UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Preliminary report on the petrography of the Upper Jurassic Morrison Formation from four surface sections, southwestern San Juan Basin, McKinley County, New Mexico

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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[Plates are in the pocket]

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DESCRIPTION OF PROJECT

This report is a continuation of a petrographic analysis of the Upper Jurassic Morrison Formation in the southwestern San Juan Basin, New Mexico (fig. 1) and contains the basic petrography of 73 samples (table 1) collected from four outcrop sections (fig. 1). The study was done in conjunction with a petrographic study on Morrison core from the Mariano Lake-Lake Valley drilling project (Steele, 1984). The Morrison Formation in this area contains some of the world's largest sandstone-hosted uranium deposits. Uranium orebodies were intersected in the drilling project (Steele, 1984) but no uranium mineralization was observed in the four surface sections. The line of section is east-west (fig. 2) and roughly perpendicular to the line of drill holes (fig. 1). Petrographic data obtained from the surface and subsurface Morrison samples examined will be combined for a future detailed report on the petrography of the Morrison.

GEOLOGY

The study area is located in the southwestern portion of the San Juan Basin, flanked by the Zuni Mountains to the south and the Defiance Plateau to the west (fig. 1). Jurassic-age rocks, including the Morrison Formation, crop out along the southern edge of the basin and dip gently northward away from the Zuni Mountains into the basin center. At all of the sections studied the Morrison is conformably underlain by and interfingers with an unnamed Jurassic eolian sandstone, formerly the Cow Springs Sandstone of Harshbarger, Repenning and Jackson (1951). Also at each section the Morrison is unconformably overlain by the Upper Cretaceous Dakota Sandstone.

In this region, the Morrison Formation is divided into three members, in ascending order: the Recapture, Westwater Canyon and Brushy Basin (fig. 3). All three members are present at the Pinedale East, Coolidge Quarry and East Thoreau sections (fig. 2) but at the White Cliffs section pre-Dakota erosion has removed the Brushy Basin and the Westwater Canyon is directly overlain by the Upper Cretaceous Dakota Sandstone. The Recapture Member consists of light-colored, thin, fine- to coarse-grained sandstone, claystone, and mudstone. Depositional environments of the Recapture Member are varied and are eolian, fluvial and lacustrine. The Westwater Canyon Member was deposited largely by fluvial processes and consists of reddish-brown, thick, fine-grained to conglomeratic sandstone interbedded with thin, greenish bentonitic mudstone. The Brushy Basin Member is dominantly gray-green bentonitic mudstone and claystone and a few thin sandstones and was deposited largely by lacustrine processes. For a more detailed discussion of the stratigraphy of the Morrison Formation in this area refer to Craig and others (1955), Freeman and Hilpert (1956), and Harshbarger, Repenning, and Irwin (1957).

METHODS

A total of 73 sandstone samples from four measured outcrop sections were examined for texture and composition. Where possible, the fine- to medium-grained portions of individual sandstone units were sampled at approximately 10-20 foot intervals. Thin sections were cut perpendicular to observed bedding. All thin sections were stained with sodium cobaltinitrate to aid in identifying potassium feldspar. Thin sections from the Pinedale East and East Thoreau measured sections were stained alizarin red-s to aid in

TABLE 1.--Distribution of surface sandstone samples from the Morrison Formation, southwestern San Juan Basin.

	White Cliffs Section[1]	Pinedale East Section[2]	Coolidge Quarry Section[3]	East Thoreau Section[4]
Brushy Basin Member........	0	0	1	3
Westwater Canyon Member....	15	16	9	12
Recapture Member...........	8	5	3	1
Total......................	23	21	13	16

[1]Section 32, T. 16 N., R. 17 W.

[2]Section 1, T. 15 N., R. 15 W.

[3]Section 33, T. 15 N., R. 14 W.

[4]Section 13, T. 14 N., R. 13 W.

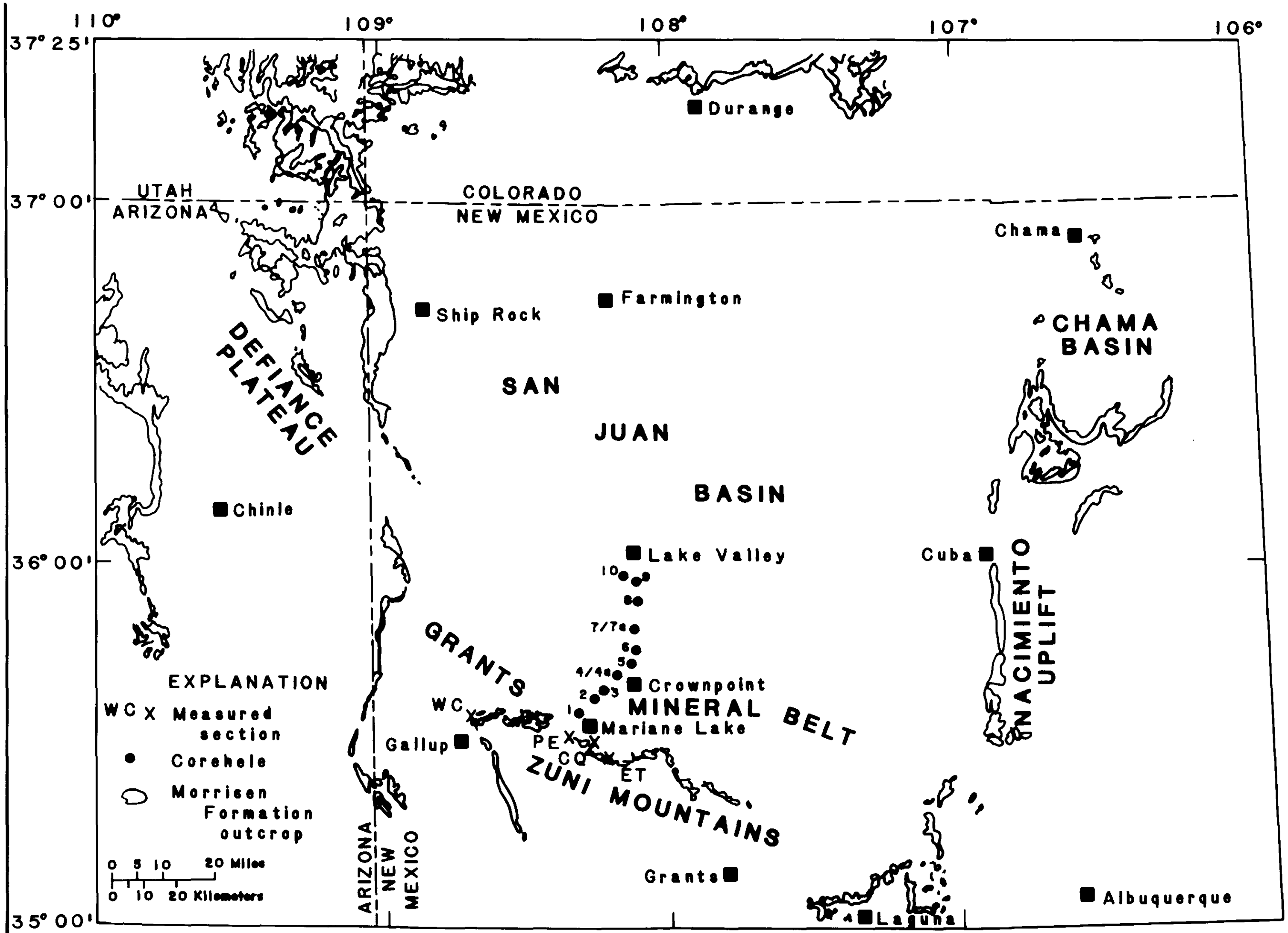
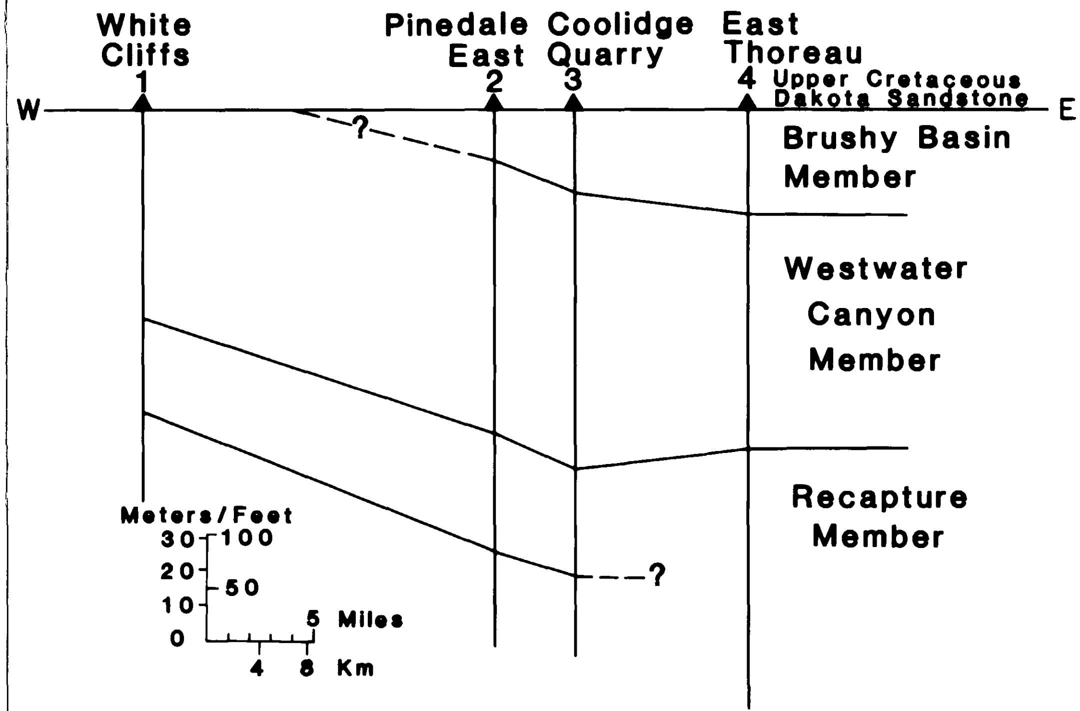


Figure 1.--Location map of study area.



1) Unpublished data, section measured and sampled by R.S. Zech, 1980.
2) Unpublished data, section measured and sampled by A.C. Huffman and S.M. Condon, 1980.
3) Unpublished data, section measured and sampled by A.C. Huffman and A.R. Kirk, 1980.
4) Unpublished data, section measured and sampled by A.C. Huffman, 1983.

Figure 2.--East-West cross section of measured sections, Upper Jurassic Morrison Formation, McKinley County, New Mexico.

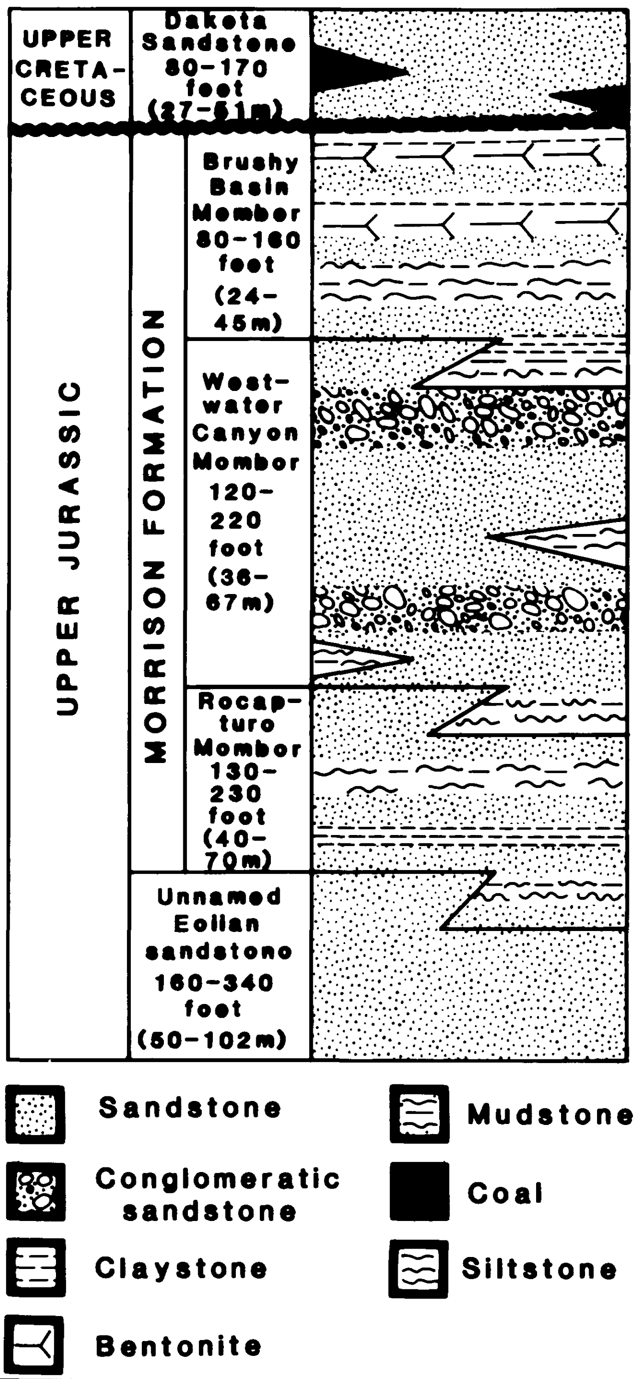


Figure 3.--Generalized stratigraphic column of Upper Jurassic Morrison Formation, southwestern San Juan Basin, New Mexico (thicknesses from Jacques Robertson, oral communication, 1983).

differentiating calcite from dolomite. Each thin section was also impregnated with blue epoxy to enhance the void spaces. Porosity was considered to be any naturally occurring void space, either primary or secondary. Care was taken to disregard any void that may have been created during sample preparation.

For most samples, 300 points were counted for composition and the longest dimension of 100 grains was measured for average grain-size determination. For a number of samples, especially from the Coolidge Quarry section, fewer points were counted due to excessive grain plucking during thin section preparation. Sorting values as phi standard deviation were determined as described by Folk (1974). Diagenetic processes have greatly altered the morphology of many of the detrital grains, thus no attempt was made to quantify either roundness or sphericity.

RESULTS

Tables 2-5 (Appendix 1) show selected textural and compositional information for individual samples from each measured section. Computer-generated plots of the data in tables 2-5 that show vertical changes within each section are in plates 1-4.

Framework constituents, in order of decreasing abundance, are quartz, feldspar, rock fragments and miscellaneous accessory mineral grains. Each of these framework constituents has been further divided. Quartz is divided into monocrystalline, polycrystalline, metamorphic, and cryptocrystalline varieties. Monocrystalline quartz is any single-crystal quartz grain. Polycrystalline quartz is any multiple-crystal quartz grain that is not clearly metamorphic or cryptocrystalline. Metamorphic quartz is any multiple-crystal quartz grain with either schistose or stretched metamorphic texture. Cryptocrystalline quartz is also multiple-crystal and consists of both chert and chalcedony.

Feldspar is divided into potassium and plagioclase varieties. Potassium feldspar types observed are microcline, orthoclase, and perthite. Due to alteration and the lack of properly oriented grains no attempt was made to further classify the plagioclase feldspars.

Rock fragment interpretation in sediments is difficult and fragments can be easily misidentified. Identification of rock fragments in the samples is only preliminary and is based largely on textural characteristics. Rock fragments have been divided into the following varieties: volcanic igneous, plutonic igneous, metamorphic, sedimentary, unknown altered, and deformed. No attempt has been made to classify the igneous rock fragments but preliminary observations do suggest an intermediate to acidic composition. Metamorphic rock fragments observed are largely schistose but nothing definite can be said about their metamorphic grade. Sedimentary rock fragments are more easily recognizable with silicified limestone, lime mudstone, siltstone, and claystone fragments identified. Unknown rock fragments are considered to be any grain that is identifiable as a rock fragment, but due to alteration its exact origin is questionable. Deformed rock fragments are any grain that is identifiable as a rock fragment but that has been deformed to some degree forming what Dickinson (1970) refers to as pseudomatrix. Even though these fragments are often deformed almost beyond recognition, they still should be considered part of the original framework.

Accessory minerals identified in order of decreasing abundance are biotite, muscovite, tourmaline, zircon, apatite, iron-titanium oxides, garnet, and sphene.

Nonframework constituents are composed of cement, matrix, and miscellaneous alteration products. According to this study, cement is considered to be any chemically precipitated mineral material. The following cements have been identified in the measured section samples: silica in the form of quartz overgrowths, carbonate in the form of calcite, kaolinite, barite, pyrite, ferric oxide, and ferric oxyhydroxide.

Matrix material observed consists of undifferentiated mixtures of one or more of the following: detrital and authigenic clay, silt, lime mud, and organic material. No attempt was made to further divide matrix material.

No detailed work on alteration products was done for this study. Alteration products that have been identified are sericite from altering plagioclase feldspar, ferric oxide and oxyhydroxides from altering iron-titanium oxides and lithic fragments, and leucoxene from altering iron-titanium oxides.

Even though porosity values obtained by point counting can be imprecise (Halley, 1978), no other method for porosity estimation on the samples was easily available. Thus, porosity values obtained from this study should only be considered as rough approximation. Most of the porosity observed is primary interparticle but some secondary porosity is also present.

Figures 4, 5, and 6 are computer-generated quartz-feldspar-lithic fragment ternary classification diagrams (Folk, 1974) of all Brushy Basin, Westwater Canyon, and Recapture samples, respectively, for the four measured sections. Major framework constituents, excluding accessory minerals, were recalculated to 100 percent and allotted to the following poles:

Q-pole: Monocrystalline quartz, polycrystalline quartz and metamorphic quartz.
F-pole: Plagioclase feldspar, potassium feldspar plus gneissic and granitic lithic fragments.
L-pole: All other lithic fragments including cryptocrystalline quartz.

Few Brushy Basin samples were examined and they show a diverse composition. Most Westwater Canyon samples are either subarkoses or lithic arkoses. Core samples from the Westwater Canyon are more feldspathic, with most being either arkoses or lithic arkoses (Steele, 1984). This difference between surface and subsurface samples is probably due to feldspar destruction as a result of surface weathering. Most Recapture samples are subarkoses and are similar to the Recapture core samples (Steele, 1984).

Composition plots (figs. 4-6) suggest some compositional differences between the three Morrison members and the surface and subsurface. The reasons for these differences are not yet entirely understood and more work needs to be done on this aspect of the petrology.

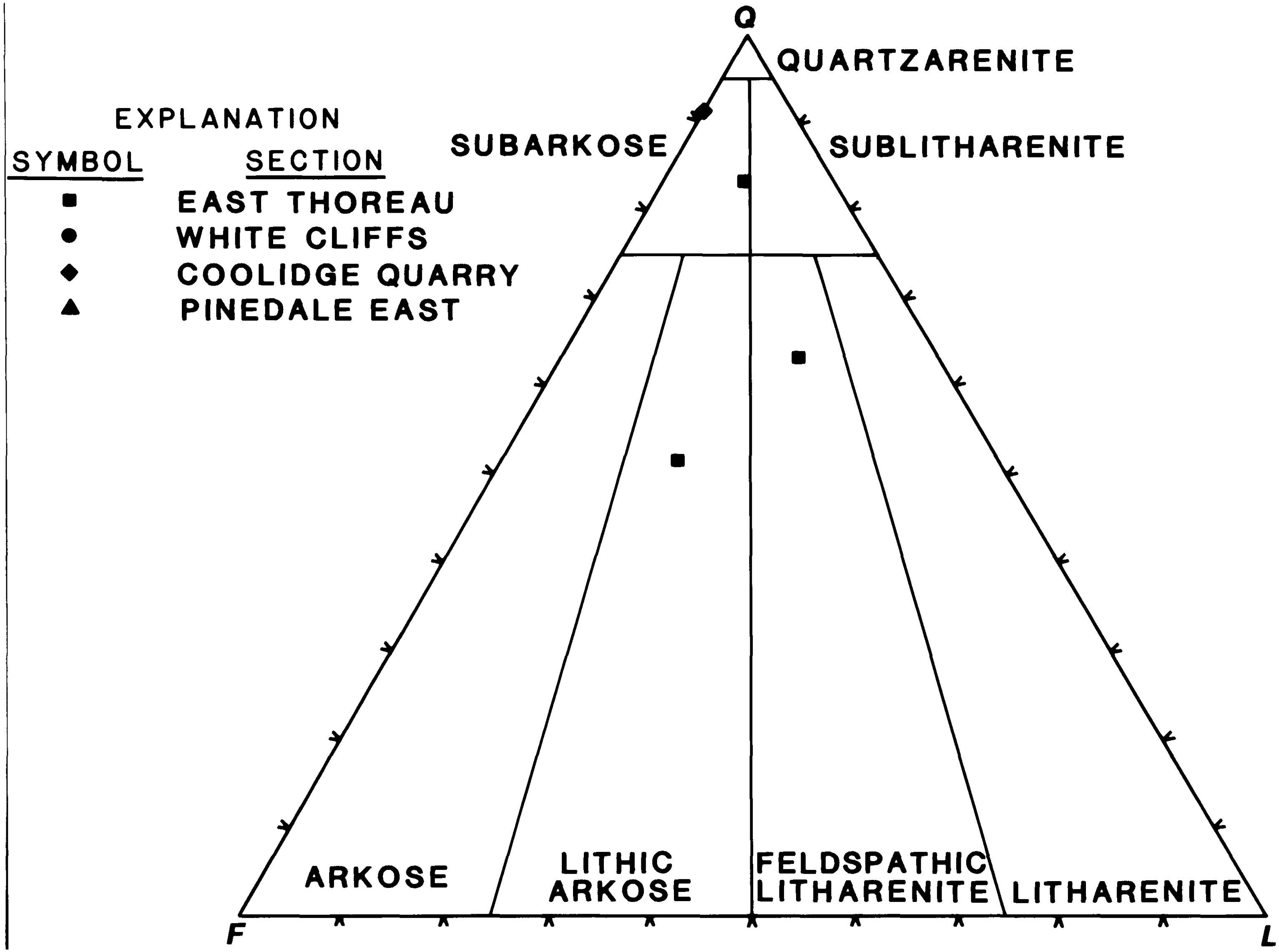


Figure 4.--Quartz-feldspar-lithic fragment ternary diagram, samples from the Brushy Basin Member of the Morrison Formation (after Folk, 1974).

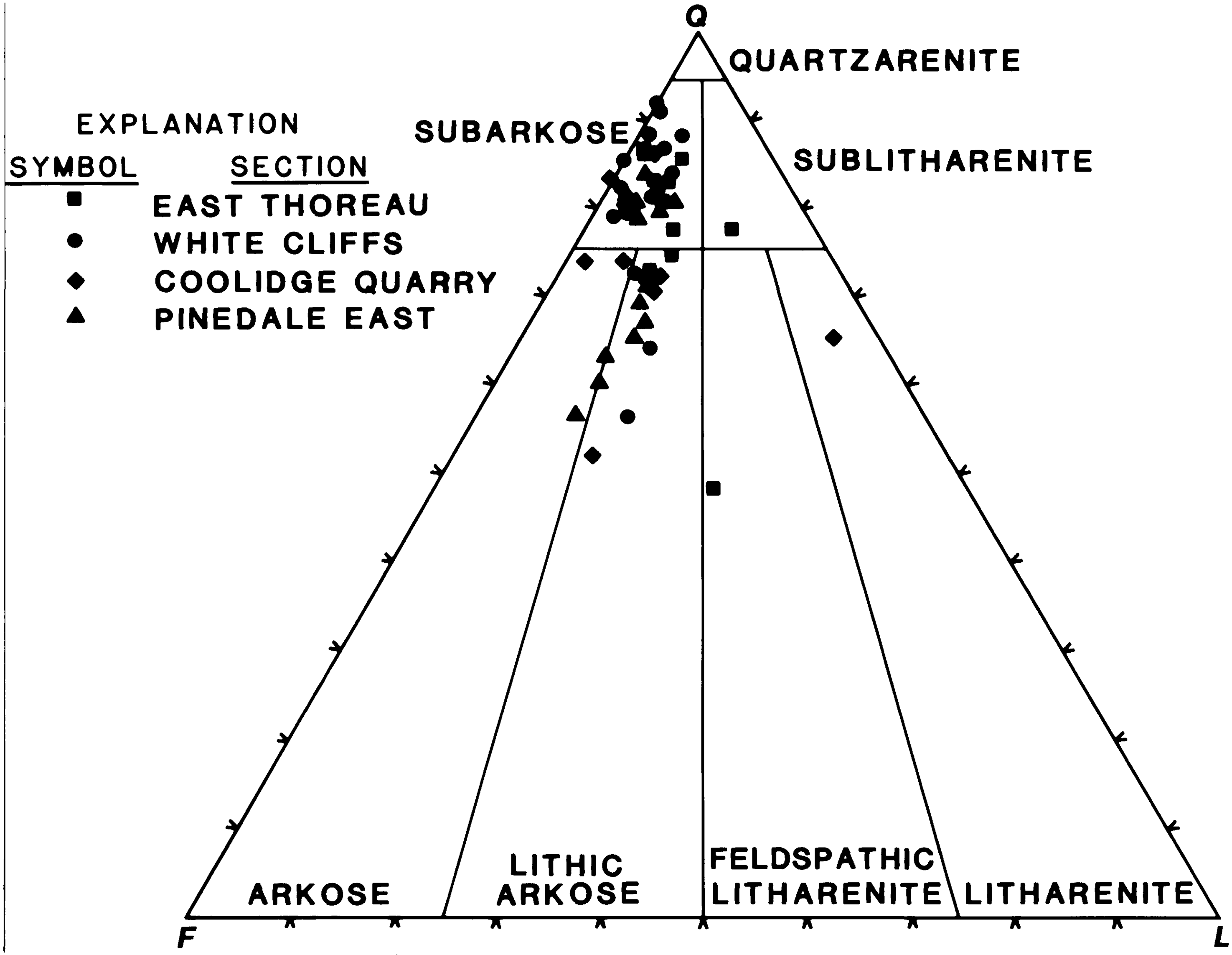


Figure 5.--Quartz-feldspar-lithic fragment ternary diagram, samples from the Westwater Canyon Member of the Morrison Formation (after Folk, 1974).

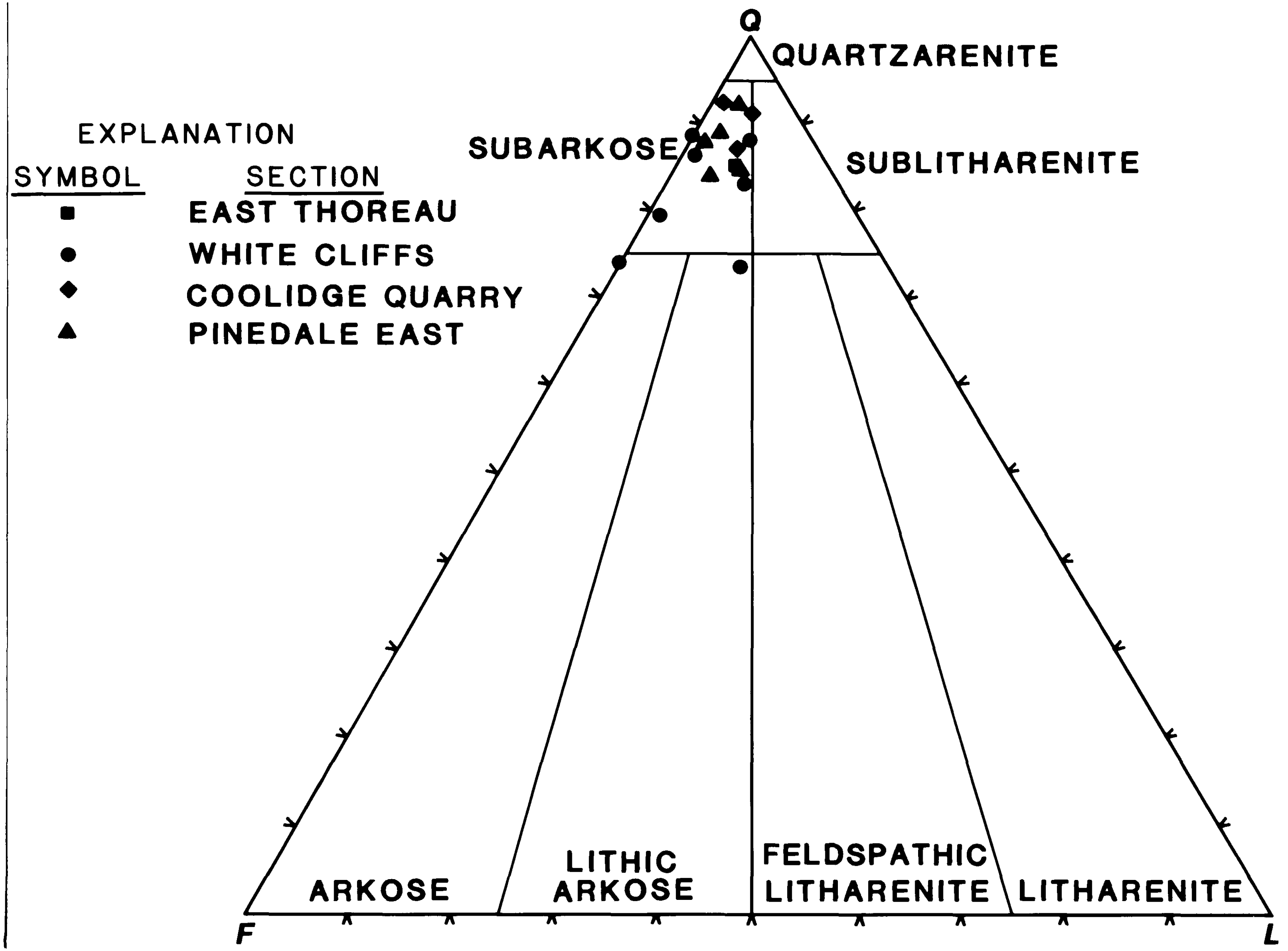


Figure 6.--Quartz-feldspar-lithic fragment ternary diagram, samples from the Recapture Member of the Morrison Formation (after Folk, 1974).

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APPENDIX I

Explanation of computer-generated tables 2-5.
Column no.

1. Sample depth in feet
2. Mean grain size (phi units)
3. Sorting index (phi standard deviation)
4. Total quartz (columns 5-8)
5. Monocrystalline quartz
6. Polycrystalline quartz
7. Cryptocrystalline quartz
8. Metamorphic quartz
9. Total feldspar (columns 10-11)
10. Plagioclase feldspar
11. Potassium feldspar
12. Sample depth in feet
13. Total rock fragments (columns 14-18)
14. Volcanic igneous
15. Plutonic igneous
16. Metamorphic
17. Sedimentary
18. Unknown altered and deformed
19. Accessory minerals
20. Total framework (columns 4, 9, 13 and 19)
21. Sample depth in feet
22. Matrix
23. Total cement (columns 24-31)
24. Silica
25. Carbonate
26. Kaolinite
27. Barite
28. Anhydrite
29. Authigenic potassium feldspar
30. Pyrite
31. Other cements
32. Sample depth in feet
33. Total alteration products
34. Total nonframework (columns 22, 23, 33)
35. Porosity

NOTE: (1) All compositional values are volume percentages.
(2) 0.00 = not observed.
(3) Any value in hundredths place represents trace quantity.
(4) Sample depth is footage from top of measured section.

SAMPLE DEPTH (FEET)	PHI MEAN	SORTING INDEX (PHI)	TOTAL QUARTZ	MONOXTAL QUARTZ	POLYXTAL QUARTZ	CRYPTOXTAL QUARTZ	METAMORPHIC QUARTZ	TOTAL FELDSPAR	PLAGIOCLASE	POTASSIUM FELDSPAR	FORMATION MEMBER
					WHITE CLIFFS						
15.0	2.40	0.61	71.91	66.20	3.70	0.01	2.00	9.00	0.30	8.70	WESTWATER CANYON MEMBER
17.0	1.0[illegible]	1.08	61.40	53.40	5.00	0.30	2.70	12.60	0.30	12.30	
35.5	1.38	0.86	65.30	57.30	4.30	2.00	1.70	10.71	0.01	10.70	
45.0	1.09	0.68	57.70	52.00	2.70	0.70	2.30	11.00	0.00	11.00	
60.0	1.95	0.67	56.81	52.40	3.70	0.01	0.70	5.30	0.00	5.30	
71.0	1.4	0.84	66.00	62.70	2.00	0.00	1.30	5.70	0.00	5.70	
88.0	1.77	0.76	65.00	60.00	1.70	0.30	3.00	5.71	0.01	5.70	
97.5	0.95	0.80	40.00	29.00	7.00	1.00	3.00	14.00	0.00	14.00	
115.0	4.8[illegible]	0.73	32.00	31.00	1.00	0.00	0.00	5.50	0.00	5.50	
120.0	3.29	0.80	47.21	45.60	1.30	0.01	0.30	9.60	0.00	9.60	
139.0	2.11	0.56	67.70	64.80	1.30	0.30	1.30	8.00	0.30	7.70	
154.0	2.91	0.94	59.21	56.50	1.70	0.01	1.00	11.60	0.00	11.60	
165.0	1.66	0.63	64.10	59.40	2.70	0.00	2.00	7.70	1.00	6.70	
188.5	0.56	0.94	49.20	42.40	2.80	2.00	2.00	15.20	2.00	13.20	
205.5	2.19	0.97	57.10	53.70	1.00	0.70	1.70	13.30	2.00	11.30	
209.5	3.52	0.72	26.00	24.00	1.00	0.30	0.70	6.31	0.01	6.30	RECAPTURE MEMBER
221.5	3.3[illegible]	0.78	56.41	55.00	0.70	0.01	0.70	7.31	0.01	7.30	
243.0	3.27	0.87	36.11	35.80	0.00	0.01	0.30	3.90	0.30	3.60	
268.5	2.87	0.76	44.00	41.40	1.30	0.00	1.30	8.61	0.01	8.60	
277.0	3.57	0.60	34.10	32.70	0.70	0.00	0.70	11.60	0.30	11.30	
345.0	1.75	0.48	58.31	55.90	0.70	0.01	1.70	4.00	0.00	4.00	
368.0	2.47	0.54	73.60	68.90	1.70	0.30	2.70	10.40	0.70	9.70	
386.5	2.91	0.58	69.41	66.10	1.30	0.01	2.00	4.30	0.30	4.00	

TABLE 2.--Computer-generated table of selected textural and compositional data from the Upper Jurassic Morrison Formation, White Cliffs measured section, McKinley County, New Mexico.

SAMPLE DEPTH (FEET)	TOTAL ROCK FRAGS	VOLCANIC IGNEOUS	PLUTONIC IGNEOUS	META-MORPHIC	SEDIMENTARY	UNKNOWN ALT & DEFM	ACCESSORY MINERALS	TOTAL FRAMEWORK	FORMATION MEMBER
					WHITE CLIFFS				
15.0	2.7	0.01	0.00	0.00	0.00	0.70	0.02	81.63	WESTWATER CANYON MEMBER
17.0	3.01	1.00	1.70	0.00	0.01	0.30	0.02	77.02	
35.5	1.71	0.30	0.01	0.00	0.00	1.40	0.01	77.71	
45.0	2.61	1.00	1.00	0.01	0.00	0.60	0.01	71.31	
60.0	0.31	0.01	0.00	0.00	0.00	0.30	0.01	62.42	
71.0	4.31	0.01	0.00	0.30	0.00	0.00	0.01	72.01	
83.0	2.70	1.70	0.00	0.00	0.00	1.00	0.01	73.41	
97.5	15.00	5.00	5.00	1.00	4.00	0.00	0.00	69.00	
115.0	0.00	0.00	0.00	0.00	0.00	0.00	1.01	38.51	
120.0	3.67	0.30	0.00	0.00	0.00	0.30	0.02	57.43	
139.0	2.01	2.00	0.01	0.00	0.00	0.00	0.02	77.72	
154.0	3.60	0.30	1.30	0.00	0.00	0.00	0.71	75.12	
165.0	4.71	2.70	.70	0.00	0.01	1.30	0.02	76.52	
188.5	9.21	5.20	1.60	0.00	0.01	2.40	0.00	73.60	
206.5	7.31	3.70	2.30	0.00	0.01	1.30	0.02	77.72	
209.5	0.01	0.01	0.00	0.00	0.00	0.00	0.01	32.32	RECAPTURE MEMBER
231.5	6.03	0.01	0.00	0.01	0.01	0.00	0.01	63.73	
243.0	3.70	0.30	0.00	0.00	3.00	0.00	0.01	43.32	
258.5	7.3	3.30	0.00	0.00	2.00	2.00	0.02	59.92	
277.0	0.3	0.00	0.30	0.00	0.00	0.00	0.02	46.02	
346.0	4.00	3.70	0.00	0.00	0.00	0.30	0.00	55.31	
368.0	0.71	0.70	0.00	0.00	0.00	0.00	0.01	94.71	
385.5	0.30	0.30	0.30	0.00	0.00	0.00	0.00	74.01	

TABLE 2.--(continued)

SAMPLE DEPTH (FEET)	MATRIX	TOTAL CEMENTS	SILICA	CARBONATE	KAOLINITE	BARITE	ANHYDRITE	AUTHIGENIC POTASSIUM FELDSPAR	PYRITE	OTHER CEMENTS	FORMATION MEMBER
WHITE CLIFFS											
15.0	4.70	6.70	0.01	0.00	6.00	0.70	0.00	0.00	0.00	0.00	WESTWATER CANYON MEMBER
17.0	8.70	9.30	0.01	0.00	9.30	0.00	0.00	0.00	0.00	0.00	
35.5	9.00	9.00	0.00	0.00	9.00	0.00	0.00	0.00	0.00	0.00	
46.0	12.30	13.70	0.01	0.00	13.70	0.00	0.00	0.00	0.00	0.00	
60.0	33.30	7.30	0.01	0.00	7.30	0.00	0.00	0.00	0.00	0.00	
71.0	9.00	15.70	0.70	0.00	14.30	0.70	0.00	0.00	0.00	0.00	
83.0	12.30	5.30	0.30	0.01	5.00	0.00	0.00	0.00	0.00	0.00	
97.5	14.00	11.00	0.01	3.00	8.00	0.00	0.00	0.00	0.00	0.00	
115.0	51.50	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
120.0	42.00	0.30	0.01	0.00	0.30	0.00	0.00	0.00	0.00	0.00	
139.0	7.30	1.70	0.01	0.00	1.70	0.00	0.00	0.00	0.00	0.00	
154.0	21.3	1.30	0.70	0.01	0.30	0.30	0.00	0.00	0.00	0.00	
155.0	11.30	0.60	0.01	0.30	0.30	0.00	0.00	0.00	0.00	0.00	
168.5	18.40	2.80	2.80	0.00	0.01	0.00	0.00	0.00	0.00	0.00	
205.5	8.30	7.30	0.01	5.30	2.00	0.00	0.00	0.00	0.00	0.00	
209.5	67.70	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	RECAPTURE MEMBER
231.5	6.0	30.00	0.00	30.00	0.01	0.00	0.00	0.00	0.00	0.00	
243.0	56.00	1.70	.00	1.70	0.00	0.00	0.00	0.00	0.00	0.00	
263.5	6.60	33.40	0.01	32.70	0.70	0.00	0.00	0.00	0.00	0.00	
277.0	53.70	0.30	0.00	0.30	0.01	0.00	0.00	0.00	0.00	0.00	
345.0	0.30	33.00	0.00	33.00	0.00	0.00	0.00	0.00	0.00	0.00	
348.0	11.0	4.00	0.01	4.00	0.00	0.00	0.00	0.00	0.00	0.00	
365.5	20.30	0.70	0.01	0.70	0.00	0.00	0.00	0.00	0.00	0.00	

TABLE 2.--(continued)

SAMPLE DEPTH (FEET)	TOTAL ALTERATION PRODUCTS	TOTAL NON-FRAMEWORK	POROSITY	FORMATION MEMBER
				WHITE CLIFFS
15.0	0.01	11.41	7.00	WESTWATER CANYON MEMBER
17.0	0.01	18.01	5.00	
35.5	0.01	19.01	4.30	
46.0	0.01	26.01	2.70	
50.0	0.01	37.51	6.00	
71.0	0.30	25.00	3.00	
83.0	0.60	18.20	9.70	
97.5	0.01	27.01	4.00	
115.0	10.01	61.51	1.00	
120.0	0.70	42.60	0.90	
139.0	1.01	9.31	13.30	
154.0	0.01	22.61	6.30	
165.0	1.30	13.20	10.30	
183.5	1.60	22.90	3.60	
215.5	1.79	16.60	5.70	
229.5	0.01	67.72	3.00	RECAPTURE MEMBER
231.5	0.01	36.91	1.30	
243.0	0.01	56.71	0.70	
248.5	0.79	46.10	0.00	
277.0	0.01	54.01	1.70	
349.0	0.7	33.70	0.00	
368.0	0.01	15.91	1.30	
385.5	0.01	21.01	5.00	

TABLE 2.--(continued)

SAMPLE DEPTH (FEET)	PHI MEAN	SORTING INDEX (PHI)	TOTAL QUARTZ	MONOXTAL QUARTZ	POLYXTAL QUARTZ	CRYPTOXTAL QUARTZ	METAMORPHIC QUARTZ	TOTAL FELDSPAR	PLAGIOCLASE	POTASSIUM FELDSPAR	FORMATION MEMBER
PINEDALE EAST											
65.5	1.60	0.64	46.41	40.10	5.50	1.30	0.01	13.70	4.70	9.00	WESTWATER CANYON MEMBER
79.0	1.26	0.75	45.40	40.40	4.00	0.30	0.70	16.60	7.30	9.30	
101.5	0.77	0.57	42.50	31.50	9.50	1.00	0.50	13.50	1.00	12.50	
130.0	1.5?	0.73	54.01	49.00	3.30	0.01	1.70	8.30	3.30	5.00	
145.5	1.03	0.64	39.30	30.40	5.30	0.30	1.30	18.01	4.70	13.31	
160.5	2.00	0.66	48.40	45.00	1.70	0.70	1.00	12.60	3.00	9.60	
174.5	2.55	0.65	57.80	55.10	2.00	0.00	0.70	11.60	2.30	9.30	
196.5	0.45	0.65	62.90	57.20	1.70	0.00	1.00	11.10	2.70	8.40	
204.5	1.62	0.69	54.01	51.00	2.50	0.01	0.50	13.51	4.00	9.51	
216.0	1.71	0.85	51.41	46.40	4.00	0.01	1.00	13.31	3.00	10.31	
225.0	1.97	0.74	54.11	52.50	1.30	0.01	0.30	8.30	0.70	7.60	
239.0	0.47	0.64	64.71	62.30	1.70	0.01	0.70	9.00	1.70	7.30	
250.0	2.0?	0.64	55.10	56.20	1.30	0.30	1.30	11.30	4.00	7.30	
267.0	1.57	0.87	43.71	42.70	0.70	0.01	0.30	10.30	2.70	7.60	
278.0	0.45	0.65	56.50	54.90	0.30	0.30	1.00	10.30	3.00	7.30	
298.5	1.61	0.72	55.60	52.30	3.00	0.30	0.00	7.70	2.70	5.00	
303.8	2.61	0.63	65.51	65.10	0.70	0.01	0.70	7.90	0.30	7.60	RECAPTURE MEMBER
320.0	2.29	0.59	65.00	63.30	0.30	0.70	0.70	6.60	0.30	6.30	
348.0	1.60	0.60	68.50	65.10	1.70	1.00	0.70	3.60	1.00	2.60	
367.5	2.35	0.41	54.00	51.10	1.30	0.30	1.30	5.70	0.70	5.00	
385.5	1.9?	0.69	59.11	55.30	2.00	0.01	1.30	8.30	0.00	8.30	

TABLE 3.--Computer-generated table of selected textural and compositional data from the Upper Jurassic Morrison Formation, Pinedale East measured section, McKinley County, New Mexico.

SAMPLE DEPTH (FEET)	TOTAL ROCK FRAGS	VOLCANIC IGNEOUS	PLUTONIC IGNEOUS	META-MORPHIC	SEDIMENTARY	UNKNOWN ALT & DEFM	ACCESSORY MINERALS	TOTAL FRAMEWORK	FORMATION MEMBER
PINEDALE EAST									
[illegible]6.5	[illegible].3	4.3[illegible]	0.30	0.00	0.00	1.70	0.02	[illegible].42	WESTWATER CANYON MEMBER
89.[illegible]	9.3[illegible]	6.00	3.00	0.00	0.00	0.30	0.01	71.31	
1[illegible]1.5	13.00	5.[illegible]	7.00	0.00	0.00	0.50	0.01	6[illegible].01	
130.0	5.[illegible]	3.30	1.00	0.00	0.00	0.70	0.02	67.33	
145.5	11.70	6.40	5.30	0.00	0.00	0.00	0.02	69.02	
160.5	7.3[illegible]	5.30	1.70	0.00	0.00	0.30	0.02	6[illegible].32	
174.5	4.3[illegible]	3.00	1.30	0.00	0.00	0.00	0.02	72.72	
195.5	[illegible].6[illegible]	[illegible].00	1.30	0.00	0.00	0.30	0.01	74.61	
214.5	8.5[illegible]	4.50	1.00	.50	0.00	1.00	0.02	76.03	
216.[illegible]	12.34	8.31	4.00	0.01	0.01	0.01	0.02	77.03	
225.0	2.30	2.00	[illegible].30	.00	0.00	0.00	0.02	64.73	
239.[illegible]	1.30	1.30	0.00	0.00	0.00	0.00	0.02	75.03	
250.0	2.70	2.00	0.70	0.00	0.00	0.00	0.01	73.11	
267.[illegible]	[illegible].6[illegible]	5.30	1.30	0.00	0.00	0.00	0.31	6[illegible].92	
273.0	2.00	1.00	1.00	0.00	0.00	0.00	0.01	68.81	
[illegible]98.5	5.4	3.70	[illegible].70	[illegible].30	0.00	0.70	0.02	68.72	
[illegible]3.8	1.3[illegible]	1.30	0.00	0.00	0.00	0.00	0.02	7[illegible].73	RECAPTURE MEMBER
320.0	1.01	1.[illegible]	0.00	0.00	0.01	0.00	0.01	72.61	
345.[illegible]	1.3[illegible]	1.00	[illegible].30	1.00	0.00	0.00	0.01	73.41	
367.8	4.[illegible]	2.30	[illegible]	.20	1.00	0.70	0.31	64.01	
3[illegible]5.8	3.00	2.70	0.70	.00	0.00	0.00	0.00	70.41	

TABLE 3.--(continued)

SAMPLE DEPTH (FEET)	MATRIX	TOTAL CEMENTS	SILICA	CARBONATE	KAOLINITE	BARITE	ANHYDRITE	AUTHIGENIC POTASSIUM FELDSPAR	PYRITE	OTHER CEMENTS	FORMATION MEMBER
					PINEDALE EAST						
66.5	3.00	5.30	0.01	0.00	5.30	0.00	0.00	0.00	0.00	0.00	WESTWATER CANYON MEMBER
89.0	5.7	5.00	.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	
111.5	1.00	7.00	.00	0.00	7.00	0.00	0.00	0.00	0.00	0.00	
130.0	17.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
145.5	27.70	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
160.5	6.30	0.70	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	
174.5	2.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
195.5	1.30	0.71	0.01	0.00	0.70	0.00	0.00	0.00	0.00	0.00	
214.5	2.50	7.00	0.00	0.00	7.00	0.00	0.00	0.00	0.00	0.00	
215.0	4.7	3.01	0.01	0.00	3.00	0.00	0.00	0.00	0.00	0.00	
225.0	27.30	1.60	0.30	1.30	0.00	0.00	0.00	0.00	0.00	0.00	
239.0	0.00	1.00	0.01	0.00	1.00	0.00	0.00	0.00	0.00	0.00	
253.0	1.30	2.30	0.30	0.00	2.00	0.00	0.00	0.00	0.00	0.00	
267.0	0.70	36.70	0.00	34.00	2.70	0.00	0.00	0.00	0.00	0.00	
279.0	2.30	0.60	0.30	0.00	0.30	0.00	0.00	0.00	0.00	0.00	
298.5	5.70	24.00	0.01	23.70	0.30	0.00	0.00	0.00	0.00	0.00	
313.5	1.30	4.30	0.01	0.00	4.30	0.00	0.00	0.00	0.00	0.00	RECAPTURE MEMBER
320.0	0.30	21.70	0.00	19.30	0.70	1.70	0.00	0.00	0.00	0.00	
343.0	0.70	21.60	0.00	19.00	0.30	2.30	0.00	0.00	0.00	0.00	
367.0	0.00	35.30	0.00	35.30	0.00	0.00	0.00	0.00	0.00	0.00	
395.8	0.00	24.30	0.00	24.30	0.00	0.00	0.00	0.00	0.00	0.00	

TABLE 3.--(continued)

SAMPLE DEPTH (FEET)	TOTAL ALTERATION PRODUCTS	TOTAL NON-FRAMEWORK	POROSITY	FORMATION MEMBER
				PINEDALE EAST
66.5	3.00	11.30	22.30	WESTWATER CANYON MEMBER
[illegible]9.[illegible]	2.70	13.[illegible]0	15.70	
111.5	7.60	15.[illegible]0	16.00	
130.0	1.79	18.71	14.00	
145.5	1.00	24.71	2.30	
160.5	1.20	9.00	23.70	
174.5	4.3[illegible]	6.31	21.00	
195.5	0.70	2.70	22.70	
204.5	2.50	12.[illegible]0	12.[illegible]0	
215.0	1.30	9.00	14.00	
225.0	0.70	29.60	5.70	
239.0	0.31	1.30	13.70	
250.0	1.35	4.90	22.00	
267.0	1.70	39.10	3.00	
278.0	1.30	4.70	27.00	
298.5	0.39	30.90	1.30	
303.8	0.70	6.70	18.00	RECAPTURE MEMBER
320.0	0.01	21.71	5.70	
348.0	0.30	21.40	4.70	
367.8	0.70	36.00	1.00	
395.8	0.00	26.30	3.70	

TABLE 3.--(continued)

SAMPLE DEPTH (FEET)	PHI MEAN	SORTING INDEX (PHI)	TOTAL QUARTZ	MONOXTAL QUARTZ	POLYXTAL QUARTZ	CRYPTOXTAL QUARTZ	METAMORPHIC QUARTZ	TOTAL FELDSPAR	PLAGIOCLASE	POTASSIUM FELDSPAR	FORMATION MEMBER
COOLIDGE QUARRY											
44.5	2.61	0.58	38.[illegible]0	34.90	0.00	0.00	0.00	4.00	0.00	4.00	BRUSHY BASIN MEMBER
115.5	0.75	0.99	41.00	33.00	5.00	2.00	1.00	12.00	1.00	11.00	WESTWATER CANYON MEMBER
159.0	1.41	0.63	58.91	57.50	0.00	0.01	1.30	12.00	2.00	10.00	
220.0	0.95	0.62	52.21	45.10	4.60	0.01	2.30	10.20	2.20	8.00	
253.5	2.15	0.73	64.10	60.93	0.00	0.60	0.60	8.50	1.70	6.80	
272.0	0.97	0.64	58.00	49.90	4.70	0.70	2.70	13.40	0.70	12.70	
278.0	0.16	0.71	53.00	51.50	0.50	0.00	1.00	13.51	1.00	12.51	
305.0	2.47	0.46	61.40	57.40	2.00	0.00	2.00	12.60	1.30	11.30	
325.5	1.56	0.58	60.70	58.00	2.50	0.00	0.70	19.30	3.30	16.00	
373.0	0.43	1.37	56.30	41.40	1.30	12.30	2.30	3.00	0.30	2.70	
376.5	0.53	0.64	55.00	51.70	1.30	1.00	1.00	5.01	0.01	5.00	RECAPTURE MEMBER
379.0	2.96	0.77	72.00	67.40	3.30	0.30	1.00	5.00	0.00	5.00	
421.0	2.27	0.79	62.10	56.60	1.30	1.80	0.40	3.00	0.00	3.00	

TABLE 4.--Computer-generated table of selected textural and compositional data from the Upper Jurassic Morrison Formation, Coolidge Quarry measured section, McKinley County, New Mexico.

SAMPLE DEPTH (FEET)	TOTAL ROCK FRAGS	VOLCANIC IGNEOUS	PLUTONIC IGNEOUS	META-MORPHIC	SEDIMENTARY	UNKNOWN ALT & DEFM	ACCESSORY MINERALS	TOTAL FRAMEWORK	FORMATION MEMBER
				COOLIDGE QUARRY					BRUSHY BASIN MEMBER
44.5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	42.01	
115.5	22.00	6.00	14.00	0.00	2.00	0.00	0.00	75.00	WESTWATER CANYON MEMBER
159.0	10.75	8.00	2.70	0.00	0.00	0.00	0.00	81.51	
220.0	8.00	3.40	4.00	0.00	0.00	0.60	0.00	70.21	
253.5	1.21	0.40	0.01	0.00	0.00	0.60	0.02	73.82	
272.0	9.31	6.00	2.00	0.00	0.01	1.30	0.00	80.70	
278.0	2.01	2.00	0.00	0.00	0.01	0.00	0.00	76.50	
305.0	0.01	0.01	0.00	0.00	0.00	0.00	0.01	74.02	
325.5	2.01	1.30	0.70	0.00	0.01	0.00	0.01	82.01	
373.0	8.00	4.30	0.01	0.01	3.70	0.00	0.00	57.30	
376.5	2.31	1.70	0.00	0.00	0.01	0.60	0.01	62.31	RECAPTURE MEMBER
389.0	0.71	0.00	0.00	0.00	0.00	0.70	0.01	77.71	
431.0	1.10	0.40	0.00	[illegible]	0.40	0.30	0.01	66.21	

TABLE 4.--(continued)

SAMPLE DEPTH (FEET)	MATRIX	TOTAL CEMENTS	SILICA	CARBONATE	KAOLINITE	BARITE	ANHYDRITE	AUTHIGENIC POTASSIUM FELDSPAR	PYRITE	OTHER CEMENTS	FORMATION MEMBER
					COOLIDGE QUARRY						**BRUSHY BASIN MEMBER**
44.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	0.00	0.00	0.00	0.00	
115.[illegible]	6.[illegible]	[illegible]	[illegible]	4.[illegible]	0.00	0.00	0.00	0.00	0.00	0.00	**WESTWATER CANYON MEMBER**
199.0	5.3[illegible]	4.6[illegible]	1.30	0.00	3.30	0.00	0.00	0.00	0.00	0.00	
220.0	4.6	7.4[illegible]	0.00	[illegible]	7.40	0.00	0.00	0.00	0.00	0.00	
253.5	1.7[illegible]	9.17	7.40	0.00	1.70	0.00	0.00	0.00	0.00	0.00	
274.0	4.[illegible]	4.71	0.01	0.00	4.70	0.00	0.00	0.00	0.00	0.00	
278.[illegible]	2.3[illegible]	4.5[illegible]	0.01	0.05	4.50	0.00	0.00	0.00	0.00	0.00	
305.0	[illegible].7[illegible]	5.40	4.70	0.00	0.70	0.00	0.00	0.00	0.00	0.00	
325.5	3.3	4.[illegible]	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	
373.[illegible]	0.7[illegible]	32.[illegible]	0.01	31.3[illegible]	0.70	0.00	0.00	0.00	0.00	0.00	
376.5	1.7[illegible]	36.00	0.01	36.00	0.00	0.00	0.00	0.00	0.00	0.00	**RECAPTURE MEMBER**
389.0	1.3	21.00	0.00	21.00	0.00	0.00	0.00	0.00	0.00	0.00	
431.0	[illegible].8[illegible]	33.00	0.00	33.00	0.00	0.00	0.00	0.00	0.00	0.00	

TABLE 4.--(continued)

SAMPLE DEPTH (FEET)	TOTAL ALTERATION PRODUCTS	TOTAL NON-FRAMEWORK	POROSITY	FORMATION MEMBER
				COOLIDGE QUARRY
44.5	0.01	58.01	0.00	BRUSHY BASIN MEMBER
115.5	3.00	18.00	7.00	WESTWATER CANYON MEMBER
149.0	1.30	11.00	7.30	
220.0	4.20	17.00	12.60	
253.5	2.80	13.60	12.60	
272.0	1.30	10.00	9.30	
278.0	2.50	9.00	12.00	
305.0	2.60	9.70	17.30	
325.5	0.70	8.00	15.00	
373.0	0.91	32.71	1.00	
376.5	0.00	37.70	1.00	RECAPTURE MEMBER
389.0	0.01	22.31	1.00	
401.0	0.01	33.01	0.00	

TABLE 4.--(continued)

SAMPLE DEPTH (FEET)	PHI MEAN	SORTING INDEX (PHI)	TOTAL QUARTZ	MONOXTAL QUARTZ	POLYXTAL QUARTZ	CRYPTOXTAL QUARTZ	METAMORPHIC QUARTZ	TOTAL FELDSPAR	PLAGIOCLASE	POTASSIUM FELDSPAR	FORMATION MEMBER
						EAST THOREAU					BRUSHY BASIN MEMBER
32.5	2.37	0.76	46.40	43.10	2.00	0.00	1.30	9.60	0.00	9.60	
51.5	1.27	0.79	34.30	30.60	2.00	0.00	1.70	17.00	4.00	13.00	
71.0	3.31	0.92	34.70	32.40	1.00	0.30	1.00	3.61	0.30	3.31	
111.0	2.15	1.12	48.71	45.40	2.00	0.01	1.30	7.00	0.70	6.30	WESTWATER CANYON MEMBER
131.5	1.20	0.77	58.60	54.60	2.00	0.00	2.00	12.30	1.00	11.30	
152.5	2.21	0.64	71.80	68.10	1.70	0.00	2.00	10.00	1.30	8.70	
167.0	0.93	1.16	40.10	37.40	1.70	0.30	0.70	16.60	2.30	14.30	
186.0	1.74	0.60	68.21	64.20	1.30	0.01	2.70	9.70	3.00	6.70	
213.0	2.72	0.69	60.00	56.00	1.70	0.00	2.30	12.01	0.30	11.71	
228.5	2.03	0.61	73.41	69.40	1.70	0.01	2.30	9.70	1.30	8.40	
239.0	2.80	0.74	70.51	67.50	1.70	0.01	1.30	9.90	1.30	8.60	
261.5	2.41	0.75	66.70	62.30	2.70	0.00	1.70	7.70	0.30	7.40	
276.0	2.76	0.70	64.60	60.60	1.30	0.00	2.70	10.71	0.01	10.70	
292.0	1.68	0.70	63.61	62.20	0.70	0.01	0.70	4.70	0.00	4.70	
306.5	1.91	0.85	58.21	54.90	1.30	0.01	2.00	6.00	0.30	5.70	
321.5	2.61	0.58	56.90	54.20	0.70	0.30	1.70	6.01	0.00	6.01	RECAPTURE MEMBER

TABLE 5.--Computer-generated table of selected textural and composiyional data from the Upper Jurassic Morrison Formation, East Thoreau measured section, McKinley County, New Mexico.

SAMPLE DEPTH (FEET)	TOTAL ROCK FRAGS	VOLCANIC IGNEOUS	PLUTONIC IGNEOUS	META-MORPHIC	SEDIMENTARY	UNKNOWN ALT & DEFM	ACCESSORY MINERALS	TOTAL FRAMEWORK	FORMATION MEMBER
					EAST THOREAU				BRUSHY BASIN MEMBER
32.5	17.30	17.00	0.30	0.00	0.00	0.00	0.00	73.30	
51.5	15.01	11.30	3.70	0.00	0.01	0.00	0.00	66.30	
71.0	3.00	3.00	0.00	0.00	0.00	0.00	0.31	41.61	
111.0	7.00	5.30	1.00	0.70	0.00	0.00	0.01	62.72	WESTWATER CANYON MEMBER
131.5	9.70	7.00	2.70	0.00	0.00	0.00	0.00	80.60	
152.5	1.60	1.30	0.30	0.00	0.00	0.00	0.01	83.41	
167.0	25.70	22.00	3.70	0.00	0.00	0.00	0.00	82.40	
186.0	4.00	3.00	0.70	0.30	0.00	0.00	0.02	81.93	
213.0	8.00	7.70	0.30	0.00	0.00	0.00	0.30	80.30	
228.5	5.70	4.00	1.70	0.00	0.00	0.00	0.02	88.83	
239.0	4.30	4.30	0.00	0.00	0.00	0.00	0.02	84.73	
261.5	2.70	1.00	1.00	0.70	0.00	0.00	0.31	77.41	
276.0	4.70	4.70	0.00	0.00	0.00	0.00	0.02	80.02	
292.0	6.00	4.00	2.00	0.00	0.00	0.00	0.00	74.31	
306.5	10.70	10.70	0.00	0.00	0.00	0.00	0.00	74.91	
321.5	3.70	3.70	0.00	0.00	0.00	0.00	0.00	66.60	RECAPTURE MEMBER

TABLE 5.--(continued)

SAMPLE DEPTH (FEET)	MATRIX	TOTAL CEMENTS	SILICA	CARBONATE	KAOLINITE	BARITE	ANHYDRITE	AUTHIGENIC POTASSIUM FELDSPAR	PYRITE	OTHER CEMENTS	FORMATION MEMBER
					EAST THOREAU						
32.5	11.70	13.30	0.00	0.00	13.30	0.00	0.00	0.00	0.00	0.00	BRUSHY BASIN MEMBER
51.5	24.00	6.30	0.00	0.00	6.30	0.01	0.00	0.00	0.00	0.00	
71.0	2.70	55.70	0.00	55.70	0.00	0.00	0.00	0.00	0.00	0.00	
111.0	26.70	9.30	0.00	0.00	9.30	0.00	0.00	0.00	0.01	0.00	WESTWATER CANYON MEMBER
131.5	4.70	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
152.5	6.00	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
167.0	12.00	0.30	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	
186.0	3.00	0.70	0.01	0.70	0.01	0.00	0.00	0.00	0.00	0.00	
213.0	16.70	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
228.5	3.30	2.60	0.30	0.00	2.30	0.00	0.00	0.00	0.00	0.00	
239.0	10.30	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	
261.5	9.70	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	
276.0	7.30	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	
292.0	14.70	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	
306.5	7.70	8.70	0.00	6.00	2.70	0.01	0.00	0.00	0.00	0.00	
321.5	5.70	27.70	0.00	27.70	0.00	0.00	0.00	0.00	0.00	0.00	RECAPTURE MEMBER

TABLE 5.--(continued)

SAMPLE DEPTH (FEET)	TOTAL ALTERATION PRODUCTS	TOTAL NON-FRAMEWORK	POROSITY	FORMATION MEMBER
				EAST THOREAU
[illegible]2.[illegible]	[illegible].01	[illegible]5.01	[illegible].[illegible]0	BRUSHY BASIN MEMBER
[illegible]1.5	1.7[illegible]	32.[illegible]0	1.70	
71.0	0.11	58.41	0.00	
111.0	1.30	37.30	[illegible].00	WESTWATER CANYON MEMBER
131.5	1.70	[illegible].70	12.70	
152.5	1.00	7.30	[illegible].30	
1[illegible]7.[illegible]	1.00	13.30	4.30	
1[illegible]6.[illegible]	0.7[illegible]	4.46	13.70	
213.0	0.30	17.01	12.70	
22[illegible].[illegible]	1.3[illegible]	7.2[illegible]	4.[illegible]0	
239.0	[illegible].3[illegible]	1[illegible].61	4.70	
261.5	[illegible].6[illegible]	1[illegible].31	12.30	
27[illegible].[illegible]	[illegible].7	[illegible].61	12.[illegible]0	
2[illegible]2.[illegible]	1.[illegible]	15.71	1[illegible].[illegible]0	
3[illegible]5.5	[illegible].0[illegible]	16.40	[illegible].70	
321.5	0.01	33.41	[illegible].[illegible]0	RECAPTURE MEMBER

TABLE 5.--(continued)

APPENDIX II

Explanation of computer-generated vertical plots.
Column no.

1. Mean grain size (phi units)
2. Sorting index (phi standard deviation)
3. Total quartz (columns 4-7)
4. Monocrystalline quartz
5. Polycrystalline quartz
6. Cryptocrystalline quartz
7. Metamorphic quartz
8. Total feldspar (columns 8-9)
9. Plagioclase feldspar
10. Potassium feldspar
11. Total rock fragments (columns 11-15)
12. Volcanic igneous
13. Plutonic igneous
14. Metamorphic
15. Sedimentary
16. Unknown altered and deformed
17. Accessory minerals
18. Total framework (columns 3, 8, 11 and 16)
19. Matrix
20. Total cement
21. Silica
22. Carbonate
23. Kaolinite
24. Barite
25. Anhydrite
26. Authigenic potassium feldspar
27. Pyrite
28. Other cements
29. Total alteration products
30. Total nonframework (columns 19, 20, and 29)
31. Porosity

NOTE: (1) All compositional values are volume percentages.
(2) X = constituent observed (when against zero line observed as trace quantity)
(3) 0 = constituent not observed.
(4) + = value of constituent greater than maximum value on scale.