Public-data File 86-50

COMPOSITION AND PROVENANCE OF SANDSTONE COBBLE CLASTS

By

Walter Tifental[1] and John Decker[2]

Alaska Division of
Geological and Geophysical Surveys

June 1986

794 University Avenue, Basement
Fairbanks, Alaska 99709

---

[1] Geology Department, University of Alaska, Fairbanks, AK 99775

[2] Division of Geological and Geophysical Surveys, 794 University Ave., Basement, Fairbanks, AK 99709.

State of Alaska
Department of Natural Resources
Division of Geological and Geophysical Surveys

COMPOSITION AND PROVENANCE OF SANDSTONE COBBLE CLASTS

by
Walter Tifental
and
John Decker

May 16, 1986

SUMMARY

This report is the product of a model analysis of sandstone clasts from cobble conglomerate, from the Wiseman quadrangle, Alaska.

The model analysis determined that a proposed source was invalid and the tectonic setting of the source of the clasts is a recycled orogenic provenance. The clasts are interpreted to come from a foreland basin, adjacent to a folded-thrust belt.

TABLE OF CONTENTS

APPENDIX

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS CONTINUED

ABSTRACT

Through a detailed analysis of eight sandstone thin sections, made from cobble conglomerate clasts, the validity of a proposed source and the tectonic provenance was determined.

The samples were collected in the Wiseman quadrangle of Alaska, off the southern flank of the Brooks Range.

The clasts were quantitatively analyzed by a model analysis. The model analysis was done using traditional point count method and was analyzed on standard ternary diagrams.

The proposed source was found to diverge from the dominant lithology of the clast; thus, their validity as the source of the clasts is not valid.

The clasts were plotted on Dickinson (1985) compositional field diagrams. The tectonic setting for the source of the clasts, is a recycled orogenic provenance. The clasts composition reflected a peripheral foreland basin adjacent to a fold-thrust belt. The detrital rock fragments reflect a sedimentary and metasedimentary source.

I. INTRODUCTION

The knowledge of sandstone provenance is vital to the understanding of geologic history of a region. This report summarizes the results of a model analysis of a suite of sandstone cobbles collected from polymictic conglomerate. The conglomerate is of Cretaceous age, and occurs within the Yukon-Koyukuk basin, between the Brooks and Ruby Ranges. The sandstone cobbles were suggested, by John Dillon of the Alaska Division of Geological and Geophysical Surveys (personal communication), to have been derived from the mono-metamorphic graywacke belt along the south flank of the Brooks Range. The objective of this study is, 1) to compare compositionally the conglomerate clasts to the proposed southern Brooks Range source and 2) to determine the tectonic setting of the source, for the clasts.

The samples were collected during the summer of 1985 by Decker and analyzed by Tifental. The cobble clasts were made into thin sections, that were each half-stained for K-spar.

Table 1 and figures 1, 2, and 3 show the location of each sample.

Table I : Sample Location

Sample Number	Location	Physical Location
85 JD 401B 85 JD 401C 85 JD 401G	NE1/4 NE1/4 NW1/4 NE1/4 Sec. 7 T26N T 13W FM.	Left Side Middle Fork Koyukuk River
85 JD 405A	NM1/4 NE1/4 NE1/4 NW1/4 Sec. 13 T26N R14W FM.	Right Side Middle Fork Koyukuk River
85 JD 406B 85 JD 406C	NW1/4 NE1/4 SW1/4 SW1/4 Sec. 14 T26N R14W FM.	Right Side Middle Fork Koyukuk River
85 JD 417A BR	NE1/4 NE1/4 NW1/4 N1/2 SEC. 14 T27N R12W FM.	East of Rosie Creek Pass
85 JD 418A BR	SE1/4 SW1/4 NE1/4 SW1/4 Sec. 11 T27N R12W FM.	East of Rosie Creek Pass
85 JD 419C	NE1/4 NE1/4 SW1/4 SW1/4 Sec 36 T26N R13W FM.	East Side Dalton Hwy
85 JD 421B	SE1/4 SE1/4 SE1/4 SW1/4 Sec 11 T25N R13W FM.	West Side Dalton Hwy

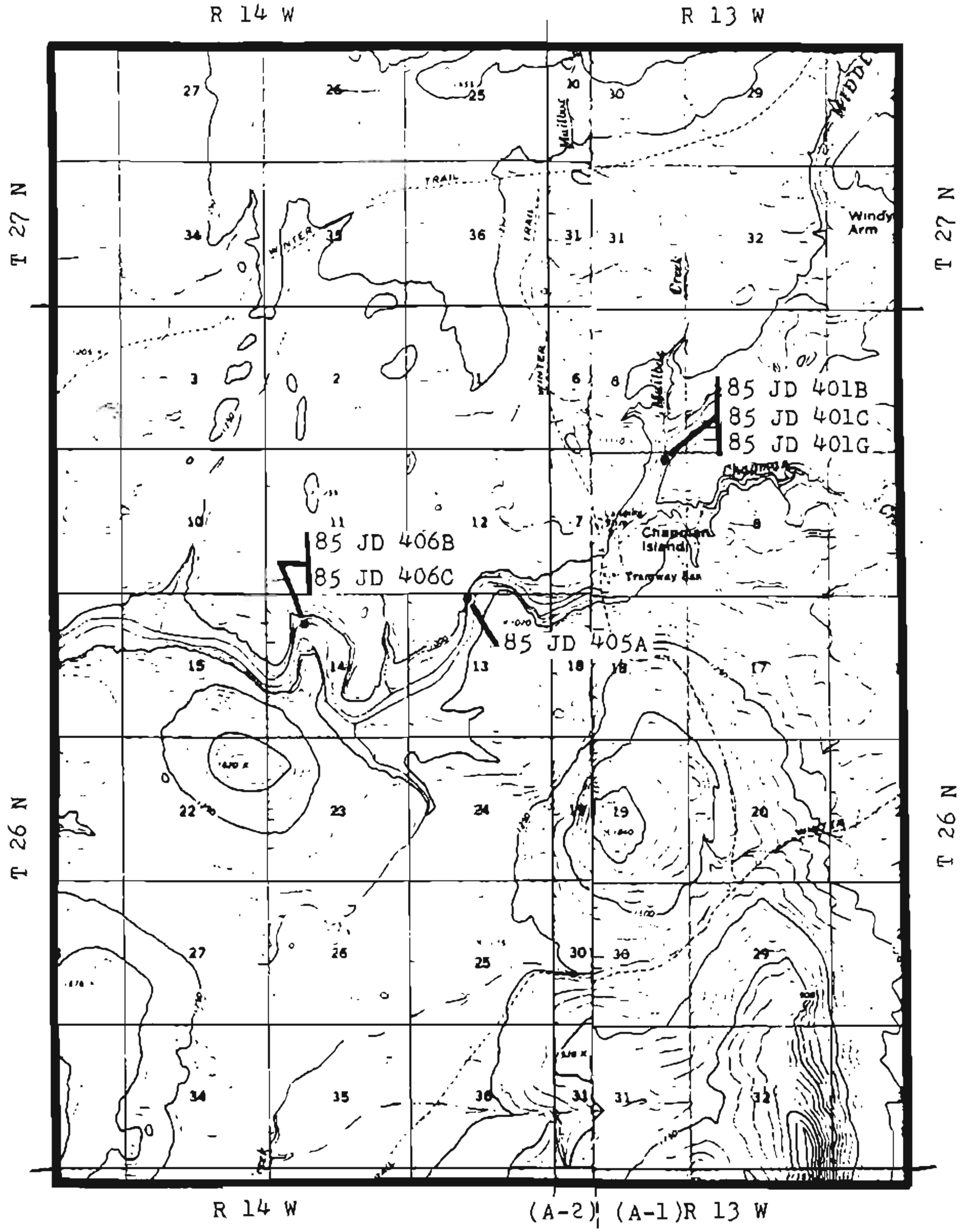


FIGURE 1, Sample Location, From U.S.G.S., Scale 1:63,360
Wiseman (A-1) & (A-2) 1970.

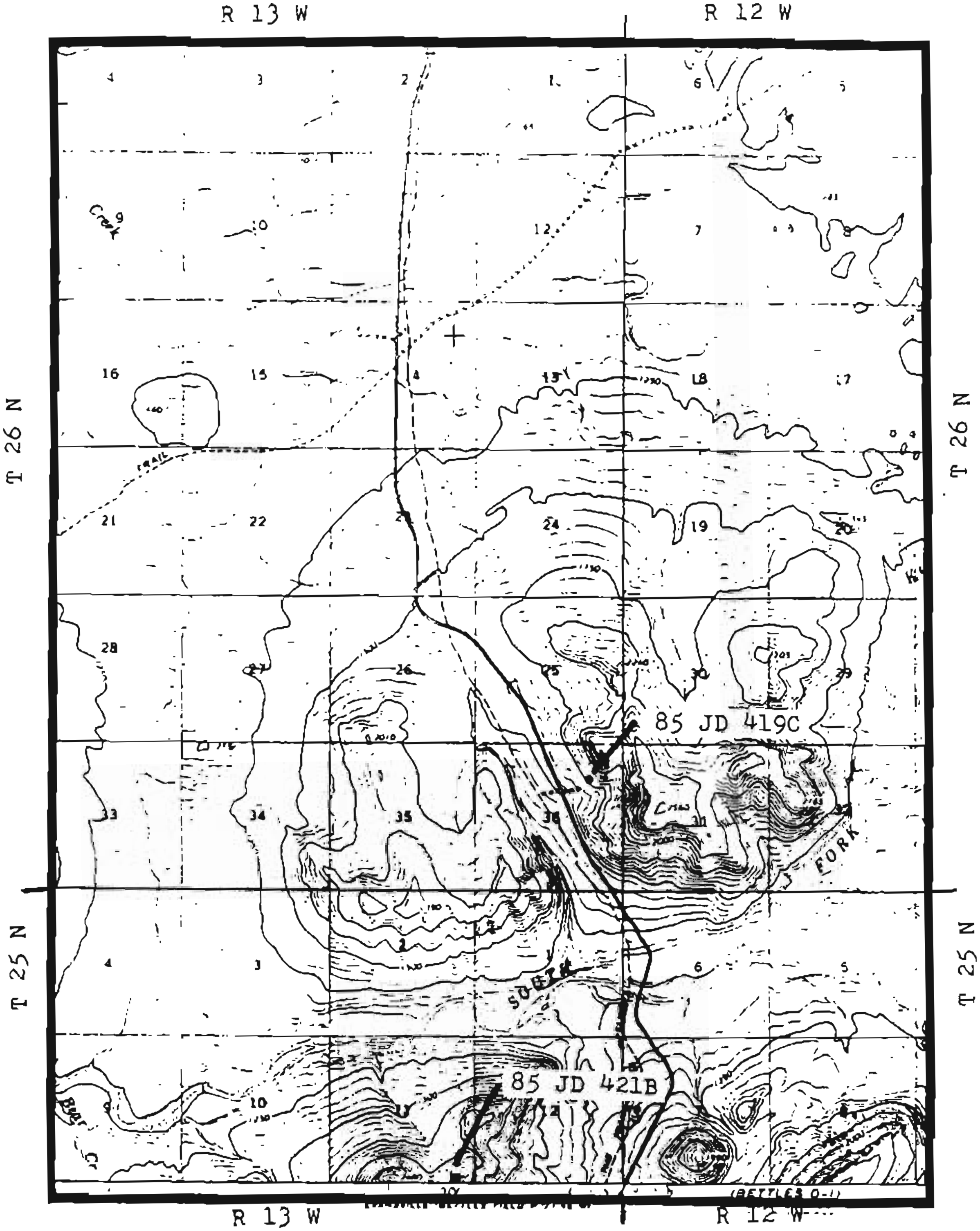


FIGURE 2, Sample Location, From U.S.G.S. Scale 1:63,360 Wiseman (A-1) 1970.

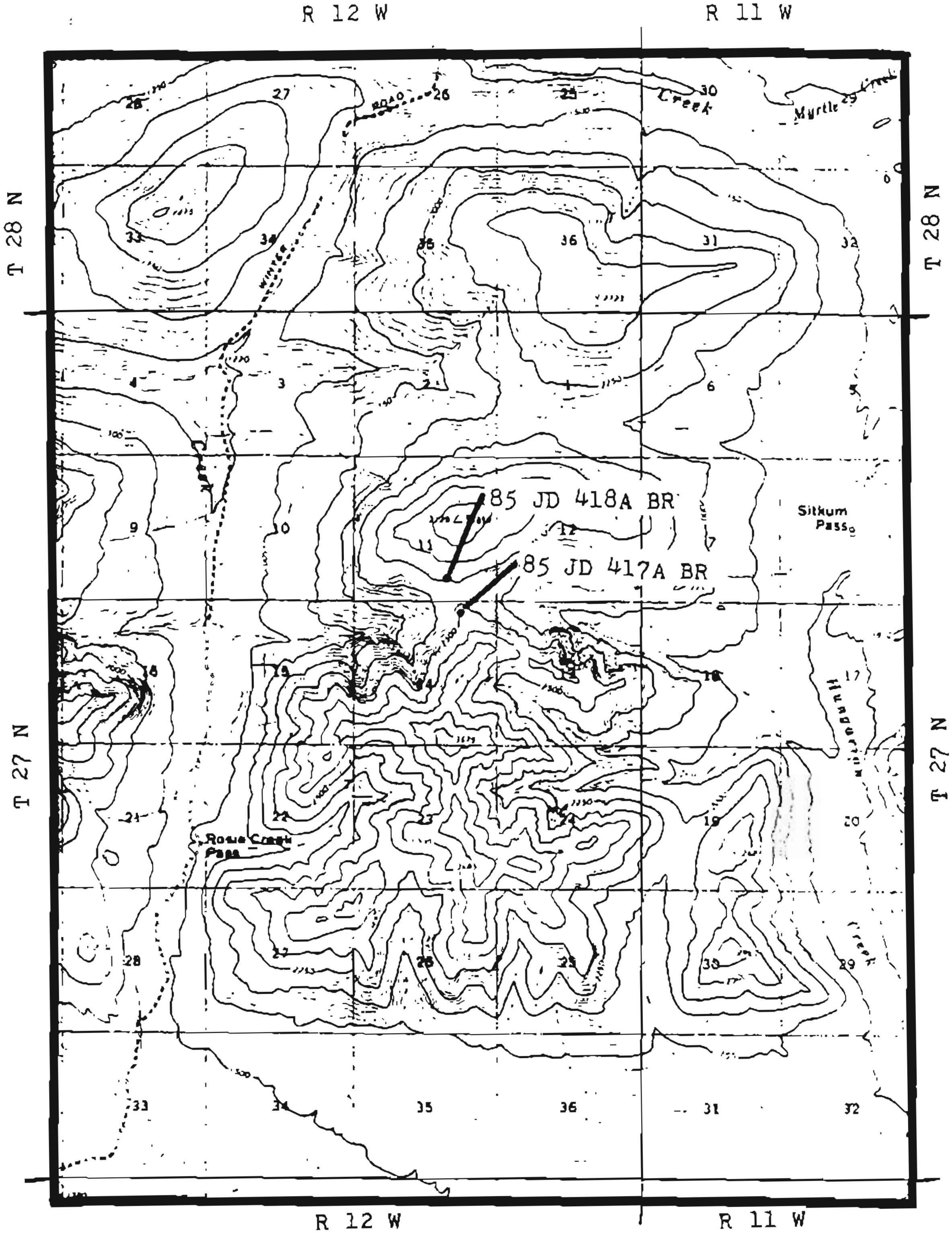


FIGURE 3, Sample Location, From U.S.G.S. Scale 1:63,360
Wiseman (A-1) 1970.

II. LABORATORY PROCEDURE

The modal analysis was done using the traditional point count method (Ingersoll and other, 1984). The method counts all polymineralic grains as rock fragments, and follows the procedure outlined by Decker (1985).

The thin sections used for model analysis were selected based on their lack of alteration, authigenic minerals and fracture filling. This lack of alteration was important, because, only detrital grains were of provenance interest. All the thin sections had similar size (0.3mm to 0.4mm, medium grained).

Samples of the proposed source were collected from nearby outcrops in the southern Brooks Range. Only rocks having similar compositions to the clasts, and thus being possible source rock, were collected.

The counting method is as follows:

1) One half millimeter was determined to be greater then 90% of the grains in the study suite and was selected as the grid spacing.

2) During the analysis a cell concept was used. This technique divides each thin section into four imaginary blocks, with 100 point in each block. The strategy is to count the first cell in each slide, then returning to the first slide, and

count the second cell of each slide, then repeating the process until 400 detrital grains are counted. This cell method will average out the operator bias developed during the study.

3) A manual stage micrometer and a standard student petrographic microscope was used in this study. Throughout the study the identical equipment was used, to minimize any alteration in the counting.

4) On each thin section 400 detrital grains were counted. The data was then entered into a computer for tabulation. The tabulation work sheet (Appendix A) shows the categories counted and the summation of the totals.

5) From the tabulated data, ternary diagrams (figure 4 through 14) were produced. Each sample is plotted on the diagram, with the clast samples shown as points and the proposed source samples shown as triangles. In the diagrams, one can see the clear groupings of the conglomerate clasts. The groupings show the dominance of quartz and the lack of feldspars. Also, the two samples from the proposed source are consistently separated from the clasts.

III. SAMPLE COMPOSITION and TECTONIC ENVIRONMENT

The QFL diagram (Figure, 4) depicts the quartz rich and the feldspar poor nature of the samples. According to Williams and others (1954) the clasts would be classified as a Lithic Arenite.

In the classification scheme of Decker (1985) the samples would be classified as follows:

1. 85 JD 401B: medium-grained, moderately sorted, subangular, matagenic, quartz sandstone/lithic quartz sandstone.
2. 85 JD 401C: medium-grained, moderately sorted, subangular, metagenic, quartz sandstone.
3. 85 JD 401G: medium-grained, very well sorted, subround, sedigenic, quartz sandstone.
4. 85 JD 405A: medium-grained, well sorted, subangular, metagenic, lithic quartz sandstone.
5. 85 JD 406B: medium-grained, moderately sorted, subround, metagenic, lithic quartz sandstone.
6. 85 JD 406C: medium-grained, well sorted, subround, matagenic, quartzose lithic sandstone.

7. 85 JD 419C: medium-grained, moderately sorted, subround, sedigenic, quartz sandstone.

8. 85 JD 421B: medium-grained, moderately sorted, subround, sedigenic, lithic quartz sandstone.

9. 85 JD 417A BR: (proposed source) medium-grained, moderately sorted, subround, polymictic, quartzose feldspathic sandstone.

10. 85 JD 418A BR: (proposed source) medium-grained, moderately sorted, subround, metagenic, feldspathic sandstone.

Figure 15, shows the compositional fields used in this classification.

Tectonic Provenance

The relationship of clastic rock composition and tectonic setting has long been realized. Krynine (1942) was the first to have the concept of sandstone composition being linked to source rock history. Although Krynine's idea was related to geocynclinal cycle, his concepts are still recognizable in modern plate tectonic theory.

Some of the modern reinterpretation, of detrital mineral composition in plate tectonic terms, have come from Dickinson (1985), Dickinson and Suczek (1979), Valloni (1985), Valloni and Maynard (1981) and Potter (1978). Through the use of a variety of ternary diagrams Dickinson and Suczek (1979) were able to show compositional fields indicative of tectonic provenance. Figure 16 and 17 show the fields of Dickinson (1985) and the point count data from this study.

In figure 16,--Q F L and Qm F Lt diagrams--the clasts fall into the recycled orogenic provenance field. According to Dickinson (1985), rocks that plot in this region are deformed, uplifted, and eroded. He states three tectonic settings: 1) subduction complexes, where trench rocks are exposed to deformation and erosion, 2) back arc thrust belts, where rocks are thrusted and eroded, 3) suture belts, where continental collision has deformed the rocks and deposited then into foreland basins.

Dickinson (1985, Table 6) averages the modal composition of sandstone suites from foreland basins. His averages correlate well with the data found for the clasts. The best fit for the conglomerate clasts was a clastic rock derived from sand-rich chert-argillite subduction complex in a peripheral foreland basin in central Navada. The comparison can be seen in table II.

Table II, Modal Composition Averages

	Qm	Qp	Qt	F	Lv	Ls	Lt
Clasts From Study	58	27	85	1	Tr	6	38
Dickinson Averages from Navada	47	26	73	2	Tr	25	51

Dickinson's (1985) Ls is Ls* in this report.

Dickinson and Suczek (1979) found foreland basin suites fall in two fields--the lithic rich and the quartz rich. The clasts of this study, are quartz rich and feldspar poor. The dominant lithic constituents are metasedimentary rock fragments, chert and polycrystalline quartz. If the clasts are derived from a foreland basin, it shows little evidence of a nearby magmatic arc. Intuitively, the clasts must be from a peripheral foreland basin, being filled with sediments from a fold-thrust or suture belt of chert, and metasedimentary rocks. Indeed this is the case, Dickinson and Suczek (1979) found that fold-thrust systems of low-grade metamorphics and sedimentary rocks plot on the Qt-L, Qm-Lt, and the Qp-Ls leg of ternary diagrams. This is exactly where the clasts plot as see in Figures 4, 6 and 12.

Source Proposal

As was noted previously, the two samples from the proposed source diverge in the ternary diagram from the clustering of the clasts. This demonstrates that the source for the conglomerate clast are not likely to be the rock unit from which the two source samples were collected. The dominant difference is the amount of feldspars present. Both source samples show a close corelation; however, more samples are needed for any conclusive interpretation of there provenance.

The study of several thin sections from the 85 JD 401 site shows a compositional change within the conglomerate clasts. In almost all the ternary diagrams, slides 85 JD 401G diverges from the other 401 slides--85 JD 401B and 85 JD 401C. The divergence can be seen most clearly in figure 11.

The compositional change within the conglomerate clasts, from the 401 site, could represent a mixed provenance, or a vertical change in lithology at the source. More information is needed to decipher this difference.

FIGURE 4

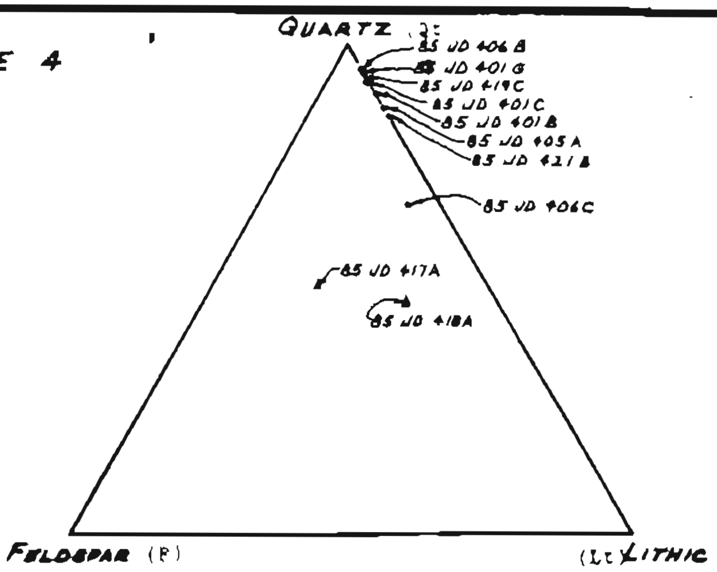


FIGURE 5

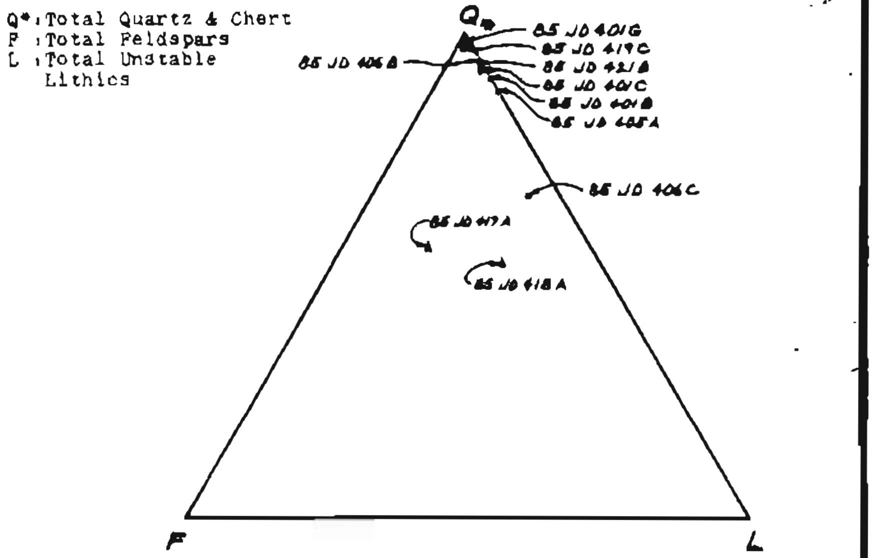


FIGURE 6

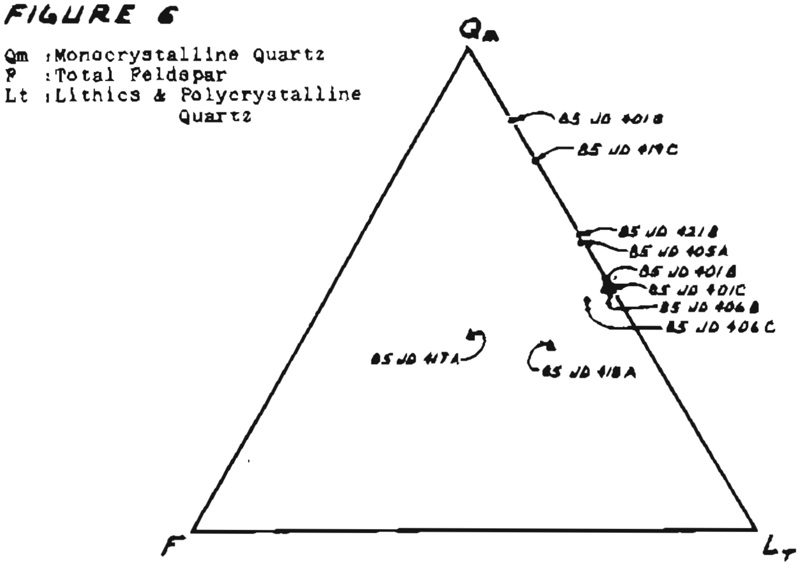


FIGURE 7

Qms :Quartz Straight Extinction
Qmu :Quartz Undulose Extinction
Qp :Quartz Polycrystalline

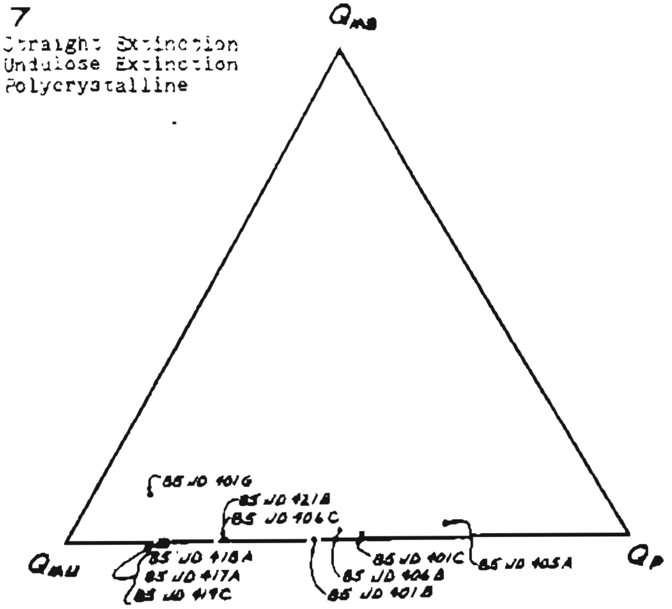


FIGURE 8

Qm: Quartz Monocrystalline
P : Plagioclase & Myrmekitic
K : K-spar & Perthitic

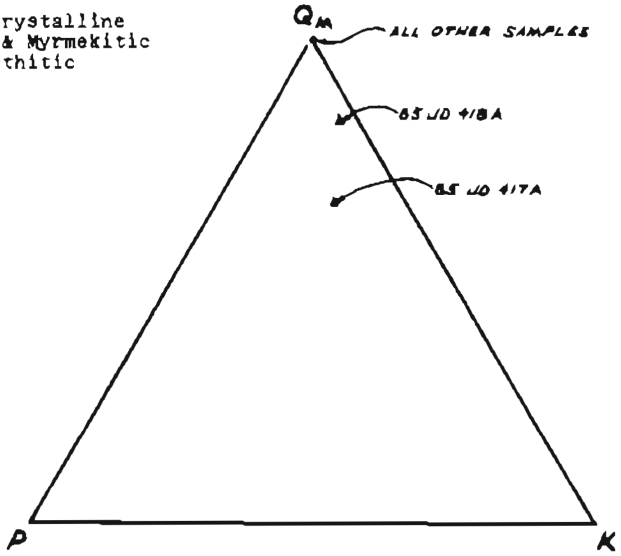


FIGURE 9

K :K-spar & Perthitic
Pz :Zoned Plagioclase
Puz:Unzoned Plagioclase

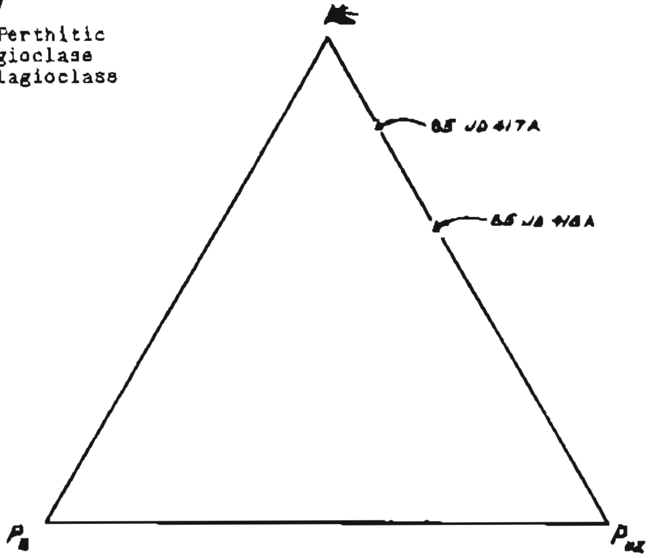


FIGURE 10

Lv :Total Volcanic Lithics
Ls-:Sedimentary Lithics - Chert
Lm :Total Metamorphic Lithics

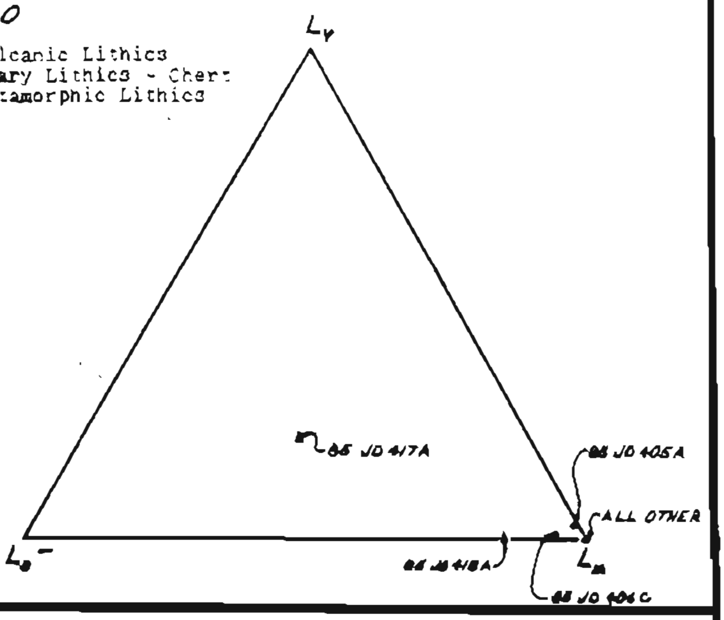


FIGURE 11

Lv :Total Volcanic Lithics
Ls+:Sedimentary Lithics & Chert
Lm :Total Metamorphic Lithics

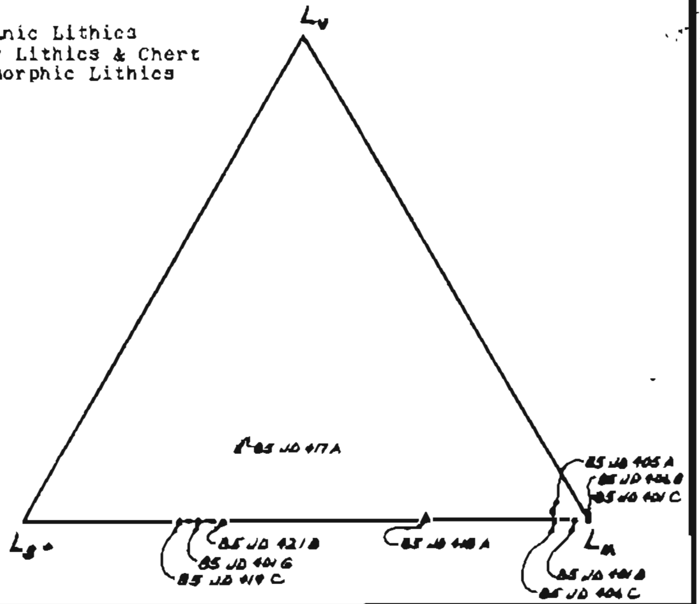


FIGURE 12

Qp :Polycrystalline Quartz
Lv*:Total Volcanics & Metavolcanics
Lithics
Ls*:(Sedimentary Lithics - Chert) &
Metavolcanic Lithics

FIGURE 13

Li :Volcanic & Plutonic Lithics
Ls+:Sedimentary Lithics & Chert
Lm :Total Metamorphic Lithics

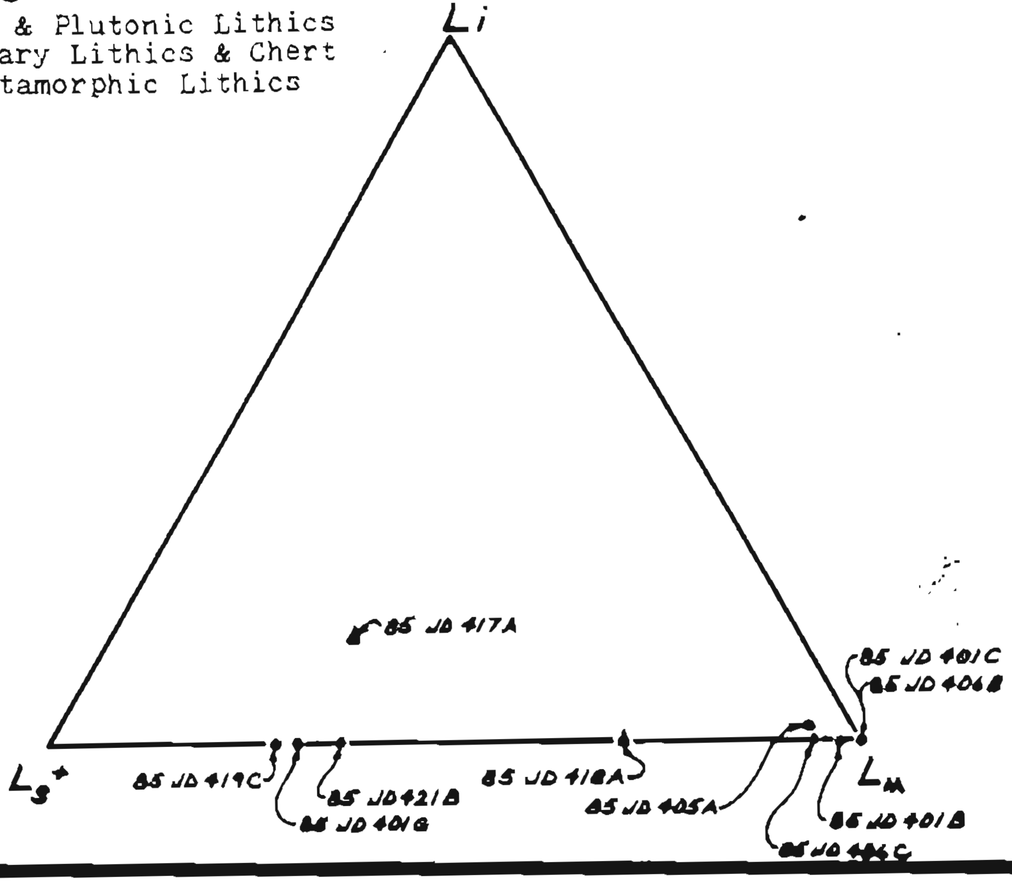
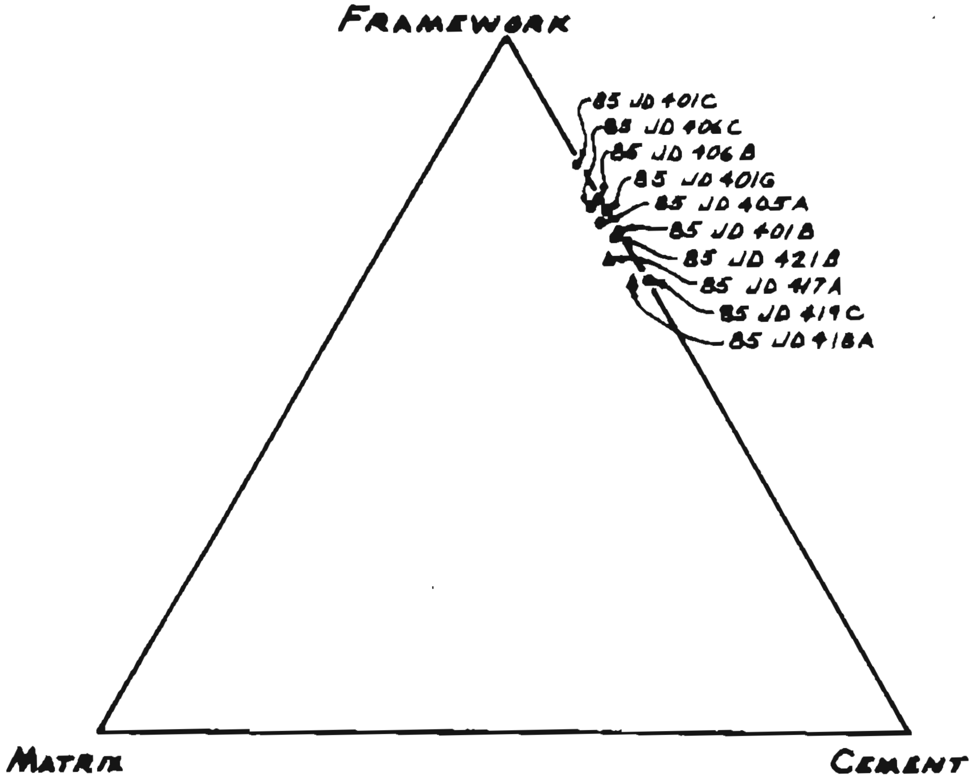


FIGURE 14



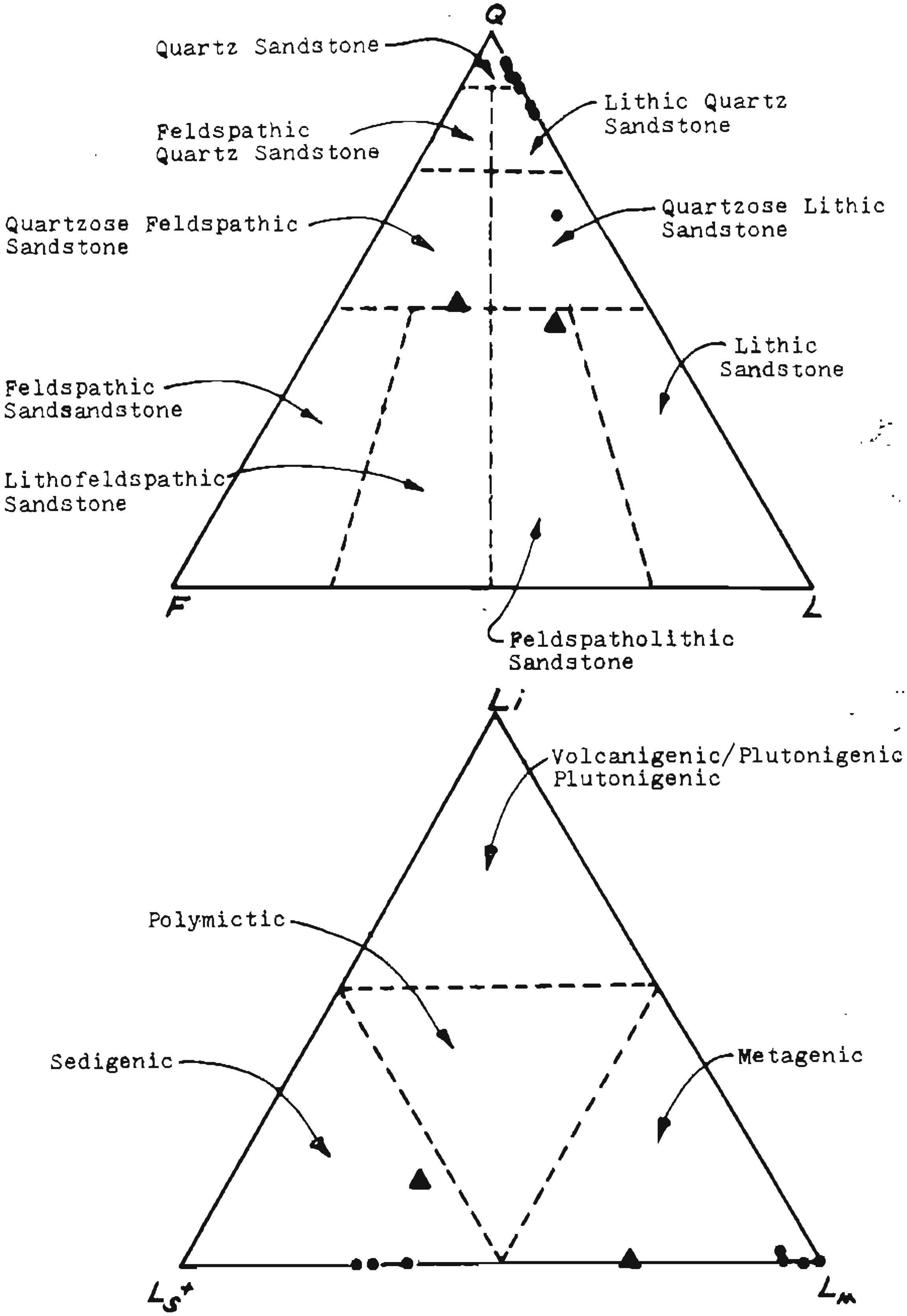


FIGURE 15 ,Sandstone Classification, From Decker (1985).

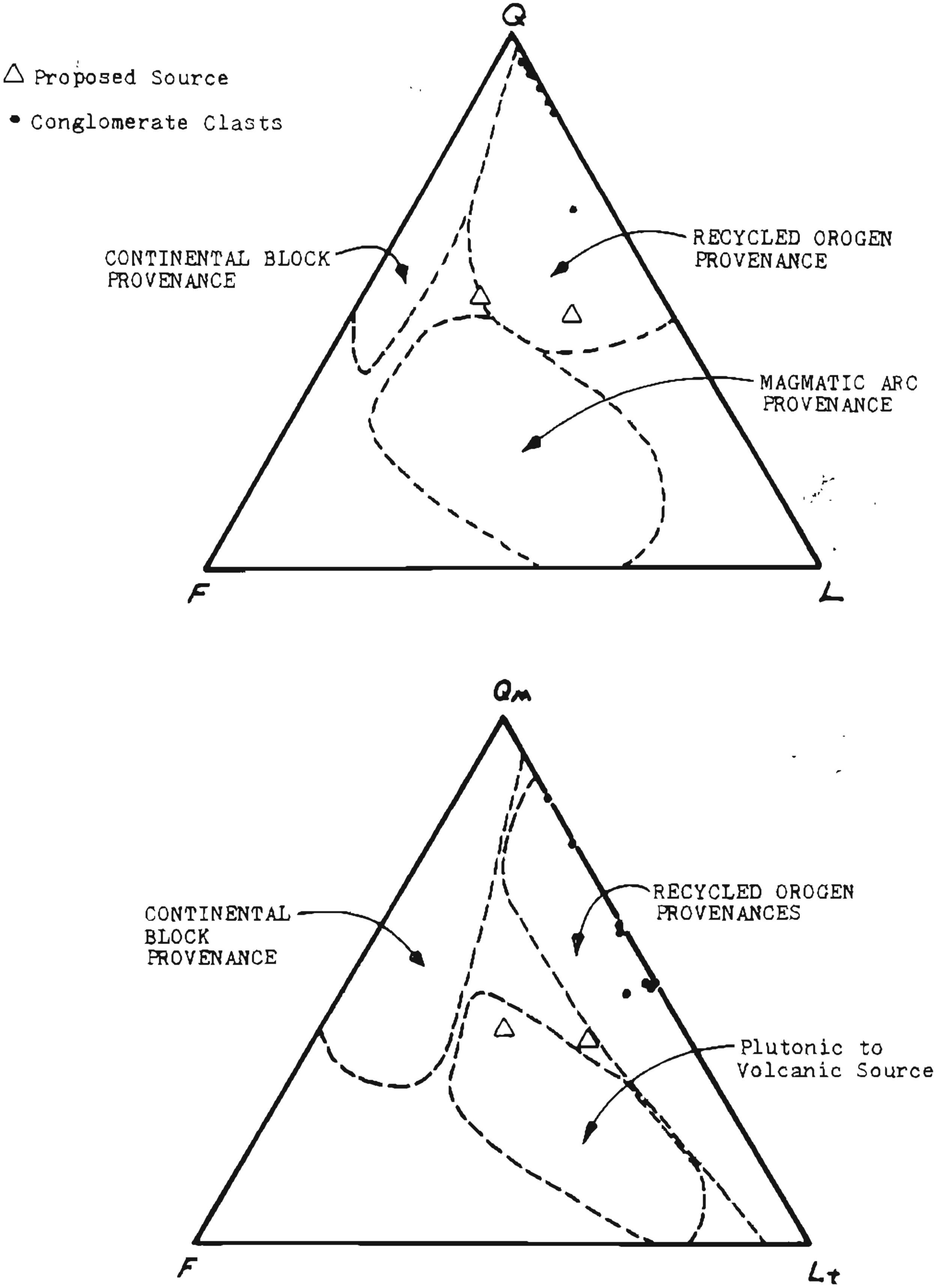


FIGURE 16 Compositional Field Diagrams, From Dickinson (1985).

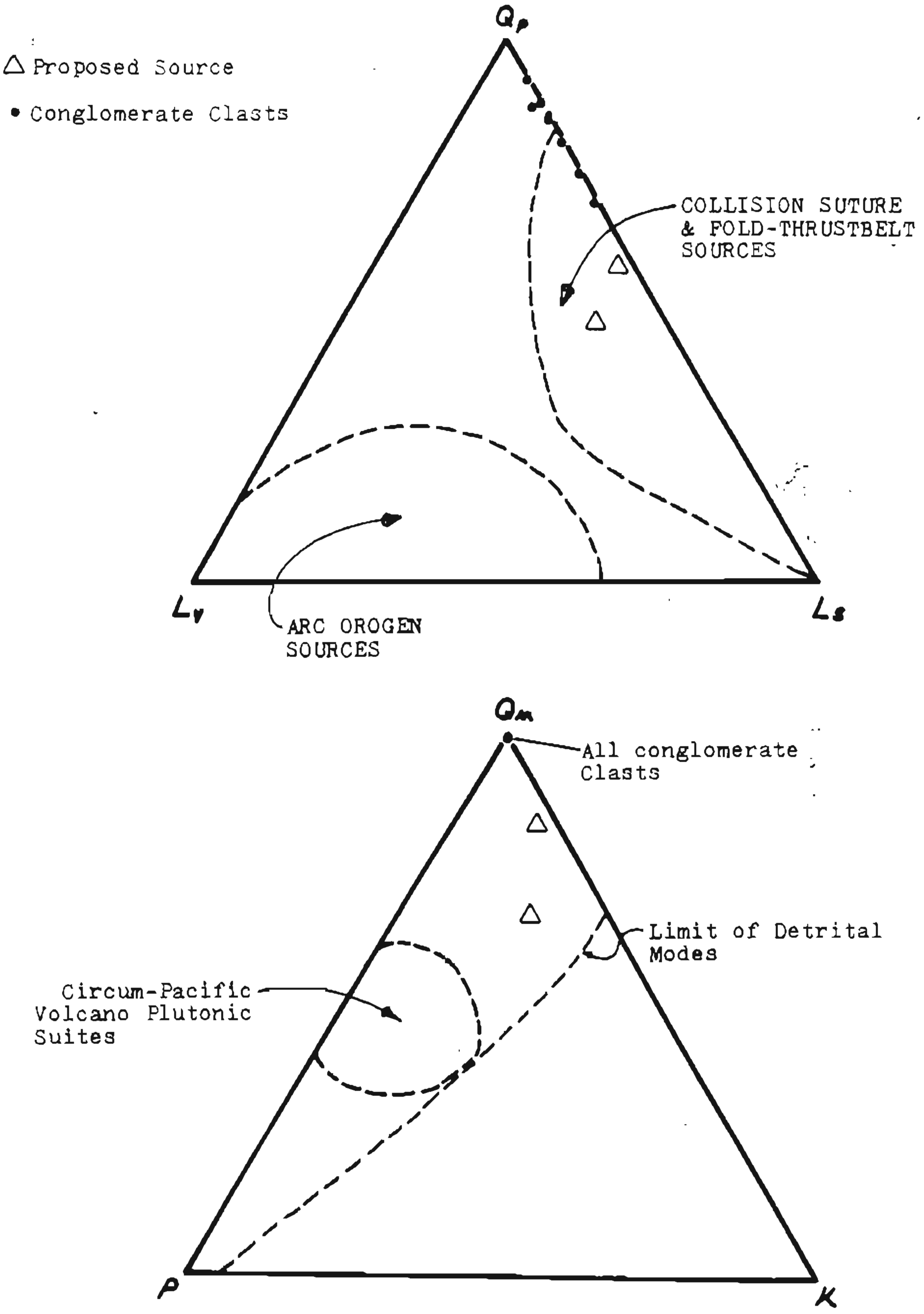


FIGURE 17. Compositional Field Diagrams, From Dickinson (1985).

DISCUSSION

Based on two samples, the proposed Brooks Range source was shown not to be the likely source of the quartz sandstone clasts. The use of ternary plots shows a distinct divergence of the clasts from the proposed source.

The tectonic setting of the source of the clasts is a recycled orogen. The nature of recycled sediments, make a precise lithologic source impossible to decipher. Comparision of the clast composition with sandstone compositions of Dickinson (1985), and with Dickinson and Suczek (1979), suggests the tectonic source to be a peripheral foreland basin, receiving sediments from a sedimentary and metamorphic fold-thrust belt. The only information for the sedimentary and metamorphic aspect of the provenance is the chert, polycrystalline quartz, and metasedimentary rock fragments, which biases this prediction by their great survival potential.

APPENDIX A

Tabulation Work Sheet

SAMPLE NUMBER ——)	85JD401B	85JD401C	85JD401E	85JD405A	85JD406B	85JD406C	85JD419C	85JD421B	AVERAGE	[illegible]	[illegible]	AVERAGE
Map Number ——)												
Quadrangle ——)	Wiseman	Wiseman	Wiseman	Wiseman	Wiseman	Wiseman	Wiseman	Wiseman		Wiseman	Wiseman	
Latitude (deg min) ——)												
Longitude (deg min) ——)												
Collected by ——)	Decker	Decker	Decker	Decker	Decker	Decker	Decker	Decker		Decker	Decker	
Point Counted by ——)	Tifental	Tifental	Tifental	Tifental	Tifental	Tifental	Tifental	Tifental		Tifental	Tifental	
Rock Unit ——)	K-seds	K-seds	K-seds	K-seds	K-seds	K-seds	K-seds	K-seds	K-seds	Pz gwky	Pz gwky	Pz gwky
QUARTZ												
Quartz, monocrystalline, undulose	198.00	194.00	300.00	237.00	218.00	191.00	294.00	245.00	55.88	174.00	162.00	39.39
Quartz, monocrystalline, straight		4.00	39.00	10.00	9.00				1.85			.00
Quartz, polycrystalline, equigranular	53.00	111.00	12.00	90.00	157.00	24.00	41.00	25.00	15.27	12.00	15.00	3.17
Quartz, polycrystalline, foliated	6.00		1.00			1.00		2.00	.30	1.00		.12
Quartz, polycrystalline, coarse	97.00	62.00	22.00	20.00	48.00	48.00	22.00	71.00	11.61	25.00	18.00	5.04
Quartz, undifferentiated									.00			.00
FELDSPAR												
Alkali feldspar, monoclinic									.00	55.00	26.00	9.50
Alkali feldspar, triclinic									.00			.00
Plutonic feldspar, perthitic									.00			.00
Plutonic feldspar, graphic									.00			.00
Plutonic feldspar, myrmekitic									.00			.00
Alkali feldspar, undifferentiated									.00			.00
Plagioclase, unzoned, A-twins									.00	34.00	6.00	4.69
Plagioclase, unzoned, C-twins									.00			.00
Plagioclase, unzoned, untwinned									.00			.00
Plagioclase, zoned									.00			.00
Plagioclase, undifferentiated									.00			.00
Feldspar, undifferentiated									.00			.00
Altered feldspar						22.00			.65	30.00	35.00	7.62
SEDIMENTARY ROCK FRAGMENTS												
Microcrystalline quartz (chert)			13.00				15.00	22.00	1.49	19.00	26.00	5.28
Radiolarian chert									.00			.00
Foliated chert	1.00		3.00				3.00	9.00	.48			.00
Fibrous chert									.00			.00
Probable cherty grains				1.00					.09			.00
Cherty argillite								1.00	.03			.00
Argillite						6.00		4.00	.30	25.00	16.00	4.81
Siltstone									.00			.00
Sandstone									.00			.00
Slate/shale									.00		2.00	.23
Carbonate, extrabasinal									.00	1.00		.12
Coal/organic detritus									.00			.00
Probable sedimentary rock fragment									.00			.00
Other or undifferentiated SRF									.00			.00
VOLCANIC ROCK FRAGMENTS												
Vitric/cryptocrystalline VRF									.00			.00
Microcrystalline felsic VRF									.00		1.00	.12
Microgranular felsic VRF									.00			.00
Microlitic VRF				1.00					.03			.00
Lathwork VRF									.00	13.00		1.52
Mafic VRF									.00			.00
Tuffaceous VRF									.00			.00
Altered VRF									.00			.00
Probable volcanic rock fragment									.00			.00
Other or undifferentiated VRF									.00			.00
METAMORPHIC ROCK FRAGMENTS												
Unfoliated metaclastic									.00	14.00		1.64
Quartz-mica phyllite	36.00	29.00	7.00	48.00	27.00	18.00	7.00	17.00	5.63	9.00	21.00	3.52
Quartz-mica schist/gneiss									.00	1.00		.12
Greenstone									.00			.00
Green phyllite									.00			.00
Greenschist/amphibolite									.00			.00
Hornfels						83.00		1.00	2.50		87.00	10.20
Probable MRF						2.00		2.00	.12			.00
Other or undifferentiated MRF									.00			.00

PLUTONIC ROCK FRAGMENTS												
Felsic PRF, quartz									.00			.00
Felsic PRF, K-spar									.00			.00
Felsic PRF, plagioclase									.00			.00
Felsic PRF, white mica									.00			.00
Felsic PRF, biotite									.00			.00
Felsic PRF, amphibole									.00			.00
Felsic PRF, other									.00			.00
Mafic PRF, plagioclase									.00			.00
Mafic PRF, pyroxene									.00			.00
Mafic PRF, olivine									.00			.00
Mafic PRF, other									.00			.00
Intermediate PRF, plagioclase									.00			.00
Intermediate PRF, amphibole									.00			.00
Intermediate PRF, white mica									.00			.00
Intermediate PRF, biotite									.00			.00
Intermediate PRF, other									.00			.00
Probable PRF									.00			.00
Other or undifferentiated PRF									.00			.00
DETRITAL MINERALS												
Biotite									.00			.00
White mica	21.00	8.00	8.00	8.00	12.00	12.00	16.00	17.00	3.04	1.00	10.00	1.29
Chlorite			3.00		2.00	2.00	1.00	6.00	.42	12.00	1.00	1.52
Clinopyroxene									.00			.00
Amphibole									.00			.00
Garnet									.00			.00
Zircon					1.00	1.00			.06	1.00		.12
Tourmaline									.00			.00
Rutile									.00			.00
Other minerals				6.00	1.00		2.00		.27			.00
Indeterminant grains									.00			.00
MATRIX												
Silty									.00			.00
Argillaceous		1.00		8.00		1.00	3.00	5.00	100.00	18.00	11.00	100.00
Pseudomatrix									.00			.00
Matrix, other or undifferentiated									.00			.00
CEMENT												
Silica	98.00	35.00	59.00	69.00	67.00	103.00	110.00	110.00	53.31	97.00	103.00	51.02
Carbonate, undifferentiated	2.00	1.00		9.00					1.02			.00
Carbonate, calcite				.00					.00			.00
Carbonate, dolomite									.00			.00
Carbonate, ankerite									.00			.00
Carbonate, siderite									.00			.00
Hematite			1.00	4.00	2.00		4.00	2.00	1.10	14.00	16.00	7.65
Clay minerals	61.00	57.00	76.00	61.00	74.00	21.00	96.00	55.00	42.57	67.00	95.00	41.33
Sulfates									.00			.00
Glaucony									.00			.00
Phosphates									.00			.00
Cement, other or undifferentiated									.00			.00
METAMORPHIC MINERALS												
Zeolite									.00			.00
Albite									.00			.00
Chlorite									.00			.00
Biotite									.00			.00
White mica									.00			.00
Epidote									.00			.00
Clinozoisite									.00			.00
Zoisite									.00			.00
Prehnite									.00			.00
Pumpellyite									.00			.00
Actinolite									.00			.00
Glaucophane									.00			.00
Lawsonite									.00			.00
Jadite									.00			.00
Other metamorphic minerals									.00			.00

OVERSIZE and INTRABASINAL GRAINS												
Oversize—neovolcanic									.00			.00
Oversize—intrabasinal carbonate									.00			.00
Oversize—clastic rip-up									.00			.00
Oversize—shell fragment									.00			.00
Detrital pebble									.00			.00
Other oversize grain									.00			.00
xxx Miscellaneous												
Oil									.00			.00
Bitumin									.00			.00
Porosity	2.00	4.00	5.00	1.00			1.00		1.63		2.00	1.00
xxx TOTALS												
TOTAL DETRITAL SAND GRAINS	412.00	408.00	408.00	421.00	475.00	410.00	401.00	422.00	419.88	427.00	426.00	426.50
TOTAL MATRIX	.00	1.00	.00	8.00	.00	1.00	3.00	5.00	2.25	18.00	11.00	14.50
TOTAL CEMENT	161.00	93.00	136.00	143.00	143.00	124.00	210.00	167.00	147.13	178.00	214.00	196.00
TOTAL METAMORPHIC MINERALS	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
TOTAL OVERSIZE GRAINS	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
TOTAL POINTS COUNTED	575.00	506.00	549.00	575.00	618.00	535.00	615.00	594.00	570.88	623.00	653.00	638.00
xxx PERCENTAGES												
Detrital grains	71.65	80.63	74.32	73.57	76.86	76.64	65.20	71.04	73.74	68.54	65.24	66.89
Matrix	.00	.20	.00	1.39	.00	.19	.49	.84	.39	2.89	1.68	2.29
Cement	28.00	18.38	24.77	24.87	23.14	23.18	34.15	28.11	25.57	28.57	32.77	30.67
Metamorphic minerals	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Oversize grains	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Porosity	.35	.79	.91	.17	.00	.00	.16	.00	.30	.00	.31	.15
Petroleum	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Porosity + Petroleum	4.16	8.24	6.02	1.71	.00	.00	1.36	.00	2.69	.00	5.26	2.63
Qm	48.06	48.53	83.09	58.39	47.79	46.59	73.32	58.06	57.98	40.75	38.03	39.39
Qms (straight extinction)	.00	.98	9.56	2.36	1.89	.00	.00	.00	1.85	.00	.00	.00
Qmu (undulose extinction)	48.06	47.55	73.53	56.03	45.89	46.59	73.32	58.06	56.13	40.75	38.03	39.39
Qp	37.86	42.40	8.58	26.00	43.16	17.80	15.71	23.22	26.84	8.90	7.75	8.32
C (chert)	.24	.00	3.92	.71	.00	.00	4.49	7.35	2.09	4.45	6.10	5.28
Qp* (Qp + C)	38.11	42.40	12.50	26.71	43.16	17.80	20.20	30.57	28.93	13.35	13.85	13.60
Q (total quartz)	85.92	90.93	91.67	84.40	90.95	64.39	89.03	81.28	84.82	49.65	45.77	47.71
Q+ (total quartz + chert)	86.17	90.93	95.59	85.11	90.95	64.39	93.52	88.63	86.91	54.10	51.88	52.99
K (K-spar + perthitic + graphic)	.00	.00	.00	.00	.00	.00	.00	.00	.00	12.88	6.10	9.49
P (plagioclase + myrmekitic)	.00	.00	.00	.00	.00	.00	.00	.00	.00	7.96	1.41	4.69
Pz (zoned plagioclase)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Puz (unzoned plagioclase)	.00	.00	.00	.00	.00	.00	.00	.00	.00	7.96	1.41	4.69
F (total feldspar grains)	.00	.00	.00	.00	.00	5.37	.00	.00	.67	27.87	15.73	21.80
Ls- (SRF - C)	.00	.00	.00	.00	.00	1.46	.00	1.18	.33	6.09	4.23	5.16
Ls+ (SRF + C)	.24	.00	3.92	.71	.00	1.46	4.49	8.53	2.42	10.54	10.33	10.43
Ls* (Ls- + Lms)	8.74	7.11	1.72	11.35	5.68	5.85	1.75	5.21	5.93	11.71	9.15	10.43
Lvf (felsic VRF)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.23	.12
Lvm (mafic and intermediate VRF)	.00	.00	.00	.24	.00	.00	.00	.00	.03	3.04	.00	1.52
Lv (total volcanic rock fragments)	.00	.00	.00	.24	.00	.00	.00	.00	.03	3.04	.23	1.64
Lv* (Lv + Lmv)	.00	.00	.00	.24	.00	.00	.00	.00	.03	3.04	.23	1.64
Lms (metasedimentary rock fragments)	8.74	7.11	1.72	11.35	5.68	4.39	1.75	4.03	5.59	5.62	4.93	5.28
Lmv (metavolcanic rock fragments)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Lm (total metamorphic rock fragments)	8.74	7.11	1.72	11.35	5.68	25.12	1.75	4.74	8.28	5.62	25.35	15.49
Lpf (felsic PRF)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Lpm (mafic PRF)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Lpi (intermediate PRF)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Lp (total plutonic rock fragments)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Li (Lv + Lp)	.00	.00	.00	.24	.00	.00	.00	.00	.03	3.04	.23	1.64
L (Ls+ + Lv + Lm + Lp)	8.98	7.11	5.64	12.29	5.68	26.59	6.23	13.27	10.72	19.20	35.92	27.56
L- (Ls- + Lv + Lm + Lp)	8.74	7.11	1.72	11.58	5.68	26.59	1.75	5.92	8.64	14.75	29.81	22.28
Lt (Qp* + Ls- + Lv + Lm + Lp)	46.84	49.51	14.22	38.30	48.84	44.39	21.95	36.49	37.57	28.10	43.66	35.88
xxx RATIOS												
Q:F:L	90.54	92.75	94.21	87.29	94.12	66.84	93.46	85.96	88.14	51.33	46.99	49.16
Q:F:L	.00	.00	.00	.00	.00	5.57	.00	.00	.70	28.81	16.14	22.48
Q:F:L	9.46	7.25	5.79	12.71	5.88	27.59	6.54	14.04	11.16	19.85	36.87	28.36
Q*:F:L-	90.79	92.75	98.24	88.02	94.12	66.84	98.17	93.73	90.33	55.93	53.25	54.59
Q*:F:L-	.00	.00	.00	.00	.00	5.57	.00	.00	.70	28.81	16.14	22.48
Q*:F:L-	9.21	7.25	1.76	11.98	5.88	27.59	1.83	6.27	8.97	15.25	30.60	22.93

Qm:F:Lt	50.64	49.50	85.39	60.39	49.46	48.35	76.96	61.40	60.26	42.13	39.04	44.33
Qm:F:Lt	.00	.00	.00	.00	.00	5.57	.00	.00	.70	28.81	16.14	22.42
Qm:F:Lt	49.36	50.50	14.61	39.61	50.54	46.08	23.04	38.60	39.04	29.06	44.82	33.24
Qp:Lv*:Ls*	81.35	85.64	87.93	69.75	88.36	75.26	92.05	85.43	83.22	47.50	59.60	53.55
Qp:Lv*:Ls*	.00	.00	.00	.62	.00	.00	.00	.00	.08	10.83	1.01	5.92
Qp:Lv*:Ls*	18.65	14.36	12.07	29.63	11.64	24.74	7.95	14.57	16.70	41.67	39.39	40.53
Qms:Qmu:Qo	.00	1.08	10.43	2.80	2.08	.00	.00	.00	2.05	.00	.00	.00
Qms:Qmu:Qo	53.93	52.29	80.21	66.39	50.46	72.35	82.35	71.43	66.43	82.08	83.08	82.58
Qms:Qmu:Qo	44.07	46.63	9.36	30.81	47.45	27.65	17.65	28.57	31.52	17.92	16.92	17.42
Qm:P:K	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	66.16	83.51	74.83
Qm:P:K	.00	.00	.00	.00	.00	.00	.00	.00	.00	12.93	3.09	8.01
Qm:P:K	.00	.00	.00	.00	.00	.00	.00	.00	.00	20.91	13.40	17.16
K:Pz:Puz	.00	.00	.00	.00	.00	.00	.00	.00	.00	61.80	81.25	71.52
K:Pz:Puz	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
K:Pz:Puz	.00	.00	.00	.00	.00	.00	.00	.00	.00	38.20	18.75	28.48
Lv:Ls+:Lm	.00	.00	.00	1.92	.00	.00	.00	.00	.24	15.85	.65	8.25
Lv:Ls+:Lm	2.70	.00	69.57	5.77	.00	5.50	72.00	64.29	27.48	54.88	28.76	41.82
Lv:Ls+:Lm	97.30	100.00	30.43	92.31	100.00	94.50	28.00	35.71	72.28	29.27	70.59	49.93
Lv:Ls-:Lm	.00	.00	.00	2.04	.00	.00	.00	.00	.26	20.63	.79	10.71
Lv:Ls-:Lm	.00	.00	.00	.00	.00	5.50	.00	20.00	3.19	41.27	14.17	27.72
Lv:Ls-:Lm	100.00	100.00	100.00	97.96	100.00	94.50	100.00	80.00	96.56	38.10	85.04	61.57
Li:Ls+:Lm	.00	.00	.00	1.92	.00	.00	.00	.00	.24	15.85	.65	8.25
Li:Ls+:Lm	2.70	.00	69.57	5.77	.00	5.50	72.00	64.29	27.48	54.88	28.76	41.82
Li:Ls+:Lm	97.30	100.00	30.43	92.31	100.00	94.50	28.00	35.71	72.28	29.27	70.59	49.93
Framework:Matrix:Cement	71.90	81.27	75.00	73.69	76.86	76.64	65.31	71.04	73.97	68.54	65.44	66.99
Framework:Matrix:Cement	.00	.20	.00	1.39	.00	.19	.49	.84	.39	2.89	1.69	2.29
Framework:Matrix:Cement	28.10	18.53	25.00	24.91	23.14	23.18	34.20	28.11	25.65	28.57	32.87	30.72
C/Q*	.00	.00	.04	.01	.00	.00	.05	.08	.02	.08	.12	.10
Qo*/Q*	.44	.47	.13	.31	.47	.28	.22	.34	.33	.25	.27	.26
P/F	.00	.00	.00	.00	.00	.00	.00	.00	.00	.29	.09	.19
Lv/L	.00	.00	.00	.02	.00	.00	.00	.00	.00	.16	.01	.08
Lv/Lt	.00	.00	.00	.01	.00	.00	.00	.00	.00	.11	.01	.06
Alteration Index	.00	.00	.00	.00	.00	1.00	.00	.00	.13	.23	.51	.37
Gazzi-Dickinson Factor	.24	.15	.05	.05	.10	.12	.05	.17	.12	.06	.04	.05
C twins/total Plagioclase	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.00	.00	.00
Zoned/Total Plagioclase	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.00	.00	.00
Secondary Porosity Potential	.70	.99	.91	1.74	.00	.00	.16	.00	.56	.16	.31	.23
xxxxxxxxxxxxxx SUMMARY xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx												
QUARTZ (Q)	85.92	90.93	91.67	84.40	90.95	64.39	89.03	81.28	84.82	49.65	45.77	47.71
FELDSPAR (F)	.00	.00	.00	.00	.00	5.37	.00	.00	.67	27.87	15.73	21.80
SEDIMENTARY ROCK FRAGMENTS (Ls+)	.24	.00	3.92	.71	.00	1.46	4.49	8.53	2.42	10.54	10.33	10.43
VOLCANIC ROCK FRAGMENTS (Lv)	.00	.00	.00	.24	.00	.00	.00	.00	.03	3.04	.23	1.64
METAMORPHIC ROCK FRAGMENTS (Lm)	8.74	7.11	1.72	11.35	5.68	25.12	1.75	4.74	8.28	5.62	25.35	15.49
PLUTONIC ROCK FRAGMENTS (Lp)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
OTHER DETRITAL MINERALS	5.10	1.96	2.70	3.31	3.37	3.66	4.74	5.45	3.78	3.28	2.58	2.93
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

APPENDIX B

List of Symbols

F	Feldspar grains: Plagioclase + K-spar grains
K	K-spar grains: include Perthite
P	Plagioclase and Myrmekitc
Pz	Zoned Plagioclase
Puz	Unzoned Plagioclase
L	Total Lithics L=Ls+ + Lv + Lm + Lp
Ls-	Sedimentary rock fragment + Chert
Ls*	Sedimentary rock fragments - Chert + Metasedimentary rock fragments
Lv	Volcanic rock fragments
Li	Volcanic rock fragments + Plutonic rock fragments
Lv*	Volcanic rock fragments + Metavolcanics
Lt	Total Lithics including Polycrystallin Quartz Lt = Qp* + Ls- + Lv + Lm + Lp
Lm	Metamorphic rock fragments
Q or Qt	Total Quartz
Qm	Monocrystalline Quartz
Qp	Polycrystallin Quartz
Q*	Total Quartz + Chert
Qmu	Undulose Quartz

LITERATURE CITED

Decker, J., 1985, Sandstone modal analysis procedure: Alaska, Department of Natural Resources, Division of Geological and Geophysical Survey, Public Data-file Report, PDF 85-3a.

Dickinson, W.R., 1985, Interpreting provenance relations from detrital modes of sandstones, in Zuffa, G.G., ed, Provenance of Arenites: Reidel Publishing Co., p. 333-362.

Dickinson, W.R., and Suczek, C.A., 1979, Plate tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 68, p. 2164-2182.

Dillon, J., 1986, Geologist, Alaska division of Geological and Geophysical Surveys, Fairbanks Ak., Conversation in April 1986.

Ingersoll,R.V., Bullard, T.F., Ford, R.L., Grimm, J.P., Pickle, J.D., and Sares, S.W., 1984, The effect of grain size on detrital modes: a test of gazzi-dickinson point-counting method: Journal of Sedimentary Petrology, v. 54, p. 103-116.

Krynine, P.D., 1942, Differential sedimentation and its products during one complete geosynclinal cycle: Ann. Prim. Congr. Panamearicano de Ingen. de Minas Geolog. (Chile), Geologia 1st. Pt., v. 2, p.537-561.

Potter, P.E.,1978, Petrology and chemistry of modern big river sands: Journal of Geology, v. 86, p.423-449.

Valloni, R., 1985, Reading provenance from modern marine sands, in Zuffa, G.G., ed., Provenance of Arenites: Reibel publishing Co., p. 309-332.

Valloni, R. and Maynard, J.B., 1981, Detrital modes of recent deep-sea sands and their relation to tectonic setting: a first approximation: Sedimentology, v. 28, p.75-83.

Williams, H., Turner, F.J., and Gilbert, C.M., 1954, Petrography, an introduction to the study of rocks in thin sections: San Francisco, W.H. Freeman and Company, 626 p.