UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Petrographic Data From the Lower Cretaceous Blackleaf Formation and Lower Upper Cretaceous Frontier Formation (lower part) in Beaverhead and Madison Counties, Montana

By

T. S. Dyman[1]

Open-File Report 85-592

1985

[1]Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

INTRODUCTION

Twelve stratigraphic sections of the Albian Blackleaf Formation and the Cenomanian Frontier Formation (lower part) were measured as part of a larger study to understand the regional stratigraphy, sedimentology, and petrography of the Cretaceous sequence in the region (Dyman, Niblack, and Platt, 1984; Dyman, 1985). Cretaceous rocks in the region (fig. 1) lie along the east flank of the Pioneer Mountains north of Dillon (measured sections 1 and 2); along the south flank of McCartney Mountain (measured sections 3 and 4); south of Dillon along Grasshopper Creek (measured section 5); along the north flank of the Blacktail Range south of Dillon (measured section 6); along the southeast flank of the Snowcrest Range (measured sections 7 and 11); in the Gravelly Range (measured sections 8, 9, and 10); and in the Lima Peaks area south of Lima (measured section 12) (Ross, Andrews, and Witkind, 1955; Schwartz, 1972; Mann, 1954; Hadley, 1980). Equivalent strata in the Gallatin and Madison Ranges east of the study area and in northwest Wyoming were also studied and sampled.

Samples described here occur in strata that overlie older Mesozoic and Paleozoic sedimentary rocks and underlie the Upper Cretaceous Beaverhead Group (fig. 2). In descending order, the following 5 preliminary lithofacies units were identified for the lower Frontier and Blackleaf Formations:

Lithofacies unit number	
(5)	Frontier Formation--lower clastic lithofacies.
(4)	Blackleaf Formation--upper volcaniclastic lithofacies.
(3)	Blackleaf Formation--upper clastic lithofacies
(2)	Blackleaf Formation--lower mudstone-shale lithofacies.
(1)	Blackleaf Formation--lower transitional clastic lithofacies.

A detailed petrographic analysis of Blackleaf and Frontier Formations was conducted in order to (1) establish petrofacies for regional correlation, (2) analyze diagenetic changes, and (3) describe vertical and lateral variations in provenance.

Thin sections were prepared from 127 sandstone samples; all were stained for potassium feldspar. Modal and diagenetic analyses were made on 99 sections using more than 300 point counts per slide; the remainder were analyzed for diagenesis only. Data presented in this report summarize the results of thin-section examination of the sandstones studied. Analyses of these data will be published elsewhere.

Appendix 1 contains outcrop locality descriptions for the 18 measured sections and sample localities used in this study.

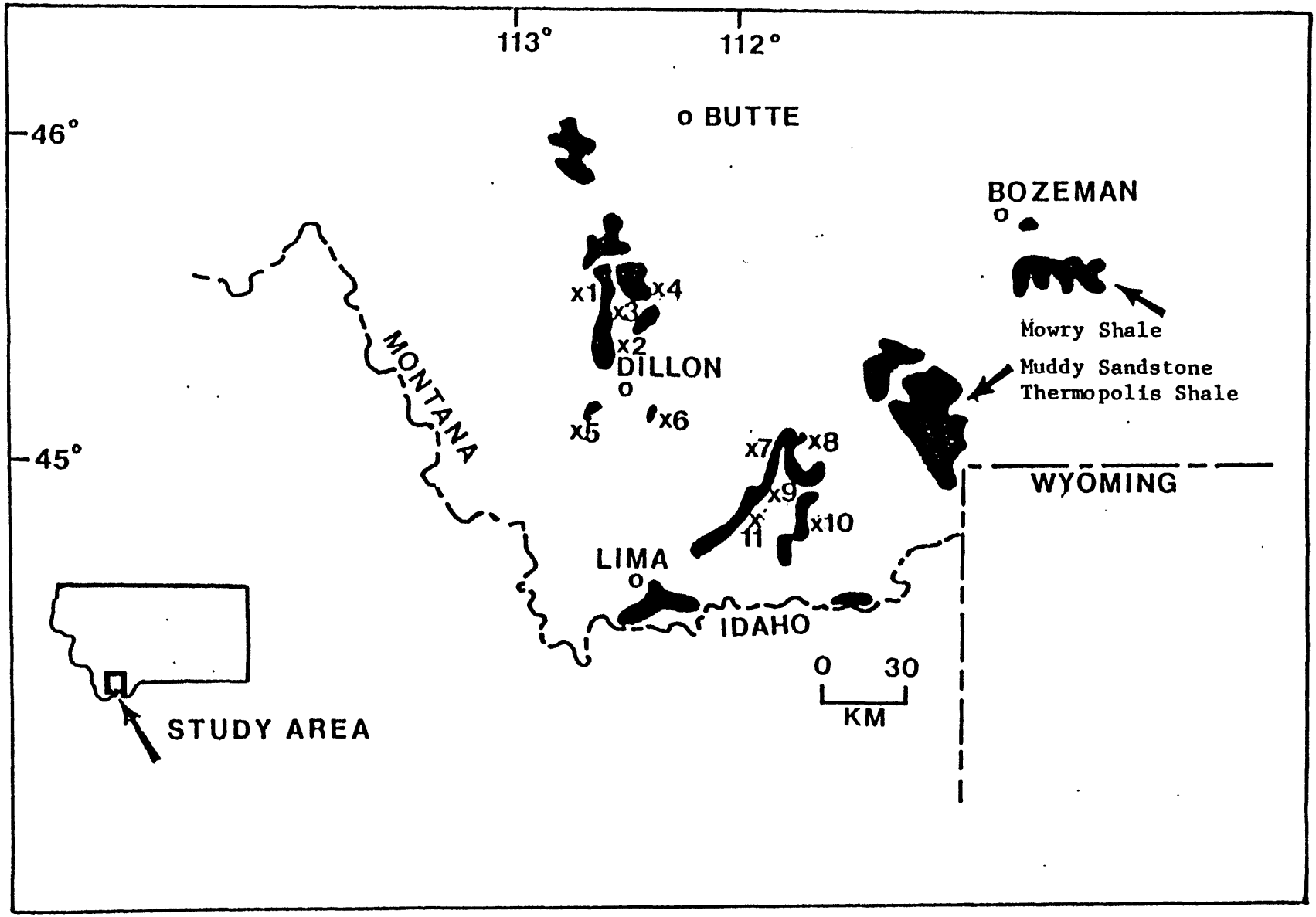

Figure 1.--Numbered outcrops of Blackleaf Formation, southwest Montana. Shaded areas represent known outcrop extent of Blackleaf Formation and its equivalents.

Maximum thickness ft. (m)	Age	Formation/ group (Gp)
5000 (1524)	Cenozoic	Undifferentiated
13000 (3962)	Upper Cretaceous	Beaverhead Gp. Frontier
2000 (610)	Lower Cretaceous	Blackleaf Kootenai
400 (133)	Jurassic	Morrison Swift Rierdon
1200 (360)	Triassic	Thaynes Woodside Dinwoody
800 (244)	Permian	Phosphoria
2900 (884)	Pennsylvanian	Quadrant Amsden
3500 (1007)	Mississippian	Big Snowy Gp. Mission Canyon Lodgepole
900 (274)	Devonian	Three Forks Jefferson
1000 (305)	Ordovician	Kinnikinic
1000 (305)	Cambrian	Pilgrim Park Meagher Wolsey Flathead

Figure 2.--Generalized geologic column, southwest Montana. Thickness values represent averages for region.

Appendix 2 contains (1) the matrix of framework grain percents, (2) presence or absence data for key accessory minerals, and (3) an explanation of data codes. Statistics were computed according to Dickinson and Suczek (1979). Sample numbers include a 3 part description including sample locality (e.g. 4-MH-82), lithofacies unit number from above (e.g. 4-MH-82), and a chronological sequence number (e.g. 4-MH-82) (Dyman, Niblack, and Platt, 1984; Dyman, 1985).

Each appendix contains the distance above the base of the section in meters at which each sample was taken. Sample numbers with asterisks were collected from outcrop sections or sample localities without knowledge of their exact stratigraphic position within a lithofacies unit. They are identified upward in chronological order (included with the other samples) with the highest number representing the stratigraphically highest sample for each locality.

Appendix 3 contains the presence or absence matrix of diagenetic alteration products, and an explanation of codes used for 127 thin sections. Alteration products were recorded as present regardless of the degree of alteration.

APPENDIX 1

CODES AND LOCATIONS FOR SECTIONS AND SAMPLE LOCALITIES DESCRIBED IN THIS STUDY

1. LP: Lima Peaks section.
   Sections 13, 14, and 18, T. 15 S., R. 8 W.,
   Lima Peaks Quadrangle, Beaverhead County, Montana
   (Dyman, Niblack, and Platt, 1984).
2. AP: Apex section.
   SE 1/2 section 7, S 1/2 section 6, T. 5 S., R. 8 W.,
   Twin Adams Mountain Quadrangle, Beaverhead County, Montana
   (Dyman, 1985).
3. FP: Frying Pan Gulch section.
   Section 30, T. 6 S., R. 9 W.,
   Bond Quadrangle, Beaverhead County, Montana
   (Dyman, 1985).
4. MM: McCartney Mountain I section.
   E 1/2 sections 21 and 28, S 1/2 section 16, T. 4 S., R. 8 W.,
   Block Mountain Quadrangle, Madison County, Montana
   (Dyman, 1985).
5. MM2: McCartney Mountain II section.
   NE 1/4 section 35, T. 4 S., R. 8 W.,
   Block Mountain Quadrangle, Madison County, Montana
   (Dyman, 1985).
6. GC: Grasshopper Creek section.
   SE 1/4 section 26, T. 8 S., R. 10 W.,
   Daleys Quadrangle, Beaverhead County, Montana
   (Dyman, 1985).
7. RR: Ruby River section.
   SE 1/4 section 18, T. 9 S., R. 3 W.,
   Home Park Ranch Quadrangle, Madison County, Montana
   (Dyman, 1985).
8. CC: Cottonwood Iron Creek section.
   N 1/2 section 25, T. 10 S., R. 3 W.,
   Monument Ridge Quadrangle, Madison County, Montana
   Dyman, 1985).
9. MH: Monument Hill section.
   Unsurveyed area about 1/2 mile west of
   Gravelly Range Road along southwest flank of
   Monument Hill, Monument Ridge Quadrangle,
   Madison County, Montana (Dyman, 1985).
10. AN and SRC: Antone Peak section.
    NW 1/4 section 22, SW 1/4 section 11,
    T. 12 S., R. 5 W., Antone Peak Quadrangle,
    Beaverhead County, Montana (Dyman, 1985).

11. WS: Warm Springs Creek section.
E 1/2 section 15, and NE 1/4 section 22, T. 9 S., R. 3 W.,
Varney Quadrangle, Madison County, Montana (Dyman, 1985).
12. SH: Shine Hill sample locality.
Lower Frontier Formation south side of Sawmill Creek
along north flank of Shine Hill. Approximately
1/4 mile south of Lima Peaks (LP) section.
13. LS: Little Sheep Creek sample locality.
N 1/2 section 26, T. 15 S., R. 9 W.,
Gallagher Gulch Quadrangle, Beaverhead County, Montana.
14. RC: Rocky Creek Canyon sample locality.
SW 1/4 section 20, T. 2 S., R. 7 E., north side highway I-90,
Gallatin County, Montana (Roberts, 1972, p. C 61).
15. WC: Willow Creek sample locality.
Sections 6 and 7, T. 38 N., R. 116 W., West side of Willow Creek,
Teton County, Wyoming (Wanless, Belknap, and Foster, 1955).
16. SR: Snake River sample locality.
Section 4, T. 37 N., R. 117 W., (unsurveyed) north side of highway
89 east of Wolf Creek, Lincoln County, Wyoming (Durkee, 1980).
17. BC: Beaver Creek sample locality.
Section 19, T. 7 S., R. 4 E., along north side of Beaver Creek,
Gallatin County, Montana (Vuke, 1984).
18. LM: Lincoln Mountain sample locality.
Section 7, T. 9 S., R. 4 E., along south flank of Lincoln Mountain,
Gallatin County, Montana (Hall, 1961).

APPENDIX 2

FRAMEWORK GRAIN ABUNDANCE AND ACCESSORY MINERALS PRESENT FOR BLACKLEAF AND FRONTIER FORMATIONS, MADISON AND BEAVERHEAD COUNTIES, MONTANA

EXPLANATION OF CODES FOR APPENDIX 2:

Qm: monocrystalline quartz

Qp: foliated and nonfoliated polycrystalline quartz

CHT: chert

P: plagioclase feldspar

K: potassium feldspar

Rock fragments

LS: limestone

MD: mudstone

SS: sandstone

VC: undifferentiated volcanic

MT: undifferentiated metamorphic

M: total mica

G: glauconite

Z: zircon

O: undifferentiated opaque minerals

X: accessory minerals present

Sample number	Meters*	Framework Grains										Accessory minerals present (X)			
		Qm	Qp	CHT	P	K	LS	MD	SS	VC	MT	M	G	Z	O
5-SH-3*	--	31		3	57	5		1		3		X			X
5-SH-1*	--	23	20	29		1	3	2	12	9	2				
5-LP-17.4*	--	32	15	21	1				14	17		X			
5-LP-145	604	27	2	11	11	4	23	4		21		X			X
5-LP-133	508	17	6	10	12	3		14	14	20		X		X	X
5-LP-129	499	16	2	6	36	16		12	3	10		X		X	X
5-LP-121	484	22	2	4	40	3		7	1	20					X
4-LP-110	448	19	17	16	22	2		13		2		X			X
4-LP-105	446	16	6	10	17	9		17	4	15	1				X
4-LP-95	424	15	6	8	22	11		18	10	8		X		X	X
4-LP-93	420	18	2	12	12	11		20	22	10		X			X
4-LP-92	417	20	4	7	22	7		17		21		X		X	X
4-LP-87	406	28	7	1	10	13		26	5	9					
4-LP-83	397	27	10	6	14	9		9	8	15		X		X	X
4-LP-79	394	18	5	16	7	16		3	25	9		X		X	X
4-LP-70	382	23	5	5		31	10	24							
4-LP-59	290	23	7	17	1	26	8	9	4	4		X		X	X
4-LP-56	288	46	1	11	1	17		13	11			X			X
3-LP-49	195	50	6	12				22	8			X			X
3-LP-42	131	52	26	5		3		10		1		X		X	X
1-LP-38	111	49	9	28			13			1					X

*meters above the base of the measured section.

Sample number	Meters*	Framework Grains									Accessory minerals present (X)			
		Qm	Qp	CHT	P	K	LS	MD	SS	VC	MT	M	G	Z	O
1-LP-31	101	45	10	28		2	10	4		1					
1-LP-26	98	47	3	16			5	30				X			X
1-LP-17	63	55	5	21		1	14	3		1				X	X
1-LP-8	34	54	6	18	1		17		2		1				X
1-GH-1	32	53	6	22		3		16							X
1-GH-4	26	40	4	23		3	14	13	1	1				X	X
4-MMD-3*	--	31	2	7	1		17	20	7	15		X			X
3-MM2-3*	--	29	6	24			16	20	5					X	X
2-MM-32	148	24	2	46			6	14	7			X			X
2-MM-28	133	33	27	25			2	11	3						
1-MM-17	90	40	5	24			16	14							X
1-MM-15	74	38	10	26			6	12	5	1	1			X	X
1-MM-13	49	43	1	14			9	8	3					X	X
1-MM-2	21	45	10	11			8	12	10	1	2			X	X
5-CC-5*	--	48	2	27		1	7	12	1	1		X		X	X
3-CC-4	11	30	3	22				32	12						X
1-CC-A*	--	77	5	4				10	3					X	
3-LM-5*	--	38		22	13			19	8	3					

*meters above the base of the measured section.

Sample number	Meters*	Framework Grains										Accessory minerals present (X)			
		Qm	Qp	CHT	P	K	LS	MD	SS	VC	MT	M	G	Z	O
5-AP-209	1021	23	1	47	4		14	2	7	2		X			
5-AP-206	985	44	6	26			4	1			1	X			X
5-AP-184	807	58	5	16				19	1	1				X	X
5-AP-168	676	28		21	10		2	18	4	15		X		X	X
5-AP-162	645	42	6	37				5	7	3		X			X
4-AP-134	466	16		40			1	20		1		X			
4-AP-120	370	370	19	1	25	44		4	5		10		X		X
4-AP-106	318	55	6	32	1		2	4				X		X	X
4-AP-94	268	42	30	17	1			6	1	2		X		X	X
3-AP-85	204	20	18	18			13	9	3						X
2-AP-70	154	39	17	15			9	3	17	1					
1-AP-60	133	37	4	20			22	15	3			X			
1-AP-52	110	51	3	17			19	7	1			X		X	X
1-AP-40	90	48	2	14			23	11	2					X	
1-AP-29	55	58	2	10	1		27	13	1					X	X
1-AP-23	45	41	5	15			23	13							
1-AP-14	26	38	4	29			22	7							X
1-AP-5	4	43	5	26			18	6				X		X	X
1-RC-6*	--	60		21		5	8	4	1						X
1-RC-1*	--	96		2		2								X	X
4-MH-1	82	18	3	4	29	1		13	1	30	1	X			X
4-MH-2	80	65		9	1	6	6	11	2			X	X	X	X
3-MH-3	66	45	4	15		1	15	17	1	2		X		X	X
3-MH-5	60	50	2	10		4	6	21	6		1				X
2-MH-7	30	72	1	3				14	6	3				X	
1-MH-12	12	93	3	1				2			1			X	
1-MH-13	10	87	1	5				5			2				X

*meters above the base of the measured section.

Sample number	Meters*	Framework Grains								Accessory minerals present (X)					
		Qm	Qp	CHT	P	K	LS	MD	SS	VC	MT	M	G	Z	O
5-RR-63	187	34	5	23			3	29	6						X
5-RR-38	149	40	2	23	1		1	18	3	11		X			X
4-RR-34	127	25	2	22	13			13	6	21		X			X
4-RR-27	99	38	5	26	7			13	7	3					
4-RR-21	82	30		5	45		13	5	1			X			X
2-RR-14	62	41	4	25	1		2	10	7	6	3	X			X
3-WS-109	108	46	12	14				25	3						
3-WS-108	107	56	8	16	1	1		6	14					X	
3-WS-9	103	55	6	14		1		16	3		5			X	
3-WS-7	92	68	1	8	3	3	3	6	2		8	X			
1-WS-4	17	94	1	3				3					X	X	
1-WS-3	13	93	3	2				3						X	X
1-WS-2	8	96	2					2						X	X
1-WS-A3*	--	49	14	28			6	1	2						X
5-FP-37	735	31		8	13		35	3	1	7		X	X		X
5-F-30	663	39	3	5	6		27	3	6			X			
5-FP-20	530	9	3	33				2	56						
5-FP-19	525	21	3	32					43	1				X	
3-FP-15	162	68	3	8				15	4		1				X
3-FP-14	141	81	2	2				2	9	1	3	X		X	X
1-FP-11	77	60	1	6			20	8	2	1	1	X			X
1-FP-8	57	37	4	13			24	16	4	1	1				X
1-FP-7	50	46	1	2			32	10	8	1					X
1-LS-2*	--	79	2	8				8	2					X	X
4-WC-4*	--	40	2	18	17	3		13		2					
4-WC-1*	--	37	4	24	1		6	12	7		1				
3-SR-3*	--	62	8	10				20	1						X

*meters above the base of the measured section.

Sample number	Meters*	Framework Grains									Accessory minerals present (X)			
		Qm	Qp	CHT	P	K	LS	MD	SS	VC	MT	M	G	Z	O
5-SRC-6	480	17	3	7	25	4	11	1	6	11		X			X
5-SRC-2	465	17	2	9	19	5		10	5	31	1	X		X	X
3-AN-7	66	35	9	23			1	23	8	1					
3-AN-6	60	57	3	11			10	13	3	2		X		X	X
1-AN-4	52	52	14	11	1		4	19					X		X
1-AN-2	17	82	15	2				1				X		X	

*meters above the base of the measured section.

APPENDIX 3

PRESENCE/ABSENCE MATRIX OF DIAGENETIC ALTERATION PRODUCTS FOR BLACKLEAF AND FRONTIER FORMATIONS, MADISON AND BEAVERHEAD COUNTIES, MONTANA

1. CP: calcite pore filling, early- or late-stage cementation.
2. LC: late-stage calcite pore filling.
3. FL: diagenetic flattening and bending of micas and sedimentary lithic grains.
4. QF: quartz-filled fractures.
5. SC: seriticization of chert grains (stage of alteration not differentiated).
6. ST: strongly sutured quartz grain contacts.
7. MA: undifferentiated mica alteration.
8. CA: pervasive unselective alteration of grains to calcite. Usually late stage.
9. MP: matrix pore filling. May incude clay and zeolite.
10. QO: quartz overgrowths. May include some overgrowths from a previous diagenetic cycle.
11. CV: calcite-filled fractures.
12. FC: fibrous chert alteration or pore-filling. Usually identified as a radial chalcedontic pore filling.
13. SL: replacement of micritic limestone or strongly calcareous shale by sparry calcite.
14. AK: albitization of potassium feldspar.
15. CR: chlorite rim. Identified predominantly on quartz grains.
16. CB: chloritized biotite.
17. SK: silicification of plagioclase or potassium feldspar.
18. CP: selective calcite replacement of plagioclase.
19. MR: unidentified rim development where not defined as chloritic.

Sample number	Meters*	Alteration products present (X)																		
		CP	LC	FL	QF	SC	ST	MA	CA	MP	QO	CV	FC	SL	AK	CR	CB	SK	CP	MR	CL
5-FP-37	735	X	X	X				X	X					X							
5-FP-30	663	X	X	X		X		X	X					X							
5-FP-20	530									X	X		X							X	
5-FP-19	525	X								X	X		X								
3-FP-15	162				X	X	X				X										
3-FP-14	141					X	X	X		X	X										
1-FP-11	77	X	X			X			X					X							
1-FP-8	57	X	X			X			X					X							
1-FP-7	50	X	X						X					X							
3-LM-5*	--					X						X							X		
5-CC-5*	--	X	X				X			X			X	X							
3-CC-4	11			X	X		X				X										
1-CC-1*	--			X	X		X				X										
5-SH-3*	--	X	X	X		X							X	X	X	X		X			
5-SH-1*	--	X	X		X				X		X		X	X							
1-GH-1	32	X	X						X					X							
1-GH-2	30	X	X						X					X							
1-GH-4	26	X	X						X					X				X			
5-SRC-6	480	X	X	X					X	X	X			X				X			
5-SRC-2	465	X	X	X				X	X					X				X			
3-AN-7	66	X	X								X		X	X		X					
3-AN-6	60	X	X		X				X					X							
3-AN-4	52	X	X		X		X		X		X			X							
1-AN-2	17						X	X		X	X									X	
4-WC-7*	--	X	X			X			X		X		X						X		
4-WC-4*	--	X	X			X		X	X		X		X								
4-WC-1*	--	X	X					X	X		X										

*meters above the base of the measured section.

Sample number	Meters*	Alteration products present (X)																		
		CP	LC	FL	QF	SC	ST	MA	CA	MP	QO	CV	FC	SL	AK	CR	CB	SK	CP	MR	CL
3-RC-7	154				X	X	X	X		X	X				X					X	
1-RC-6	133		X					X	X	X	X			X						X	
1-RC-2	1				X		X	X		X	X									X	
1-RC-1	0		X		X		X		X	X	X			X						X	
5-RR-Z2	216	X	X	X		X			X	X			X							X	
5-RR-63	187	X	X		X			X	X		X		X	X						X	
5-RR-43	155		X			X			X					X							
5-RR-38	149		X					X	X	X	X		X	X	X						
4-RR-34	127							X			X		X					X			
4-RR-27	99	X	X					X	X		X		X								
4-RR-21	82		X					X	X	X									X		
2-RR-14	62		X		X	X	X	X			X		X							X	
2-RR-13	61		X			X		X	X	X				X						X	
3-BC-5*	--	X	X			X			X		X			X							
3-BC-4*	--	X	X			X		X	X					X						X	
3-BC-3*	--	X	X			X	X		X		X			X							
1-BC-1*	--	X	X			X		X	X		X		X	X						X	
5-LP-17.4*	--						X			X	X		X			X					
5-LP-145	604	X	X	X					X					X							
5-LP-137	515		X			X		X													
5-LP-133	508			X		X		X		X						X		X			
5-LP-132	506		X						X					X							
5-LP-129	499	X	X	X					X					X				X	X		
5-LP-121	484	X	X	X					X					X					X		
5-LP-119	475					X		X		X								X		X	
4-LP-117	473					X		X		X			X					X			
4-LP-110	448					X				X			X			X			X		
4-LP-106	447					X		X		X			X								
4-LP-105	446	X	X									X	X					X			
4-LP-96	425							X		X			X					X			
4-LP-95	424	X						X		X								X	X		
4-LP-93	420	X						X	X	X			X								

*meters above the base of the measured section.

Sample number	Meters*	Alteration products present (X)																		
		CP	LC	FL	QF	SC	ST	MA	CA	MP	QO	CV	FC	SL	AK	CR	CB	SK	CP	MR	CL
4-LP-92	417			X				X		X			X					X			
4-LP-87	406	X	X						X	X				X		X		X			
4-LP-85	404		X					X	X	X			X	X							
4-LP-83	397			X		X		X		X			X								
4-LP-79	394		X			X				X		X	X		X				X	X	
4-LP-73	385							X	X	X											
4-LP-70	382	X	X	X					X	X				X		X				X	
4-LP-59	290	X		X				X	X					X							
4-LP-56	288	X		X				X	X	X				X							
3-LP-49	195	X	X						X					X		X					
3-LP-42	131			X			X	X		X	X										
1-LP-38	111	X	X					X						X							
1-LP-31	101	X	X					X						X							
1-LP-26	98	X	X			X		X						X							
1-LP-25	96		X					X						X							
5-AP-209	1021	X		X				X	X	X				X							
5-AP-206	985	X	X			X			X	X			X	X					X		
5-AP-184	807					X				X			X			X					
5-AP-168	676	X	X			X		X	X	X				X					X		
5-AP-162	645									X	X		X								
4-AP-153	597					X		X	X			X		X					X		
4-AP-134	466					X			X					X					X		
4-AP-120	370	X		X		X		X	X	X				X					X		
4-AP-106	318	X	X					X	X					X							
4-AP-94	268					X	X	X			X		X			X			X		
3-AP-85	204		X	X	X	X			X				X	X							
2-AP-70	154			X							X			X							
1-AP-60	134	X	X	X					X	X				X							
1-AP-52	110	X	X			X			X					X							

*meters above the base of the measured section.

Sample number	Meters*	Alteration products present (X)																		
		CP	LC	FL	QF	SC	ST	MA	CA	MP	QO	CV	FC	SL	AK	CR	CB	SK	CP	MR	CL
1-AP-40	90	X	X	X					X	X				X							
1-AP-29	55	X	X		X				X	X				X							
1-AP-23	45	X	X					X	X	X	X			X							
1-AP-14	26	X	X			X		X	X		X			X							
1-AP-5	4	X	X			X			X					X							
4-MH-1	82			X				X		X			X					X			
4-MH-2	80	X	X						X												
3-MH-3	66	X		X					X		X		X								X
3-MH-5	60	X	X	X		X			X												
3-MH-6	51	X	X					X	X		X			X							
2-MH-7	30	X	X				X		X		X									X	
1-MH-12	12						X				X									X	
1-MH-13	10						X				X									X	
4-MMD-3*	--	X	X			X			X					X					X		
3-MM2-107*	--	X	X						X					X							
3-MM2-3*	--		X						X		X			X							
3-MM-36	180	X	X						X		X			X							
3-MM-35	175	X	X			X	X				X			X							
2-MM-32	148	X	X					X	X		X	X		X						X	
2-MM-28	133						X				X		X							X	
2-MM-19	92	X	X			X			X					X							
1-MM-17	90	X	X			X								X						X	
1-MM-16	80		X				X		X		X	X		X							
1-MM-15	74	X	X			X	X		X		X			X							
1-MM-13	49		X			X			X					X							
1-MM-2	21		X			X			X				X	X							
3-SR-6*	--					X	X	X			X		X							X	
3-SR-5*	--					X	X	X		X	X									X	
3-SR-3*	--					X	X	X		X	X		X							X	
3-SR-1*	--					X	X	X	X		X									X	

*meters above the base of the measured section.

Sample number	Meters*	Alteration products present (X)																		
		CP	LC	FL	QF	SC	ST	MA	CA	MP	QO	CV	FC	SL	AK	CR	CB	SK	CP	MR	CL
1-LP-23	88	X	X					X	X					X							
1-LP-17	63	X	X					X	X					X							
1-LP-15	62	X	X			X		X	X					X							
1-LP-8	34	X	X						X					X							
3-WS-108	109		X			X		X			X		X							X	
3-WS-9	103		X			X	X	X			X			X							
3-WS-7	92	X	X			X		X	X	X				X					X		
1-WS-4	17				X	X	X				X										
1-WS-3	13				X	X	X				X										
1-WS-2	8				X		X				X										
1-WS-A*	--	X	X		X		X		X		X									X	
1-LS-2*	--				X	X	X			X	X										

*meters above the base of the measured section.

REFERENCES

Dickinson, W. R., and Suczek, C. A., 1979, Plate-tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 63, p. 2164-2182.

Dyman, T. S., 1985, Measured stratigraphic sections of Lower Cretaceous Blackleaf Formation and lower Upper Cretaceous Frontier Formation (lower part) in Beaverhead and Madison Counties, Montana: U.S. Geological Survey Open-File Report 85-431, 70 p.

Dyman, T. S., Niblack, R., and Platt, J. E., 1984, Measured stratigraphic section of Lower Cretaceous Blackleaf Formation and lower Upper Cretaceous Frontier Formation (lower part) near Lima, in southwest Montana: U.S. Geological Survey Open-File Report 84-838, 25 p.

Durkee, S. K., 1980, Depositional environments of the Lower Cretaceous Smiths Formation within a portion of the Idaho-Wyoming thrust belt: Wyoming Geological Association 31st Annual Field Conference Guidebook, p. 101-116.

Hadley, J. B., 1980, Geology of the Varney and Cameron Quadrangles, Madison County, Montana: U.S. Geological Survey Bulletin 1459, 108 p.

Hall, W. B., 1961, Geology of part of the upper Gallatin Valley of southwestern Montana, Unpublished PhD. Dissertation, University of Wyoming, 239 p.

Mann, J. A., 1954, Geology of part of the Gravelly Range, Montana: The Yellowstone--Bighorn Research Project Contribution 190, 92 p.

Roberts, A. E., 1972, Cretaceous and early Tertiary depositional history of the Livingston area, southwestern Montana: U.S. Geological Survey Professional Paper 526-C, 120 p.

Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana, United States Geological Survey, scale 1:500,000.

Schwartz, R. K., 1972, Stratigraphic and petrographic analysis of the Lower Cretaceous Blackleaf Formation, southwestern Montana, Unpublished PhD, Dissertation, Indiana University, 268 p.

Vuke, S. M., 1982, Depositional environments of the Cretaceous Thermopolis, Muddy, and Mowry Formations, southern Madison and Gallatin Ranges, Montana: Unpublished M.S. Thesis, University of Montana, 141 p.

Wanless, H. R., Belknap, R. L., and Foster, H., 1955, Paleozoic and Mesozoic rocks of the Gros Ventre, Teton, Hoback, and Snake River Ranges, Wyoming: Geological Society of America Memoir 63, 68 p.