench Creek quarry (see site list in Figure 3.1)

Geochemical comparison of coastal black chert pebbles with Wrench Creek quarry will show if this quarry was their bedrock source. Geochemical study of black chert outcrops on the coast and their comparison with coastal pebbles and Wrench Creek quarry will answer if an additional coastal source for black chert pebbles that is geochemically equivalent to the Wrench Creek was available. Extending the database by studying more outcrops in the region can eventually reveal geological sources for those artifacts that were left unidentified and highlight artifacts made of foreign sources suggesting long distant prehistoric communications.

3.8. Conclusions

1. The geological-geochemical approach provides a powerful tool for determining geological sources of prehistoric chert artifacts. The combination of mineralogical and geochemical signatures provides strict criteria for discrimination of those cherts that are indistinguishable by petrological properties (color, surface of fracture, etc) and bulk chemical composition. In northwestern Alaska, only 20% of all artifacts analyzed were firmly assigned to four outcrops determined as prehistoric chert quarries in the western Brooks Range. The rest of artifacts (80%) were left unidentified despite the fact that they were visually (i.e. by color) similar to those definitely correlated with quarries. This fact, in particular, strongly indicates that color of chert artifacts is not a reliable signature for chert correlation.

2. A regional database of geological-geochemical signatures of chert outcrops in the study area is the basic requirement for the successful sourcing of prehistoric artifacts. Detailed study of chert outcrops in the region, as well as proper sampling (15 samples from each chert variety) are required to obtain petrological and

geochemical signatures and their variability for each chert variety.

3. Similarity or differences between artifact and outcrop by depositional (Ce_n/Ce_n^*), provenance (Eu_n/Sm_n or Eu_n/Eu_n^*) or diagenetic (Ba/Fe) signatures overrides their similarities by all other signatures. Correlation of artifacts with series of outcrops that have similar provenance, depositional, and diagenetic characteristics should be based on geochemical signatures specific for lithofacies.

4. Correlation of artifacts with outcrops characterized by overlapping geochemical fields can be done by an iterative process of progressive outcrop selection and delineations.

5. The most complete range of chemical variability in the prehistoric quarry can be determined by combining outcrop samples and associated prehistoric flakes (that were mined in the quarry) into one data set.

6. The glacial history of the region, as well as other geological and archaeological aspects, need to be considered for correct interpretation of distribution patterns obtained by chert artifact sourcing.

CHAPTER FOUR:
DISTRIBUTION PATTERNS OF CHERTS FROM PREHISTORIC QUARRIES IN THE WESTERN BROOKS RANGE

4.1. Abstract

Four prehistoric chert quarries identified in the western Brooks Range, Alaska, during regional geological-geochemical sourcing of chert artifacts were compared with a series of chert artifacts from prehistoric sites located in northwestern Alaska. Ninety samples from chert quarry layers, as well as 37 prehistoric chert artifacts from workshops located at these quarries and 252 artifacts from 53 northwestern Alaska prehistoric sites, were included in the study. Each sample was analyzed by instrument neutron activation to detect the trace element composition and by electron microprobe and X-ray diffraction to determine the mineralogy of mineral inclusions. Discriminative mineralogical and geochemical signatures specific for each quarry were used for artifact-quarry correlations. Fifty one chert artifacts from 29 prehistoric sites were firmly correlated with quarries. Results are summarized in maps that show geographic and cultural distribution of cherts from each quarry throughout prehistoric time in northwestern Alaska. The distribution patterns of chert artifacts to four prehistoric quarries in the western Brooks Range show wide distribution from the quarry area to the Kobuk valley, the Bering Strait coast and Chukchi Sea. Patterns also suggest transport of the western Brooks Range cherts across the Bering Strait, to the Arctic Ocean, and to the northeast. Four quarries were used by people from the American Paleo-Arctic tradition (~10,000 B.P.) to the Arctic Woodland Eskimo (1,000 B.P. to Recent). Results of chert sourcing provide critical information for the reconstruction of prehistoric migration routes in the western part of eastern Beringia.

4.2. Introduction

The determination of the prehistoric human network in Beringia and the expansion of paleolithic humans into other parts of Alaska and the New World comprise some of the most difficult questions in North American archaeology. Many prehistoric sites dating from 10,000 B.P. to Recent occur in this region (Giddings,1960; Anderson, 1970a, 1970b, 1972, 1984, 1984, 1988; Hall, 1975; Bockstoce, 1979; Gal, 1982; Gerlach and Hall, 1986; Giddings and Anderson, 1986, Gal, 1993, 1994) (Fig. 4.1). They represent (from oldest to youngest): 1) the American Paleo-Arctic tradition (10,000-8,000 B. P.) bearing resemblance to finds from Siberia and central and southwestern Alaska, 2) the Northern Archaic tradition (5,800-4,000 B.P.), 3) the Arctic Small Tool tradition (4,000-1,000 B. P.), and 4) the prehistoric Eskimo cultures (1,000-present) (Mochanov, 1980; West, 1981; Gal, 1982; Anderson, 1984, 1988; Dikiv and Titov, 1984; Giddings, and Anderson, 1986; Gerlach and Hall, 1986). Most of the sites are surficial, unstratified, and undated by radiocarbon. Chert artifacts are commonly the only surviving archaeological remains and typology of artifacts is generally the only source of information about prehistoric cultures and their sequence (Gerlach and Mason, 1992). Therefore, chert artifact sourcing that was proven important for reconstructing interaction network of prehistoric cultures (Luedtke, 1979, 1993, 1995; Nagle, 1984; Selivanona, 1984; Andrefsky, 1994) is crucial in this region. It provides unique information for tracing intergroup contacts and traveling patterns, and leads to improved understanding of the mechanisms of population dynamics from the earliest Americans to recent northwestern Alaskan Eskimos.

The Seward Peninsula, Kobuk River drainage, and Noatak River drainage with their numerous inland and coastal prehistoric sites were important routes of travel and migration

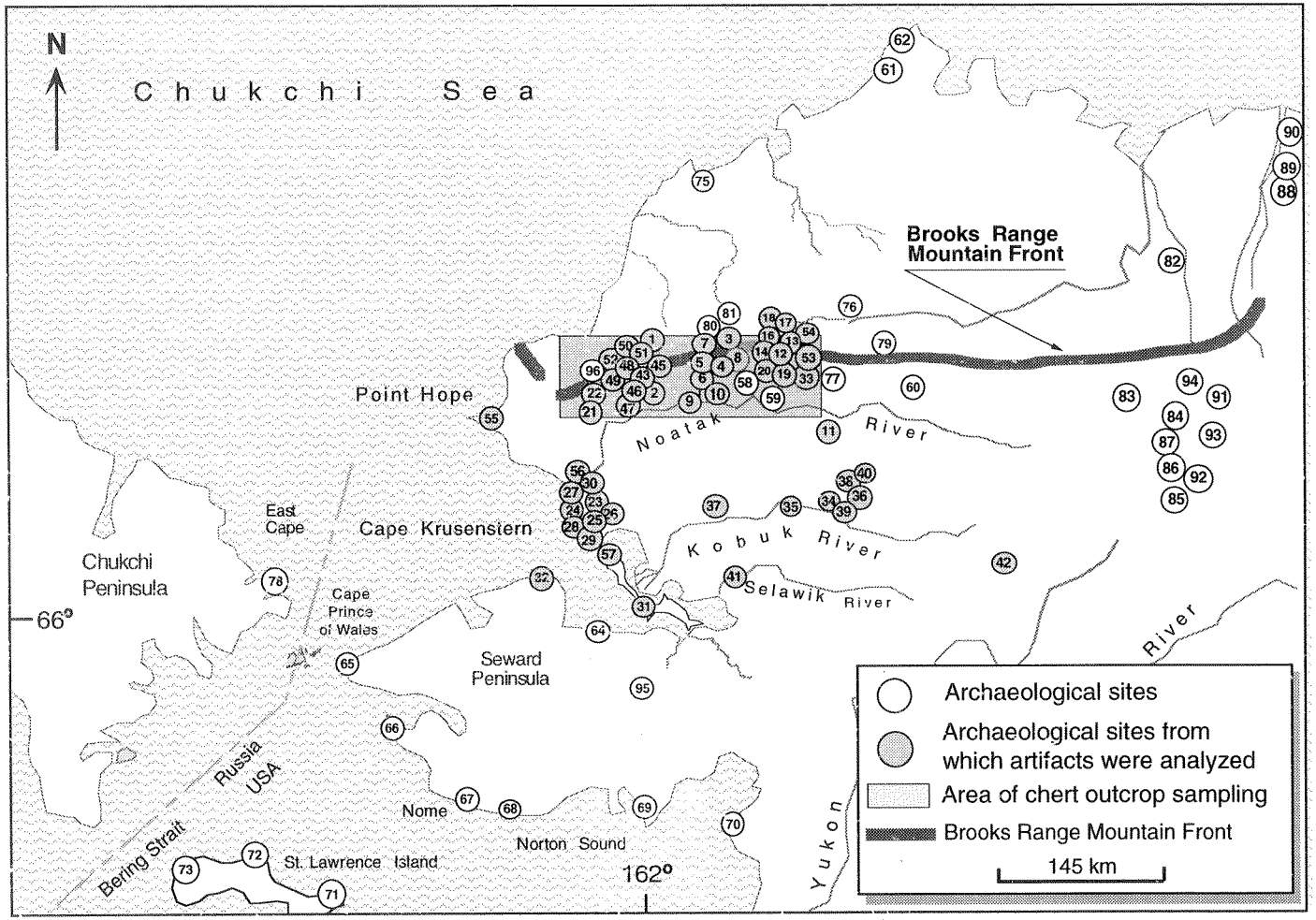

N
Chukchi Sea
Brooks Range
Mountain Front
Point Hope
Noatak River
East
Cape
Cape Krusenstern
Chukchi
Peninsula
66°
Cape
Prince
of Wales
Seward
Peninsula
Kobuk River
Selawik River
Yukon River
Russia
USA
Bering Strait
Nome
Norton Sound
St. Lawrence Island
162°
Archaeological sites
Archaeological sites from
which artifacts were analyzed
Area of chert outcrop sampling
Brooks Range Mountain Front
145 km

Figure 4.1.

Figure 4.1. Map of study area and prehistoric sites (data from Solecki, 1951; Giddings, 1960; Anderson, 1970b, 1972, 1984; Hall and Mull, 1976; Stanford, 1976; Bockstoce, 1979; Giddings and Anderson, 1986, NPS archaeological survey during 1993, 1994).

Archaeological sites from which chert artifacts were analyzed: 1) Upper Kelly River quarry, 2) Kelly River chipping stations NKR-1; **Kugururok River sites**: 3) Upper Kugururok River quarry, 4) NKUR-1, 5) KU02, 6) KU03, 7) Kaguik (KO02), 8)NU03 (Noat_3062); **Noatak River sites**: 9) N-5, 10) NR-17, 11) NR-27; **Nimiuktuk River sites**: 12) Nim 5-1, 13) Nim-7, 14) Nim-11, 15) Nim-15, 16) - 94108, 17) -94141, 18) -94127; **Anisak River sites**: 19) Anisak quarry, 20) AN08; 21) Red Dog Del-168, 22) Red Dog Del-166; **Cape Krusenstern** sites: 23) Battle Rock, 24) Palisades, 25) Lower Bench, 26) Sisualik, 27) Birnirk, 28) Ipiutak, 29) Denbigh, 30) Old Whaling; 31) Choris, 32) Cape Espenberg, 33) Burial Lake site; **Kobuk River basin sites**: 34) Onion Portage, 35) Atheut, 36) Lookout site on Knoll, 37) Kiana Bench, 38) High Old Bench, 39) Locality-2, 1963, 40) Ambler River site; 41) Selawik; 42) Lake Norotuk; **Saxsot Creek sites**: 43) Noat.-3006, 44) Noat.-3009, 45) Noat.- 3011; **Wrench Creek sites**: 46) Noat.-3014, 47) Noat.-3015, 48) Noat.-3018, 49) Noat.-3023, 50) Noat.-3024, 51) Noat.-3046, 52) Noat.-3047; **Nimiuktuk River sites**: 53) Picnic Creek site, 54) Setting Sun site; 55) Point Hope site, 56) Rabbit Creek site, 57) Kotzebue.

Archaeological sites from which artifacts were not analyzed: 58) Kugururok River chipping stations Kug-2 through Kug-5, 59) Noatak River chipping stations NR-9, -10, -14, 15, 19-23, 60) Punjik Point, 61) Coffin, 62) Walakpa, 63) Tugulak, 64) Deering, 65) Walles sites, 66) Point Spencer, 67) Cape Nome sites, 68) New Beach sites at Cape Nome, 69) Cape Darby, 70) Cape Denbigh sites, 71) Punic Island sites, 72) Kukulik Mound, 73) Gambell sites, 74) Indian Port, Siberia, 75) Tunalik, 76) Tukuto Lake, 77) Feniak Lake, 78) Uelen sites, 79) Mesa, 80) Kugururok (by Lechenbruch), 81) Utukok River sites, 82) Itkillik River sites, 83) Natvakrunk Lake , 84) Franklin Bluff, 85) Kayuk, 86) Avingak, 87) Tuluak Lake, 88) Peters Lake, 89) Schreder Lake, 90) Katalaturuk, 91) Utu Lake, 92) Tuktu Lake, 93) Okiotak, 94) Kogruk, 95) Trail Creek caves, 96) Tugulak quarry.

of prehistoric populations in the westernmost part of eastern Beringia (Burch, 1976, Anderson, 1984) (Fig. 4.1). However, no tool quality chert sources are known on the Seward Peninsula, nor in the Kobuk River drainage (Beikman and Lathram, 1976; Karl et al., 1989) suggesting that chert was mined elsewhere and transported into the region.

The Noatak basin was crossed by major interior routes from west to east and north to south (Anderson, 1972; Burch, 1976). Tributaries of the Noatak River dissect the Brooks Range permitting easy access to the Arctic Slope and shores of the Arctic Ocean. These are the same routes used presently by caribou. The Noatak basin (particularly in the northern Brooks Range) is underlain with chert-rich sedimentary deposits cropping out along the Brooks Range mountain front (Mull et al., 1982; Mayfield et al., 1983, 1988; Ellersieck et al., 1983, 1990; Karl, 1989; Karl et al., 1989; Curtis et al., 1990; Moore et al., 1994) (Fig. 4.1). Many chert chipping stations, and a few large workshops, are closely associated with chert outcrops indicating that the western Brooks Range was a prehistoric mining area for raw chert materials that were transported throughout Beringia (Anderson, 1972; Hall and Mull 1976; Malyk-Selivanova and Ashley, 1994a, 1994b, 1995; Malyk-Selivanova et al., 1996a, 1996b, 1997).

Comparison of 252 chert artifacts from 53 prehistoric sites located in northwestern Alaska with nine chert outcrops (twelve chert varieties) resulted in identification of four prehistoric quarries in the Noatak River basin. Chert was transported from these quarries to prehistoric sites widely distributed throughout the region (Malyk-Selivanova et al., 1996b, 1997).

The objectives of this chapter are to present the application of chert sourcing to resolve the following archaeological questions: 1) how far and in what directions were chert

artifacts that are geochemically correlated with the western Brooks Range quarries transported from their geological sources, 2) how early (by what prehistoric culture) was each chert variety mined and distributed, and 3) what varieties were preferred by which cultures? I present in this chapter results of application of chert sourcing in northwestern Alaska to archaeological problems. These results include: 1) geological and geochemical characteristics of each prehistoric quarry in the western Brooks Range, 2) maps showing the geographic distribution of each chert variety from each quarry, 3) and maps showing quarry use by different prehistoric cultures from American Paleo-Arctic tradition to prehistoric Eskimo.

4.3. Chert Sourcing in Northwestern Alaska

4.3.1. Background

Anderson (1972) describes a few prehistoric locations in the Noatak Canyon, Kelly and Kugururok basins that contain abundant flaking detritus and the presence of artifact blanks suggesting that these were chert mining areas where artifacts were roughed out. He also reported detailed information about the quantitative distribution of differently colored chert types in Onion Portage sequences (Anderson, 1988). The aboriginal Upper Kelly River quarry located in the headwaters of Kelly River (Fig. 4.1) was first discovered by Mull and studied by Hall in 1970 (Hall and Mull, 1976). Their study suggests that people were using this specific location for chert in addition to casually searching stream bottoms for raw material. Another prehistoric quarry, Tulugak quarry, was discovered by E. Hall near Wrench Creek, a tributary of Kelly River (Gerlach and Hall, 1986; Burch, 1990) (Fig. 4.1).

Lorne Young created a provisional chert identification flow chart based on visual petrographic study for cherts from the archaeological sites in the Red Dog area, northwestern

Alaska (Gerlach and Hall, 1986). Based on visual chert characteristics, Gerlach and Hall (1986) made important conclusions about the raw material provenance of about two thousand lithic artifacts from the Red Dog (DEL-166 and -168) prehistoric collection (Fig. 1). Hall and Bowers (1987) identified 95 lithic flakes from NOA-135 location in Red Dog area with upper Siksikpuk chert source using Young's chart.

The first regional chert sourcing in northwestern Alaska based on the geological-geochemical approach is presented in this work. The sourcing method included: 1) mapping and sampling good knapping quality chert outcrops in the Kelly, Kugururok, Nimiuktuk and Anisak River basins (northern tributaries of Noatak River, western Brooks Range), 2) sampling the artifacts from prehistoric sites in northwestern Alaska during archaeological survey and from museum collections, 3) analyzing the samples from outcrops and artifacts, and 4) correlating artifacts with outcrops. Twelve varieties of colored chert (including black, gray, and red varieties) from nine outcrops were analyzed and compared with 252 artifacts from 53 prehistoric sites in northwestern Alaska based on geochemical and mineralogical signatures (Malyk-Selivanova et al., 1996b, 1997). A total of 51 artifacts from 30 prehistoric sites were firmly correlated with four of the nine studied outcrops that eventually were determined to be prehistoric chert quarries: Wrench Creek, Upper Kelly River, Upper Kugururok River and Anisak quarries (Fig. 4.2). The other 201 artifacts did not correlate with any one of the studied chert varieties.

4.3.2. Analytical Methods

Major, minor, and trace element compositions of cherts were obtained by instrumental neutron activation analysis (INAA) at the Missouri University Research Reactor (MURR). Detailed description of the analytical methodology is given in Chapter 2. The

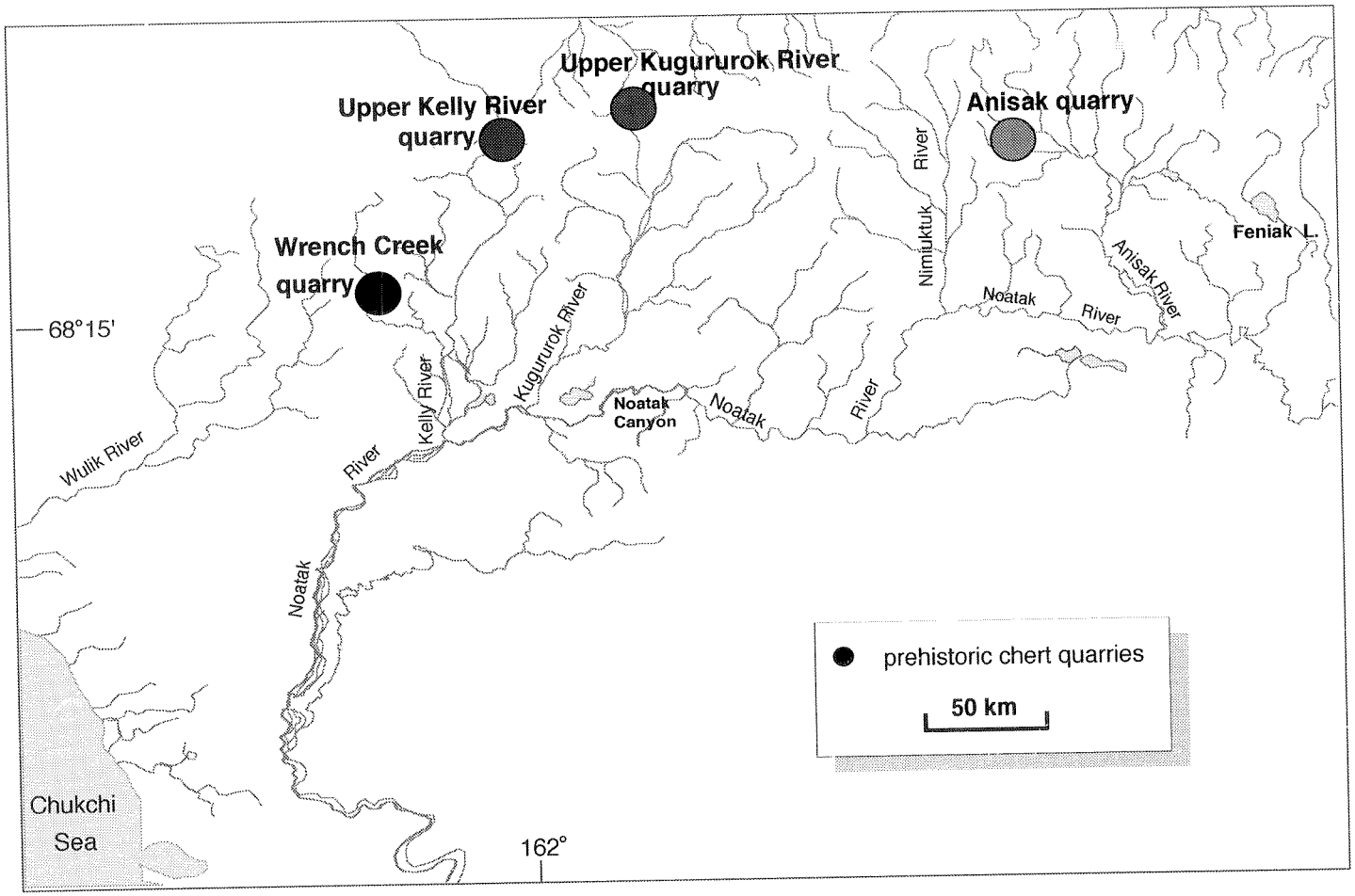


Figure 4.2. Location map of prehistoric chert quarries in the western Brooks Range. **Wrench Creek quarry**: N68^{0}09'47", W162^{0}32'44", Delong Mountain quadrangle (U.S.G.S 1:250,000). **Upper Kelly River quarry**: N68^{0}27'44", W162^{0}01'41", Delong Mountain quadrangle (U.S.G.S 1:250,000). **Upper Kugururok River quarry**: N68^{0}33'01", W161^{0}27'08", Misheguk Mountain quadrangle (U.S.G.S 1:250,000). **Anisak quarry:** N68^{0}22'36", W159^{0}36'22", Misheguk Mountain quadrangle (U.S.G.S 1:250,000).

mineral composition of inclusions in chert outcrops and chert artifacts was determined by electron microprobe analysis and X-ray diffraction at Rutgers, the State University of New Jersey.

4.3.3. Data processing

Data processing included: 1) clear separation of each quarry from other quarries based on mineralogical and geochemical signatures. This included constructing the variation diagrams that provide error bars and geochemical fields of elemental abundances and elemental ratio values (at one, two and three deviations calculated for 15 samples from each chert variety), 2) correlation of each artifact with quarries by matching geochemical signatures. Artifact signatures were superimposed on the quarry geochemical fields and error bars that provided the greatest separation of quarries. Full details of sampling chert in outcrops, analytical procedures of chert samples, as well as data processing are given in Chapter 3.

4.4. Geological Setting of Quarries

Chert varieties from the four prehistoric quarries studied belong to different stratigraphic units of Lisburne and Etivluk Groups of Mississippian to Jurassic age (Fig. 4.3). Their stratigraphy, main geochemical and mineralogical signatures, as well as depositional environment, provenance, and diagenetic patterns are given in Figure 4.3. The detailed geological description of quarries can be found in Appendix I.1. A brief description is given below.

4.4.1. Wrench Creek Quarry

The outcrop identified as Wrench Creek quarry (Chapter 3) is located in the area of the Tulugak quarry (Gerlach and Hall, 1986; Burch, 1990) (Fig. 4.2). The outcrop is

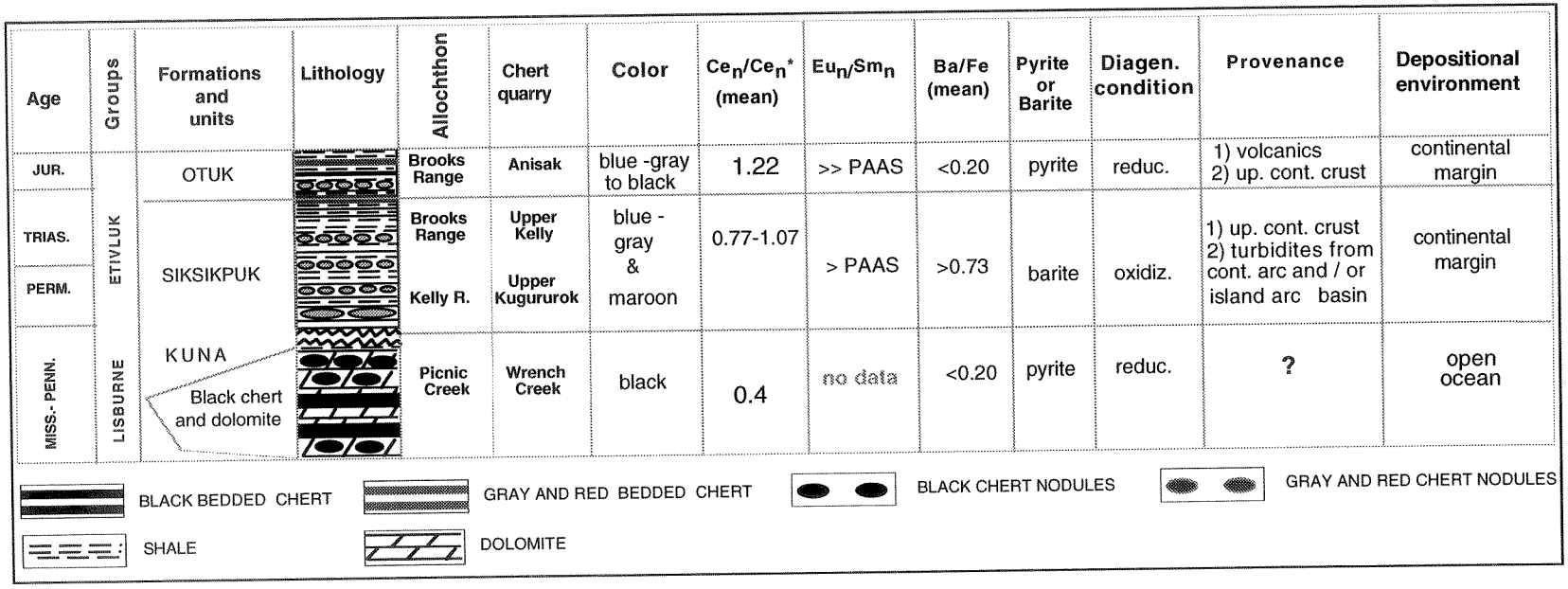


Figure 4.3. Summary of stratigraphy, main geochemical and mineralogical characteristics , depositional environment, provenance and diagenetic patterns.

blanketed locally with colluvium covering the long slope of the western bank of the Wrench Creek that dissects DeLong Mountain (Fig. 4.4). The colluvium consists of gravel and large blocks (up to 90 cm) of black, glassy chert layers and chert nodules interbedded with thin layers of dolomite. The thickness of the chert layers varies from 4 to 86 cm. The outcrop represents the Chert and Dolomite Unit of Kuna Formation (by Curtis et al., 1990) or Akmalik Chert (by Mull et al., 1987) belonging to Lisburne Group (Mississippian-Pennsylvanian), Picnic Creek allochthon (Fig. 4.2).

4.4.2. Upper Kelly River Quarry

The quarry is located on a pass between the southern slope and the northern slope of the Brooks Range (Hall and Mull, 1976). It is situated in the headwaters of the Kelly River, on a modern caribou route (Fig. 4.2) and is approximately 2.5 km^2 in area (Hall and Mull, 1976). The part of the quarry studied for chert sourcing is represented by colluvium on the slope (Fig. 4.5) that is composed of black poor tool quality chert gravel weathered from the Kogruk Formation, and gray, blue-gray, red and red-and-gray cherts from the Siksikpuk Formation (Brooks Range allochthon) (Ellersieck et al., 1990) (Fig. 4.3). The nodules and lenses of Siksikpuk chert are from 3 x 4 cm to 25 x 40 cm in size. Gray or blue-gray nodules and lenses often contain thin (1-2 mm) veins, dendritic in shape and 2-2.5 cm in length. Many nodules are mottled red-gray and some of them have zonation from a gray periphery to maroon then to gray in the center of the nodule. Some predominantly maroon nodules have a gradual transition from red to gray spots. Chert is of very high tool quality when unfractured, but has concoidal fracture when broken.

Colluvium covering the upper part of the slope contains abundant prehistoric artifacts (both flakes and tools). They are made of local Siksikpuk noduled chert; most of them are

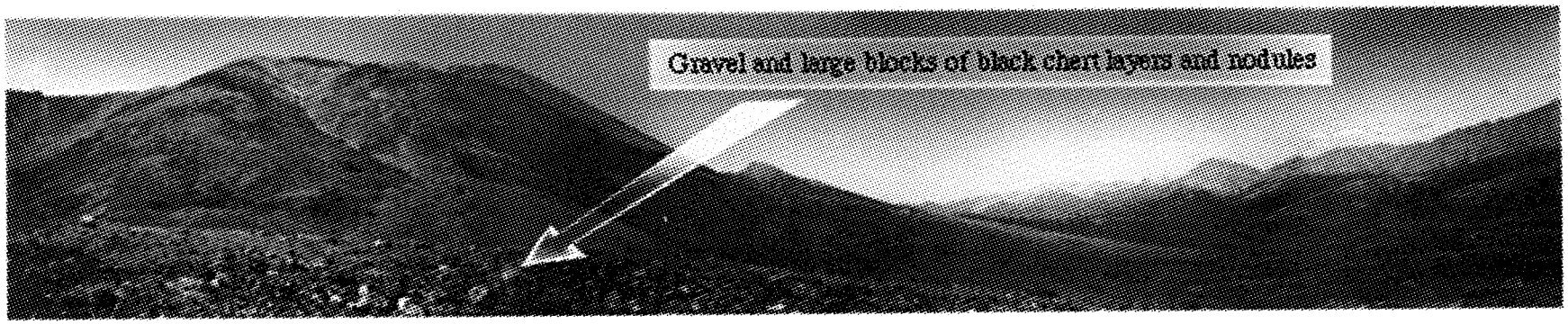


Figure 4.4. Wrench Creek quarry, general view.



Figure 4.5 Upper Kelly River quarry, general view to the north from the top of the pass through the Brooks Range. The slope (in the foreground of the photo) is covered by gravel of gray, blue-gray and red chert nodules weathered from Siksikpuk Formation

gray, and few flakes are red.

4.4.3. Upper Kugururok River Quarry

The quarry is located in the Kugururok River headwater region in a pass through the Brooks Range front (Malyk-Selivanova, 1997) (Fig. 4.2). A narrow cleft dissects the eastern bank of Nunaviksak Creek and the southern cleft wall (~11 m in high) exposes Etivluk Group chert-shale deposits in the Kelly River allochthon (Curtis et al., 1984) (Fig. 4.6a). Deposits are represented almost entirely by bedded and nodular blue-gray and red cherts with no more than 7% shale (Fig. 4.6b). The lower part of the outcrop consists of nodules (up to 10 x 25 cm), lenses (up to 40 cm in length and 25 cm in thickness) and layers (5-10 cm) of blue-gray and mottled red-and-blue-gray chert. The color zonation in some of the nodule chains is similar to that in the Upper Kelly River quarry nodules. The upper part of the exposure consists of red chert layers 5-10 cm in thickness.

About 500 m north of the outcrop, a large chert workshop (documented as Noat. 3060 site by NPS survey) represented by hundreds of prehistoric flakes and tools was found. It is located on the eastern bank of Nunaviksak Creek in a pass through the Brooks Range, used by modern caribou. The color of chert artifacts is black, dark smoky-gray, maroon, blue-gray and mottled gray-maroon.

4.4.4. Anisak Quarry

The quarry is located in the middle part of Anisak River valley (Malyk-Selivanova, 1997) (Fig. 4.2). The quarry occurs on the southwest slope of a steep bank of a small tributary of the Anisak River (Fig. 4.7a) and is composed of exposed bedrock of the gray cherts of Otuk Formation (Etivluk Group, Triassic-Jurassic) from the Brooks Range allochthon (Mayfield et al., 1984). Chert layers are 5 - 8 cm thick with no interbedded shale

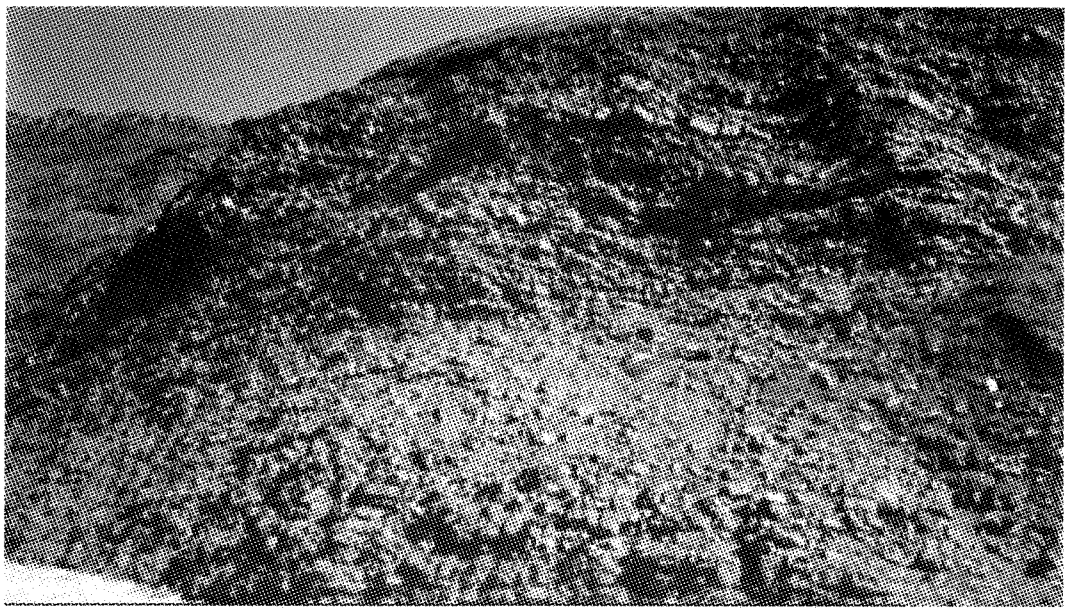


Figure 4.6a. Upper Kugururok River quarry, general view.



Figure 4.6b. Upper Kugururok River quarry. Layers and nodules of gray chert.

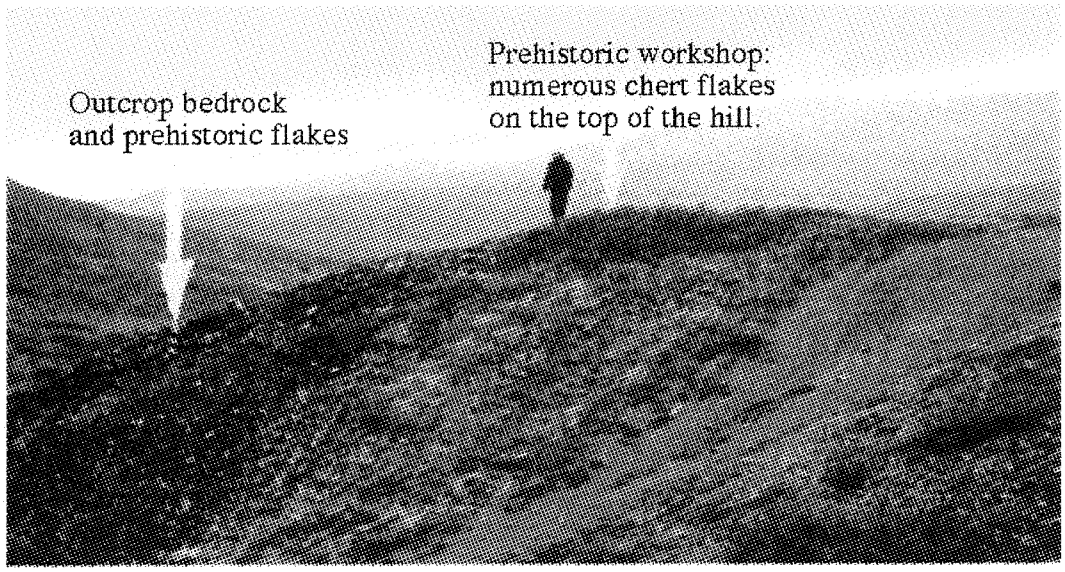


Figure 4.7a. Anisak quarry, general view.



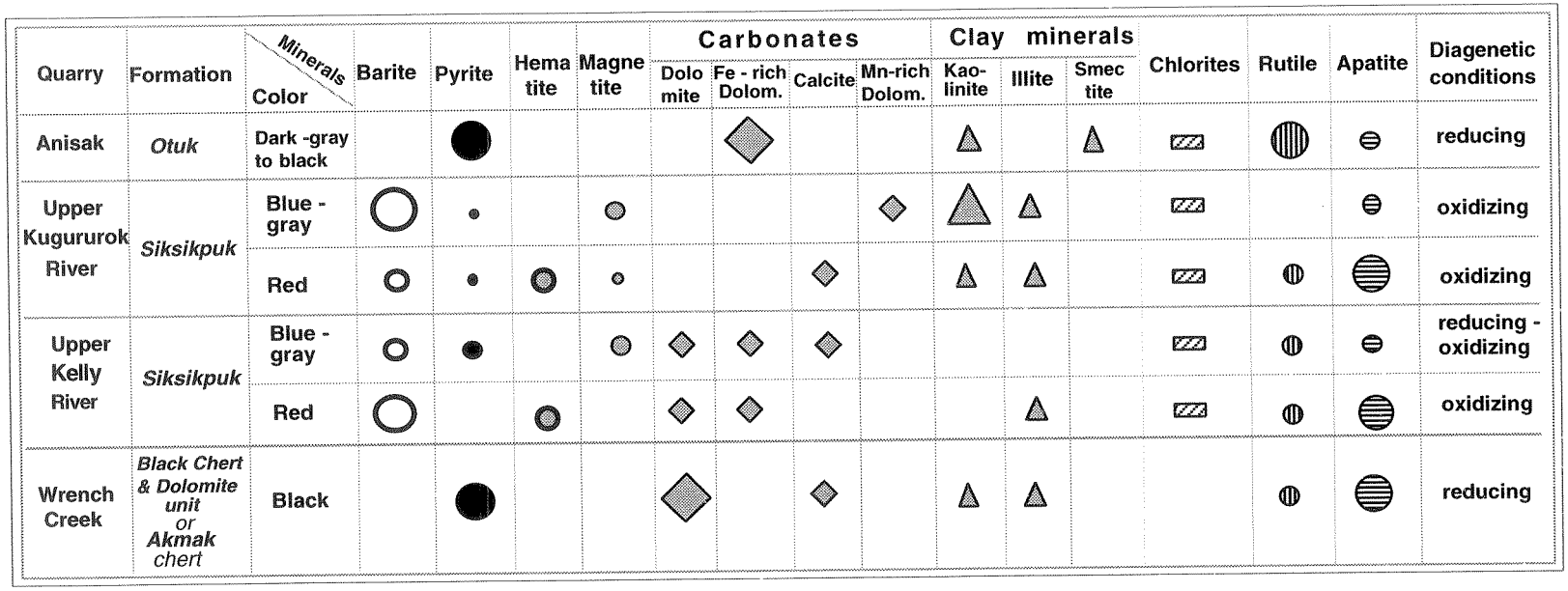
Figure 4.7b. Anisak quarry. The flags show location of prehistoric artifacts.

and are tightly bedded and commonly fractured (Fig. 4.7b). Chert nodules of different sizes (often slightly fractured, 4-5 cm to 45 cm in diameter) occur in colluvium on the slope, as well as on the top of the bank. Some nodules are blue-gray and black mottled (black spots in the middle part). Abundant, sporadically located pyrite inclusions (1 - 3 mm) in both black and blue-gray colored zones are typical features of Anisak cherts.

There are four locations with concentrated prehistoric artifacts (flakes and cores) made of blue-gray and blue-gray-black mottled chert on the exposure: two immediately in the slope colluvium and two others on the top of the bank (Fig. 4.7a,b). No tools were found suggesting that the site served solely as a quarry.

4.5. Mineralogy and Geochemistry of Quarries

The mineral composition of inclusions in the chert varieties from four quarries is shown in Figure 4.8. Two main mineralogical types were determined (Fig. 4.3). Pyrite inclusions (indicating reducing diagenetic conditions, see Chapter 2) are characteristic of black Wrench Creek chert and gray and black Anisak chert. Presence of barite and iron oxides (indicating dominant oxidizing conditions, see Chapter 2) with single pyrite inclusions is characteristic for all blue-gray and red cherts of Upper Kelly River and Upper Kugururok River quarries (Siksikpuk Formation). Presence of hematite (determined by XRD) was found in red cherts of these two quarries, but not in the blue-gray cherts. This is consistent with the red color in cherts being caused by hematite micro inclusions (Loope and Watkins, 1989). It was also determined that the very sharp contact between black and blue-gray zones in Anisak chert nodules is characterized with the sharp enrichment of black zone with organic carbon, whereas all other geochemical signatures are similar (see Chapter 2).



Quarry	Formation	Minerals / Color	Barite	Pyrite	Hematite	Magnetite	Carbonates: Dolomite	Carbonates: Fe-rich Dolom.	Carbonates: Calcite	Carbonates: Mn-rich Dolom.	Clay minerals: Kaolinite	Clay minerals: Illite	Clay minerals: Smectite	Chlorites	Rutile	Apatite	Diagenetic conditions
Anisak	*Otuk*	Dark -gray to black		●				◆			▲		▲	▨	◍	⊖	reducing
Upper Kugururok River	*Siksikpuk*	Blue - gray	○	•		○				◆	▲	▲		▨		⊖	oxidizing
		Red	○	•	◎	•			◆		▲	▲		▨	◍	◍	oxidizing
Upper Kelly River	*Siksikpuk*	Blue - gray	○	●		○	◆	◆	◆					▨	◍	⊖	reducing - oxidizing
		Red	○		◎		◆	◆				▲		▨	◍	◍	oxidizing
Wrench Creek	***Black Chert & Dolomite unit*** *or* ***Akmak*** *chert*	Black		●			◆		◆		▲	▲			◍	◍	reducing

Figure 4.8. Mineralogical composition of cherts from the western Brooks Range quarries.

A summary of instrumental neutron activation analysis data for the four western Brooks Range quarries is presented in Table 4.I. Based on these data, sets of geochemical signatures (elemental abundances and elemental ratios) were created for correlation of artifacts with quarries. The specific signatures selected for correlation of each color group of artifacts with quarries and method of selection of signatures are described in Appendix I.

4.6. Correlation of Artifacts with Quarries

4.6.1. Geological-Geochemical Approach

The geological-geochemical approach is based on the thesis that both the prehistoric artifact and its geological source have identical mineralogy, microfossils, and bulk trace element chemistry that reflect their identical geological history. Geochemical signatures record specific geological conditions of chert formation and are unique for each chert layer and unit. Geochemical signatures such as Ce_n/Ce_n^*, Eu_n/Sm_n, and Ba/Fe were taken for key signatures as they reflect depositional environment, provenance, and diagenetic patterns, respectively, and thus are firm indicators for correlation of artifacts with stratigraphic units of chert deposits. Other signatures (such as Th/Sc, Rb/Sr, Cs/<Mn, Mn/Al, Fe/Al) based on elements (or their ratios) that are diagenetically mobile during chert formation reflect the local geochemistry of a stratigraphic formation, and can be used for correlation of artifacts with a specific outcrop belonging to the same formation. The procedure of selection of signatures for correlation of artifacts with quarries is discussed in detail in Chapter 3.

The correlation of artifacts with outcrop cherts includes the superposition of each artifact composition on a number of geochemical fields selected for each chert variety (Fig. 4.9). Geochemical fields describe the variability of geochemical signature values within the

C. SUMMARY OF REE DATA (ppm)

Outcrop index	Color	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	La_n/Yb_n	Ce_n/Ce_n*	Eu_n/Sm_n
Anisak quarry:													
AN10	gray	2.31±0.86	6.42±3.01	2.30±1.28	0.54±0.23	0.15±0.06	0.10±0.03	0.47±0.15	0.34±0.09	0.06±0.02	0.49± 0.10	1.22 ± 0.17	1.48 ± 0.12
Upper Kugururok quarry:													
NU02g	gray	2.57±0.58	5.86±1.59	2.64±0.91	0.55±0.17	0.13±0.04	0.09±0.03	0.52±0.12	0.30±0.05	0.04±0.01	0.64± 0.08	1.01 ± 0.11	1.25 ± 0.09
NU02r	red	1.80±0.60	4.65±1.73	2.17±0.79	0.56±0.19	0.14±0.05	0.11±0.05	0.70±0.39	0.42±0.10	0.06±0.01	0.31± 0.05	1.07 ± 0.08	1.29 ± 0.07
Upper Kelly quarry:													
KE13g	gray	1.36±0.30	2.60±0.75	1.82±0.72	0.31±0.07	0.07±0.02	0.04±0.03	0.27±0.14	0.17±0.04	0.03±0.01	0.61± 0.05	0.77 ± 0.11	1.19 ± 0.06
KE13 r	red	7.26±4.20	15.94±9.32	7.89±4.72	1.51±0.81	0.37±0.20	0.27±0.16	1.35±0.71	0.69±0.27	0.11±0.05	0.73± 0.21	0.93 ± 0.08	1.25 ± 0.08
Wrench Creek quarry:													
WC04	black	2.02±0.30	1.66±0.27	1.42±0.34	******	0.05±0.01	0.03±0.01	0.20±0.07	0.12±0.02	0.03±0.00	1.32± 0.30	0.40 ± 0.03	******

Note: ****** - data for Sm have been affected by Sm-U interference in U-enriched chert from Wrench Creek quarry (WC04 outcrop).

TABLE 4.I SUMMARY OF INAA DATA FOR PREHISTORIC QUARRIES IN THE WESTERN BROOKS RANGE
(based on the INAA of 15 samples from each chert variety)

A. SUMMARY OF MAJOR ELEMENT DATA (ppm)

Outcrop index	Color	Al	Ca	K	Mn	Na	Fe	Ba
Anisak quarry:								
AN10	gray	8300 ± 1700	100 ± 190	2200 ± 1100	162 ± 215	700 ± 80	4550 ± 3230	830 ± 87
Upper Kugururok quarry:								
NU02g	gray	8700 ± 140	490 ± 600	2200 ± 1100	343 ± 41	1150 ± 80	3200 ± 450	7720 ± 4816
NU02r	red	6700 ± 410	2500 ± 960	800 ± 1300	147 ± 62	700 ± 175	3650 ± 1300	1770 ± 380
Upper Kelly quarry:								
KE13g	gray	4900 ± 240	920 ± 400	1900 ± 900	255 ± 123	600 ± 280	4000 ± 1920	22440 ± 10820
KE13 r	red	13600 ± 4900	360 ± 920	380 ± 1900	194 ± 255	2000 ± 580	8100 ± 4000	28750 ± 22440
Wrench Creek quarry:								
WC04	black	3000 ± 600	15300 ± 7800	500 ± 400	10 ± 3	400 ± 100	750 ± 100	80 ± 30

Note: *** - below detection limit.

B. SUMMARY OF TRACE ELEMENT DATA (ppm)

Outcrop index	Color	Cr	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	Sb	Co
Anisak quarry:												
AN10	gray	8.50 ± 5.20	0.03 ± 0.06	0.85 ± 0.20	3.19 ± 0.74	0.79 ± 0.17	0.66 ± 0.08	12.30 ± 3.20	64.30 ± 27.20	0.08 ± 0.01	0.82 ± 0.23	5.10 ± 2.40
Upper Kugururok quarry:												
NU02g	gray	8.50 ± 0.50	0.02 ± 0.08	0.79 ± 0.09	2.71 ± 0.25	0.62 ± 0.08	0.58 ± 0.07	8.90 ± 1.30	314.00 ± 130.10	0.07 ± 0.01	0.44 ± 0.05	2.00 ± 0.50
NU02r	red	1.80 ± 0.70	0.26 ± 0.20	0.30 ± 0.11	2.03 ± 2.03	0.20 ± 0.20	0.39 ± 0.39	3.10 ± 3.10	70.00 ± 70.00	0.04 ± 0.04	0.24 ± 0.02	2.60 ± 4.10
Upper Kelly quarry:												
KE13r	red	9.80 ± 3.00	0.04 ± 0.16	1.63 ± 0.53	7.87 ± 3.66	0.92 ± 0.36	1.31 ± 0.47	15.50 ± 6.00	902.00 ± 666.30	0.16 ± 0.06	0.49 ± 0.05	4.80 ± 3.80
KE13g	gray	3.00 ± 1.50	0.16 ± 0.08	0.53 ± 0.26	3.66 ± 1.76	0.36 ± 0.18	0.47 ± 0.22	6.00 ± 2.90	666.30 ± 321.20	0.06 ± 0.03	0.21 ± 0.03	3.30 ± 1.50
Wrench Creek quarry:												
WC04	black	7.00 ± 1.20	2.26 ± 0.44	0.28 ± 0.03	0.29 ± 0.04	0.61 ± 0.03	0.20 ± 0.03	2.40 ± 0.50	9.70 ± 4.60	0.03 ± 0.00	0.11 ± 0.02	0.23 ± 0.04



Figure 4.5 Upper Kelly River quarry, general view to the north from the top of the pass through the Brooks Range. The slope (in the foreground of the photo) is covered by gravel of gray, blue-gray and red chert nodules weathered from Siksikpuk Formation

gray, and few flakes are red.

4.4.3. Upper Kugururok River Quarry

The quarry is located in the Kugururok River headwater region in a pass through the Brooks Range front (Malyk-Selivanova, 1997) (Fig. 4.2). A narrow cleft dissects the eastern bank of Nunaviksak Creek and the southern cleft wall (~11 m in high) exposes Etivluk Group chert-shale deposits in the Kelly River allochthon (Curtis et al., 1984) (Fig. 4.6a). Deposits are represented almost entirely by bedded and nodular blue-gray and red cherts with no more than 7% shale (Fig. 4.6b). The lower part of the outcrop consists of nodules (up to 10 x 25 cm), lenses (up to 40 cm in length and 25 cm in thickness) and layers (5-10 cm) of blue-gray and mottled red-and-blue-gray chert. The color zonation in some of the nodule chains is similar to that in the Upper Kelly River quarry nodules. The upper part of the exposure consists of red chert layers 5-10 cm in thickness.

About 500 m north of the outcrop, a large chert workshop (documented as Noat. 3060 site by NPS survey) represented by hundreds of prehistoric flakes and tools was found. It is located on the eastern bank of Nunaviksak Creek in a pass through the Brooks Range, used by modern caribou. The color of chert artifacts is black, dark smoky-gray, maroon, blue-gray and mottled gray-maroon.

4.4.4. Anisak Quarry

The quarry is located in the middle part of Anisak River valley (Malyk-Selivanova, 1997) (Fig. 4.2). The quarry occurs on the southwest slope of a steep bank of a small tributary of the Anisak River (Fig. 4.7a) and is composed of exposed bedrock of the gray cherts of Otuk Formation (Etivluk Group, Triassic-Jurassic) from the Brooks Range allochthon (Mayfield et al., 1984). Chert layers are 5 - 8 cm thick with no interbedded shale

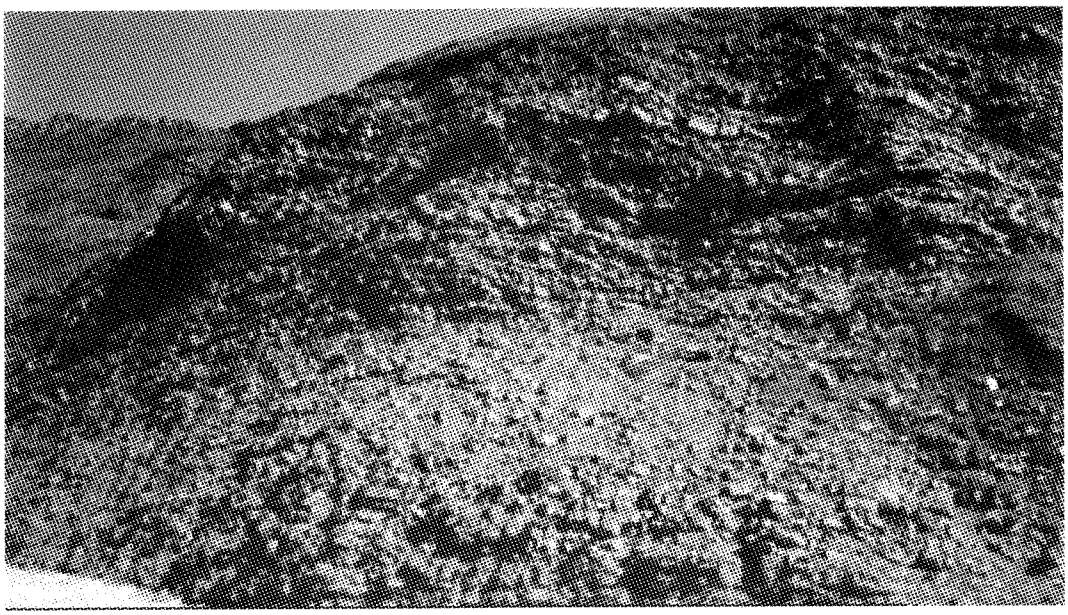


Figure 4.6a. Upper Kugururok River quarry, general view.



Figure 4.6b. Upper Kugururok River quarry. Layers and nodules of gray chert.

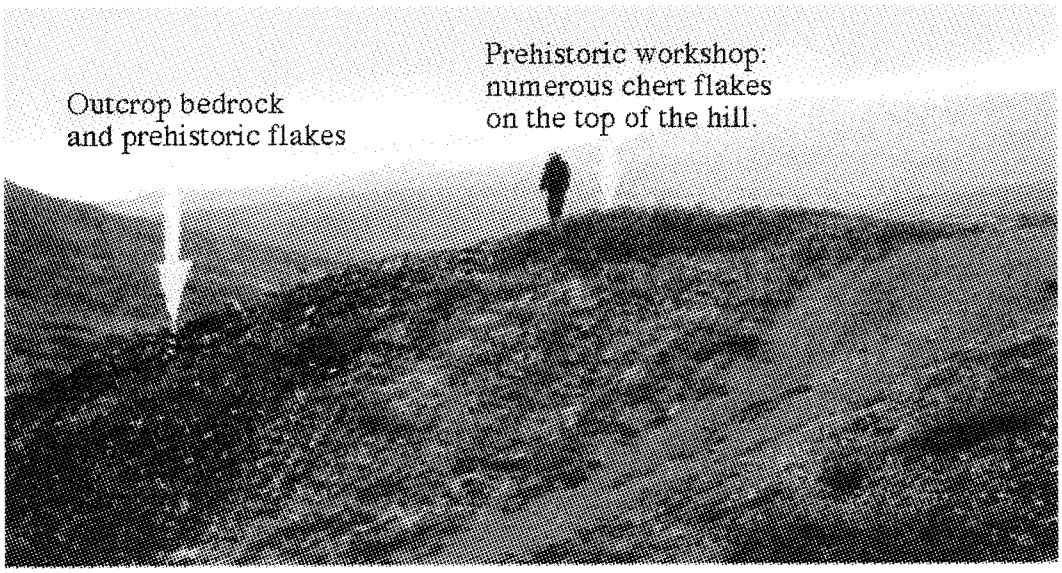


Figure 4.7a. Anisak quarry, general view.



Figure 4.7b. Anisak quarry. The flags show location of prehistoric artifacts.

and are tightly bedded and commonly fractured (Fig. 4.7b). Chert nodules of different sizes (often slightly fractured, 4-5 cm to 45 cm in diameter) occur in colluvium on the slope, as well as on the top of the bank. Some nodules are blue-gray and black mottled (black spots in the middle part). Abundant, sporadically located pyrite inclusions (1 - 3 mm) in both black and blue-gray colored zones are typical features of Anisak cherts.

There are four locations with concentrated prehistoric artifacts (flakes and cores) made of blue-gray and blue-gray-black mottled chert on the exposure: two immediately in the slope colluvium and two others on the top of the bank (Fig. 4.7a,b). No tools were found suggesting that the site served solely as a quarry.

4.5. Mineralogy and Geochemistry of Quarries

The mineral composition of inclusions in the chert varieties from four quarries is shown in Figure 4.8. Two main mineralogical types were determined (Fig. 4.3). Pyrite inclusions (indicating reducing diagenetic conditions, see Chapter 2) are characteristic of black Wrench Creek chert and gray and black Anisak chert. Presence of barite and iron oxides (indicating dominant oxidizing conditions, see Chapter 2) with single pyrite inclusions is characteristic for all blue-gray and red cherts of Upper Kelly River and Upper Kugururok River quarries (Siksikpuk Formation). Presence of hematite (determined by XRD) was found in red cherts of these two quarries, but not in the blue-gray cherts. This is consistent with the red color in cherts being caused by hematite micro inclusions (Loope and Watkins, 1989). It was also determined that the very sharp contact between black and blue-gray zones in Anisak chert nodules is characterized with the sharp enrichment of black zone with organic carbon, whereas all other geochemical signatures are similar (see Chapter 2).

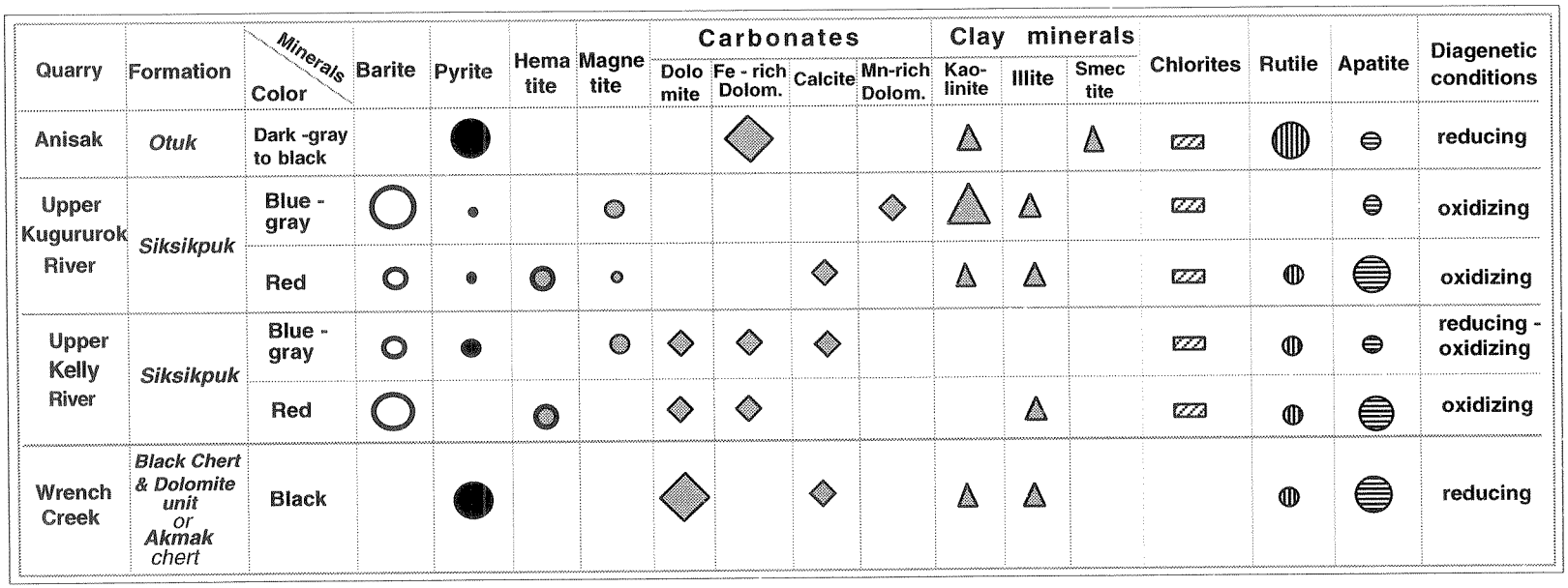


Figure 4.8. Mineralogical composition of cherts from the western Brooks Range quarries.

A summary of instrumental neutron activation analysis data for the four western Brooks Range quarries is presented in Table 4.I. Based on these data, sets of geochemical signatures (elemental abundances and elemental ratios) were created for correlation of artifacts with quarries. The specific signatures selected for correlation of each color group of artifacts with quarries and method of selection of signatures are described in Appendix I.

4.6. Correlation of Artifacts with Quarries

4.6.1. Geological-Geochemical Approach

The geological-geochemical approach is based on the thesis that both the prehistoric artifact and its geological source have identical mineralogy, microfossils, and bulk trace element chemistry that reflect their identical geological history. Geochemical signatures record specific geological conditions of chert formation and are unique for each chert layer and unit. Geochemical signatures such as Ce_n/Ce_n^*, Eu_n/Sm_n, and Ba/Fe were taken for key signatures as they reflect depositional environment, provenance, and diagenetic patterns, respectively, and thus are firm indicators for correlation of artifacts with stratigraphic units of chert deposits. Other signatures (such as Th/Sc, Rb/Sr, Cs/<Mn, Mn/Al, Fe/Al) based on elements (or their ratios) that are diagenetically mobile during chert formation reflect the local geochemistry of a stratigraphic formation, and can be used for correlation of artifacts with a specific outcrop belonging to the same formation. The procedure of selection of signatures for correlation of artifacts with quarries is discussed in detail in Chapter 3.

The correlation of artifacts with outcrop cherts includes the superposition of each artifact composition on a number of geochemical fields selected for each chert variety (Fig. 4.9). Geochemical fields describe the variability of geochemical signature values within the

C. SUMMARY OF REE DATA (ppm)

Outcrop index	Color	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	La_n/Yb_n	Ce_n/Ce_n^*	Eu_n/Sm_n
Anisak quarry:													
AN10	gray	2.31±0.86	6.42±3.01	2.30±1.28	0.54±0.23	0.15±0.06	0.10±0.03	0.47±0.15	0.34±0.09	0.06±0.02	0.49± 0.10	1.22 ± 0.17	1.48 ± 0.12
Upper Kugururok quarry:													
NU02g	gray	2.57±0.58	5.86±1.59	2.64±0.91	0.55±0.17	0.13±0.04	0.09±0.03	0.52±0.12	0.30±0.05	0.04±0.01	0.64± 0.08	1.01 ± 0.11	1.25 ± 0.09
NU02r	red	1.80±0.60	4.65±1.73	2.17±0.79	0.56±0.19	0.14±0.05	0.11±0.05	0.70±0.39	0.42±0.10	0.06±0.01	0.31± 0.05	1.07 ± 0.08	1.29 ± 0.07
Upper Kelly quarry:													
KE13g	gray	1.36±0.30	2.60±0.75	1.82±0.72	0.31±0.07	0.07±0.02	0.04±0.03	0.27±0.14	0.17±0.04	0.03±0.01	0.61± 0.05	0.77 ± 0.11	1.19 ± 0.06
KE13 r	red	7.26±4.20	15.94±9.32	7.89±4.72	1.51±0.81	0.37±0.20	0.27±0.16	1.35±0.71	0.69±0.27	0.11±0.05	0.73± 0.21	0.93 ± 0.08	1.25 ± 0.08
Wrench Creek quarry:													
WC04	black	2.02±0.30	1.66±0.27	1.42±0.34	******	0.05±0.01	0.03±0.01	0.20±0.07	0.12±0.02	0.03±0.00	1.32± 0.30	0.40 ± 0.03	******

Note: ****** - data for Sm have been affected by Sm-U interference in U-enriched chert from Wrench Creek quarry (WC04 outcrop).

TABLE 4.1 SUMMARY OF INAA DATA FOR PREHISTORIC QUARRIES IN THE WESTERN BROOKS RANGE
(based on the INAA of 15 samples from each chert variety)

A. SUMMARY OF MAJOR ELEMENT DATA (ppm)

Outcrop index	Color	Al	Ca	K	Mn	Na	Fe	Ba
Anisak quarry:								
AN10	gray	8300 ± 1700	100 ± 190	2200 ± 1100	162 ± 215	700 ± 80	4550 ± 3230	830 ± 87
Upper Kugururok quarry:								
NU02g	gray	8700 ± 140	490 ± 600	2200 ± 1100	343 ± 41	1150 ± 80	3200 ± 450	7720 ± 4816
NU02r	red	6700 ± 410	2500 ± 960	800 ± 1300	147 ± 62	700 ± 175	3650 ± 1300	1770 ± 380
Upper Kelly quarry:								
KE13g	gray	4900 ± 240	920 ± 400	1900 ± 900	255 ± 123	600 ± 280	4000 ± 1920	22440 ± 10820
KE13 r	red	13600 ± 4900	360 ± 920	380 ± 1900	194 ± 255	2000 ± 580	8100 ± 4000	28750 ± 22440
Wrench Creek quarry:								
WC04	black	3000 ± 600	15300 ± 7800	500 ± 400	10 ± 3	400 ± 100	750 ± 100	80 ± 30

Note: *** - below detection limit.

B. SUMMARY OF TRACE ELEMENT DATA (ppm)

Outcrop index	Color	Cr	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	Sb	Co
Anisak quarry:												
AN10	gray	8.50 ± 5.20	0.03 ± 0.06	0.85 ± 0.20	3.19 ± 0.74	0.79 ± 0.17	0.66 ± 0.08	12.30 ± 3.20	64.30 ± 27.20	0.08 ± 0.01	0.82 ± 0.23	5.10 ± 2.40
Upper Kugururok quarry:												
NU02g	gray	8.50 ± 0.50	0.02 ± 0.08	0.79 ± 0.09	2.71 ± 0.25	0.62 ± 0.08	0.58 ± 0.07	8.90 ± 1.30	314.00 ± 130.10	0.07 ± 0.01	0.44 ± 0.05	2.00 ± 0.50
NU02r	red	1.80 ± 0.70	0.26 ± 0.20	0.30 ± 0.11	2.03 ± 2.03	0.20 ± 0.20	0.39 ± 0.39	3.10 ± 3.10	70.00 ± 70.00	0.04 ± 0.04	0.24 ± 0.02	2.60 ± 4.10
Upper Kelly quarry:												
KE13r	red	9.80 ± 3.00	0.04 ± 0.16	1.63 ± 0.53	7.87 ± 3.66	0.92 ± 0.36	1.31 ± 0.47	15.50 ± 6.00	902.00 ± 666.30	0.16 ± 0.06	0.49 ± 0.05	4.80 ± 3.80
KE13g	gray	3.00 ± 1.50	0.16 ± 0.08	0.53 ± 0.26	3.66 ± 1.76	0.36 ± 0.18	0.47 ± 0.22	6.00 ± 2.90	666.30 ± 321.20	0.06 ± 0.03	0.21 ± 0.03	3.30 ± 1.50
Wrench Creek quarry:												
WC04	black	7.00 ± 1.20	2.26 ± 0.44	0.28 ± 0.03	0.29 ± 0.04	0.61 ± 0.03	0.20 ± 0.03	2.40 ± 0.50	9.70 ± 4.60	0.03 ± 0.00	0.11 ± 0.02	0.23 ± 0.04

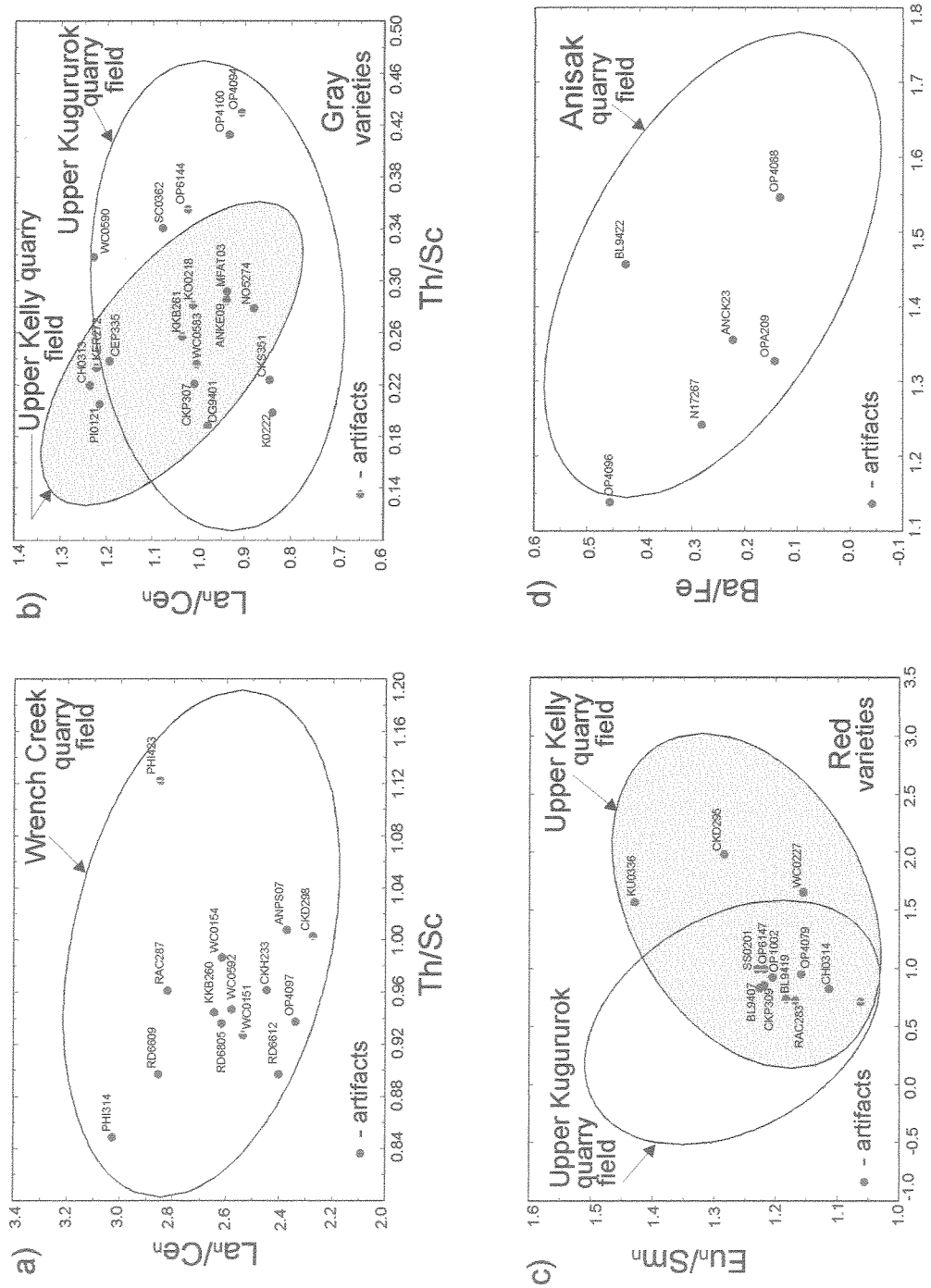

a)
Wrench Creek quarry field
- artifacts
La_n/Ce_n
Th/Sc
b)
Upper Kelly quarry field
Upper Kugururok quarry field
Gray varieties
- artifacts
La_n/Ce_n
Th/Sc
c)
Upper Kugururok quarry field
Upper Kelly quarry field
Red varieties
- artifacts
Eu_n/Sm_n
Th
d)
Anisak quarry field
- artifacts
Ba/Fe
Eu_n/Sm_n

Figure 4.9.

Figure 4.9. Illustration of artifacts - quarries correlation by superposition of artifact data on the quarry geochemical fields obtained at 3σ from the mean of the signature values. Artifact was correlated with quarry if it fell systematically by all 37-40 signatures into the fields of appropriate quarry; (a) all 14 black artifacts fell into the Wrench Creek quarry geochemical fields, (b) all 19 gray and (c) 23 red artifacts fell into Upper Kelly River and Upper Kugururok River quarry fields, and (d) six gray chert artifacts- within the Anisak quarry fields.

geological chert source. They were determined statistically (three standard deviations from the mean) based on analysis of 15 samples from each chert variety. Outcrops associated with prehistoric workshops provide a unique opportunity for determining the variability of mined raw materials within the prehistoric quarries where many different layers may have been mined by different prehistoric people. In order to determine geochemical fields that describe the variability of raw material in each of four quarries, data of artifacts found in each quarry were combined with the data for chert layers sampled in that quarry. These new geochemical "quarry" fields were then used for correlation of artifacts with quarries.

Each of the 252 artifacts sampled during the archaeological survey and from museum collections were compared with similarly colored chert varieties from quarries. A total of 51 artifacts from 29 prehistoric sites were firmly correlated with the western Brooks Range quarries at 99.7% confidence (three standard deviation from the mean of geochemical signature values) (Appendix II.1).

4.6.2. Wrench Creek Quarry.

Wrench Creek chert is characterized with negative Ce anomalies (Chapter 3) that, according to Murray (1994), indicate an open ocean depositional environment. The range of $Ce_n/Ce_n^* = 0.40 \pm 0.09$ (three standard deviations from the mean) is characteristic for the Wrench Creek quarry chert and provides a powerful tool for correlation of black artifacts. All black artifacts that fall outside this range most likely come from a different depositional environment and consequently from a different geological source. They can not be assigned to the Wrench Creek quarry even if all other signatures are identical.

One hundred and six black chert artifacts sampled from 40 prehistoric sites of northwestern Alaska are essentially identical based on visual properties. However, 75 of

them lie outside the range of Ce_n/Ce_n^* values in the Wrench Creek chert indicating a different depositional environment (Fig. 4.10). Twenty-seven artifacts are within the range of Ce_n/Ce_n^* values in the Wrench Creek chert (Fig. 10), but only 14 of them were correlated with the Wrench Creek quarry based on the similarity by all other geochemical signatures (Table 4.II, Fig 4.9a). These 14 artifacts comprise only 13% of 106 black chert artifacts analyzed. Ninety two black chert artifacts (87%) were not correlated with Wrench Creek quarry. Some of them have negative Ce anomalies that are, however, different from Wrench Creek chert (Fig. 4.10) indicating that they originated from one of the chert units of Lisburne Group (that are characterized by such anomalies) (Fig. 4.3). Many black chert artifacts have no or positive Ce anomalies, and thus came from unknown black cherts deposited in a tectonical setting (continental margin) distinctly different from that of the Wrench Creek chert.

4.6.3. Upper Kelly River and Upper Kugururok River Quarries.

These quarries are located a relatively short distance from each other (and belong to the same stratigraphic units and allochthon (Fig. 4.3). Their outcrop layers are clearly distinguished from each other geochemically. However, their geochemical quarry fields that were determined by combining layers and artifact data (for both gray and red chert varieties) often overlap (Fig. 4.9b,c). Some artifacts that fall into the overlapping zones were assigned to both of them. Therefore, it is appropriate to present the results of artifact correlation with both quarries together.

Most of the gray and blue chert artifacts are visually indistinguishable. Of 120 artifacts from 41 prehistoric sites (excluding quarries), only 19 artifacts from 15 sites (16%)

Table 4. II. Black Chert Artifacts Correlated with Wrench Creek Quarry

#	Artifact ID	Color	Prehistoric site # on the map	Prehistoric site Name	Culture	Quarry
1	WC0151	Black	46	Wr. Cr., Noat 3014	?	Wrench Creek
2	WC0154	Black	46	Wr. Cr., Noat 3014	?	Wrench Creek
3	WC0592	Black	49	Wr. Cr., Noat 3023	?	Wrench Creek
4	RD6805	Black	21	Red Dog Del-168	American Paleo-Arctic	Wrench Creek
5	RD6609	Black	22	Red Dog Del-166	American Paleo-Arctic	Wrench Creek
6	RD6612	Black	22	Red Dog Del-166	American Paleo-Arctic	Wrench Creek
7	OP4097	Black	34	On. Port., 4 band,	Denbigh	Wrench Creek
8	KKB260	Black	37	Kiana Bench	Pleist. site above Kiana	Wrench Creek
9	CKH233	Black	30	C. Krusenstern	Old Whaling	Wrench Creek
10	CKD298	Black	29	C. Krusenstern	Denbigh	Wrench Creek
11	ANPS07	Black	24	C. Krusenstern	Palisades	Wrench Creek
12	RAC287	Black	56	Rabbit Creek	American Paleo-Arctic?	Wrench Creek
13	PHI314	Black	55	Point Hope	Ipiutak	Wrench Creek
14	PHI423	Black	55	Point Hope	Ipiutak	Wrench Creek

Wr.Cr. = Wrench, On. Port. = Onion Portage, Creek; C.=Cape.

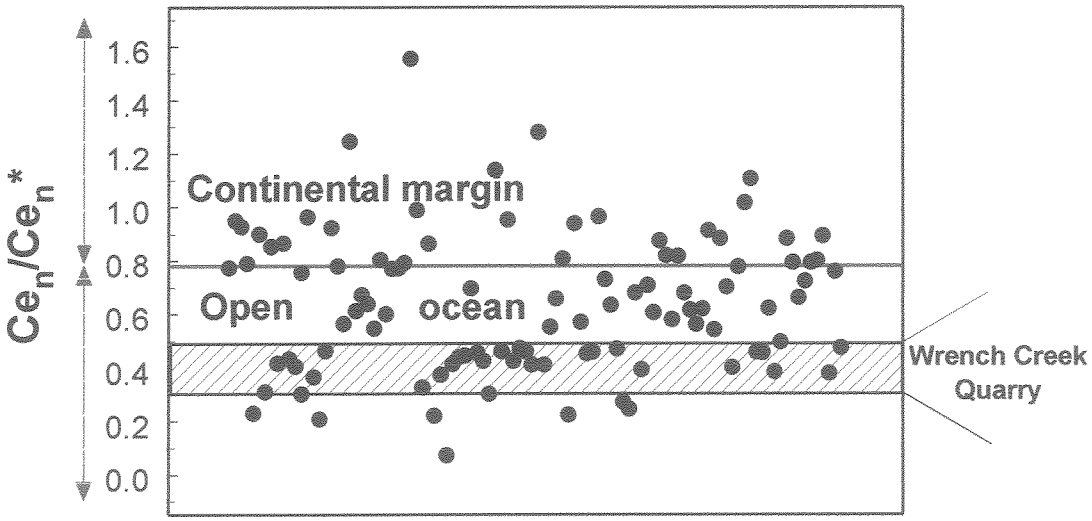


Figure 4.10. Correlation of black chert artifacts with the Wrench Creek quarry by Ce_n/Ce_n^* values. The hatched area shows the range of $Ce_n/Ce_n^* = 0.40 \pm 0.09$ (three standard deviations from the mean) in the Wrench Creek quarry.

were firmly correlated with Upper Kelly River and Upper Kugururok River quarries: seven with Upper Kelly River quarry, two with Upper Kugururok River quarry, and ten with both of them (Table 4.III, Fig. 4.9b). The other six gray artifacts were correlated with Anisak quarry and are considered below. Ninety five gray artifacts were left unidentified.

Red-maroon chert artifacts, also visually indistinguishable, are less common in prehistoric assemblages than black and gray artifacts. Twelve (46%) of 26 analyzed red chert artifacts were correlated with Upper Kelly River and Upper Kugururok River quarries: four with Upper Kelly River, and eight with both of them (Table 4.IV, Fig. 4.9c). Fourteen artifacts (54%) were not identified.

4.6.4. Anisak Quarry.

Anisak quarry is a possible source for both gray and black chert artifacts. Anisak chert is basically blue-gray, but some of nodules are mottled blue-gray-and-black. Therefore, all black and gray artifacts were compared with it.

High Ce_n/Ce_n^* and Eu_n/Sm_n values characteristic for the Anisak quarry discriminate black Anisak chert (Etivluk Group) from those Lisburne black chert outcrops (including the Wrench Creek quarry) that commonly have negative Ce anomalies and significantly lower Eu_n/Sm_n. They were used as the key geochemical signatures for correlation of black artifacts with Anisak chert (Chapter 3). No black chert artifacts were correlated with the Anisak quarry.

Pyrite inclusions and very low Ba/Fe (0.26 ± 0.13) values in Anisak chert indicate reducing diagenetic conditions. They firmly discriminate the Anisak quarry from the blue-gray cherts of Upper Kelly River and Upper Kugururok River quarries that are characterized with oxydizing signatures (barite and iron oxides inclusions and high Ba/Fe values) (Chapter

Table 4. III. Gray Artifacts Correlated with Upper Kelly River and Upper Kugururok River Quarries.

#	Artifact ID	Color	Prehistoric site # on the map	Name and Index	Culture	Quarry
1	WC0583	Gray	52	Wrench Cr., Noat 3047	?	Upper Kelly
2	WC0590	Gray	49	Wrench Cr., Noat 3023	?	Upper Kelly
3	ANKE09	Gray	2	Kelly R., NKR1#2	?	Upper Kelly
4	KER272	Gray	2	Kelly R., NKR1#2	?	Up. Ke/Ku
5	SC0362	Gray	45	Saxot Cr., Noat 3011	?	Upper Kelly
6	KU0222	Gray	57	Kugururok R., 1993	?	Upper Kelly
7	KO0218	Gray	7	Kugururok R. (KO02),	?	Upper Kelly
8	NO5274	Gray	9	Noatak R. site N-5	?	Upper Kelly
9	DG9401	Gray	16	Nim. R., Noat 94108	?	Up. Kugurur
10	PI0121	Gray	53	Picnic Creek, 94	?	Up. Kugurur
11	OP4094	Gray	34	On. Port., 4 band,	Denbigh	Up. Ke/Ku
12	OP4100	Gray	34	On. Port., 4 band,	Denbigh	Up. Ke/Ku
13	OP6144	Gray	34	On. Port., 6 band	Palisades	Up. Ke/Ku
14	KKB261	Gray	37	Kiana Bench	Pleist.above Kiana	Up. Ke/Ku
15	MFAT03	Gray	35	Atheut	Early Arctic Woodl.	Up. Ke/Ku
16	CKP301	Gray	24	C. Krusenstern	Palisades	Up. Ke/Ku
17	CKS351	Gray	26	C. Krus., Sisualik	Western Thule	Up. Ke/Ku
18	CHO313	Gray	31	Chor. site, Ch. Pen.	Choris	Up. Ke/Ku
19	CEP335	Gray	32	C. Espenberg	Choris	Up. Ke/Ku

Upper Kelly = Upper Kelly River quarry; Up.Kugurur = Upper Kugururok River quarry
Up. Ke/Up. Ku = Upper Kelly River or Upper Kugururok River quarry, On. Port. = Onion Portage, Chor. site, Ch. Pen. = Choris site on Choris Peninsula,
Nim. R = Nimiuktuk River, C. Krus.= Cape Krusenstern, Pleist. = Pleistocene site.

Table 4. IV. Red Artifacts Correlated with Upper Kelly River and Upper Kugururok River Quarries.

#	Artifact ID	Color	Prehistoric site # on the map	Name	Culture	Quarry
1	WC0227	Red	45	Wrench Cr., Noat 3015	?	Upper Kelly
2	KU0336	Red	6	Kugururok R., 1993, KU03	?	Upper Kelly
3	BL9407	Red	33	Burial Lake	?	Up. Ke/Ku
4	BL9419	Red	33	Burial Lake	?	Up. Ke/Ku
5	SS0201	Red	54	Setting Sun Creek	?	Up. Ke/Ku
6	OP1002	Red	34	On. Port.,1 band,	Arc. Woodl. Eskimo	Up. Ke/Ku
7	OP4079	Red	34	On. Port., 4 band,	Denbigh	Up. Ke/Ku
8	OP6147	Red	34	On. Port., 6 band	Palisades	Up. Ke/Ku
9	CKD295	Red	29	C. Krusenstern	Denbigh	Upper Kelly
10	CKP309	Red	24	C. Krusenstern	Palisades	Upper Kelly
11	RAC283	Red	56	Rabbit Creek	Amer. Paleo-Arctic?	Up. Ke/Ku
12	CH0314	Red	31	Choris site	Choris	Up. Ke/Ku

Upper Kelly = Upper Kelly River quarry;
Up. Ke/Up. Ku = Upper Kelly River quarry or Upper Kugururok River quarry; C.=Cape;
On. Portage=Onion Portage; Cr. =Creek; R.=River.

Table 4. V. Gray Artifacts Correlated with Anisak Quarry

#	Artifact ID	Color	Prehistoric site # on the map	Name	Culture	Quarry
1	N17267	Gray	10	Noatak R. site N-17	?	Anisak
2	BL9422	Gray	33	Burial Lake	?	Anisak
3	OP4088	Gray	34	On. Portage, 4 band,	Denbigh	Anisak
4	OP4096	Gray	34	On. Portage, 4 band,	Denbigh	Anisak
5	OPA209	Gray	34	On. Portage, Akmak	Akmak	Anisak
6	ANCK23	Gray	56	Rabbit Creek	Amer. Paleo-Arctic?	Anisak

3). Six gray chert artifacts (0.05% of gray artifacts) were correlated with the Anisak quarry by all signatures (Table 4.V, Fig. 4.9d).

4.7. Distribution Patterns

4.7.1. Wrench Creek Chert

Eleven prehistoric sites in the study area contain artifacts that are firmly correlated with Wrench Creek quarry (Table 4.II): chipping stations Noat.-3014 and Noat-3023 in the Wrench Creek drainage, Red Dog sites DEL-166 and DEL-168, Point Hope (Ipiutak), Cape Krusenstern sites (Palisades, Denbigh, Old Whaling), Rabbit Creek site, and the Kobuk valley sites (Kiana Bench and Onion Portage). The map of the distribution of this chert (Fig. 4.11) shows that transportation of the chert from the Wrench Creek quarry was both up and down the Wrench Creek (Noat. 3023 and Noat. 3014 respectively), as well as to the Walik River valley (Red Dog sites), and to the sea coast (Point Hope and Cape Krusenstern sites). It also indicates the transportation up the Kobuk River to Kiana Bench and Onion Portage. No Wrench Creek black cherts were identified in sites located up the Noatak River, nor the Kobuk River further upstream than Onion Portage, nor to the south in the site on the Selawik River (Fig. 4.11).

The earliest (American/post-American Paleo-Arctic Tradition) usage of the Wrench Creek chert is recorded in the Red Dog sites and Rabbit Creek (Fig. 4.12). Palisades, Denbigh and Old Whaling people used the Wrench Creek chert in the Cape Krusenstern settlements. It was also used by Ipiutak people in Point Hope. At Onion Portage, the only complex containing Wrench Creek chert is Denbigh complex (band IV), Arctic Small Tool Tradition. All these sites (with exception of one located in the Wrench Creek valley) contain black chert artifacts composed of unidentified cherts, but clearly different

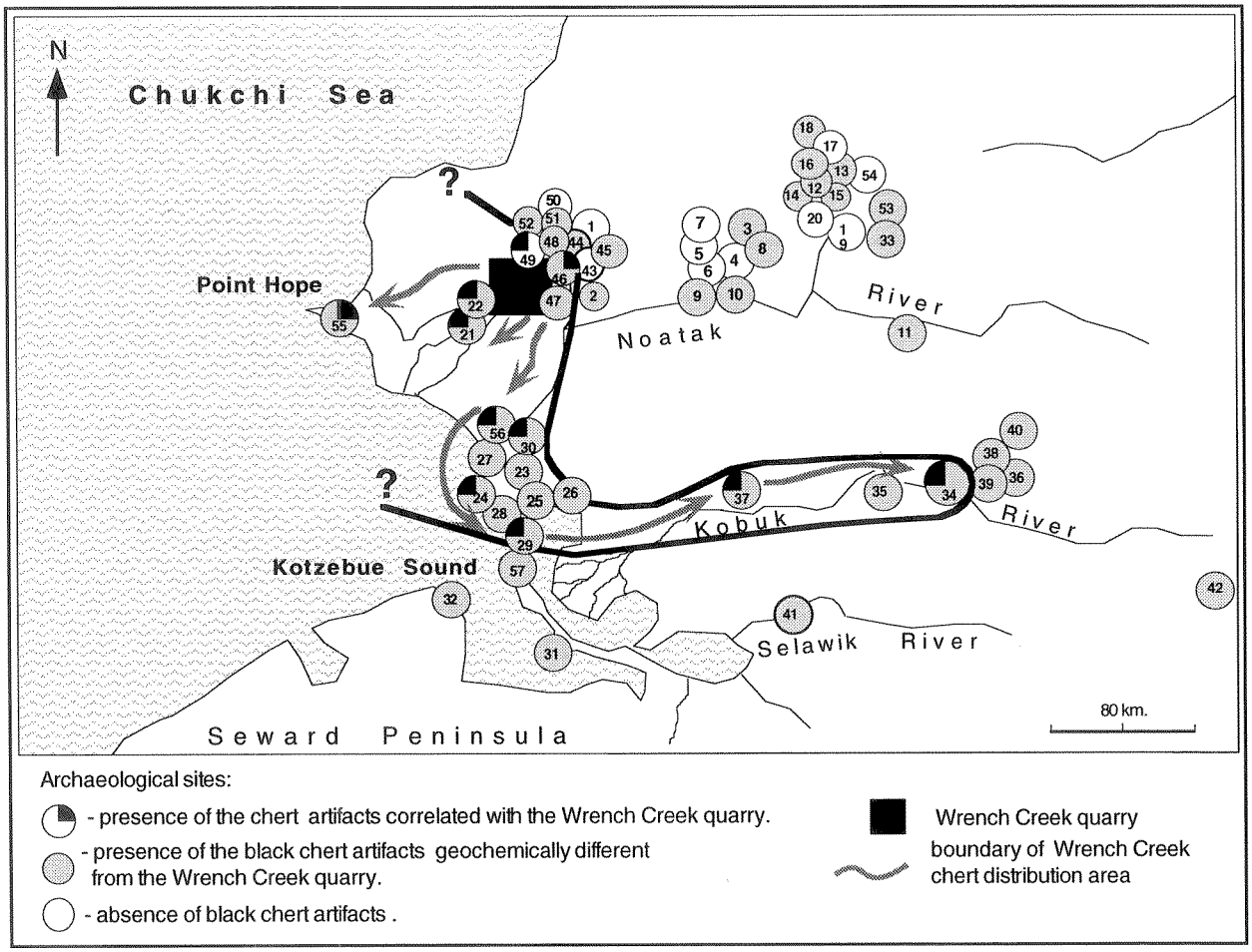

N
Chukchi Sea
Point Hope
Noatak River
Kobuk River
Kotzebue Sound
Selawik River
Seward Peninsula
80 km.
Archaeological sites:
- presence of the chert artifacts correlated with the Wrench Creek quarry.
- presence of the black chert artifacts geochemically different from the Wrench Creek quarry.
- absence of black chert artifacts .
Wrench Creek quarry
boundary of Wrench Creek chert distribution area

Figure 4.11.

Figure 4.11. Map of distribution of black chert artifacts correlated with the Wrench Creek quarry:1) Upper Kelly River quarry, 2) Kelly River chipping stations NKR-1; **Kugururok River sites**: 3) Upper Kugururok River quarry, 4) NKUR-1, 5) KU02, 6) KU03, 7)Kaguik (KO02), 8)NU03 (Noat_3062); **Noatak River sites**: 9) N-5, 10) NR-17, 11) NR-27; **Nimiuktuk River sites**: 12) Nim 5-1, 13) Nim-7, 14) Nim-11, 15) Nim-15, 16) - 94108, 17) -94141, 18) -94127; **Anisak River sites**: 19) Anisak quarry, 20) AN08; 21) Red Dog Del-168, 22) Red Dog Del-166; **Cape Krusenstern sites**: 23) Battle Rock, 24) Palisades, 25) Lower Bench, 26) Sisualik, 27) Birnirk, 28) Ipiutak, 29) Denbigh, 30) Old Whaling; 31) Choris, 32) Cape Espenberg, 33) Burial Lake site; **Kobuk River basin sites**: 34) Onion Portage, 35) Atheut, 36) Lookout site on Knoll, 37) Kiana Bench, 38) High Old Bench, 39) Locality-2, 1963, 40) Ambler River site; 41) Selawik; 42) Lake Norotuk; **Saxsot Creek sites**: 43) Noat.-3006, 44) Noat.-3009, 45) Noat.- 3011; **Wrench Creek sites**: 46) Noat.-3014, 47) Noat.-3015, 48) Noat.-3018, 49) Noat.-3023, 50) Noat.-3024, 51) Noat.-3046, 52) Noat.-3047; **Nimiuktuk River sites**: 53) Picnic Creek site; 54) Setting Sun site; 55) Point Hope site, 56) Rabbit Creek site, 57) Kotzebue.

Prehistoric Traditions	Quarries / Prehistoric complexes and cultures	B.P.	Wrench Creek	Upper Kelly River		Up. Kugururok River		Anisak
				Gray	Red	Gray	Red	
	Arctic Woodland Eskimo	1000-present		Atheut		Atheut	On. Port.	
	Western Thule	1000 - 500		C. K.- Sisualik		C. K.-Sisualik		
Arctic Small Tool	Ipiutak culture	1900-1500	P. Hope					
	Choris culture	2641 ± 150 3600-2500?		Choris on Pen. C.Espenb.	Choris on Pen.			
	Old Whaling	3179 ± 59	C. Krusen.					
	Denbigh	4000-2600	On. Port. C. Krusen.	On. Port.	On. Port.	On. Port.	On. Port.	On. Port.
Northern Archaic	Palisades	5800-4100	C. Krusen.	On. Port. C. Krusen.	On. Port. C. Krusen.	On. Port. C. Krusen.	On. Port. C. Krusen.	
American Paleo-Arctic	?	10000-7500?	Red Dog Rabbit Creek	Kiana Bench	Rabbit Creek	Kiana Bench	Rabbit Creek	Rabbit Creek
	Akmak	9700-9600						On. Port.

Figure 4.12. Cultural distribution of cherts from the western Brooks Range quarries, northwestern Alaska. C. Krusen. and C.K. = Cape Krusenstern, C. Espenb. = Cape Espenberg, P. Hope = Point Hope; On. Port. = Onion Portage; Pen. = Peninsula.

geochemically from the Wrench Creek chert. For instance, of the twenty-two black chert artifacts representing different prehistoric complexes of Onion Portage analyzed in this study, only one artifact was firmly correlated with the Wrench Creek quarry. Twenty-one black artifacts from Onion Portage were made of unknown black chert.

4.7.2. Gray Cherts from Upper Kelly River and Upper Kugururok River Quarries.

Gray and blue-gray chert artifacts are very common in northwestern Alaska prehistoric sites. Artifacts made of Upper Kelly River and Upper Kugururok River cherts were found in fifteen prehistoric sites: eight sites in Noatak River basin (in Kelly, Kugururok and Nimiuktuk drainages), four costal sites (Palisades and Sisualik on Cape Krusenstern, Choris and Cape Espenberg) and in three inland sites from the Kobuk River drainage (Kiana Bench, Athute, and Onion Portage) (Table 4.III). Distribution patterns (Fig. 4.13) indicate transportation of the Upper Kelly River chert to the east to the Kugururok River valley, and the Upper Kugururok River chert to the Nimiuktuk and Anisak River valleys in their headwater areas. Patterns also show transportation of gray Upper Kelly River and Upper Kugururok River cherts down Kelly and Kugururok Rivers to Noatak River and to the sea coast and then up the Kobuk River.

The cultural affiliation of gray cherts from the Upper Kelly River and Upper Kugururok River quarries ranges from Northern Archaic tradition to Arctic Small Tool tradition and to Arctic Woodland Eskimo (Fig. 4.12). They were identified in Palisades (in NKR-1#2 on Kelly River, in Onion Portage and on Cape Krusenstern), in Denbigh (in Onion Portage, Choris in Choris site and in Cape Espenberg), in Western Thule (in the Sisualik site on Cape Krusenstern), as well as in a few prehistorical complexes that were not identified.

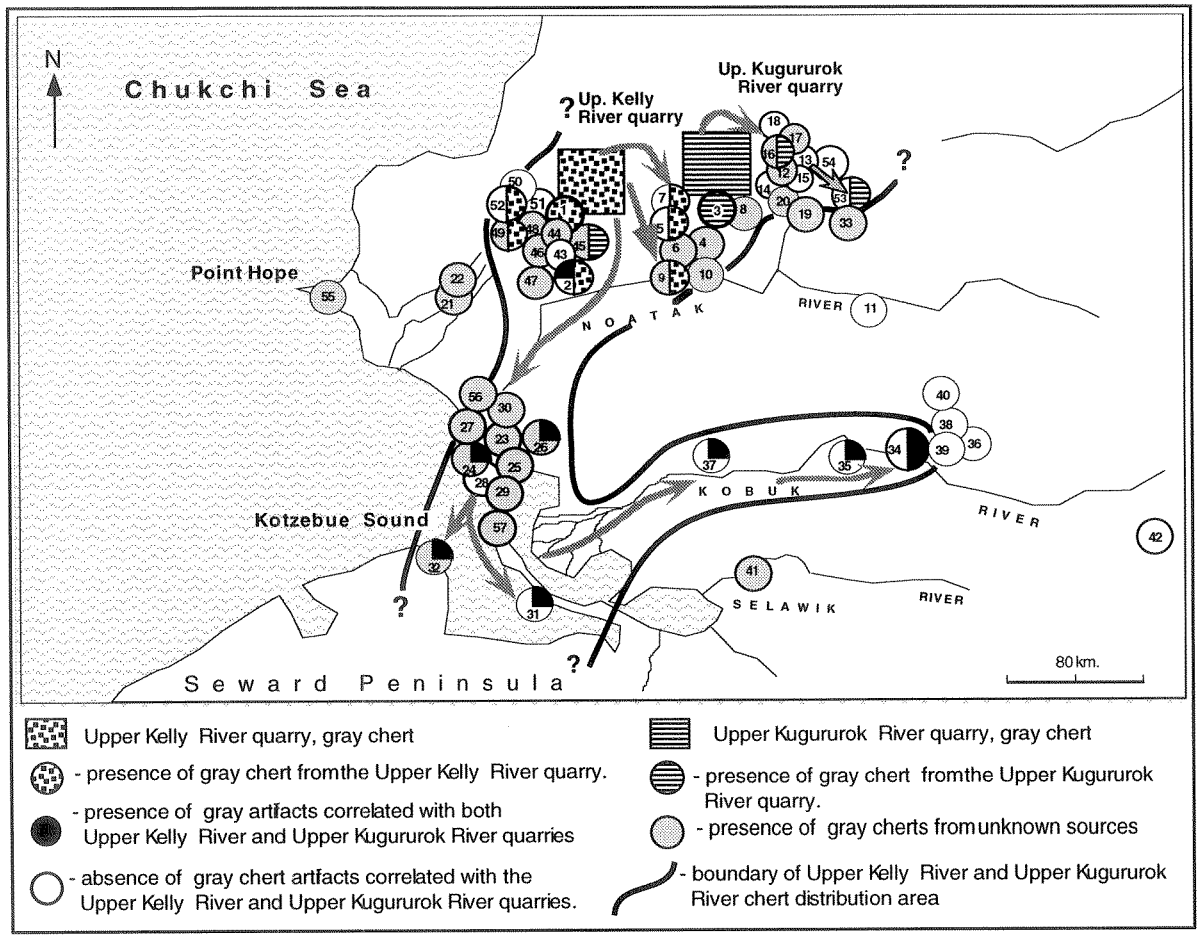


Figure 4.13. Distribution of gray cherts from the Upper Kelly River and Upper Kugururok River quarries (see site list in Figure 4.11).

4.7.3. Red Cherts from Upper Kelly River and Upper Kugururok River Quarries

A total of nine prehistoric sites contain red artifacts that were correlated with Upper Kelly River and Upper Kugururok River quarries (Table 4.IV). Four of them are located in the western Brooks Range: two in the Kelly and Kugururok River drainages, and two sites from the Nimiuktuk River drainage. Red artifacts made of Upper Kelly and Upper Kugururok cherts were also identified in four coastal sites (Battle Rock and Palisades on Cape Krusenstern and Choris site), and in Onion Portage located in Kobuk River drainage. Distribution patterns of red cherts from quarries are generally analogous to those of gray cherts and indicate similar transportation routes (Fig. 4.14).

The cultural distribution of red cherts from Upper Kelly River and Upper Kugururok River quarries is also generally similar to that of gray cherts (Fig. 4.12). They are found in Palisades (Onion Portage, band YI, and Cape Krusenstern), Denbigh (in Onion Portage, band IY , Cape Krusenstern and Noat. 3018), Choris (Choris site), and in the Arctic Woodland Eskimo (Onion Portage, band I) complexes.

4.7.4. Gray Anisak Chert

Gray chert artifacts correlated with Anisak quarry were determined in two local sites (Burial Lake in Anisak River valley and Noatak-17), and in two distal (Rabbit Creek, and Onion Portage) prehistoric sites (Table 4.V). The geographic distribution indicates transportation of Anisak chert from the quarry (down the Anisak and /or Nimiuktuk Rivers) to the Noatak River, then to sea coast area and up the Kobuk River (Fig. 4.15). The Anisak cherts were identified in the Akmak and Denbigh complexes in Onion Portage, and in indefinite prehistoric complexes of American Paleo-Arctic in Rabbit Creek and in an unknown complex in Burial Lake, and Noatak-17 sites (Fig. 4.12).

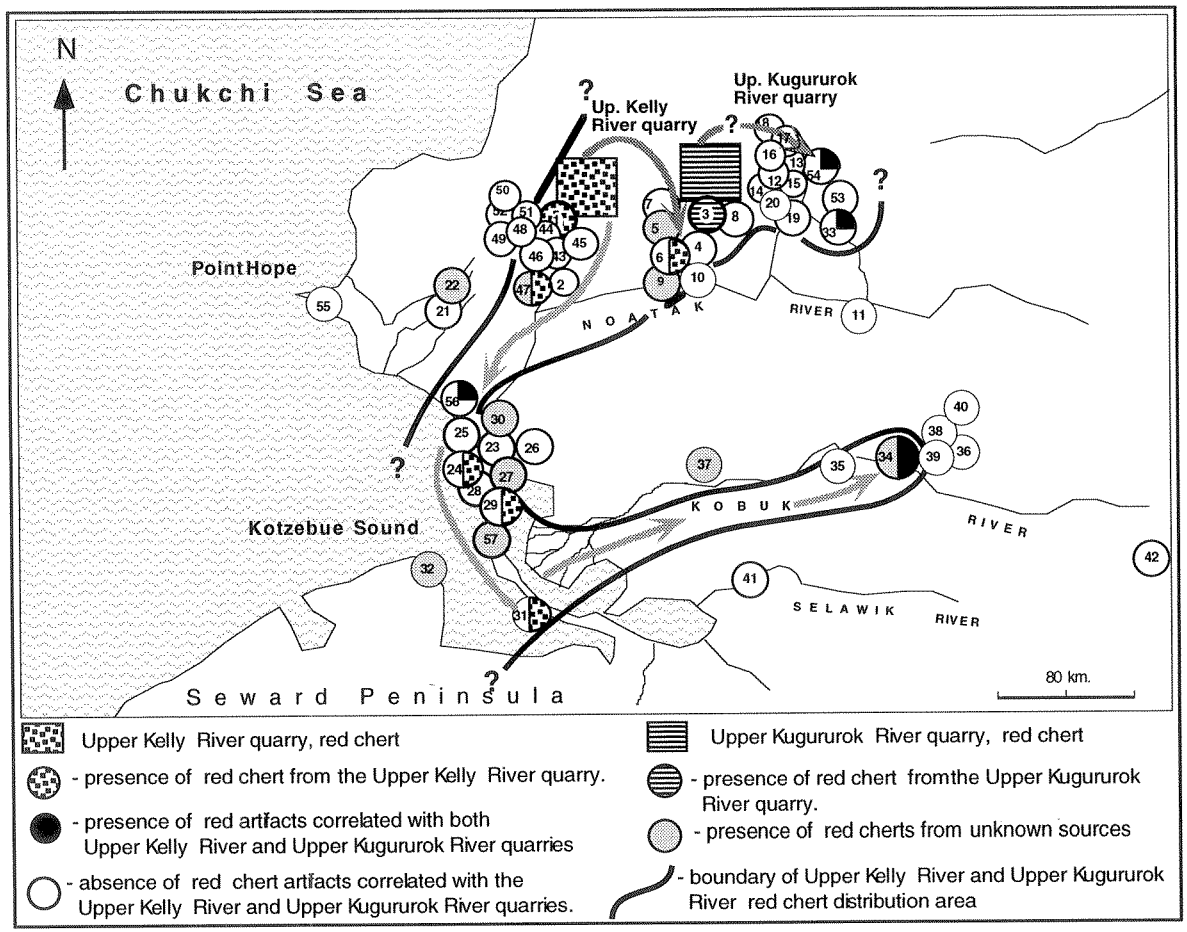


Figure 4.14. Distribution of red cherts from the Upper Kelly River and Upper Kugururok River quarries (see site list in Figure 4.11).

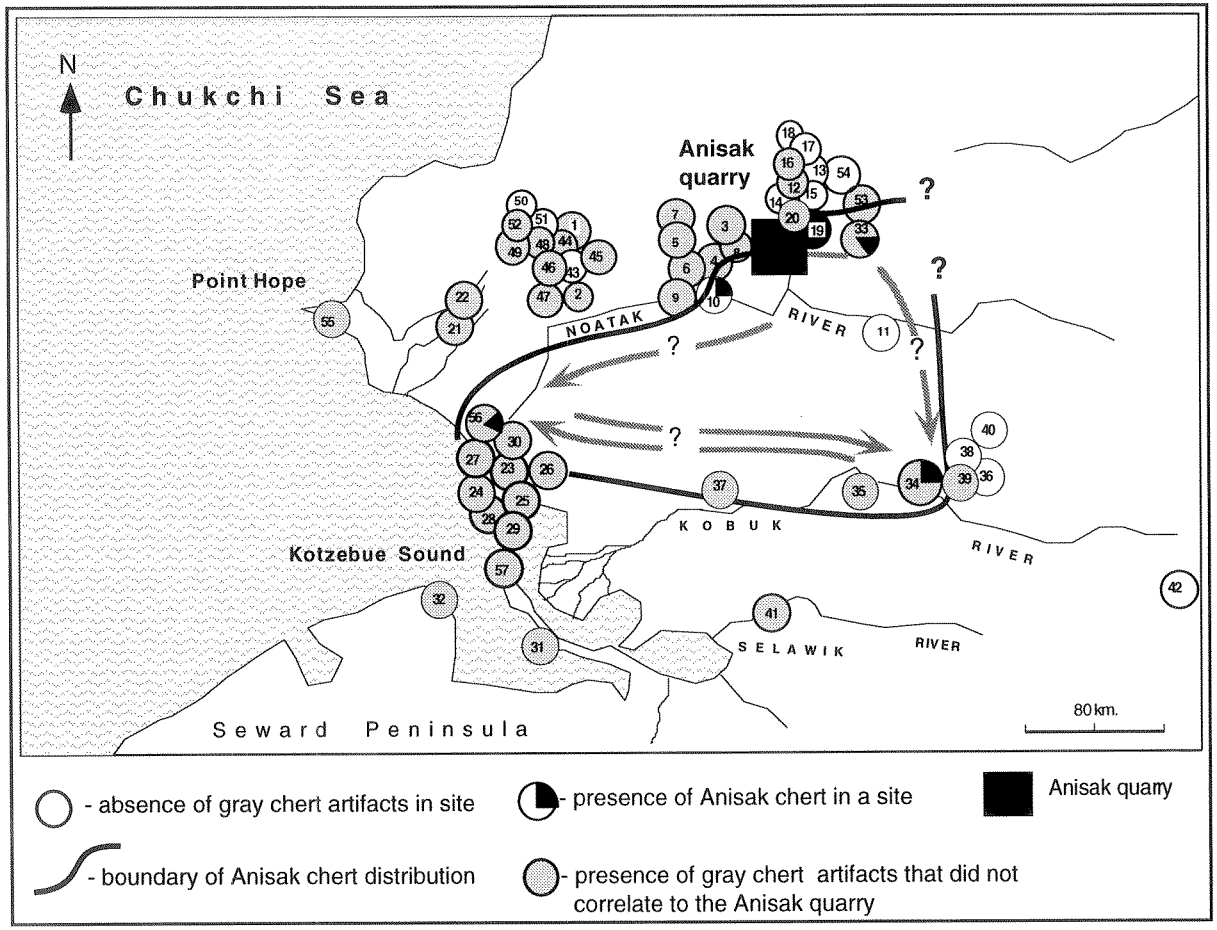


Figure 4.15. Distribution of gray chert from the Anisak quarry (see site list in Figure 4.11).

4.8. Discussion

4.8.1. Reliability of chert sourcing

The comparison of prehistoric artifacts with their geological sources (based on geochemical and mineralogical signatures specific for each source) resulted in firm correlation of 51 chert prehistoric artifacts with a specific quarry. One might ask if it is possible that two or more quarries in the western Brooks Range would have the exact similar geochemical signatures? If so, artifacts correlated with a certain western Brooks Range quarry may have come from some unknown one that is geochemically similar. The study of twelve Mississippian to Jurassic chert varieties in the western Brooks Range shows, however, that cherts from specific geological formations, specific outcrops, and color varieties within outcrops can all be distinguished by combined geochemical and mineralogical criteria. Only those artifacts that are correlated with quarry chert by all 37 to 40 geochemical signatures at 97 % confidence (3σ from the mean) were assigned to that quarry. Assignment of some gray and red artifacts to both the Upper Kelly River and Upper Kugururok River quarries occurred because of partial overlapping of geochemical fields obtained at 3σ for these quarries by combination of chert layer and artifact data. It was possible to assign these artifacts to either one or another quarry at lower confidence (using field constructed at 2σ or 1σ). However, it was not necessary because of the relatively close location of two quarries to each other.

Only 20% of all analyzed artifacts (not counting those from quarry workshops) were correlated with the specific quarry cherts. Geological sources of the other 80% artifacts were left unidentified despite the fact that these artifacts are visually undistinguishable from those correlated with quarries. Often they have very little geochemical difference from quarries.

However, even small deviation from 3σ geochemical field of one signature excludes their correlation with the quarry. Strict geochemical and statistical criteria limited the list of correlated artifacts, but provide a high confidence in correlation and minimizes errors in prehistoric interpretations.

4.8.2. Problems in interpretation

One problem in the interpretation of chert distribution patterns is the possibility that some of the artifacts correlated with the prehistoric quarries were not actually quarried, but were created from clasts mined from alluvial or glacial deposits. Glaciation had an effect on the distribution of chert cobbles and pebbles and thus possibly on the distribution of chert sources. Our study of alluvial chert pebbles and cobbles in the Noatak basin shows that the quality of pebble cherts is often "bad" for tool making due to many thin fractures within them (Gal, personal communication). However, single cobbles should not be excluded as possible sources for making small size tools. Thus, it is possible that some artifacts that were correlated with a specific quarry were not quarried, but made of cobbles collected down stream in the same valley. However, it is reasonable to assume that artifacts uniquely correlated with the particular quarry were sourced in the vicinity of the quarry, whether from alluvial cobbles or at the quarry itself.

We can be sure therefore, that Denbigh, Palisades and possibly Akmak people that settled in Onion Portage, as well as people from Kiana Bench and Atheut sites in the Kobuk valley certainly traveled to Noatak drainage whether they mined cherts in Upper Kelly River, Upper Kugururok River and Anisak quarries, or selected alluvial or glacial cobbles originating from these sources. There are several questions remaining, however: 1) did they travel down the Noatak River to the sea coast and then up the Kobuk River, or 2) did they

4.9. Synthesis

4.9.1. Geographic Distribution.

The general map of distribution patterns of cherts from all quarries (Fig. 4.16) shows their wide distribution from the quarry area to the Bering Strait coast (including Cape Krusenstern, Kotzebue Sound and Seward Peninsula) and to the Chukchi Sea coast (including Point Hope) on the west, and to Kobuk River valley on the south. Assuming transportation of cherts down the Noatak River by humans, the greatest distance of transport of cherts from quarries to a prehistoric site exceeds 400 air km and nearly 500 km over land (from the Upper Kugururok River quarry to Onion Portage).

The areas of geographic distribution of cherts are different for each quarry and partially overlap (Fig. 4.16). The distribution area of black chert from the Wrench Creek quarry is shifted to the west when compared to other quarries. Its eastern and southern boundary has been determined, whereas the northwestern and western boundary remain uncertain. Cherts from the Upper Kelly River and Upper Kugururok River quarries cover the largest area on the map. On the east it is limited by Onion Portage in Kobuk valley, on the southeast by Kobuk River and on the northwest by Wrench Creek. However, we do not have data yet to determine its northeastern and southwestern boundary. The distribution area of Anisak cherts on the map has an uncertain border on the east.

4.9.2. Cultural Distribution.

Cultural affiliation of artifacts correlated with the western Brooks Range quarries ranges from American Paleo-Arctic tradition to Recent Eskimo, including eight known prehistoric complexes and cultures: Akmak, Palisades, Denbigh, Choris, Ipiutak, Old Whaling, Western Thule and Woodland Eskimo, as well as some unknown cultures. Figures

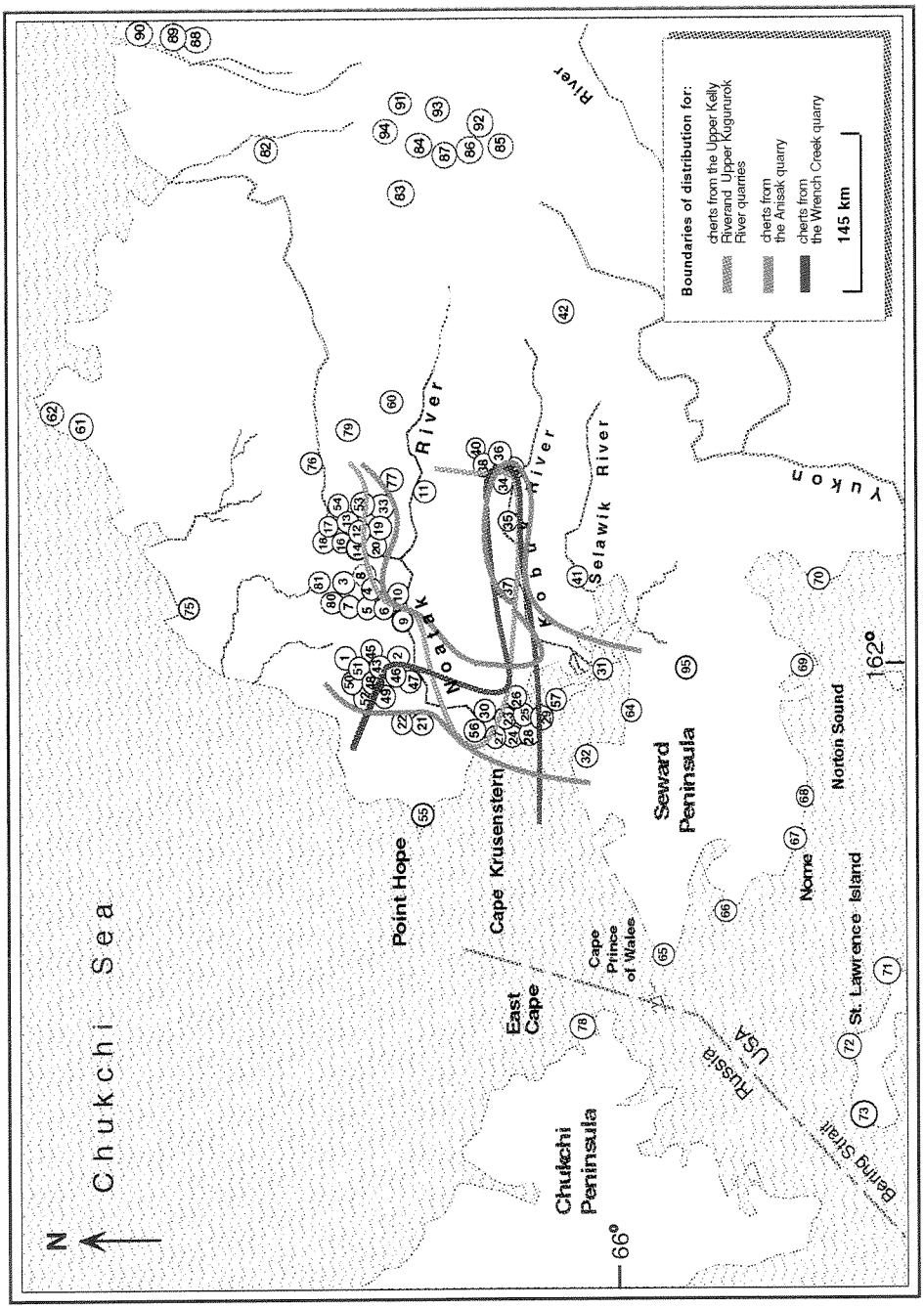


Figure 4.16. Map of general distribution of cherts from four prehistoric quarries in the western Brooks Range (see site list in Fifure 4.11).

4.12, 4.17, 4.18 and 4.19 show sites - quarry connections during different prehistoric periods.

During American Paleo-Arctic time Akmak (Onion Portage) settlers used chert from Anisak quarry, people from undetermined complexes in Red Dog sites used only Wrench Creek quarry, whereas populations from Rabbit Creek used all four quarries (Fig. 4.17). During Northern Archaic time, Palisades dwellers from Onion Portage used only Upper Kelly River/Upper Kugururok River quarries, whereas the Palisades complex in Cape Krusenstern contains cherts from Upper Kelly River /Upper Kugururok River and Wrench Creek quarries (Fig. 4.17b). During Arctic Small Tool time, Denbigh settlers in the Onion Portage used cherts from all four quarries, whereas Denbigh artifacts from Cape Krusenstern correlate only with Wrench Creek quarry (Fig. 4.18a). Choris people both from Choris site on Choris Peninsula and from Cape Espenberg, used cherts only from Upper Kelly River quarry (Fig. 4.18d). Ipiutak people from Point Hope used just Wrench Creek quarry (Fig. 4.18b). Old Whaling settlers from Cape Krusenstern used just Wrench Creek quarry (Fig. 4.19a). The latest Eskimo cultures Western Thule from Sisualik (Cape Krusenstern) and Arctic Woodland from Onion Portage used Upper Kelly River/Upper Kugururok River quarries (Fig. 4.18b).

The multilayered site, Onion Portage, provides a unique opportunity for reconstructing the use of cherts from the four quarries though time (Fig. 4.12). The Akmak complex contains cherts from the gray Anisak quarry that is the easternmost and the closest (in air distance) to Onion Portage (Fig. 4.17a). The Palisades complex has cherts from more distal (to the west) Upper Kelly River and /or Upper Kugururok River quarries (Fig. 4.17b). Denbigh complex contain cherts from all four studied quarries. (Fig. 4.18a). This may indicate that the earliest settlers (~10,000 B.P.) in Onion Portage used mostly unknown chert

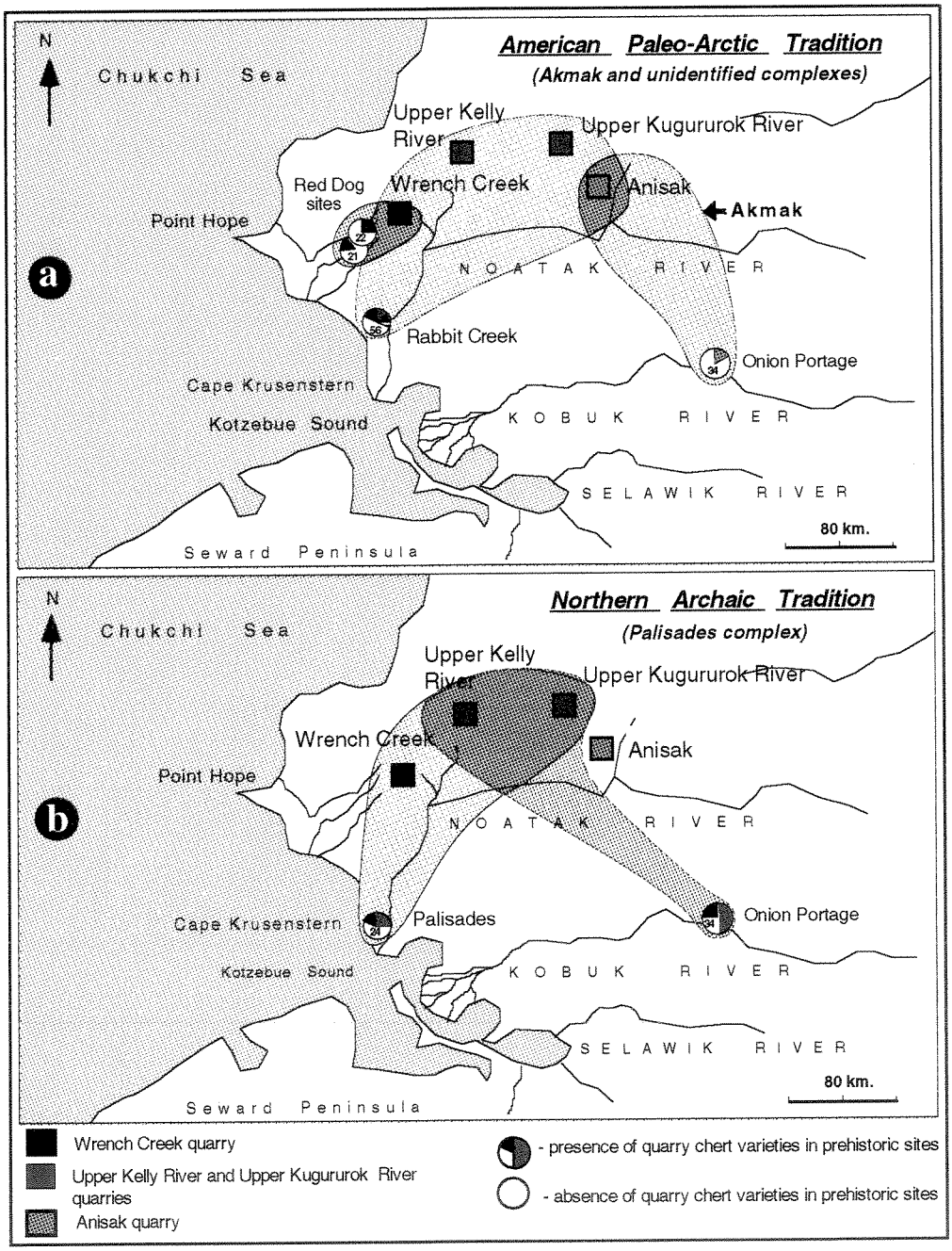


Figure 4.17. Cultural distribution of cherts from the western Brooks Range quarries: a) sites of American Paleo-Arctic tradition, b) Northern Archaic tradition.

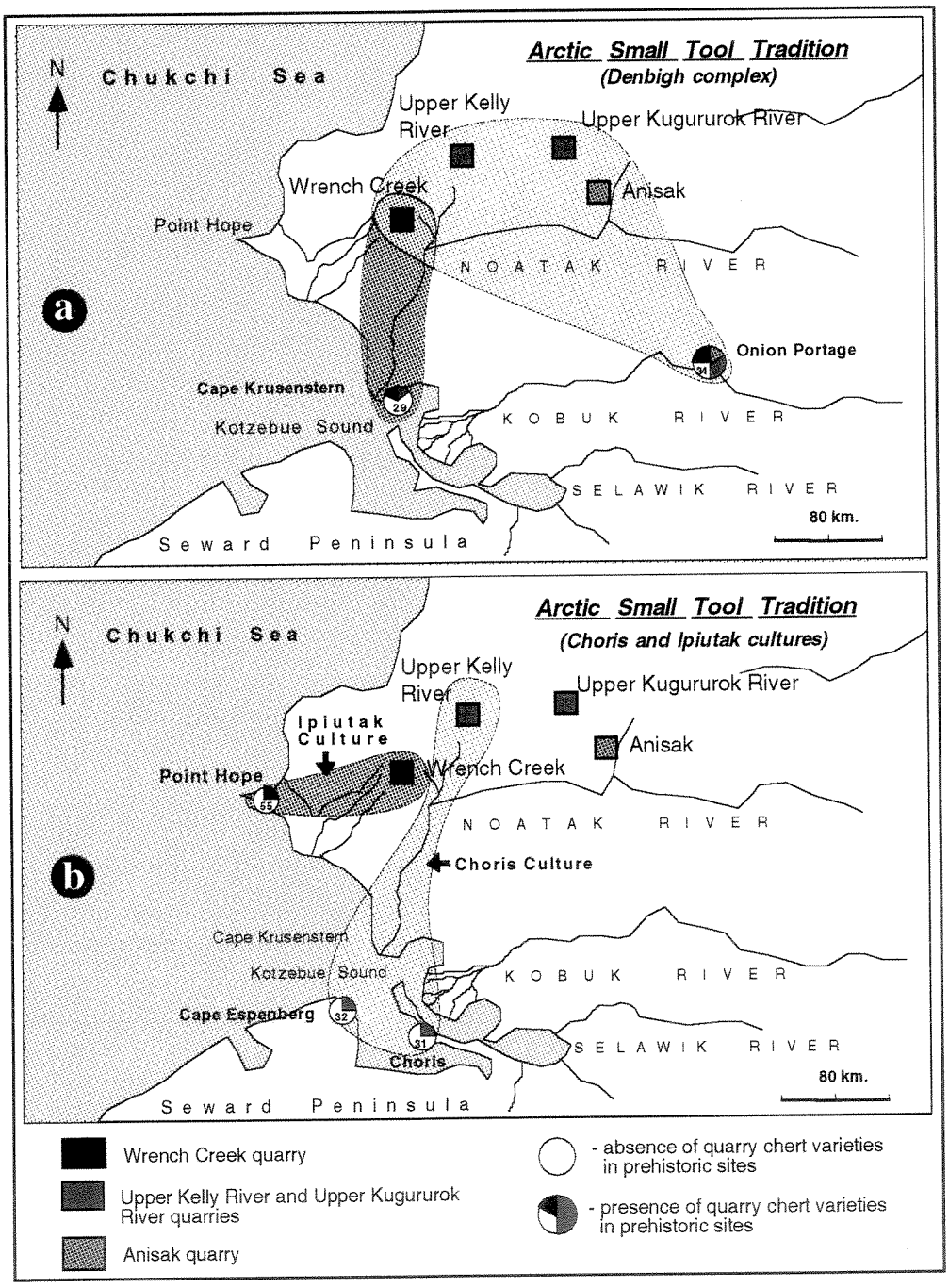


Figure 4.18. Cultural distribution of cherts from the western Brooks Range quarries: a) Denbigh complex, b) Choris and Ipiutak cultures.

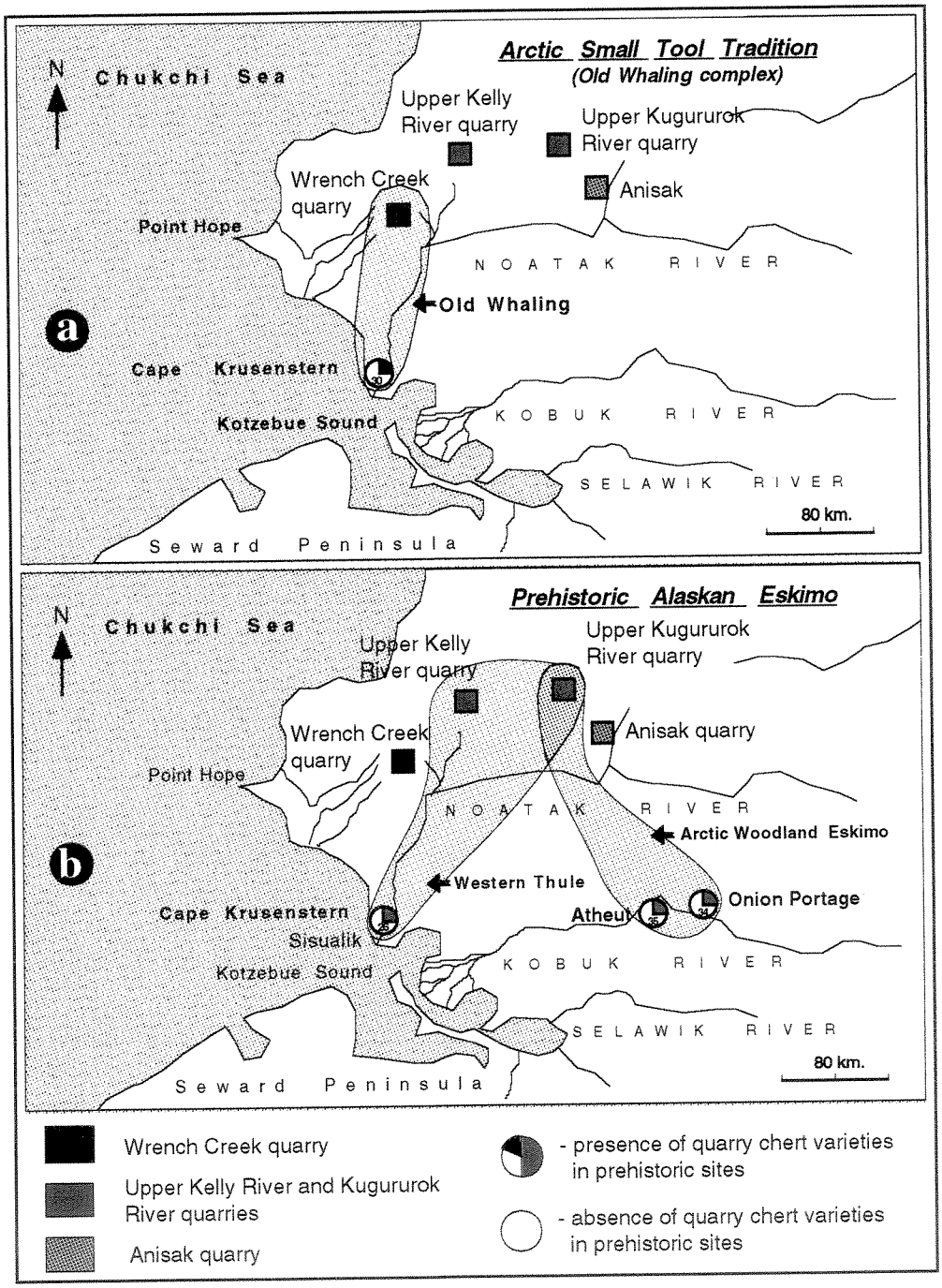


Figure 4. 19. Cultural distribution of cherts from the western Brooks Range quarries: a) Old Whaling complex, b) Prehistoric Alaskan Eskimo.

sources. The only identified western Brooks Range chert source that they used was the Anisak which is inland, the easternmost and the closest to the site. The later settlers progressively discovered(?) additional chert sources to the west within the Noatak basin.

Despite the limited number of identified artifacts (20%), a preliminary delineation of inter-cultural group contacts (or travel routes?) and preferable chert quarries by different cultures can be recognized. My data provide important information to archaeologists for reconstructing prehistoric migration routes or inter-group contacts within the same prehistoric cultures, and possibly inter-cultural connections in northwestern Alaska.

Geological sources of the other 80% artifacts analyzed in 57 sites are still unknown. Extending the outcrop database by studying more outcrops in the Brooks Range will hopefully discover new prehistoric quarries for those artifacts that were left unidentified during this study. Adding Chukchi Peninsula (Siberia) outcrops, located on the west margin of Bering Platform, to the database might eventually lead to the discovery of intercontinental prehistoric connections (Fig. 4.16). Analysis of additional artifacts from other prehistoric sites in northwestern Alaska and Chukchi Peninsula will delineate prehistoric inter- and intra-cultural contacts in Beringia.

4.10. Conclusions

1. The geological-geochemical sourcing of prehistoric chert artifacts in northwestern Alaska revealed critical information on prehistoric migration routes in this part of Beringia of populations ranging from the American Paleo-Arctic tradition dated as early as 10,000 B.P. to the Recent Eskimo.
2. The distribution patterns of black, gray and red chert artifacts that are geochemically identical to four prehistoric chert quarries in the western Brooks Range show wide

distribution from the quarry area to the Bering Strait coast (including Cape Krusenstern, Kotzebue Sound and Seward Peninsula) and to the Chukchi Sea coast (including Point Hope) on the west, and to the Kobuk River valley. None of these cherts were identified in prehistoric sites located to the east of Onion Portage in Kobuk River drainage, and to the south of Kobuk Basin in the Selavik River drainage. The greatest distance of the distribution is over 400 air km. The distribution patterns show also potential for movement to the Seward Peninsula, across the Bering Strait, to the Arctic Ocean and inland to the northeast.

3. The boundaries limiting the geographic distribution of the western Brooks Range cherts are left open to the Seward Peninsula, across the Bering Strait, to the Arctic Ocean and to the northeast showing the plausible extension of the distribution patterns in these directions.

4. The cultural affiliation of cherts from the western Brooks Range quarries ranges from American Paleo-Arctic tradition to Recent Eskimo including eight known prehistoric complexes and cultures: Akmak, Palisades, Denbigh, Choris, Ipitak, Old Waling, Western Thule and Arctic Woodland Eskimo.

5. The potential of chert artifact sourcing for detailed regional prehistoric reconstructions was demonstrated based on 51 identified chert artifacts. A crucial issue here has been the determination of boundaries between geographic areas of usage of different Noatak cherts within each prehistoric tradition and culture. It provided information for preliminary reconstruction of prehistoric travel routes or group contacts in northwestern Alaska.

6. The results presented here suggest several potential research issues which should be

addressed in the near future. Extension of the chert outcrop database in the Brooks Range and Chukchi Peninsula, the sampling chert cobbles from alluvial and glacial deposits (in river valleys and on the coast), as well as additional analysis of more artifacts from more prehistoric sites in northwestern Alaska and in Chukchi Peninsula will provide data for large scale prehistoric inter-group contacts and migration routes in Beringia.

CHAPTER FIVE: SYNTHESIS AND CONCLUSIONS

Chert artifacts in prehistoric sites are often made of chert varieties differing by color, luster, etc. These physical characteristics are typically used by archaeologists to correlate chert artifacts with each other and with chert sources. Accurate correlation is possible in very rare cases when artifacts are made of cherts of material from a well known source characterized with very unique colored patterns that are not likely to be duplicated (Nagle, 1984). However, an overwhelming majority of prehistoric sites contain cherts with no unique properties and originated from unknown sources.

Chert is an extremely difficult rock for study, in particular for comparison and correlation amongst a large number of samples. The determination of geological sources for prehistoric chert artifacts is a complicated geological problem that requires a geological approach to resolve. Chert consists of up to 99% SiO_2 characterized with uniform structure (crypto- and microcrystalline quartz). Therefore, cherts differ from each other just by impurities of minerals and elements in silica that often comprise <1%. The small size of mineral inclusions does not usually allow identification under the petrographic microscope and requires study by EMPA and X-Ray diffraction. Trace element concentrations require very sensitive techniques (such as INAA) for detection of bulk chemical composition. However, even application of these techniques not always allow chert samples from different outcrop sites to be distinguished by their chemical or mineralogical compositions because of typically low concentrations of these impurities. On the other hand, geological study of chert shows a high variability of color, luster and other physical properties, as well as chemical composition within the same outcrop, same layer and even within the same nodule. This variability within the geological source is another important problem in chert sourcing.

It makes it impossible to correlate cherts by sample-to-sample comparison.

In order to identify the geological source of artifacts it is necessary to determine the range of variability of petrological, mineralogical and geochemical signatures for each possible source and then compare artifacts with these data. The most important problem in chert sourcing is to determine what set of signatures should be selected for correlation.

5.1. Geological-Geochemical Approach.

An artifact is a very small portion of a chert layer, but it shares the record of all nuances of its geological history: depositional environment, provenance, and diagenetic changes of regional and local scales. Relative to their source layers, however, some artifacts can have small chemical and mineralogical changes (leaching and /or input of additional elements) while in the archaeological site (due to contact with soil in stratified site or weathering in a surficial site). However, the inner part of most artifacts is not affected by the weathering and retains signatures of the source layer. Therefore, signatures recording conditions during geological formation of the chert layer must be determined and are first priority in attempting to correlate artifacts with outcrops. The selection of the proper signatures is of primary importance and must be based on geological criteria. Assigning artifacts to sources based on equal treatment of all elements can lead to erroneous results.

The geological-geochemical approach to the sourcing of prehistoric chert artifacts developed in this study is based on the idea that both the prehistoric artifact and its geological source have identical mineralogy, fossils and bulk trace element chemistry that reflect their identical geological history. The approach consists of two main parts: (1) the regional study of chert deposits in a defined geographic area and construction of a database of signatures discriminating each possible chert source, and (2) comparison of artifacts with

this database using statistics in order to identify their sources.

5.2. A Regional Study of Chert Deposits.

A comprehensive regional study utilizes geological reports and maps to select areas where "tool quality" chert outcrops are concentrated. Field study includes reconnaissance of outcrops exposing "good quality" chert and their proper sampling. Sampling of each chert variety (either in layers or colluvium) requires no less than 15 samples from each variety to sufficiently determine the statistical range of chemical variability. Laboratory study includes study of samples in hand specimens, by optical microscopy in thin sections and analysis of samples by sensitive techniques such as INAA, EMPA , ICS-MS and X-ray diffraction to obtain characteristics of each chert variety as precise as possible. Data processing utilizes, math and graphic computer programs to construct a database containing signatures separating each chert outcrop and /or variety.

The western Brooks Range was selected as a possible prehistoric mining area in northwestern Alaska because 1) this area is underlain with chert-rich deposits, 2) numerous prehistoric chert chipping sites are known there, some of which are located at chert outcrops or in close proximity suggesting that the area was a possible prehistoric mining area, and 3) this area was free of ice since ~ 10,000 B.P. and thus, most chert outcrop sources were accessible for prehistoric population.

The tectonics in the Brooks Range and in particularly in its western part is very complex (Moore et al., 1994). My study of the twelve chert varieties from the nine outcrops in the western Brooks Range showed that the thrust sheet structure of the region is favorable to discrimination between chert outcrops and particularly to those exposing the same unit. Thrust sheets contain different lithofacies of coeval units that are characterized by distinctive

geochemical signatures. Thus, outcrops exposing these lithofacies can be disriminated from each other. It is logical to assume, however, that the method is applicable to areas with simpler tectonics as well, and that sourcing there might provide other advantages. Geological-geochemical chert sourcing in the Upper Volga and other regions on the Russian Platform, for example, has shown a platform sequence that is undeformed by complex tectonics. This allowed construction of a more detailed database for the whole stratigraphic sequence (Selivanova and Galibin, 1992). Under this condition foreign chert from the distal area would be easily recognizable in the chert artifact assemblages. Sourcing in different regions provides specific geological conditions that would demand specific modification to the geological-geochemical approach.

5.2.1. Analysis of Samples.

Accurate determination of distinctive signatures requires combination of mineralogical, petrological and geochemical data. Instrumental neutron activation analysis (INAA) is the ideal technique for chemical chert analysis as it determines up to 31 trace elements at very low concentrations. However, INAA of the western Brooks Range cherts revealed a phenomenon that must to be taken into consideration for analyzing cherts. Very low REE concentrations in cherts causes Nd (91 kv)-Ba (92 kv) peak interference in Ba-rich cherts from Siksikpuk Formation. This requires using other peaks for Nd identification. Also, LREE - U fission product interference in U-rich Lisburne cherts causes higher LREE concentration that has to be recalculated (Glascock et al., 1986). Unfortunately, concentrations of Sm cannot be recalculated because of Sm (103 kv)- U fission product (106 kv) peak interference. Ignoring this features leads to erroneous data and misleading conclusions.

5.2.2.. Discrimination of Chert Outcrops.

Being able to separate specific outcrops from all others is a crucial part of the approach. Most geologists dealing with chert deposits are skeptical regarding the possibility of correlating artifacts with outcrops even using very sensitive analytical techniques. The common opinion is that the discrimination of chert sources is limited by geochemical discrimination between main stratigraphic groups or formations. They believe that it is impossible to distinguish units within formations and especially outcrops within the same formation or unit. However, this research showed that proper sampling combined with use of sensitive analytical techniques for detection of mineralogical and chemical composition of impurities in cherts, as well as accurate selection of discriminative geochemical signatures is crucial. It allows separation not only stratigraphic groups and formations, but also units within formations, as well as individual outcrops and individual chert varieties within outcrops.

The study of twelve chert varieties from the Mesozoic-Paleozoic chert deposits in the western Brooks Range was the first detailed mineralogical and geochemical study of chert deposits in the Brooks Range. Determination of their depositional environment is fundamental for tectonostratigraphic and paleogeographic reconstructions in the Arctic Alaska terrane prior to the Brooks Range orogeny (late Jurassic - early Cretaceous). My research revealed several important geological implications concerning depositional environment, provenance and diagenesis based on accurate determination of petrological, mineralogical and geochemical signatures.

5.2.3. Geological Results:

1. Geochemical signatures have divided upper Mississippian to Jurassic chert deposits

in the western Brooks Range into two main types that are correlated with two main stratigraphic groups: Lisburne Group (late early Mississippian to early Pennsylvanian) and Etivluk Group (upper Pennsylvanian to Jurassic). Difference in these signatures reflects difference in depositional environment (Fig. 11).

2. Ce_n/Ce_n^* values = 0.24-0.63 (negative anomalies) and La_n/Ce_n = 0.76-3.92 in three of the four studied Lisburne cherts (from Tupik, Akmalik and Kuna Formations) suggest open ocean depositional environment, whereas Ce_n/Ce_n^* = 0.79- 1.3 and La/Ce=0,76-1.0 in all Etivluk cherts (Siksikpuk and Otuk Formations) and the youngest Kuna chert indicate their transitional and continental margin deposition.
3. The gradual increase of terrigenous component (Al_{sample}/Al_{PAAS}) and Ce_n/Ce_n^* values (from 0.25 in the oldest Tupik, chert to 1.17 in the youngest Kuna chert) in Lisburne cherts possibly record the gradual change in their depositional setting from open ocean to continental margin during the late early Mississippian - Pennsylvanian time.
4. The continental margin depositional environment of Etivluk cherts during Pennsylvanian to Jurassic time suggests an increasing input of volcanic debris.
5. No correlation between Ce_n/Ce_n^* patterns and observed oxidizing-reducing patterns has been found in the late Paleozoic-middle Mesozoic cherts from the western Brooks Range.

5.3. Regional Database

Geological study of chert outcrops in the western Brooks Range resulted in the construction of a database of petrological, mineralogical and geochemical signatures that are represented with mineralogical composition of mineral inclusions in the chert matrix, trace element composition and elemental ratios (Appendix I). The database also includes (as a

supplement) a series of diagrams (error bar, elemental concentration and elemental ratio variation diagrams) that separate chert varieties based on the most discriminating geochemical signatures.

Geochemical signatures such as Ce_n/Ce_n^*, Eu_n/Sm_n and Ba/Fe were taken for key signatures as they reflect depositional environment, provenance and diagenetic patterns respectively. These ratios are firm indicators for correlation of artifacts with stratigraphic units of chert deposits. Similarities or differences between artifacts and outcrops by depositional (Ce_n/Ce_n^*), provenance (Eu_n/Sm_n or Eu_n/Eu_n^*) or diagenetic (Ba/Fe) signatures overrides their similarities by all other signatures. The range of Ce_n/Ce_n^* values in outcrop is crucial for artifact-outcrop correlation. If outcrops have similar provenance, depositional and diagenetic characteristics (like in the Siksikpuk cherts) discrimination can be based on concentrations and elemental ratios of those elements (such as Th/Sc, Rb/Sr, Cs/<Mn, Mn/Al, Fe/Al etc.) that are mobile during chert formation and reflect lithofacies geochemistry and mineralogy. Using this approach, unique signatures distinguishing each of twelve studied chert varieties in the western Brooks Range were identified.

5.4. Comparison of Artifacts with the Database of Chert Outcrops.

The most significant advantage of the geological-geochemical approach is the identification of specific geochemical signatures that show if artifact chert has identical geological history as outcrop. All previous workers relied on the statistical correlation based on the assumption that all measured elements should be considered equal importance However, some elements are more diagnostic than others as noticed by Luedtke (1979) and thus assigning artifacts to a source based on equal treatment of all elements can lead to erroneous results. Figuratively speaking, according to geological-geochemical approach

99% similarity between artifact and outcrop obtained by statistics will mean nothing if Ce_n/Ce_n^* or Eu_n/Sm_n values in artifact do not fall into the range of Ce_n/Ce_n^* and Eu_n/Sm_n values in outcrop. Ce_n/Ce_n^* shows the difference in depositional environment, and Eu_n/Sm_n shows the difference in provenance. The "small" difference in 1% in terms of statistics means 100% geological difference between the actual artifact source and the outcrop it was compared with.

An important problem in chert artifact-outcrop correlation is the selection of proper statistics. Most of the previous workers on chert sourcing use multivariate statistical analysis of INAA data for artifact-outcrop correlation. However, such "pure" statistical approach to chert correlations is potentially dangerous because it combines data on chemical composition obtained for both chert artifacts and outcrops into one single population. From the geological point of view, outcrop samples represent a population that form a multivariate normal distribution. However, artifacts found in archaeological sites represent a mixture of cherts that might have been mined in geochemically different chert sources. These sources may be located in different tectonostratigraphic terranes and thus do not form a multivariate normal distribution. Therefore, combining both artifact and outcrop data into one population to apply multivariate discriminant and principal component analysis to artifact-outcrop correlation may lead to misinterpretations.

The preferred technique used in this study is simple descriptive statistics providing "confidence interval" (Luedtke, 1979) or "intervals of variability" (Selivanova, 1984) of signature values within the chert source at three, two and one standard deviations from the means. These intervals turn into geochemical fields on bivariate diagrams. The correlation of artifacts with outcrop chert varieties includes the superposition of each artifact

composition on these geochemical fields. Only those artifacts that are correlated with chert variety by all (from 37 to 40) selected geochemical signatures at 97 % confidence (3σ from the mean) were assigned to that variety (Appendix III).

Strict geochemical and statistical criteria limited the list of correlated artifacts, but provides a high confidence in correlation and minimizes errors in archaeological interpretations. Only 20% of all analyzed artifacts were correlated with specific quarry cherts. Geological sources of the other 80% artifacts (visually similar to those correlated with quarries) were left unidentified. This fact indicates the high accuracy of distinguishing cherts from different sources using the geological-geochemical approach.

One of very important aspects in the developed approach is using *"geochemical quarry fields"*. In the western Brooks Range, outcrops associated with prehistoric workshops provide a unique opportunity for determining the range of chemical variability in the prehistoric quarry, because many others (not analyzed) might have been mined by different prehistoric people. This range can be determined by combining outcrop samples and associated prehistoric flakes (that were mined in the quarry) into one data set. These new "geochemical quarry fields" (Fig. 3.9) were then used for correlation of artifacts with quarries (Appendix I. 4).

Another important aspect is the correlation of artifacts with those outcrops characterized by overlapping geochemical fields. Selection of the proper chert source can be done by an iterative process of progressive outcrop selection/delineations. However, it was not possible to assign some gray and red artifacts to either Upper Kelly River or Upper Kugururok River quarries because of partial overlapping of "quarry geochemical fields" obtained at 3σ (Fig. 3.12). It was possible, however, to assign some of these artifacts to

either one or another quarry at lower confidence (at 2σ or 1σ). However, this was not necessary because of the relatively close location of two quarries to each other.

5.4.1. Results of Artifact-Quarry Correlation:

Four prehistoric chert quarries were identified in the western Brooks Range, Alaska as a result of comparison of 252 chert artifact from 53 prehistoric sites with nine studied chert outcrops. Fifty one chert artifacts from 29 prehistoric sites were firmly correlated with these quarries, 201 artifacts were left unidentified (Appendix II.1).

5.5. Archaeological Implications

Chert sourcing in northwestern Alaska provides critical information for archaeologists for the reconstruction of prehistoric migration routes in the western part of eastern Beringia from the earliest known populations ~ 10,000 B.P. (American Paleo-Arctic tradition) to the Recent Eskimo. Results of the sourcing are summarized in a series of maps that show cultural and geographic distribution of cherts from each quarry throughout prehistoric time in northwestern Alaska.

Interpretation of distribution patterns must be based on two important assumptions: (1) all studied outcrops were accessible to people since 10,000 B.P. based on glacial history of the western Brooks Range, and (2) artifacts correlated with a particular quarry were sourced in the vicinity of the quarry whether from alluvial cobbles or the quarry itself.

Cultural affiliation of artifacts correlated with the western Brooks Range quarries includes eight known prehistoric complexes and cultures: Akmak, Palisades, Denbigh, Choris, Ipiutak, Old Whaling, Western Thule and Woodland Eskimo, as well as some unknown cultures. Maps of cultural distribution of cherts from the four western Brooks Range quarries show site - quarry connections during different prehistoric periods (Figs. 4.17,

4.18, 4.19).

Use of the same quarries by populations from different sites (overlapping zones on maps) might be interpreted as the mining of these quarries by different coeval groups, and thus, possible connection between these groups. On the other hand, they can be interpreted as tracing prehistoric routes of the same prehistoric group from one quarry to another. Map on the Figure 4.18b for example, clearly shows connection between two Choris culture sites on the northern coast of Seward Peninsula (Cape Espenberg and Choris Peninsula site) suggesting either the close communication between their settlements, or a single group movement from one site to another.

Maps also reveal the preference of different quarries by different prehistoric cultures in Onion Portage (the only stratified site containing almost all known prehistoric complexes) during the time period from 10,000 B.P. to Recent. Akmak people used only the closest and easternmost quarry (Anisak) (Fig. 4.17a). Palisades people used Upper Kelly River and Upper Kugururok River quarries (Fig. 4.17b). Denbigh people used all four quarries (Fig. 4.18a). Choris people from Onion Portage did not use any of these quarries (Fig. 4.18b). It raises doubts about their connection with coeval Choris people on the Seward Penisula. The latest settlers, Woodland Eskimo, certainly used the Upper Kugururok River quarry (Fig. 4.19b).

It is clearly seen from the maps that both coastal Ipiutak people and Old Whaling settlers (that have very specific cultural patterns and known only in the coastal area) used only the quarry closest to the coast (Wrench Creek quarry) (Figs. 4.18b, 4.19a).

It is important to remember, however, that all mentioned sites contain remains of artifacts made of the black, gray and red cherts that are visually undistinguishable from those

correlated with four western Brooks Range quarries. This fact indicates that future comparison of the unidentified artifacts from these sites with additional chert outcrops in the area including both coastal (westernmost Brooks Range) and inland might reveal new prehistoric quarries in the area.

The geographic distribution patterns of cherts show their broad distribution from the quarry area in the western Brooks Range to the Bering Strait coast, Chukchi Sea and to the Kobuk valley (Fig. 4.16). Assuming transportation of cherts down the Noatak River by humans, the greatest distance of transport of cherts from quarries to a prehistoric site exceeds 400 air km and nearly 500 km over land (from the Upper Kugururok River quarry to Onion Portage). The boundaries limiting the geographic distribution of each quarry cherts are open to the Bering Strait, to the Arctic Ocean, and to the northeast.

Extending the outcrop database by studying more outcrops in the Brooks Range may possibly discover new prehistoric quarries for those artifacts that were left unidentified during this study. Adding the Chukchi Peninsula (Siberia) outcrops to the database may eventually lead to the discovery of intercontinental prehistoric connections. Analysis of additional artifacts from other prehistoric sites in northwestern Alaska and Chukchi Peninsula will reveal additional information on prehistoric inter- and intra-cultural contacts in Beringia.

APPENDICES

Appendix I:

Database of Geochemical And Mineralogical Signatures of Twelve Chert Varieties from Nine Chert Outcrops in the Western Brooks Range, Alaska

Appendix I.1:
Geological Description of Nine Chert Outcrops

NU01 outcrop of black chert.

Location: N68°33'36", W161°27'17", on the left bank of the Nunaviksak Creek, Upper of Kugururok River basin, Misheguk Mountain quadrangle (U.S.G.S 1:250,000). Tupik Formation (Kelly River allochthon) is exposed in the banks of small creeks cutting the bedrock. Thick (up to 40 cm) layers of black glassy chert dominate in chert-limestone interbedded deposits. Limestone layers (up to 40 cm in thickness) contain chains of black chert nodules of 5 cm to 10 cm in thickness. Dip direction of layers is SW110°, dip angle is 48°.

WC04 outcrop, Wrench Creek prehistoric black chert Quarry

Location: N 68^0 09' 47" and W 162^0 32' 44", in the area discovered by E. Hall (Burch, 1990; Gerlach and Hall, 1986) and named Tugulak quarry. Black chert belongs to Chert and Dolomite Unit of Kuna Formation (Curtis et al., 1990) or to Akmalik Chert (Mull et al., 1987), Lisburne Group (Mississippian-Pennsylvanian), Picnic Creek allochthon.

The outcrop is represented by the colluvium covering the long slope of a high mountain on the western bank of Wrench Creek that dissects DeLong Mountain (Fig. 4a). Colluvium consists of gravel and large (up to 90 cm) blocks of black, glassy chert layers and chert nodules interbedded with thin layers of dolomite. The thickness of chert layers is commonly 4 -5 cm. However, some layers reach up to 86 cm in thickness. Such thick chert layers consist of a set of chert layers or chert nodule chains that are stacked closely together and often are separated with white siliceous material having low density. Some of the chert layers have a dark gray to gray outer zone with black central one. Dolomite layers commonly

are no more than 4-6 cm in thickness. However, some thicker dolomite layers are interbedded with very thin (0.5 cm) chert nodule chains.

KE12 outcrop of black chert.

Location: N68°20'25", W162°02'37", the steep slope of the right bank of Kelly River, in the upper part of the drainage, DeLong Mountain quadrangle (U.S.G.S. 1:250,000). Outcrop represents a thick (40 m) sequence of interbedded chert and shale deposits of Kuna Formation and shale (with rare thin chert layers) of overlying Siksikpuk Formation.

Kuna Formation is represented by thick (up to 60 cm) layers of black chert interbedded with minor weathered shale and fine grained greenish-yellow sandstone. Dip direction of layers varies along strike from NW280° to NE30°, the dip angle ~10-15°.

At the bottom of the outcrop, deposits are mostly black glassy chert layers (10-60 cm) with thin (3-5 cm) shale interbeds. The thick beds are comprised of subparallel layers of cherts that ere not interbedded with shale. This part of the outcrop was sampled and analyzed in this study

In the middle part of the outcrop, Kuna deposits are enriched in shale intercalations, and chert is comprised of mainly lenses and nodules. The contact with Siksikpuk Formation in the upper part of the outcrop is easy recognizable by a sharp change from the black color of Kuna to yellow color of Siksikpuk deposits. There is no bedrock exposure of the contact.

Siksikpuk Formation is brown-yellow weathered shale with single thin (1-2 cm) interbeds of gray chert.

WC01 outcrop: WC01b (black) and WC01g (gray) chert varieties.

Location: N68°09'43", W162°20'46", on the left bank of Wrench Creek, Kelly River drainage, DeLong Mountain quadrangle (U.S.G.S. 1:250,000). Bedrock and colluvium exposure of

Kuna and Siksikpuk Formations alternate along the hillsides because of folding; Brooks Range allochthon.

Kuna Formation is represented by black chert layers, lenses and nodules that comprise a large proportion of the chert-shale intebedded deposits. The thickness of chert layers is 5-30 cm. Layers are fractured perpendicular to the bedding. The surfaces of fractures are covered by iron oxides.

Siksikpuk Formation is represented by greenish and red silicified shale interbedded with chains of blue-gray and olive-gray chert nodules. The size of the nodules is from 15 cm x 20 cm to 15 cm x 40 cm. The chert is generally homogeneous and produces smooth surfaces when broken. However, some pieces are fractured and produce angular pieces when broken.

KO01 outcrop of gray chert

Location: N28°61'16", W162°23'17", the steep slope of the north bank of Kogvik Creek, Kugururok River drainage.

Bedrock and colluvial exposures of Siksikpuk Formation (Picnic Creek allochthon) are composed of silicified red and gray mudstone and shale interbedded with chert layers and chert nodule chains. The dip direction of layers is SW 110°, dip angle is 60°. Some chert layers are not actually chert, but rather strongly silicified argillites. Some layers appear to represent a gradation between silicified argillite and chert. Color of cherts (both layered and noduled) is gray and gray-greenish as well as gray with red zones.

WC05 outcrop of gray chert.

Location: N68°20'25", W162°02'37", on the west bank of Wrench Creek, Kelly River drainage, DeLong Mountain quadrangle (U.S.G.S. 1:250,000).

The outcrop represents the colluvial and bedrock exposure of the tectonic contact between Siksikpuk Formation (Brooks Range allochthon) and Kogruk Formation (Kelly River allochthon).

Kogruk Formation is represented with gray limestone interbedded with black chert layers (20cm-25 cm in thickness). Layers of limestone and chert are verticalwith a NE strike. The gray limestone contains abundant shell fossils.

Siksikpuk Formation is represented by colluvium of red-yellow shale and blocks of chert layers (up to 15 cm thick). Chert is blue-gray and gray-greenish in color and is characterized with concoidal fracture.

KE13 outcrop: KE13r (red) and KE13g (gray) chert varieties, Upper Kelly River prehistoric gray and red chert Quarry

Location: N 68^0 27' 41", W 162^0 01' 41", DeLong Mountain quadrangle (U.S.G.S. 1:250,000; discovered by G. Mull in 1970.

The quarry is located on the pass from the southern slope to the northern slope of the Brooks Range, between the two small tributaries of the Kelly River in its headwater in the DeLong Mountains, Western Brooks Range (Fig. 5). Hall and Mull (1976) gave detailed description of the topography and geology of the site which extends over a large area (about 2.5 km^2). The part of the quarry that I studied in 1993 for chert sourcing is represented by colluvium on the slope that is composed of black chert gravel weathered from of Kogruk Formation (Lisburne Group, Mississippian-Pennsylvanian, Kelly River allochthon) and gray, blue-gray, red and blue-gray cherts from Siksikpuk Formation (Etivluk Group, Pennsylvanian-Triassic, Kelly River or Brooks Range allochthon) (Ellersieck et al., 1990b).

Colluvium of ***Kogruk deposits*** is typically composed of light gray limestone containing layers of black chert that is intensively fractured and thus is not of high "tool

quality".

Siksikpuk Formation colluvium is composed of broken and unbroken gray, red and red-and-gray chert nodules and lenses, as well as with clasts of weathered shale. The exact position of the contact between Kogruk and Siksikpuk Formations is unclear because bedrock is not exposed. The nodules and lenses of Siksikpuk chert are from 3 x 4 cm to 30 x 50 cm in size. Most of the nodules and lenses are gray or blue-gray containing thin (1-2 mm) veins that are dendrite-like in shape and 2-2.5 cm in length. Many nodules are red-gray mottled and some of them have zonation (gray to maroon to gray) from the periphery to the center of the nodule. Contacts between red and gray zones may be either sharp or gradual. Some of nodules are predominantly maroon with gradual transition from gray to red. The chert is of very high "tool quality"; unfractured but has concoidal fracture when broken open.

The colluvium covering the upper part of the slope contains abundant prehistoric artifacts: flakes and tools. They are made of local Siksikpuk noduled chert: most are gray chert with a few red flakes.

NU02 outcrop: NU02g (gray) and NU02r (red) chert varieties, Upper Kugururok River prehistoric gray and red chert Quarry

Location: N 68^0 33' 01", W 161^0 27' 08", Misheguk Mountain quadrangle (USGS 1:250,000); discovered by N. Malyk-Selivanova in 1993; blue-gray and red cherts belonging to Etivluk Group (Pennsylvanian-Triassic), Kelly River allochthon.

The quarry is located in the pass on the southern slope of the Brooks Range front in the Kugururok River headwater region. A narrow cleft dissects the eastern bank of Nunaviksak Creek (the tributary of Kugururok River). The southern wall (11 m high) of the cleft exposes the chert-shale deposits of Etivluk Group of formations (Pennsylvanian-

Jurassic), whereas the northern one exposes the chert-limestone deposits of Tupik Formation of Lisburne Group (Mississippian) (Fig. 6a) (Curtis et al., 1984). The tectonic contact between the Tupik Formation and Etivluk Group can be traced along the cleft filled in with a small glacier that marks the beginning of the small creek. The Etivluk deposits are almost entirely cherts with no more than 7% shale (Fig. 6b). The lower part of the outcrop consists of nodules (up to 10 cm x 20 cm), lenses (up to 50 cm in length and 30 cm in thickness) and layers (5-10 cm thick) of blue-gray chert and mottled blue-gay and red chert. The color zonation (similar to that in the Upper Kelly River quarry nodules) occurs in some chains of nodules (Fig. 6c). The upper part of exposure consists of red chert layers 5-10 cm in thickness.

About 500 m north of the outcrop, a huge chert workshop was found where hundreds flakes and tools were documented (Noat. 3060 by NPS survey nomenclature) (Fig. 6c). It is located on the eastern bank of Nunaviksak Creek in its headwater, on a pass through the Brooks Range being used now as a seasonal caribou route. The colors of chert artifacts are black, dark smoky-gray, maroon, blue-gray and mottled gray-maroon.

AN10 outcrop, Anisak prehistoric gray (and black) chert Quarry

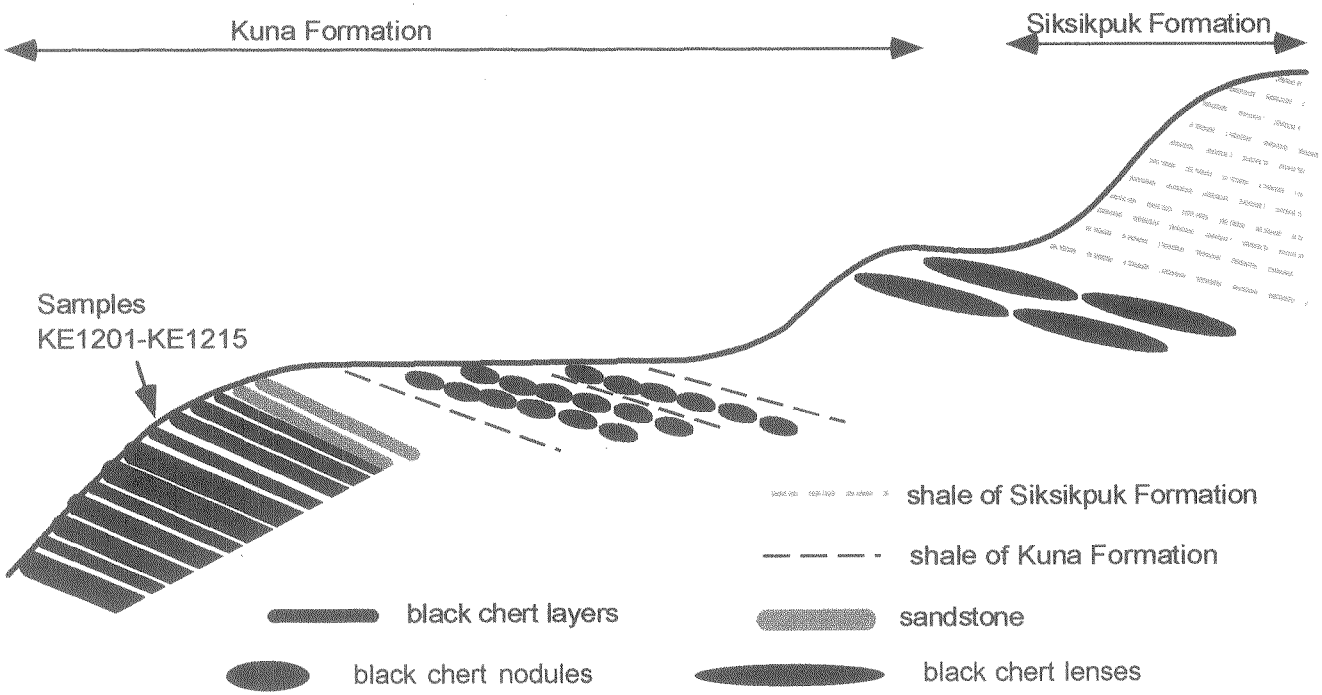
Location: N 68^0 22' 36", W 159^0 36' 22", Misheguk Mountain quadrangle (U.S.G.S. 1:250,000); discovered by N. Malyk-Selivanova in 1994; gray chert belonging to Otuk Formation of Etivluk Group (Triassic-Jurassic), Brooks Range allochthon.

The quarry is located on the southwest slope of a steep bank of a small southflowing tributary of the Anisak River in its headwater region (Fig. 7a). The quarry represents the bedrock exposure of the chert deposits of Otuk Formation (Mayfield et al., 1984). Blue-gray chert layers (5 - 8 cm thick) are tightly bedding (Fig. 7b). No interbedded shale occurs. Chert

layers are mostly fractured. Chert nodules of different sizes occur in colluvium on the slope, as well as on the top of the bank (average size of most nodules is 15 cm). However, abundant small nodules (4-5 cm in diameter), as well as very large nodules (up to 45 cm in diameter) occur. Some nodules are blue-gray and black mottled: black spots are located in the middle part of them (Fig. 7c). A typical feature of Anisak cherts, both black and gray, is abundant sporadically spread pyrite inclusions (1-3 mm). There is no correlation between distribution of pyrite inclusions and black or blue-gray colored zones. Most nodules and layers are slightly fractured. No nodule chains were observed *in situ*.

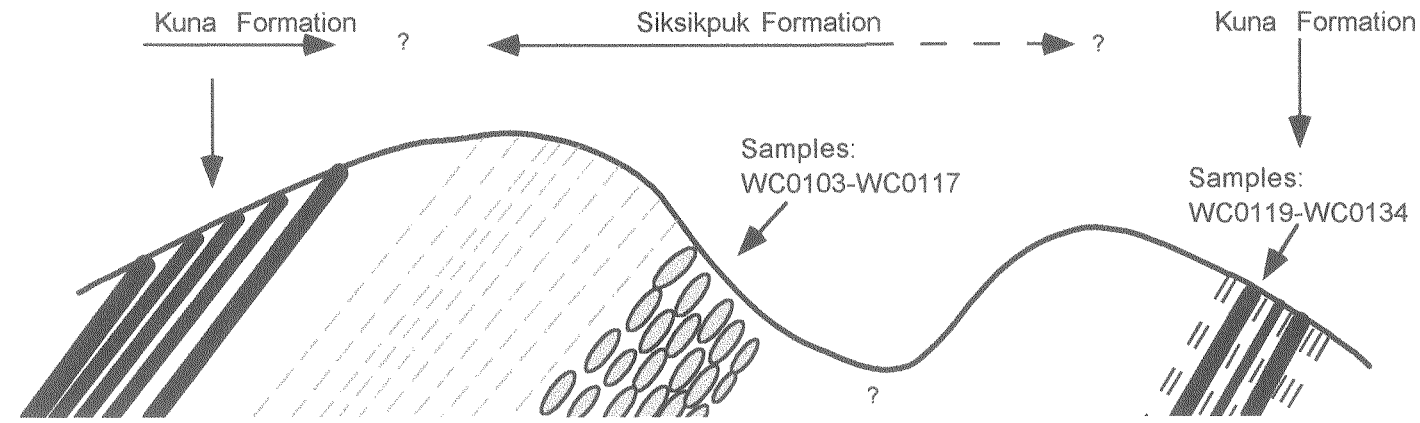
There are four locations with concentrated chert artifacts (flakes and cores) made of blue-gray and blue-gray-black mottled chert on the exposure: two in the slope blanketed with colluvium (Fig. 7b) and two others on the top of the bank. No tools were found indicating that the site served just as a quarry.

KE12 outcrop



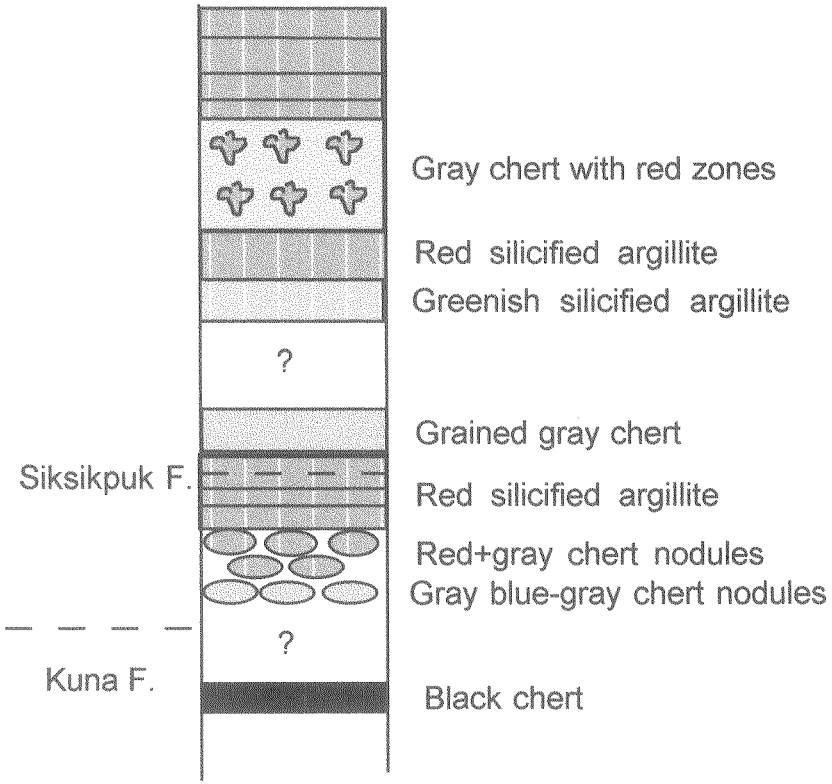
Appendix I.1.

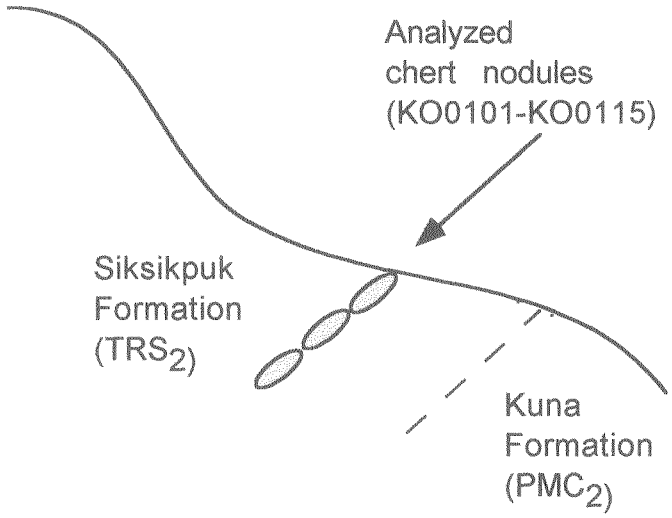
WC01 outcrop



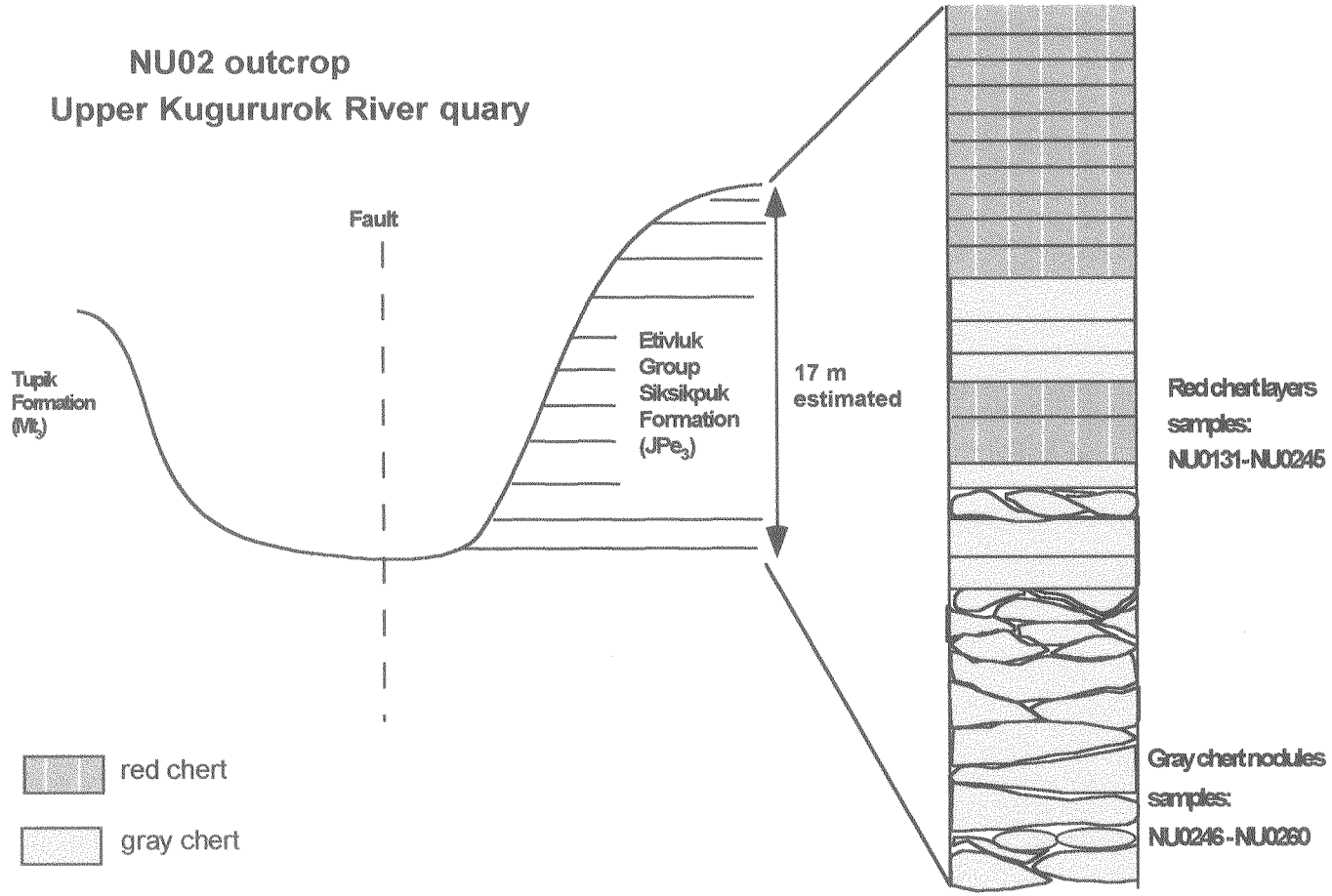
Appendix I.1.

KO01 outcrop





Appendix I.1.


NU02 outcrop
Upper Kugururok River quary
Fault
Tupik
Formation
(Mt3)
Etivluk
Group
Siksikpuk
Formation
(JPe3)
17 m
estimated
Red chert layers
samples:
NU0131-NU0245
Gray chert nodules
samples:
NU0246-NU0260
red chert
gray chert

Appendix I.1.

Appendix I.2.:

Instrumental Neutron Activation Analysis Data on 12 Chert Varieties from Nine Chert Outcrops in the Western Brooks Range

Appendix I.2. A. INAA Data of Major, Minor and Trace Elements (ppm).

	Al	Ca	K	Mn	Na	Fe	Ba	Cr	Co	Ni	Zn	Sb	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	V	As
Etivluk Group																						
Otuk Formation																						
AN10, gray to black; Anisak Quarry.																						
AN1001	9800	**	3400	89	690	3390	837	8.06	5.84	0.00	27.77	0.65	**	0.96	4.75	1.12	0.79	20.23	38.73	0.08	10.00	2.22
AN1002	1300	**	600	846	660	14720	761	5.06	10.50	30.00	56.11	0.59	**	0.79	4.01	0.54	0.59	6.85	0.00	0.08	11.80	**
AN1003	8900	300	2500	48	690	7960	716	7.64	4.31	8.60	0.00	0.94	**	0.81	2.97	0.76	0.66	12.56	77.48	0.07	10.50	3.03
AN1004	9100	**	3200	65	700	6460	954	5.58	5.77	9.64	0.00	1.00	**	1.17	4.72	0.87	0.69	15.49	63.43	0.08	7.10	5.80
AN1005	7900	**	2100	555	790	2540	977	22.30	4.63	0.00	0.00	0.69	0.17	0.74	2.66	0.69	0.64	11.04	73.27	0.07	0.00	8.28
AN1006	6100	**	1600	209	650	2220	889	23.40	2.12	0.00	7.46	0.66	**	0.70	2.44	0.74	0.58	10.46	70.78	0.06	5.20	3.16
AN1007	5900	200	1800	85	750	1780	897	5.15	6.44	8.19	0.00	1.03	0.16	0.89	2.47	0.74	0.60	9.46	71.66	0.07	5.50	0.94
AN1008	7500	**	2100	67	670	6460	697	6.43	2.51	0.00	0.00	1.31	**	0.63	2.48	0.66	0.55	8.56	84.41	0.06	7.70	3.90
AN1009	8000	300	2800	95	690	3330	827	5.71	4.16	0.00	0.00	0.81	**	0.91	3.04	0.87	0.70	15.29	128.60	0.08	7.80	**
AN1010	9100	300	3100	114	690	2220	753	10.40	2.23	5.08	0.00	0.62	0.17	0.65	3.38	0.75	0.71	14.83	38.56	0.07	10.40	**
AN1011	7000	**	2300	46	740	7840	825	5.73	3.63	7.17	0.00	1.20	**	1.07	2.68	0.74	0.62	11.69	74.68	0.07	5.30	2.56
AN1012	10000	**	3700	69	850	4660	982	8.22	5.67	11.30	0.00	0.84	**	1.31	3.55	1.29	0.79	16.92	38.67	0.10	11.20	**
AN1013	6100	**	**	326	540	1630	716	6.26	3.44	6.19	7.98	0.83	**	0.86	2.34	0.56	0.49	9.21	71.08	0.06	0.00	3.96
AN1014	7000	700	**	320	690	3700	758	8.09	3.53	0.00	0.00	0.82	**	0.65	3.13	0.79	0.70	13.56	39.01	0.07	9.40	2.70
AN1015	7000	**	1700	34	630	7140	786	5.00	3.06	0.00	0.00	1.20	**	0.91	2.61	0.77	0.60	11.68	78.85	0.07	6.70	1.50
DU0517	8900	**	2300	31	860	3240	909	7.22	7.70	18.70	5.26	0.57	**	1.01	3.59	0.81	0.75	12.71	83.14	0.08	8.60	2.06
DU0518	9400	**	3100	26	800	2940	810	7.51	9.76	26.10	8.17	0.65	**	0.90	3.96	0.83	0.78	13.08	38.20	0.10	8.00	4.64
DU0519	8200	**	2500	18	860	2330	879	7.79	5.49	0.00	4.88	0.58	**	0.59	2.86	0.72	0.67	10.36	79.54	0.07	6.20	13.60
DU0520	8500	200	2500	41	750	2300	849	7.13	6.98	9.54	4.87	0.57	**	0.58	2.89	0.72	0.66	10.73	71.77	0.07	7.00	6.49
Siksikpuk Formation																						
NU02g, gray to blue-gray; Upper Kugururok River Quarry.																						
NU0246	12000	**	4000	331	1190	3760	20765	8.59	2.51	13.40	14.96	0.39	**	0.68	2.86	0.69	0.60	10.49	687.70	0.07	14.70	**
NU0247	6900	**	2000	291	134	2860	3481	9.32	1.74	0.00	9.94	0.47	**	0.69	2.57	0.60	0.54	8.03	209.50	0.07	11.40	**
NU0248	8400	**	**	418	1250	2740	10006	8.32	1.85	9.44	9.57	0.45	**	0.67	2.50	0.52	0.61	7.82	361.40	0.05	11.30	**
NU0249	8700	**	1800	417	1200	3530	11546	8.26	2.07	7.00	13.83	0.37	**	0.92	3.00	0.70	0.76	9.34	422.30	0.08	15.10	**
NU0250	9800	1400	2200	394	1240	3010	5138	9.10	1.62	0.00	10.94	0.43	**	0.82	2.71	0.60	0.63	9.38	246.40	0.08	12.90	**
NU0251	7500	1500	320	358	1030	2940	4967	8.73	1.65	6.26	10.80	0.47	**	0.74	2.55	0.61	0.49	8.54	229.90	0.07	14.20	**
NU0252	8300	**	2700	318	1090	4110	2293	9.65	3.47	14.70	17.86	0.38	**	0.68	3.15	0.75	0.54	11.30	173.50	0.08	18.00	**
NU0253	11000	1200	3100	306	1120	3770	6003	8.74	2.66	0.00	15.41	0.38	**	0.90	3.01	0.72	0.65	10.31	293.80	0.08	16.50	**
NU0254	8700	500	2200	332	1050	3340	4317	8.40	1.93	8.02	12.30	0.44	**	0.81	2.70	0.63	0.52	9.11	240.30	0.07	11.10	**
NU0255	7200	**	2100	321	105	2740	5926	8.51	1.75	0.00	9.28	0.52	**	0.78	2.37	0.52	0.53	7.55	274.70	0.07	11.50	**
NU0256	8900	1400	2800	355	1150	2880	5555	8.38	1.61	0.00	10.34	0.50	**	0.85	2.38	0.56	0.54	8.30	264.70	0.07	12.90	**
NU0257	8000	1200	2500	345	1180	3060	6876	7.90	1.78	0.00	10.40	0.45	**	0.86	2.76	0.59	0.59	8.41	296.20	0.07	16.00	**
NU0258	8500	**	1500	283	1090	2840	7184	7.90	1.68	0.00	10.51	0.49	**	0.78	2.49	0.55	0.55	8.12	284.60	0.06	9.40	**

Appendix I.2. A. INAA Data of Major, Minor and Trace Elements (ppm).

	Al	Ca	K	Mn	Na	Fe	Ba	Cr	Co	Ni	Zn	Sb	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	V	As
NU0259	7000	**	**	355	120	2640	7036	8.30	1.92	6.34	9.66	0.52	**	0.75	2.51	0.51	0.59	6.52	250.30	0.07	6.80	**
NU0260	10200	**	2200	323	1140	3620	14730	8.57	2.43	8.23	18.10	0.37	**	0.95	3.04	0.70	0.58	9.78	475.30	0.08	14.40	**
NU02r, red-maroon; Upper Kugururok River Quarry.																						
NU0231	4900	1900	**	82	540	2850	1199	1.27	1.04	0.00	4.23	0.24	0.39	0.24	1.47	0.16	0.26	2.32	62.42	0.02	6.10	**
NU0232	4200	2300	**	106	610	2300	1640	1.22	0.94	0.00	2.52	0.21	0.36	0.21	1.50	0.13	0.25	1.94	68.56	0.02	0.00	**
NU0233	5200	3700	**	179	540	3200	1256	1.28	1.51	0.00	3.39	0.25	0.48	0.23	1.72	0.14	0.26	2.12	72.38	0.02	0.00	**
NU0234	19700	**	3300	338	780	6910	2409	2.27	16.80	52.30	21.53	0.23	**	0.38	2.98	0.29	0.43	5.05	72.52	0.03	15.70	**
NU0235	4900	2200	**	119	550	3720	1698	1.36	1.63	**	3.35	0.26	0.36	0.22	1.86	0.15	0.22	1.66	50.92	0.02	0.00	**
NU0236	7800	2900	1900	187	820	4730	1635	3.43	1.68	9.82	**	0.28	**	0.48	2.98	0.28	0.70	4.99	78.82	0.11	14.30	**
NU0237	8300	2700	2600	129	840	3610	1016	1.75	1.17	**	**	0.26	0.35	0.34	2.08	0.21	0.52	2.89	73.88	0.07	17.80	**
NU0238	6300	2400	**	132	780	3080	5577	1.69	1.54	9.40	**	0.20	0.34	0.28	1.92	0.18	0.34	2.47	105.80	0.02	0.00	**
NU0239	4700	4500	**	197	590	2380	4261	1.47	1.03	4.08	2.85	0.22	0.40	0.21	1.47	0.17	0.29	1.82	89.15	0.02	0.00	**
NU0240	4900	2600	**	118	610	3920	1454	1.52	1.29	**	0.00	0.24	0.00	0.34	2.13	0.21	0.48	3.45	63.52	0.06	0.00	**
NU0241	10900	1900	3400	144	1170	4730	593	1.95	4.43	15.00	10.24	0.24	0.00	0.37	2.74	0.28	0.43	5.40	60.85	0.03	10.90	**
NU0242	4200	25	**	148	590	2650	1017	1.19	0.81	**	**	0.23	0.32	0.24	1.48	0.14	0.30	2.01	61.82	0.02	0.00	**
NU0243	5700	21	1100	120	640	5260	1238	3.40	3.22	20.50	10.30	0.24	**	0.54	3.07	0.35	0.72	7.11	59.38	0.09	8.40	**
NU0244	3900	23	**	87	530	2690	610	1.26	0.86	**	**	0.25	0.47	0.22	1.48	0.14	0.29	1.61	65.81	0.02	0.00	**
NU0245	4400	2900	**	123	540	2520	986	1.18	0.80	**	**	0.25	0.49	0.21	1.52	0.15	0.28	1.67	64.51	0.02	0.00	**
KE13g, gray to blue-gray; Upper Kelly River Quarry																						
KE1301	5500	**	900	16	870	750	403	6.43	1.73	**	8.35	0.18	0.25	0.46	1.94	0.29	0.32	4.14	477.50	0.04	8.20	**
KE1302	6500	500	1300	21	940	980	707	5.29	2.98	13.80	**	0.20	0.16	0.38	2.01	0.32	0.37	4.42	149.70	0.04	13.10	**
KE1303	5500	**	1500	14	871	870	888	5.85	2.19	7.76	4.62	0.18	0.20	0.38	1.71	0.31	0.31	4.25	156.70	0.05	6.20	**
KE1304	5300	**	1700	36	860	920	587	4.50	3.65	12.00	8.81	0.24	0.15	0.50	2.00	0.34	0.33	4.59	135.30	0.04	7.40	**
KE1305	4300	**	1200	14	860	950	576	5.50	2.44	**	0.00	0.20	0.18	0.44	2.03	0.32	0.34	4.43	167.00	0.05	6.50	**
KE1306	6210	**	1400	28	870	1140	836	5.30	6.12	19.00	7.01	0.25	**	0.66	2.26	0.41	0.44	5.99	135.00	0.05	7.60	**
KE1307	5200	**	10400	27	850	930	833	4.56	3.51	16.00	5.56	0.24	0.11	0.43	2.45	0.33	0.32	3.89	133.20	0.05	7.00	**
KE1308	8300	**	2800	52	1260	1090	2842	5.41	5.46	21.60	6.48	0.27	0.19	0.62	2.26	0.40	0.49	6.88	239.70	0.06	12.70	**
KE1309	6200	**	1200	27	850	880	1438	5.97	2.35	**	13.21	0.20	0.22	0.51	2.00	0.31	0.36	4.61	189.70	0.04	8.00	**
KE1310	5200	**	1200	24	840	980	1996	4.84	3.90	15.40	7.42	0.21	0.00	0.47	2.20	0.37	0.44	4.73	251.20	0.05	7.90	**
KE1311	6700	**	1600	26	980	1130	1131	5.49	4.29	17.70	5.72	0.22	0.19	0.51	2.01	0.36	0.42	4.34	300.50	0.05	10.10	**
KE1312	5600	**	1400	21	900	1060	686	6.29	3.95	13.70	11.76	0.23	0.15	0.47	2.28	0.40	0.48	5.79	108.10	0.06	6.70	**
KE1313	6500	**	2100	34	990	1270	1465	6.93	5.30	14.30	16.24	0.22	0.13	0.57	2.44	0.48	0.63	7.47	135.30	0.07	9.60	**
KE1314	2400	21900	**	13	420	900	666	5.28	4.85	17.00	4.62	0.23	0.31	0.36	1.73	0.32	0.32	5.98	124.40	0.04	5.20	**
KE1315	4600	**	1300	18	840	770	499	5.53	1.85	**	5.53	0.16	0.18	0.38	1.90	0.30	0.28	3.81	245.00	0.04	5.60	**
DU0309	4700	500	1600	22	790	850	379	4.91	1.27	**	5.69	0.17	**	0.43	2.04	0.31	0.31	3.86	101.60	0.04	6.90	**
DU0310	4500	**	1300	12	780	880	1920	5.65	1.73	8.73	4.98	0.18	**	0.43	1.85	0.28	0.33	3.32	128.60	0.04	4.90	**

Appendix I.2. A. INAA Data of Major, Minor and Trace Elements (ppm).

	Al	Ca	K	Mn	Na	Fe	Ba	Cr	Co	Ni	Zn	Sb	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	V	As
DU0311	4300	700	900	15	750	750	774	5.40	3.64	15.00	4.62	0.22	**	0.43	1.62	0.30	0.32	2.81	129.10	0.04	7.80	**
DU0312	5100	700	1000	21	790	970	1281	5.18	1.57	**	5.08	0.16	**	0.41	2.01	0.32	0.33	3.82	215.30	0.04	7.50	**
KE13r, red-maroon, Upper Kelly River Quarry.																						
KE1331	13400	3700	**	1170	2270	11860	68619	12.20	8.79	44.60	67.12	0.43	**	2.14	11.20	1.17	1.46	17.71	2067.00	0.21	23.10	**
KE1332	11300	**	3200	58	1590	4230	8929	7.42	1.48	**	18.11	0.47	**	1.02	4.67	0.65	0.96	10.53	305.60	0.11	7.60	**
KE1333	21200	**	8200	64	2320	9910	21731	9.28	5.20	22.20	45.24	0.54	**	1.78	8.51	1.01	1.66	18.79	688.00	0.17	20.40	**
KE1334	8400	400	3300	102	1410	3830	10676	7.45	1.57	**	16.47	0.46	0.71	1.21	4.40	0.60	0.95	10.47	327.40	0.11	6.70	**
KE1335	9600	**	320	98	1420	4210	7826	8.44	1.71	**	18.53	0.43	**	1.10	5.54	0.76	1.01	13.73	277.70	0.11	8.00	**
KE1336	24400	**	7400	166	3220	10560	60660	12.00	7.36	38.50	55.66	0.39	**	2.07	10.20	1.13	1.65	18.52	1799.00	0.21	33.30	**
KE1337	5400	**	2600	80	1550	3690	4890	8.50	1.54	**	18.03	0.45	**	1.05	4.68	0.67	0.90	11.02	154.90	0.11	10.60	**
KE1338	12000	**	3400	67	1590	7550	74196	9.53	4.76	28.10	38.84	0.34	**	1.58	7.32	0.86	1.36	14.16	2275.00	0.14	14.50	**
KE1339	14600	**	4400	68	1980	8600	35471	10.10	3.42	26.90	36.85	0.61	**	1.67	8.25	0.99	1.15	18.72	1143.00	0.16	18.00	**
KE1340	17000	**	3400	276	2140	13660	46925	12.90	11.30	50.80	82.82	0.44	**	2.06	11.20	1.23	1.37	21.16	1438.00	0.20	26.50	**
KE1341	21800	**	7100	152	2710	16760	30645	17.10	12.40	66.00	89.38	0.55	**	2.96	15.50	1.88	2.44	30.86	937.80	0.28	33.40	**
KE1342	16500	**	4400	384	2420	14360	40212	15.50	11.50	45.20	81.92	0.48	**	2.47	16.10	1.57	2.35	25.10	1221.00	0.25	25.50	**
KE1343	18400	**	3900	139	3170	10830	51091	11.60	6.44	28.30	56.80	0.52	**	1.95	9.97	1.11	1.42	19.52	1588.00	0.21	27.70	**
KE1344	9900	**	2400	123	1520	5100	10791	7.32	2.00	**	15.03	0.57	**	1.38	4.85	0.59	0.97	10.24	349.70	0.10	8.90	**
KE1345	13200	**	3800	85	1380	7180	26297	9.23	4.12	16.80	27.74	0.44	**	1.49	6.79	0.84	1.45	12.83	829.30	0.14	16.50	**
DU0205	9500	**	2400	104	1790	4360	5461	6.25	1.30	0.00	13.12	0.56	**	1.14	4.31	0.47	0.78	7.41	231.40	0.09	7.30	**
DU0206	9300	800	2700	85	1460	5310	8390	7.40	1.93	0.00	18.67	0.56	**	1.30	4.99	0.67	1.05	10.99	289.00	0.11	8.00	**
DU0207	8800	200	2600	101	1570	5240	12641	7.39	1.71	0.00	17.48	0.54	**	1.28	5.23	0.64	1.11	11.24	473.10	0.11	14.30	**
DU0208	10200	1700	3190	367	1870	6260	20786	7.19	2.64	0.00	24.23	0.52	**	1.32	5.78	0.68	0.87	10.72	742.70	0.12	6.70	**
KO01, gray																						
KO0101	7800	600	2100	129	770	1700	6515	6.86	1.25	**	5.04	0.24	0.25	0.70	2.86	1.07	0.68	10.30	116.40	0.06	14.30	**
KO0102	9600	400	2400	124	850	1810	4826	6.80	1.45	**	6.50	0.23	0.25	0.80	2.94	1.14	0.64	11.18	159.00	0.07	21.60	**
KO0103	8000	900	2100	740	920	3970	14691	9.14	33.70	13.20	17.76	1.12	0.38	0.95	2.67	0.71	0.52	10.65	720.20	0.08	18.30	3.42
KO0104	9200	1000	2200	745	1040	4070	13121	9.17	29.40	14.90	20.99	0.99	0.40	1.07	2.69	0.74	0.84	10.53	646.70	0.08	18.20	4.47
KO0105	7900	1500	3300	679	930	5840	10095	10.10	14.00	10.30	20.35	0.76	**	1.13	2.92	0.88	0.84	14.34	485.20	0.09	14.10	**
KO0106	11300	1500	4000	1409	820	5360	3780	16.20	6.39	11.50	16.52	0.73	0.25	1.11	2.99	0.94	0.60	16.51	202.40	0.08	32.20	**
KO0107	9200	**	3500	761	1110	3960	19017	8.95	36.60	22.40	20.27	1.21	0.43	0.85	2.70	0.69	0.48	8.89	934.90	0.08	15.30	4.34
KO0108	10100	1800	3200	1041	890	40650	16523	9.59	29.60	10.80	20.52	1.29	0.51	0.91	2.73	0.71	0.81	11.29	801.80	0.07	15.50	2.90
KO0109	10000	1400	2300	680	1010	5060	8089	9.66	15.70	13.60	18.25	0.94	0.29	1.01	2.84	0.88	0.71	14.39	413.40	0.09	12.40	**
KO0110	9200	300	2200	77	840	2140	8577	7.77	1.86	**	10.51	0.23	0.39	0.88	3.49	1.27	0.83	14.24	108.90	0.08	14.00	**
KO0111	9100	1600	3100	667	910	4820	11886	10.00	14.20	14.20	23.88	0.92	0.13	0.76	2.89	0.75	0.78	12.33	564.00	0.09	15.80	2.15
KO0112	10000	1500	2100	710	1000	7590	13991	9.96	21.50	12.90	28.05	1.07	0.55	0.83	3.18	0.91	0.84	13.22	668.80	0.07	17.10	2.39
KO0113	8700	1700	**	770	1020	3960	20155	8.68	47.20	26.70	19.20	1.47	**	1.12	2.58	0.70	0.47	9.42	1028.00	0.07	22.20	2.98
KO0114	11000	1800	**	773	1010	4900	18905	9.80	29.80	15.30	19.54	1.02	0.49	1.05	2.95	0.80	0.59	12.74	921.20	0.09	22.30	**

Appendix I.2. A. INAA Data of Major, Minor and Trace Elements (ppm).

	Al	Ca	K	Mn	Na	Fe	Ba	Cr	Co	Ni	Zn	Sb	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	V	As
KO0115	9400	1700	2800	628	960	4160	15929	9.39	23.00	15.30	24.51	1.09	0.43	0.68	2.79	0.71	0.53	11.16	752.60	0.08	13.20	4.93
WC05, gray																						
WC0531	6000	3100	2100	446	910	1140	29964	4.69	5.90	10.30	11.38	0.57	**	0.68	2.33	0.37	0.49	4.75	441.40	0.06	8.10	4.26
WC0532	6600	1100	1800	90	880	1070	31200	4.70	5.33	11.30	19.37	0.56	**	0.75	2.27	0.42	0.49	5.60	418.10	0.08	6.80	5.45
WC0533	6200	1900	1670	320	820	1610	6001	4.49	6.94	11.70	4.19	0.52	**	0.66	2.72	0.35	0.57	4.02	141.30	0.07	2.70	1.77
WC0534	9800	4600	2300	772	1970	4740	5859	9.77	2.41	5.07	13.61	0.33	0.31	1.34	3.27	0.64	0.98	11.58	269.00	0.12	13.00	**
WC0535	6300	1600	1600	83	890	940	19601	4.70	6.53	12.10	8.19	0.49	0.23	0.72	2.22	0.35	0.44	6.09	280.60	0.05	4.80	5.06
WC0536	6300	3500	1300	289	980	850	34025	4.97	7.66	10.70	4.58	0.50	**	0.71	2.27	0.33	0.44	4.86	439.30	0.07	4.00	4.23
WC0537	10100	9100	**	1158	1550	4100	9512	9.85	2.63	12.50	17.16	0.26	0.35	1.25	2.96	0.64	1.10	11.81	302.20	0.12	0.00	**
WC0538	9900	8900	2400	147	1010	2320	31839	6.09	5.17	15.70	11.64	0.41	**	0.82	2.26	0.44	0.55	6.21	430.30	0.09	11.90	**
WC0539	7200	1200	2700	26	1800	2160	1861	8.42	11.00	19.40	7.93	0.55	0.42	0.49	3.66	0.35	0.48	7.53	61.60	0.04	17.30	3.21
WC0540	4800	600	1000	62	790	1100	16414	4.47	5.15	**	3.47	0.93	**	0.37	3.00	0.31	0.38	3.84	624.90	0.06	3.40	**
WC0541	8700	5500	**	839	2080	4090	23354	9.15	2.61	5.49	23.19	0.23	0.19	1.25	3.16	0.64	0.86	11.49	587.40	0.11	15.60	**
WC0542	7400	1100	2200	23	1836	2160	2203	7.72	8.90	21.10	8.04	0.48	0.36	0.42	3.46	0.32	0.48	7.25	70.18	0.04	15.70	4.01
WC0543	5700	800	1800	23	1220	1240	2244	4.41	8.42	18.50	3.32	0.46	0.40	0.29	2.53	0.27	0.34	5.23	73.21	0.02	8.20	2.55
WC0544	5800	1200	1800	24	1260	1240	1185	4.44	5.56	13.80	3.63	0.37	0.33	0.32	2.47	0.28	0.33	5.32	62.45	0.03	9.10	1.95
WC0545	11300	700	2100	113	1040	3250	29413	6.87	7.38	19.10	20.24	0.61	**	1.01	3.11	0.46	0.62	5.97	399.90	0.10	14.30	12.50
WC01g, gray to blue-gray																						
WC0103	10900	**	2400	393	780	5490	18485	6.20	1.23	10.40	16.61	0.33	**	1.00	4.48	1.25	1.39	12.98	254.60	0.08	0.00	**
WC0104	79700	**	1600	233	790	5720	19916	6.01	1.48	10.20	19.83	0.33	**	1.04	4.79	1.26	1.47	13.99	333.70	0.08	11.30	**
WC0105	10600	**	**	750	1010	5730	31328	5.28	2.17	**	26.52	0.22	**	0.90	5.03	1.06	0.93	12.01	396.60	0.08	13.70	**
WC0106	7200	**	1500	657	760	2720	4452	5.08	3.10	11.90	12.48	0.54	0.16	0.90	3.69	1.05	0.93	10.17	87.86	0.08	0.00	3.82
WC0107	9000	**	2100	100	930	4100	8831	12.40	1.05	**	11.89	0.43	**	1.05	4.00	1.04	1.14	11.92	196.80	0.09	9.70	**
WC0108	9800	**	2100	362	860	4320	14236	5.03	0.79	**	14.53	0.29	**	0.85	4.07	1.12	1.19	11.64	229.50	0.06	14.40	**
WC0109	10100	**	2900	195	1000	5230	21224	5.56	1.41	**	19.54	0.26	**	0.88	4.59	1.16	1.34	12.35	249.00	0.09	12.50	**
WC0110	9500	**	2900	244	970	5750	17825	5.90	1.20	**	17.17	0.34	**	1.06	4.41	1.24	1.36	12.63	272.60	0.08	14.50	**
WC0111	7000	**	1900	276	740	3130	3037	5.54	2.43	**	16.51	0.49	0.31	0.89	3.77	1.05	0.88	9.91	75.51	0.08	6.80	2.04
WC0112	8700	**	2000	236	870	5750	26587	5.58	1.59	**	22.10	0.25	**	0.96	5.09	1.12	1.00	12.64	407.70	0.09	9.00	**
WC0113	8900	**	1900	251	930	5090	17027	5.44	1.44	16.70	20.80	0.23	**	0.83	4.54	1.08	1.23	11.76	275.00	0.07	12.00	**
WC0114	10400	**	2900	227	1110	4320	26222	5.43	1.28	18.60	19.05	0.23	**	1.00	5.02	1.21	1.00	14.03	403.20	0.08	8.90	**
WC0115	8500	**	3700	473	840	3930	15796	4.92	0.86	8.46	11.78	0.24	**	0.85	3.65	0.99	1.17	10.49	266.60	0.08	10.70	**
WC0116	11200	**	2300	827	1040	4520	8575	5.26	0.73	0.00	11.58	0.36	**	0.83	3.40	1.02	0.96	9.77	163.30	0.07	0.00	**
WC0117	8800	**	2200	185	900	3860	6699	14.90	0.95	0.00	13.97	0.40	0.41	0.92	3.68	0.83	0.92	10.13	204.30	0.08	10.10	**
DU0101	10900	**	3000	410	890	6970	28921	5.01	3.28	18.30	35.25	0.20	**	0.91	4.79	1.19	1.06	12.33	441.10	0.08	7.90	**
DU0102	8700	**	1300	315	790	6140	27418	4.13	3.41	24.70	34.29	0.19	**	0.76	4.35	1.08	0.88	11.78	482.50	0.08	8.50	**
DU0103	10400	**	2600	382	740	9340	29512	4.31	6.19	32.70	51.97	0.17	**	0.82	5.13	1.11	1.15	12.17	480.20	0.06	0.00	**
DU0104	7800	**	1900	324	760	5720	29551	4.59	3.04	16.20	31.85	0.17	**	0.75	4.17	1.10	0.97	12.63	544.80	0.07	7.60	**

Appendix I.2. A. INAA Data of Major, Minor and Trace Elements (ppm).

	Al	Ca	K	Mn	Na	Fe	Ba	Cr	Co	Ni	Zn	Sb	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	V	As
											Lisburne Group											
Kuna Formation																						
WC01b, black																						
WC0119	8200	900	1600	52	640	1990	846	9.46	1.83	15.30	18.57	0.56	1.82	0.45	3.41	1.12	0.45	8.02	46.88	0.05	23.10	**
WC0120	6500	**	1700	62	680	1700	858	7.77	2.14	11.70	39.96	0.64	0.72	0.53	2.50	1.12	0.55	7.36	34.45	0.05	18.90	2.38
WC0121	7800	**	1800	33	720	1610	839	7.31	2.98	16.20	54.89	0.56	0.62	0.48	2.67	1.07	0.64	6.96	30.59	0.04	26.00	3.36
WC0122	5700	**	**	94	590	1520	723	5.89	7.21	37.60	44.06	0.48	0.84	0.56	2.39	0.95	0.92	5.63	44.74	0.04	8.40	2.87
WC0123	10600	**	2400	4	890	1640	1011	12.20	5.01	31.70	55.75	0.64	1.34	0.70	4.05	1.15	0.53	11.01	71.33	0.05	59.00	**
WC0124	10700	**	3000	35	770	2870	861	12.90	6.20	50.00	169.20	0.85	1.42	0.63	3.98	1.25	0.54	10.67	55.45	0.05	64.60	2.61
WC0125	10200	**	3000	32	790	2490	854	11.70	2.52	23.60	69.62	0.75	1.17	0.59	4.03	1.18	0.52	9.50	48.18	0.04	56.30	**
WC0126	6400	600	1400	49	620	1630	729	6.54	4.06	19.90	22.99	0.47	1.11	0.59	2.40	0.99	1.06	6.45	47.61	0.05	9.80	2.83
WC0127	7900	**	1700	39	760	3090	1495	12.40	4.00	28.70	48.40	0.73	0.92	0.60	3.08	1.35	0.46	10.14	53.89	0.05	28.50	**
WC0128	7600	**	1900	36	690	1940	905	8.14	12.20	57.30	39.71	0.72	1.28	0.67	2.61	1.22	0.77	9.38	39.76	0.06	23.70	3.35
WC0129	7900	**	1700	31	690	1870	832	8.79	5.63	30.90	34.82	0.58	0.73	0.57	2.59	1.21	0.79	9.37	38.87	0.06	22.80	**
WC0130	7100	**	1600	28	680	2380	909	8.93	2.53	16.50	21.11	0.57	0.99	0.61	2.45	1.26	0.71	9.79	38.38	0.06	17.90	2.48
WC0131	6000	**	1700	71	657	4230	835	5.16	2.37	27.30	32.98	0.86	0.72	0.43	2.31	0.93	1.06	5.95	42.39	0.04	12.00	2.73
WC0132	8300	**	1900	66	710	2530	923	10.90	1.97	10.80	36.05	0.68	1.27	0.54	4.33	1.27	0.50	9.87	43.78	0.05	27.60	2.10
WC0133	5500	**	1200	48	630	1500	777	5.86	1.37	14.80	14.31	0.42	0.78	0.57	2.57	0.94	0.90	6.07	29.09	0.04	8.60	1.26
KE12,black																						
KE1201	3300	2700	400	9	570	1760	126	9.22	0.34	6.14	13.43	0.11	1.27	0.26	0.53	0.29	0.16	2.46	16.16	0.03	7.60	1.31
KE1202	3200	5400	700	13	630	2130	124	10.00	0.33	5.22	9.14	0.13	1.19	0.24	0.55	0.30	0.18	2.69	19.24	0.03	12.30	1.52
KE1203	3200	4400	700	7	430	1240	64	17.10	0.34	10.10	17.58	0.06	0.59	0.54	0.84	0.26	0.13	2.69	18.88	0.02	18.20	1.61
KE1204	4500	3800	700	8	420	1700	81	21.50	0.47	11.40	22.08	0.09	0.90	0.44	0.68	0.39	0.18	4.64	22.19	0.04	18.40	1.39
KE1205	3600	3100	700	9	610	1590	96	7.65	0.34	5.94	13.18	0.09	1.56	0.25	0.48	0.26	0.13	1.70	15.92	0.02	8.70	0.87
KE1206	4200	**	1400	5	540	1460	137	13.90	0.46	8.01	19.42	0.10	1.45	0.35	0.70	0.39	0.20	4.30	9.16	0.04	17.60	**
KE1208	3500	1800	**	7	710	1950	134	9.10	0.37	5.64	7.37	0.12	0.91	0.25	0.43	0.34	0.19	3.24	14.64	0.03	5.10	2.36
KE1209	3000	1000	**	5	560	1180	106	8.38	0.25	5.27	10.43	0.07	1.07	0.29	0.48	0.24	0.15	1.91	18.33	0.02	4.90	**
KE1210	3200	5900	1000	12	640	1760	131	8.48	0.32	4.95	5.44	0.10	1.41	0.35	0.44	0.33	0.18	2.69	25.23	0.03	10.40	1.15
KE1211	3900	1700	1100	8	710	1870	129	9.28	0.33	**	5.76	0.11	0.95	0.23	0.44	0.33	0.18	3.14	20.21	0.03	7.90	1.68
KE1212	3300	2000	900	8	680	1960	132	11.00	0.39	5.68	7.14	0.12	1.47	0.25	0.55	0.36	0.17	2.69	14.35	0.03	9.10	1.18
KE1213	5000	**	1400	5	480	1680	116	16.30	0.59	11.30	23.48	0.11	1.39	0.42	0.75	0.39	0.20	4.76	16.92	0.05	16.60	**
KE1214	3800	3400	800	7	470	1480	109	14.70	0.40	12.80	21.10	0.10	1.46	0.36	0.68	0.31	0.16	3.93	13.53	0.04	18.60	2.12
KE1215	3700	6000	1000	10	440	1330	106	10.10	0.29	6.72	13.61	0.08	0.93	0.29	0.49	0.26	0.14	2.00	16.06	0.02	30.60	1.19
WC04, black (Akmalik Chert); Wrench Creek Quarry.																						
WC0462	3300	28200	600	14	370	710	52	7.59	0.23	**	10.72	0.10	2.81	0.31	0.31	0.59	0.22	2.49	7.04	0.03	**	1.57
WC0463	3300	20600	1000	12	340	700	53	7.37	0.23	**	34.82	0.11	2.35	0.30	0.31	0.57	0.21	2.27	21.94	0.03	4.80	1.81
WC0464	3400	9300	900	8	380	810	53	7.24	0.26	5.35	11.17	0.11	1.74	0.32	0.28	0.60	0.24	3.38	9.64	0.03	3.10	1.22

Appendix I.2. A. INAA Data of Major, Minor and Trace Elements (ppm).

	Al	Ca	K	Mn	Na	Fe	Ba	Cr	Co	Ni	Zn	Sb	U	Th	Sc	Cs	Hf	Rb	Sr	Ta	V	As
WC0465	2500	13600	1000	10	400	810	106	7.36	0.24	5.37	15.10	0.13	2.60	0.28	0.29	0.65	0.19	2.36	4.19	0.03	2.80	0.00
WC0466	3700	21700	400	11	390	690	54	6.99	0.22	3.75	14.43	0.10	2.47	0.30	0.31	0.63	0.22	2.30	15.50	0.03	**	1.53
WC0467	2400	29400	**	14	400	510	54	5.12	0.16	**	10.77	0.07	2.19	0.21	0.22	0.61	0.17	1.70	13.00	0.02	**	0.73
WC0468	2300	28500	**	14	390	520	52	5.47	0.16	2.72	14.22	0.07	2.84	0.21	0.24	0.58	0.18	1.49	13.29	0.02	1.80	1.02
WC0469	2400	13200	400	9	380	800	110	7.59	0.23	4.09	14.69	0.12	2.43	0.27	0.28	0.64	0.18	2.52	5.76	0.03	4.30	0.92
WC0470	5000	**	**	20	790	510	56	5.79	0.17	**	13.72	0.07	3.03	0.23	0.25	0.57	0.17	1.57	11.27	0.02	4.80	0.84
WC0471	2600	14400	1100	10	380	800	53	7.70	0.26	3.65	13.78	0.12	2.18	0.32	0.32	0.61	0.26	2.99	6.51	0.03	3.70	1.55
WC0472	2700	24200	**	13	390	690	58	7.50	0.22	3.99	11.53	0.10	3.03	0.30	0.30	0.62	0.23	2.17	15.72	0.03	**	1.33
WC0473	3200	6300	700	5	410	700	97	5.78	0.22	5.70	12.06	0.11	2.43	0.27	0.26	0.61	0.18	2.46	3.43	0.02	**	1.02
WC0474	3300	12400	500	9	400	800	109	7.32	0.25	3.61	11.73	0.14	1.91	0.31	0.29	0.66	0.23	2.48	11.50	0.03	5.90	1.40
WC0475	2300	14600	**	8	390	710	101	5.48	0.22	5.03	10.28	0.11	2.21	0.26	0.25	0.61	0.17	2.05	9.64	0.02	4.00	1.00
WC0476	2700	7600	800	7	390	650	99	5.04	0.21	**	12.00	0.11	2.35	0.25	0.25	0.59	0.17	2.03	5.98	0.02	4.10	0.62
DU0413	3000	16100	600	10	300	840	49	8.41	0.29	4.05	13.13	0.12	1.71	0.33	0.37	0.55	0.24	3.05	11.33	0.03	3.40	0.00
DU0413x	2900	13000	900	9	350	890	97	7.96	0.27	5.27	26.73	0.15	1.89	0.30	0.32	0.61	0.19	2.49	9.51	0.03	4.80	1.28
DU0414	3100	6700	500	6	350	750	97	5.49	0.26	4.12	7.53	0.12	1.70	0.27	0.28	0.60	0.18	2.20	5.10	0.02	4.00	0.00
DU0415	2700	13000	700	9	350	820	106	7.97	0.27	3.93	14.62	0.13	2.00	0.28	0.32	0.62	0.18	2.70	10.45	0.02	4.10	1.86
DU0415x	2600	13800	700	9	340	920	191	8.68	0.27	4.20	27.31	0.14	1.69	0.28	0.32	0.63	0.20	3.09	4.29	0.03	3.60	0.74
DU0416	3000	15600	600	11	360	780	108	8.46	0.25	4.21	12.79	0.12	1.77	0.28	0.30	0.63	0.18	2.53	8.35	0.03	3.00	0.92
Tuplk Formation																						
NU01, black																						
NU0131	1600	14700	200	11	350	370	24	5.43	0.10	2.29	3.94	0.07	4.37	0.16	0.15	0.07	0.11	0.33	37.72	0.01	1.90	1.41
NU0132	1900	13100	100	11	390	360	20	5.80	0.10	4.36	5.67	0.07	3.93	0.14	0.15	0.07	0.11	0.46	37.44	0.01	3.20	1.35
NU0133	1400	15100	**	14	307	440	24	8.14	0.12	3.69	8.72	0.10	4.74	0.18	0.19	0.06	0.10	0.36	43.79	0.01	2.70	2.00
NU0134	1400	14300	**	12	350	390	23	7.21	0.11	3.54	4.99	0.07	4.66	0.17	0.17	0.06	0.10	0.44	46.77	0.01	3.20	1.28
NU0135	1500	16200	200	11	350	360	21	5.41	0.10	3.12	3.76	0.08	3.39	0.14	0.15	0.07	0.12	0.42	45.68	0.01	2.20	1.14
NU0136	2200	12500	**	9	460	360	18	5.06	0.09	3.88	3.44	0.08	3.86	0.15	0.15	0.07	0.11	0.41	48.68	0.01	**	2.22
NU0137	1400	14600	**	12	320	420	21	8.21	0.12	4.35	4.27	0.09	4.72	0.18	0.19	0.05	0.11	0.37	43.72	0.01	3.40	1.66
NU0138	1500	13800	**	11	290	420	24	6.66	0.11	3.90	3.79	0.08	4.45	0.16	0.17	0.06	0.10	0.34	42.68	0.01	2.60	1.93
NU0139	1800	18300	200	12	350	350	17	4.95	0.09	4.38	8.04	0.08	3.51	0.14	0.14	0.07	0.11	0.56	46.00	0.01	4.00	1.51
NU0140	1500	15900	**	12	340	440	28	7.20	0.12	3.86	6.02	0.09	5.04	0.17	0.18	0.06	0.11	0.38	39.88	0.01	0.00	1.59
NU0141	1600	15900	**	12	330	400	23	6.36	0.10	4.17	9.21	0.09	4.84	0.16	0.17	0.06	0.10	0.38	43.13	0.01	0.00	2.31
NU0142	1600	14200	**	11	310	390	27	6.17	0.10	4.87	7.94	0.08	4.54	0.15	0.18	0.06	0.10	0.40	38.96	0.01	2.80	1.52
NU0143	1600	16500	**	13	320	450	23	8.71	0.12	4.41	6.12	0.09	4.50	0.19	0.19	0.05	0.11	0.41	41.59	0.01	2.70	1.60
NU0144	1600	14300	100	11	360	400	26	6.70	0.11	3.27	5.05	0.07	4.49	0.14	0.17	0.07	0.10	0.41	51.94	0.01	**	1.24
NU0145	1600	13000	**	10	360	380	23	5.99	0.10	3.66	7.93	0.08	4.83	0.16	0.16	0.06	0.10	0.35	37.67	0.01	2.20	1.45

Note: ** below detection limit.

Appendix I. 2. B. INAA data of REE composition (ppm).

	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	Ce_n/Ce_n^*	La_n/Yb_n	La_n/Ce_n	Eu_n/Sm_n
Etivluk Group													
Otuk Formation													
AN10, gray to black; Anisak Quarry													
AN1001	2.54	7.18	1.96	0.57	0.15	0.11	0.44	0.47	0.08	1.38	0.40	0.75	1.36
AN1002	1.44	3.03	1.05	0.40	0.13	0.11	0.50	0.32	0.08	1.05	0.33	1.00	1.62
AN1003	2.25	6.53	2.18	0.54	0.16	0.10	0.54	0.35	0.06	1.31	0.48	0.73	1.54
AN1004	3.31	10.70	2.35	0.86	0.25	0.12	0.61	0.47	0.08	1.62	0.52	0.65	1.50
AN1005	1.33	2.91	0.56	0.31	0.10	0.08	0.35	0.25	0.05	1.24	0.40	0.97	1.60
AN1006	1.42	2.84	0.88	0.30	0.09	0.07	0.24	0.22	0.04	1.05	0.48	1.05	1.46
AN1007	2.39	7.74	3.08	0.61	0.16	0.13	0.44	0.37	0.06	1.31	0.48	0.65	1.30
AN1008	1.31	3.11	0.93	0.26	0.09	0.06	0.40	0.23	0.04	1.20	0.42	0.88	1.72
AN1009	2.55	7.66	2.44	0.65	0.18	0.16	0.53	0.42	0.07	1.36	0.45	0.70	1.44
AN1010	1.68	3.80	1.99	0.35	0.09	0.10	0.33	0.34	0.05	0.95	0.36	0.93	1.32
AN1011	2.87	9.83	3.60	0.67	0.22	0.05	0.60	0.35	0.06	1.40	0.60	0.61	1.70
AN1012	4.51	12.11	5.52	1.12	0.29	0.17	0.89	0.52	0.09	1.11	0.64	0.78	1.34
AN1013	2.02	5.56	2.49	0.55	0.15	0.10	0.29	0.27	0.05	1.13	0.54	0.77	1.35
AN1014	1.84	4.82	1.78	0.39	0.12	0.10	0.43	0.33	0.05	1.19	0.41	0.80	1.57
AN1015	2.91	9.85	3.63	0.71	0.21	0.11	0.45	0.32	0.06	1.39	0.67	0.62	1.52
DU0517	3.23	8.95	4.13	0.68	0.19	0.11	0.43	0.38	0.06	1.12	0.63	0.76	1.46
DU0518	3.08	8.35	2.72	0.62	0.17	0.08	0.67	0.37	0.07	1.27	0.61	0.78	1.42
DU0519	1.51	3.27	1.24	0.28	0.08	0.05	0.42	0.26	0.04	1.04	0.43	0.97	1.46
DU0520	1.74	3.79	1.11	0.32	0.09	0.06	0.43	0.23	0.04	1.13	0.55	0.97	1.43
Siksikpuk Formation													
NU02g, gray to blue-gray; Upper Kugururok River Quarry.													
NU0246	2.26	4.56	2.20	0.40	0.12	0.08	0.57	0.26	0.03	0.91	0.08	1.04	1.50
NU0247	1.90	4.01	1.95	0.34	0.08	0.06	0.34	0.25	0.04	0.93	0.07	1.00	1.24
NU0248	2.00	4.21	2.23	0.38	0.09	0.06	0.34	0.24	0.03	0.90	0.07	1.00	1.22
NU0249	3.55	8.22	2.97	0.76	0.19	0.12	0.59	0.39	0.05	1.10	0.14	0.91	1.25
NU0250	2.56	5.11	3.68	0.75	0.18	0.14	0.55	0.35	0.06	0.77	0.15	1.05	1.20
NU0251	2.24	5.20	2.13	0.45	0.10	0.08	0.55	0.24	0.04	1.06	0.09	0.91	1.16
NU0252	1.97	3.94	1.92	0.42	0.11	0.07	0.76	0.28	0.04	0.90	0.08	1.05	1.36
NU0253	3.28	8.04	3.53	0.68	0.18	0.11	0.67	0.33	0.05	1.07	0.13	0.86	1.31
NU0254	2.86	7.11	2.95	0.60	0.15	0.11	0.40	0.38	0.04	1.10	0.12	0.85	1.26
NU0255	2.23	5.19	1.94	0.45	0.11	0.08	0.55	0.24	0.04	1.09	0.09	0.91	1.23
NU0256	2.53	6.02	2.33	0.59	0.14	0.06	0.50	0.33	0.05	1.10	0.09	0.88	1.25
NU0257	2.89	6.95	2.95	0.58	0.14	0.09	0.41	0.30	0.04	1.07	0.11	0.87	1.26
NU0258	2.48	6.02	1.83	0.53	0.12	0.09	0.47	0.27	0.05	1.20	0.10	0.87	1.16
NU0259	2.10	4.66	1.95	0.45	0.10	0.06	0.53	0.23	0.04	1.02	0.08	0.95	1.13

Appendix I. 2. B. INAA data of REE composition (ppm) (continued).

	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	Ce_n/Ce_n^*	La_n/Yb_n	La_n/Ce_n	Eu_n/Sm_n
NU0260	3.77	8.65	5.08	0.93	0.21	0.13	0.56	0.36	0.05	0.91	0.17	0.92	1.15
NU02r, red-maroon; Upper Kugururok River Quarry													
NU0231	1.20	3.09	1.79	0.39	0.09	0.04	0.44	0.29	0.04	0.97	0.30	0.82	1.22
NU0232	1.36	3.51	1.57	0.40	0.10	0.07	0.40	0.32	0.05	1.09	0.32	0.82	1.25
NU0233	1.51	3.69	1.55	0.44	0.11	0.08	0.36	0.45	0.07	1.08	0.25	0.86	1.27
NU0234	2.77	6.90	3.34	0.82	0.23	0.15	1.23	0.47	0.06	1.03	0.44	0.85	1.43
NU0235	1.51	3.67	2.35	0.48	0.12	0.08	0.53	0.37	0.06	0.90	0.30	0.86	1.25
NU0236	2.55	7.06	2.83	0.86	0.22	0.23	1.12	0.58	0.08	1.19	0.33	0.76	1.30
NU0237	1.80	4.90	2.71	0.57	0.15	0.12	1.60	0.48	0.07	1.02	0.28	0.78	1.37
NU0238	1.96	5.03	2.10	0.59	0.15	0.15	0.80	0.44	0.06	1.12	0.33	0.82	1.34
NU0239	1.35	3.27	1.57	0.41	0.10	0.09	0.48	0.33	0.05	1.02	0.30	0.87	1.23
NU0240	2.00	5.06	1.95	0.61	0.16	0.14	0.59	0.45	0.07	1.14	0.33	0.83	1.31
NU0241	2.53	6.30	3.23	0.78	0.21	0.14	1.12	0.45	0.06	1.01	0.41	0.84	1.34
NU0242	1.29	3.17	1.48	0.39	0.10	0.08	0.45	0.34	0.05	1.04	0.28	0.86	1.29
NU0243	2.82	8.16	3.58	0.86	0.23	0.17	0.66	0.62	0.09	1.18	0.33	0.73	1.37
NU0244	1.13	2.90	1.23	0.35	0.08	0.08	0.35	0.31	0.05	1.11	0.27	0.82	1.20
NU0245	1.21	2.99	1.24	0.39	0.09	0.08	0.30	0.34	0.05	1.10	0.27	0.85	1.23
KE13g, gray to blue-gray; Upper Kelly River Quarry													
KE1301	1.24	2.41	1.02	0.31	0.07	0.05	0.21	0.18	0.03	0.93	0.50	1.08	1.13
KE1302	1.17	2.21	2.60	0.26	0.06	0.04	0.23	0.14	0.02	0.58	0.60	1.11	1.22
KE1303	1.03	1.84	1.38	0.24	0.06	0.02	0.34	0.11	0.02	0.71	0.68	1.18	1.24
KE1304	1.32	2.61	1.28	0.30	0.07	0.00	0.32	0.16	0.03	0.89	0.60	1.07	1.22
KE1305	1.22	2.24	1.79	0.27	0.06	0.00	0.19	0.14	0.02	0.70	0.63	1.14	1.22
KE1306	2.13	4.56	2.91	0.51	0.11	0.10	0.34	0.25	0.03	0.84	0.63	0.99	1.13
KE1307	1.25	2.23	2.39	0.27	0.06	0.05	0.28	0.14	0.02	0.60	0.66	1.18	1.19
KE1308	1.91	3.95	3.39	0.42	0.10	0.00	0.75	0.24	0.03	0.72	0.59	1.02	1.21
KE1309	1.28	2.33	2.02	0.29	0.07	0.00	0.20	0.16	0.04	0.67	0.60	1.15	1.24
KE1310	1.48	2.68	1.25	0.31	0.07	0.06	0.34	0.20	0.02	0.86	0.55	1.16	1.17
KE1311	1.64	3.40	1.54	0.39	0.09	0.06	0.31	0.19	0.03	0.95	0.64	1.01	1.20
KE1312	1.40	2.92	2.52	0.34	0.08	0.06	0.20	0.17	0.03	0.72	0.60	1.01	1.18
KE1313	1.79	3.53	2.27	0.40	0.10	0.08	0.41	0.24	0.04	0.80	0.56	1.07	1.26
KE1314	1.08	2.00	1.48	0.24	0.06	0.04	0.15	0.12	0.02	0.73	0.64	1.14	1.21
KE1315	1.04	1.95	0.81	0.23	0.06	0.04	0.17	0.12	0.02	0.91	0.62	1.12	1.28
DU0309	1.27	2.27	2.19	0.29	0.06	0.03	0.18	0.15	0.03	0.63	0.61	1.17	1.06
DU0310	1.15	2.08	1.03	0.27	0.06	0.03	0.17	0.15	0.02	0.84	0.58	1.16	1.15
DU0311	1.14	2.06	1.27	0.26	0.06	0.03	0.20	0.11	0.02	0.77	0.73	1.17	1.11

Appendix I. 2. B. INAA data of REE composition (ppm) (continued).

	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	Ce_n/Ce_n^*	La_n/Yb_n	La_n/Ce_n	Eu_n/Sm_n
DU0312	1.25	2.20	1.37	0.27	0.06	0.03	0.23	0.17	0.02	0.76	0.56	1.19	1.13
Ke13r, red-maroon; Upper Kelly River Quarry													
KE1331	13.03	27.52	11.78	2.51	0.63	0.49	2.08	0.84	0.15	0.98	1.15	1.00	1.28
KE1332	2.29	4.36	2.35	0.51	0.13	0.10	0.78	0.39	0.06	0.84	0.43	1.10	1.25
KE1333	8.40	20.07	8.66	1.93	0.48	0.25	2.29	0.80	0.13	1.06	0.77	0.88	1.28
KE1334	2.69	4.94	3.19	0.66	0.15	0.11	0.64	0.44	0.08	0.77	0.45	1.15	1.16
KE1335	2.48	4.56	2.27	0.64	0.17	0.20	0.62	0.48	0.08	0.85	0.38	1.14	1.32
KE1336	10.48	21.94	7.35	1.98	0.52	0.43	3.08	0.94	0.15	1.05	0.82	1.01	1.35
KE1337	2.15	3.91	2.07	0.52	0.13	0.00	0.79	0.42	0.06	0.82	0.38	1.16	1.26
KE1338	8.15	17.39	7.96	1.51	0.43	0.38	1.21	0.65	0.11	0.96	0.92	0.99	1.43
KE1339	8.07	18.26	9.20	1.56	0.40	0.32	1.60	0.72	0.12	0.96	0.83	0.93	1.30
KE1340	10.72	23.92	11.94	2.12	0.54	0.43	1.55	0.90	0.15	0.96	0.88	0.94	1.30
KE1341	15.79	35.23	20.70	3.30	0.79	0.52	2.41	1.41	0.23	0.89	0.83	0.94	1.22
KE1342	13.60	29.54	14.91	2.80	0.68	0.44	1.49	1.09	0.18	0.94	0.92	0.97	1.24
KE1343	10.30	22.43	9.27	2.05	0.53	0.38	1.80	0.86	0.14	1.01	0.88	0.97	1.33
KE1344	4.16	9.42	5.01	0.92	0.21	0.19	0.63	0.47	0.09	0.94	0.66	0.93	1.17
KE1345	7.32	16.55	8.77	1.49	0.37	0.32	1.08	0.65	0.10	0.94	0.83	0.93	1.26
DU0205	3.95	9.31	7.35	0.86	0.20	0.09	1.00	0.41	0.08	0.80	0.71	0.89	1.15
DU0206	3.25	7.35	3.15	0.74	0.17	0.09	0.68	0.45	0.07	1.02	0.53	0.93	1.17
DU0207	5.69	13.46	6.53	1.24	0.27	0.18	0.93	0.51	0.08	1.00	0.82	0.89	1.12
DU0208	5.44	12.78	7.42	1.30	0.29	0.16	0.91	0.63	0.10	0.93	0.63	0.90	1.15
KO01, gray													
KO0101	3.03	7.52	3.24	0.70	0.19	0.08	0.42	0.27	0.04	1.08	0.82	0.85	1.40
KO0102	3.34	7.98	3.54	0.82	0.21	0.10	0.65	0.32	0.05	1.04	0.78	0.88	1.29
KO0103	3.63	8.87	3.48	0.84	0.19	0.10	0.41	0.35	0.05	1.11	0.76	0.86	1.15
KO0104	3.83	9.30	3.18	0.87	0.19	0.14	0.65	0.39	0.06	1.16	0.72	0.87	1.12
KO0105	4.05	9.75	2.96	0.95	0.23	0.12	0.63	0.45	0.06	1.20	0.67	0.87	1.24
KO0106	4.73	12.76	6.73	1.13	0.27	0.15	0.90	0.43	0.07	1.04	0.82	0.78	1.19
KO0107	3.20	6.97	2.16	0.63	0.15	0.09	0.36	0.36	0.05	1.11	0.66	0.97	1.18
KO0108	3.26	7.41	2.96	0.68	0.15	0.08	0.50	0.32	0.04	1.05	0.75	0.93	1.15
KO0109	3.73	8.73	3.62	0.86	0.21	0.12	0.70	0.37	0.06	1.06	0.75	0.90	1.21
KO0110	3.13	7.11	1.79	0.73	0.21	0.23	0.54	0.40	0.06	1.21	0.58	0.93	1.47
KO0111	2.83	5.53	2.51	0.59	0.14	0.07	0.23	0.32	0.05	0.91	0.65	1.08	1.16
KO0112	3.04	6.33	3.53	0.57	0.13	0.07	0.52	0.34	0.05	0.88	0.66	1.01	1.20
KO0113	3.75	9.92	3.57	0.82	0.18	0.09	0.44	0.32	0.05	1.20	0.87	0.79	1.14
KO0114	3.81	8.42	5.32	0.78	0.19	0.07	0.26	0.40	0.04	0.86	0.70	0.95	1.23
KO0115	2.49	4.69	18.80	0.44	0.10	0.06	0.37	0.33	0.04	0.24	0.56	1.12	1.14

Appendix I. 2. B. INAA data of REE composition (ppm) (continued).

	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	Ce_n/Ce_n^*	La_n/Yb_n	La_n/Ce_n	Eu_n/Sm_n
WC05, gray													
WC0531	3.12	6.58	3.48	0.61	0.16	0.10	0.41	0.31	0.04	0.90	0.12	1.00	1.32
WC0532	3.12	6.79	3.00	0.62	0.17	0.08	0.61	0.32	0.04	0.99	0.11	0.97	1.40
WC0533	2.87	6.69	2.46	0.70	0.17	0.10	0.57	0.41	0.05	1.10	0.13	0.90	1.20
WC0534	4.45	10.45	5.23	1.16	0.31	0.18	1.68	0.54	0.08	0.98	0.22	0.90	1.35
WC0535	3.04	6.74	3.88	0.69	0.18	0.10	0.50	0.33	0.05	0.90	0.13	0.95	1.30
WC0536	3.22	6.53	2.82	0.60	0.14	0.07	0.48	0.30	0.04	0.95	0.10	1.04	1.22
WC0537	3.86	8.92	4.73	0.88	0.23	0.12	0.72	0.43	0.07	0.95	0.16	0.91	1.33
WC0538	4.24	9.24	5.01	0.85	0.23	0.14	0.89	0.39	0.05	0.91	0.16	0.97	1.41
WC0539	5.76	16.49	5.54	1.28	0.31	0.17	0.76	0.45	0.07	1.30	0.23	0.73	1.22
WC0540	1.25	1.86	1.58	0.18	0.04	0.03	0.19	0.17	0.02	0.61	0.04	1.42	1.12
WC0541	3.85	9.04	3.55	0.85	0.24	0.14	0.60	0.44	0.07	1.08	0.16	0.90	1.43
WC0542	5.23	14.13	7.05	1.14	0.27	0.15	0.84	0.45	0.06	1.07	0.20	0.78	1.21
WC0543	3.90	10.81	4.35	0.89	0.21	0.12	0.54	0.33	0.05	1.19	0.16	0.76	1.18
WC0544	3.82	10.69	3.60	0.83	0.20	0.09	0.54	0.29	0.05	1.28	0.14	0.75	1.22
WC0545	5.59	12.16	6.07	1.17	0.30	0.16	1.17	0.53	0.07	0.94	0.21	0.97	1.31
WC01g, gray to blue-gray													
WC0103	5.10	12.82	6.53	1.28	0.31	0.13	1.07	0.50	0.09	1.02	0.75	0.84	1.22
WC0104	7.40	19.78	11.32	1.93	0.46	0.23	0.87	0.66	0.09	1.00	0.83	0.79	1.23
WC0105	9.74	25.66	10.75	2.56	0.61	0.30	1.58	0.62	0.09	1.13	1.15	0.80	1.21
WC0106	4.43	13.48	5.44	1.14	0.26	0.12	0.60	0.41	0.06	1.25	0.79	0.69	1.17
WC0107	4.99	14.15	4.95	1.34	0.30	0.14	0.83	0.47	0.07	1.27	0.78	0.74	1.13
WC0108	4.50	11.49	4.76	1.20	0.28	0.11	1.06	0.58	0.08	1.12	0.57	0.82	1.19
WC0109	7.30	19.10	9.10	2.00	0.46	0.20	1.39	0.52	0.07	1.07	1.03	0.81	1.17
WC0110	5.10	12.84	6.64	1.26	0.30	0.20	1.08	0.50	0.08	1.01	0.74	0.84	1.22
WC0111	3.79	11.02	4.41	0.94	0.22	0.00	0.63	0.39	0.07	1.23	0.71	0.72	1.19
WC0112	8.74	23.48	8.36	2.36	0.54	0.23	0.96	0.58	0.09	1.22	1.11	0.78	1.17
WC0113	8.08	22.05	8.74	2.24	0.52	0.31	1.39	0.60	0.08	1.18	1.00	0.77	1.18
WC0114	8.47	22.32	9.41	2.43	0.59	0.23	1.53	0.58	0.08	1.13	1.08	0.80	1.24
WC0115	5.03	13.79	4.52	1.43	0.33	0.15	0.88	0.50	0.07	1.27	0.74	0.77	1.17
WC0116	3.82	10.02	4.40	1.06	0.25	0.10	0.98	0.47	0.07	1.11	0.60	0.80	1.18
WC0117	3.59	9.85	4.88	0.96	0.21	0.13	0.79	0.38	0.06	1.08	0.69	0.77	1.11
DU0101	7.69	21.18	10.72	2.31	0.59	0.25	1.20	0.47	0.09	1.07	1.21	0.76	1.29
DU0102	8.40	23.60	10.41	2.78	0.68	0.26	0.89	0.47	0.07	1.15	1.33	0.75	1.24
DU0103	8.07	23.10	9.27	2.93	0.79	0.30	1.13	0.49	0.09	1.21	1.22	0.74	1.37
DU0104	8.84	24.07	13.73	2.81	0.70	0.11	1.15	0.49	0.07	1.01	1.34	0.77	1.26

Appendix I. 2. B. INAA data of REE composition (ppm) (continued).

	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	Ce_n/Ce_n^*	La_n/Yb_n	La_n/Ce_n	Eu_n/Sm_n
Lisburne Group													
Kuna Formation													
WC01b, black													
WC0119	3.39	8.00	3.85	0.93	0.18	0.15	1.10	0.55	0.09	1.00	0.45	0.89	0.98
WC0120	3.38	9.01	3.82	0.73	0.15	0.09	0.70	0.45	0.06	1.14	0.55	0.79	1.05
WC0121	2.60	7.08	1.98	0.63	0.14	0.07	0.61	0.39	0.07	1.33	0.49	0.77	1.12
WC0122	3.41	10.08	5.12	0.92	0.18	0.14	0.53	0.42	0.06	1.11	0.60	0.71	0.99
WC0123	4.02	11.92	4.53	1.18	0.22	0.13	1.06	0.56	0.10	1.26	0.53	0.71	0.94
WC0124	3.84	10.88	3.70	1.06	0.21	0.14	0.94	0.54	0.10	1.29	0.52	0.74	1.00
WC0125	3.69	10.40	4.02	0.95	0.19	0.13	0.94	0.54	0.10	1.22	0.51	0.75	1.04
WC0126	3.46	10.08	3.79	1.02	0.20	0.06	0.92	0.49	0.07	1.26	0.52	0.72	0.99
WC0127	3.96	11.12	3.34	0.81	0.17	0.09	0.74	0.41	0.07	1.33	0.71	0.75	1.08
WC0128	4.20	12.30	4.06	1.00	0.19	0.12	0.79	0.50	0.08	1.33	0.62	0.72	0.99
WC0129	3.48	9.69	4.68	0.83	0.18	0.05	0.84	0.49	0.07	1.10	0.52	0.76	1.09
WC0130	4.06	11.39	4.66	0.87	0.18	0.10	0.75	0.48	0.08	1.19	0.63	0.75	1.03
WC0131	2.48	6.47	3.38	0.60	0.13	0.00	0.56	0.34	0.05	1.03	0.54	0.81	1.11
WC0132	3.46	8.60	5.75	0.81	0.19	0.24	0.98	0.55	0.08	0.89	0.47	0.85	1.21
WC0133	3.12	9.09	4.99	0.84	0.18	0.14	0.94	0.43	0.06	1.06	0.54	0.72	1.10
KE12,black													
KE1201	1.11	1.34	1.13	****	0.05	0.02	0.24	0.15	0.03	0.54	0.53	1.74	****
KE1202	1.30	1.45	1.39	****	0.05	0.02	0.22	0.15	0.03	0.49	0.63	1.89	****
KE1203	2.51	2.05	1.93	****	0.10	0.07	0.27	0.32	0.05	0.40	0.57	2.58	****
KE1204	1.85	2.08	1.44	****	0.06	0.04	0.22	0.22	0.04	0.55	0.62	1.87	****
KE1205	0.89	1.04	0.70	****	0.04	0.02	0.19	0.12	0.03	0.57	0.57	1.80	****
KE1206	1.28	1.89	1.32	****	0.05	0.03	0.21	0.15	0.03	0.65	0.64	1.43	****
KE1208	0.87	1.29	0.85	****	0.03	0.01	0.13	0.10	0.02	0.67	0.63	1.41	****
KE1209	1.04	1.05	0.73	****	0.05	0.03	0.00	0.14	0.03	0.50	0.53	2.10	****
KE1210	1.18	1.56	2.00	****	0.06	0.04	0.21	0.13	0.03	0.47	0.69	1.59	****
KE1211	0.80	1.23	0.59	****	0.03	0.01	0.16	0.10	0.02	0.76	0.62	1.37	****
KE1212	1.03	1.31	0.95	****	0.04	0.03	0.11	0.11	0.03	0.58	0.68	1.66	****
KE1213	1.36	2.10	1.72	****	0.06	0.04	0.19	0.17	0.04	0.63	0.58	1.36	****
KE1214	1.24	1.64	0.75	****	0.06	0.03	0.26	0.18	0.03	0.69	0.51	1.59	****
KE1215	1.25	1.32	1.52	****	0.05	0.03	0.58	0.16	0.03	0.44	0.58	2.00	****
WC04, black (Akmalik Chert); Wrench Creek Quarry													
WC0462	2.07	1.66	2.03	****	0.05	0.03	0.30	0.13	0.04	0.36	1.16	2.62	****

Appendix I. 2. B. INAA data of REE composition (ppm) (continued).

	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	Ce_n/Ce_n^*	La_n/Yb_n	La_n/Ce_n	Eu_n/Sm_n
WC0463	2.11	1.71	1.72	****	0.05	0.02	0.20	0.13	0.03	0.39	1.21	2.59	****
WC0464	2.04	1.78	1.60	****	0.05	0.03	0.09	0.12	0.02	0.43	1.25	2.40	****
WC0465	2.10	1.66	1.33	****	0.05	0.03	0.22	0.12	0.03	0.41	1.28	2.67	****
WC0466	2.08	1.71	1.78	****	0.05	0.04	0.24	0.16	0.03	0.39	0.95	2.57	****
WC0467	1.48	1.21	1.18	****	0.04	0.02	0.13	0.09	0.03	0.39	1.22	2.58	****
WC0468	1.60	1.18	0.69	****	0.04	0.02	0.00	0.13	0.03	0.42	0.88	2.84	****
WC0469	2.03	1.59	2.03	****	0.05	0.03	0.19	0.12	0.03	0.35	1.20	2.69	****
WC0470	1.58	1.16	1.15	****	0.04	0.02	0.20	0.10	0.03	0.37	1.20	2.87	****
WC0471	2.10	1.83	1.59	****	0.05	0.02	0.23	0.13	0.03	0.43	1.15	2.42	****
WC0472	2.12	1.56	1.79	****	0.05	0.03	0.13	0.18	0.04	0.35	0.88	2.86	****
WC0473	1.97	1.45	1.23	****	0.04	0.02	0.20	0.11	0.03	0.38	1.31	2.85	****
WC0474	2.23	1.78	1.56	****	0.05	0.03	0.24	0.14	0.03	0.40	1.19	2.65	****
WC0475	2.15	1.50	1.01	****	0.04	0.02	0.19	0.11	0.03	0.39	1.49	3.01	****
WC0476	1.85	1.39	1.10	****	0.04	0.02	0.14	0.10	0.02	0.40	1.33	2.80	****
DU0413	2.60	2.16	1.53	****	0.06	0.03	0.29	0.14	0.03	0.44	1.36	2.54	****
DU0413x	2.55	1.99	1.33	****	0.05	0.05	0.23	0.14	0.03	0.42	1.37	2.70	****
DU0414	2.10	1.77	1.55	****	0.04	0.01	0.18	0.09	0.03	0.42	1.78	2.50	****
DU0415	2.32	1.90	1.16	****	0.05	0.02	0.20	0.08	0.03	0.45	2.06	2.57	****
DU0415x	2.55	2.01	1.26	****	0.05	0.04	0.20	0.10	0.03	0.43	1.80	2.68	****
DU0416	2.31	1.88	1.20	****	0.05	0.02	0.30	0.11	0.03	0.44	1.61	2.59	****
Tupik Formation													
NU01, black													
NU0131	1.59	0.87	1.67	****	0.04	0.03	0.16	0.07	0.04	0.24	1.58	3.85	****
NU0132	1.58	0.90	1.78	****	0.04	0.02	0.12	0.08	0.03	0.24	1.38	3.69	****
NU0133	2.28	1.26	2.11	****	0.06	0.04	0.18	0.11	0.04	0.26	1.47	3.79	****
NU0134	1.74	0.99	1.83	****	0.04	0.03	0.19	0.08	0.04	0.25	1.53	3.72	****
NU0135	1.61	0.89	1.97	****	0.04	0.03	0.15	0.10	0.03	0.23	1.16	3.82	****
NU0136	2.55	1.37	2.30	****	0.07	0.04	0.30	0.13	0.04	0.25	1.41	3.93	****
NU0137	2.30	1.27	2.22	****	0.05	0.04	0.19	0.12	0.04	0.25	1.46	3.80	****
NU0138	1.95	1.00	1.48	****	0.05	0.03	0.14	0.11	0.04	0.25	1.32	4.11	****
NU0139	1.65	0.91	1.17	****	0.04	0.02	0.19	0.09	0.03	0.28	1.35	3.83	****
NU0140	2.24	1.17	2.20	****	0.05	0.03	0.22	0.11	0.04	0.24	1.46	4.02	****
NU0141	2.20	1.16	1.96	****	0.05	0.03	0.20	0.11	0.04	0.25	1.47	3.98	****
NU0142	1.86	0.93	1.92	****	0.04	0.03	0.17	0.10	0.04	0.22	1.41	4.19	****
NU0143	2.38	1.31	2.47	****	0.06	0.04	0.27	0.11	0.04	0.24	1.59	3.82	****
NU0144	1.90	1.01	1.61	****	0.04	0.03	0.13	0.09	0.03	0.25	1.52	3.95	****
NU0145	1.89	0.92	1.55	****	0.04	0.03	0.11	0.10	0.04	0.23	1.33	4.31	****

Note: **** - data for Sm have been affected by Sm-U interference in U-enriched outcrops : NU01, WC04 and KE12.

Appendix I. 2.C.: INAA Data, Elemental ratios

	Ba/Al	Fe/Al	Th/Sc	Ba/Fe	Rb/Sr	Fe/Mn	Mn/Al	Co/Al	Co/Fe	Cs/Co	Cs/Mn	Cs/Rb	La/Al	Ba_n/La_n	La_n/Yb_n	Eu_n/Sm_n	Ce_n/Ce_n^*	La_n/Ce_n
Etivluk Group																		
Otuk Formation																		
AN10, grav; Anisak Quarry																		
AN1001	0.09	0.35	0.20	0.25	0.52	38.01	0.01	0.0006	0.002	0.19	0.013	0.06	0.0003	19.03	0.40	1.36	1.38	0.74
AN1002	0.06	1.13	0.20	0.05	0.00	17.41	0.06	0.0008	0.001	0.05	0.001	0.08	0.0001	30.50	0.34	1.62	1.04	1.00
AN1003	0.08	0.89	0.27	0.09	0.16	166.00	0.01	0.0005	0.001	0.18	0.016	0.06	0.0003	18.36	0.48	1.54	1.31	0.72
AN1004	0.11	0.71	0.25	0.15	0.24	99.80	0.01	0.0006	0.001	0.15	0.014	0.06	0.0004	16.64	0.53	1.50	1.62	0.65
AN1005	0.12	0.32	0.28	0.38	0.15	4.58	0.07	0.0006	0.002	0.15	0.001	0.06	0.0002	42.82	0.40	1.60	1.26	0.96
AN1006	0.15	0.37	0.29	0.40	0.15	10.62	0.03	0.0003	0.001	0.35	0.004	0.07	0.0002	36.28	0.48	1.46	1.05	1.04
AN1007	0.15	0.30	0.36	0.50	0.13	20.98	0.01	0.0011	0.004	0.12	0.009	0.08	0.0004	21.80	0.48	1.30	1.31	0.65
AN1008	0.09	0.86	0.25	0.11	0.10	96.61	0.01	0.0003	0.000	0.26	0.010	0.08	0.0002	30.83	0.42	1.72	1.19	0.88
AN1009	0.10	0.42	0.30	0.25	0.12	34.94	0.01	0.0005	0.001	0.21	0.009	0.06	0.0003	18.71	0.45	1.44	1.36	0.70
AN1010	0.08	0.25	0.19	0.34	0.38	19.45	0.01	0.0002	0.001	0.33	0.007	0.05	0.0002	26.11	0.37	1.32	0.94	0.93
AN1011	0.12	1.12	0.40	0.11	0.16	171.36	0.01	0.0005	0.001	0.20	0.016	0.06	0.0004	16.63	0.61	1.70	1.39	0.61
AN1012	0.09	0.43	0.37	0.21	0.44	67.42	0.01	0.0005	0.001	0.23	0.019	0.08	0.0004	12.56	0.64	1.34	1.10	0.78
AN1013	0.12	0.27	0.37	0.44	0.13	4.98	0.05	0.0006	0.002	0.16	0.002	0.06	0.0003	20.45	0.55	1.35	1.12	0.76
AN1014	0.11	0.53	0.21	0.20	0.35	11.56	0.05	0.0005	0.001	0.22	0.003	0.06	0.0003	23.81	0.41	1.57	1.18	0.80
AN1015	0.11	1.01	0.35	0.11	0.15	212.86	0.00	0.0004	0.000	0.25	0.023	0.07	0.0004	15.63	0.68	1.52	1.38	0.62
DU0517	0.10	0.37	0.28	0.28	0.15	106.08	0.00	0.0009	0.002	0.11	0.027	0.06	0.0004	16.25	0.64	1.46	1.12	0.76
DU0518	0.09	0.31	0.23	0.27	0.34	115.42	0.00	0.0010	0.003	0.09	0.033	0.06	0.0003	15.17	0.62	1.42	1.26	0.77
DU0519	0.11	0.29	0.21	0.38	0.13	132.46	0.00	0.0007	0.002	0.13	0.041	0.07	0.0002	33.65	0.43	1.46	1.03	0.97
DU0520	0.10	0.27	0.20	0.37	0.15	56.77	0.00	0.0008	0.003	0.10	0.018	0.07	0.0002	28.21	0.56	1.43	1.12	0.96
Siksikpuk Formation																		
NU02g, grav; Upper Kugururok River Quarry.																		
NU0246	1.79	0.32	0.24	5.66	0.02	11.07	0.03	0.0002	0.001	0.27	0.002	0.07	0.0002	531.56	0.65	1.50	0.91	1.04
NU0247	0.51	0.42	0.27	1.22	0.04	9.85	0.04	0.0003	0.001	0.35	0.002	0.08	0.0003	107.31	0.55	1.24	0.93	1.00
NU0248	1.19	0.33	0.27	3.65	0.02	6.56	0.05	0.0002	0.001	0.28	0.001	0.07	0.0002	289.36	0.61	1.22	0.90	0.99
NU0249	1.32	0.40	0.31	3.27	0.02	8.48	0.05	0.0002	0.001	0.34	0.002	0.08	0.0004	187.77	0.67	1.25	1.10	0.91
NU0250	0.52	0.31	0.30	1.71	0.04	7.64	0.04	0.0002	0.001	0.37	0.002	0.06	0.0003	116.08	0.55	1.20	0.76	1.05
NU0251	0.66	0.39	0.29	1.69	0.04	8.22	0.05	0.0002	0.001	0.37	0.002	0.07	0.0003	128.01	0.70	1.16	1.05	0.90
NU0252	0.28	0.49	0.22	0.56	0.07	12.94	0.04	0.0004	0.001	0.22	0.002	0.07	0.0002	67.20	0.53	1.36	0.90	1.05
NU0253	0.55	0.34	0.30	1.59	0.04	12.30	0.03	0.0002	0.001	0.27	0.002	0.07	0.0003	105.90	0.75	1.31	1.06	0.85
NU0254	0.49	0.38	0.30	1.29	0.04	10.03	0.04	0.0002	0.001	0.32	0.002	0.07	0.0003	87.16	0.57	1.26	1.09	0.84
NU0255	0.83	0.38	0.33	2.16	0.03	8.54	0.04	0.0002	0.001	0.30	0.002	0.07	0.0003	153.23	0.68	1.23	1.09	0.90
NU0256	0.62	0.32	0.36	1.93	0.03	8.12	0.04	0.0002	0.001	0.35	0.002	0.07	0.0003	126.99	0.56	1.25	1.10	0.88
NU0257	0.86	0.38	0.31	2.25	0.03	8.87	0.04	0.0002	0.001	0.33	0.002	0.07	0.0004	137.57	0.71	1.26	1.06	0.87
NU0258	0.84	0.33	0.31	2.53	0.03	10.03	0.03	0.0002	0.001	0.32	0.002	0.07	0.0003	167.46	0.69	1.16	1.20	0.86
NU0259	1.01	0.38	0.30	2.67	0.03	7.42	0.05	0.0003	0.001	0.27	0.001	0.08	0.0003	193.64	0.67	1.13	1.01	0.94
NU0260	1.44	0.35	0.31	4.07	0.02	11.19	0.03	0.0002	0.001	0.29	0.002	0.07	0.0004	225.49	0.78	1.15	0.90	0.91
NU02r, red; Upper Kugururok River Quarry.																		
NU0231	0.25	0.59	0.17	0.42	0.04	34.78	0.02	0.0002	0.000	0.16	0.002	0.07	0.0002	59.51	0.30	1.22	0.97	0.82
NU0232	0.39	0.55	0.14	0.71	0.03	21.66	0.03	0.0002	0.000	0.14	0.001	0.07	0.0003	71.29	0.31	1.25	1.09	0.82
NU0233	0.24	0.62	0.13	0.39	0.03	17.83	0.03	0.0003	0.001	0.09	0.001	0.07	0.0003	49.53	0.24	1.27	1.09	0.86
NU0234	0.12	0.35	0.13	0.35	0.07	20.45	0.02	0.0009	0.002	0.02	0.001	0.06	0.0001	50.21	0.44	1.43	1.03	0.84
NU0235	0.35	0.76	0.12	0.46	0.03	31.22	0.02	0.0003	0.000	0.09	0.001	0.09	0.0003	66.65	0.29	1.25	0.90	0.87
NU0236	0.21	0.60	0.16	0.35	0.06	25.27	0.02	0.0002	0.000	0.17	0.002	0.06	0.0003	37.05	0.33	1.30	1.18	0.76
NU0237	0.12	0.43	0.16	0.28	0.04	28.01	0.02	0.0001	0.000	0.18	0.002	0.07	0.0002	33.18	0.28	1.37	1.02	0.77
NU0238	0.89	0.49	0.15	1.81	0.02	23.39	0.02	0.0002	0.001	0.12	0.001	0.07	0.0003	167.26	0.33	1.34	1.12	0.82
NU0239	0.90	0.50	0.14	1.79	0.02	12.06	0.04	0.0002	0.000	0.16	0.001	0.09	0.0003	187.82	0.30	1.23	1.02	0.87
NU0240	0.30	0.80	0.16	0.37	0.05	33.21	0.02	0.0003	0.000	0.16	0.002	0.06	0.0004	42.05	0.33	1.31	1.14	0.83
NU0241	0.06	0.44	0.14	0.13	0.09	32.85	0.01	0.0004	0.001	0.06	0.002	0.05	0.0002	13.56	0.42	1.34	1.01	0.84

Appendix I. 2.C.: INAA Data, Elemental ratios (continued).

	Ba/Al	Fe/Al	Th/Sc	Ba/Fe	Rb/Sr	Fe/Mn	Mn/Al	Co/Al	Co/Fe	Cs/Co	Cs/Mn	Cs/Rb	La/Al	Ba_n/La_n	La_n/Yb_n	Eu_n/Sm_n	Ce_n/Ce_n^*	La_n/Ce_n
NU0242	0.24	0.63	0.17	0.38	0.03	17.99	0.03	0.0002	0.000	0.18	0.001	0.07	0.0003	46.56	0.27	1.29	1.04	0.86
NU0243	0.22	0.92	0.18	0.24	0.12	43.75	0.02	0.0006	0.001	0.11	0.003	0.05	0.0005	25.39	0.34	1.37	1.17	0.72
NU0244	0.16	0.69	0.15	0.23	0.02	30.76	0.02	0.0002	0.000	0.16	0.002	0.09	0.0003	32.50	0.26	1.20	1.12	0.82
NU0245	0.22	0.57	0.14	0.39	0.03	20.45	0.03	0.0002	0.000	0.18	0.001	0.09	0.0003	48.95	0.26	1.23	1.11	0.85
KE13g, grey; Upper Kelly River Quarry																		
KE1301	0.07	0.14	0.24	0.53	0.01	46.73	0.00	0.0003	0.002	0.17	0.018	0.07	0.0002	19.19	0.49	1.13	0.93	1.09
KE1302	0.11	0.15	0.19	0.72	0.03	47.18	0.00	0.0005	0.003	0.11	0.016	0.07	0.0002	35.41	0.60	1.22	0.57	1.12
KE1303	0.16	0.16	0.22	1.02	0.03	63.41	0.00	0.0004	0.003	0.14	0.022	0.07	0.0002	50.62	0.67	1.24	0.70	1.19
KE1304	0.11	0.18	0.25	0.64	0.03	25.76	0.01	0.0007	0.004	0.09	0.009	0.07	0.0003	25.95	0.60	1.22	0.89	1.07
KE1305	0.14	0.22	0.22	0.61	0.03	67.16	0.00	0.0006	0.003	0.13	0.022	0.07	0.0003	27.76	0.62	1.22	0.69	1.15
KE1306	0.14	0.18	0.29	0.74	0.04	40.37	0.00	0.0010	0.005	0.07	0.015	0.07	0.0003	22.61	0.63	1.13	0.84	0.98
KE1307	0.16	0.18	0.17	0.90	0.03	34.90	0.01	0.0007	0.004	0.09	0.012	0.09	0.0002	38.84	0.66	1.19	0.59	1.18
KE1308	0.34	0.13	0.27	2.59	0.03	20.95	0.01	0.0007	0.005	0.07	0.008	0.06	0.0002	86.75	0.59	1.21	0.71	1.02
KE1309	0.23	0.14	0.26	1.62	0.02	32.80	0.00	0.0004	0.003	0.13	0.011	0.07	0.0002	66.05	0.60	1.24	0.66	1.16
KE1310	0.39	0.19	0.21	2.03	0.02	41.08	0.00	0.0008	0.004	0.10	0.016	0.08	0.0003	78.12	0.55	1.17	0.86	1.16
KE1311	0.17	0.17	0.26	1.00	0.01	42.97	0.00	0.0006	0.004	0.08	0.014	0.08	0.0002	40.37	0.64	1.20	0.95	1.01
KE1312	0.12	0.19	0.21	0.65	0.05	49.94	0.00	0.0007	0.004	0.10	0.019	0.07	0.0003	28.54	0.60	1.18	0.71	1.01
KE1313	0.22	0.20	0.23	1.15	0.06	37.03	0.01	0.0008	0.004	0.09	0.014	0.06	0.0003	47.65	0.56	1.26	0.80	1.07
KE1314	0.28	0.38	0.21	0.74	0.05	71.53	0.01	0.0020	0.005	0.07	0.025	0.05	0.0004	36.72	0.63	1.21	0.72	1.15
KE1315	0.11	0.17	0.20	0.64	0.02	42.01	0.00	0.0004	0.002	0.16	0.016	0.08	0.0002	28.12	0.62	1.28	0.91	1.13
DU0309	0.08	0.18	0.21	0.45	0.04	38.95	0.00	0.0003	0.002	0.25	0.014	0.08	0.0003	17.29	0.61	1.06	0.63	1.17
DU0310	0.43	0.20	0.23	2.17	0.03	76.45	0.00	0.0004	0.002	0.16	0.025	0.09	0.0003	96.52	0.59	1.15	0.84	1.16
DU0311	0.18	0.17	0.27	1.04	0.02	48.88	0.00	0.0008	0.005	0.08	0.020	0.11	0.0003	39.19	0.74	1.11	0.77	1.16
DU0312	0.25	0.19	0.21	1.33	0.02	45.08	0.00	0.0003	0.002	0.20	0.015	0.08	0.0002	59.36	0.56	1.13	0.76	1.19
KE13r, red; Upper Kelly River Quarry																		
KE1331	5.13	0.89	0.19	5.79	0.01	10.13	0.09	0.0007	0.001	0.13	0.001	0.07	0.0010	304.23	1.16	1.28	0.98	0.99
KE1332	0.79	0.37	0.22	2.11	0.03	73.36	0.01	0.0001	0.000	0.44	0.011	0.06	0.0002	225.18	0.44	1.25	0.84	1.10
KE1333	1.02	0.47	0.21	2.19	0.03	154.01	0.00	0.0002	0.001	0.19	0.016	0.05	0.0004	149.45	0.78	1.28	1.05	0.88
KE1334	1.27	0.46	0.28	2.79	0.03	37.53	0.01	0.0002	0.000	0.38	0.006	0.06	0.0003	234.97	0.44	1.16	0.76	1.16
KE1335	0.82	0.44	0.20	1.86	0.05	43.07	0.01	0.0002	0.000	0.44	0.008	0.06	0.0003	182.70	0.39	1.32	0.85	1.14
KE1336	2.48	0.43	0.20	5.74	0.01	63.54	0.01	0.0003	0.001	0.15	0.007	0.06	0.0004	334.49	0.83	1.35	1.05	1.00
KE1337	0.51	0.39	0.22	1.33	0.07	46.20	0.01	0.0002	0.000	0.44	0.008	0.06	0.0002	131.07	0.39	1.26	0.82	1.15
KE1338	6.17	0.63	0.22	9.83	0.01	112.26	0.01	0.0004	0.001	0.18	0.013	0.06	0.0007	526.03	0.93	1.43	0.96	0.98
KE1339	2.43	0.59	0.20	4.13	0.02	126.16	0.00	0.0002	0.000	0.29	0.015	0.05	0.0006	253.82	0.84	1.30	0.96	0.93
KE1340	2.75	0.80	0.18	3.43	0.01	49.58	0.02	0.0007	0.001	0.11	0.005	0.06	0.0006	252.86	0.89	1.30	0.95	0.94
KE1341	1.41	0.77	0.19	1.83	0.03	110.31	0.01	0.0006	0.001	0.15	0.012	0.06	0.0007	112.15	0.84	1.22	0.89	0.94
KE1342	2.45	0.87	0.15	2.80	0.02	37.40	0.02	0.0007	0.001	0.14	0.004	0.06	0.0008	170.75	0.93	1.24	0.93	0.96
KE1343	2.78	0.59	0.20	4.72	0.01	78.12	0.01	0.0004	0.001	0.17	0.008	0.06	0.0006	286.66	0.89	1.33	1.01	0.96
KE1344	1.09	0.52	0.28	2.12	0.03	41.62	0.01	0.0002	0.000	0.30	0.005	0.06	0.0004	149.70	0.67	1.17	0.94	0.93
KE1345	2.00	0.55	0.22	3.66	0.02	84.04	0.01	0.0003	0.001	0.20	0.010	0.07	0.0006	207.47	0.84	1.26	0.94	0.93
DU0205	0.58	0.46	0.26	1.25	0.03	41.71	0.01	0.0001	0.000	0.36	0.005	0.06	0.0004	79.87	0.72	1.15	0.79	0.89
DU0206	0.90	0.57	0.26	1.58	0.04	62.18	0.01	0.0002	0.000	0.35	0.008	0.06	0.0004	149.40	0.54	1.17	1.02	0.93
DU0207	1.44	0.60	0.25	2.41	0.02	52.00	0.01	0.0002	0.000	0.38	0.006	0.06	0.0007	128.37	0.83	1.12	1.00	0.88
DU0208	2.05	0.62	0.23	3.32	0.01	17.07	0.04	0.0003	0.000	0.26	0.002	0.06	0.0005	220.84	0.64	1.15	0.92	0.89
KO01, gray																		
KO0101	0.83	0.22	0.25	3.83	0.09	13.18	0.02	0.0002	0.001	0.86	0.008	0.10	0.0004	125.13	0.82	1.40	1.08	0.85
KO0102	0.50	0.19	0.27	2.67	0.07	14.58	0.01	0.0002	0.001	0.79	0.009	0.10	0.0004	83.99	0.78	1.29	1.04	0.88
KO0103	1.83	0.49	0.36	3.70	0.01	5.36	0.09	0.0042	0.009	0.02	0.001	0.07	0.0005	236.17	0.77	1.15	1.11	0.86
KO0104	1.42	0.44	0.40	3.22	0.02	5.47	0.08	0.0032	0.007	0.03	0.001	0.07	0.0004	200.07	0.72	1.12	1.16	0.86
KO0105	1.28	0.74	0.39	1.73	0.03	8.59	0.09	0.0018	0.002	0.06	0.001	0.06	0.0005	143.94	0.68	1.24	1.19	0.87
KO0106	0.34	0.48	0.37	0.71	0.08	3.80	0.13	0.0006	0.001	0.15	0.001	0.06	0.0004	46.38	0.82	1.19	1.04	0.78

Appendix I. 2.C.: INAA Data, Elemental ratios (continued).

	Ba/Al	Fe/Al	Th/Sc	Ba/Fe	Rb/Sr	Fe/Mn	Mn/Al	Co/Al	Co/Fe	Cs/Co	Cs/Mn	Cs/Rb	La/Al	Ba_n/La_n	La_n/Yb_n	Eu_n/Sm_n	Ce_n/Ce_n^*	La_n/Ce_n
KO0107	2.07	0.43	0.32	4.80	0.01	5.20	0.08	0.0040	0.009	0.02	0.001	0.08	0.0003	347.46	0.66	1.18	1.11	0.97
KO0108	1.64	0.40	0.33	4.06	0.01	3.90	0.10	0.0029	0.007	0.02	0.001	0.06	0.0003	297.31	0.75	1.15	1.05	0.93
KO0109	0.81	0.51	0.36	1.60	0.03	7.45	0.07	0.0016	0.003	0.06	0.001	0.06	0.0004	126.08	0.75	1.21	1.06	0.90
KO0110	0.93	0.23	0.25	4.01	0.13	27.94	0.01	0.0002	0.001	0.68	0.017	0.09	0.0003	160.34	0.58	1.47	1.22	0.92
KO0111	1.31	0.53	0.26	2.46	0.02	7.24	0.07	0.0016	0.003	0.05	0.001	0.06	0.0003	243.50	0.65	1.16	0.91	1.07
KO0112	1.40	0.76	0.26	1.84	0.02	10.70	0.07	0.0021	0.003	0.04	0.001	0.07	0.0003	270.41	0.65	1.20	0.87	1.02
KO0113	2.33	0.46	0.43	5.08	0.01	5.15	0.09	0.0054	0.012	0.01	0.001	0.07	0.0004	310.70	0.88	1.14	1.20	0.79
KO0114	1.72	0.45	0.36	3.86	0.01	6.34	0.07	0.0027	0.006	0.03	0.001	0.06	0.0003	289.98	0.70	1.23	0.86	0.95
KO0115	1.70	0.44	0.24	3.83	0.01	6.63	0.07	0.0024	0.006	0.03	0.001	0.06	0.0003	375.87	0.56	1.15	0.24	1.12
WC05, gray																		
WC0531	5.01	0.19	0.29	26.30	0.01	2.56	0.07	0.0010	0.005	0.06	0.001	0.08	0.0005	555.40	0.75	1.32	0.90	0.99
WC0532	4.73	0.16	0.33	29.17	0.01	11.92	0.01	0.0008	0.005	0.08	0.005	0.07	0.0005	578.31	0.72	1.40	0.98	0.96
WC0533	0.96	0.26	0.24	3.72	0.03	5.04	0.05	0.0011	0.004	0.05	0.001	0.09	0.0005	121.01	0.53	1.20	1.10	0.90
WC0534	0.60	0.49	0.41	1.24	0.04	6.14	0.08	0.0002	0.001	0.27	0.001	0.06	0.0005	76.51	0.61	1.35	0.98	0.89
WC0535	3.14	0.15	0.32	20.88	0.02	11.26	0.01	0.0010	0.007	0.05	0.004	0.06	0.0005	375.07	0.68	1.30	0.89	0.95
WC0536	5.40	0.13	0.31	40.19	0.01	2.93	0.05	0.0012	0.009	0.04	0.001	0.07	0.0005	610.80	0.81	1.23	0.95	1.03
WC0537	0.94	0.41	0.42	2.32	0.04	3.54	0.11	0.0003	0.001	0.24	0.001	0.05	0.0004	143.47	0.67	1.33	0.95	0.91
WC0538	3.22	0.23	0.36	13.74	0.01	15.79	0.01	0.0005	0.002	0.09	0.003	0.07	0.0004	433.48	0.80	1.41	0.91	0.96
WC0539	0.26	0.30	0.13	0.86	0.12	81.67	0.00	0.0015	0.005	0.03	0.013	0.05	0.0008	18.81	0.95	1.22	1.30	0.73
WC0540	3.45	0.23	0.12	14.88	0.01	17.93	0.01	0.0011	0.005	0.06	0.005	0.08	0.0003	758.33	0.55	1.12	0.60	1.41
WC0541	2.67	0.47	0.39	5.70	0.02	4.88	0.10	0.0003	0.001	0.24	0.001	0.06	0.0004	352.25	0.65	1.43	1.08	0.89
WC0542	0.30	0.29	0.12	1.02	0.10	95.07	0.00	0.0012	0.004	0.04	0.014	0.04	0.0007	24.52	0.86	1.21	1.07	0.77
WC0543	0.40	0.22	0.11	1.81	0.07	53.85	0.00	0.0015	0.007	0.03	0.012	0.05	0.0007	33.59	0.87	1.18	1.19	0.76
WC0544	0.21	0.21	0.13	0.96	0.09	52.56	0.00	0.0010	0.005	0.05	0.012	0.05	0.0007	18.06	0.99	1.22	1.28	0.75
WC0545	2.61	0.29	0.32	9.05	0.01	28.68	0.01	0.0007	0.002	0.06	0.004	0.08	0.0005	304.11	0.79	1.31	0.94	0.96
WC01g, gray																		
WC0103	1.70	0.50	0.22	3.36	0.05	13.97	0.04	0.0001	0.000	1.01	0.003	0.10	0.0005	209.57	0.76	1.22	1.01	0.83
WC0104	2.50	0.72	0.22	3.48	0.04	24.61	0.03	0.0002	0.000	0.85	0.005	0.09	0.0009	155.53	0.84	1.23	0.99	0.78
WC0105	2.93	0.54	0.18	5.46	0.03	7.65	0.07	0.0002	0.000	0.49	0.001	0.09	0.0009	185.80	1.17	1.21	1.13	0.80
WC0106	0.61	0.37	0.24	1.63	0.12	4.15	0.09	0.0004	0.001	0.34	0.002	0.10	0.0006	58.20	0.80	1.17	1.25	0.69
WC0107	0.98	0.45	0.26	2.15	0.06	40.83	0.01	0.0001	0.000	1.00	0.010	0.09	0.0006	102.23	0.79	1.13	1.27	0.74
WC0108	1.45	0.44	0.21	3.30	0.05	11.94	0.04	0.0001	0.000	1.42	0.003	0.10	0.0005	182.67	0.57	1.19	1.11	0.82
WC0109	2.10	0.52	0.19	4.06	0.05	26.86	0.02	0.0001	0.000	0.82	0.006	0.09	0.0007	167.88	1.04	1.17	1.07	0.80
WC0110	1.88	0.61	0.24	3.10	0.05	23.58	0.03	0.0001	0.000	1.03	0.005	0.10	0.0005	201.93	0.75	1.22	1.01	0.83
WC0111	0.44	0.45	0.24	0.97	0.13	11.35	0.04	0.0003	0.001	0.43	0.004	0.11	0.0005	46.73	0.71	1.19	1.22	0.72
WC0112	3.07	0.66	0.19	4.62	0.03	24.37	0.03	0.0002	0.000	0.70	0.005	0.09	0.0010	175.70	1.12	1.17	1.22	0.78
WC0113	1.92	0.57	0.18	3.34	0.04	20.26	0.03	0.0002	0.000	0.75	0.004	0.09	0.0009	121.78	1.01	1.18	1.18	0.77
WC0114	2.53	0.42	0.20	6.06	0.03	19.09	0.02	0.0001	0.000	0.94	0.005	0.09	0.0008	178.74	1.09	1.24	1.13	0.80
WC0115	1.87	0.47	0.23	4.02	0.04	8.31	0.06	0.0001	0.000	1.16	0.002	0.09	0.0006	181.35	0.75	1.17	1.27	0.76
WC0116	0.77	0.40	0.24	1.90	0.06	5.47	0.07	0.0001	0.000	1.40	0.001	0.10	0.0003	129.58	0.61	1.18	1.10	0.80
WC0117	0.76	0.44	0.25	1.74	0.05	20.86	0.02	0.0001	0.000	0.87	0.005	0.08	0.0004	109.06	0.69	1.11	1.08	0.76
DU0101	2.64	0.64	0.19	4.15	0.03	16.99	0.04	0.0003	0.001	0.36	0.003	0.10	0.0007	217.15	1.23	1.29	1.07	0.76
DU0102	3.17	0.71	0.18	4.46	0.02	19.52	0.04	0.0004	0.001	0.32	0.003	0.09	0.0010	188.57	1.35	1.24	1.15	0.75
DU0103	2.83	0.90	0.16	3.16	0.03	24.43	0.04	0.0006	0.001	0.18	0.003	0.09	0.0008	211.28	1.24	1.37	1.21	0.73
DU0104	3.71	0.72	0.18	5.16	0.02	17.66	0.04	0.0004	0.001	0.36	0.003	0.09	0.0011	193.13	1.36	1.26	1.00	0.77

Appendix I. 2.C.: INAA Data, Elemental ratios (continued).

	Ba/Al	Fe/Al	Th/Sc	Ba/Fe	Rb/Sr	Fe/Mn	Mn/Al	Co/Al	Co/Fe	Cs/Co	Cs/Mn	Cs/Rb	La/Al	Ba_n/La_n	La_n/Yb_n	Eu_n/Sm_n	Ce_n/Ce_n^*	La_n/Ce_n
Lisburne Group																		
Kuna Formation																		
WC01b, black																		
WC0119	0.10	0.24	0.13	0.42	0.17	38.02	0.01	0.0002	0.001	0.61	0.021	0.14	0.0004	15.19	0.44	0.98	1.01	0.90
WC0120	0.13	0.26	0.21	0.51	0.21	27.23	0.01	0.0003	0.001	0.52	0.018	0.15	0.0005	14.97	0.55	1.05	1.14	0.79
WC0121	0.11	0.21	0.18	0.52	0.23	49.59	0.00	0.0004	0.002	0.36	0.033	0.15	0.0003	19.04	0.49	1.12	1.35	0.77
WC0122	0.13	0.27	0.24	0.48	0.13	16.05	0.02	0.0013	0.005	0.13	0.010	0.17	0.0006	12.53	0.60	0.99	1.11	0.71
WC0123	0.10	0.16	0.17	0.62	0.15	373.48	0.00	0.0005	0.003	0.23	0.262	0.10	0.0004	15.00	0.52	0.94	1.28	0.71
WC0124	0.08	0.27	0.16	0.30	0.19	82.40	0.00	0.0006	0.002	0.20	0.036	0.12	0.0003	13.45	0.51	1.00	1.31	0.74
WC0125	0.08	0.25	0.15	0.34	0.20	77.93	0.00	0.0002	0.001	0.47	0.037	0.12	0.0004	13.79	0.50	1.04	1.23	0.74
WC0126	0.12	0.26	0.25	0.45	0.14	33.40	0.01	0.0006	0.003	0.24	0.020	0.15	0.0005	12.57	0.51	0.99	1.27	0.72
WC0127	0.19	0.39	0.19	0.48	0.19	80.12	0.00	0.0005	0.001	0.34	0.035	0.13	0.0005	22.34	0.70	1.08	1.35	0.75
WC0128	0.12	0.26	0.26	0.47	0.24	54.39	0.00	0.0016	0.006	0.10	0.034	0.13	0.0005	12.83	0.61	0.99	1.34	0.71
WC0129	0.11	0.24	0.22	0.44	0.24	60.74	0.00	0.0007	0.003	0.22	0.039	0.13	0.0004	14.08	0.52	1.09	1.10	0.75
WC0130	0.13	0.34	0.25	0.38	0.26	84.66	0.00	0.0004	0.001	0.50	0.045	0.13	0.0006	13.26	0.62	1.03	1.20	0.75
WC0131	0.14	0.70	0.19	0.20	0.14	59.93	0.01	0.0004	0.001	0.39	0.013	0.16	0.0004	20.05	0.53	1.11	1.03	0.80
WC0132	0.11	0.31	0.12	0.37	0.23	38.42	0.01	0.0002	0.001	0.65	0.019	0.13	0.0004	16.00	0.46	1.21	0.89	0.85
WC0133	0.14	0.27	0.22	0.52	0.21	30.99	0.01	0.0002	0.001	0.68	0.019	0.15	0.0006	14.71	0.53	1.10	1.06	0.72
KE12, Black																		
KE1201	0.04	0.54	0.49	0.07	0.15	201.49	0.00	0.0001	0.000	0.83	0.033	0.12	0.0003	6.64	0.53	0.81	0.54	1.74
KE1202	0.04	0.66	0.45	0.06	0.14	169.72	0.00	0.0001	0.000	0.91	0.024	0.11	0.0004	5.56	0.63	0.86	0.49	1.88
KE1203	0.02	0.38	0.64	0.05	0.14	181.08	0.00	0.0001	0.000	0.76	0.038	0.10	0.0008	1.49	0.57	1.05	0.40	2.58
KE1204	0.02	0.38	0.65	0.05	0.21	201.46	0.00	0.0001	0.000	0.82	0.046	0.08	0.0004	2.56	0.62	0.98	0.55	1.87
KE1205	0.03	0.45	0.51	0.06	0.11	181.26	0.00	0.0001	0.000	0.75	0.029	0.15	0.0002	6.34	0.57	0.71	0.57	1.80
KE1206	0.03	0.35	0.51	0.09	0.47	318.64	0.00	0.0001	0.000	0.85	0.085	0.09	0.0003	6.22	0.65	0.74	0.65	1.43
KE1208	0.04	0.56	0.58	0.07	0.22	272.36	0.00	0.0001	0.000	0.93	0.048	0.11	0.0003	9.05	0.63	0.73	0.67	1.42
KE1209	0.04	0.39	0.59	0.09	0.10	257.68	0.00	0.0001	0.000	0.97	0.054	0.13	0.0003	5.93	0.53	0.71	0.51	2.09
KE1210	0.04	0.54	0.79	0.07	0.11	145.07	0.00	0.0001	0.000	1.04	0.028	0.12	0.0004	6.49	0.69	0.74	0.47	1.59
KE1211	0.03	0.48	0.52	0.07	0.16	246.06	0.00	0.0001	0.000	1.01	0.044	0.11	0.0002	9.41	0.62	0.76	0.76	1.37
KE1212	0.04	0.59	0.46	0.07	0.19	257.42	0.00	0.0001	0.000	0.92	0.047	0.13	0.0003	7.48	0.68	0.72	0.58	1.67
KE1213	0.02	0.34	0.56	0.07	0.28	353.69	0.00	0.0001	0.000	0.65	0.082	0.08	0.0003	5.01	0.58	0.73	0.63	1.36
KE1214	0.03	0.39	0.53	0.07	0.29	216.44	0.00	0.0001	0.000	0.77	0.045	0.08	0.0003	5.14	0.51	0.74	0.69	1.60
KE1215	0.03	0.36	0.58	0.08	0.12	127.15	0.00	0.0001	0.000	0.89	0.025	0.13	0.0003	4.95	0.58	0.84	0.44	2.00
WC04, black (Akmak chert); Wrench Creek Quarry																		
WC0462	0.02	0.21	0.98	0.07	0.35	49.15	0.00	0.0001	0.000	2.54	0.041	0.24	0.0006	1.47	1.16	0.55	0.36	2.62
WC0463	0.02	0.21	0.96	0.08	0.10	56.67	0.00	0.0001	0.000	2.51	0.046	0.25	0.0006	1.47	1.21	0.58	0.39	2.59
WC0464	0.02	0.24	1.16	0.07	0.35	107.44	0.00	0.0001	0.000	2.27	0.080	0.18	0.0006	1.52	1.25	0.63	0.43	2.40
WC0465	0.04	0.33	0.97	0.13	0.56	82.47	0.00	0.0001	0.000	2.69	0.066	0.27	0.0008	2.94	1.28	0.58	0.41	2.67
WC0466	0.01	0.19	0.97	0.08	0.15	61.94	0.00	0.0001	0.000	2.86	0.056	0.28	0.0006	1.50	0.95	0.56	0.39	2.57
WC0467	0.02	0.21	0.97	0.11	0.13	36.40	0.01	0.0001	0.000	3.76	0.044	0.36	0.0006	2.14	1.22	0.51	0.40	2.58
WC0468	0.02	0.23	0.90	0.10	0.11	37.71	0.01	0.0001	0.000	3.56	0.042	0.39	0.0007	1.89	0.88	0.50	0.42	2.84
WC0469	0.05	0.33	0.96	0.14	0.44	89.65	0.00	0.0001	0.000	2.79	0.072	0.25	0.0008	3.15	1.20	0.59	0.35	2.70
WC0470	0.01	0.10	0.90	0.11	0.14	25.09	0.00	0.0000	0.000	3.42	0.028	0.36	0.0003	2.08	1.21	0.43	0.37	2.87

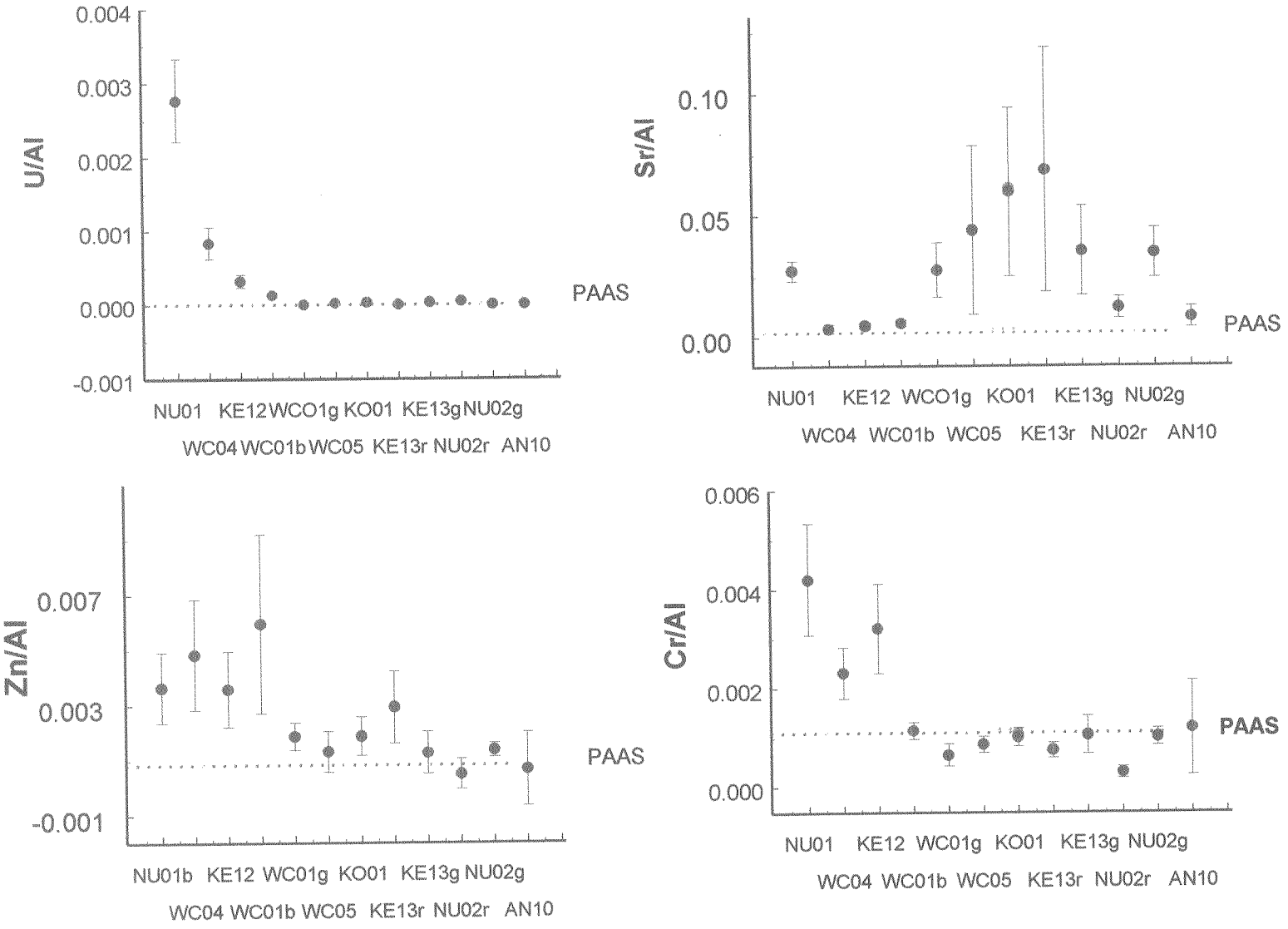
Appendix I. 2.C.: INAA Data, Elemental ratios (continued).

	Ba/Al	Fe/Al	Th/Sc	Ba/Fe	Rb/Sr	Fe/Mn	Mn/Al	Co/Al	Co/Fe	Cs/Co	Cs/Mn	Cs/Rb	La/Al	Ba_n/La_n	La_n/Yb_n	Eu_n/Sm_r	Ce_n/Ce_n^*	La_n/Ce_n
WC0471	0.02	0.30	1.00	0.07	0.46	80.02	0.00	0.0001	0.000	2.37	0.061	0.21	0.0008	1.47	1.15	0.65	0.43	2.42
WC0472	0.02	0.26	1.02	0.08	0.14	53.42	0.00	0.0001	0.000	2.82	0.047	0.28	0.0008	1.60	0.88	0.51	0.35	2.86
WC0473	0.03	0.22	1.04	0.14	0.72	130.49	0.00	0.0001	0.000	2.77	0.114	0.25	0.0006	2.90	1.31	0.54	0.39	2.84
WC0474	0.03	0.24	1.07	0.14	0.22	91.11	0.00	0.0001	0.000	2.61	0.075	0.27	0.0007	2.84	1.19	0.66	0.40	2.65
WC0475	0.04	0.30	1.04	0.14	0.21	84.24	0.00	0.0001	0.000	2.76	0.073	0.30	0.0009	2.74	1.49	0.62	0.39	3.01
WC0476	0.04	0.25	1.01	0.15	0.34	98.49	0.00	0.0001	0.000	2.86	0.090	0.29	0.0007	3.13	1.33	0.54	0.40	2.80
DU0413	0.02	0.28	0.89	0.06	0.27	82.03	0.00	0.0001	0.000	1.87	0.053	0.18	0.0009	1.10	1.36	0.65	0.44	2.54
DU0413x	0.03	0.31	0.96	0.11	0.26	95.85	0.00	0.0001	0.000	2.26	0.066	0.25	0.0009	2.21	1.37	0.61	0.42	2.70
DU0414	0.03	0.24	0.96	0.13	0.43	116.46	0.00	0.0001	0.000	2.35	0.094	0.27	0.0007	2.68	1.78	0.57	0.42	2.51
DU0415	0.04	0.30	0.88	0.13	0.26	92.13	0.00	0.0001	0.000	2.31	0.070	0.23	0.0009	2.67	2.06	0.59	0.45	2.57
DU0415x	0.07	0.35	0.87	0.21	0.72	104.56	0.00	0.0001	0.000	2.33	0.072	0.20	0.0010	4.38	1.80	0.59	0.43	2.68
DU0416	0.04	0.26	0.92	0.14	0.30	70.47	0.00	0.0001	0.000	2.51	0.057	0.25	0.0008	2.72	1.61	0.61	0.44	2.59
Tupik Formation																		
NU01,black																		
NU0131	0.02	0.24	1.02	0.07	0.01	33.86	0.01	0.0001	0.000	0.66	0.006	0.20	0.0010	0.89	1.57	0.34	0.24	3.83
NU0132	0.01	0.19	0.93	0.06	0.01	31.52	0.01	0.0001	0.000	0.67	0.006	0.15	0.0008	0.75	1.38	0.36	0.24	3.67
NU0133	0.02	0.31	0.94	0.05	0.01	32.85	0.01	0.0001	0.000	0.47	0.004	0.16	0.0016	0.62	1.48	0.42	0.26	3.79
NU0134	0.02	0.28	1.00	0.06	0.01	32.75	0.01	0.0001	0.000	0.57	0.005	0.14	0.0012	0.78	1.53	0.34	0.25	3.72
NU0135	0.01	0.25	0.94	0.06	0.01	32.50	0.01	0.0001	0.000	0.73	0.006	0.17	0.0011	0.77	1.16	0.42	0.23	3.83
NU0136	0.01	0.16	1.03	0.05	0.01	41.38	0.00	0.0000	0.000	0.69	0.008	0.16	0.0012	0.41	1.41	0.52	0.25	3.92
NU0137	0.02	0.31	0.94	0.05	0.01	35.78	0.01	0.0001	0.000	0.45	0.004	0.14	0.0017	0.53	1.46	0.41	0.25	3.81
NU0138	0.02	0.29	0.96	0.06	0.01	38.88	0.01	0.0001	0.000	0.54	0.006	0.18	0.0013	0.73	1.32	0.38	0.25	4.10
NU0139	0.01	0.19	1.01	0.05	0.01	28.59	0.01	0.0001	0.000	0.75	0.006	0.13	0.0009	0.61	1.35	0.40	0.28	3.82
NU0140	0.02	0.30	0.95	0.06	0.01	35.63	0.01	0.0001	0.000	0.50	0.005	0.15	0.0015	0.72	1.46	0.39	0.24	4.03
NU0141	0.01	0.24	0.93	0.06	0.01	32.98	0.01	0.0001	0.000	0.60	0.005	0.17	0.0013	0.61	1.47	0.38	0.25	3.99
NU0142	0.02	0.25	0.83	0.07	0.01	36.72	0.01	0.0001	0.000	0.57	0.006	0.15	0.0012	0.86	1.41	0.36	0.22	4.17
NU0143	0.01	0.28	0.99	0.05	0.01	34.33	0.01	0.0001	0.000	0.43	0.004	0.13	0.0015	0.56	1.59	0.42	0.24	3.81
NU0144	0.02	0.25	0.83	0.07	0.01	36.57	0.01	0.0001	0.000	0.59	0.006	0.16	0.0012	0.80	1.52	0.36	0.25	3.97
NU0145	0.01	0.24	1.01	0.06	0.01	39.08	0.01	0.0001	0.000	0.55	0.006	0.16	0.0012	0.71	1.34	0.34	0.23	4.33

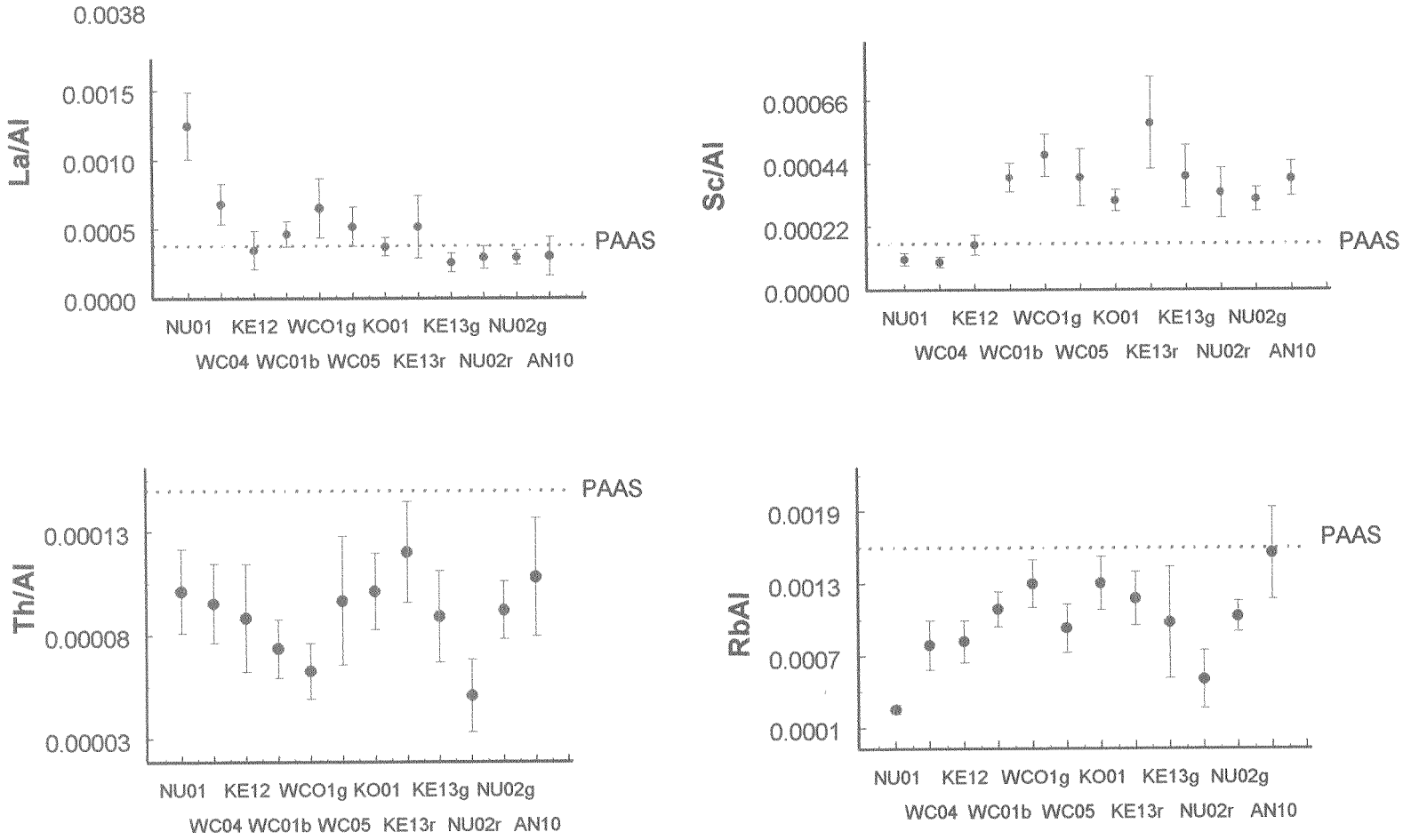
Appendix I.3:

Discrimination Diagrams

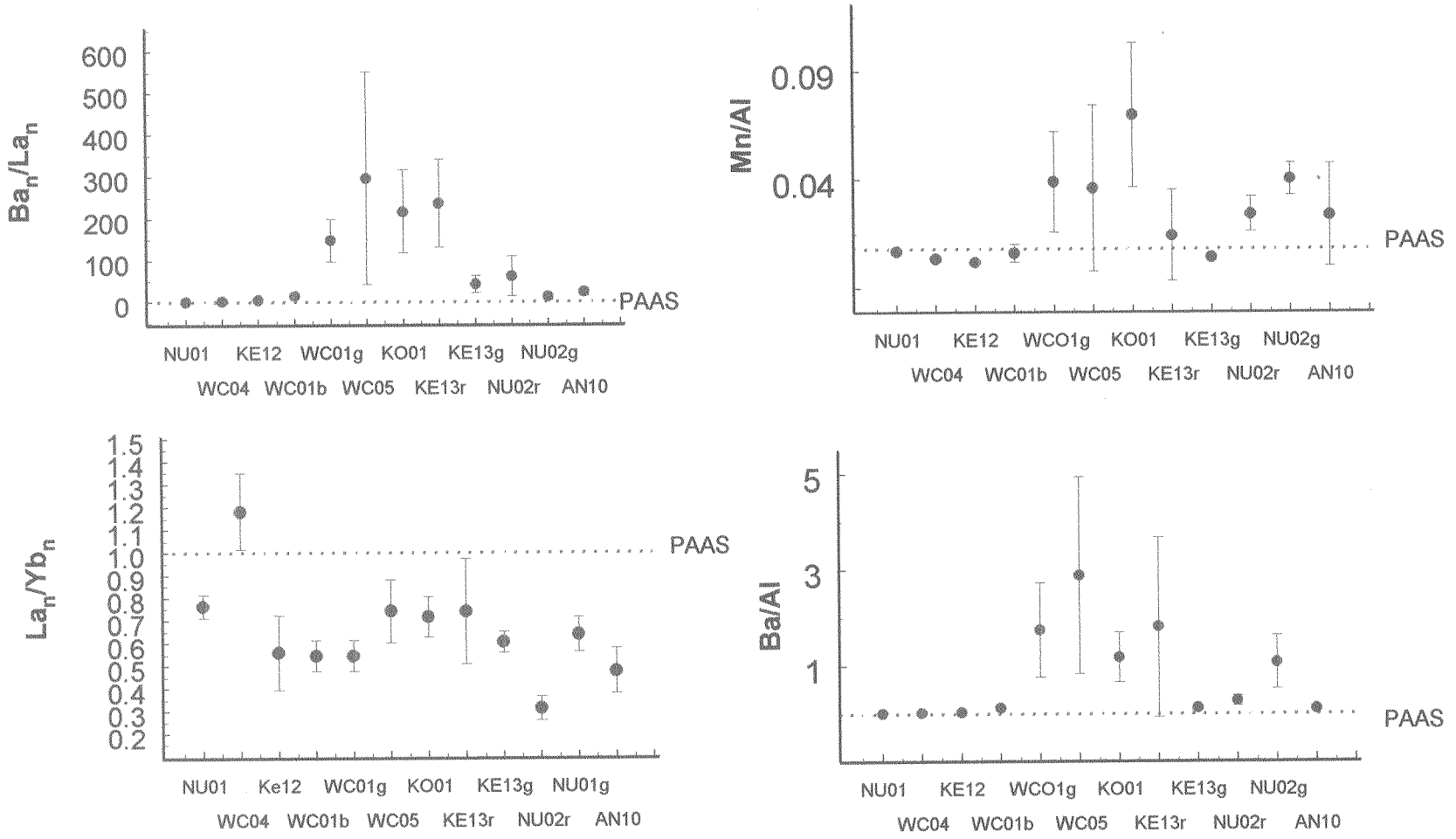
Appendix 1.3.A: ranges of variability at one standard deviation



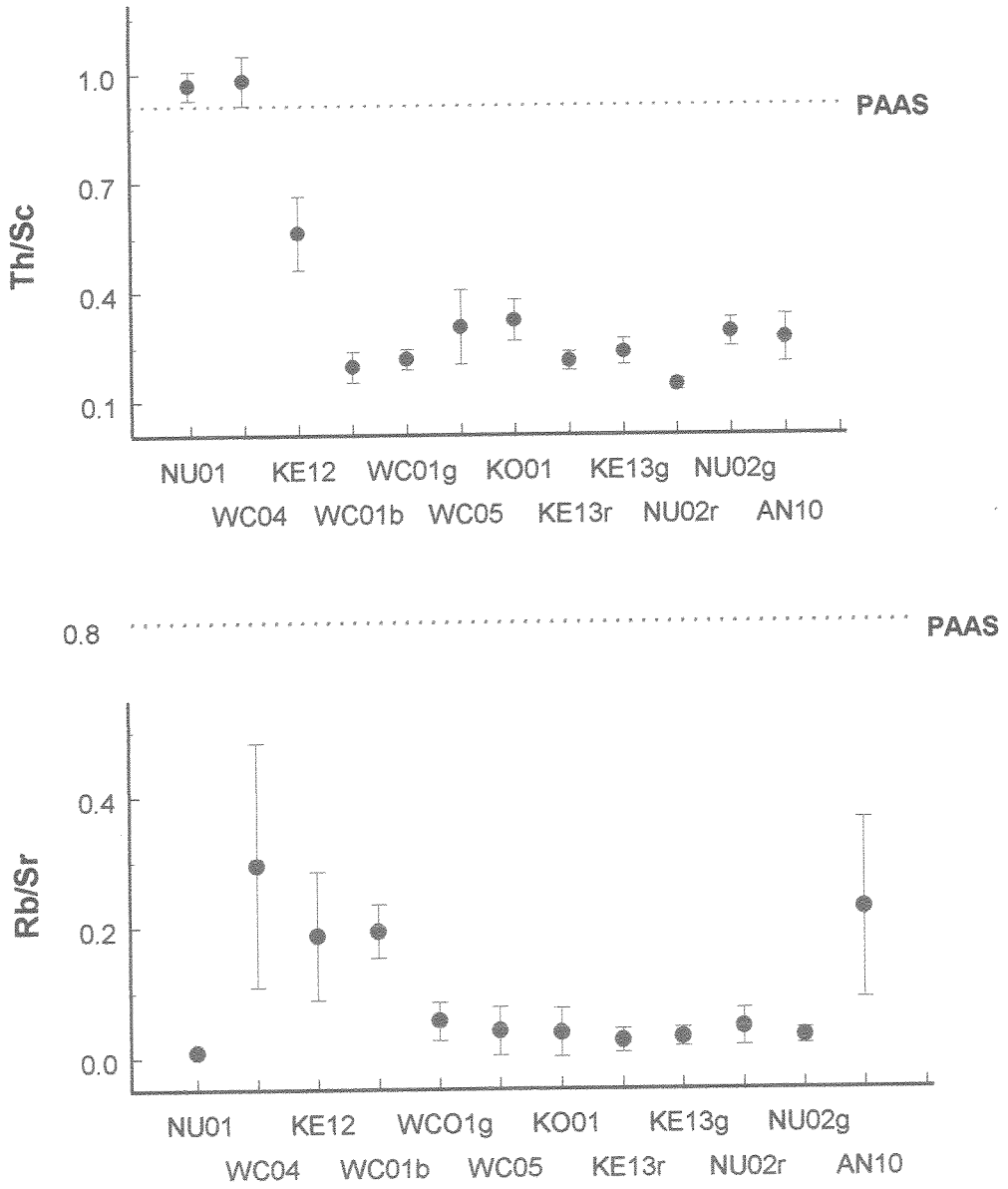
Appendix I.3. A: Twelve chert varieties. Error bars at one standard deviation



Appendix I.3. A: elemental ratio variability in twelve chert varieties (at one standard deviation).

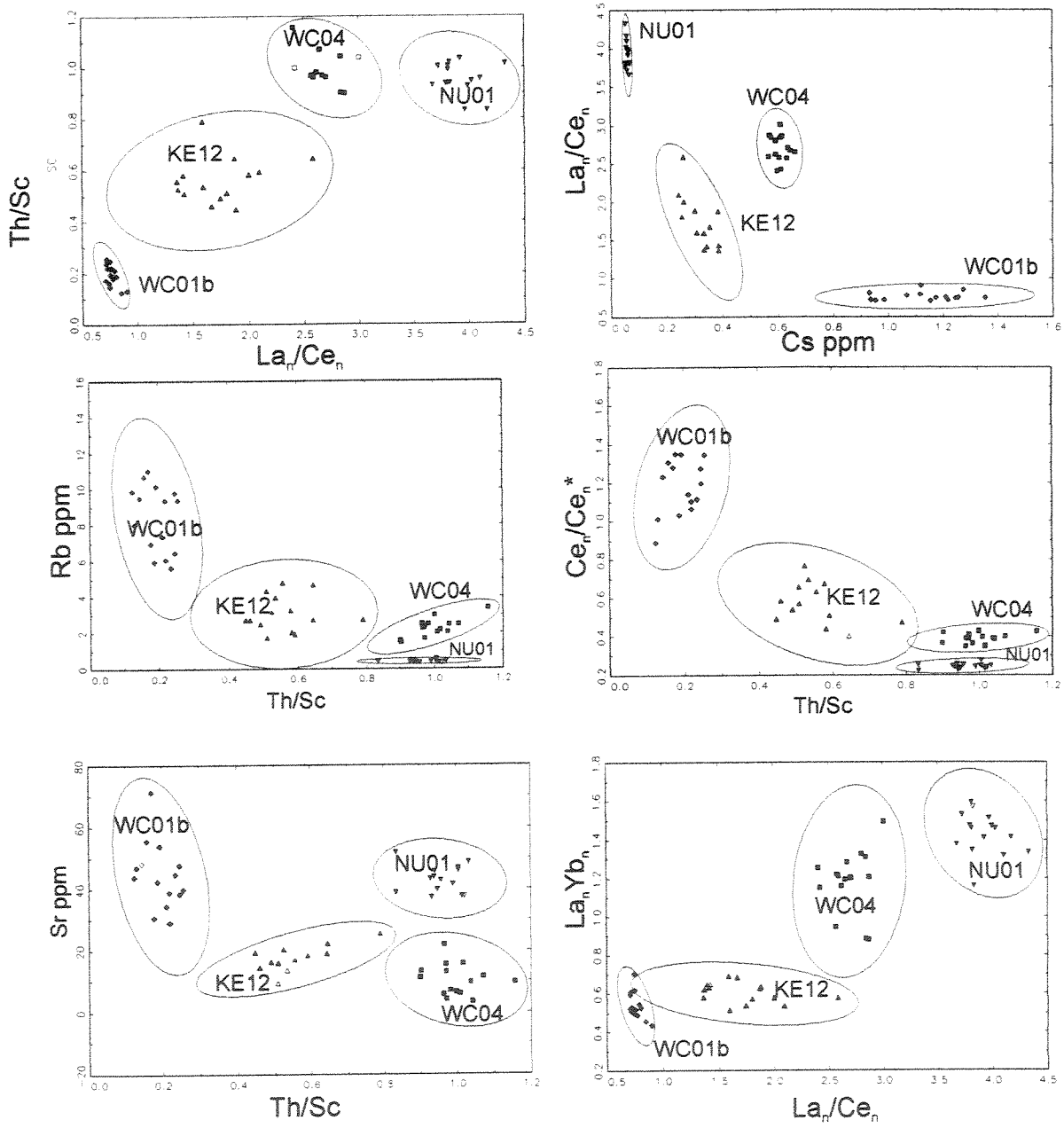


Appendix I.3. A: Elemental ratio variability in twelve chert varieties at one standard deviation

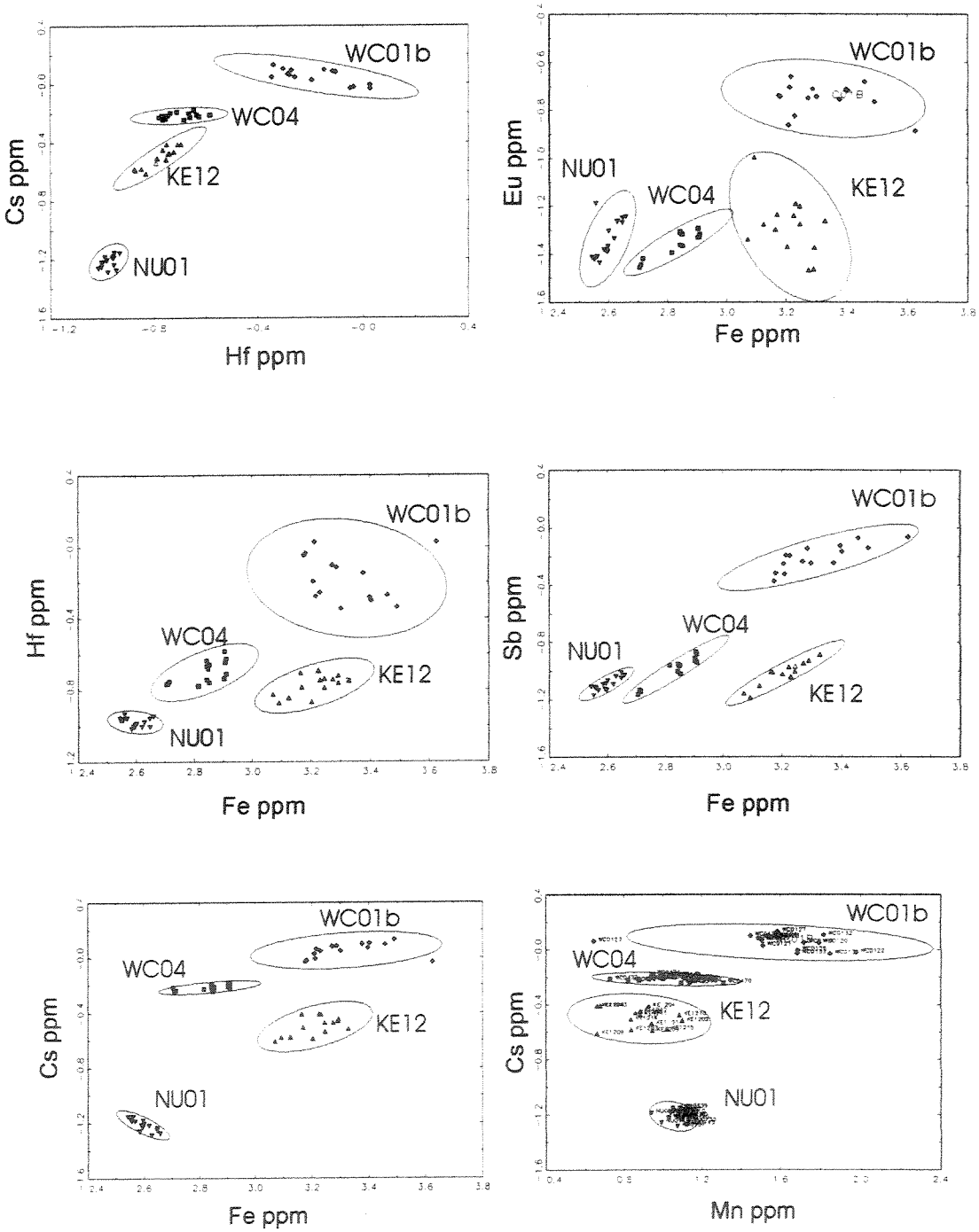


Appendix I.3. A: Elemental ratio variation in twelve chert varieties (at one standard deviation)

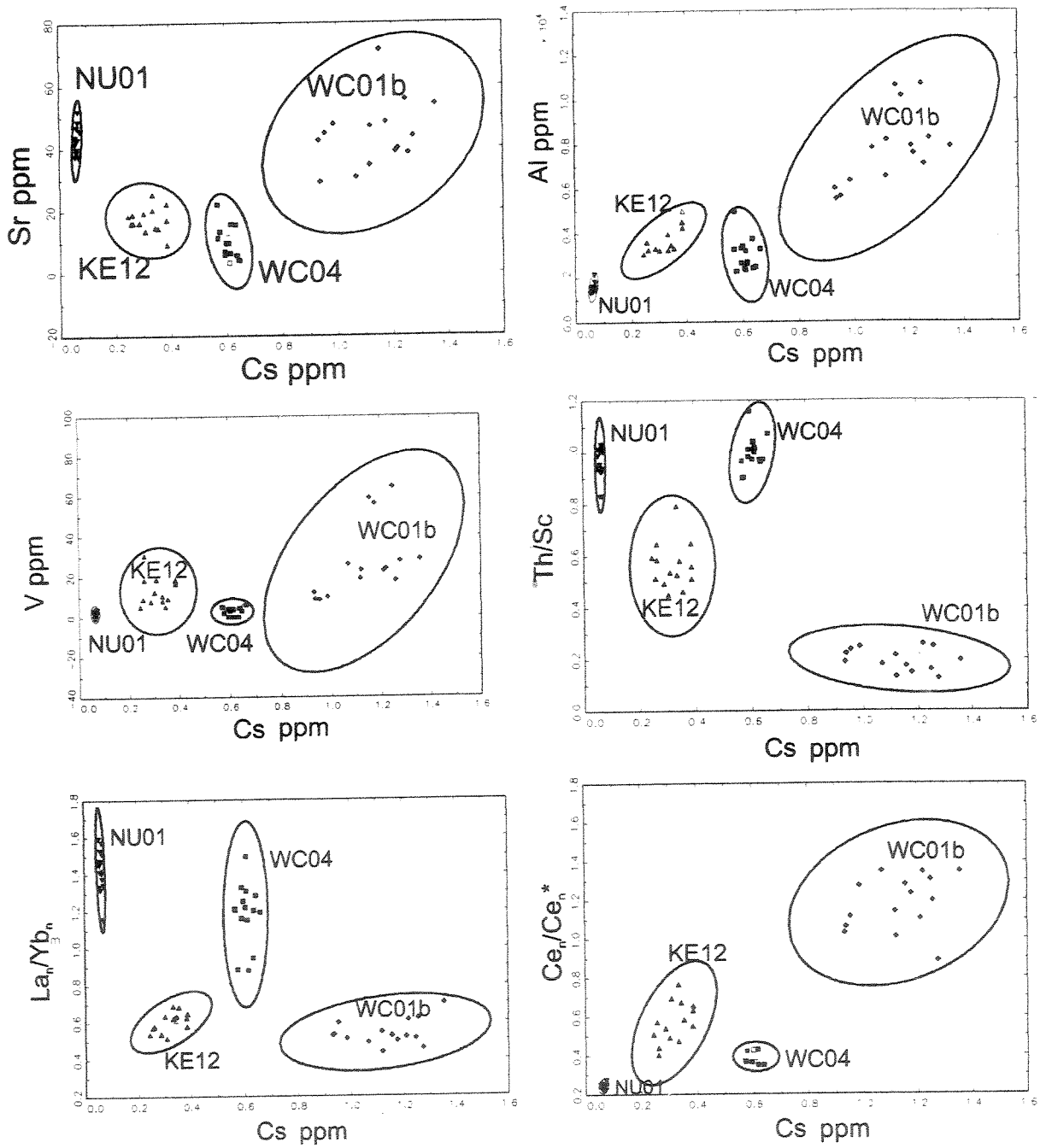
Appendix I.3.B: Bivariate diagrams with geochemical fields at one, two and three standard deviations



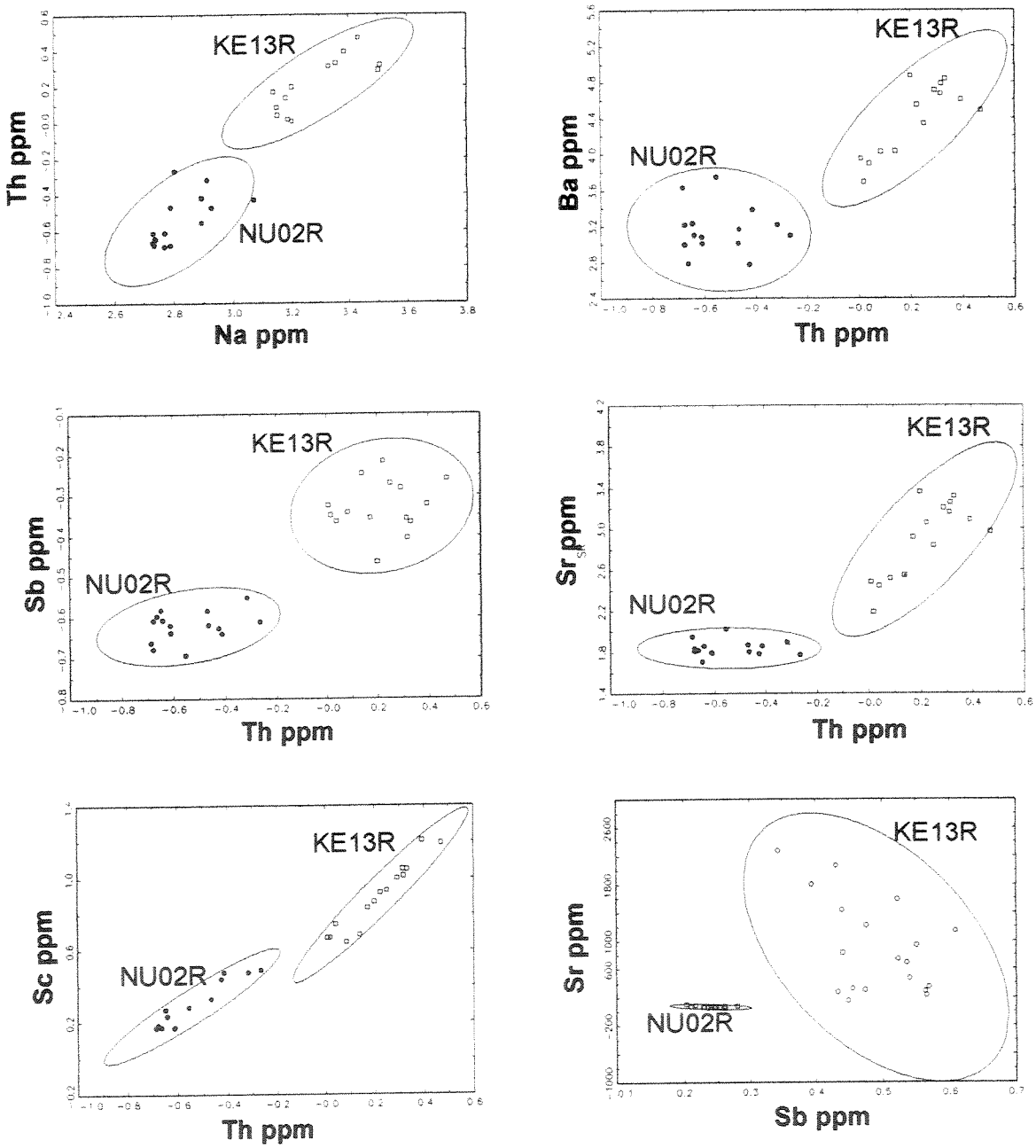
Appendix I.3.B: Lisburne Group chert outcrop separation at 3 σ



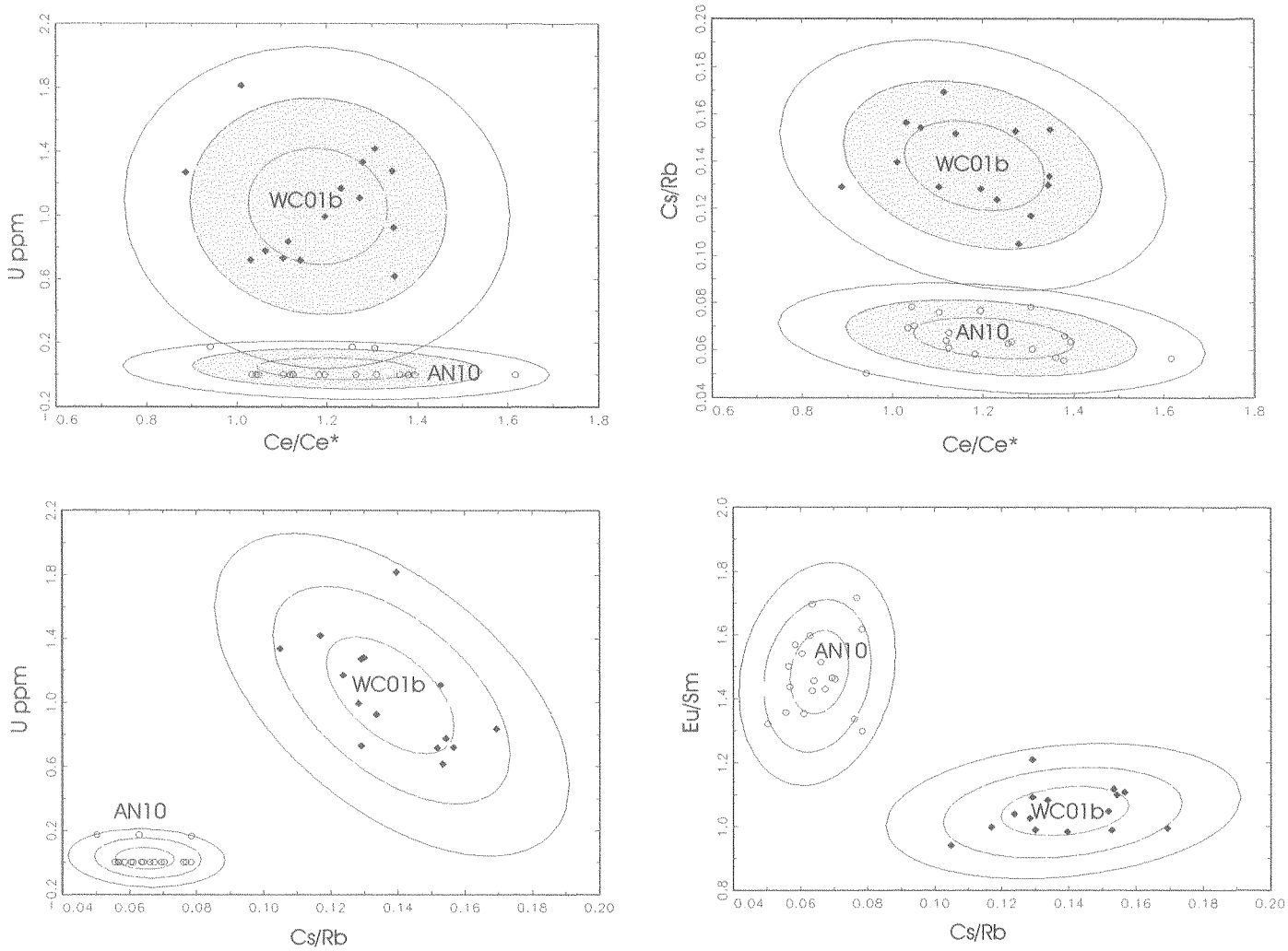
Appendix I.3.B: Chert outcrop's separation at 3σ.
Lisburne Group



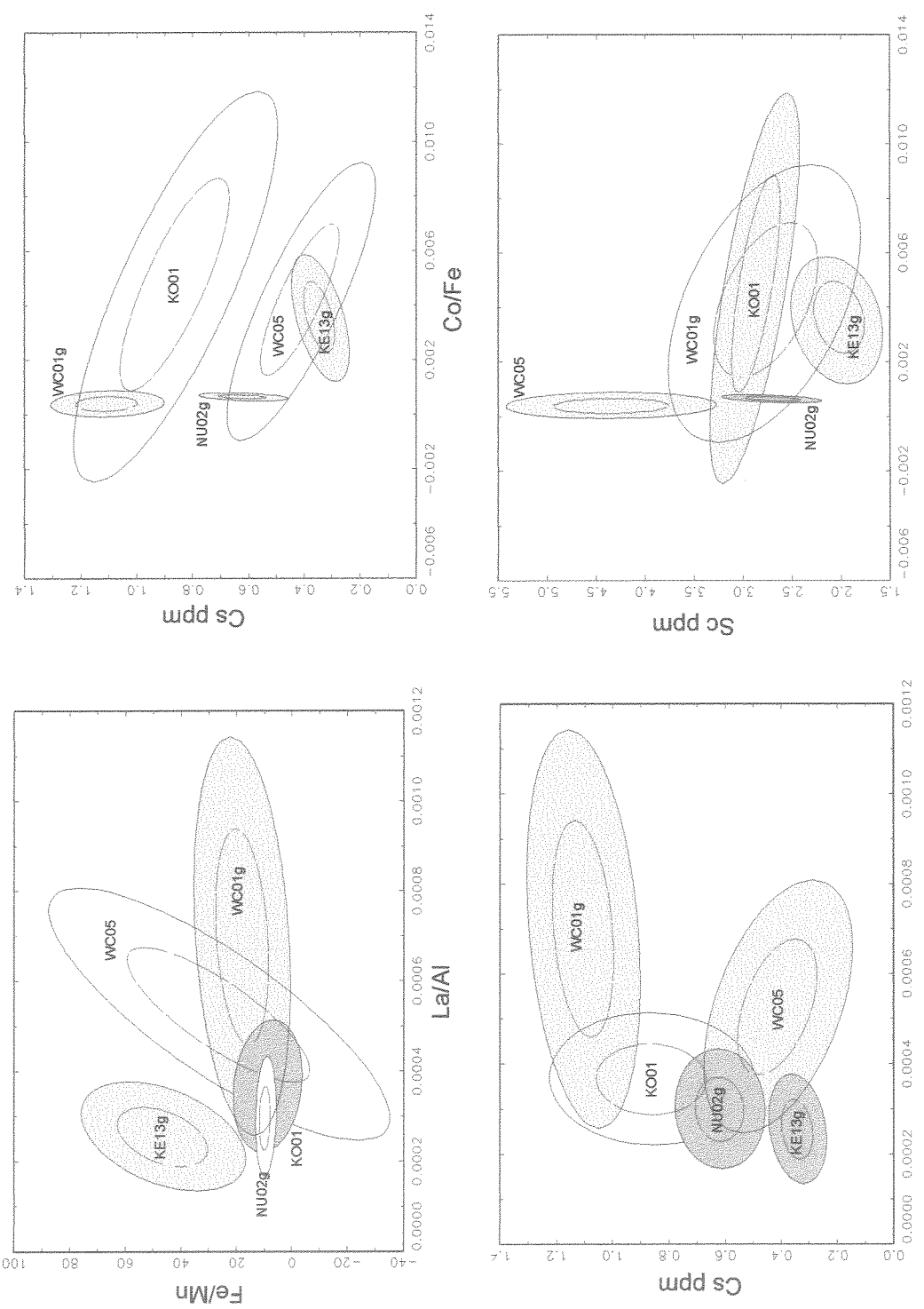
Appendixl.3.B: Lisburne Group chert outcrop separation at 3 σ



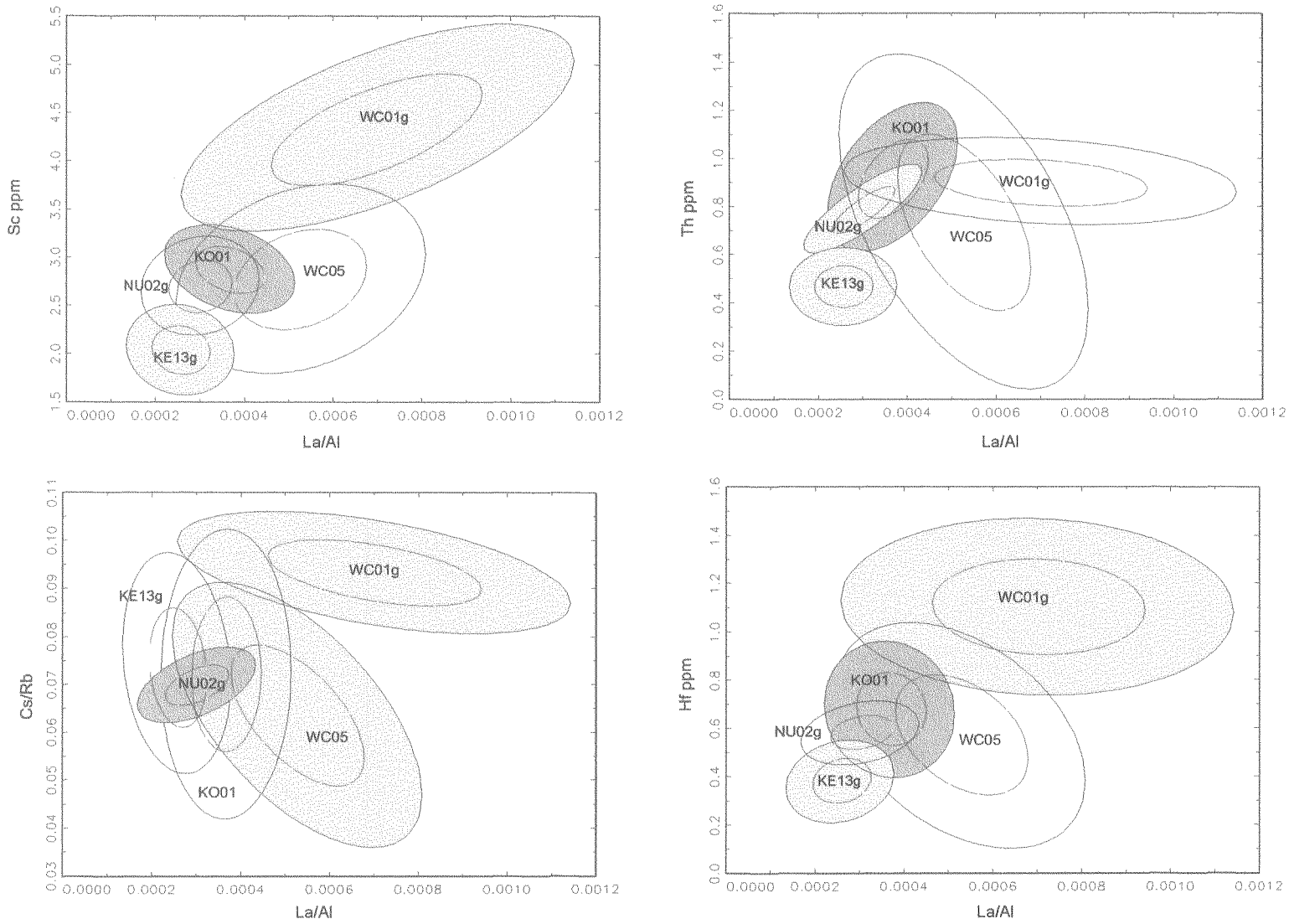
Appendix I.3.B: Separation of red chert varieties KE13r and NU02r Siksikpuk Formation, Etivluk Group, at 3σ



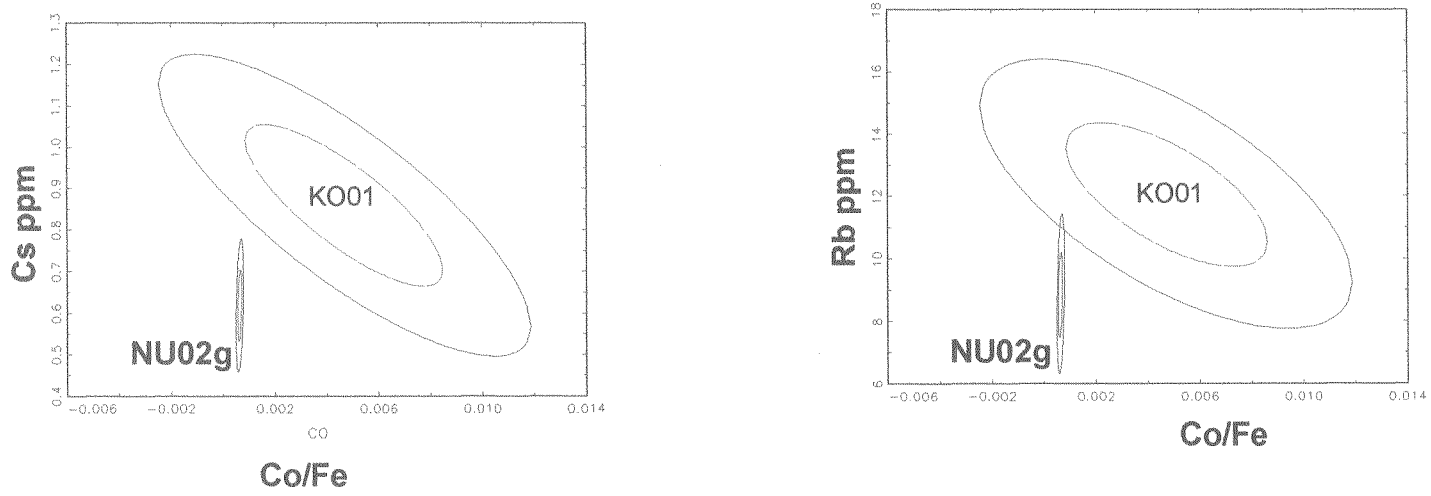
Appendix I. 3.B: Separation of mottled black-gray AN10 chert (Otuk Formation , Etivluk Group) from black WC01b outcrop (Kuna Formation, Lisburne Group)



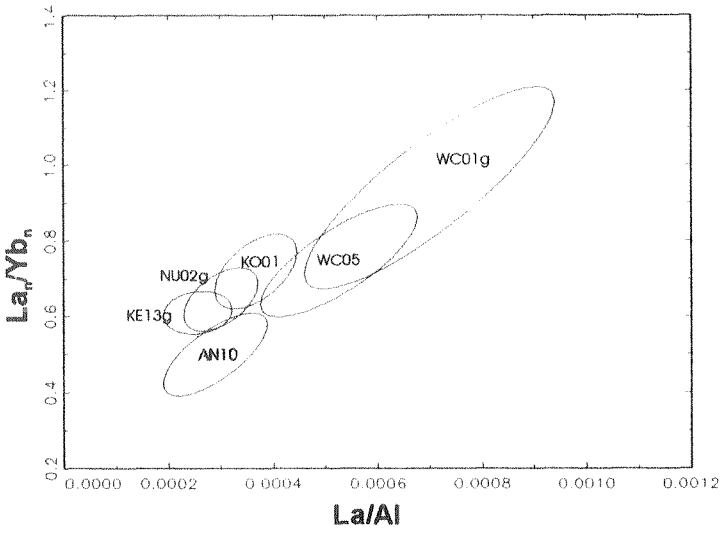
Appendix I.3.B: Separation of gray chert outcrops of Siksikpuk Formation (Etivluk Group) from each other at one and two standard deviations

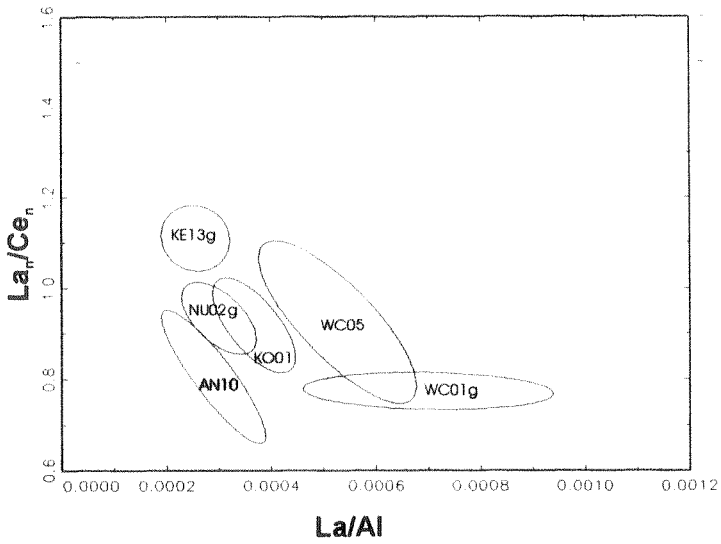


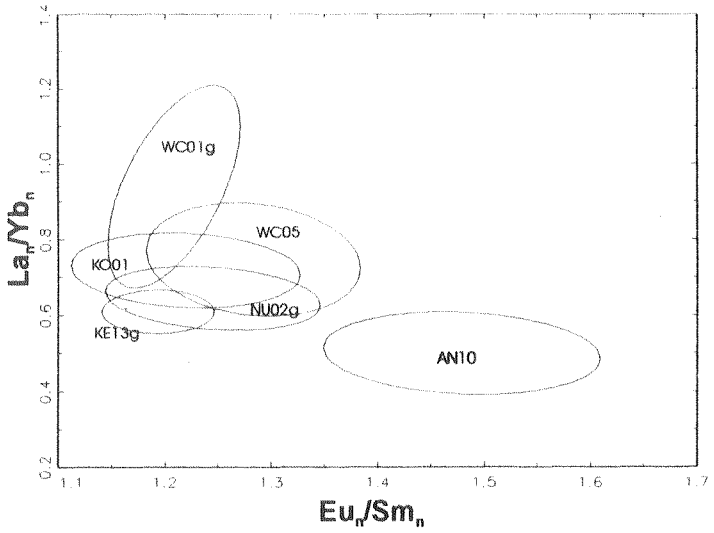
Appendix I.3.B: Separation of gray chert outcrops of Siksikpuk Formation (Etivluk group) from each other.



Appendix I.3.B: Separation of NU02g and KO01 chert varieties at one and two standard deviations

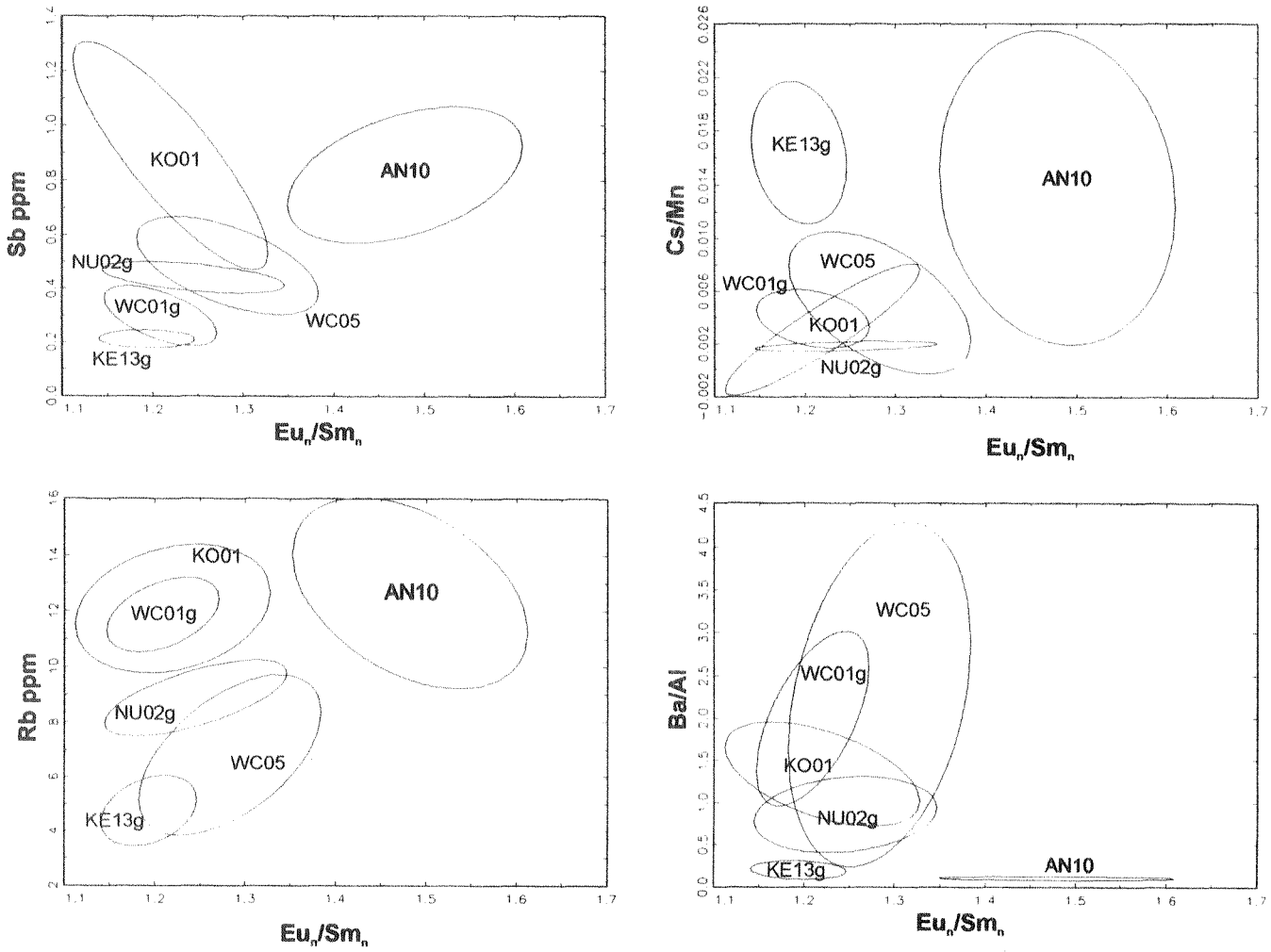




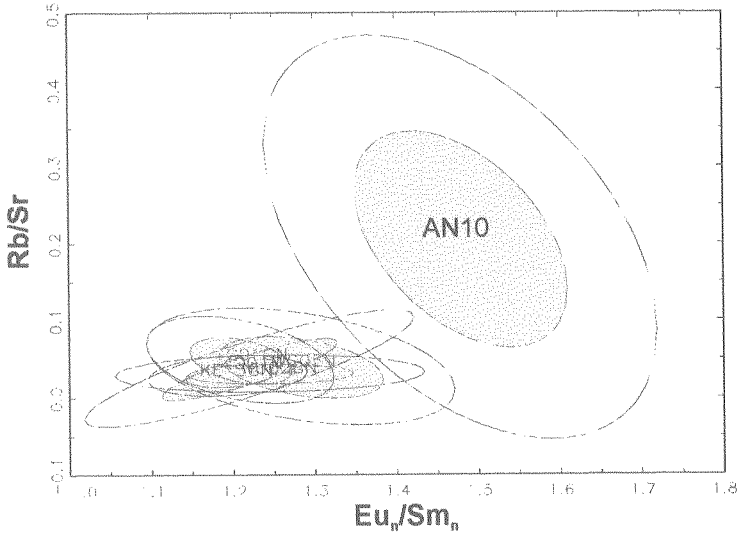


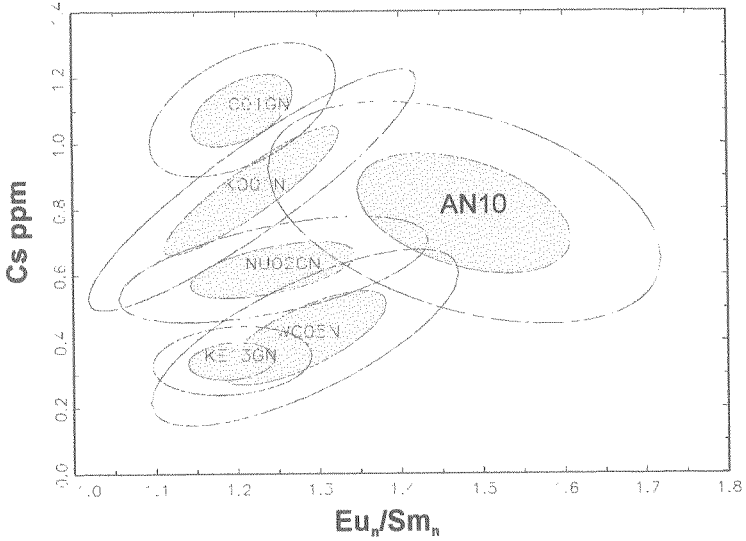
Appendix I.3.B.:

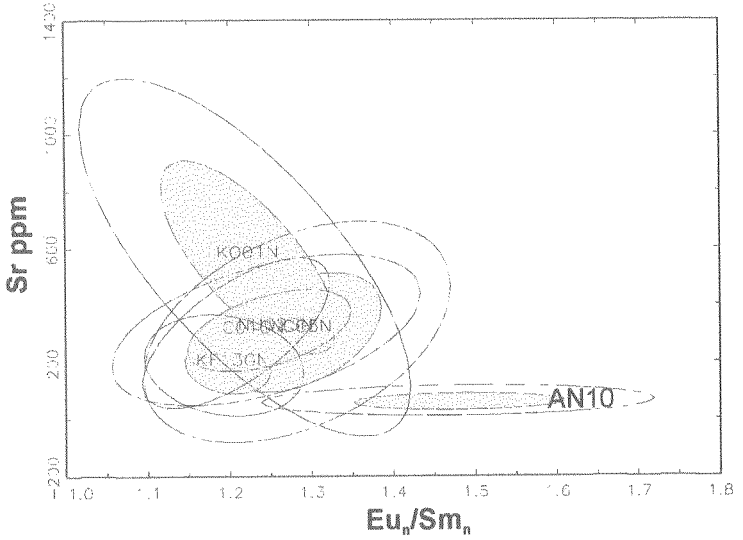
Separation of gray chert from AN10 outcrop (Otuk Formation) from all gray varieties of Siksikpuk Formation at one standard deviation.



Appendix I.3.B.: Separation of gray chert from AN10 outcrop (Otuk Formation) from all gray varieties of Siksikpuk Formation at one standard deviation.

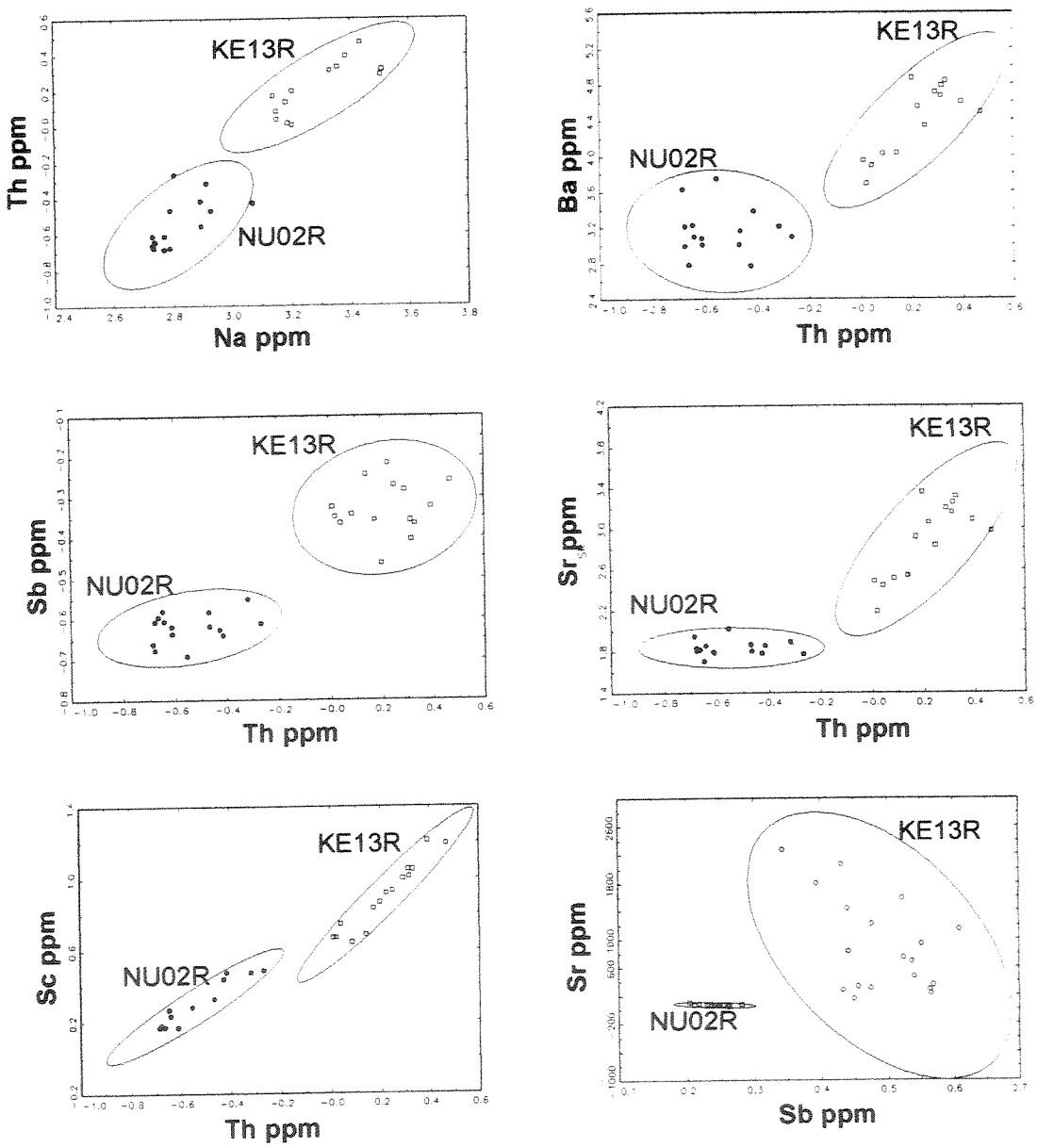






Appendix I.3.B:

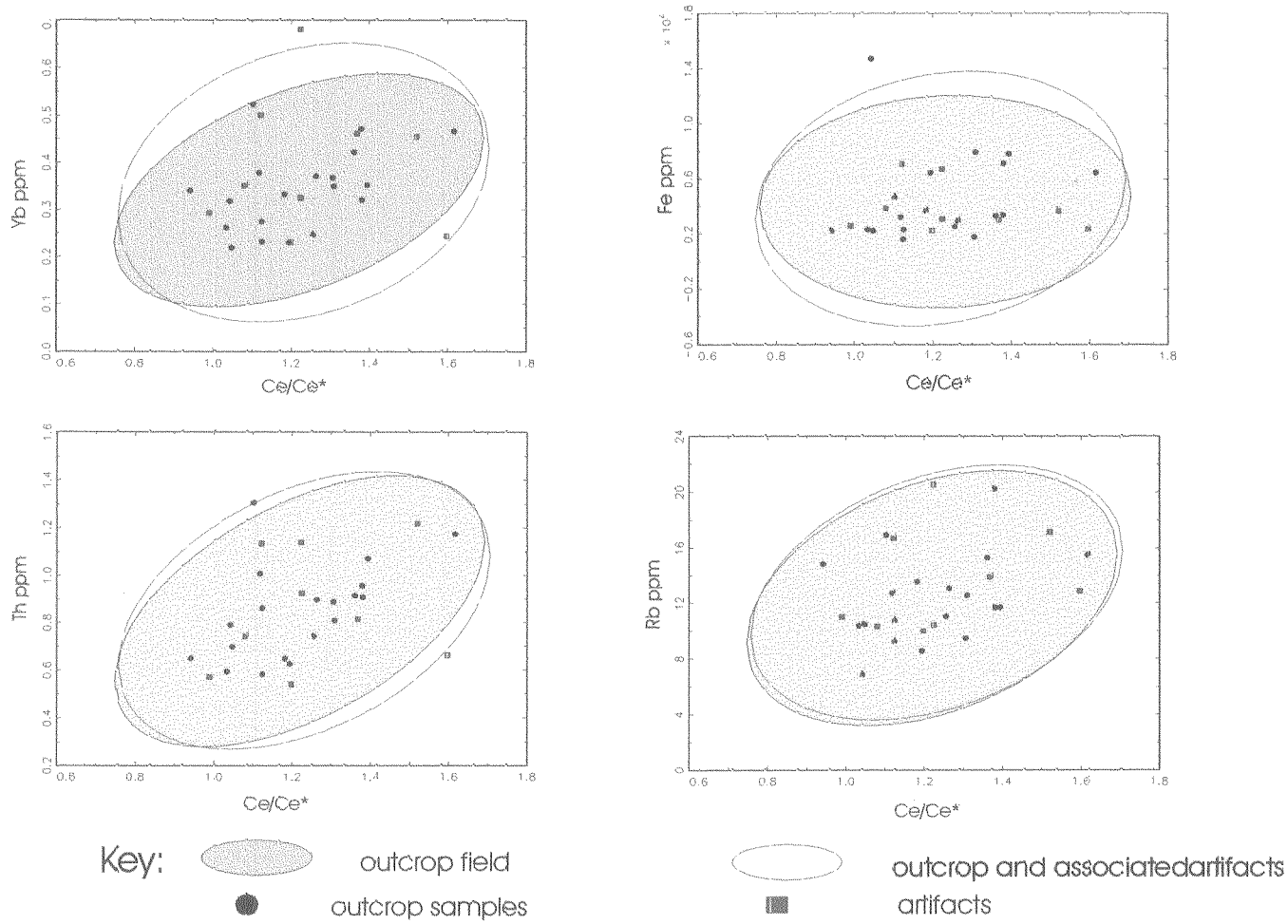
Discrimination between gray chert of Otuk Formation from AN10 outcrop and gray cherts of Siksikpuk Formation (both of Etivluk Group) at1σ (gray) and 2σ.



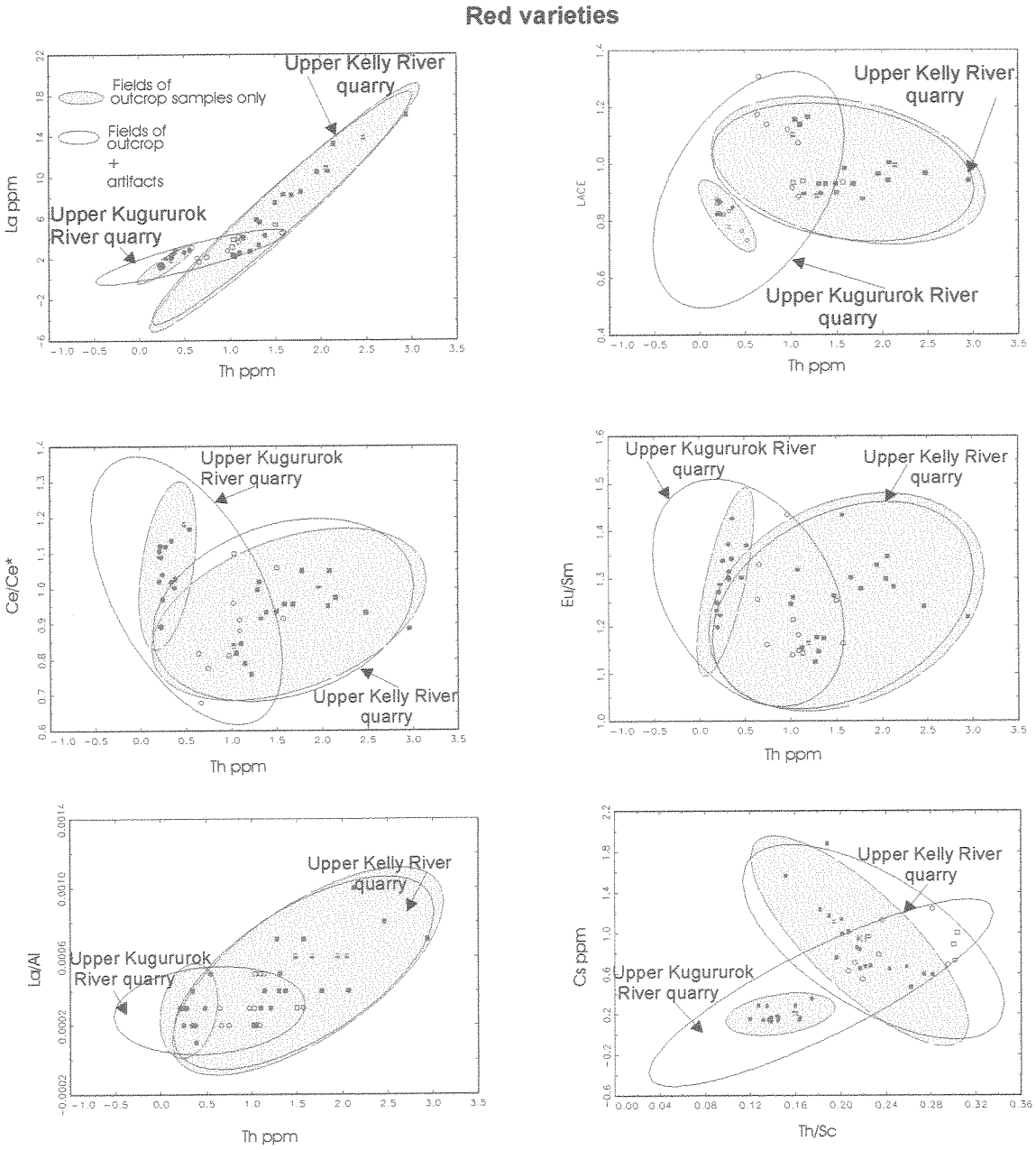
Appendix I.3.B: Separation of red chert varieties KE13r and NU02r Siksikpuk Formation, Etivluk Group, at 3σ

Appendix I.4:

Quarry Geochemical Fields

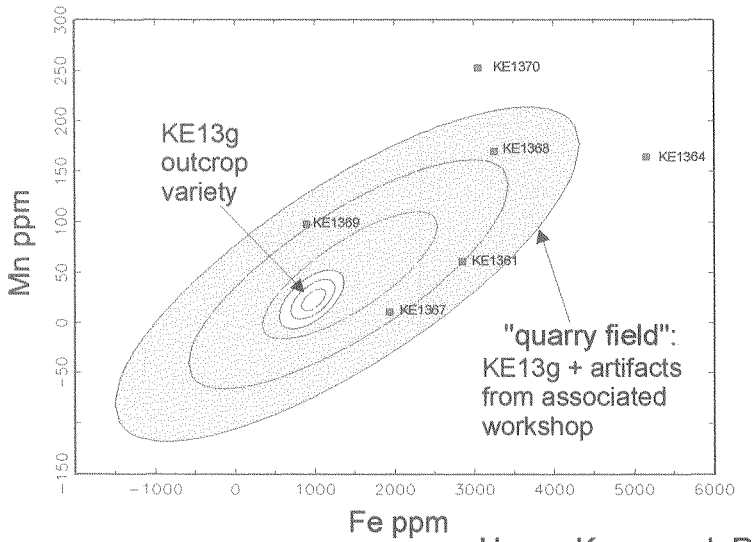


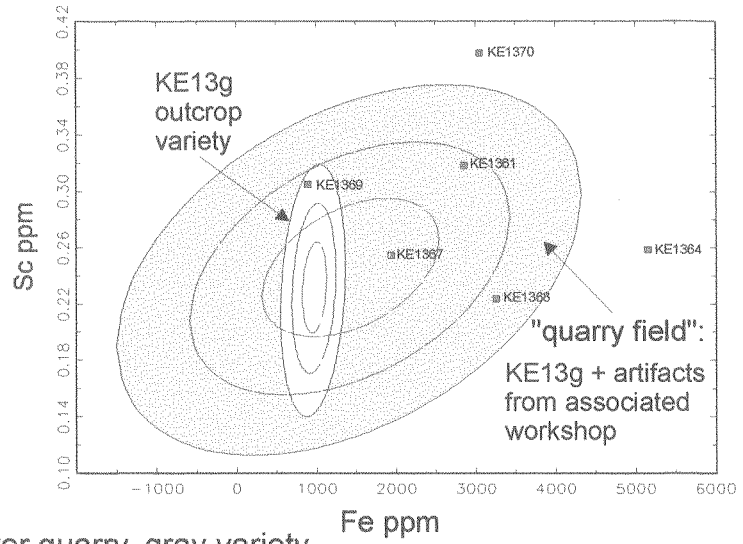
Appendix I.4: Determination of the chemical variability within Anisak quarry:
Comparison of the geochemical fields (at three standard deviations) of outcrop (gray) with "quarry field" by combination of data for outcrop and associated artifacts.



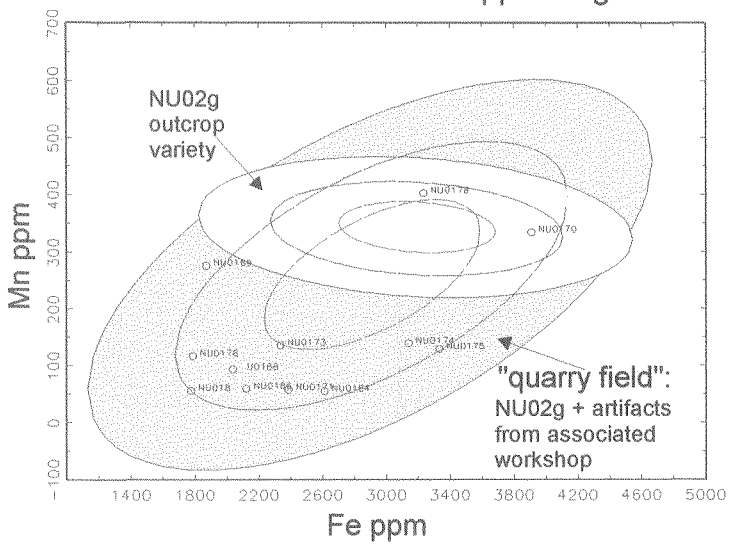
Appendix I.4: Variability within Upper Kelly River and Upper Kugururok River quarries. Red varieties
Comparison of the "quarry fields" (white+black) with outcrop fields (gray+red) at 3σ.

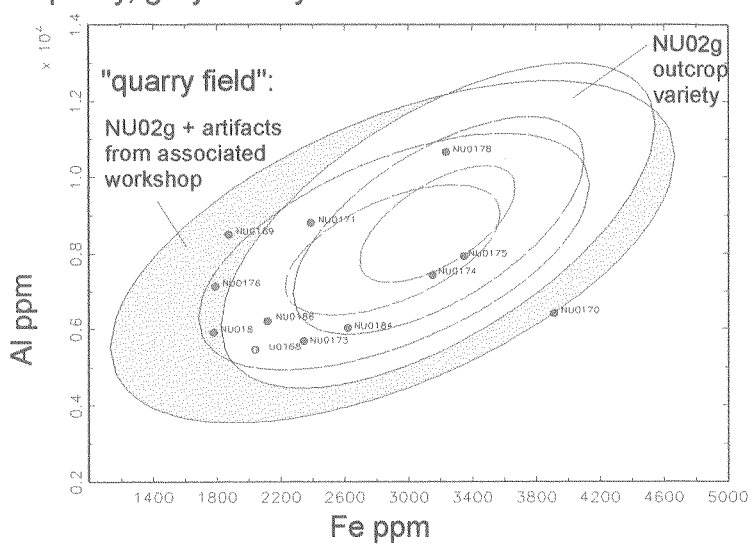
Upper Kelly River quarry, gray variety



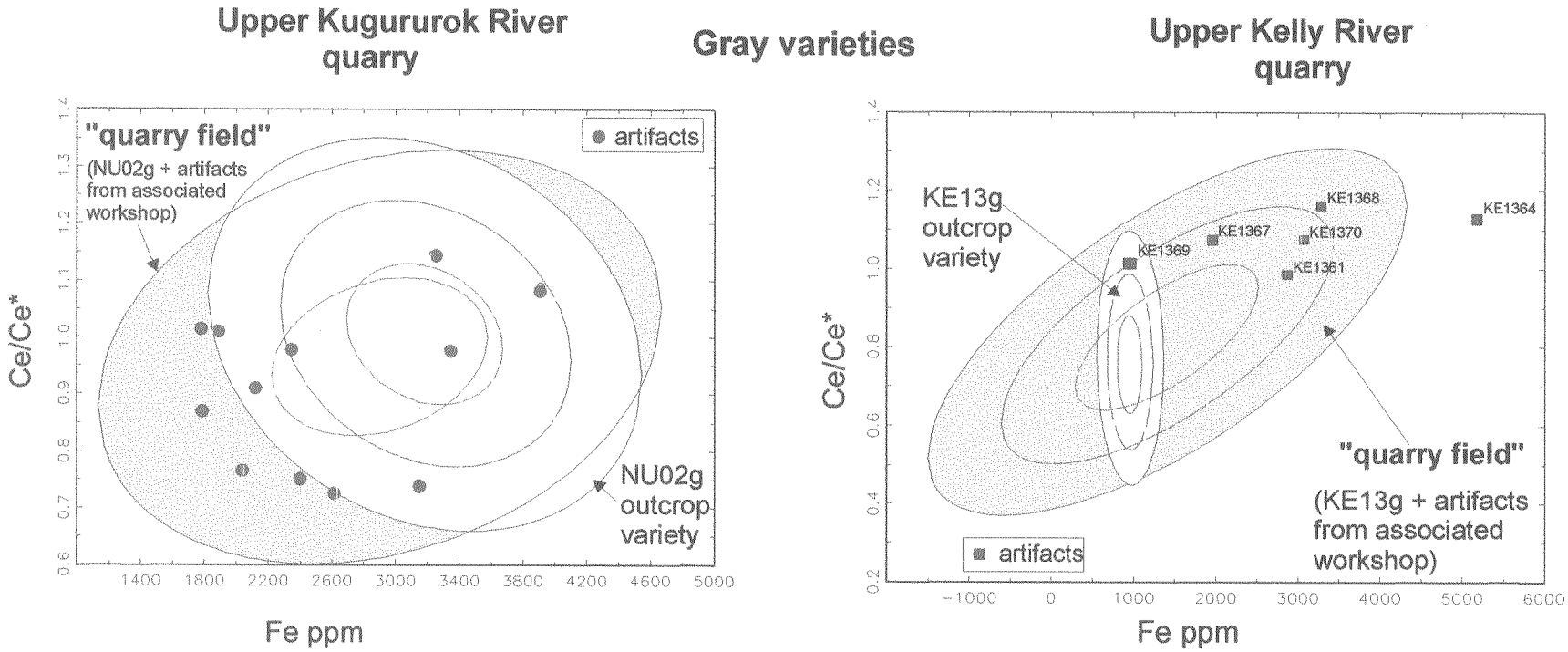


Upper Kugururok River quarry, gray variety





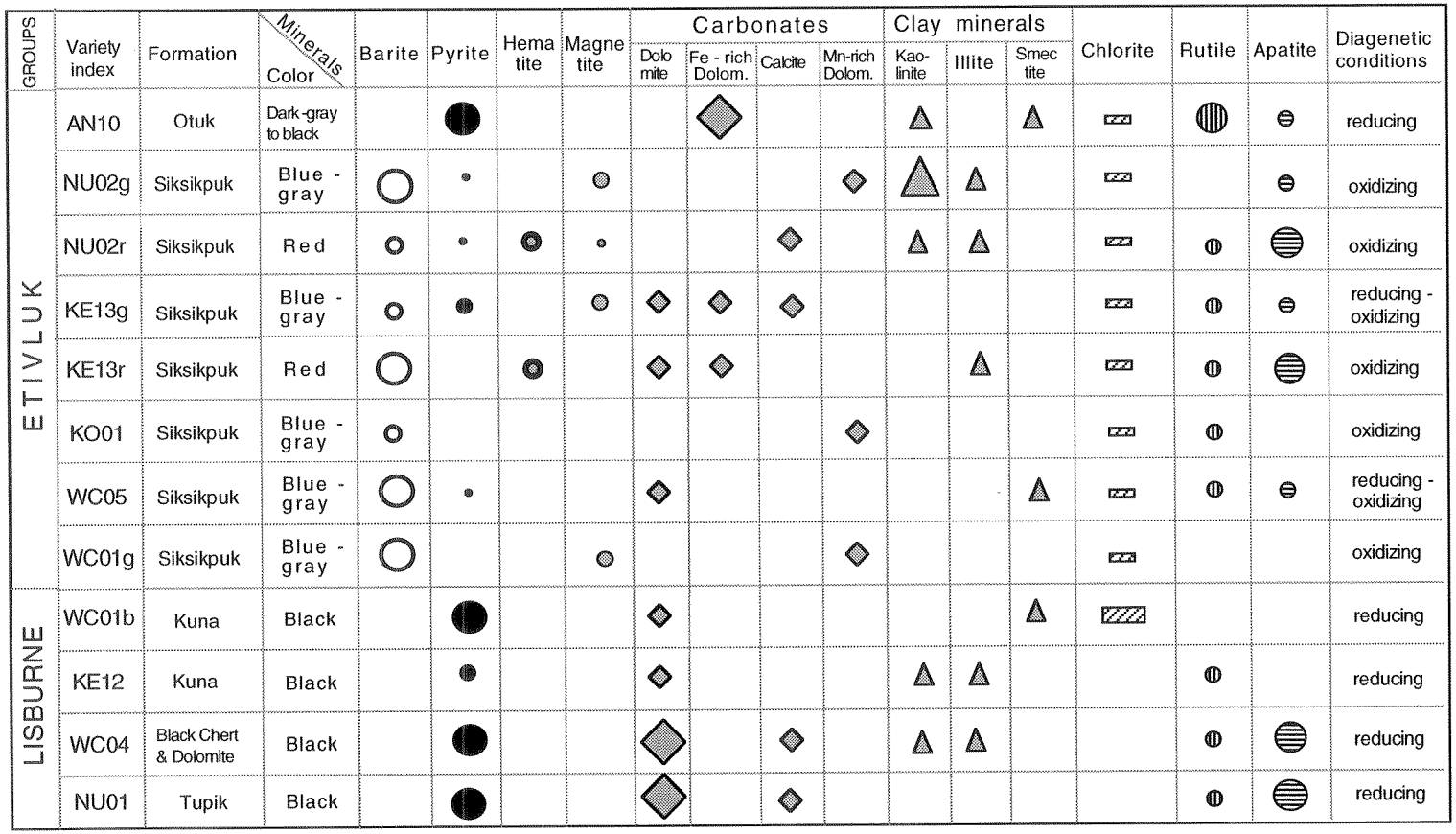
Appendix I.4: The variability within the quarries (continued).



Appendix I.4: Upper Kelly River and Upper Kugururok River quarries, gray varieties.
The variability within the quarry: yellow are fields of outcrop chert varieties KE13g and NU02g; gray are "quarry fields" (combination of outcrop chert samples and artifacts from associated workshops); fields show 3σ from the means.

Appendix I.5:

Mineralogical composition of inclusions



Appendix I.5. Mineralogical composition and diagenetic patterns of 12 chert varieties from Lisburne and Etivluk Groups,western Brooks Range, Alaska. The size of the symbols is proportional to the abundance of minerals.

Appendix II:

Database of Geochemical Signatures

for 289 Chert Artifacts from 57 Prehistoric Sites

Located in Northwestern Alaska