

KGS
OF
55-1

The Gypsum Spring Formation (Middle
Jurassic) of Western Wyoming

JOHN C. WILSON
1955

TABLE OF CONTENTS

	Page
ABSTRACT	1
THE GYPSUM SPRING FORMATION (MIDDLE JURASSIC)	5
INTRODUCTION	5
Purpose and scope OF WESTERN WYOMING	5
Geography	5
Accessibility	6
Methods of investigation by	7
Previous work	8
Acknowledgments	9
GEOLOGIC HISTORY John C. Wilson	10
Pre-Jurassic B.S., California Institute of Technology, 1953	10
Jurassic	13
Lower Jurassic	13
Upper Jurassic	17
Submitted to the Department of Geology and the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Science.	21
STRATIGRAPHY	21
General	21
Definition of the Gypsum Spring formation.	21
Confusion in stratigraphy.	23
Sedimentary facies	25
Evaporite facies	25
Normal marine facies	27
SEDIMENTATION	29
March, 1955	29

W. A. Inland
Instructor in charge

M. L. Thompson
For the department

TABLE OF CONTENTS

	Page
ABSTRACT	1
INTRODUCTION	5
Purpose and scope	3
Geography	5
Accessibility	6
Methods of investigation.	7
Previous work	8
Acknowledgements.	9
GEOLOGIC HISTORY	10
Pre-Jurassic.	10
Jurassic.	13
Lower Jurassic	13
Middle Jurassic.	17
STRATIGRAPHY	21
Nomenclature.	21
History of name.	21
Definition of the Gypsum Spring formation.	21
Confusion in stratigraphy.	23
Sedimentary facies of the Middle Jurassic	25
Evaporite facies	25
Normal marine facies	27
SEDIMENTATION.	29
General	29

Basal evaporites	30
Sequence	30
Sedimentation	30
Theory of reflux	32
Arid cyclothem hypothesis	34
Depositional sequence	34
Environment of deposition	37
Lithologic evidence supporting the hypothesis	38
Lithologic sequence	38
Continuity of beds	39
Clastic content of nonclastic phases	39
Red beds	40
Environment of deposition	40
Origin of gypsum lenses in red beds	41
Factors affecting environmental variables	43
Relative importance of factors	43
Depth of deposition	44
Climate	44
Salinity of the Utah sea	46
Morphology of the basin	47
Chemistry of the evaporites	48
Order of precipitation	48
Rates of precipitation	51
Postdepositional changes	52
Origin of dolomite	53
Source of dissolved solids	54

LITHOLOGY.	56
General.	56
Member A.	57
Description.	57
Basal Gypsum Spring formation contact.	61
Environment of deposition.	62
Member B.	63
General.	63
Gypsum	65
Dolomite	65
Solution breccias.	72
Environment of deposition.	78
Lithologic types of members C through H	79
Member C.	83
Description.	83
Environment of deposition.	85
Member D.	86
General.	86
Basal evaporites	86
Central clastic beds	88
Algal limestone.	88
Sedimentary environment.	96
Member E.	93
Description.	93
Environment of deposition.	99
APPENDIX	142
Description of sections	142

Member F.	100
Figure General.	100
1. Central Basal nonclastics.	100
2. Paleozoic Gradation from limestone to red silty calcarenite	101
3. Paleozoic Origin of the calcarenite.	106
4. Paleozoic Uppermost saline deposits.	108
5. Typical Mixed lithologies.	108
6. Oxfordian Sedimentary environment.	112
7. Type section of the Gypsum Spring formation	115
8. Member H.	115
9. Average composition and thickness of the Gypsum General.	115
10. Basal saline lenses.	115
11. Central limestone bed.	115
12. Isopach-lithofacies map of the Middle Jurassic of Uppermost marine strata.	117
13. Typical Sedimentary environment.	119
14. Gypsum Spring - "Lower Sundance" contact.	121
15. Typical Lithologic comparison.	121
16. Unconformity	122
17. Distribution of basal conglomerate in the Owl Creek Mountains.	122
18. Change in Intraformational conglomerates in the Wind River Mountains.	128
19. Stratigraphic position of correlation planes on Penecontemporaneous deformation of member H	128
20. Stratigraphic position of correlation planes on	
SUMMARY.	134
CONCLUSIONS.	137
REFERENCES	140
APPENDIX	142
Description of sections	142

Figure		Page
1.	Central western Wyoming	4
2.	Paleotectonic map of the Permian.	11
3.	Paleotectonic map of the Triassic	12
4.	Paleotectonic map of the Lower and Middle Jurassic.	14
5.	Typical Nugget sandstone (Lower Jurassic)	15
6.	Oxfordian paleogeography of the Boreal region	19
7.	Type section of the Gypsum Spring formation	20
8.	Average composition and thickness of the Gypsum Spring formation in Fremont County, Wyoming.	22
9.	Distribution of Middle Jurassic deposits in the Western Interior region.	26
10.	Isopach-lithofacies map of the Middle Jurassic of the Western Interior	28
11.	Typical siltstone-dolomite-gypsum sequence of member B.	31
12.	Typical basal lithology of member B	31
13.	Arid cyclothem.	35
14.	Transgressive sequence at the base of member H.	36
15.	White gypsum lenses in red-brown siltstone.	42
16.	Change in solubility of calcium sulfate	50
17.	Stratigraphic position of correlation planes on cross section B-B'	58
18.	Stratigraphic position of correlation planes on cross section A-A'	59
19.	Mottling in member A.	60
20.	Cliff-forming gypsum of member B.	64
21.	Contorted dolomite laminae included in the basal gypsum bed of Section 18	66

Figure	Page
22. White, weathered gypsum	66
23. Band of dolomitic clay laminations in white, translucent gypsum	67
24. Dolomitic shale bands in white gypsum	68
25. Typical dolomite from member B.	69
26. Light-red laminated dolomite.	71
27. Chemical precipitate at base of Section 1	73
28. Etched surface of specimen in Figure 27	73
29. Limestone-siltstone breccia	74
30. Dolomite microbreccia	74
31. Bed of limestone breccia.	76
32. Limestone breccia	76
33. Siltstone breccia	77
34. Siltstone breccia	77
35. Laminated limestone characteristic of members D, F, and H.	82
36. Banded and laminated limestone.	82
37. Gypsum lenses in siltstone of member C.	84
38. Basal part of member D.	87
39. Algal limestone	90
40. Algal limestone bed	91
41. Algal limestone illustrating varieties in shapes and sizes.	92
42. Algal limestone	93
43. Symbols used in stratigraphic sections.	94
44. Correlation of member D	95
45. Basal beds of member F.	102

Figure	Page
46. Gradation from limestone to siltstone	104
47. Red and green mottled, silty limestone of member F	105
48. Speckled and mottled, silty limestone from member F	107
49. Etched oolitic limestone from member F.	110
50. Fossiliferous micro-oolite.	110
51. Bryozoans from member F	111
52. Bryozoans from member F	111
53. Correlation of member F	114
54. Dolomite from member H.	116
55. Limestone of member H	118
56. Correlation of member H on cross section B-B' . . .	120
57. Fossiliferous, oolitic limestone.	123
58. Fossiliferous, oolitic limestone.	123
59. Fossiliferous, oolitic limestone.	124
60. Basal Sundance sandy, oolitic limestone	125
61. Limestone-pebble conglomerate	125
62. Bryozoan, coarse-grained calcarenite with gypsum matrix	127
63. Detrital bryozoan fragments	127
64. Basal Sundance unconformity	129
65. Basal Sundance unconformity	129
66. Limestone-pebble conglomerate	130

Figure	Page
67. Penecontemporaneous folding and faulting of member H.	132
68. Penecontemporaneous brecciation of limestone at top of member H.	132
69. Correlation of members F, G, and H and basal "Lower Sundance" beds on cross section A-A'.	133
70. Symbols used in stratigraphic sections.	142a
71. Location map of Sections 1, 2, and 3	143
72. Location map of Sections 4 and 5	144
73. Location map of Sections 6, 7, 8, 9, and 10.	145
74. Location map of Sections 11, 12, 13, and 14.	146
75. Location map of Sections 15, 16, and 17.	147
76. Location map of Sections 18 and 19	148
77. Location map of Sections 20.	148
78. Location map of Sections 21 and 23	149
79. Location map of Sections 24, 25, and 26.	150
80. Location map of Sections 27 and 28	151

concentration necessary for the precipitation of gypsum. Subsequent concentration after the return to normal dry climate resulted in the LIST OF TABLES

Table	Page
1. Correlation of the Middle Jurassic of the Western Interior.	16
2. Salts precipitated in concentration of sea water	49

marine evaporitic deposits commonly consist of the top and base, dolomite in the middle and the third, and laminated limestone in the center. The red bed sequences which separate

ABSTRACT

the three groups of marine deposits contain gypsum lenses at the Twenty-nine sections of the Gypsum Spring formation (Middle Jurassic) were measured and described in Fremont, Hot Springs, Sublette and Teton counties, Wyoming. Study of the sections indicates that the Gypsum Spring formation is divisible into three stratigraphic units. These are: 1) basal 25-foot red bed sequence, 2) 75 feet of thick-bedded gypsum, and 3) cyclically deposited evaporites alternating with red beds with an average thickness of 95 feet.

The basal red beds of unit 1 grade downward into the Nugget sandstone (Lower Jurassic) in western Wyoming, and into the Chugwater red beds (Triassic) in central Wyoming.

The prominent gypsum in unit 2 contains interbedded red siltstone and brown dolomite. The long span of gypsum deposition was interrupted only by short changes to a humid climate, which caused the lowering of the salinity below the concentration necessary for the precipitation of gypsum. Subsequent concentration after the return to normal dry climate resulted in the deposition of a thin bed of dolomite followed by thick beds of gypsum.

The third stratigraphic unit contains three successive cycles of sedimentation. Each cycle has red beds at the base and top and marine evaporite deposits in the center. The marine nonclastic deposits commonly contain gypsum at the top and base, dolomite in the basal and top third, and laminated limestone in the center. The red bed sequences which separate

the three groups of marine strata, contain gypsum lenses at the top and base.

Purpose and Scope

The term "arid cyclothem" is introduced to describe the idealized depositional sequence interpreted from these cycles of sedimentation. The idealized sequence is: A) ~~Transgression~~: 1) red beds, 2) red beds with gypsum lenses, 3) gypsum, 4) dolomite, and 5) laminated limestone; B) Regression: 6) dolomite, 7) gypsum, 8) red beds with gypsum lenses, and 9) red beds. The conditions of deposition of the arid cyclothem are the following: 1) dry climate, 2) systematically fluctuating sea level, and 3) a landmass of low slope and low relief, 4) a source for red-stained elastics. Changes in climate, morphology of the basin, minor fluctuations in depth of depth are largely responsible for the departures from the ideal arid cyclothem found in the Gypsum Spring formation. Middle Jurassic in central Wyoming to the normal marine facies on the Idaho-Wyoming border. Owing to the inaccessibility of unaltered exposures west of the Wind River Mountains, the regional aspect of the problem had to be abandoned.

Because the Gypsum Spring formation is notably lacking in well-preserved fossils, no extensive paleontological discussion will be presented. The age of beds and correlations made by previous authors will be summarized under "Stratigraphy".

INTRODUCTION

Purpose and Scope

Middle Jurassic outcrops in Fremont, Hot Springs, Sublette and Teton counties in western Wyoming (Fig. 1) were investigated with emphasis on evidence for sedimentary environments of the Gypsum Spring formation. Outcrops are limited to the flanks of the major mountain ranges and to the minor associated folds in the intervening basins.

A study of the lateral changes in the lithology and environment within a restricted stratigraphic unit, prompted the selection of the Gypsum Spring formation of western Wyoming for research work. Originally, it was planned to study all gradations in the sedimentary environments represented in this unit, from the continental facies of the Middle Jurassic in central Wyoming to the normal marine facies on the Idaho-Wyoming border. Owing to the inaccessibility of unaltered exposures west of the Wind River Mountains, the regional aspect of the problem had to be abandoned.

Because the Gypsum Spring formation is notably lacking in well-preserved fossils, no extensive paleontological discussion will be presented. The age of beds and correlations made by previous authors will be summarized under "Stratigraphy".

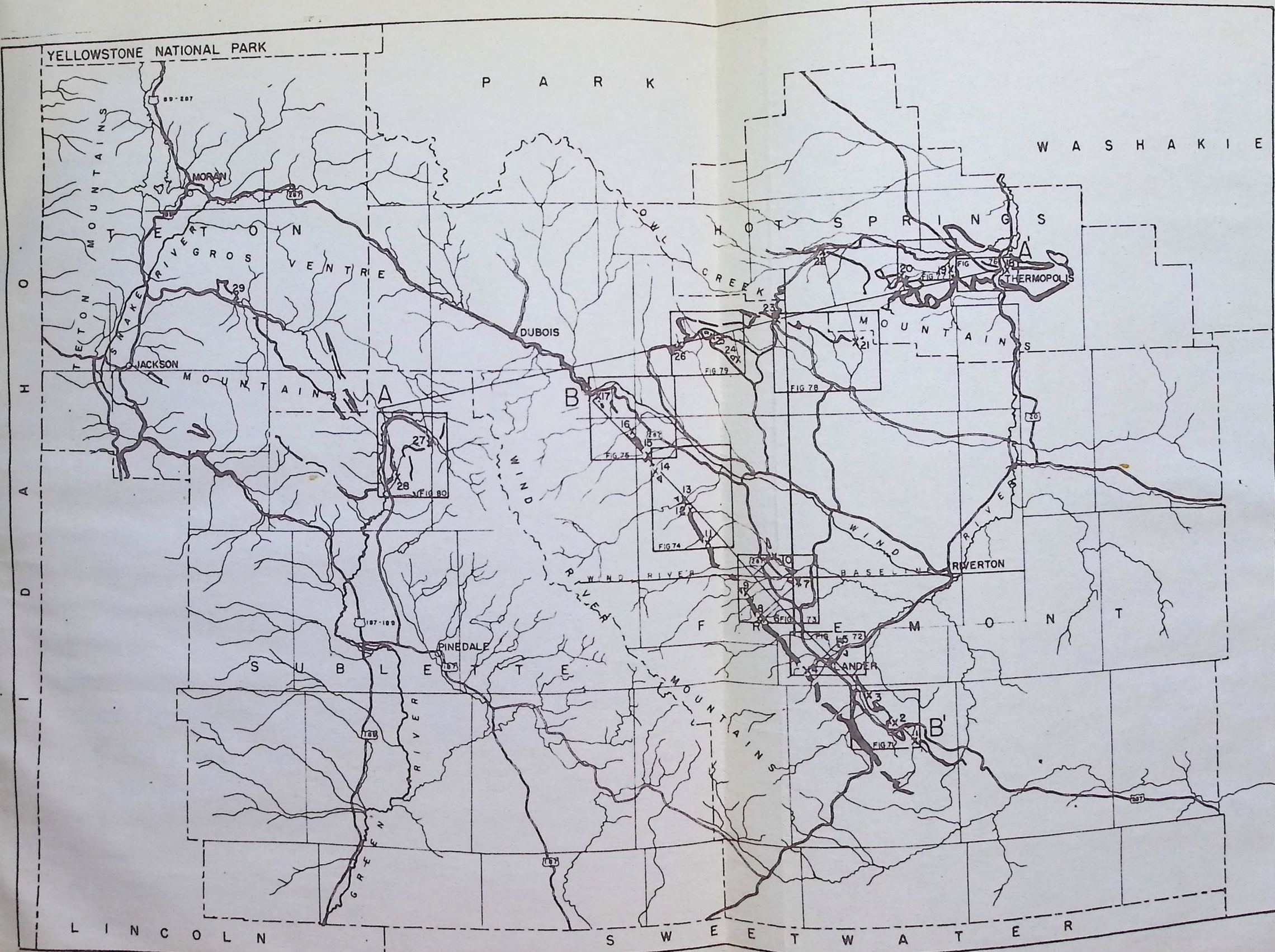


FIG. 1. Central western Wyoming. Middle Jurassic outcrops are shown by heavy lines. Measured sections are numbered 1 to 29. Figure numbers refer to location maps in the Appendix. Scale: 1 inch = approximately 16 miles.

Conclusions concerning sedimentary environments have been made on the basis of petrographic investigations, field studies, laboratory^{work} and the previous work of other men concerning western Wyoming tectonics and stratigraphy. No subsurface data were used. larger rivers. The only population centers in the area are Lander (pop. 3,319), Riverton (pop. 4,126), and Dubois (Geography) in Fremont County; Thermopole (pop. 2,834) in Hot Springs County; Jackson (pop. 1,239) in Teton County; and Pinedale (pop. 847) in Sublette County.

Western Wyoming is a region of high relief. The elevation of the intermontane valley floors ranges from 4,500 to 7,000 feet. Mountain peaks higher than 12,000 feet are common in the Wind River Mountains. The mountain ranges are broad anticlines flanked with inclined sedimentary rocks ranging in age from Cambrian to Cretaceous. Steep gradient streams have carved bold relief in the flanks of the ranges producing excellent exposures of most Paleozoic and Mesozoic formations. The elevation of outcrops of the Gypsum Spring formation on ranges from 5,000 to 7,500 feet. Section 28 was the only outcrop above 10,000 feet which was studied.

The area is drained by tributaries of the Missouri, Columbia, and Colorado rivers. The continental divides separating these three river systems meet at a point 20 miles east of Dubois, Wyoming (Fig. 1). Fremont County is drained by Wind River, Sublette County is drained by Green River, and Teton County is drained by Snake River.

Several glacial advances are recorded at the higher elevations in most of the Wind River Range. The accompanying glacial outwash has locally covered exposures.

The area is mostly ranching country and population is concentrated along the larger rivers. The only population centers in the area are Lander (pop. 3,319), Riverton (pop. 4,126), and Dubois (pop. 376) in Fremont County; Thermopoliis (pop. 2,834) in Hot Springs County; Jackson (pop. 1,239) in Teton County; and Pinedale (pop. 647) in Sublette County.

Accessibility

Easy automobile travel in central and western Wyoming is limited to the few major paved highways in the intermontane areas. With moderate caution, access to outcrops on the mountain flanks can be made in a passenger automobile on county gravel roads, ranch roads, and bulldozed seismograph-trails. The travelable roads in the vicinity of each measured section are shown on Figures 71 to 80 in the Appendix.

Because of the late spring thaw, the best months for travel and field study in this area are July, August, and September.

Determined by this dye method, but mixtures of dolomite and calcite registered as calcite. Apparently, the small crystal size cannot be distinguished by this dye technique. Dilute hydrochloric acid was used in the distinction of carbonate minerals.

Methods of Investigation

Between June 3 and July 16, 1954, twenty-nine sections of the Middle Jurassic were described and sampled. Eighteen stratigraphic sections were measured on the eastern flank of the Wind River Mountains, two on the western side of the Wind River Mountains, eight in the Owl Creek Mountains, and one in the Gros Ventre Range. Measurements were made with Brunton clinometer and 8-foot tape. Because of differences in thickness with those of previously published sections, the accuracy of the method used was tested mathematically and by repetition. Compensating human and operational errors most likely keep the inaccuracies of the larger measurements less than 10 percent. Laboratory work was begun in July, 1954 and was continued through February, 1955. Flat-ground, unpolished slabs of nearly all of the 245 field samples were etched and then studied under a binocular microscope, using a maximum magnification of x100. In addition, analyses of thin sections and insoluble residues were made of selected specimens. Distinction of dolomite from calcite by means of Lemberg's solution was attempted in the laboratory. Pure dolomite could be determined by this dye method, but mixtures of dolomite and calcite registered as calcite. Apparently, the small crystal size cannot be distinguished by this dye technique. Dilute hydrochloric acid was used in the distinction of carbonate minerals.

formation and equivalent strata is included in the publication, but Schmitt studied only 6 sections in the area covered in it. Before 1939, little mention was made of the gypsiferous Jurassic sediments of western Wyoming. Love (1939) defined the Gypsum Spring formation as a member of the Chugwater formation (Triassic), and presented a generalized description of the type section.

Imlay (1945) investigated Mesozoic stratigraphy and gathered fossil evidence to establish the correct age of the Gypsum Spring formation.

Love, et al. (1945) published 37 stratigraphic sections of Mesozoic rocks, 20 of which contained the Gypsum Spring formation. The information was presented in graphic form at a scale of 100 feet to the inch, but had no accompanying written description. Two years later, Love (1947) published seven written descriptions of representative sections taken from his 1945 publication. None of this work was done in the detail of the work included herein.

Imlay's paper (1952a) on the paleoecology of Jurassic seas in the western interior region discussed the regional distribution and facies changes of the Gypsum Spring formation and interregional correlation with other Jurassic formations.

Schmitt (1953) conducted a lithofacies analysis of the marine Middle and Upper Jurassic in the Northern Rocky Mountains. An isopach-lithofacies map of the Gypsum Spring

formation and equivalent strata is included in the publication, but Schmitt studied only 6 sections in the area covered in this present investigation.

None of the workers mentioned has published a detailed petrologic investigation of the Gypsum Spring formation.

undergoing strong change. In order to understand the effect of this change on Mid-Permian sedimentation, the geologic

Acknowledgments

The Geology Department of the California Institute of Technology made their research facilities available to the author in July and August, 1954. Jack Murphy of the U. S. Geol. Survey, Ralph King of the University of Kansas, and Jacob Booth of Lander, Wyoming, gave advice on the location and accessibility of exposures. Raymond Cole of Montebello, California, and Robert Fay of the University of Kansas gave advice on the special photographic techniques used in this paper. John Koriagin of Glendale, California, drafted the location maps in the Appendix.

Shallow, epicontinental seas covered most of the Western Interior region in Permian time (Fig. 2). The Phosphoria formation, which includes all but the uppermost Permian deposits, is only 300 feet thick in Fremont County, Wyoming, but the formation thickens to more than 3,000 feet in the center of the Utah trough.

Triassic deposits were more restricted than those of the Permian (Fig. 3). Although the Utah trough was enlarged and received more sediments than previously, few marine

GEOLOGIC HISTORY

Pre-Jurassic

The Gypsum Spring formation was deposited at a time when the tectonic framework of the Western Interior was undergoing strong change. In order to understand the effect of this change on Middle Jurassic sedimentation, the geologic history from the late Paleozoic through the Jurassic is summarized.

The growth of the Manhattan geanticline to the west in post-Devonian time caused the migration of the eastern part of the Cordilleran geosyncline to form the Utah trough across central Utah and Nevada in Permian time (Fig. 2). Pre-Jurassic sedimentation in western Wyoming was largely controlled by the position of the Utah trough. The Pacific Ocean was connected to this intracratonic trough.

Shallow, epicontinental seas covered most of the Western Interior region in Permian time (Fig. 2). The Phosphoria formation, which includes all but the uppermost Permian deposits, is only 300 feet thick in Fremont County, Wyoming, but the formation thickens to more than 5,000 feet in the center of the Utah trough.

Triassic deposits were more restricted than those of the Permian (Fig. 3). Although the Utah trough was enlarged and received more sediments than previously, few marine



FIG. 3. Paleotectonic map of the Triassic. Symbols are the same as for Figure 2. (After Bardley, 1949.)

sediments of Triassic age are found on the flanking epicontinental shelves. Outlets to open ocean were limited to a few small sags in the continuous Manhattan arch (Bardley, 1949).

Triassic sediments of the Western Interior outside the Utah trough, are composed of a thick series of red siltstones and shales. The Chugwater formation, which includes all but the basal Triassic, has a thickness of 1500 feet in Fremont County and thickens to several thousand feet on the Wyoming-Idaho border. Deposition of the red beds began in Late Permian time and continued into the Jurassic.

Jurassic

Lower Jurassic. At the beginning of the Jurassic, the Utah trough continued to be the dominant area of sedimentation in the Western Interior. The shelf areas accompanying this trough (Fig. 4) were even more areally restricted than those of the Triassic. The only connection to the open sea was approximately at the position of the present Gulf of California.

The basal Jurassic formation in Fremont County, Wyoming, is the Nugget sandstone, which is crossbedded and composed of frosted, rounded, quartz sand grains (Fig. 5). The formation is found from Montana to northern Arizona and has various names (Table 1). In southeastern Idaho, it reaches a maximum thickness of over 2,000 feet.

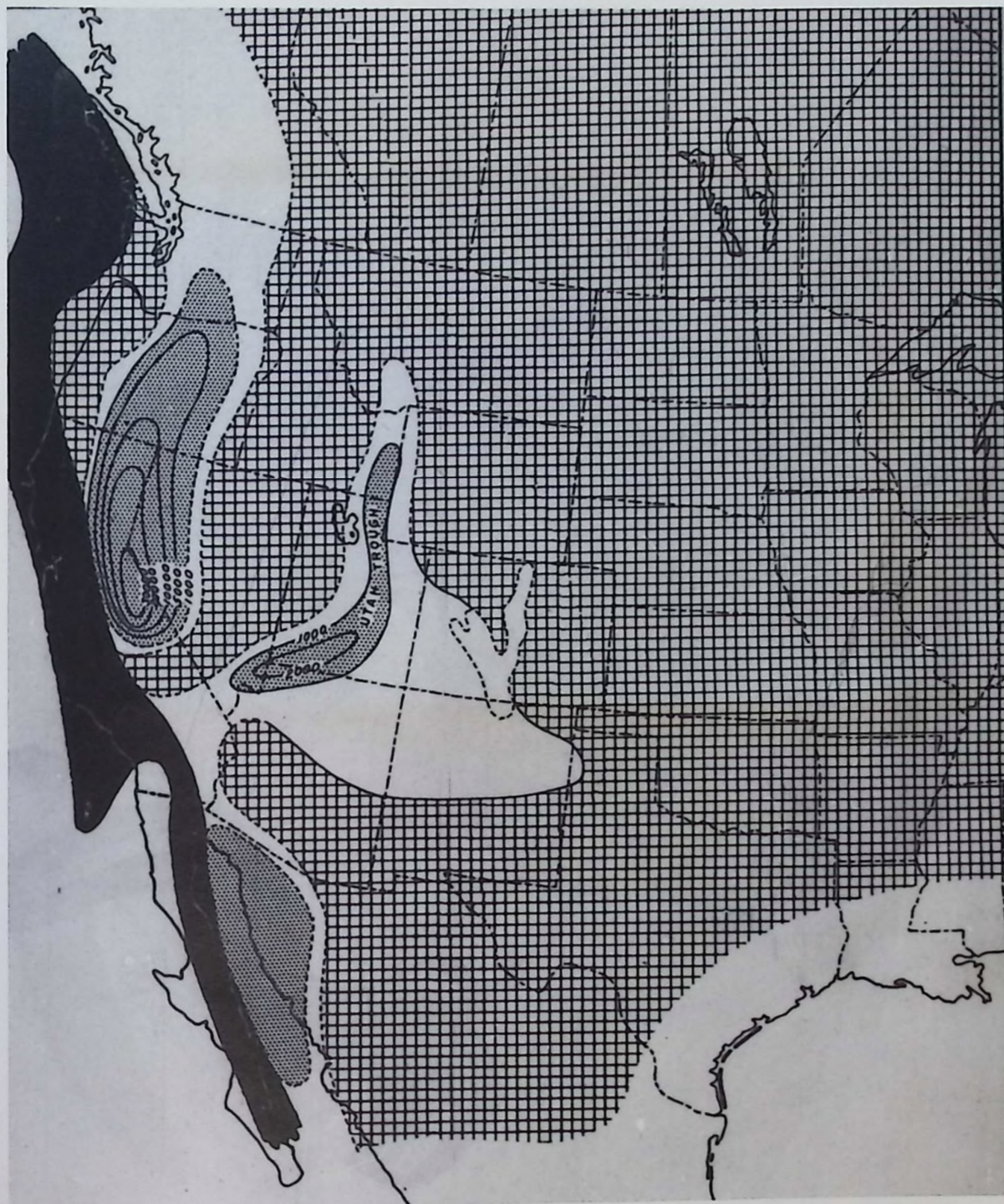


FIG. 4. Paleotectonic map of Lower and Middle Jurassic, excluding the Bathonian. See Figure 2 for explanation of symbols. (After Bardley, 1949.)

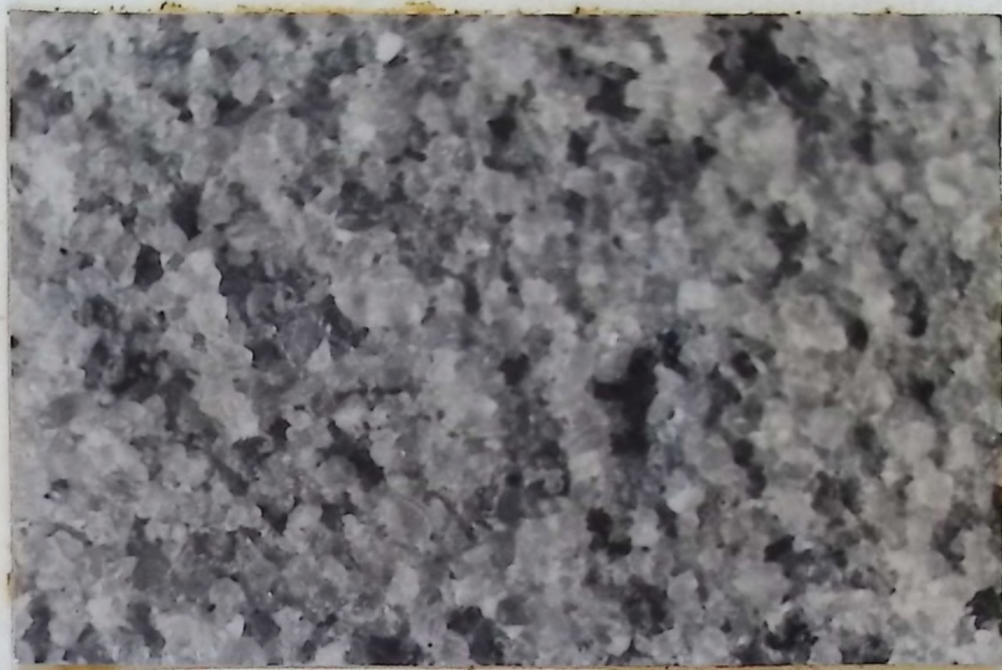


FIG. 5. Typical Nugget sandstone (Lower Jurassic)¹.
Section 3. x10

¹
Unless denoted otherwise, all figures showing rock specimens are photomicrographs taken perpendicular to bedding with top of specimen at top of photograph.

EUROPEAN STAGES (Arkell, 1946)	NORTHWEST EUROPE STANDARD ZONES (Arkell, 1946)	CHARACTERISTIC FOSSILS IN THE WESTERN INTERIOR REGION	WEST CENTRAL AND NORTH CENTRAL MONTANA	SOUTH CENTRAL AND SOUTHERNEAST MONTANA	WIND RIVER BASIN OF CENTRAL WYOMING	FREEDOM QUADRANGLE OF SOUTHEASTERN IDAHO	SAN RAFAEL SWELL OF MIDDLE EASTERN UTAH	BLACK HILLS, WESTERN SOUTH DAKOTA AND NORTHEASTERN WYOMING	
UPPER JURASSIC	Turonian	<i>Titanites giganteus</i>							
		<i>Kerberites olivaceus</i>							
	Kimmeridgian	<i>Glaucolites gowi</i>							
		<i>Zenaidites albica</i>							
		<i>Pachia pallasioides</i>							
		<i>Pachia rubens</i>							
		<i>Pachia parviflora</i>							
		<i>Schizophoria obtusirostris</i>							
		<i>Schizophoria sp.</i>							
		<i>Grewia gipsi</i>							
		<i>Grewia gracilis</i>							
		<i>Asplenophoria pseudonotata</i>							
		<i>Rosaria notata</i>							
		<i>Rosaria symbolae</i>							
		<i>Purina longi</i>							
Oxfordian	<i>Elphidium pseudonotata</i>								
	<i>Darwinia darwini</i>								
	<i>Paraphoria costatipes</i>								
	<i>Paraphoria planifolia</i>								
	<i>Cardiocrinus</i> spp.								
	<i>Cardiocrinus cordiformis</i>								
	<i>Quadrifolius varius</i>								
	<i>Quadrifolius lacherti</i>								
	<i>Ptilonites atiles</i>								
	<i>Erymocrinus rostratum</i>								
Columbian	<i>Erymocrinus jeani</i>								
	<i>Siphocrinus collareus</i>								
	<i>Protophilites howeyi</i>								
	<i>Protophilites macrocephalus</i>								
	<i>Artiocrinus</i>								
	<i>Artiocrinus dani</i>								
	<i>Artiocrinus</i>								
Bathonian	(Not yet determined)								
	<i>Pachia parviflora</i>								
	<i>Strophomena amphiplicata</i>								
Bajocian	<i>Orthis exilis</i>								
	<i>Saxonia axonifera</i>								
Middle Jurassic	<i>Laticrinus mercurialis</i>								
	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
Turonian	<i>Laticrinus sp.</i>								
	<i>Laticrinus sp.</i>								
Flemishian	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								
Sinuotian	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								
Bathonian	<i>Harporthis argentea</i>								
	<i>Harporthis argentea</i>								

TABLE 1. Correlation of the Middle Jurassic formations of the Western Interior.
(After Imlay, 1952a).

The rise of the Mesocordilleran geanticline at the end of the Triassic produced an arid climate in the Western Interior (Imlay, 1952a), and a source of sediment for the Utah trough. In this dry climate, the Nugget sandstone was deposited. Most authors refer to the formation as an eolian deposit, but fluvial deposition has not been disproven.

In the Wind River Mountains, the Gypsum Spring formation conformably overlies the Nugget sandstone. Because of erosion and nondeposition, the Nugget sandstone is not found in outcrops in the Owl Creek Mountains. East of the type locality Section 28, the Gypsum Spring formation was unconformably deposited on the Chugwater formation. However, west of the Wind River Basin, no erosional surface exists at the base of the Middle Jurassic. Imlay (1950) surmises from the difference in induration of the two formations, that a hiatus separates the Nugget sandstone and the Middle Jurassic beds of western Wyoming.

Middle Jurassic. At the end of the Lower Jurassic, a large positive area extended from the western coast of Mexico to the Arctic Ocean, thus blocking the former oceanic entrances to the Utah trough. It was in this enclosed sea that the basal evaporites of the Gypsum Spring formation were deposited.

Coincident with the uplift, a seaway was formed in west-central Canada, connecting the nearly landlocked Utah trough with the Arctic Ocean (Fig. 6). The presence of islands and

probably shallow water restricted movement of new sea water into the Utah sea. This passage was over 2,000 miles long, but at no time during the Jurassic was it connected with the Mexican and Pacific Oceans. The separating strip of land, however, may have been as narrow as 200 miles. Imlay (1952a) finds evidence for this separation by comparison of the Triassic and Lower Jurassic faunas with the faunas of the Middle and Upper Jurassic. Fossils older than Middle Jurassic are similar to those found on the Pacific and Gulf coasts, while Middle and Upper Jurassic faunas have affinities with fossil groups from Greenland and northern Europe.

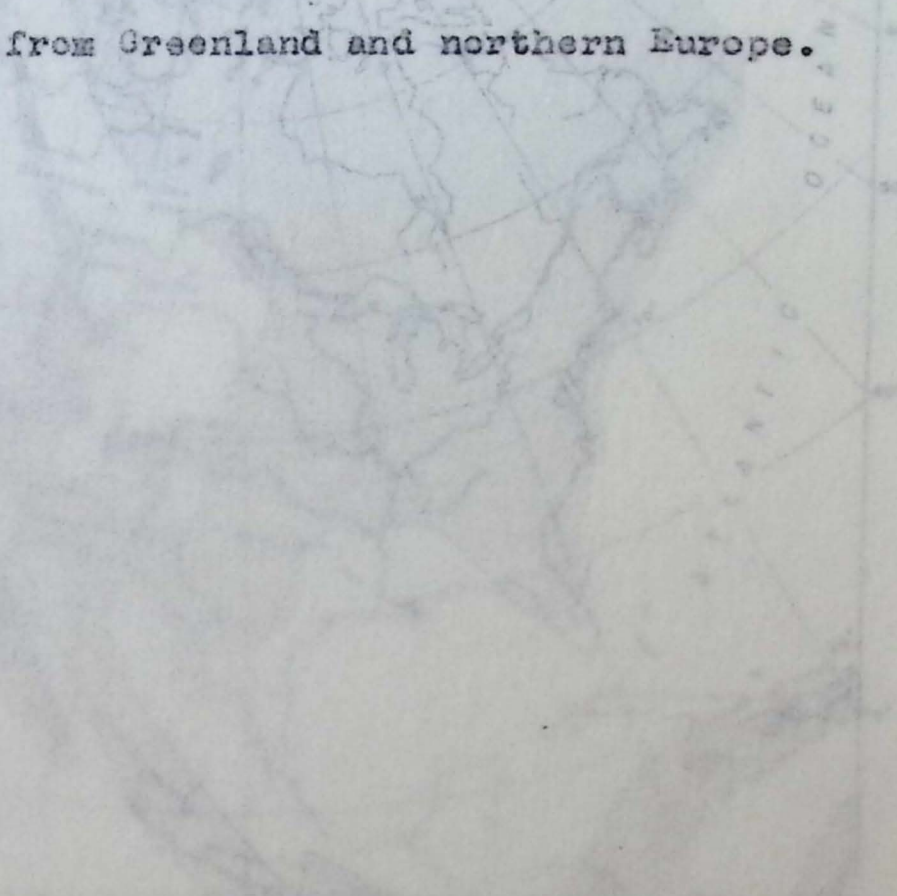


Fig. 1. Paleogeographic reconstruction of the Pacific region (after Imlay, 1952).

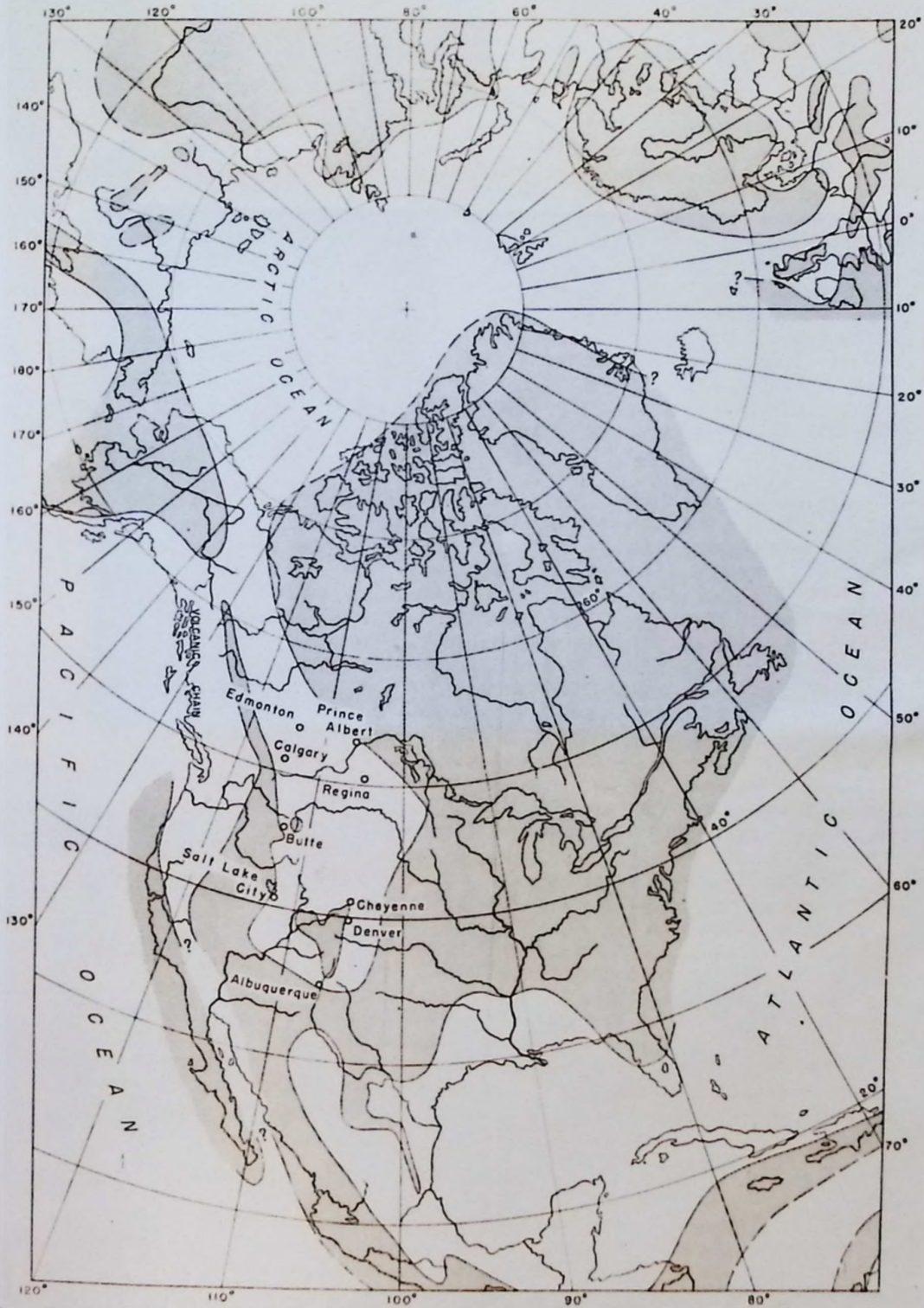
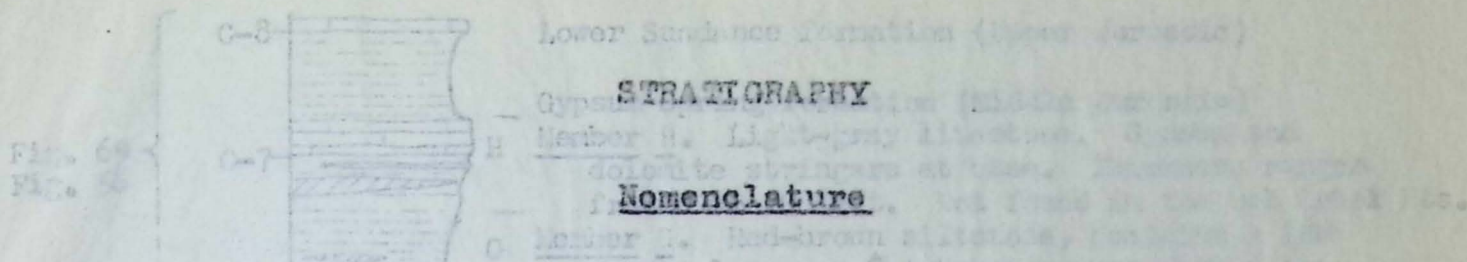


FIG. 6. Oxfordian paleogeography of the Boreal region.
(After Imlay, 1950.)



FIG. 7. Type section of the Gypsum Spring formation. View looking east across Red Creek. (Section 26, appendix.)



History of name. The Gypsum Spring formation was defined by Love (1939) as the uppermost member of the Chugwater formation (Triassic). The type section (Fig. 7) is located on Red Creek in the Owl Creek Mountains (Fig. 1), and is Section 26 (Appendix) of the present work.

The Gypsum Spring formation was given official formational status and assigned its correct Middle Jurassic age by Imlay (1945). After a regional paleontological study of Middle Jurassic deposits in the Western Interior region, Imlay (1950, 1952a, 1952b) restricted the Gypsum Spring formation to rocks of Bajocian age. This definition includes only strata of members A and B shown in Figure 8. He places the remaining, younger strata under the provisional formational name of "Lower Sundance". (See Table 1.)

Definition of the Gypsum Spring formation. The average lithology of the Middle Jurassic in Fremont County, Wyoming, as determined from stratigraphic descriptions and measurements connected with the present study is shown in Figure 8. As used in this paper, the formation includes beds placed by Imlay (1952a) in the Bajocian and Bathonian stages, and is the time equivalent of the Piper formation of Montana.

FIG. 8. Average composition of the Gypsum Spring formation. For the purpose of discussion, I have divided the formation into eight members, lettered A to H. Members A and B at left indicate interval indicated in correlation figures. Vertical scale is in feet.

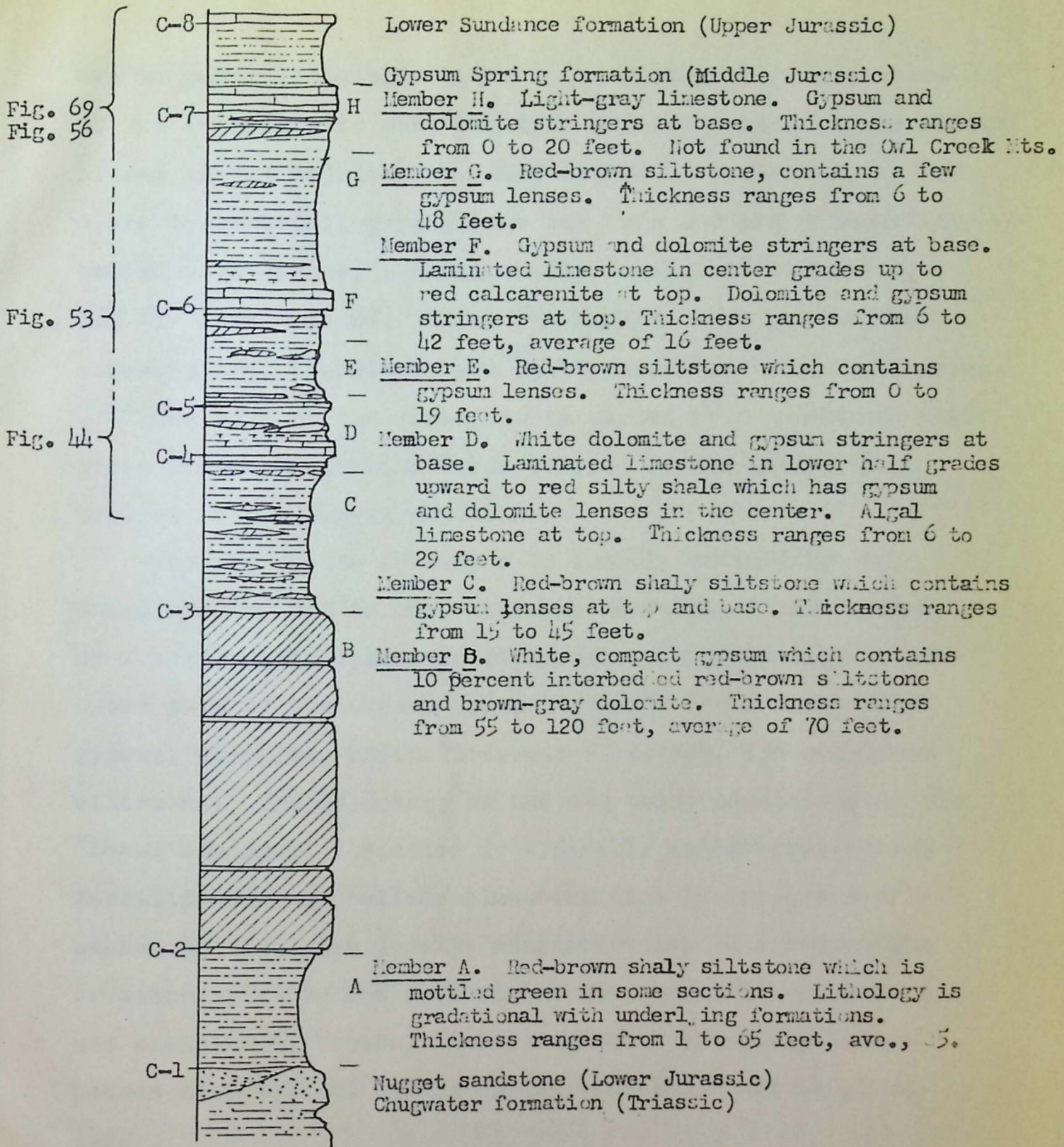


FIG. 8. Average composition and thickness of the Gypsum Spring formation in Fremont County, Wyoming. Correlation planes (C-1, C-2, etc.) are planes used as datums for correlation in figures 16, 17, 44, 53, 56, and 69. Brackets at left indicate interval included in each of the four correlation figures. Vertical scale: 1 inch = approx. 30 feet.

are mappable lithologic units and comprise over 40 percent of the formation in many sections and correspond to the strata placed in the Bajocian by Imlay (1952a). Members C, E, and G are terrestrial, gypsiferous red beds and are alternately bedded with marine, predominantly nonclastic members D, F, and H. (See Fig. 8). These six members have gradational contacts and, therefore, are ^{not} easily mappable lithologic units.

The base of the formation is marked by a red-brown siltstone (member A), which lacks frosted quartz sand grains typical of the Nugget sandstone.

The top of the formation is locally defined by an unconformity, but in most sections measured, it is marked by a conformable change in lithology. The lithology of the upper part of the Gypsum Spring formation is a mixture of gypsum, dolomite, unfossiliferous limestone, and red-brown siltstone. The lithology of the overlying basal beds of the "Lower Sundance" formation is typically yellow-gray shale, fossiliferous and oolitic limestone, and coarse-grained sandstone which are locally conglomeratic. The two groups of lithologies do not have strict stratigraphic separation, and examples of typical "Lower Sundance" lithology interbedded with typical Gypsum Spring lithology will be given later.

Confusion in stratigraphy. Many of the arguments concerning Middle Jurassic stratigraphy result from Love's choice of a type section. His section at Red Creek (measured by me as Section 26) is unique rather than typical of Middle

Jurassic rocks in central Wyoming. Members A to D are present in this section, but are overlain by a thick gypsum bed unlike the average composition of members E to H (Fig. 8).

The basal conglomerate of the "Lower Sundance" represents a period of localized erosion which has removed at least 30 feet of beds from the top of the underlying formation. Such a strong unconformity is not found in any other measured section.

Apparently, most persons who have restudied Love's type section have assumed that the massive gypsum beds at the base and top of the type section are one continuous depositional sequence and are equivalent to the persistent, but thinner gypsum beds found in the lower half of all other complete Middle Jurassic sections in Fremont County. However, this is not the case. The upper gypsum beds at the type section (units 16 to 18, Section 26, Appendix) represent deposition in an areally restricted environment, possibly a lagoon, and are not found in adjacent sections. The facies changes between sections measured in the northwestern part of the Wind River basin will be discussed later.

For the purpose of regional stratigraphic correlation, the Gypsum Spring formation could be divided into three depositional sequences: 1) the basal red beds, 2) the thick-bedded gypsum of member B, and 3) the younger red beds interbedded with limestone, dolomite, gypsum and marine shale of members C to H. (See Fig. 8.) In the Wind River basin, all

three of these sequences are separate, distinct, mappable lithologic units, and were deposited in roughly similar environments. However, the environment of the youngest depositional sequence discussed above is radically different from the environment of the overlying "Lower Sundance" formation. Therefore the inclusion of the beds of members C to H in the "Lower Sundance" formation is viewed as unreasonable in the Wind River basin.

In order to avoid further stratigraphic confusion, I shall not propose a formal reclassification of Middle Jurassic stratigraphy, but revision is necessary. Intelligent subdivision cannot be made until detailed stratigraphic work in the northern Big Horn Mountains and in the outcrops near Cody, Wyoming, is done and a connection made between the Middle Jurassic exposures in the Wind River basin and equivalent beds in Montana.

Sedimentary Facies of the Middle Jurassic

Evaporite facies. The Gypsum Spring and Piper formations are the supersaline marine and continental facies of the Middle Jurassic. The deposits are generally less than 300 feet thick and are found in northern and central Wyoming, eastern Utah, and northeastern South Dakota (Imlay, 1952a). The lower portion, which consists of the basal red beds and thick massive gypsum, is found as far west as the Idaho-Wyoming

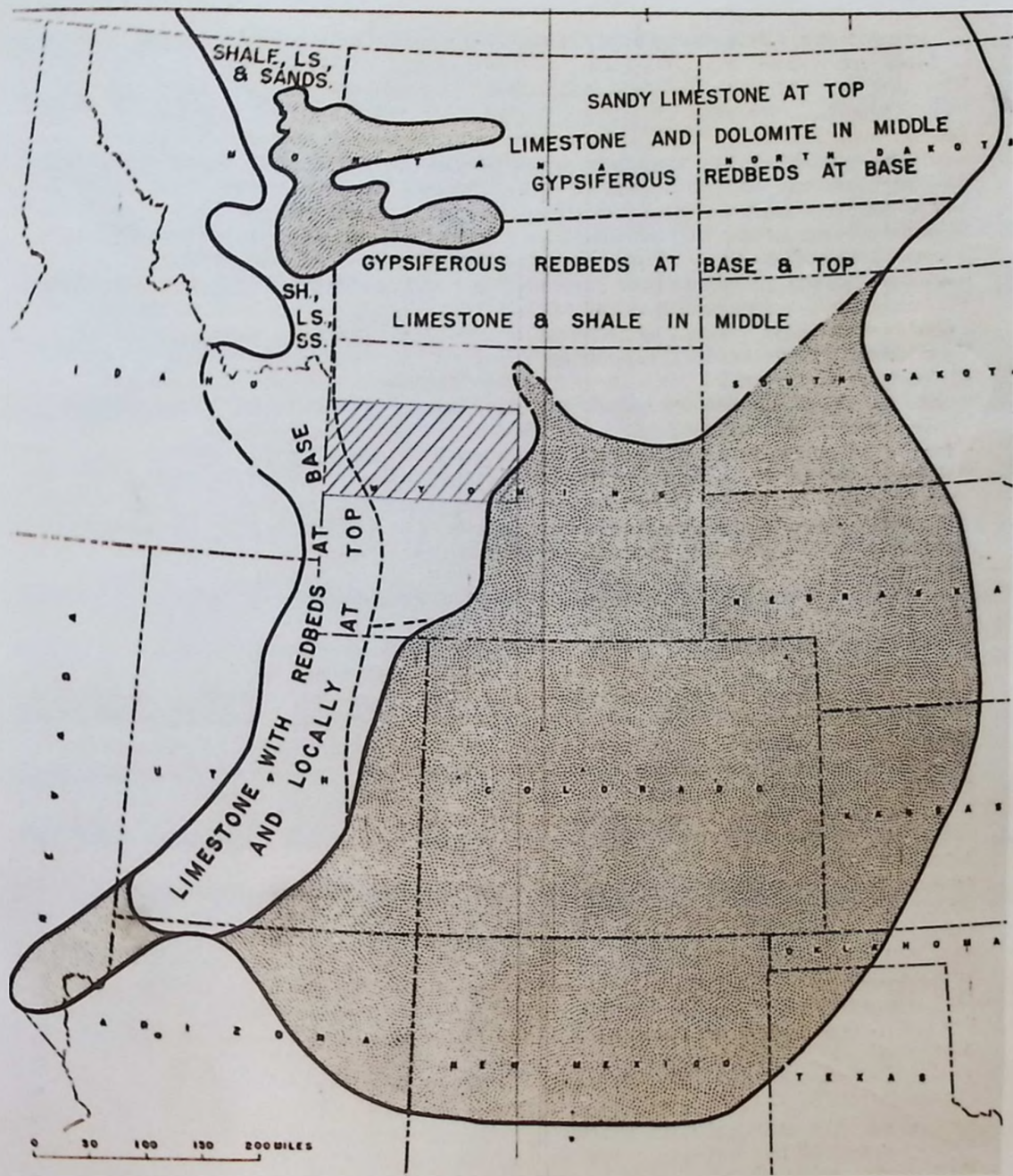


FIG. 9. Distribution of Middle Jurassic deposits in the Western Interior region. Maximum distribution of Jurassic deposits is enclosed. Unstippled enclosed area indicates extent of the Middle Jurassic. Stippled area in central Montana is Belt Island, a positive area during most of Jurassic time. (After Imlay, 1952a.) Area included in Figure 1 is cross-ruled.

border, and as far north as southern Saskatchewan. The eastern and southern boundaries are shown in Figure 9. The upper part of this facies contains red beds, dolomites and thin gypsum beds and is limited to exposures in central Wyoming and southern Montana.

Normal marine facies. The strata of the evaporite facies grade laterally into fossiliferous limestone and gray, marine shales of the Twin Creek limestone and Sawtooth formation (Table 1). This normal marine facies is as much as 300 feet thick in southeastern Utah and 500 feet in Saskatchewan (Fig. 10). In no exposure has this gradation in facies been clearly demonstrated with detailed stratigraphic work. In the area studied in this report, the change in facies occurs in the inaccessible mountains of northern Sublette and eastern Teton counties. The magnitude of this facies change may be seen by comparing Sections 27, 28, and 29 of the Appendix with the composite section shown in the eastern interior. (After Schmitt, 1953.) Area of Figure 1 is outlined.

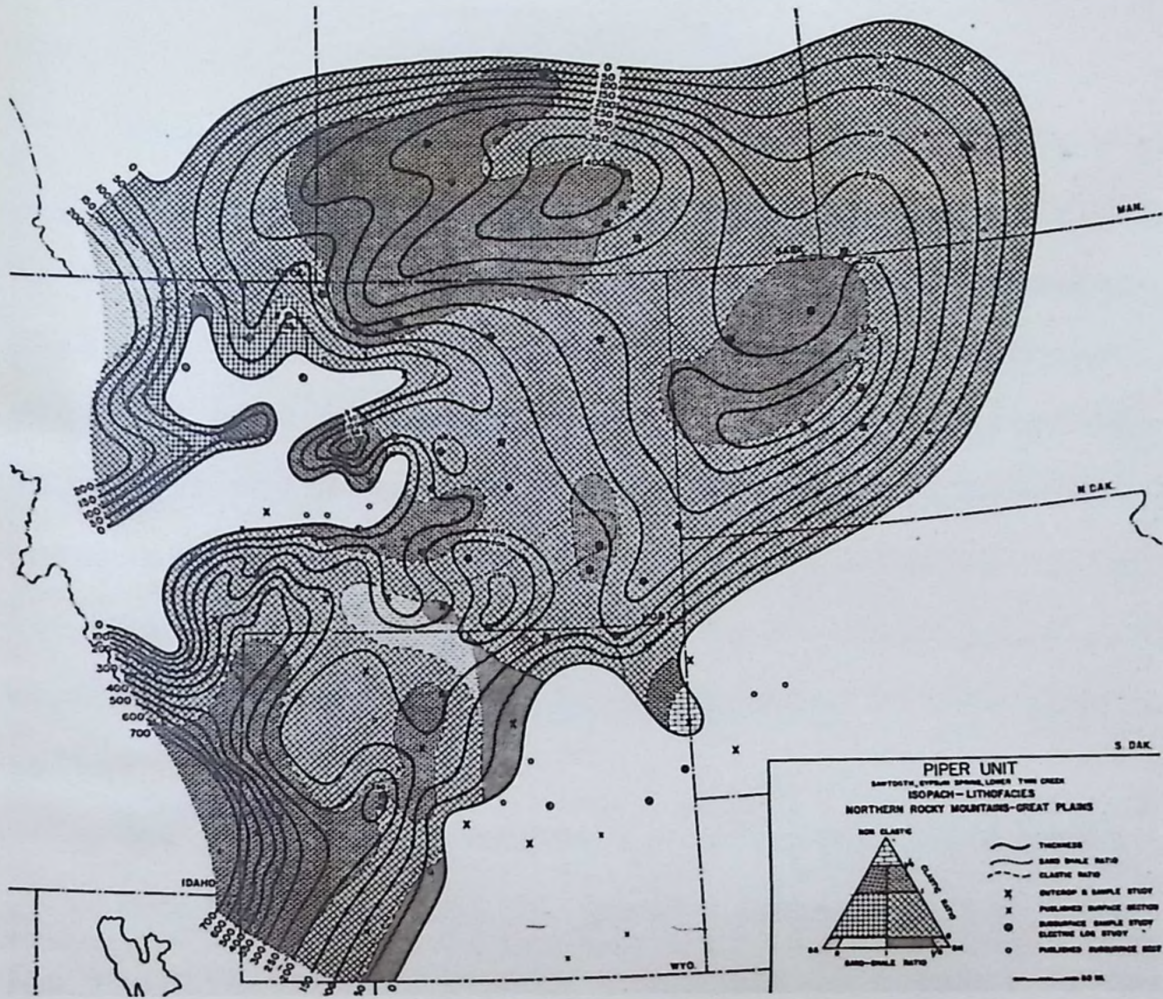


FIG. 10. Isopach-lithofacies map of the Middle Jurassic of the Western Interior. (After Schmitt, 1953.) Area of Figure 1 is outlined.

A different and ~~no~~SEDIMENTATION form of sequential deposition occurred in later Gypsum Spring time. Oscillations of sea level over a salinid precipitating evaporites resulted

General

The Gypsum Spring formation was deposited in a shallow-marine salinid to the east of the Middle Jurassic Utah trough. Free interchange with the nearly normal marine waters of the Utah sea was restricted by the shallowness of the salinid and possibly by a partial closure on the west side of it. The formation was deposited under a dry climate affected by minor changes to a more humid climate. The salinity of the sea in the Utah trough was not excessive, although ionic proportions were probably weighted heavily in favor of the more soluble salts.

Sequence. The lithologic sequences found interbedded with the massive gypsum beds, and also at the base of member B, are shown in Figures 11 and 12. The siltstone-dolomite sequences found between massive gypsum beds range in thickness from 0.2 to 2.5 feet. The thickness of the dolomite, limestone, and siltstone in the upper half of the formation. The base of member B ranges from 0.1 to 0.8 feet. The character of each part of the sequence will be treated more fully in the section describing lithology.

Deposition in repetitive sequences was common in the Western Interior during the Middle Jurassic. Chemical precipitation by evaporation was the predominant depositional process during the time of deposition of member B. However, gypsum of member B (Fig. 12) represents progressive increase in salinity of the Middle Jurassic sea. The succession is similar to Usiglio's order of precipitation of saline salts (p. 49). The calcium carbonate phase of his sequence would be mite, and gypsum.

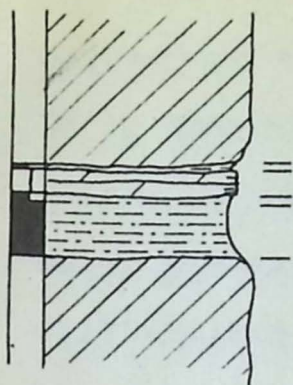
Sedimentation. The sequence found at the base of the process during the time of deposition of member B. However, gypsum of member B (Fig. 12) represents progressive increase in salinity of the Middle Jurassic sea. The succession is similar to Usiglio's order of precipitation of saline salts (p. 49). The calcium carbonate phase of his sequence would be mite, and gypsum.

A different and more pronounced form of sequential deposition occurred in later Gypsum Spring time. Oscillations of sea level over a salinid precipitating evaporites resulted in cyclic deposition of marine nonclastic sediments and non-marine clastic beds. These cyclic deposits are similar to the repetition of beds in late Paleozoic cyclothem as described by Weller (1930), Moore (1931; and 1936), and Elias (1937). Because of this similarity, the type of sedimentation recorded in the upper part of the Gypsum Spring formation is termed the "arid cyclothem".

Basal Evaporites

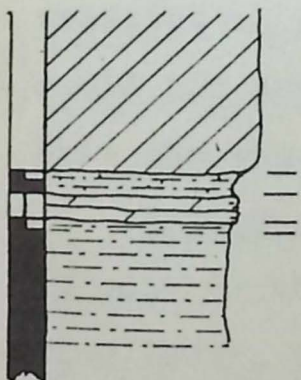
Sequence. The lithologic sequences found interbedded with the massive gypsum beds, and also at the base of member B, are shown in Figures 11 and 12. The siltstone-dolomite sequences found between massive gypsum beds range in thickness from 0.2 to 2.5 feet. The thickness of the dolomite at the base of member B ranges from 0.1 to 0.8 feet. The character of each part of the sequence will be treated more fully in the section describing lithology.

Sedimentation. The sequence found at the base of the gypsum of member B (Fig. 12) represents progressive increase in salinity of the Middle Jurassic sea. The succession is similar to Usiglio's order of precipitation of saline salts (p. 49). The calcium carbonate phase of his sequence would



Gypsum.
 Light-brown dolomite, usually scale parting at top.
 Green shaly siltstone.
 Red-brown siltstone, calcareous in some sequences.
 Gypsum .

FIG. 11. Typical siltstone-dolomite-gypsum sequence of member B. Total thickness ranges from 0.2 to 2.5 feet.



Gypsum.
 Red-brown or green siltstone.
 Light-brown dolomite.
 Red-brown siltstone, usually with green-gray siltstone
 at top.
 Gypsum.

FIG. 12. Typical basal lithology of member B. Dolomite bed ranges in thickness from 0.1 to 0.8 foot.

correspond to the calcareous green shale shown on Figure 12. It is inferred that dolomite formed at a higher salinity either by penecontemporaneous dolomitization of lime muds, or by primary precipitation. Gypsum was deposited at a still higher salinity.

The interbedded sequences (Fig. 11) represent periods of lower salinity accompanied by a higher rate of elastic deposition. The sequences probably correspond to changes to a more humid climate during which rainfall and runoff diluted the salinid waters and caused more rapid elastic deposition. These sequences may have been caused also by removal of restrictions in the basin which allowed a higher rate of influx of new sea water, thus diluting the supersaline waters in the evaporating pan. Because change in morphology of the basin would not account for the change in clastic content, I believe that the sequences correspond to climatic fluctuations.

Theory of reflux. In order to account for the scarcity of salt in the Castile anhydrite (Permian) of West Texas, King (1947, p. 476-477), formulated the theory of reflux. He stated, ". . . in a basin such as the Delaware basin, enclosed on all sides but connected to the open sea by a restricted channel, the water becomes differentiated into an underlying concentrated brine of uniform density, which lies below wave base and is ponded behind the barrier, and a surface layer of somewhat less average density." He brings out that the water of the surface layer is normal sea water near the entrance, but increases in density and salinity toward

above the critical value necessary for precipitation. The the shore. The specific gravity of the surface layer increases from 1.02 at the entrance to 1.20 near the shore. Precipitation of calcium sulfate begins when the brine reaches a specific gravity of 1.08. Transfer of water from the upper layer to the lower concentrated layer takes place near shore. As each increment of dense water is added to the concentrated brine layer, a corresponding increment is forced over the bar into the open ocean. No precipitation takes place from the lower brine layer. In the Castile sea, King believes 90 percent of the water was removed by evaporation in the surface layer, 10 percent was returned to the sea by way of the underlying concentrated brine layer².

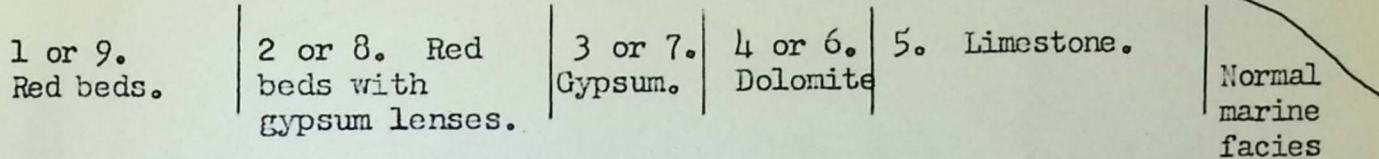
The theory of reflux may be applicable to Gypsum Spring sedimentation, but no evidence of basin enclosure was found in the area under investigation. It is possible that part of the Middle Jurassic Belt Island in central Montana acted as a submarine constriction of the environment of deposition of member B. However, the reflux theory is unnecessary to explain the lack of halite in the upper half of the formation. The thin beds of gypsum indicate that evaporite deposition was not extensive enough to increase the concentration of halite

² Scruton's (1953) paper on the deposition of evaporites should also be consulted for further information on the theory of reflux.

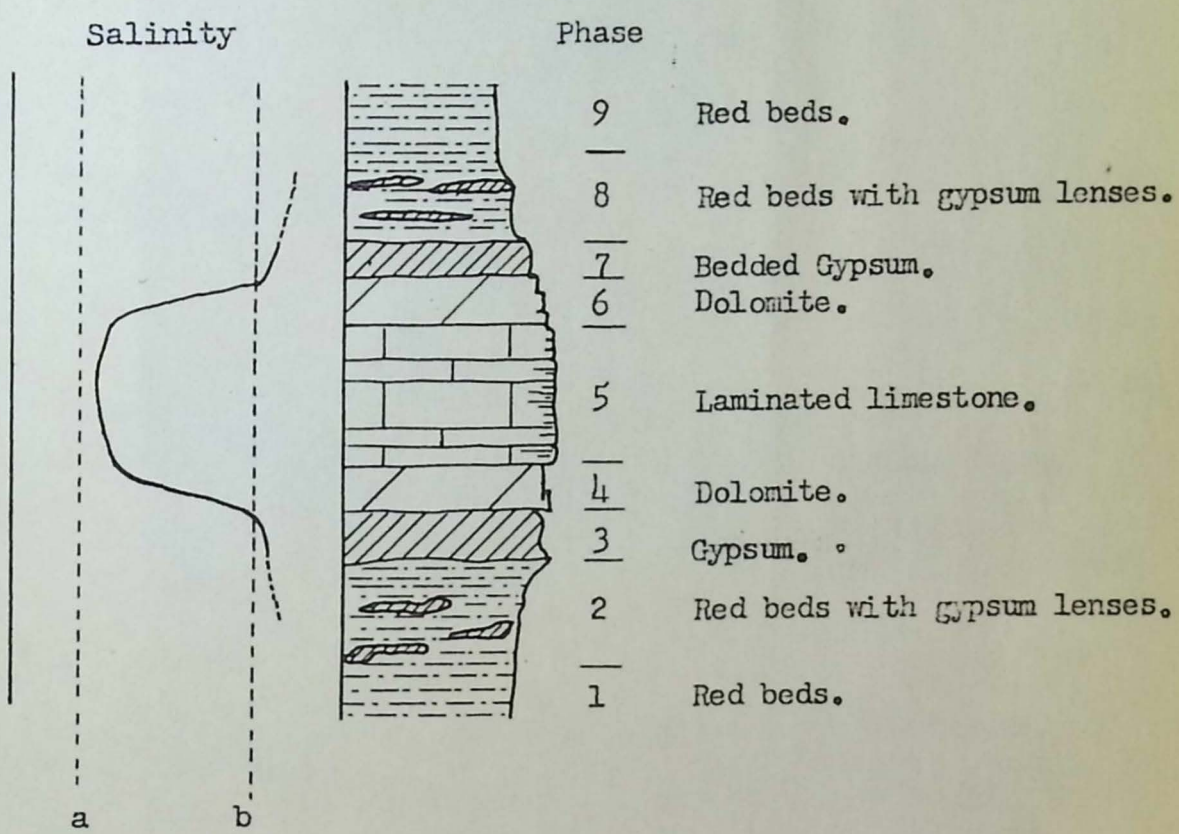
above the critical value necessary for precipitation. The lack of brecciation in stratigraphic sections containing large percentages of gypsum indicates that any halite formed was subsequently removed by solution prior to lithification.

Arid Cyclothem Hypothesis

Depositional sequence. The arid cyclothem is the sequence of evaporite and clastic deposition resulting from oscillations of sea level over a salinid in a dry climate (Fig. 13). The conditions of deposition are 1) dry climate, 2) systematically fluctuating sea level, and 3) a land surface of low slope and low relief. The relationship between water depth, salinity, and type of deposit are shown in Figure 13. It may be seen that gypsum is precipitated in the shallowest water at both ends of the cyclothem, dolomite is formed at an intermediate depth and salinity, and limestone is precipitated in the greatest depth of water and at the lowest salinity. An example of the transgressive half of the cycle is shown in Figure 14. Ideally, additional beds of limestone deposited in water of lower salinity than shown in Figure 13 could be added to the sequence. This extension would show phases of limestone which would contain normal organic development. However, such an extension is not shown by field studies. The lack of fossils in the Gypsum Spring limestone beds indicates that the salinity remained well above the average salinity



A



- a. Average salinity of normal marine environment.
- b. Minimum salinity necessary for the precipitation of calcium sulfate.

B

FIG. 13. Arid cyclothem. A) Cross section of a salinid showing distribution of environments. B) Idealized lithologic sequence.



23. Limestone

22. Yellow
shale

21. Silty
dolomite

20. Dolomite

19. Gypsum

18. Red beds

FIG. 14. Transgressive sequence at the base of member H. Section 10, units 19 to 23. Stratigraphic thickness from base of unit 19 to top of unit 22 is 6.0 feet. Unit 20 contains 20.0 percent insoluble residue, unit 23 contains 4.5 percent.

Spring formation. The complete character of the spring of these variables in hydrothermal deposition will be given later.

Each phase of the acid cycle then characterized by a hydrothermal which has a definite range of salinity, rate of particle precipitation, and possibly hydrogen-ion concentration, and oxidation-reduction potential.

of the Jurassic seas, but still within the range of calcium carbonate precipitation.

The regressive half of the arid cyclothem would theoretically be a mirror image of the transgression. The limestone of phase 3 would be overlain by dolomite, gypsum and gypsiferous red beds in that order. In members D, F, and H, however, the central limestone commonly grades upward into red silty limestone which in turn is overlain in only a few sections by dolomite stringers and gypsum lenses. The short stratigraphic interval of the regression indicates a quick return to continental conditions after sea level began to decline. The limestone siltstone gradation at the top of member F and in member D, may indicate the seaward movement of the strand line by the normal processes of seaward growth of the coast due to stream deposition.

Depth is the variable responsible for the sequence of deposition. Changes in climate, morphology of the basin, minor fluctuations in depth of water are largely responsible for the irregularities of the sequence found in the Gypsum Spring formation. A more complete discussion of the effect of these variables on cyclothem deposition will be given later.

Environment of deposition. Each phase of the arid cyclothem characterizes an environment which has a definite range of salinity, rate of clastic sedimentation, and possibly hydrogen-ion concentration, and oxidation-reduction potential.

Salinity of the shallow sea in a dry climate is inversely proportional to water depth and will be greater nearshore. Shallow, nearshore water will have a higher temperature and poorer interchange with fresh sea water, than will the water of deeper open sea. Consequently, nearshore waters will be precipitating gypsum, while calcite and dolomite will be formed farther from the coast.

Because of the gentle slope of the sea bottom seaward, the environments of deposition will parallel the shore in wide strips. A fluctuation in sea level will cause the geographic distribution of the strips and their accompanying environments to change accordingly.

Lithologic Evidence Supporting the Hypothesis

Lithologic sequence. With only casual examination, the beds in the upper part of the Gypsum Spring formation appear to be a colorful, but meaningless jumble of gypsum, red beds, varicolored shales, laminated limestone, and dolomite. More detailed stratigraphic study shows that nearly the same succession of beds occurs in each of the nonclastic members. Beds and stringers of gypsum and dolomite are commonly found at the base and less commonly at the top of nonclastic members D, F, and H. Laterally persistent beds of limestone are found in the center of the marine members in almost all sections. In addition, an ascending sequence of gypsiferous red

beds, bedded gypsum, dolomite, and laminated limestone is prevalent in the lower half of all three marine nonclastic members.

Continuity of beds. The gypsum and dolomite beds at the top and base of marine members D, F, and H are less persistent than the limestone in the center of the member. It is logical that the topography of the sea floor would have more effect on nearshore, shallow water sedimentation than on deeper water deposition. Therefore, the more persistent beds (phase 5) would be deposited farther from the shore line than the lenticular strata (phases 2, 3, 5, 7, and 8).

Clastic content of nonclastic phases. The relationship between lithology and distance of deposition from shoreline is supported by insoluble residues. The average dolomite from members D, F, and H contains 16.0 percent insoluble material, whereas the limestones contain an average of only 5.0 percent. The residue from the dolomite, in general contains larger quartz grains than is found in the residue from the limestone. Gypsum crystals were found in a few of the residues from dolomite, but were lacking in the limestone. If the rate of deposition of the carbonate minerals is reasonably equivalent, it follows that the dolomite was deposited closer to the shoreline than was the limestone.

Origin of Gypsum Lenses Red Beds Beds. Each of the thick

continental red beds separating various members D, E, and F contains lenses of gypsum at the top and base (Fig. 14). The environment of red bed deposition during Gypsum Spring time extended from the littoral zone through the coastal plain belt and graded into the floodplain and col-luvial deposits in the source area of exposed Chugwater red beds. The cyclothem arrangement of the nonclastic strata indicates that the environment of red bed deposition develops at the maximum of regression in an arid climate. However, it is difficult to determine from the sedimentary record, the seaward limit of red bed deposition. Red coloration resulting from clastic deposition of ferric oxide would be preserved in an environment as long as oxidizing conditions prevail. It is conceivable that in a warm, shallow sea, relatively free of organic material, oxidizing conditions would be maintained to a water depth of 50, perhaps, in excess of 100 feet. Therefore, the environment favorable to the preservation of red coloring matter could extend from 30 to 40 miles off shore. The seaward extension of red bed deposition seems improbable in the case of the Gypsum Spring formation. Microscopic examination of thin sections shows that most of the iron coloration is present as a film on the silt grains. Because the transporting power of currents in a shallow salinid is very definitely limited, it is doubtful that the silt and consequently the red coloring matter was transported more than a few miles from shore.

Origin of gypsum lenses in red beds. Each of the thick continental red beds separating marine members D, F, and H contains lenses of gypsum at the top and base (Fig. 15). The lenses could be the product of leaching of overlying gypsum beds and redeposition in the underlying soft shaly siltstones. Although a secondary mode of origin is possible, it is thought to be less probable when the following relationships are considered: 1) the lenses are oriented parallel to time planes even though bedding is lacking, 2) the lack of gradational contacts between the pure gypsum and the enclosing siltstone, 3) the lack of visual cause for secondary deposition, and 4) the occurrence of similar lenses in many other parts of the formation where no secondary action has occurred.

It seems more probable that the gypsum was deposited penecontemporaneously with the red beds. The gypsiferous red beds represent an environment corresponding to phase 7 of the arid cyclothem, where supersaline, coastal plain, mud flat conditions existed. Following the retreat of each of the three marine advances represented by members B, D, and F, intermittent streams transported red silt eroded from Chugwater red beds toward the shoreling in a north and west direction.

Direct flooding with supersaline sea water probably supplied the greatest volume of soluble salts to the evaporation flats along a wide belt parallel to the coast. Some of the gypsum may have been precipitated by evaporation of

supersaline ground water brought to the surface by capillary rise. Either source not only would supply the constituents for gypsum, but for halite and other more soluble salts as well. Although absence of sodium and magnesium salts in the



FIG. 15. White gypsum lenses in red-brown siltstone.
Section 10, unit 10.

likely deposited solution, but were... of each phase of the... is the result of chemical... of elastic deposition in the... are affected by... climate, 2) composition of the epicontinental sea... 3) water depth, and 4) morphology of the basin. If all four of these factors change at the same rate, the sediments deposited would not have systematic order. Changes in depth of deposition, however, had the dominant influence on the sedimentary record during Gypsum Spring time. Changes in the other three factors were probably unsystematic and less frequent, but nevertheless resulted in many departures from the systematic depositional sequence.

supersaline ground water brought to the surface by capillary rise. Either source not only would supply the constituents for gypsum, but for halite and other more soluble salts as well. Although absence of sodium and magnesium salts in the gypsiferous red beds has not been proven, it seems likely that the runoff from intermittent rainfall not only deposited red silt and reshaped the gypsum lenses by partial solution, but also removed any of these more soluble salts that were originally precipitated.

Factors Affecting Environmental Variables

Relative importance of factors. The lithology of each phase of the arid cyclothem is the result of chemical precipitation and clastic deposition. Both the salinity and rate of clastic deposition in the environment are affected by: 1) climate, 2) composition of the epicontinental sea as a whole, 3) water depth, and 4) morphology of the basin. If all four of these factors changed at the same rate, the sediments deposited would not have systematic order. Changes in depth of deposition, however, had the dominant influence on the sedimentary record during Gypsum Spring time. Changes in the other three factors were probably unsystematic and less frequent, but nevertheless resulted in many departures from the systematic depositional sequence.

Depth of deposition. Depth of deposition was the most important factor affecting Gypsum Spring sedimentation. Because of the small, uniform slope of the land surface, minor fluctuations in sea level caused interfingering of continental, evaporite, and nearly normal marine sediments. The shallowness of the salinid caused poor circulation, limited the seaward transportation of detritus, and increased the salinity of nearshore waters.

The high rate of evaporation of nearshore waters maintained a shoreward flow of normal marine waters under hydrostatic flow. Because of the decrease in water volume by evaporation, there was no corresponding seaward current. Consequently, the rate and amount of clastic deposition was greatest at the shoreline and decreased rapidly seaward.

Changes in water depth in the salinid may have been caused by one or a combination of the following three ways: 1) eustatic change in sea level, 2) small-scale epeirogenic movements, or 3) constriction of the trans-Canada seaway. The predominant, ultimate cause of the cyclothem deposition is difficult to determine.

Climate. The fundamental principle for the deposition of evaporites is that evaporation must exceed the combined volume of runoff, precipitation, and inflowing normal sea water which reaches the basin. Although a dry climate is assumed to be characteristic of the Middle Jurassic, a com-

plete lack of rainfall is not necessary for the precipitation of salts from sea water. Baker (1929) cites an example of salt deposition in lagoons on the Gulf of Mexico under a climate with a mean annual rainfall of 25 inches per year. Large changes in climate could produce a lithologic sequence which would be difficult to distinguish from parts of the arid cyclothem. An increase in aridity would increase the salinity, but would cause a decrease in the influx of clastics into the environment of deposition. This change in climate would result in a sequence resembling a regression, but theoretically could be distinguished from the true arid cyclothem by the lack of high elastic content in the more saline phases.

A change to a more humid climate would cause a decrease in the salinity, result in greater elastic influx, and cause precipitation of a lithologic series similar to that of a transgression, but the limestone phase would contain a high percentage of clastics. Recognition of sedimentary environments affected by the fluctuations of climate is difficult, because climatic changes result in a sedimentary record similar to that produced by changes in other variables. The siltstone-dolomite sequence interbedded with the gypsum beds of member B are the only lithologic features attributed to changes in environment resulting from fluctuations to a humid climate.

salinity of the sea itself. Although the salinity of the

Utah Salinity of the Utah sea. The open ocean during the Middle Jurassic may have had the same composition as sea water today. However, the Utah sea most likely had a higher concentration of dissolved solids and markedly different ionic proportions than did its Arctic Ocean source. Excessive evaporation in the Western Interior developed hydrostatic pressure which maintained a south-flowing current of normal ocean water from the Arctic region. The probable shallowness of the seaway and the presence of islands (Fig. 9) resulted in constriction of the flow. Consequently, the water became warmer and evaporation faster, which resulted in a southward increase in salinity within the trans-Canada seaway.

Changes in climate may have produced marked fluctuations in salinity at the margins of the sea, but affected the sea as a whole very little. The Middle Jurassic sedimentary and biologic record at the center of the Utah trough, indicates moderately deep water with a salinity not prohibitive to life (Imlay, 1952a). There is no lithologic evidence in the normal marine facies (Fig. 9) of large fluctuations in salinity corresponding to the rapidly changing sedimentary environments represented in the upper part of the Gypsum Spring formation. The Utah sea probably acted as a buffer body which diluted the highly saline waters returned to it from the flanking salinids without greatly affecting the salinity of the sea itself. Although the salinity of the

Utah epicontinental sea as a whole was only slightly altered, the ionic proportions may have been greatly different from those of normal Jurassic sea water.

Morphology of the basin. Changes in the shape of the sea bottom as well as in the position of the shoreline must have caused significant changes in the salinity and rate of clastic deposition in the environment. Delineation of these topographic features is difficult. Two examples of submarine topographic control of sedimentation are the gypsum lenses at the base of member F and the lenticular beds of dolomite, gypsum, and limestone in the clastic unit in the middle of member D. (See correlation Figures 44 and 53.)

Submarine ridges, and possibly islands, may have marked the geographic boundary between the salinid and the Utah sea. Unfortunately, the inaccessibility of certain exposures prevented the study of the transition from the normal marine sediments on the west and north across geographic boundaries to the evaporite sequence on the east.

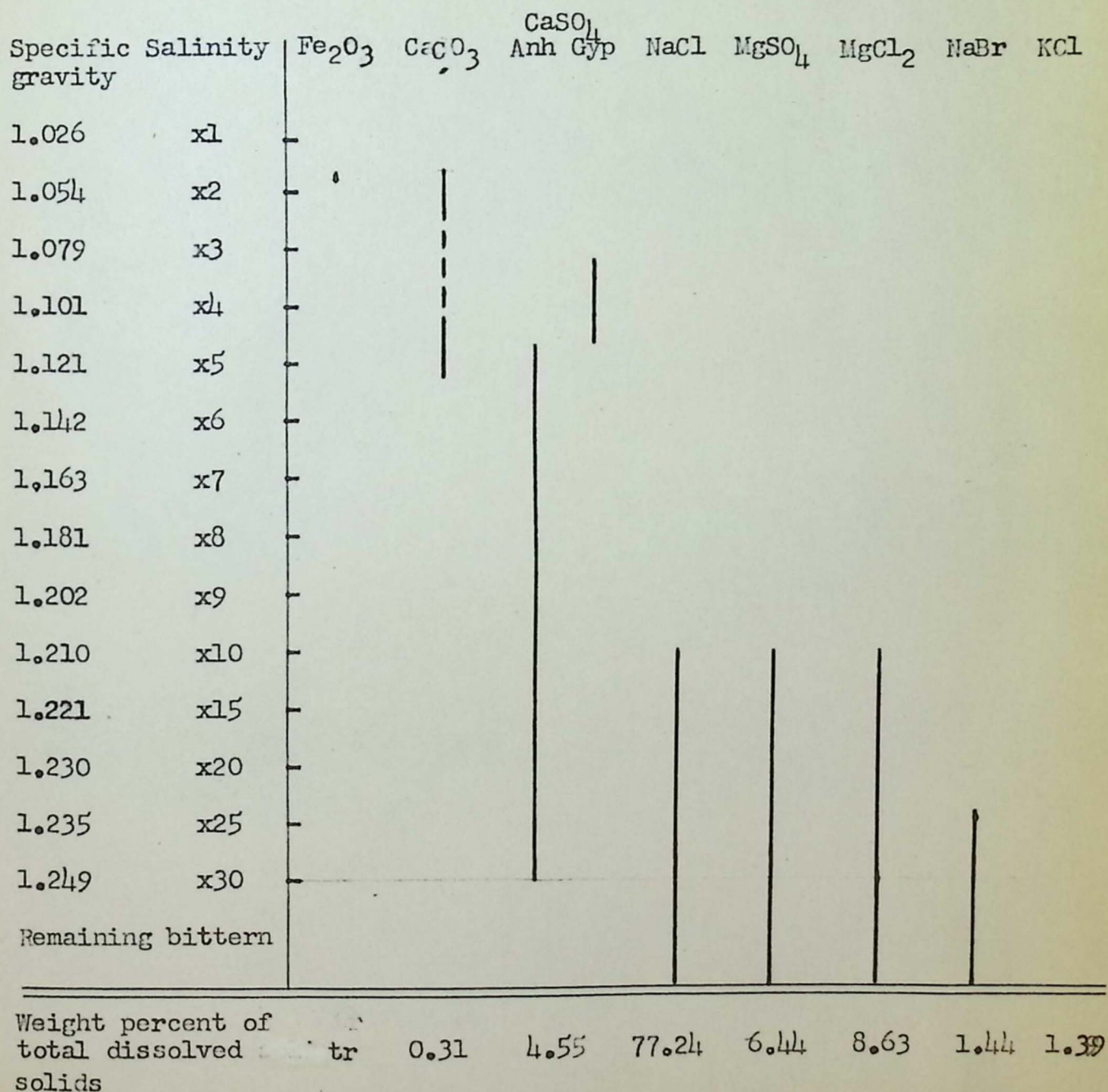
Chemistry of the Evaporites

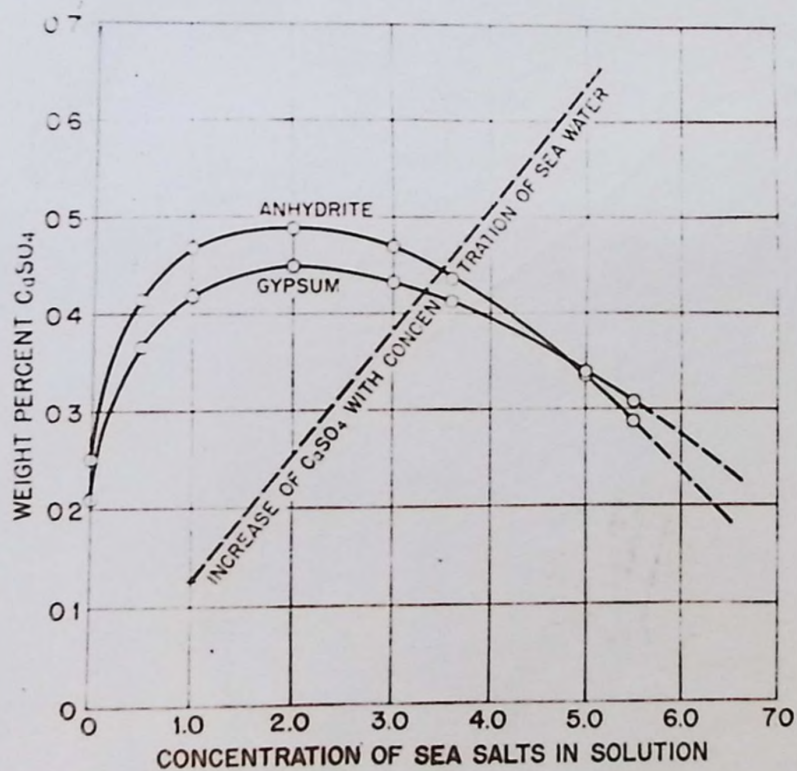
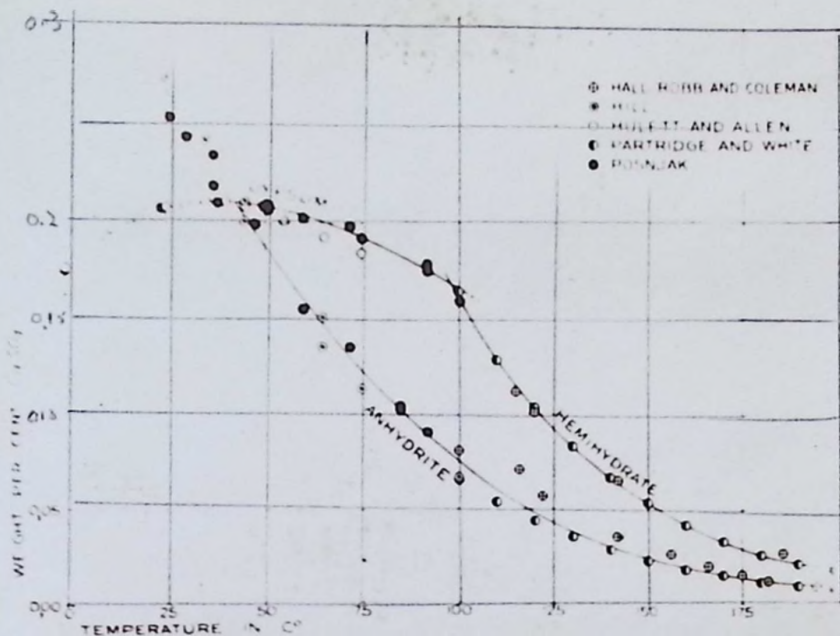
Order of precipitation. When ocean water is concentrated by evaporation, precipitation of the dissolved solids takes place in the reverse order of their solubilities, the least soluble first, the most soluble last. In the 1840's, Usiglio (Clarke, 1916) experimented with the evaporation of sea water and determined the order of deposition and quantity of saline

precipitates formed with increased concentration of Mediterranean sea water. Measurements of specific gravity and analyses of bitterns and precipitated salts were made at different stages in the process of concentration by evaporation. A portion of his results is summarized in Table 2. In water with a salinity up to ten times that of normal sea water, the minerals in order of precipitation are: calcite, gypsum, anhydrite, and salt. At higher concentrations slight changes in the ionic proportions produces different mineral suites (Phillips, 1947). These ultrasaline minerals are not present in Gypsum Spring beds and need not be discussed here.

The solubility of saline minerals depends on 1) temperature, 2) ionic concentrations, and 3) the presence of other ions. The effect of changes in environmental factors on the solubility of saline constituents has been only superficially studied, and remains a fertile field for research. Posnjak (1938; and 1940) is one of the few persons who has conducted exhaustive research on the change in the solubility of saline minerals with changes in salinity and temperature. In his studies of the system $\text{CaSO}_4\text{-H}_2\text{O}$, he found that from 0°C . to 35°C ., the solubility of gypsum increases with temperature, but above 35°C . it decreases with temperature. The solubility of anhydrite, on the other hand, decreases with increased temperature in the range from 25°C . to 200°C . (Fig. 16a). Below a concentration of 2, as shown on Figure 16b, the solu-

TABLE 2. Salts precipitated in concentration of sea water. After Usiglio (in Clarke, 1924), and incorporating modifications by Posnjak (1940).





B

FIG. 16. Change in the solubility of calcium sulfate: (A) with changing temperature, (B) with changing concentration of sea salts. (From Posnjak, 1938 and 1940.)

bility of both gypsum and anhydrite increases with increased concentration of sea water, and the solubility decreases with further concentration of sea salts. These relationships are presented in order to suggest the complex changes that take place in the solubility of other saline minerals with changes in environmental variables.

Usiglio's work indicates that there are certain ranges of salinity in which two or more minerals precipitate simultaneously. These mixtures are found in the Gypsum Spring formation as gypsiferous dolomites and dolomitic limestones. It also seems reasonable that environmental factors could interact to produce a range in salinity in which no precipitation of saline constituents takes place. The shale partings separating the nonclastic phases of the arid cyclothem in members D, F, and H may be the record of periods of marine deposition without precipitation of nonclastic rocks.

Rates of precipitation. The rate and kind of evaporite deposition depends upon the algebraic sum of the following factors: 1) rate of solar evaporation, 2) rate of rainfall, 3) amount of runoff from the adjacent landmass, and 4) rate of influx of sea water with lower salinity. The absolute rate of deposition cannot be determined, because quantitative figures are not known. One way to calculate the relative rate of deposition of saline salts would be to assume that the rates are directly proportional to the amounts of saline

minerals in solution in normal sea water. The rate of deposition in modern sea water (Table 2) would then be about 15 times greater than the rate of limestone deposition, because sea water contains 15 times as much calcium sulfate as calcium carbonate. In other words, during the same period of evaporation, and within the ranges of precipitation respectively for each mineral, 15 times as much calcium sulfate would be precipitated as calcium carbonate. Considerable research will have to be conducted on this subject before much will be known of the absolute rates of evaporite precipitation³.

Postdepositional changes. Solution, hydration, increased pressure and temperature result in the removal, redeposition, change to polymorphic forms, and change in chemistry of evaporite minerals. Thus gypsum may be changed to anhydrite, and anhydrite may be changed to one of its polymorphic forms, or to gypsum (Posnjak, 1938). Limestone may be changed to dolomite. Exclusive of solution, postdepositional changes have greater effect on minerals precipitated at higher concentrations.

³ The physico-chemical conditions necessary for the origin of dolomite in the Permian Castile sea has been estimated at 1.6 mm per year (King, 1947).

Solution is the most obvious postdepositional change affecting the Gypsum Spring formation. Comparison of surface sections with subsurface sections given by Love, et al. (1945) shows that changes from anhydrite to gypsum have occurred during the process of weathering which has exposed the formation.

Origin of dolomite. As seen in Table 2, Usiglio did not find dolomite in his saline residues. Subsequent experiments have failed to indicate the conditions under which dolomite can be precipitated directly at ordinary temperatures and pressures (Van Tuyl, 1916).

The repeated occurrence of dolomite in the same position in the arid cyclothem suggests either primary deposition or a secondary origin penecontemporaneous with deposition. The field relationships of the lithologic sequences suggest that dolomite, or the rock which was altered to dolomite, was deposited in water with salinity intermediate between that necessary for the precipitation of calcite and that necessary for the precipitation of gypsum. A postlithification origin for the dolomites in the Gypsum Spring formation seems improbable because closely associated limestones are not dolomitized.

The physico-chemical conditions necessary for the origin of dolomite are a subject for extended research with the same degree of detail in Posnjak's study of calcium sulfate.

If Middle Jurassic paleogeography (Figs. 5 and 6) has been Source of dissolved solids. The source of the large volume of saline salts remains the most perplexing problem in the origin of evaporite deposits. Baker (1929) calculates that the volume of the Castile anhydrite alone is 2.5 percent of the total volume of calcium sulfate in the oceans today. When the additional volume of the other large evaporite deposits is considered, it seems more than possible that the volume of evaporite material may exceed the total volume of dissolved solids in the oceans today.

There are many hypotheses concerning the origin and development of the ocean's salinity, but it is beyond the scope of this paper to discuss the subject, other than to mention possible sources of saline salts in the Gypsum Spring formation.

It is possible that the concentration of calcium and magnesium, as well as other elements in the oceans during the Middle Jurassic was considerably greater than they are today. Rankama and Sahama (1949, p. 294) calculate that only 2 percent of the calcium and 10 percent of the magnesium supplied to the sea water in the geologic past is in the ocean water at the present time. Inclusion in clastic deposits would account for a good portion of this difference. Chemical precipitation undoubtedly has also removed a large part from solution.

If Middle Jurassic paleogeography (Figs. 5 and 6) has been correctly determined, the waters which deposited the evaporites of the Gypsum Spring formation were essentially confined from the time hydrostatic pressure initiated their southward flow from the Arctic Ocean. Any addition to the saline content of these waters, either by normal terrestrial erosion processes or by volcanic emanations, would stay in the sea until removed from solution by inclusion in a clastic sediment or until precipitated by evaporation.

Minor amounts of bentonitic clays and tuffaceous siltstones have been found in the Gypsum Spring formation, indicating a possible volcanic source of saline material. Further investigations of the clastic portions of the formation may reveal a higher percentage of volcanic material.

Figure 8 should be consulted to obtain a rough idea of the beds included in each section.

For the purpose of correlation, the stratigraphic sections are projected to two lines of cross section (Fig. 1). Cross section A-A' is drawn S 75° W from Kharmpolis, Wyoming, (Section 18) and is 25 miles long. Cross section B-B' is drawn N 45° W from Noble Basin (Section 1) and is 25 miles long. The two cross sections intersect 7 miles north of Section 17. Because solution of gypsum has reduced the thickness of practically all measured sections, correlation based upon any single well trend in the region would not demonstrate adequately the continuity and uniformity of the nonclastic beds. The correlation charts accompanying the following lithologic discussion show more detailed strati-

LITHOLOGY

General

The Gypsum Spring formation is divided into eight members on the basis of continental clastic versus marine non-clastic environment. Members A and B are two different lithologies. Members C to H have similar lithologies and environments of deposition and will be discussed under a separate head. All of the members can be traced for at least 25 miles, and most can be recognized in all sections measured in Fremont and Hot Springs counties. The lithologies of adjacent members are generally gradational. Because the stratigraphic sections are drafted on such a large scale, contacts between them cannot be represented by a line. Figure 8 should be consulted to obtain a rough idea of the beds included in each member.

For the purpose of correlation, the stratigraphic sections are projected to two lines of cross section (Fig. 1). Cross section A-A' is drawn S 75° W from Thermopolis, Wyoming, (Section 18) and is 92 miles long. Cross section B-B' is drawn N 45° W from Noble Ranch (Section 1) and is 65 miles long. The two cross sections intersect 7 miles north of Section 17. Because solution of gypsum has reduced the thickness of practically all measured sections, correlation based upon any single unit found in the formation would not demonstrate adequately the continuity and uniformity of the nonclastic beds. The correlation charts accompanying the following lithologic discussion show more detailed strati-

graphic units which are based on local datum planes and are represented in Figures 44, 53, 56, and 69. The stratigraphic position of each datum is shown in Figure 8. The correlation of these datum planes, the spacing of the sections, and projection of the sections on the lines of cross section are shown in Figures 17 and 18.

Member A

Description. The basal red beds of the Gypsum Spring formation comprise member A. The red beds are red-brown siltstones ranging in thickness from 1 to about 50 feet. The siltstones contain iron-stained, subangular quartz silt ranging in size from less than 0.01 up to 0.05 mm. Approximately 10 percent of the red beds consist of clay size material.

A green, calcareous shaly siltstone ranging in thickness from 0.1 to 1.0 foot is found at the top of the member.

The red-brown color of member A has been altered locally to light green resulting in mottled areas (Fig. 19). Each mottled area is measurable in feet with the horizontal dimension 3 to 5 times larger than the vertical measurement. The green-colored areas are elongated parallel to the bedding, and their contacts with red-brown areas are clear-cut and transect the bedding planes. The shape and general discordance with bedding of the green areas surrounded by red-brown siltstone, indicate ground water alteration during the weathering process. Their general horizontal elongation

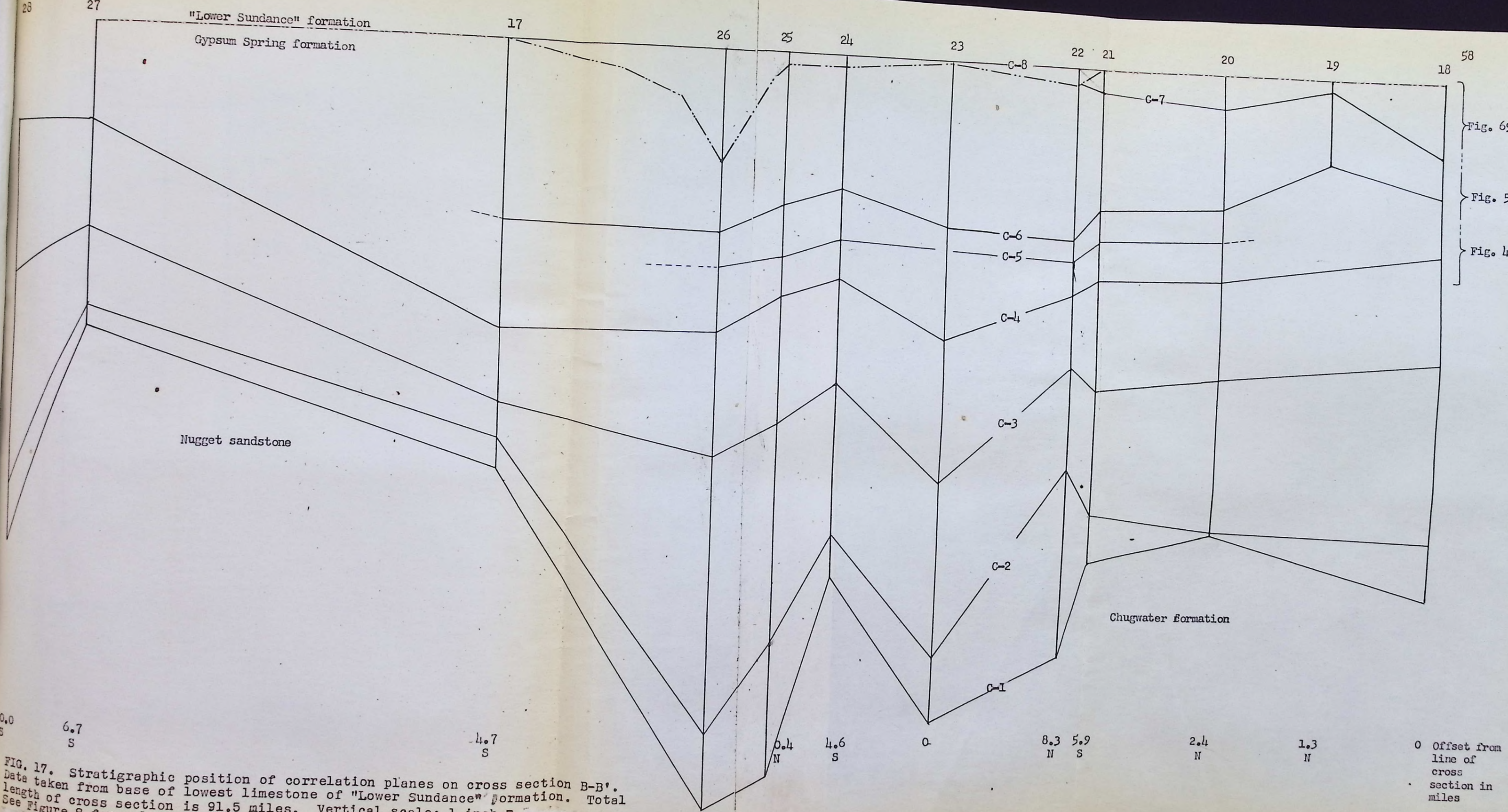


FIG. 17. Stratigraphic position of correlation planes on cross section B-B'. Data taken from base of lowest limestone of "Lower Sundance" formation. Total length of cross section is 91.5 miles. Vertical scale: 1 inch = 10.0 feet. See Figure 8 for relationship of correlation planes to member boundaries.

0 Offset from line of cross section in miles

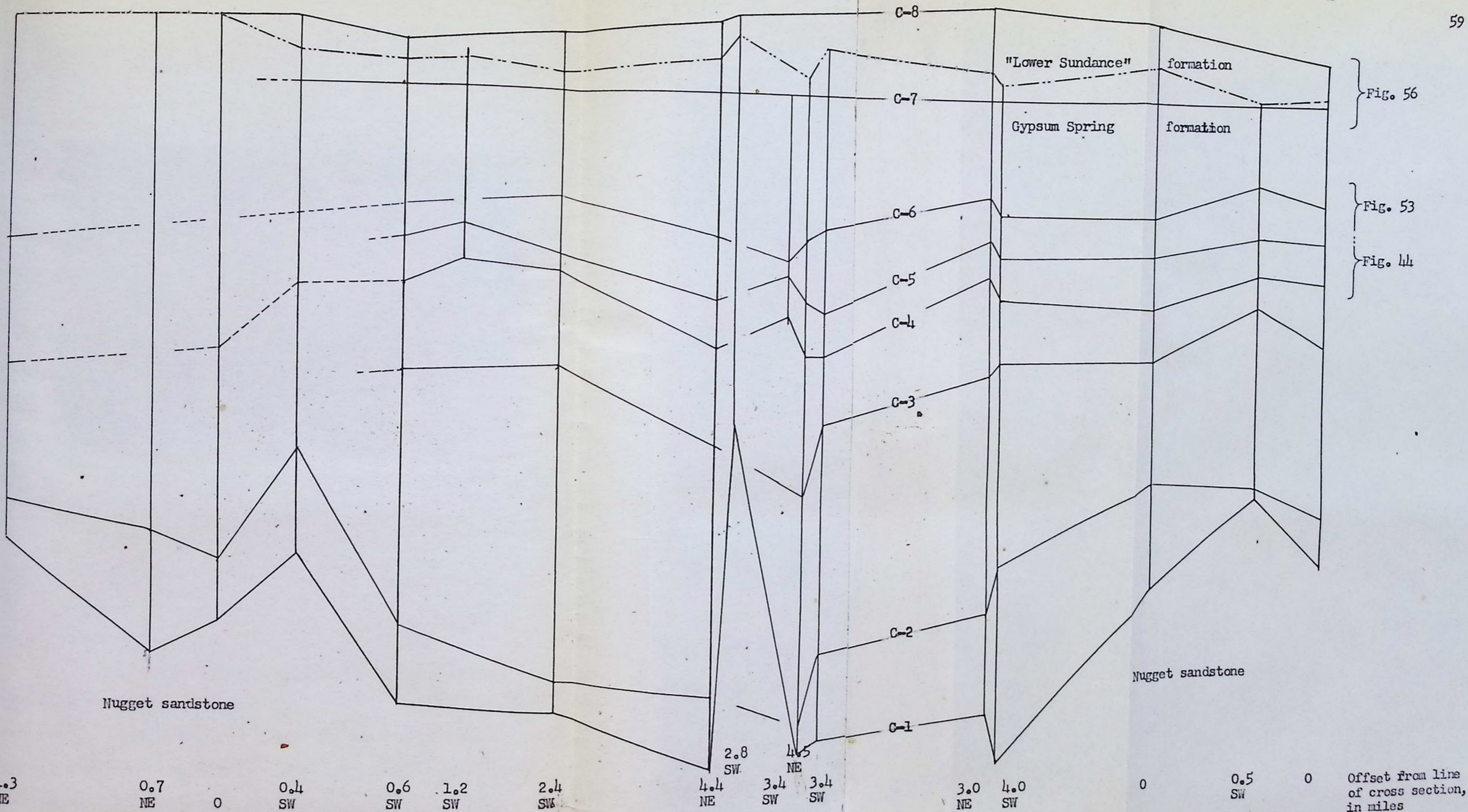


FIG. 18. Stratigraphic position of correlation planes on cross section A-A'. Data taken from base of limestone of member H in Sections 1 to 14, and from base of lowest limestone of "Lower Sundance" formation in Sections 14 to 17. See Figure 8 for relationship of correlation planes to member boundaries. Total length of cross section is 70.0 miles. Vertical scale: 1 inch = 30 feet. Horizontal scale: 1 inch = 5 miles.

reflects the greater ease of ground water movement parallel to bedding.

Basal Gypsum Spring formation contact. In the area



FIG. 19. Mottling in member A. White area is green, dark area at base and top of photograph is red-brown. Section 6, unit 1.

the Gypsum Spring formation lies on Nugget sandstone. Inlay (1950) suggests that the contact between the Nugget sandstone and the Twin Creek limestone (equivalent to the Gypsum Spring) is not gradational but represents a period of nondeposition.

North of the wedge-out of the Nugget formation in the Owl Creek Mountains, member A was deposited unconformably on the gently tilted beds of the Chugwater formation. Field measurements on the change in thickness between the top of a distinctive olive-yellow sandstone in the Chugwater and the base of the bedded gypsum of member B indicate that the regional dip of the Chugwater at the time of gypsum deposi-

reflects the greater ease of ground water movement parallel to bedding.

Basal Gypsum Spring formation contact. In the area investigated, the lower contact of member A is gradational to the underlying Chugwater or Nugget formations as the case may be. Along the west side of the Wind River basin, member A lies on the Nugget formation which is steeply cross-bedded and composed of rounded, fine-grained quartz sand. The uppermost part of the formation contains increasing amounts of very fine grained, angular sand and red silt. These transitional beds range in thickness from 0 to 30 feet. They are not laterally continuous, and intertongue as well as blend into the red beds of member A and the sandstones of the Nugget and Chugwater formations. Consequently,

West of the Wind River Mountains, the basal member of the Gypsum Spring formation lies on Nugget sandstone. Imlay (1950) suggests that the contact between the Nugget sandstone and the Twin Creek limestone (equivalent to the Gypsum Spring) is not gradational but represents a period of nondeposition.

North of the wedge-out of the Nugget formation in the Owl Creek Mountains, member A was deposited unconformably on the gently tilted beds of the Chugwater formation. Field measurements on the change in thickness between the top of a distinctive olive-yellow sandstone in the Chugwater and the base of the bedded gypsum of member B indicate that the regional dip of the Chugwater at the time of gypsum deposi-

tion was at least 2 feet per mile to the southwest.

In most areas, the poorly consolidated, red-brown siltstones of member A lie on the dark-red ripple-marked sandstones of the Chugwater formation. However, at Section 20, the bedded gypsum of member B lies directly on Chugwater beds.

Environment of deposition. If the Nugget sandstone is predominantly a wind-laid arid deposit, member A represents a change from desert eolian conditions to a semiarid, fluvial environment of deposition. Red silt and sand eroded from the exposed edges of the Chugwater formation in eastern Wyoming were transported to the Utah trough and deposited on the Nugget. Increased rainfall may have caused the increased erosion of Chugwater red beds and consequent encroachment of the streams on the former Nugget desert. Consequently, the upper layers of eolian sand were reworked and mixed with detrital red Chugwater silt and deposited in the depressions of the post-Nugget topography. Continued alluviation covered exposures of Nugget sandstone and deposited the fine red silt of member A.

The thickness of the individual units of the sequence is not uniform. The following features are common to most of the sequences studied: 1) the beds are predominantly red-brown siltstone, 2) green coloration is accompanied by less silt and more clay than the red siltstone, and 3) dolomite beds occur in the upper third of the layers.

A sequence of dolomite and green shaly siltstone is found at the base of member B in most sections (Fig. 13).

Member B

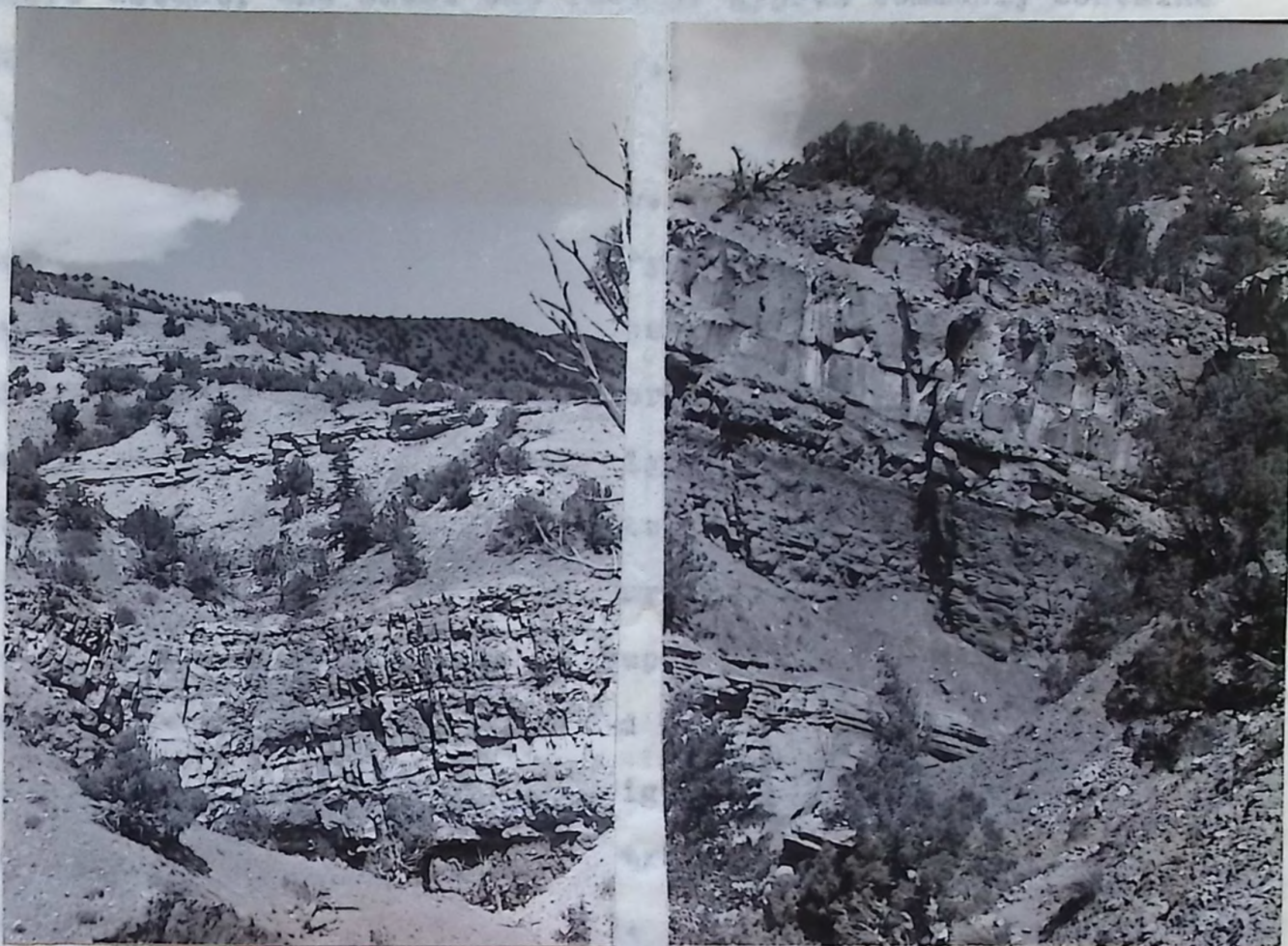
General. Member B is composed of 55 to 120 feet of gypsum⁴ in 3- to 12-foot beds (Fig. 20). Near the former termini of glaciers and in the larger valleys, the gypsum has been removed from outcrops by solution. In interstream areas, the gypsum forms a steep cliff and weathers into large joint blocks. The surficial 0.1 to 0.5 foot of these blocks is composed of a soft, coarse-crystalline aggregate of gypsum crystals mixed with slope wash of red silt.

The thick gypsum beds are separated by shale partings and by sequences of siltstone, shale, and dolomite, which range from 0.3 to 2.5 feet in thickness. Typical spacing of the rock types within the sequence is shown in Figure 11. No more than five sequences were found interbedded with the gypsum of member B in any one section measured. The aggregate thickness of shale partings and siltstone-dolomite sequences does not exceed 10 percent of the total thickness of the member. The thickness of the individual units of the sequence is not uniform. The following features are common to most of the sequences studied: 1) the beds are predominantly red-brown siltstone, 2) green coloration is accompanied by less silt and more clay than the red siltstone, and 3) dolomite beds occur in the upper third of the layers.

A sequence of dolomite and green shaly siltstone is found at the base of member B in most sections (Fig. 12).

⁴

Reported to be anhydrite in the subsurface (Love, 1945).



A B
 Columnar lamination can be traced for only a few inches,
 the bands of impure lamination can be traced for many feet

FIG. 20. Cliff-forming gypsum of member B, at Section 13. Nugget sandstone and members A, and C to E are also shown.
 A) Looking down dip, B) Looking along strike.

for the variety of bedding and internal structures. In general, the gypsiferous sandstones are grayish brown, silty, dense, fine-grained, and very brown. The average texture and structure of the sandstone of member B is shown in Figure 25. The average grain size ranges from 0.075 to 0.25 mm with an average of 0.15 mm. The defective laminae are 2 mm wide and are separated by a thin film of clay size elastic material, which prevents exhibiting sharp laminations. There is no change of crystal size across boundaries between laminae.

Where absent, the basal one foot of gypsum commonly contains 20 to 40 percent of reddish-gray, shaly, contorted dolomite (Fig. 21).

Gypsum. On a fresh surface, the gypsum is white, has a dense texture, and an average crystal size of 0.02 mm. Thin edges of the gypsum are translucent. On weathered surfaces, the gypsum is porous, coarsely crystalline with crystal sizes ranging from 0.05 to 0.30 mm (Fig. 22). The gypsum contains about 10 percent dolomite, quartz, and clay in silt and clay sizes. The majority of the impurities are concentrated in 5- to 15-millimeter bands made up of light-brown, wrinkled, paper-thin laminations separated by 1-millimeter laminations of white, translucent gypsum (Fig. 23). The bands are separated by 1 to 3 millimeters of translucent, white gypsum relatively free from impurities. Although each thread-like dolomitic lamination can be traced for only a few inches, the bands of impure laminations can be traced for many feet along the outcrop (Fig. 24).

Dolomite. The dolomites of member B are outstanding for the variety of impurities and internal structures. In general, the dolomites are laminated, gypsiferous, silty, dense, fine-crystalline, and gray brown. The average texture and structure of the dolomites of member B is shown in Figure 25. The crystal size ranges from 0.007 to 0.25 mm with an average of 0.01 mm. The dolomite laminae are 2 mm wide and are separated by a thin film of clay size clastic material, which promotes splitting along laminations. There is no change of crystal size across boundaries between laminae.

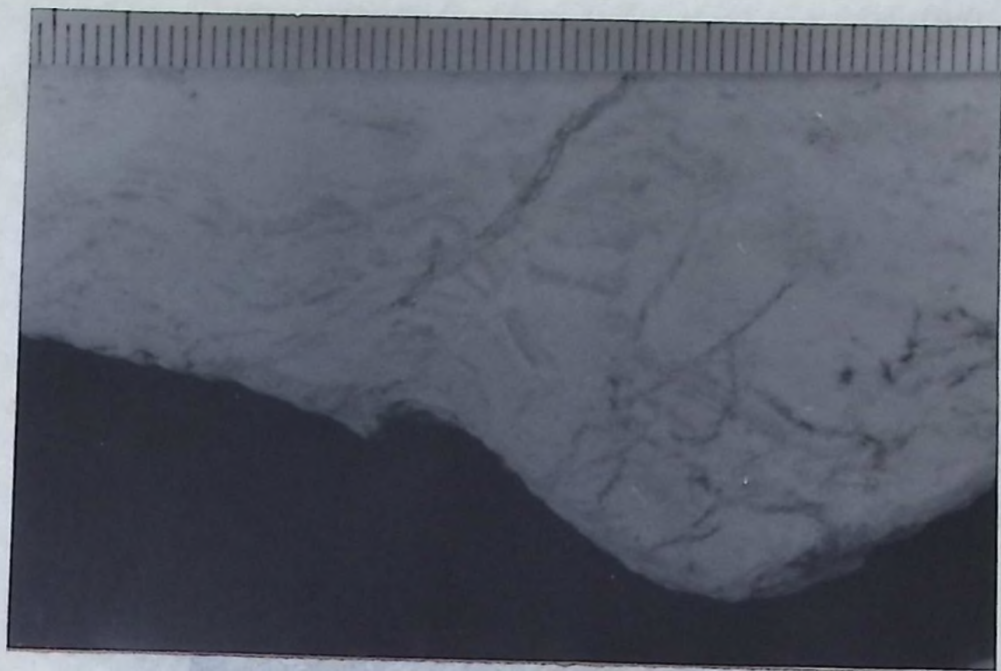


FIG. 21. Contorted dolomite laminae included in the basal gypsum bed of Section 18. $\times 1\frac{1}{2}$

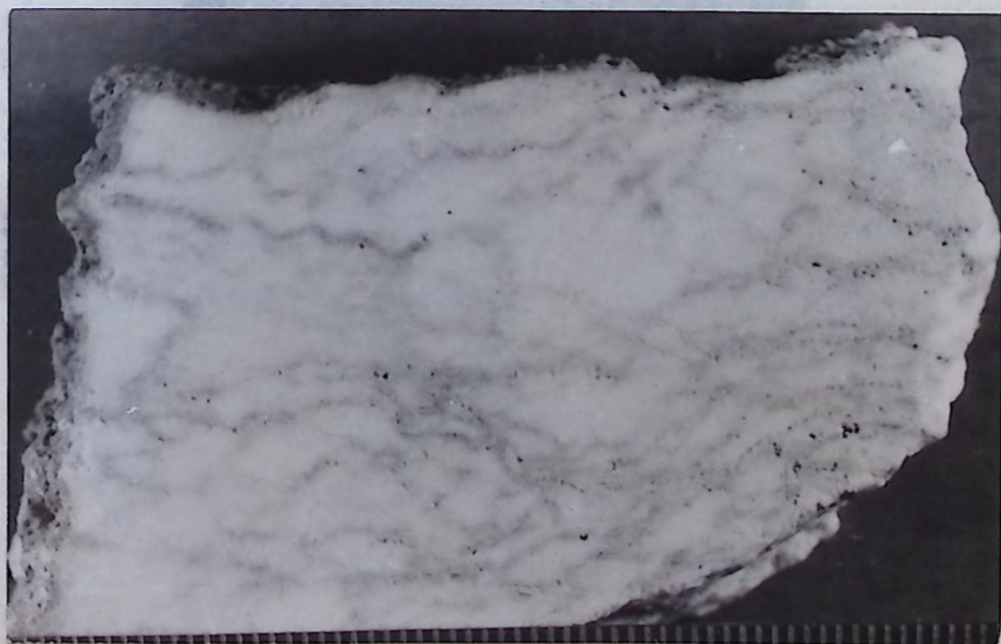


FIG. 22. White, weathered, porous gypsum with gray dolomite shale lamina. Section 5, unit 2. $\times 2$

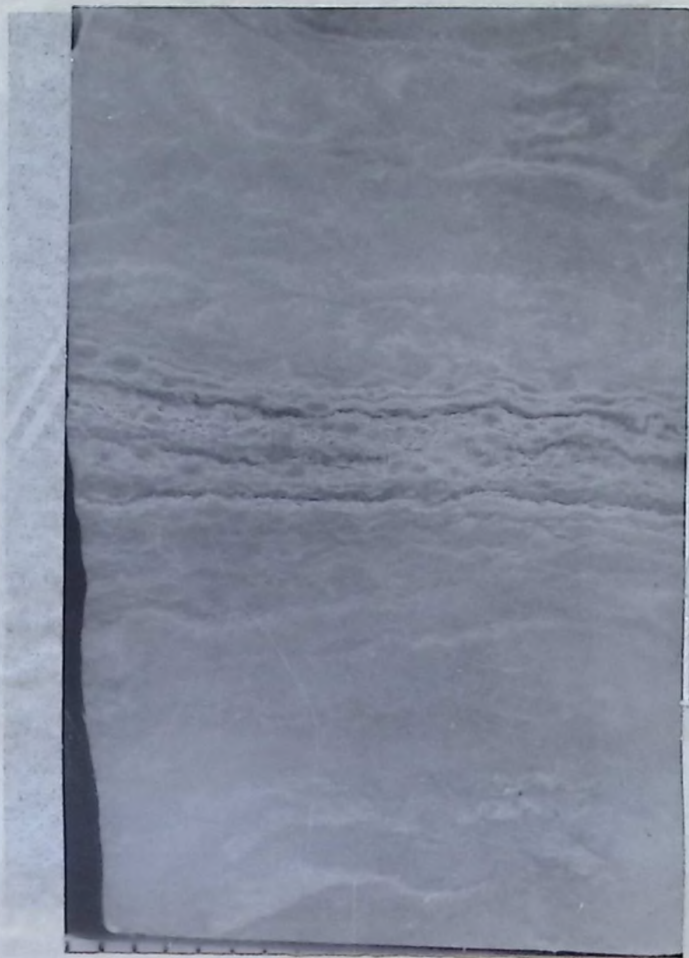


FIG. 23. Band of dolomitic clay laminations in white,
translucent gypsum. Section 13, unit 3. x4 Section 13.



FIG. 25. Slightly indurated dolomite from member B. Specimens contain 10.8 percent insoluble residue. $\times 3$

FIG. 24. Wavy, dolomitic shale bands in white, sugary gypsum from a slightly weathered surface. Each dark streak is a band similar to the one shown in Figure 22. Section 13.

The dolomites of member B contain 10 to 50 percent quartz silt and intergrown gypsum crystals. Although a large part of the gypsum is present as secondary fracture fillings, gypsum is also present as primary crystals (Fig. 26).

The dolomite contains alternating layers of white and red dolomite, 1.5 mm. thick. The dolomite is finely crystalline, and contains small, irregularly shaped crystals, 0.1 to 0.5 mm. in diameter, scattered throughout. The lowest 5 cm contain about 30 percent red silt, dolomite in broken and contorted laminations averaging 1.5 mm thick.

Above the basal 0.5 foot of gypsum, the member is banded.

FIG. 25. Typical fine-crystalline, slightly laminated dolomite from member B. Specimen contains 10.5 percent insoluble residue. x2

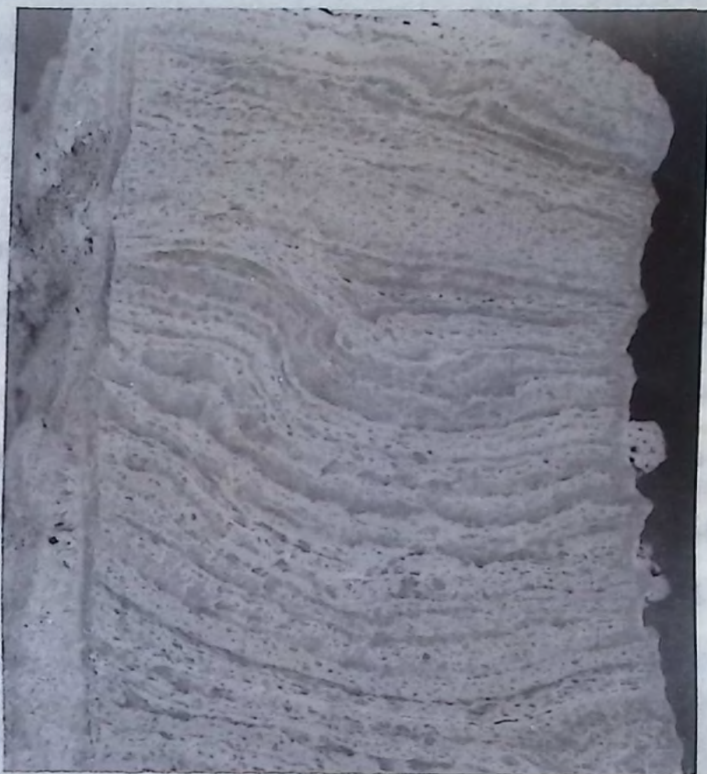
The chemical precipitate at the base of member B in Section 1 (Figs. 27 and 28) is an example of precipitation in waters of highly changing salinity. The bed is divided into two distinct parts by a deeply pocked-surfaced surface. The lower, lighter, finely crystalline part contains 0.01 mm dolomite crystals and subangular quartz silt. The upper, darker half contains approximately 40 percent crystalline, iron-stained dolomite; 20 percent detrital, subhedral, 0.5 to 1.0 mm quartz crystals, generally bipyramidal; 10 percent subangular quartz silt; and 30 percent gypsum (in part

The dolomites of member B contain 10 to 50 percent quartz silt and intergrown gypsum crystals. Although a large part of the gypsum is present as secondary fracture fillings, gypsum is also intermixed with dolomite crystals (Fig. 26).

The thin nonclastic bed at the base of member B contains alternating, crust-like laminations of red silty dolomite, and white gypsum. The thickness ranges from 0.5 to 1.5 mm. The dolomite laminae are fine-crystalline, gray to red, and contain a few gypsum crystals 0.5 mm in size. The size of the crystals within the gypsum lamina range from 0.1 to 0.5 mm. In a few sections, the basal dolomite is incorporated in the bottom part of the lowest gypsum bed (Fig. 21). The lowest 5 cm contain about 30 percent red silty dolomite in broken and contorted laminations averaging 1.5 mm thick. Above the basal 0.5 foot of gypsum, the member is banded similarly to the specimen shown in Figure 24.

The chemical precipitate at the base of member B in Section 1 (Figs. 27 and 28) is an example of precipitation in waters of highly changing salinity. The bed is divided into two distinct parts by a deeply pocked-marked surface. The lower, lighter, finely crystalline part contains 0.01 mm dolomite crystals and subangular quartz silt. The upper, darker half contains approximately 40 percent crystalline, iron-stained dolomite; 20 percent detrital, euhedral, 0.5 to 1.0 mm quartz crystals, generally bipyramidal; 10 percent subangular quartz silt; and 30 percent gypsum (in part

crystalline dolomite, in part (possibly) gypsiferous dolomite.
 The quantity of quartz crystals, which may be seen
 gypsum crystals (possibly weathered) and the presence of white
 gypsum and dolomite, as well as the presence of
 of the rock, which is generally vertically dis-



The lower part of the section is believed to be a continuation of the dolomite which is
 relatively of a few tenths of a foot of thickness of
 gypsum was deposited in the same localities as the
 the surrounding dolomite.

The dolomite is believed to have been deposited in water of low salinity.

FIG. 26. Light-red laminated dolomite. Dark bands composed of gypsum crystals 0.25 to 0.50 mm in diameter. Light bands are composed of finely crystalline silty calcareous dolomite. Section 20, base of unit 2. x2

the upper part of the section is believed to be a continuation of the dolomite which is relatively of a few tenths of a foot of thickness of gypsum was deposited in the same localities as the the surrounding dolomite.

Normally, the dolomite is believed to have been deposited in water of low salinity. The dolomite is believed to have been deposited in water of low salinity. The dolomite is believed to have been deposited in water of low salinity.

crystalline precipitate, in part clastic gypsum crystals). The quantity of quartz crystals, quartz silt, and loose gypsum crystals decreases upwards. The laminations of white gypsum and iron-stained dolomite, do not modify the profile of the underlying depositional surface, but concentrically reflect its irregularities for a considerable vertical distance.

The lower half of the specimen in Figures 27 and 28 is believed to have been deposited as evaporation increased the salinity of the sea from normal up to the point where gypsum would be precipitated. The normal sequence of a few tenths of a foot of dolomite overlain by a large thickness of gypsum was interrupted by exposure to low-salinity waters. The same low-salinity waters transported detrital quartz to the environment of deposition.

The laminated upper half of the bed indicates deposition in waters with an average salinity which overlapped the ranges of precipitation of both dolomite and gypsum. Because the irregular shape of the solution surface is reflected in the upper laminations, growth apparently was by crystal accretion upward from the salinid floor.

Solution breccias. In western Wyoming, unaltered exposures of the Gypsum Spring formation are not common. Normally, all or part of the gypsum of member B has been dissolved, leaving a breccia of the interbedded dolomites and siltstones (Fig. 29). Brecciation may be effective,

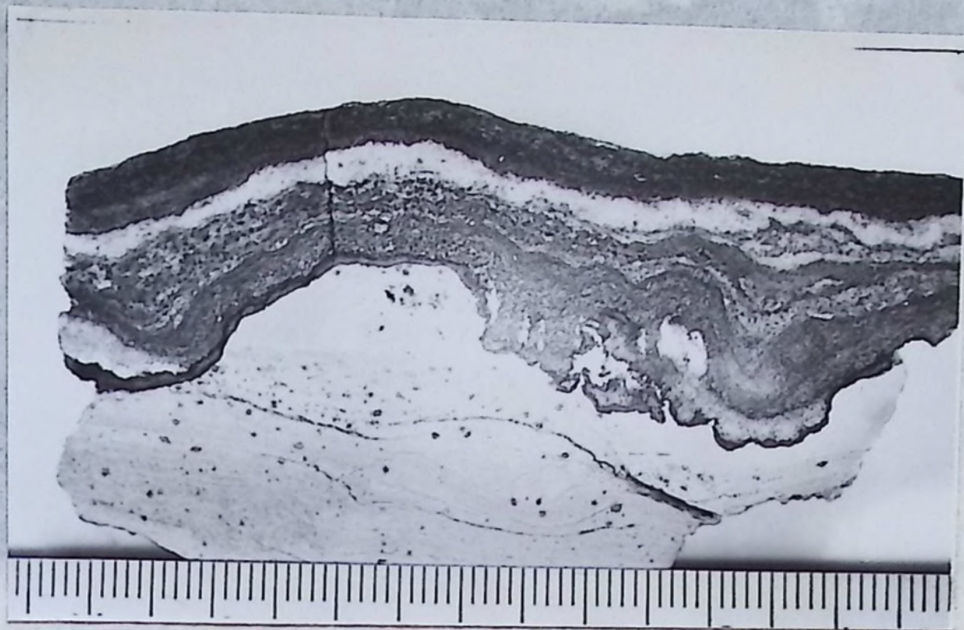


FIG. 27. Chemical precipitate at base of Section 1. $x1\frac{1}{2}$
 and altered dolomite. Scale. Taken east of Wind
 River in NE $\frac{1}{4}$, Sec. 11, T. 5 N., R. 3 W., Wind River Meridian.
 (Photograph by J. M. Kelly.)

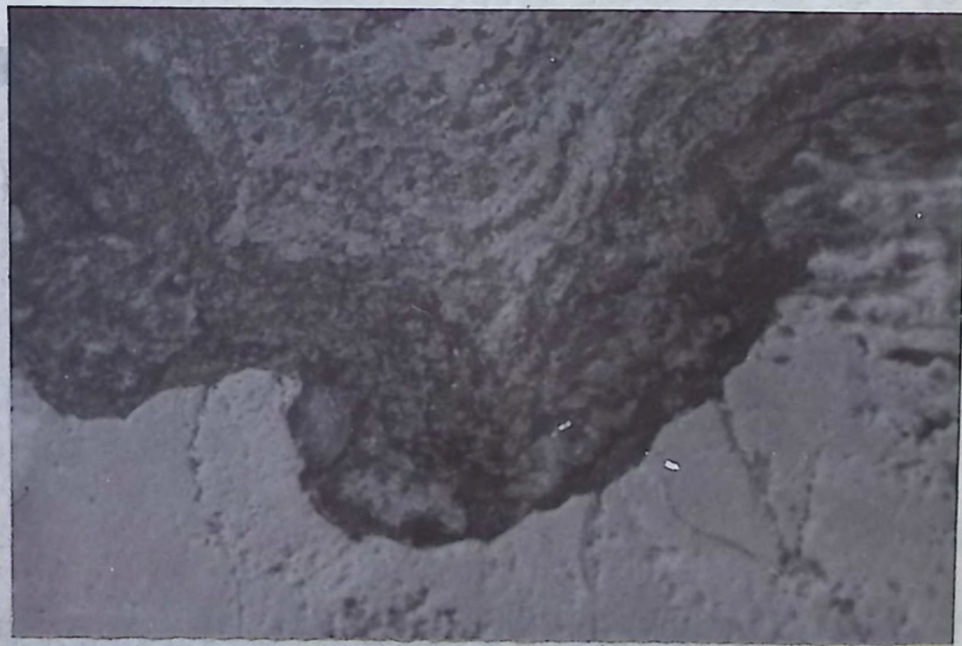


FIG. 28. Etched surface of specimen in Figure 27. $x7$



FIG. 29. Limestone-siltstone breccia. Result of solution of main gypsum bed and collapse of interbedded siltstone and altered dolomite. Hammer for scale. Taken east of Wind River in NE $\frac{1}{4}$, Sec. 11, T. 5 N., R. 6 W., Wind River Meridian. (Photograph by J. W. Kelly.)

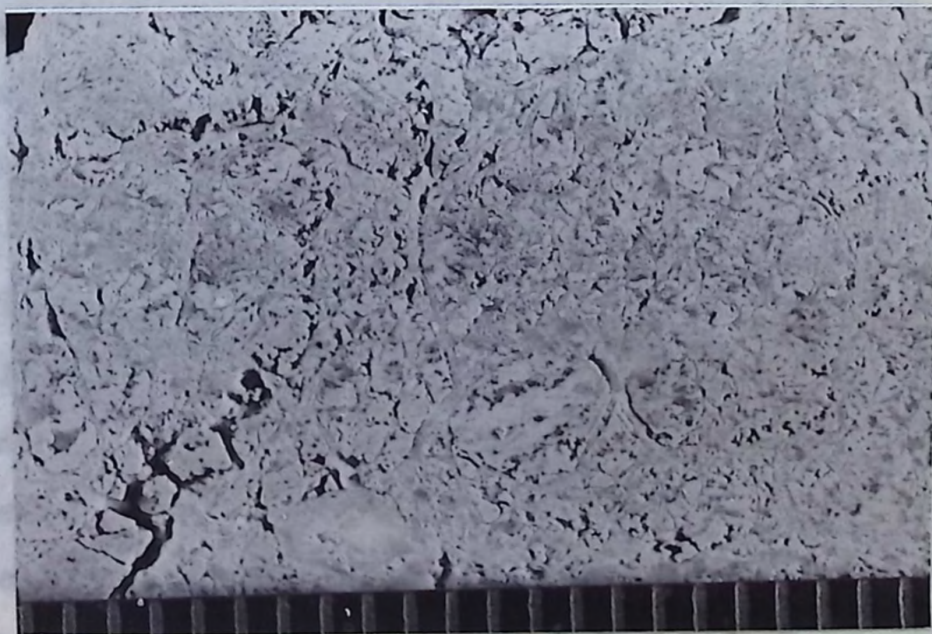


FIG. 30. Dolomite microbreccia. Section 28, unit 3. x5

even to microscopic dimensions (Fig. 30). In general, the breccias equivalent to member B are composed of angular 0.5-fragments of altered dolomite in a matrix of red-brown siltstone loosely cemented by calcite. Stratification of the breccia is caused by alternating layers of siltstone and limestone which settle as units as the intervening gypsum was removed. The initial stage of solution can be seen in the basal beds of gypsum shown in Figure 20.

Solution of gypsum in member B may occur so rapidly that almost all of the overlying units of the formation may be brecciated. However, the breccias of members C to H commonly remain as irregularly shaped beds, but internally are completely fragmented (Figs. 31 to 34).

Depth at which solution takes place could not be accurately determined. Section 9 on Crooked Creek is brecciated but has no gypsum exposed. The attitude of the overlying "Lower Sundance" beds is nearly horizontal at the outcrop face, but is 12 degrees to the northeast, 200 feet back. The absence of the gypsum indicates that solution takes place at a shallow depth. Proof of solution could be obtained if a hole was drilled 200 feet back from the exposure.

Brecciation was particularly prevalent near areas of Pleistocene ^{surfaces.} erosion and glacial moraines. These features are well-developed north of Bull Lake, and no gypsum is exposed north of Section 13.



FIG. 33. Siltstone breccia. Section 8, unit 1. x20

FIG. 31. Bed of recemented limestone breccia. Section 16, unit 10.

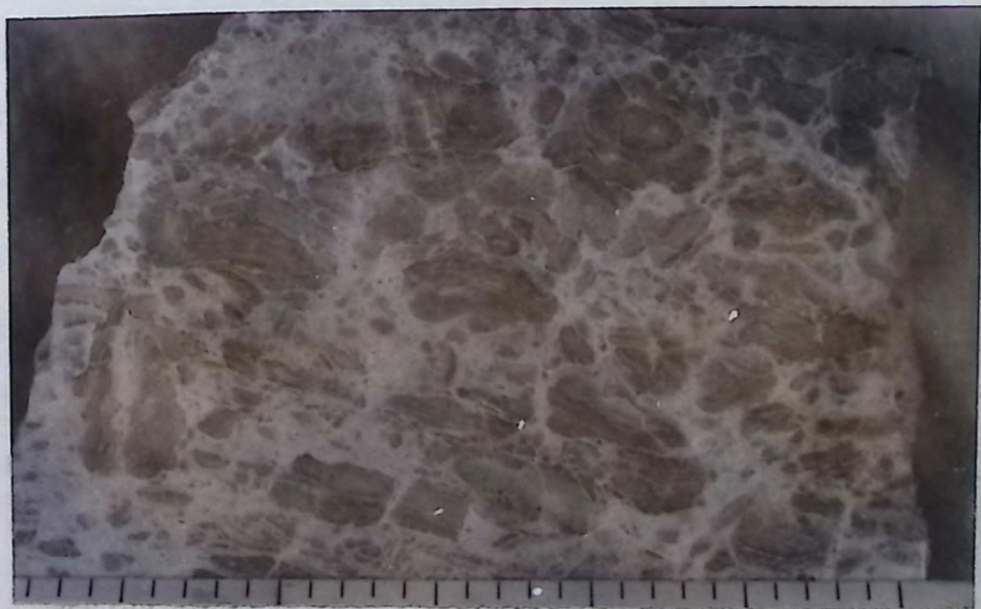


FIG. 32. Limestone breccia, cemented by coarse crystalline calcite. Photomicrograph of specimen from bed shown in Fig. 28.

FIG. 34. Siltstone breccia. Etched specimen, photographed with grazing light. Section 8, unit 9. x8

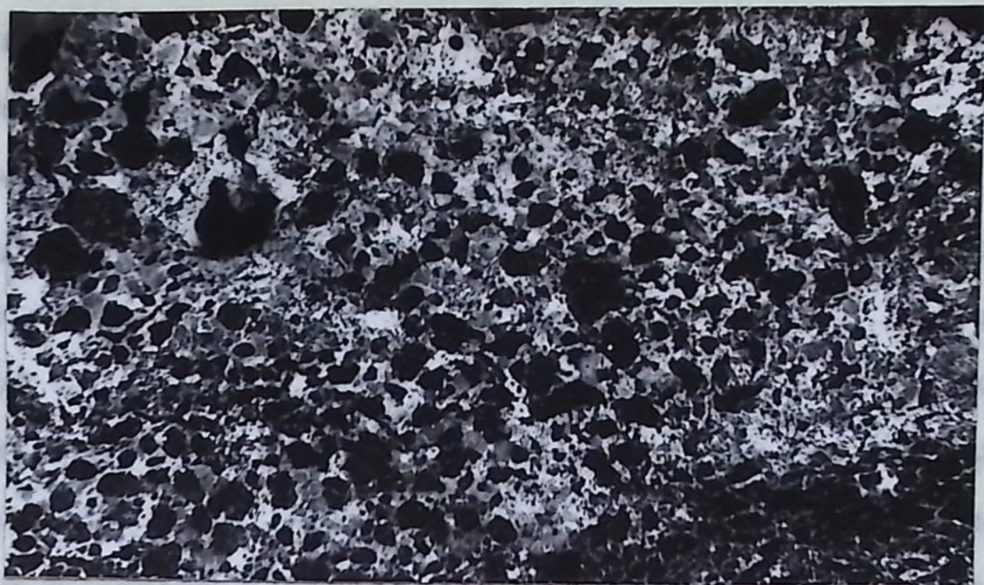


FIG. 33. Siltstone breccia. Section 8, unit 1. $\times 2\frac{1}{2}$



FIG. 34. Siltstone breccia. Etched specimen, photographed with grazing light. Section 3, unit 9. $\times 6$

Environment of deposition. The environment of deposition of member B is difficult to determine without knowledge of its relationship with adjacent sedimentary environments. The sedimentary record of the member in Fremont and Hot Springs counties, only indicates that the supersaline marine conditions were uniform throughout the area. The lamination and banding of the beds indicates that sedimentation was interrupted only by relatively minor fluctuations in evaporite precipitation and elastic deposition. In the case of member B, these fluctuations are believed to have resulted from climatic oscillations. Changes in climate, apparently, caused corresponding changes in salinity and rate of erosion of the adjacent landmass. The relation of width of laminations to time is conjectural. The paper-thin impure laminae (Fig. 23) may correspond to annual wet seasons in which little precipitation took place, whereas the laminae relatively free from impurities would correspond to dry seasons in which the rate of chemical precipitation was at a maximum. The larger 0.5- to 1.5-centimeter bands may correlate with alternating periods, a few decades in duration, of wetter and drier climates. The impurity-rich bands would be related to wet periods with deposited dolomite, limestone, and gypsum. The impurity scarce bands would be the record of dry periods with high evaporation. The cause of the broader climatic fluctuations is a problem for the meteorologist.

In contrast to the alternating fluctuations in climate that caused lamination of the gypsum and dolomite, the siltstone beds of member B are the result of sporadic sharp decreases in salinity produced by change to a wetter climate. Increased rainfall resulting in more runoff from coastal areas supplied abnormal quantities of red silt to the area of deposition. Some of these occasional climatic changes are recorded as siltstone partings a few tenths of a foot thick between gypsum beds. More pronounced changes toward more humid climate reduced the salinity below the concentration necessary for the precipitation of dolomite or gypsum. Subsequent concentration by evaporation after the return to the normal dry climate, caused precipitation of dolomite on the red siltstone. Further concentration raised the salinity to the normal level at which gypsum was continuously deposited.

Lithologic Types of Members C through E

The lithology of the upper six members is the record of rapid, but cyclic changes in sedimentary environment. Approximately two-thirds of the sediments are red-brown siltstone and green shaly siltstone; the other third are cyclically deposited dolomite, limestone, and gypsum. The petrology of each lithologic type is similar. General descriptions are given below.

Gypsum is found at the base and, in a few cases at the top of nonclastic members D, F, and H. In addition, many lenses of gypsum occur in the red beds between marine sequences. If a fresh specimen could be obtained, the texture of the gypsum would probably resemble the texture of the specimen shown in Figure 23. Because of the thinness of the beds and lenses, alteration and solution are effective for a considerable distance into the outcrop. Consequently, the texture of the gypsum at the outcrop is coarse crystalline and porous. The thread-like laminations of impurities are more crinkly and darker brown than on fresh specimens. (Compare Figures 22 and 23.)

In contrast to member B, the dolomites in the upper part of the Gypsum Spring formation contain little silt and no gypsum, are light gray, generally un laminated, and have a dense sublithographic texture. Dolomite beds generally weather into small irregularly shaped blocks, but in some sections weather into distinctive chalk-white, vertical splinters. The dolomites contain 9.5 to 25.0 percent sub-angular quartz silt ranging in size from less than 0.005 up to 0.07 mm. The clay mineral fraction is estimated to range from 10 to 50 percent of the insoluble residue. The average crystal size of the dolomite specimens ranges widely, but is generally less than 0.01 mm.

Brown-gray, laminated, fine-crystalline limestone (Fig. 35) is found at most outcrops in the middle beds of members D and F. The crystal size ranges from less than 0.006 to 0.02 mm with an average of 0.01 mm. The limestones contain an average of 5.0 percent subangular silt with an average grain size of 0.02 mm. Unequal distribution of silt defines the laminations in the limestone. The silty, laminations have a lighter color than the silt-free laminae and are more resistant to weathering. The width of the laminations ranges from 0.1 to 1.0 mm. In some specimens, the laminations of silty limestone occur in bands more than a centimeter in width (Fig. 36). About 25 percent of the limestones have a nearly even distribution of impurities and therefore are unlaminated.

The limestones also contain algal nodules, oolites, clastic calcite grains, and contorted laminations, but these types have limited stratigraphic distribution and will be discussed later under appropriate headings.

Red-brown, shaly, nonresistant siltstone constitutes 60 percent of members C to H. The color ranges from light red to dark brown, but most differences from the average red-brown color can be attributed to weathering. The siltstone locally forms resistant beds which are either sandy, calcareous, or dolomitic. Gypsum lenses and shale are more

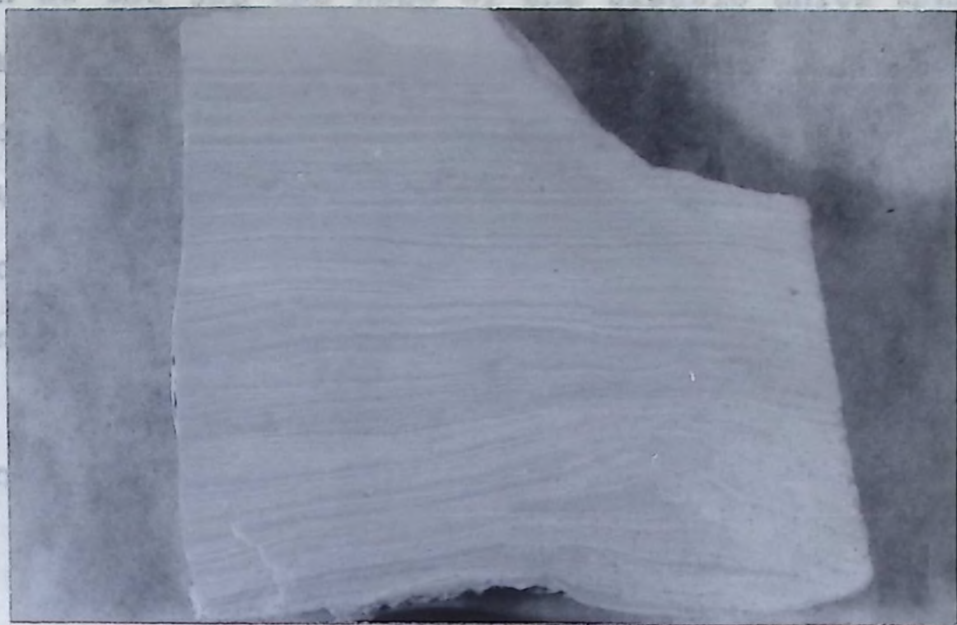


FIG. 35. Laminated limestone characteristic of members D, F, and H. Section 6, unit 20. x4

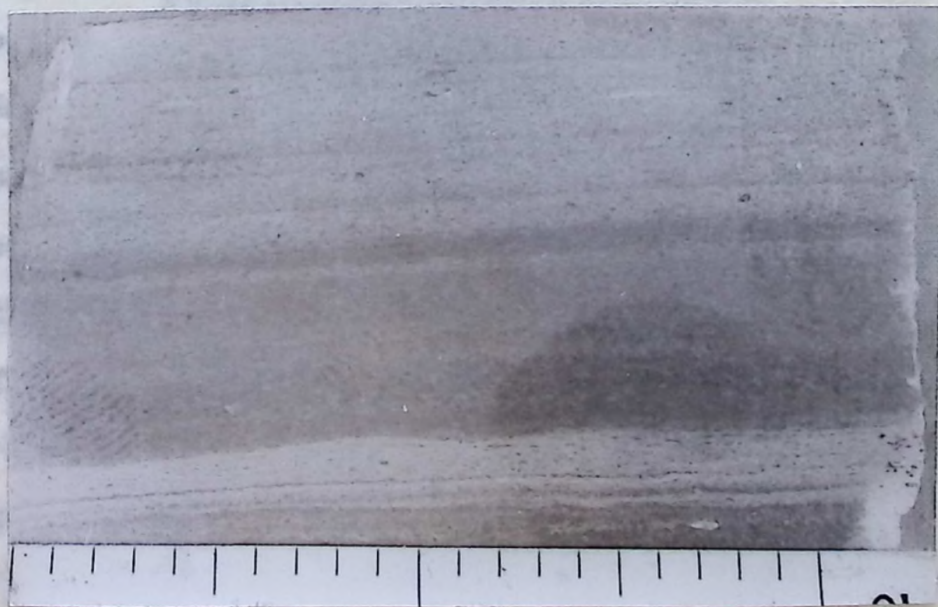


FIG. 36. Banded and laminated limestone. Thin, white streaks are silty. Section 9, unit 4. Etched, x2

common at the top and base of the clastic units than in the center of the members. Mottling is common in brecciated sections.

Varicolored, silty shales are found interbedded with the nonclastic beds of members D and F. The colors include combinations of green, red, purple, and brown, but shades of green are predominant. The shales are commonly calcareous and in a few cases contain gypsum.

Member C

Description. Member C is composed of nonresistant, red-brown shaly siltstone which contains gypsum stringers and lenses (Fig. 37). The siltstone is commonly mottled green or gray, but in Section 24, the upper half of the member is green. The thickness of the member ranges from 10 to 55 feet, but most sections are about 25 feet thick.

Except for a few very fine-grained sandstone layers in the upper half, the member is generally unbedded. In almost all sections the uppermost 1 to 3 feet contains more shale than the average composition of the member.

The gypsum of member C occurs in shapes and sizes that range from roughly ellipsoidal masses a half foot across, to stringers a foot and a half thick and several tens of feet long. In a third of the sections, the gypsum lenses of member C get larger toward the contacts of the member and

merge into the gypsum beds of members B and D. This feature may have been common to the other of the sections of member C, but is not recorded.



FIG. 37. Gypsum lenses in siltstone of member C. Section 24, units 2, 3, 4, and 5. Total thickness of units 3 and 4 is 35 feet.

depressions which formed the saline ponds. Further regression of the sea removed the saline ponds of saline water to the area. Consequently, few gypsum lenses are found in the central part of member C. The increased number of gypsum lenses in the upper part of the member, indicates that a supersaline mud flat environment returned to a portion of the area shortly before the deposition of the marine strata of member D.

merge into the gypsum beds of members B and D. This feature may have been common to the other of the sections of member C, but solution has removed the evidence from the sedimentary record.

In the vicinity of Section 11, deposition of bedded gypsum continued up to the time of deposition of member D. Consequently, the siltstone of member C is not present. (See Appendix.)

Environment of deposition. The red-brown siltstone of member C apparently was deposited on a saline mud flat. Deposition of gypsum in the thick, pure beds typical of member B was halted by regression of the sea and a general return to continental conditions. Gypsum continued to be deposited, however, in ephemeral saline ponds which were replenished with salt water by occasional large fluctuations in sea level as well as by tidal action. A few of the gypsum lenses were probably formed by precipitation of saline salts from ground water brought to the surface by capillary rise. Alluviation by streams filled the depressions which formed the saline ponds. Further regression of the sea removed the major source of saline water to the area. Consequently, few gypsum lenses are found in the central part of member C. The increased number of gypsum lenses in the upper part of the member, indicates that a supersaline mud flat environment returned to a portion of the area shortly before the deposition of the marine strata of member D.

Member D

General. The first group of nonclastic marine beds above the thick-bedded gypsum constitute member D. The lithology of the member can be divided into three parts: 1) the basal evaporite sequence corresponding to the transgressive part of the arid cyclothem (Fig. 13); 2) the central part which contains red and green shale with stringers of evaporites, representing lagoonal conditions; and 3) the algal limestone, and other beds possibly correlative with the regressive part of the arid cyclothem.

The thickness of the member ranges from 12 to 21 feet. The strata have remarkable areal continuity; some beds 3 feet thick or less can be traced for over 50 miles.

Basal evaporites. Beds of dolomite, shale, and gypsum 1 to 10 feet thick constitute the lowermost marine strata. The most persistent nonclastic bed of member D is a 2- to 4-foot bed of brown-gray, unfossiliferous, fine-crystalline limestone which overlies the basal beds (Fig. 38). It is used to define the reference plane in correlation Figure 44. In general, the dolomite and gypsum beds of member D below the reference plane thin to the south, and are not found south of Section 12, near Bull Lake. Gypsum, or its brecciated equivalent, marks the earliest marine nonclastic deposition of member D in only Sections 7, 8, 18, 24, 25, and 26. In almost all other sections the base of member D is marked by a white, blocky weathering dolomite 1 to 3 feet thick. Where present in the Wind River Mountains (Sections

1, 12, 13, and 14), this dolomite directly underlies the laminated limestone used for correlation. In the Owl Creek Mountains the dolomite is separated from the marker limestone by an



FIG. 38. Basal part of member D. Section 26, units 4 to 7 and parts of 3 and 8. Unit 3 contains a 4-foot bed of gypsum 2 feet below base of the dolomite of unit 4. Unit 5 is a green noncalcareous siltstone. Unit 6 is a brown-gray, laminated limestone. Unit 7 is a laminated limestone with red shale partings. Unit 8 is a red and yellow-brown shale.

23, 26, and 27), or white dolomite (Sections 4, 6, and 8), gypsum or its brecciated equivalent (Sections 7, 17, 20, 24, 25, and 26). These interbedded nonclastic rocks can be traced between adjacent measured sections in only a few localities.

Algal limestones. A brown-gray algal limestone is found at or near the top of the marine strata of member D. Because of its lateral continuity, the bed is used for correlation in Figure 44. One of the better examples of this bed is

1, 12, 13, and 17), this dolomite directly underlies the variety of shapes and sizes, but in general are 5 to 40 mm laminated limestone used for correlation. In the Owl Creek Mountains the dolomite is separated from the marker limestone by an interval 1 to 5 feet of green shale which contains a few thin stringers of dolomite and limestone. Gypsum crystals are found in this shale and was most likely formed by precipitation of gypsum dissolved from higher levels.

Central clastic beds. The prominent laminated limestone of member L grades upward into a red and green silty shale 5 to 12 feet thick, which locally contains over 50 percent nonclastic material. The gradation is marked by 0.5 to 3.5 feet of thin beds of red or gray, silty limestone separated by red and green, calcareous shale partings. Quantitatively, green and red silty shale comprise the greater part of the strata between the top of the limestone-siltstone gradation and the base of the algal limestone. However, this interval locally contains 1 to 5 feet of limestone (Sections 12, 22, 23, 26, and 27), or white dolomite (Sections 4, 6, and 8), gypsum or its brecciated equivalent (Sections 7, 17, 20, 24, 25, and 26). These interbedded nonclastic rocks can be traced between adjacent measured sections in only a few localities.

Algal limestone. A brown-gray algal limestone is found at or near the top of the marine strata of member D. Because of its lateral continuity, the bed is used for correlation in Figure 44. One of the better examples of this bed is

shown in Figures 39 and 40. The algal nodules exhibit a variety of shapes and sizes, but in general are 5 to 40 mm in maximum diameter, ellipsoidal, flattened parallel to bedding, and concentrically banded with alternate layers of dark-brown pure calcite and light-brown silty clastic limestone. The silty matrix of the bed, and the silty bands in the nodules, have a grain and crystal size ranging from 0.015 to 0.1 mm, and commonly contains angular fine-grained sand size fragments of brown calcite. The crystal size of calcite in the brown bands is approximately 0.015 mm. Some of the silty stringers that are transverse to the banding were implaced during burial and compaction. In other algal specimens, the silt was apparently included during the growth of the algae.

The algae range in form from the concentrically banded, megascopic fossils shown in Figure 41 to the small, fragmental, questionably organic remains shown in Figure 42. Despite the variety in shape, the fossil algae can be used for correlation because they are confined to the single bed near the top of member D as shown in Figure 44, and are not found in younger or older strata.

The uppermost marine beds of member D do not have uniform lithology throughout the area. The algal limestone is found in the majority of sections, but marks the end of marine deposition only in outcrops along the Wind River Mountains. In sections on cross section A-A' and in a few sections on B-B', the algal limestone is overlain by dolomite and gypsum stringers. These noncontinuous beds belong

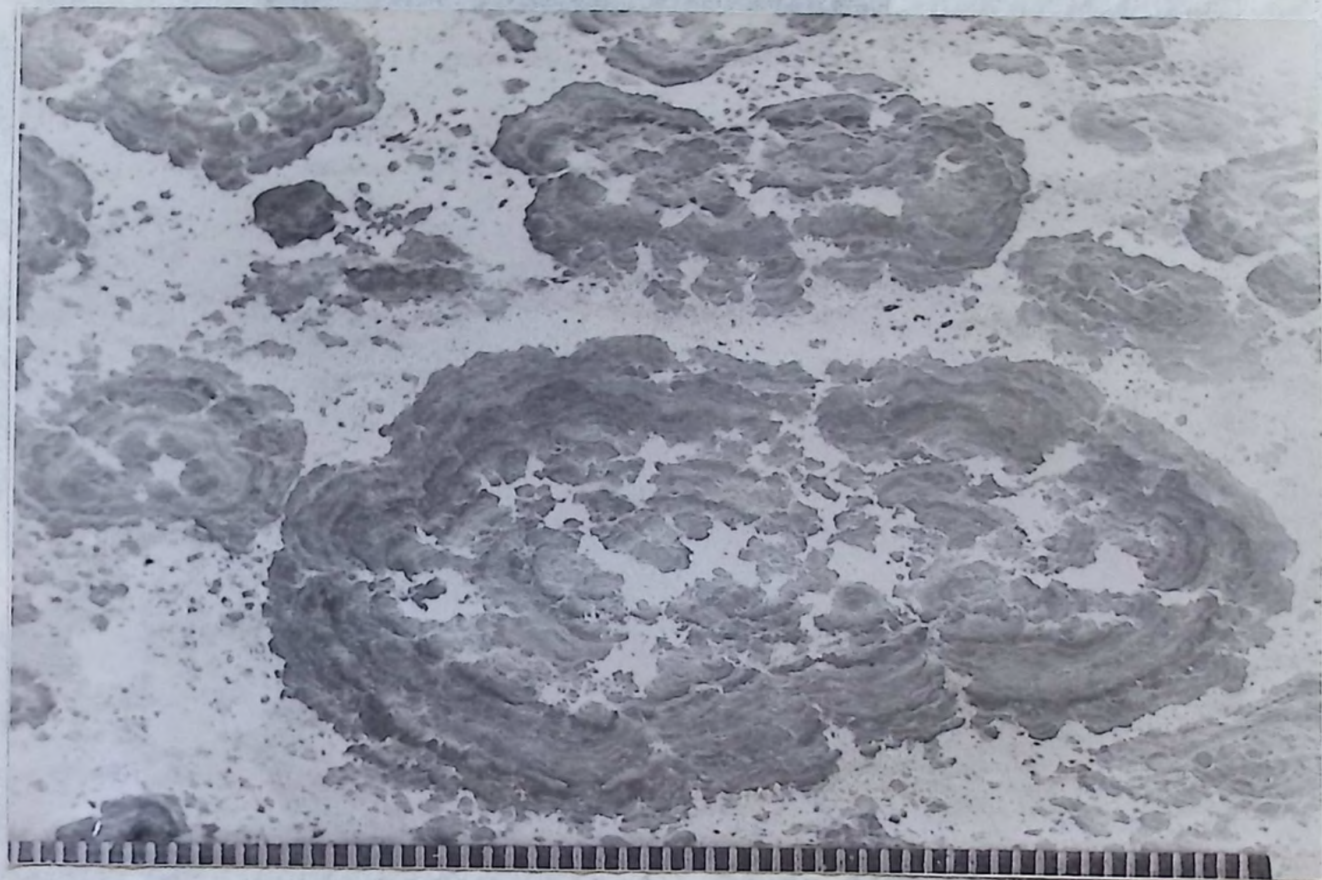


FIG. 39. Algal limestone. Algal nodules are fine-crystalline calcite embedded in a silty limestone matrix. Section 12, unit 5. (Fig. 40). Etched $\times 2\frac{1}{2}$



FIG. 40. Algal limestone bed. Brown algal nodules compose 80 percent of rock. Section 12, unit 5.

Fig. 40. Algal limestone bed. Brown algal nodules compose 80 percent of rock. Section 12, unit 5.

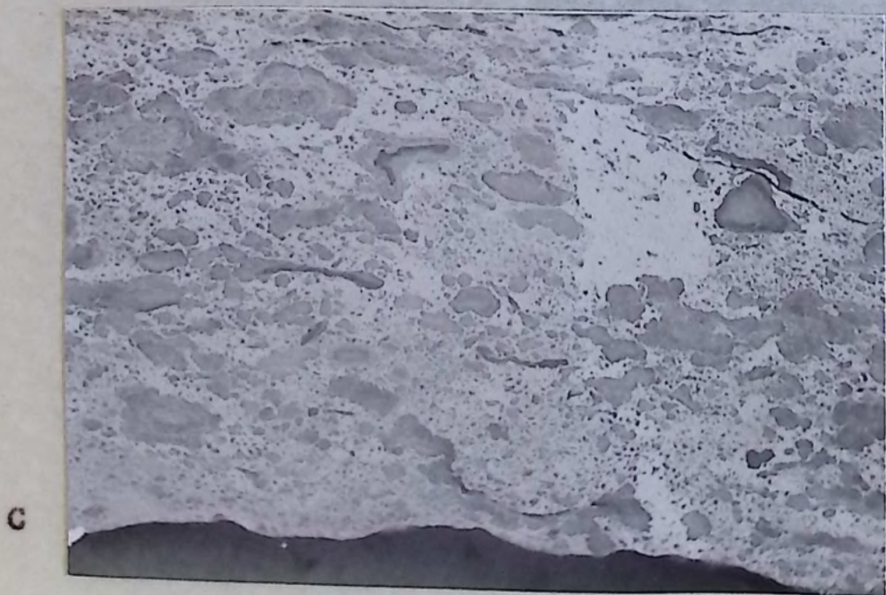
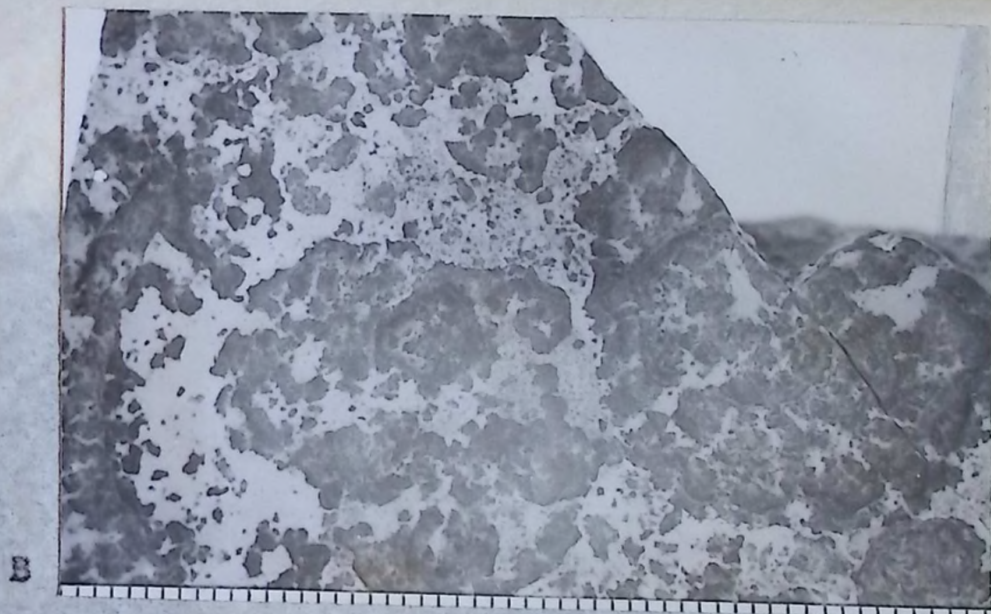
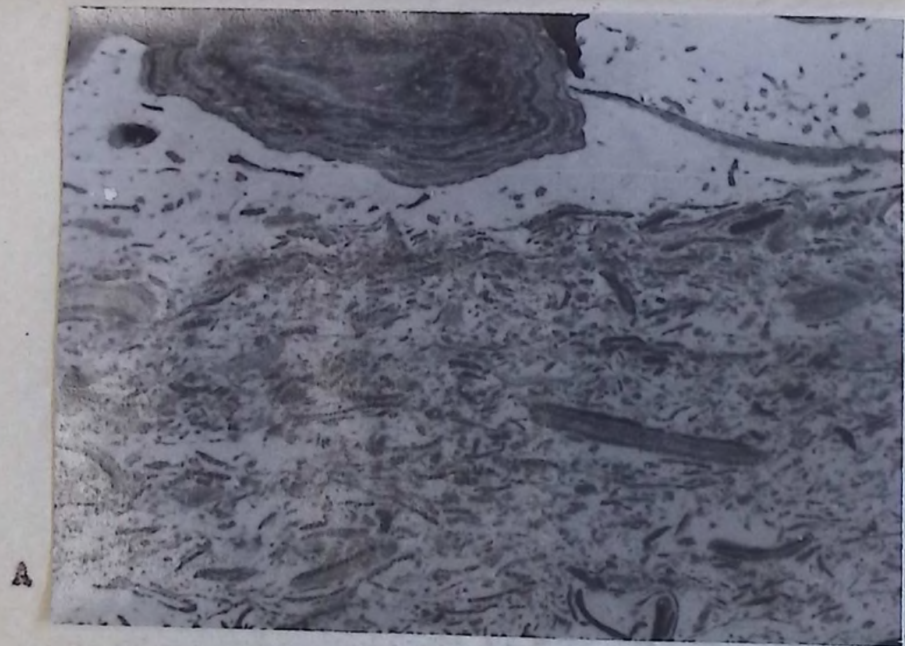


FIG. 41. Algal limestone illustrating varieties in shapes and sizes. A) Section 8, unit 8. $\times 4$. B) Section 26, unit 14. $\times 2$. C) Section 7, unit 8, $\times 2\frac{1}{2}$. D) Section 22, unit 14. $\times 4\frac{1}{2}$



A



B

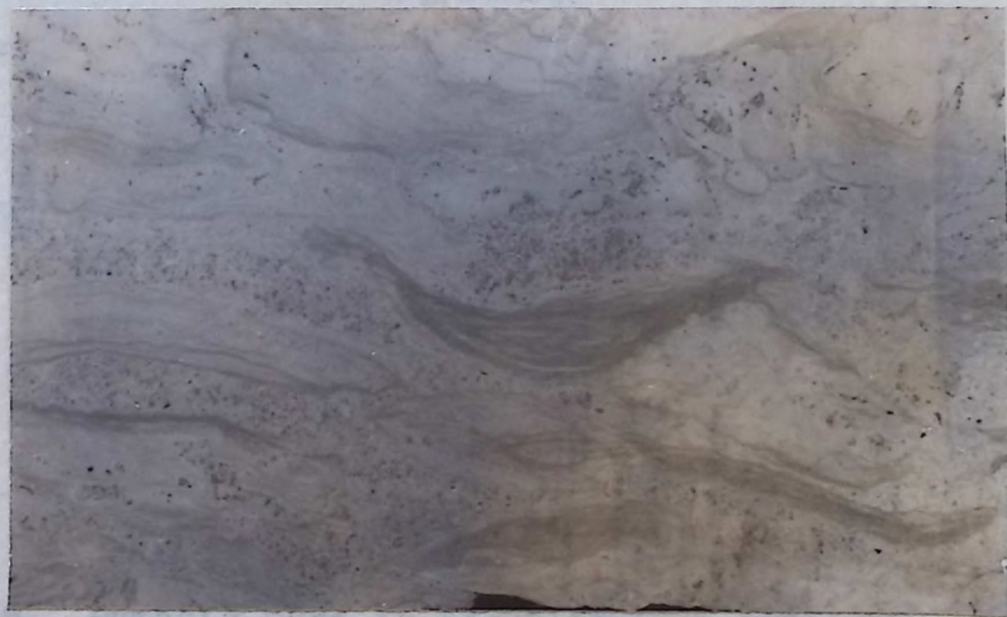


FIG. 42. Algal limestone. A) Section 11, unit 6. x4
 B) Section 5, unit 7. x8. C) Section 6, unit 7. x3


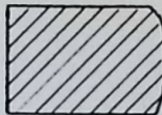

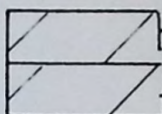

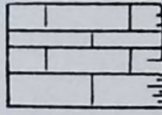

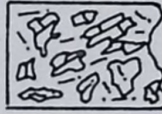



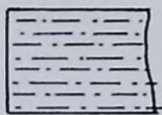

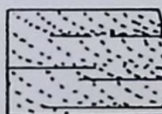

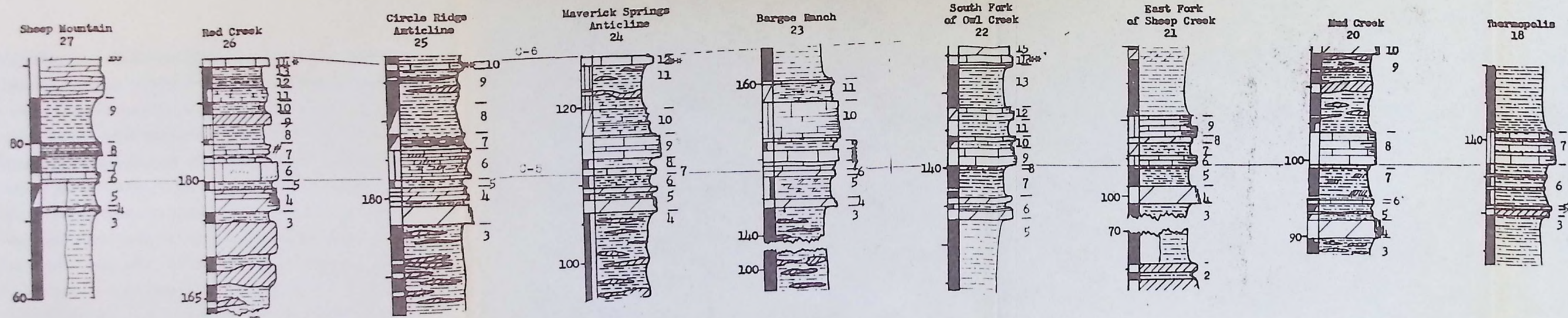
Color Symbols		Lithology Symbols	
	white, light gray		Gypsum
	dark gray		dolomite
	blue gray		limestone, laminated
	yellow, yellow gray		breccia
	green		shale
	red, brown		siltstone
	variegated		sandstone, cross-bedded
	mottled		
Special Features			
oo	oolitic		
##	fossiliferous		
**	algal		
bry	bryozoan		

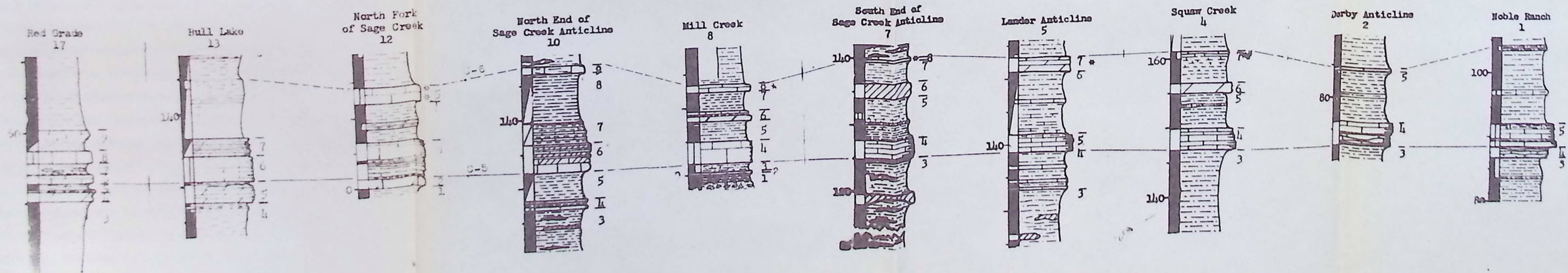
FIG. 43. Symbols used in stratigraphic sections.

A



A'

B



B'

FIG. 44. Correlation of member 3. See Figure 43 for explanation of symbols, Figure 1 for position of cross sections and location of measured sections, and Figure 8 for relation of adjacent beds to member 3.

to the regressive sequence of member D. In the eastern part of Owl Creek Mountains, member E is absent. Consequently, in this area, separation of the regressive phases of member D from the transgressive phases of member B is difficult.

Sedimentary environment. The littoral and coastal plain conditions of member C were replaced by the shallow, supersaline sea environment of member D. Member D can be subdivided into four units of different environments. In ascending order, they are: 1) initial shallow transgressing sea, 2) partially interconnected lagoons which had a wide range in salinity and rate of elastic deposition, 3) widespread moderately deep water of normal salinity capable of supporting lime secreting algae, and 4) regressive sea having limited distribution.

The nonclastic sedimentation of member D began as the sea transgressed from the north. As water depth increased, circulation became more efficient, and the salinity decreased. Consequently, gypsum, dolomite, and limestone were successively precipitated in the northern part of the area as the shoreline moved to the south.

In the northern part of the area, deposition of red beds with gypsum lenses (member C) was followed by the deposition of bedded gypsum (member D). At the same time, nongypsiferous red beds were being deposited in a continental environment in the south. Further southward spreading of the sea resulted in dolomite deposition over most of the area. The transgressive phase ended during the time when the salin-

ity was within the range of calcite precipitation. The lower salinity limit at which dolomite no longer formed was first reached in the northern part of the area. Therefore, the limestone bed is probably the time equivalent to part of the dolomite deposited at the base of member in the Wind River Mountains (Sections 1, 12, 13, and 17). The shale partings and nonclastic stringers in the initial transgressive beds of member D indicates that sedimentation was not a regular, simple function of water depth. Fluctuations in climate, changes in the shape of the basin, and irregular increase of water depth are causes of these departures from the ideal transgressive sequence.

The central clastic unit represents sedimentation in small, partially closed basins with wide range of marine environments. This is in contrast to the widespread, uniform marine conditions prevailing during the deposition of the limestone phase of the transgressive sequence. Depression of the sea floor (or rise of general sea level), ceased after the deposition of the subjacent, persistent limestone. Local restriction of circulation in basins caused by submarine bars, and possibly by minor tectonic adjustments, may have resulted in localized precipitation of these limestone, dolomite, and gypsum stringers. The general lack of silt size material in this unit indicates continuing marine conditions. Small portions of the sea floor may have been elevated for short periods of time and restricted flow of fresh sea water into

the salinid. The shoreline of the landmass was far removed from the sites of deposition represented in the sections and measured.

After the deposition of the middle elastic interval, the sea deepened and the environment was conducive to algal life. The algal limestone grades laterally into shaly limestone and dolomite (Section 5) which apparently are nearshore sediments (Sections 1 to 3, 12, and 18 to 20) of an environment unfavorable for algal life.

Deposition of the algal limestone was halted by an increase in salinity due to decrease in water depth. With a decreased supply of fresh sea water, the saline salts were precipitated quickly as thin, stringers in each of many topographic depressions in the sea floor and consequently, are not continuous. The complete regressive sequence is found only in Section 22, but in many localities, dolomite or gypsum lies between the algal limestone and the red beds of member D.

the north, however, was increased owing to the decreased water depth and poorer Member E with normal marine water

Description. Member E is the littoral and continental deposits which separate the marine deposits of member D from the marine nonclastics of member F. Red-brown siltstone is the predominant lithology, but marls, green siltstone, lenticular gypsum, and a tuff (Section 5) are also found. In the central part of the area (Sections 7, 10, 24, and 25) member

E is gypsiferous and in many cases it is impossible to separate the gypsum lenses from the gypsum beds of members D and F. Because of this gradation in lithology, the contacts of member E are impossible to establish in many sections.

From a maximum thickness of 31 feet in the central part of the Owl Creek Mountains (Section 23) member E thins both east and west to a feather edge. In the eastern part of the Owl Creek Mountains (Sections 18 to 22), and at Section 26 in the western part, member E is absent, which indicates that marine deposition was continuous in the northern part of the area beginning with member D and ending with member F.

Environment of deposition. Following the deposition of member D in the south, the sea regressed to the northern part of the Fremont County. Ephemeral, low gradient streams deposited silt and clay size material on the coastal plain south of the shoreline, but marine conditions were continuous in the northern part of the area. The salinity of the sea in the north, however, was increased owing to the decreased water depth and poorer interchange with normal marine water farther to the north and west.

The position of the shoreline divided the area into three sites of sedimentary deposition: 1) the coastal plain in the south, 2) the littoral zone and mud flats in the central part of the area, and 3) the shallow supersaline sea in the north. The sediments deposited at the first two

are equivalent of all three.

Basal nonclastic. Gypsum, or a solution breccia, generally marks the base of member F in the Owl Creek Mountains.

sites of deposition comprise member E. The sediments deposited at site 3 are equivalent marine beds included in members D and F. The environments of the three sites grade laterally and are contemporaneous. While red-brown siltstone was being deposited in the south on the coastal plain, gypsiferous siltstone was being deposited closer to the shoreline and, at the same time, evaporites and varicolored shales were being deposited in a shallow supersaline sea in the northern part of the area.

Member F

General. Member F is the record of the third marine advance in Gypsum Spring time. It is underlain and overlain by sequences of continental red beds which are up to three times thicker than the marine strata. With one exception, Section 26, the thickness of the member ranges from 6 to 27 feet. The member is predominantly a laminated limestone which grades upward to a red silty limestone. The base of this bed is used as the datum plane in correlation Figure 53. The lithology of member F may be divided into three parts: 1) basal nonclastics, 2) gradation of laminated limestone to red siltstone in the center of the member, and 3) supersaline deposits. An oolitic, fossiliferous and gypsiferous facies found in the northwestern part of the Wind River basin is the equivalent of all three.

Basal nonclastics. Gypsum, or a solution breccia, generally marks the base of member F in the Wind River Moun-

tains. This gypsum is a lenticular mass up to 12 feet thick and crops out between Section 2 to Section 11. It is separated from the overlying middle limestone by less than 2 feet of red and green shale (Fig. 45). Dolomite was not found between the two beds. Although dolomite is ^{the} only nonclastic bed in the lower part of the member in Sections 12 and 13, the breccia beds in the upper part of the Gypsum Spring formation in sections north of Bull Lake (Fig. 1) indicate the former presence of the gypsum bed in the northern part of the Wind River Range.

In the eastern part of the Owl Creek Mountains (Sections 18 to 22), gypsum was not found below the limestone used as a datum plane shown in correlation Figure 53. Instead, the basal beds of member F contain stringers of white, sublithographic dolomite, and red-brown siltstone which contains gypsum stringers and lenses.

In Section 26, the type locality for the formation, member F contains a total of 2 feet of white dolomite, 5 feet of dolomitic shale, and 35 feet of gypsum. Such a large quantity of gypsum in member F, is unusual in the area studied. The dolomite in the middle of the gypsum is questionably correlated with the prominent laminated limestone of member F used as a datum in the correlation chart.

Gradation from limestone to red silty calcarenite. The middle part of member F contains a prominent, gray, laminated limestone, 3 to 5 feet thick (correlation chart, Fig. 53).

The bed is laminated and splits along the more silty layers.

It is gradational into the overlying red, mottled, silty, clastic limestone.

grades into the

Gray limestone

red, irregular

beds interbedded

shown in Figure

fairly well-developed

is not sharp.

The red limestone,

limestone, which

ture. (Fig. 45)

in samples from

0.02 mm. However

the center of the

grains which are six times as large



FIG. 45. Basal beds of member F. Gypsum at base, red and green shale back of 6-inch rule, laminated limestone at top. Section 3, units 6, 7, and 8.

0.01 mm in diameter (Fig. 47a). The elongate areas

areas show stratification which may be cross-lamination

(Fig. 47b). Most of the dark-green areas apparently are not

gradational with the surrounding finer matrix. Although

large calcite grains are most common in the elongate areas,

smaller grains are sparsely scattered throughout other portions

of the rock. The small clastic stratified areas are

The bed is laminated and splits along the more silty layers. It is gradational into the overlying red, mottled, silty, clastic limestone (Fig. 46). The red calcarenite in turn grades into the red-brown shaly siltstone of member G.

Gray laminated limestone is also found in the overlying red, irregularly bedded part of the sequence as thin platy beds interbedded with red silty limestone. In the exposure shown in Figure 46, this break in color and lithology is fairly well-defined, but in most other sections the contact is not sharp.

The red calcarenite is a hard, green mottled, silty limestone, which is poorly laminated, and has a hackly fracture. (Fig. 47.) Most quartz grains and calcite crystals in samples from the silty bed range in size from 0.01 to 0.02 mm. However, the gray, elongate, angular masses in the center of the green mottling contain subangular calcite grains which are six times as large (0.075 mm) as the average grain size of the rock (Fig. 47b). When etched these grains are outlined by ridges of quartz silt which is smaller than 0.01 mm in diameter (Fig. 47c). Many of these coarser-grained areas show stratification which may be cross-lamination (Fig. 47b). Most of the dark-green areas apparently are not gradational with the surrounding finer matrix. Although large calcite grains are most common in the elongate areas, similar grains are sparsely scattered throughout other portions of the rock. The small clastic stratified areas are



25.0 %

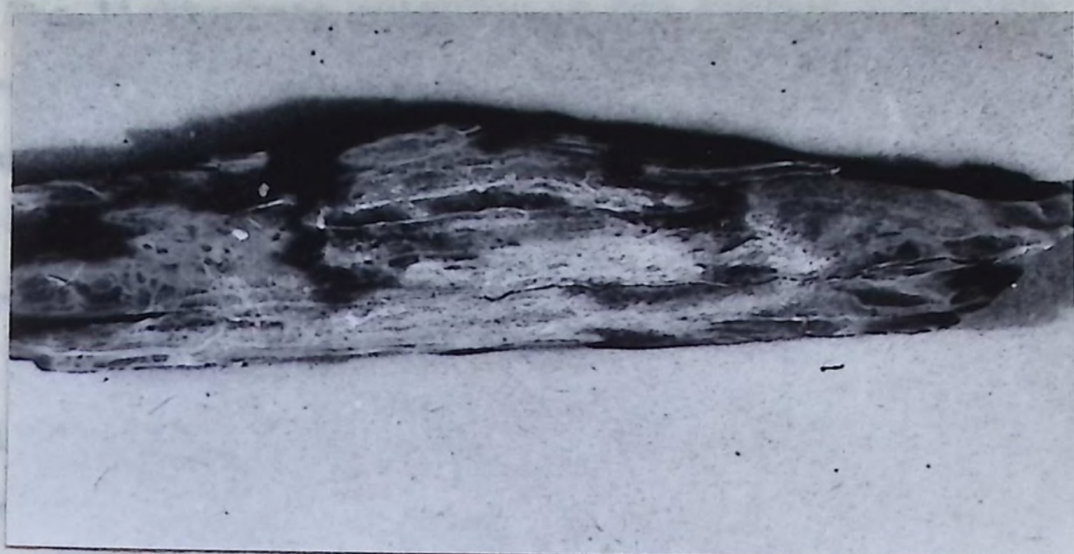
19.0 %

9.0 %

FIG. 46. Gradation from gray, laminated limestone below to red-brown siltstone above. Member F, Section 5, units 10 and 11. Insoluble residue percentages shown at right of photograph opposite point of collection.

gray-green, and in all cases the mottling is due to the presence of a halo of finer crystalline limestone.

the r
in sa
less
notes

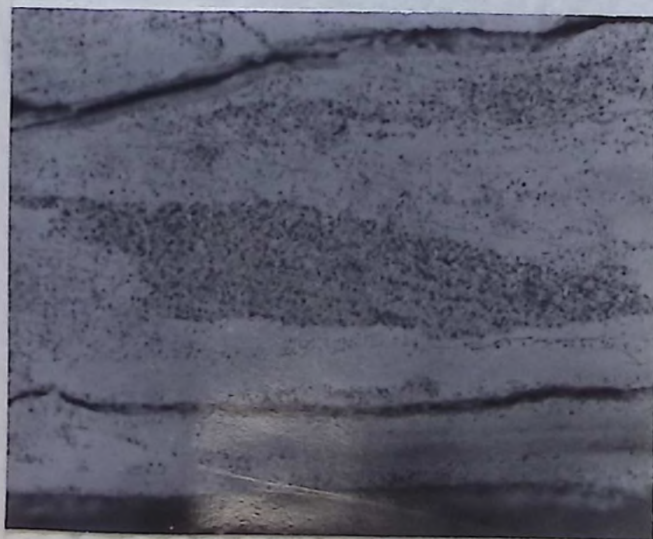


sample
Figure

grains
origia.

difficult

from clastic



crystals,

laminae, and the mottling is due to the presence of a halo of finer crystalline limestone.

B

C

FIG. 47. Red and green mottled, silty limestone of member F. A) mottling of limestone x 1, B) cross stratification of clastic calcite grains x 7½, C) Peel photograph of clastic calcite grains (dark dots) x 16. Sample taken at X below hammer head in Figure 37.

gray-green, and in all cases are surrounded by light-green halo of finer crystalline limestone.

The light-green coloring is not sharply separated from the red-coloration. The red coloring matter is concentrated in small irregularly spaced specks of dark-red iron oxide, less than 1 mm in diameter, and are spaced at 1- to 3-millimeter intervals throughout the red part of the rock (Fig. 48).

Origin of the calcarenite. The insoluble residue of a sample taken from the upper part of the gradation shown in Figure 46 was 25 percent. However, the detrital calcite grains indicate at least half of the rock had a clastic origin. Recrystallization after lithification makes it difficult to distinguish chemically precipitated limestone from clastic calcite grains.

Without more detailed field observations of member F, it is impossible to determine accurately the environment of deposition of the calcarenite. However, the environment can be limited by comparison with sedimentary features of the less puzzling marine members of the Gypsum Spring formation. First of all, the red color indicates deposition in an oxidizing environment. Second, the lack of gypsum, or solution breccia, and the apparent though unproven paucity of dolomite laminae, indicates a low salinity at the site of deposition. Third, the three-fold increase in insoluble residue in a stratigraphic interval of 3.5 feet (Fig. 46) indicates a

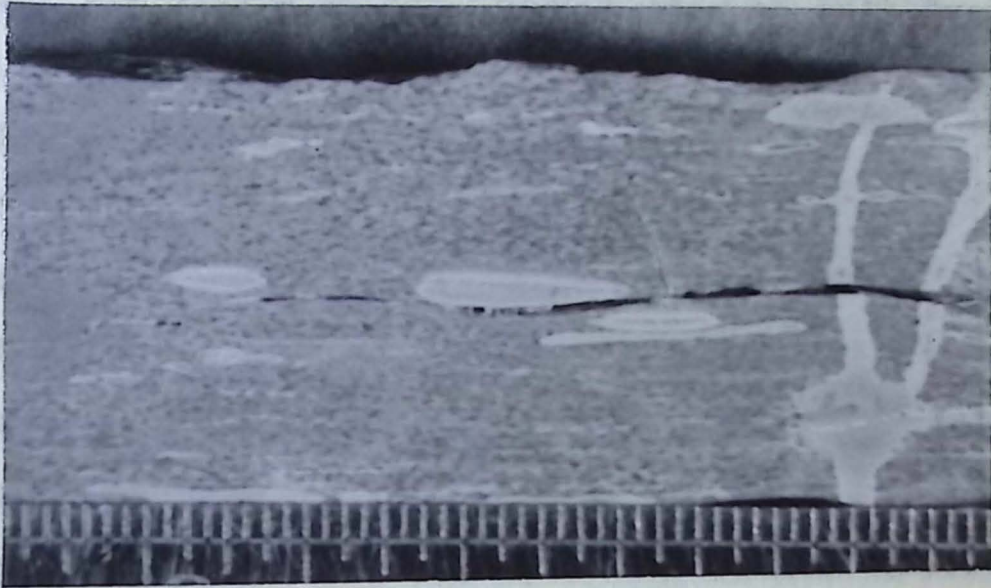


FIG. 48. Speckled and mottled, silty limestone from member F.
Section 21, center of unit 15. x

slow but steady decrease in the distance between the source of supply (the shoreline) and the site of deposition. These three inferences point to a transition from marine conditions to a continental environment. The origin of the microstratification, the source of the clastic calcite grains, and the reason for the green mottling centered around the coarser-grained areas, are not clear to me. It is possible that the stratification represents cross-bedding in the littoral environment and that the calcite grains represent calcite crystals developed on mud flats and washed to the site of deposition by tidal currents. The green mottled areas may represent postlithification reduction of the iron oxide by organic matter deposited with the cross-bedded calcite grains.

Uppermost saline deposits. Red dolomitic siltstones were difficult to identify during the field work, because a calcareous siltstone and a dolomite have the same reaction with dilute hydrochloric acid. However, dolomite was found to overlie the red silty calcarenite in Sections 8, 10, 19, and 22.) In three of these sections the dolomite is white or light gray, but in Section 22 the bed is silty and red brown. A 3-foot bed of gypsum was found also in this position in Section 10.

Mixed lithologies. Gypsum, oolitic fossiliferous limestone, and red shale are not ordinarily thought of as occurring together but these lithologies are mixed in Section 23, 24, and 25. However, in the Gypsum Spring formation, where

incongruities are the rule rather than the exception, this assemblage seems most appropriate.

Oolitic limestones were found in three localities: in the basal beds of Sections 23 and 24, and at three levels in Section 25. (See correlation Fig. 53.) In all three sections the oolitic limestones are closely associated with gypsum beds. The three oolitic limestones of Section 25 are interspaced with 2- to 5-foot beds of gypsum. The 0.5-foot oolite at the base of member F is overlain by a 3.5-foot bed of gypsum and is underlain by 29 feet of gypsiferous red beds.

Except in one bed (Section 25, unit 13), the ooliths contain as many as five concentric shells of silt, range in size from 0.1 to 0.5 mm, and have 0.02 to 0.1 mm nuclei of subangular calcite or quartz grains (Fig. 49). At the base of member F in Section 25, the ooliths are only 0.05 mm in diameter and have less than three concentric rings. This bed of micro-oolite also contains pelecypod fragments up to 4 mm long (Fig. 50).

Bryozoan fragments associated with ooliths were found at the top of member F in Section 25 (Fig. 51). The fragments are less than 3 mm long and have a maximum width of 1.5 mm. In all cases the cell structure in the center of the colony has been completely obliterated, giving the appearance that all zoecia open into a central cavity. The surface arrangement of zoecial openings can be seen in Figure 52. Where preserved, the aperture is foliated, producing longitudinal

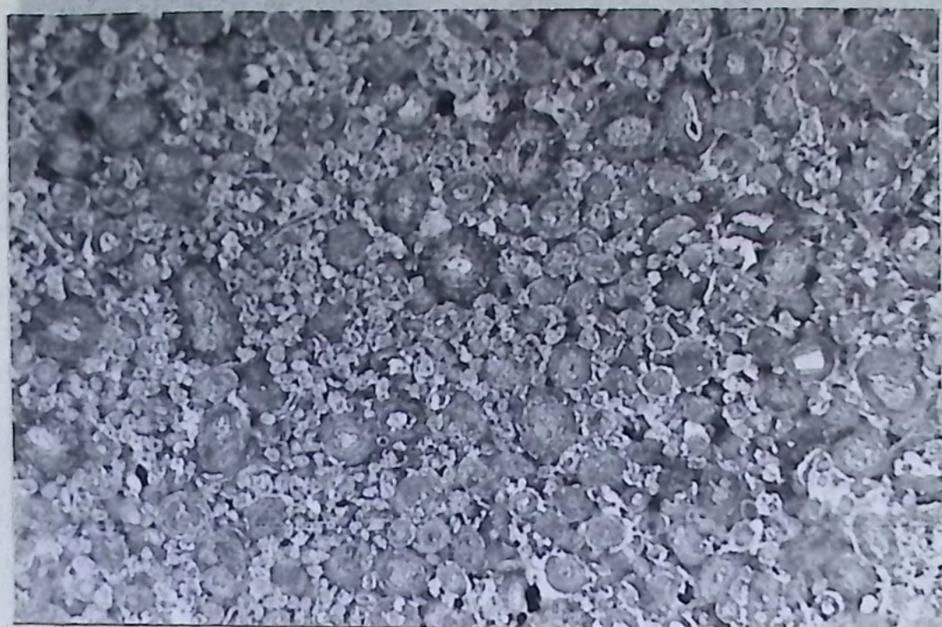


FIG. 49. Etched oolitic limestone from member F. Largest ooliths are 0.1 mm in diameter. View is 10 mm wide. x12
Section 25, unit 15.

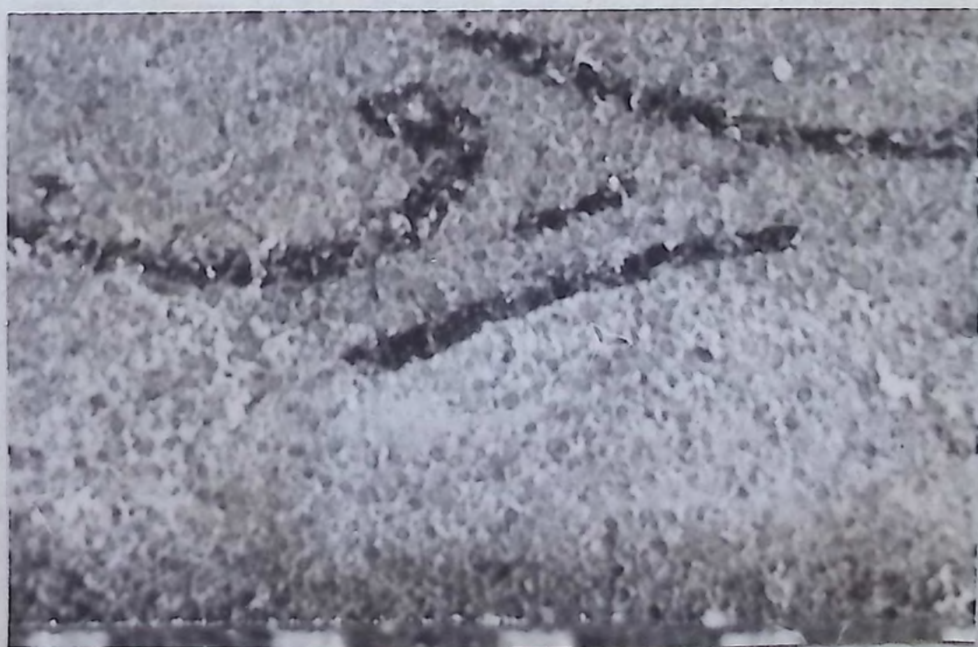


FIG. 50. Fossiliferous micro-oolite. Ooliths are less than 0.05 mm in diameter. This bed is separated from the one illustrated in Figure 49 by a 6-foot bed of gypsum. x27.
Section 25, unit 13.



FIG. 51. Bryozoans from member F. Largest individual is 2.5 mm long. Limestone contains about 25 percent coliths. Section 25, top of unit 17. x20



FIG. 52. Bryozoans from member F. Section 17, unit 13. x14

partitions which extend a short distance into the zoecial tube. No other detailed features have been preserved in the bryozoans. Similar fossils (Fig. 52) were found in a corresponding stratigraphic position in Section 17, 20 miles to the west. No other fossils were associated with either occurrence of bryozoans.

Sedimentary environment. Excluding the incongruities discussed previously, member F is the record of a simple marine transgression-regression sequence. In the early part of the transgression, water depth increased and the littoral zone shifted to the south from its position at the end of deposition of member E. Where member E is absent along the line of cross section B-B', nonclastic marine deposition was essentially continuous from the beginning of member D, but marine deposition in the southern and western parts of the area was interrupted by continental sedimentation during this period.

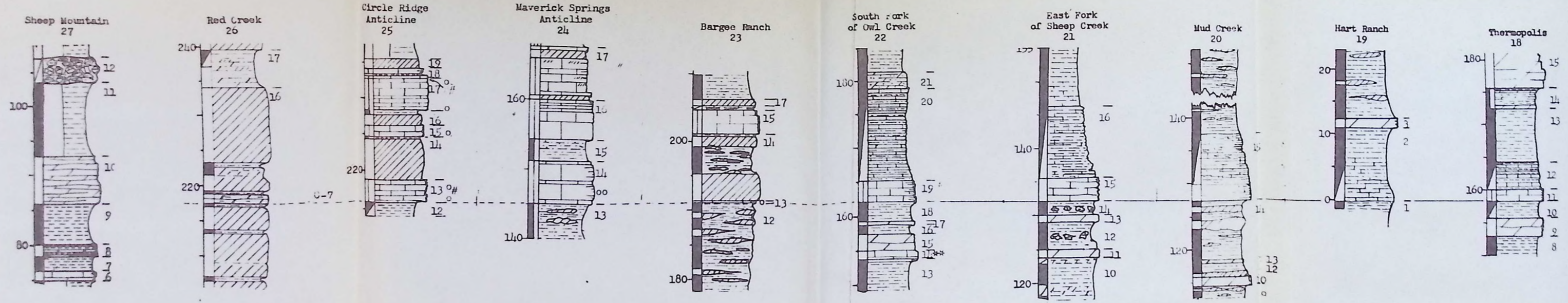
The marine transgression resulted in the shift of position of supersaline environments. Limestone replaced dolomite deposition in the northern part of the area, and gypsum replaced red bed deposition in the south. The dolomite below correlation plane 6 in Sections 12 and 13 was probably deposited contemporaneously with the gypsum at the base of member F in Sections 8 and 10, and was deposited because of lower salinity resulting from deeper water or because of the proximity to the mouth of the stream.

Rapid increase in water depth resulted in the transition from gypsum to limestone deposition without transition through the intermediate dolomite phase. The prominent, gray, laminated limestone is found in all unbrecciated sections, except in Sections 12 and in the incongruous lithologies of Sections 23 to 26.

The area outlined by Sections 23 to 26 (Fig. 1) was the site of an environment which was markedly different from that of the surrounding localities. Neither a lateral gradation of lithology, nor the boundary conditions of this aberrant environment could be determined from field observations. It is possible that Sections 23 to 26 represent an interfingering of normal marine environment of the Utah trough to the west and the typical supersaline environment of central Wyoming. If this is true, the boundary between these two facies and, therefore, the cause of restriction of the supersaline environment of the Gypsum Spring formation may be found with detailed field work in the western Owl Creek Mountains.

Marine deposition of member F was ended by encroachment of continental conditions and is overlain by a thick sequence of red beds. The gradual upward increase in clastic content in the laminated limestone probably indicates the slow approach toward shore conditions. Apparently, the supply of normal-saline sea water was not inhibited during the latter part of member F time and therefore dolomite and gypsum were deposited only under isolated circumstances.

A



B

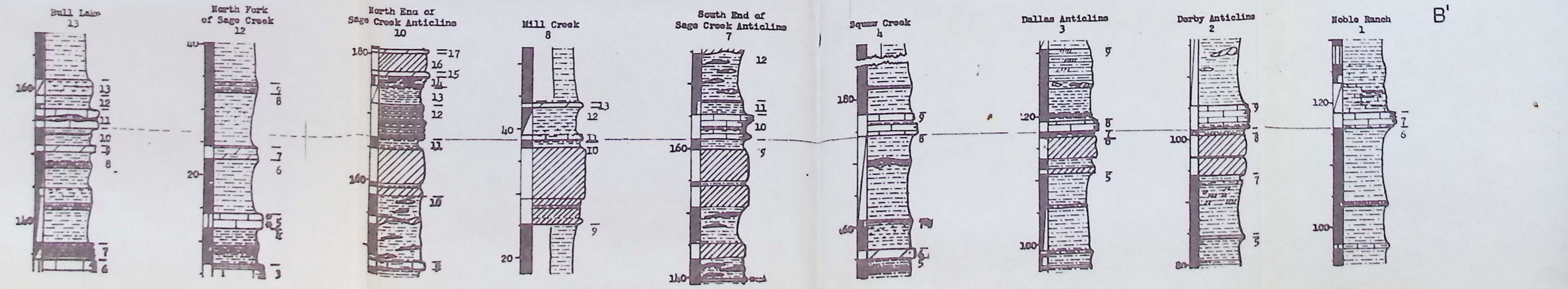


FIG. 53. Correlation of member 7. See figure 43 for explanation of symbols, figure 1 for position of cross sections and location of measured sections, and figure 8 for relation of adjacent beds to member 7.

Member H

General. Member H was deposited during the fourth marine inundation and contains the youngest nonclastic deposits of the Gypsum Spring formation. The member crops out on the west side of the Wind River basin and in Sections 19 and 20 on the north side of the Owl Creek Mountains. The thickness of the member ranges from 0 to 27 feet with most sections about 13 feet thick. Although limestone beds comprise the greater part of the member, beds of gypsum and dolomite as much as 9 feet thick are also found.

The member can be divided roughly into three depositional units: 1) the lower, lenticular saline deposits, 2) the homogenous and laminated limestones which form the bulk of the marine strata, and 3) the uppermost marine beds of the formation.

Basal saline lenses. Dolomite or gypsum commonly forms the basal bed of member H. The complete transgressive sequence of the arid cyclothem is found in some sections (Fig. 14). The basal supersaline deposits are as much as 9 feet thick in some sections, but cannot be correlated with adjacent sections. In other sections, dolomite or dolomitic limestone is found at the base of the marine transgression. These dolomites are commonly laminated (Fig. 54) and gradational with the overlying laminated limestone.

Central limestone bed. The limestone beds which form the larger part of member H are light gray to brown gray, fine crystalline, nonsilty, and even-bedded. Because this

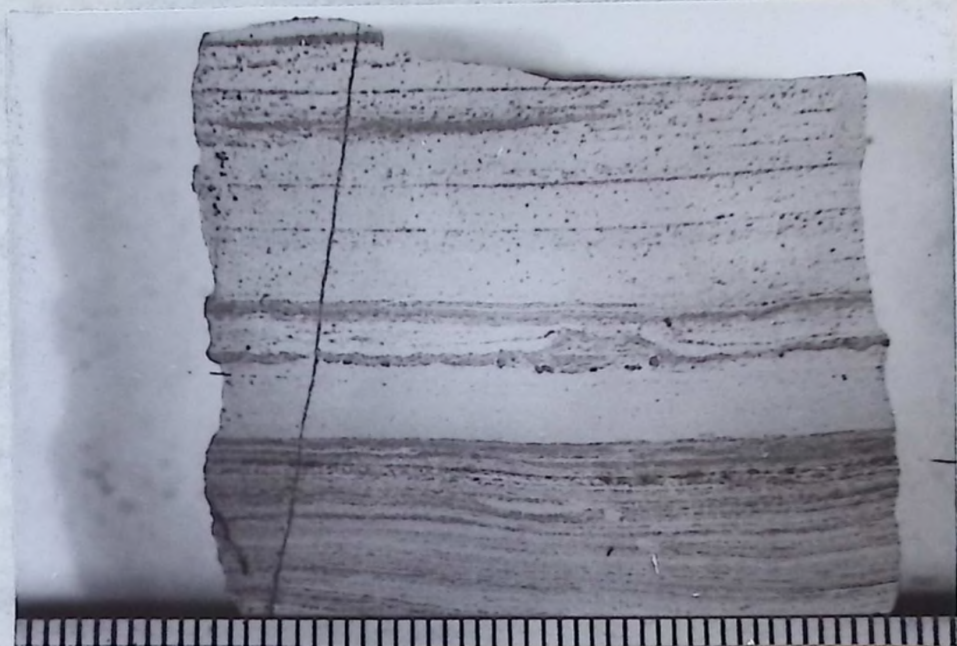


FIG. 54. Reddish-gray silty laminated dolomite from member H. The darker bands contain iron-stained quartz silt, sand-size calcite grains, and a few subhedral quartz grains. x2. Section 13, unit 15. Specimen contains 7.5 percent insoluble residue.

bed is laterally continuous, the base of it is used as a correlation datum in Figure 56. The basal few feet of the bed are commonly laminated, silty, and dolomitic. The uppermost three-fourths of the bed, however, contain even-bedded resistant, gray, poorly laminated limestones in 0.5- to 1.5-foot beds interbedded with thin gray and yellow shale partings (Fig. 55). Lamination in specimens collected from most beds near the top of the unit could be detected only after careful etching and study under the binocular microscope.

As a whole, the limestone portion of member H is remarkably pure. Nine insoluble residue of this bed had an average of 4.0 percent quartz and clay in sizes less than 0.05 mm. In contrast, four dolomites collected from the base of the member contained 7.5, 12.0, 18.0, and 20.0 percent insoluble residue. This upward decrease in insoluble residue is believed to indicate increasing distance between shoreline and site of deposition.

Uppermost marine strata. In a few sections, the central limestone bed of member H grades into calcareous and dolomitic shales and siltstones (Sections 9, 10, and 14), or is directly overlain by supersaline nonclastic beds (Sections 3 and 6). The dolomite and breccia at the top of the Gypsum Spring formation in Sections 19 and 20 may be correlative with the youngest supersaline deposits in sections of member H in cross section B-B'. More likely, however, the youngest

supersaline deposits of cross section A-B' are time equivalents of the middle limestone bed of member H. Member H is overlain by shales, sandstones, or shales.



FIG. 55. Limestone of member H. Section 12, units 11, 12, and 13. Stratigraphic thickness of the member in this exposure is 9.1 feet.

the 9-foot bed of dolomite in Section 20 thins to 1 foot in 2 miles along the outcrop. There is no apparent erosional surface at the top of this unit. Deposition of these isolated supersaline masses in the northern part of the area may have taken place in lagoons and flooded valleys found on part of the topographic development during the last stage of member G.

supersaline deposits of cross section A-A' are time equivalents of the middle limestone bed of member H. Member H is overlain by typical "Lower Sundance" limestones, sandstones, or shales.

Sedimentary environment. In contrast to the southward advancing sea which deposited members D and F, member H was deposited by a sea transgressing from the southwest. The fairly uniform composition of member H in sections along the eastern flank of the Wind River Mountains, indicates that the shoreline was probably roughly parallel to the line of cross section B-B' (Fig. 1). Except in Sections 19 and 20, there is no corresponding record of marine deposition in the Owl Creek Mountains, or in the northern part of the Wind River Mountains. The continental red bed deposition of member G was continuous to the end of Gypsum Spring time north of Section 14. During the period of maximum water depth in the southern and western parts of Fremont County, dolomite and possibly gypsum (Sections 20 and 26) were deposited in areally restricted submarine topographic depressions in the northern part of the area. This is shown by the 9-foot bed of dolomite in Section 20 thinned to 1 foot in 2 miles along the outcrop. There is no apparent erosional surface at the top of this unit. Deposition of these isolated supersaline masses in the northern part of the area may have taken place in lagoons and flooded valleys found on part of the topographic development during the last stage of member G.

B

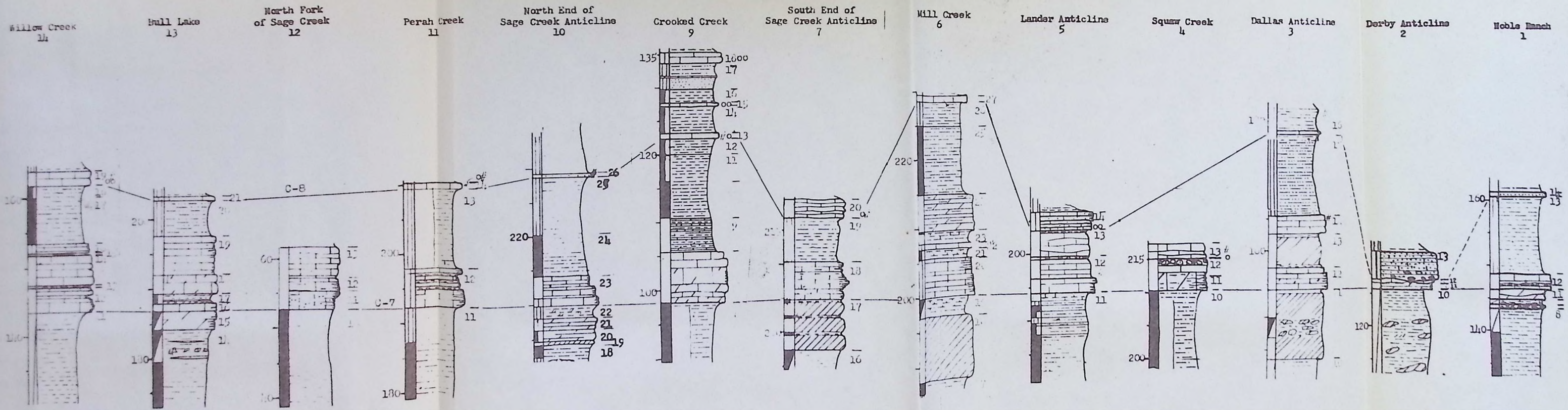


FIG. 56. Correlation of member I on cross section B-B'. See Figure 44 for explanation of symbols, Figure 1 for position of cross section and location of measured sections, Figure 8 for relation of adjacent beds to member H.

Gypsum Spring - "Lower Sundance" Contact

Lithologic Comparison

In the area of investigation, the "Lower Sundance" formation was deposited across members F, G, and H of the Gypsum Spring formation at different places. Consequently, at various places the lithology directly below the formational contact includes the red beds of member G, the gray, laminated, unfossiliferous limestone of member H, and the gypsum of member F (Section 26). Where conformable relationships exist in the Owl Creek Mountains, the upper contact of the Gypsum Spring formation is placed on the top of the red beds of member G. Where the typical yellow shales of the "Lower Sundance" are interbedded with typical red beds of member G, the contact is arbitrarily placed at the top of the youngest red bed.

In the Wind River Mountains, the upper contact of the Gypsum Spring formation is drawn at the base of the lowest yellow sandy shale of the "Lower Sundance" formation. This position coincides with the top of the limestone of member H in most sections. In a few localities, red-brown shaly siltstones separate the yellow sandy shales from the non-clastic rocks of member H.

The basal beds of the "Lower Sundance" formation are typically thin, oolitic, fossiliferous limestones interbedded with yellow-gray, sandy shales and a few fine- to medium-

grained calcareous sandstones. This is in contrast to the red beds, unfossiliferous laminated limestone, light-gray dolomite, and white gypsum of the upper part of the Gypsum Spring formation. Representative "Lower Sundance" fossiliferous oolites are shown in Figures 57 and 58. Complete fossils are uncommon in the oolitic limestones, and the fragments commonly have secondary overgrowths of calcite. Some of the ooliths have two, three or four nuclei. Most of the ooliths in the specimen shown in Figures 57 and 59 are inside the coils of gastropod shells.

An abundance of fossils is the most distinguishing characteristic of the "Lower Sundance" formation. In specimens such as the one shown in Figure 59, the limestone contains almost 50 percent fossil fragments.

Unconformity

Distribution of basal conglomerate in the Owl Creek Mountains. The lowest bed of the "Lower Sundance" formation is a calcareous, conglomeratic, coarse-grained sandstone (Fig. 60) in Sections 18 to 22, and 26. The fragments range from sand sizes to cobbles 8 centimeters in diameter. The pebbles are composed of angular quartzite fragments and subrounded, unfossiliferous, fine-crystalline limestone fragments. The limestone fragments (Fig. 61) are probably pellets and mud rolls derived from the Gypsum Spring forma-

FIG. 59. Fossiliferous, oolitic limestone from "Lower Sundance" formation. Contains numerous multicentered ooliths, notice overgrowths on calcite plates. Section 18, unit 2, 125

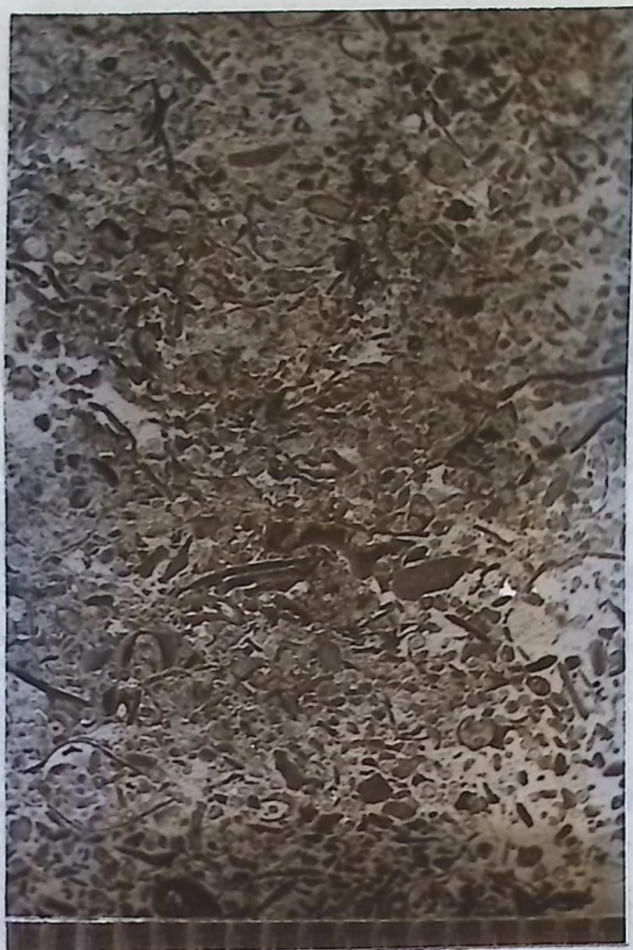


FIG. 57. Fossiliferous, oolitic limestone. Typical "Lower Sundance" limestone lithology. Section 7, unit 20. x 4.0



FIG. 58. Fossiliferous, oolitic limestone from "Lower Sundance" formation. Contains numerous multicentered ooliths, notice overgrowths on calcite plates. Section 15, unit 9, x15

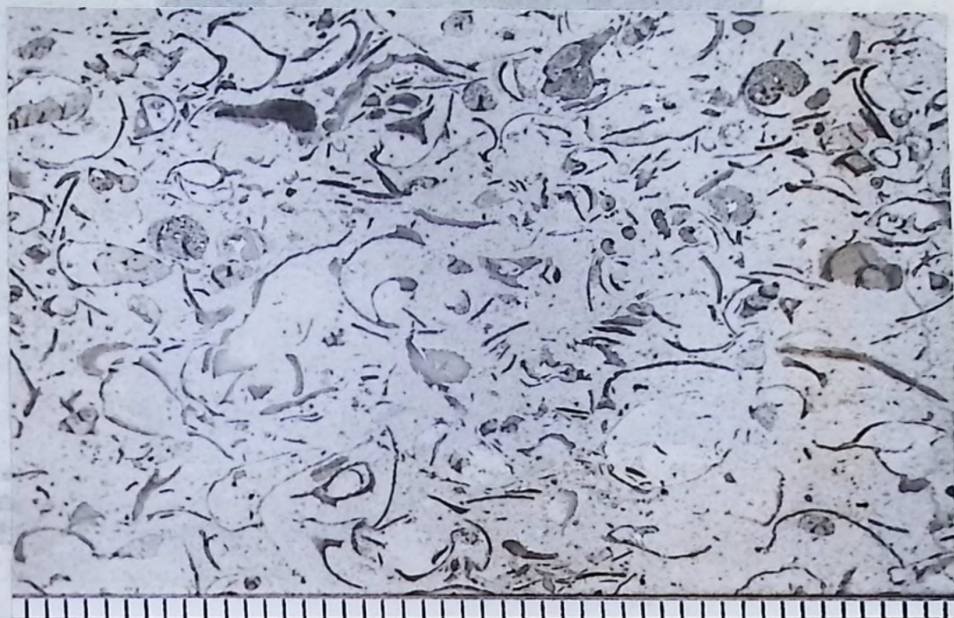


FIG. 59. Fossiliferous, oolitic limestone from basal beds of "Lower Sundance" formation. Most of the oolites are inside the coils of gastropod shells. Section 24, unit 19. $\times 2\frac{1}{2}$

FIG. 61. Limestone-pebble conglomerate in coarse-grained matrix composed of oolites and limestone pebbles. Basal Sundance conglomerate from exposure shown in Figure 59. $\times 1$



FIG. 60. Basal Sundance sandy, oolitic limestone. Limestone pebble conglomerate at the base (Fig. 60). Bed is 7.5 feet thick, but thins laterally in a distance of 500 feet to less than 3 feet. Section 26, unit 20.



FIG. 61. Limestone-pebble conglomerate in coarse-grained matrix composed of ooliths and limestone pellets. Basal Sundance conglomerate from exposure shown in Figure 59. xl

ation, however, Some of the pellets may have been precipitated at the environment of deposition.

The upper part of the basal Sundance clastic bed of Section 26 contains a unique clastic rock composed of detrital bryozoan fragments (Figs. 62 and 63). The 1.5-foot lens is composed of bryozoan fragments up to 2 mm in diameter, embedded in a matrix of white gypsum. Recrystallization has destroyed the details of the fossils, but in general, the fragments from this lens have the same character as those described in member F.

The lenticular basal "Lower Sundance" conglomerate developed at Section 26 is overlain by 30 feet of red siltstones which contain gypsum lenses in the lower 10 feet. By reason of their position above the unconformity, these beds are included in the "Lower Sundance" formation. The environment of deposition of this unit as well as the gypsiferous bryozoan sandstone described previously, was similar to the coastal plain, mud flat environment in which the gypsiferous red beds of members C, E, and G were deposited. They may be, in part, equivalent in time to the beds of member G at Section 25.

A definite erosion surface at the top of the Gypsum Spring formation can be demonstrated in only Section 26. Channeling to a depth of 35 feet is suggested in Figure 69, but one cannot be too sure because of the questionable extension of correlation planes 6 and 8. However, the continuous

62. 63. Detrital bryozoan fragments collected from basal Sundance clastic beds. Individual in center is oriented with axis perpendicular to page. Fragments were taken from sample shown in Figure 61. Section 26, unit 20. x10

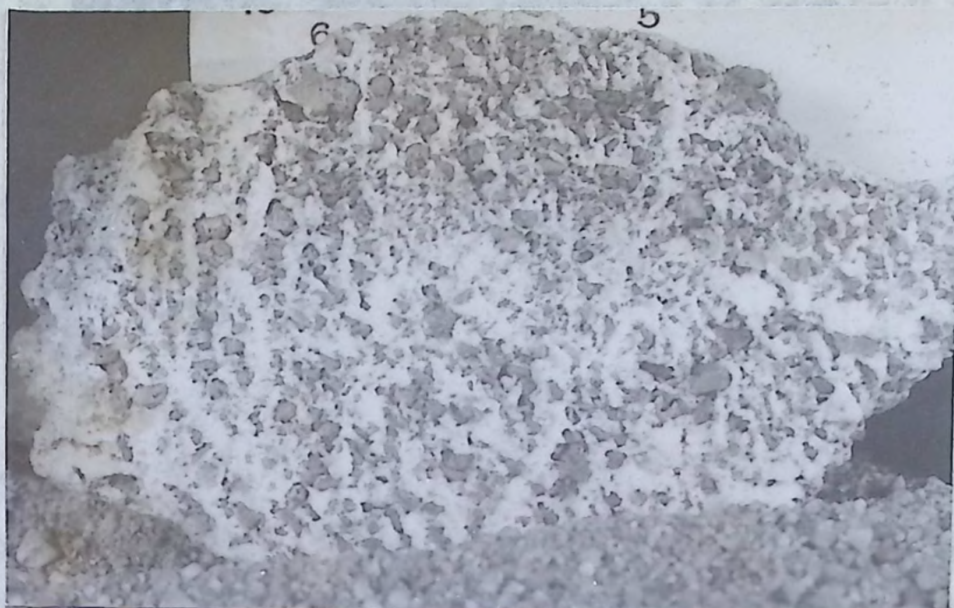


FIG. 62. Bryozoan, coarse-grained calcarenite with gypsum matrix. Collected from top of unit 20, Section 26 (Fig. 59). x4



FIG. 63. Detrital bryozoan fragments collected from basal Sundance clastic beds. Individual in center is oriented with axis perpendicular to page. Fragments were taken from sample shown in Figure 61. Section 26, unit 20. x16

marine deposition from the beginning of member D time indicates that Section 26 was in a topographically low area during much of late Gypsum Spring time. Apparently, the thick gypsum beds of member F made this region more susceptible to subsequent subareal and possibly submarine erosion, and part of the record may have been lost.

Intraformational conglomerates in the Wind River Mountains. On cross section E-B', either oolitic limestone or yellow, sandy shale is the lowest bed of the "Lower Sundance" formation. The limestones of member H are directly overlain by sandstones or conglomerates in only Sections 2 and 5. In Section 5, the basal "Lower Sundance" sandstone is separated from the limestones of member H by only a shale parting. The sandstone contains no fragments larger than coarse sand.

Member H of Section 2 is unconformably overlain by a limestone-cobble conglomerate (Figs. 64 and 65). In some specimens (Fig. 66) nearly all of the fragments are angular and the rock can be classed as a breccia. This clastic bed grades up into an oolitic sandstone found at the top of the overlying 4-foot bed.

Penecontemporaneous deformation of member H. The basal "Lower Sundance" conglomerate and local unconformable relationships suggest uplift and erosion at the end of Gypsum Spring time. (Microfolding and small scale brecciation of member H limestones also are evidence of small scale deformation at the end of Gypsum Spring time. In the southern part of the Wind River Mountains, the upper 5 feet of member



FIG. 64. Basal Sundance unconformity. White dolomite at base of photograph (unit 11), slab of penecontemporaneously deformed limestone under unconformity (unit 12), limestone-pebble conglomerate above unconformity (unit 13). Section 2.



FIG. 65. Basal Sundance unconformity. Limestone-cobble conglomerate (unit 13) above unconformity (Fig. 66), gray, laminated limestone below unconformity (unit 12). Notice cross-bedding above unconformity. View is 1.5 feet wide.
Section 2.



FIG. 66. Limestone-pebble conglomerate. Section 2, unit 13. $\times 1\frac{1}{2}$

H commonly contains contorted laminations and in a few cases microthrust faulting was observed (Fig. 67). In Section 2, the 0.5-foot bed below the unconformity contains a laminated limestone which was subjected to erosion before lithification. The upper two-thirds of this bed (Fig. 68) contains brecciated fragments of laminated limestone. Brecciation and contortion of laminae of member H is limited to outcrops south of Section 6.

I believe that compaction, and possibly local warping, produced the microstructures in the limestones of member H and created conditions which caused the ^{local} subareal removal of a significant part of the Gypsum Spring formation.

FIG. 68. Contemporaneous brecciation of limestone at top of member H. Note the best case of brecciation in lower half of specimen. Section 2, well 12-12.

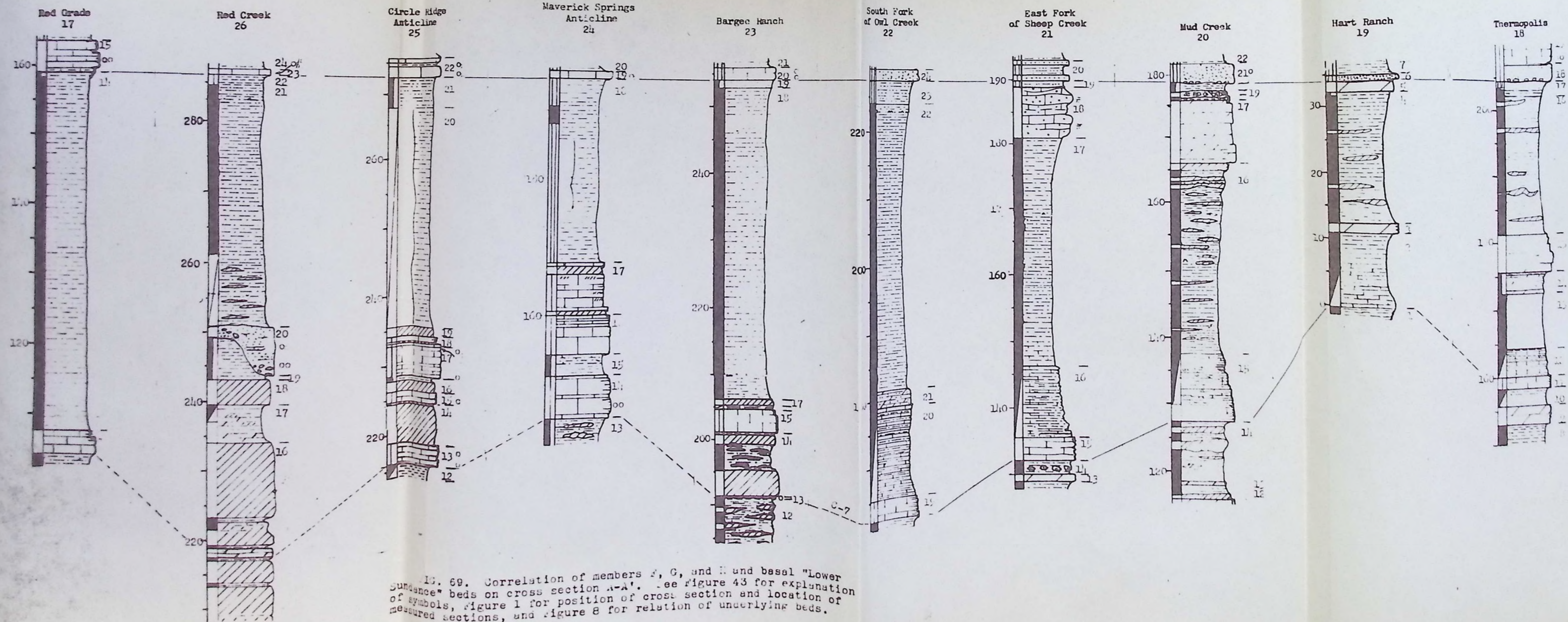


FIG. 67. Penecontemporaneous folding and faulting of member H.
Section 5, unit 13.



FIG. 68. Penecontemporaneous brecciation of limestone at
top of member H. Notice the bent ends of laminae in lower
half of specimen. Section 2, unit 12. x2

A



13. 69. Correlation of members F, G, and H and basal "Lower Sundance" beds on cross section A-A'. See figure 43 for explanation of symbols, figure 1 for position of cross section and location of measured sections, and figure 8 for relation of underlying beds.

A'

SUMMARY

The Gypsum Spring formation is the evaporite facies of the Middle Jurassic in the Western Interior region. The facies is found in western and northern Wyoming, northeastern Utah and in the eastern half of Montana. In Fremont County, Wyoming, the average thickness of the formation is about 200 feet. It is divisible into three stratigraphic units on the basis of lithology and environment of deposition: 1) basal red beds, 2) thick-bedded gypsum, and 3) alternating sequences of red beds and evaporites. For the purpose of discussion in this paper, the formation was divided into eight members, lettered A to H. Members A and B correspond respectively to units 1 and 2, and comprise 40 percent of the formation. Unit 3 is subdivided into members C to H. The members in unit 3 are defined on the basis of environment of deposition and have gradational contacts. They are not easily mappable units.

Member A is the red-brown siltstone at the base of the formation which has an average thickness of 25 feet. It overlies the Chugwater formation (Triassic) in central Wyoming and the Nugget sandstone (Lower Jurassic) in western Wyoming. The siltstone of member A is gradational with the beds of the underlying formations.

Member B is composed of 55 to 120 feet of gypsum in 3- to 12-foot beds which are interbedded with shale partings and sequences of siltstone and dolomite. Both the gypsum and

dolomite beds have laminations and bands which range in thickness from less than 0.5 to 30 mm and are defined by variations in dolomite, gypsum and clastic content. The member contains less than 10 percent interbedded siltstone and dolomite.

Member C has an average thickness of 30 feet and is composed of nonresistant, red-brown, shaly, gypsiferous siltstone. Lenses and stringers of gypsum are commonly found at the base and top of the member, and in some cases are gradational in size with the beds of gypsum included in the top of member B and the base of member D.

Member D contains coarse-crystalline gypsum stringers and light-gray, chalky-weathering, sublithographic dolomite beds at the base; a persistent, laminated, brown-gray limestone bed in the middle part; varicolored silty shales with gypsum and dolomite lenses in the upper half; and an algal limestone at the top. The thickness of the member ranges from 12 to 21 feet with an average of 16 feet. Gypsum or dolomite stringers overlie the algal limestone in a few sections.

Member E is the 11-foot red bed sequence which lies between the marine strata of members D and F in the Wind River Mountains and in the central part of the Owl Creek Mountains. In the eastern part of the Owl Creek Mountains, member E is absent, and member F lies directly on member D. Gypsum lenses found in member E in Sections 7, 10, 24, and 25.

Member F is composed of nonclastic rocks which have an average thickness of 15 feet. In most sections, gypsum and

dolomite beds are found at the base of member and less commonly at the top. A laminated limestone which grades upward into a red silty calcarenite generally forms the central part of the member. Member F in Sections 23, 24, and 25 contains interbedded gypsum oolitic and fossiliferous limestones. In Section 26, member F consists of 42 feet of gypsum which contains a minor amount of dolomite.

Member G is the youngest and thickest (average of 26 feet) red bed sequence of the Gypsum Spring formation. In the Owl Creek Mountains, the member generally is the uppermost unit of the Gypsum Spring formation. In the Wind River Mountains, the member is overlain by the nonclastic rocks of member H.

Member H contains the youngest rocks of the Gypsum Spring formation. Poorly laminated limestone constitutes the greater part of the unit, and gypsum and dolomite beds are generally found at the base of the member. The member is found in Sections 1 to 13 in the Wind River Mountains, but only as a dolomite bed in Sections 19 and 20 in the Owl Creek Mountains.

In contrast to the red beds, unfossiliferous laminated limestone, light-gray dolomite, and white gypsum of the upper members of the Gypsum Spring formation, the lithology of the "Lower Sundance" formation is typically oolitic, fossiliferous limestones; yellow-gray, sandy shales; and fine- to medium-grained calcareous sandstones. In most sections, the

Gypsum Spring formation is separated from the overlying "Lower Sundance" by a break in lithology, but in Sections 2 and 26, the uppermost beds of the Gypsum Spring formation are missing and the base of the "Lower Sundance" is marked by a limestone-pebble conglomerate.

CONCLUSIONS

1. The basal beds of the Gypsum Spring formation are gradational with the underlying Nugget sandstone in western Wyoming. In central Wyoming, erosion has removed the Nugget and part of the Chugwater formation. Consequently, the Gypsum Spring lies unconformably on the Chugwater red beds.

2. The siltstone-dolomite interbeds in the thick-bedded gypsum represent deposition during short periods of less dry climate. Increased rainfall and lessening of the effective evaporation rate, caused dilution of the waters and increased the rate of clastic deposition. The dolomite bed at the top of the interbed was deposited after the return of the normal dry climate during the process of reconcentration of the sea water.

3. The uppermost part of the Gypsum Spring formation was deposited in a supersaline environment and, therefore, should not be included with the overlying normal marine beds of the "Lower Sundance" formation.

4. The beds of the upper half of the formation were deposited in a salinid under the influence of rhythmically changing sea level. If depth of deposition were the only variable, the sequence of beds produced in one cycle would be: A) Transgression; 1) red beds, 2) red beds with gypsum lenses, 3) bedded gypsum, 4) dolomite, 5) limestone; B) Regression: 6) dolomite, 7) gypsum, 8) red beds with gypsum lenses, and 9) red beds. The conditions of deposition are the following: 1) a climate conducive to evaporite deposition, 2) systematically fluctuating sea level, 3) a landmass of low slope and low relief, and 4) a source of red-stained clastics.

5. The red siltstones found at intervals throughout the formation are believed to be reworked Chugwater red beds eroded from exposures in eastern Wyoming. The environment of deposition of red beds in the Gypsum Spring formation extends from nearshore waters in which oxidizing conditions are prevalent, through the coastal plain belt, and into the colluvial deposits in the source area of exposed Chugwater red beds. Gypsum lenses were deposited with the red beds in the littoral and mud flat environments of the coastal plain and signify the beginning of the transgression.

6. Dolomite was precipitated, or was formed by alteration of lime muds when sea water had a salinity intermediate between that necessary for the precipitation of gypsum and calcite.

7. The oolitic and sparsely fossiliferous limestones interbedded with evaporites in the northwestern part of Fremont County represent an interfingering normal marine facies on the northwest and the evaporite facies represented by the Gypsum Spring formation in central Wyoming. The 42-foot bed of gypsum of Section 26 represents an isolated basin at the geographic boundary between the two facies.

8. The brecciation of beds was produced by solution of gypsum when the formation was subjected to weathering.

- IMLAY, R. W., 1943, Occurrence of Middle Jurassic rocks in the Western Interior in the United States; Am. Assoc. Petroleum Geologists Bull., v. 29, p. 1018-1027.
- _____, 1943, Marine Jurassic formations of Montana; U. S. Geol. Survey Oil & Gas Investigations Preliminary Chart 32.
- _____, 1940, Jurassic rocks in the mountains along the west side of the Green River Basin; Wyoming Geological Assoc., Fifth annual field conference guidebook.
- _____, 1932a, Paleogeology of Jurassic seas in the western interior of the United States; Report of the Committee on a Treatise on Marine Geology and Paleogeology, National Research Council, No. 9, 1942-1949, p. 72-103.
- _____, 1932b, Correlation of the Jurassic formations of North America, exclusive of Canada; Bull. Geol. Soc. America, v. 53, p. 953-968.
- KING, R. H., 1947, Sedimentation in Wyoming basins; Am. Assoc. Petroleum Geologists Bull., v. 31, p. 470-487.
- LOVE, J. D., 1939, Geology along the southern margin of the Absaroka Range, Wyoming; Bull. Geol. Soc. America, Special paper 20, p. 1-134.
- _____, 1945, Stratigraphic sections and thicknesses of Jurassic rocks in central Wyoming; U. S. Geol. Survey, Oil & Gas Investigations Preliminary Chart 14.
- _____, et al., 1947, Stratigraphic sections of Mesozoic rocks in central Wyoming; Wyoming Geol. Survey Bull. 20, p. 1-89.

REFERENCES

- BAKER, C. L., 1929, Depositional history of the red beds and saline residues of the Texas Permian: University of Texas Bull., No. 2901, p. 9-72.
- CLARKE, F. W., 1916, Data of geochemistry, 3rd edition: U. S. Geol. Survey Bull. 616.
- EARDLEY, A. J., 1949, Paleotectonic and paleogeologic maps of central and western North America: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 655-682.
- ELIAS, M. K., 1937, Depth of deposition of the Big Blue (Late Paleozoic) sediments in Kansas, Bull. Geol. Soc. America, v. 48, p. 403-432.
- IMLAY, R. W., 1945, Occurrence of Middle Jurassic rocks in the Western Interior in the United States: Am. Assoc. Petroleum Geologists Bull., v. 29, p. 1019-1027.
- _____, 1948, Marine Jurassic formations of Montana: U. S. Geol. Survey Oil & Gas Investigations Preliminary Chart 32.
- _____, 1950, Jurassic rocks in the mountains along the west side of the Green River Basin: Wyoming Geological Assoc., Fifth annual field conference guidebook.
- _____, 1952a, Paleoecology of Jurassic seas in the western interior of the United States: Report of the Committee on a Treatise on Marine Ecology and Paleoecology, National Research Council, No. 9, 1948-1949, p. 72-103.
- _____, 1952b, Correlation of the Jurassic formations of North America, exclusive of Canada: Bull. Geol. Soc. America, v. 63, p. 953-992.
- KING, R. H., 1947, Sedimentation in Permian Castile sea: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 470-477.
- LOVE, J. D., 1939, Geology along the southern margin of the Absaroka Range, Wyoming: Bull. Geol. Soc. America, Special paper 20, p. 1-134.
- _____, 1945, Stratigraphic sections and thickness maps of Jurassic rocks in central Wyoming: U. S. Geol. Survey, Oil & Gas Investigations Preliminary Chart 14.
- _____, et al, 1947, Stratigraphic sections of Mesozoic rocks in central Wyoming: Wyoming Geol. Survey Bull. 38, p. 1-59.

- MOORE, R. C., 1931, Pennsylvanian cycles in the northern Mid-Continent region: Illinois Geol. Survey Bull., 60, p. 247-257.
- _____, 1936, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Geol. Survey of Kansas Bull. 22, p. 1-266.
- PETTITJOHN, F. J., 1949, Sedimentary Rocks: Harper & Brothers, New York.
- PHILLIPS, F. C., 1947, Oceanic salt deposits: Quarterly Review Chemical Soc. London, v. 1, p. 91-111.
- POSNJAK, E., 1938, The system, $\text{CaSO}_4 - \text{H}_2\text{O}$: Am. Jour. Sci., v. 235, p. 247-272.
- _____, 1940, Deposition of calcium sulfate from sea water: Am. Jour. Sci., v. 238, p. 559-568.
- RANKAMA, K. & SAHAMA, Th. G., 1949, Geochemistry: Univ. Chicago Press, p. 1-911.
- SCHMITT, G. T., 1953, Regional stratigraphic analysis of middle and upper marine Jurassic in Northern Rocky Mountains - Great Plains: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 355-393.
- SCRUTTON, F. C., 1953, Deposition of evaporites: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2498-2511.
- VAN TUYL, F. M., 1916, The origin of dolomite: Annual Rept. Iowa Geol. Survey, v. 25, p. 251-421.
- WILLIS, R., 1929, Preliminary correlation of the Texas and New Mexico Permian: Am. Assoc. Petroleum Geologists Bull., v. 13, p. 997-1031.
- WANLASS, H. R., 1931, Pennsylvanian cyclothemic cycles in western Illinois: Illinois Geol. Survey Bull. 60, p. 179-193.
- WELLER, J. M., 1930, Cyclical sedimentation of the Pennsylvanian Period and its significance: Jour. Geol., v. 38, p. 97-135.

APPENDIX

Description of Sections

Twenty-nine sections of the Gypsum Spring formation are described and illustrated below. Lithology and color symbols are explained in Figure 70. Land lines, drainage, and roads in the vicinity of the sections are shown in Figures 71 to 79. The location of the sections and the area covered by each of the location maps is shown in Figure 1. Comparison of the Sections with Figure 8 will indicate the strata included in each member.

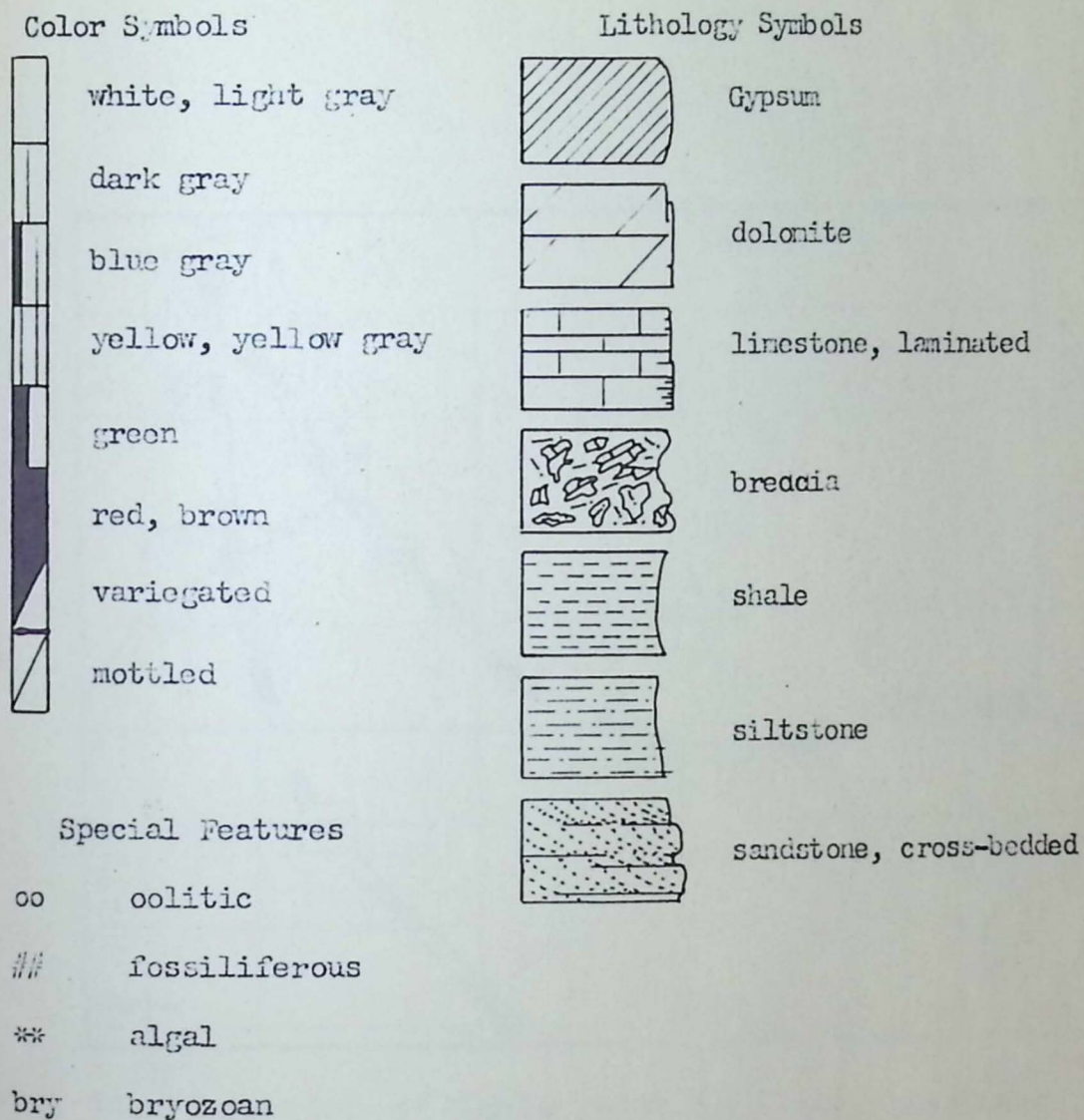


FIG. 70. Symbols used in stratigraphic sections. Same as Figure 43.

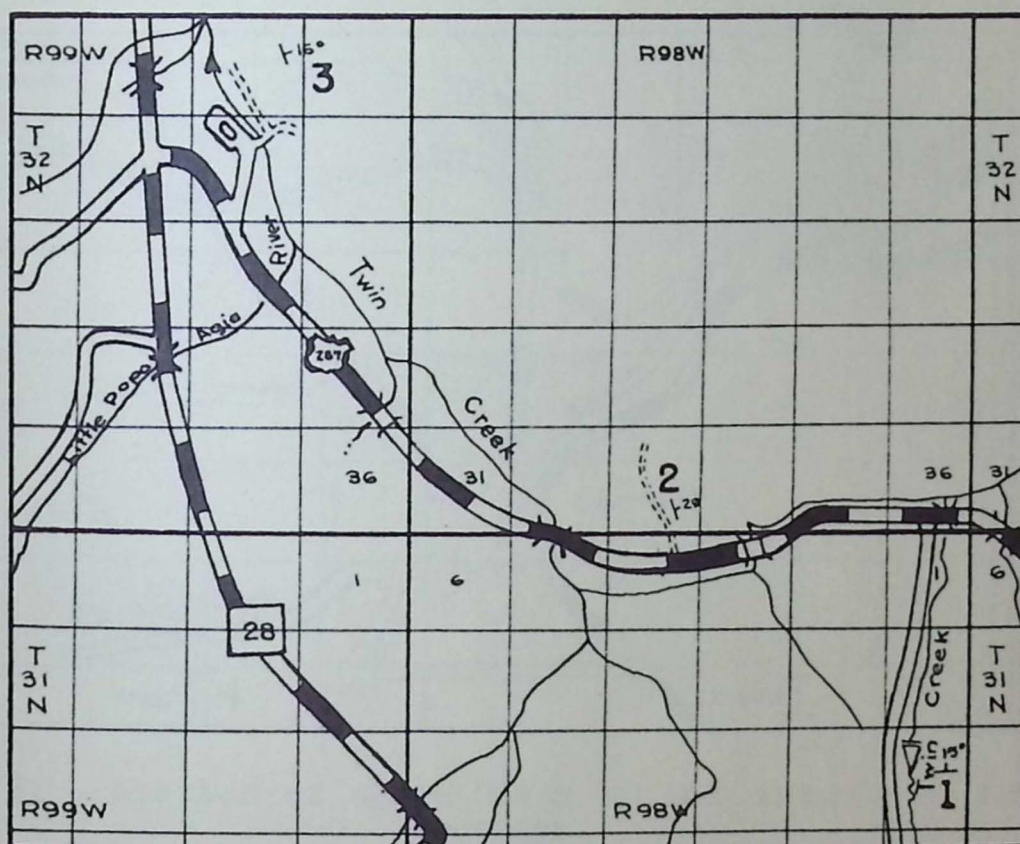


FIG. 71. Location of Noble ranch (1), Derby anticline (2), and Dallas anticline (3) sections.

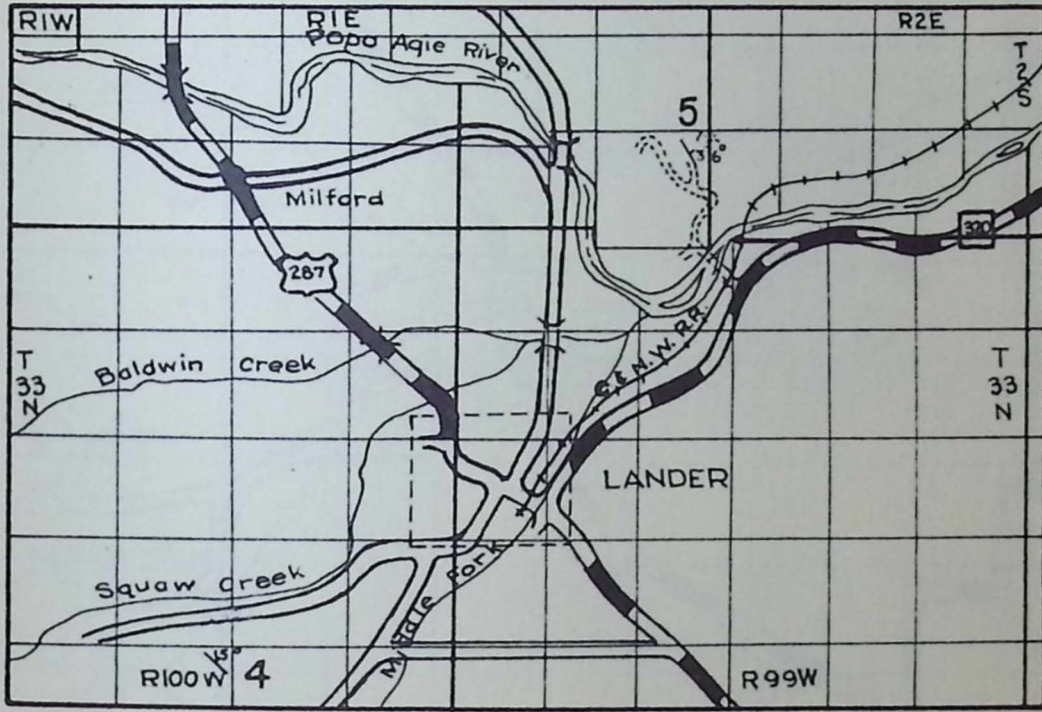


FIG. 72. Location of Squaw Creek (4) and Lander anticline (5) sections.

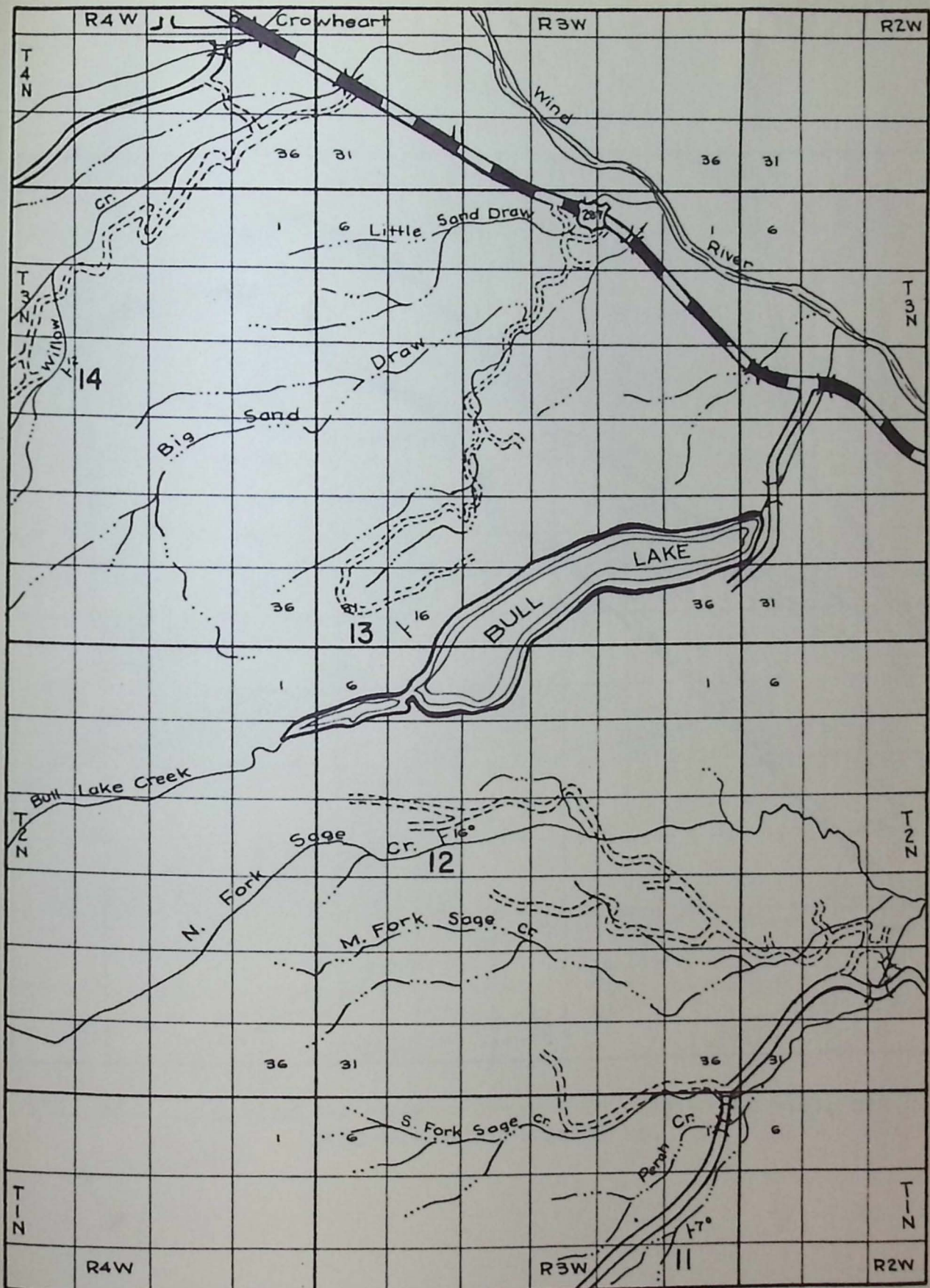


FIG. 74. Location of Perah Creek (11), North fork of Sage Creek (12), Bull Lake (13), and Willow Creek (14) sections.

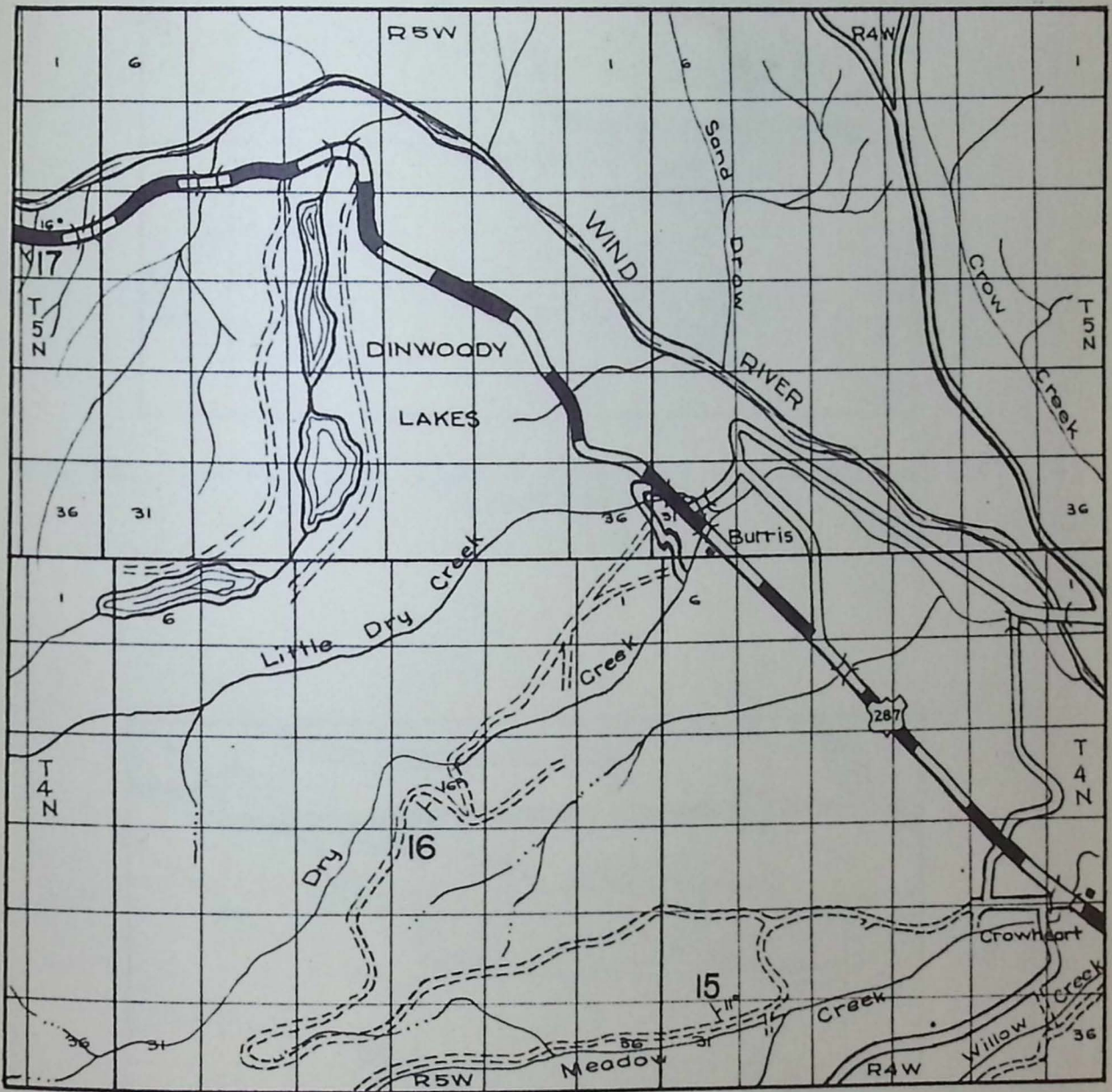


FIG. 75. Location of Meadow Creek (15), Dry Creek (16), and Red Grade (17) sections.

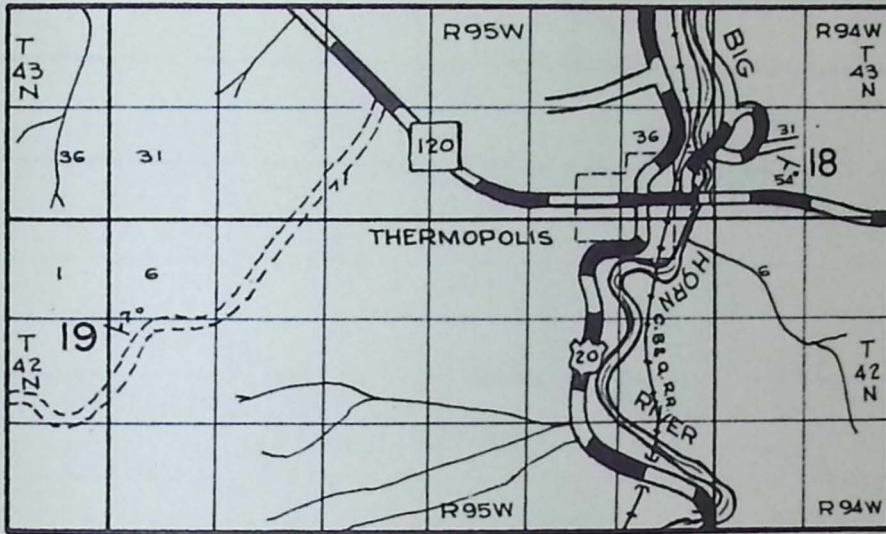


FIG. 76. Location of Thermopolis (18) and Hart ranch (19) sections.

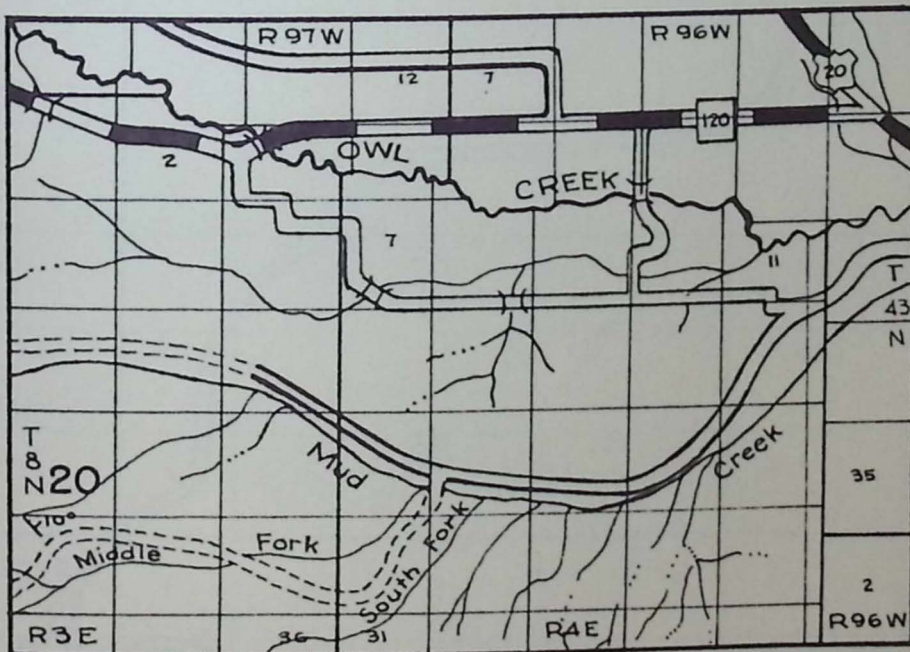


FIG. 77. Location of Mud Creek (20) Section.

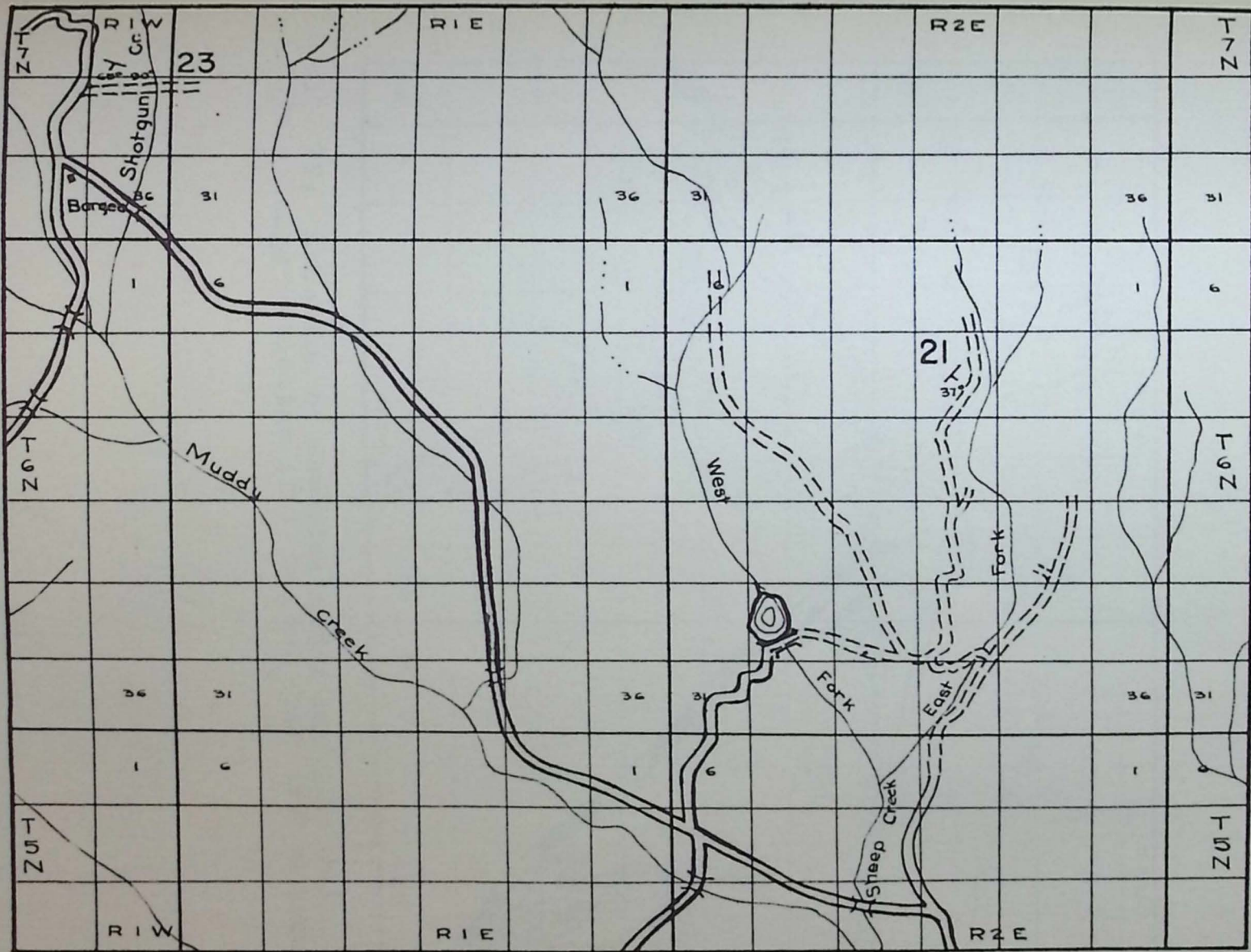


FIG. 78. Location of East fork of Sheep Creek (21) and Bargee (23) sections.

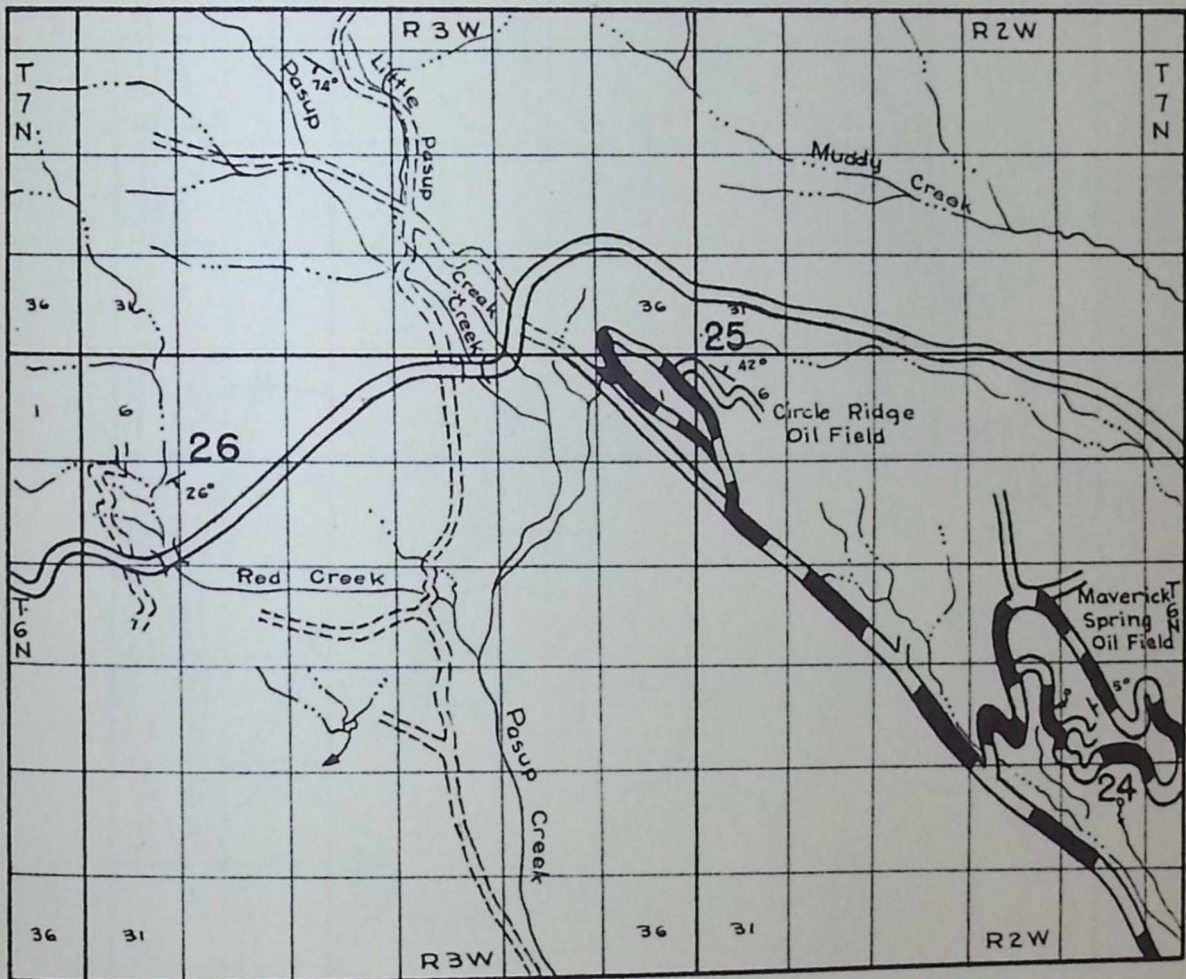


FIG. 79. Location of Maverick spring anticline (24), Circle Ridge anticline (25), and Red Creek (26) sections.

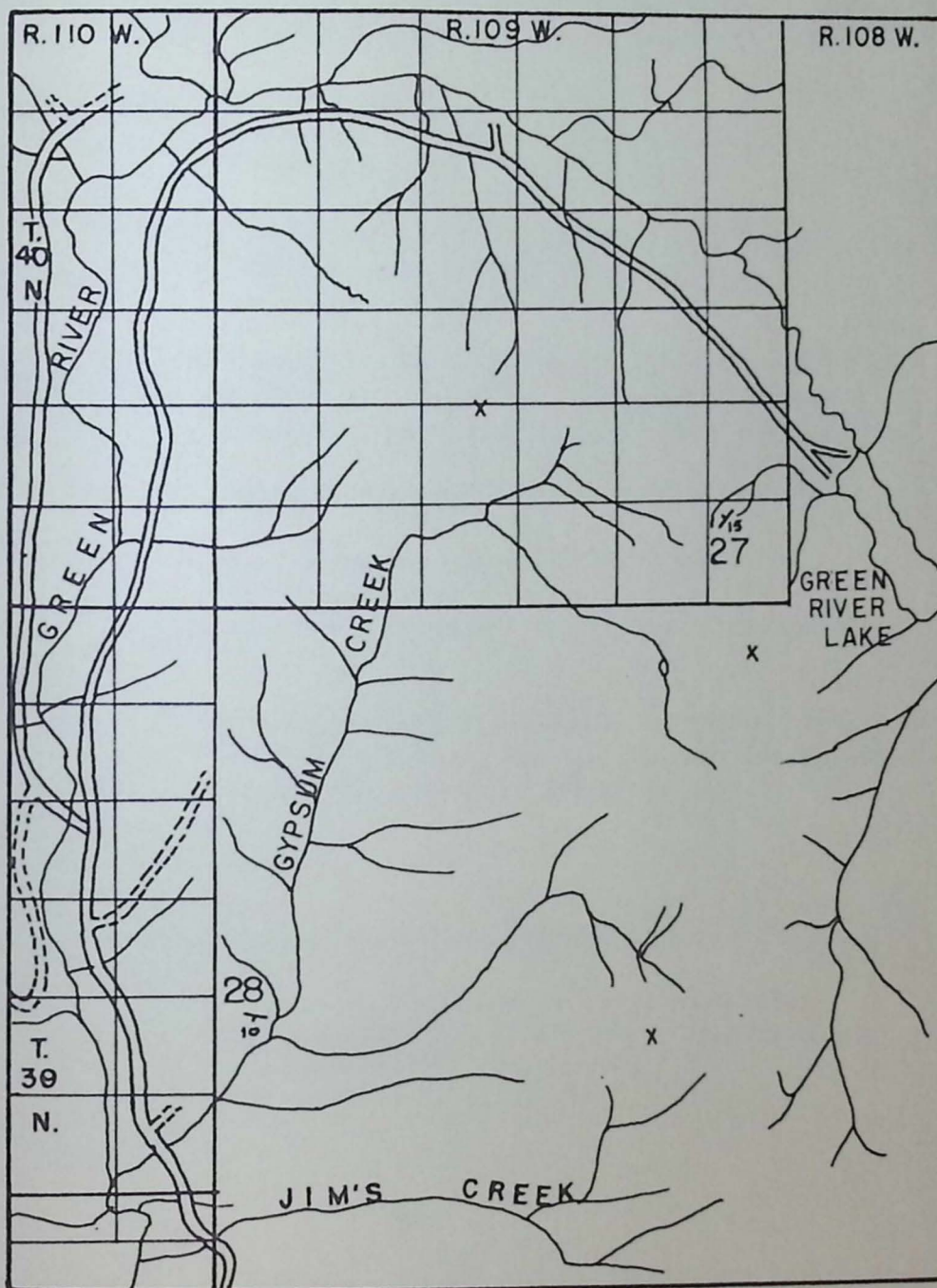
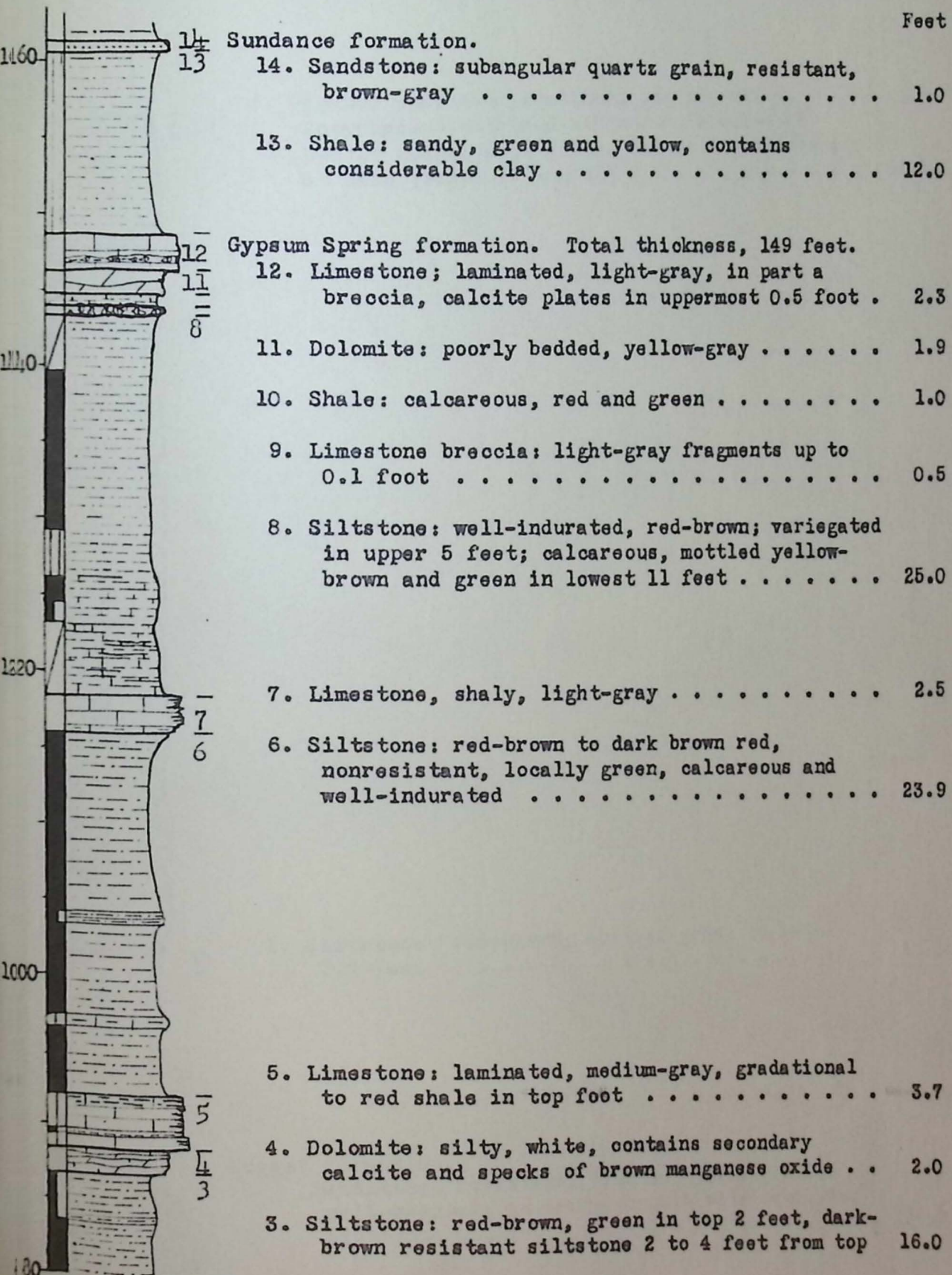
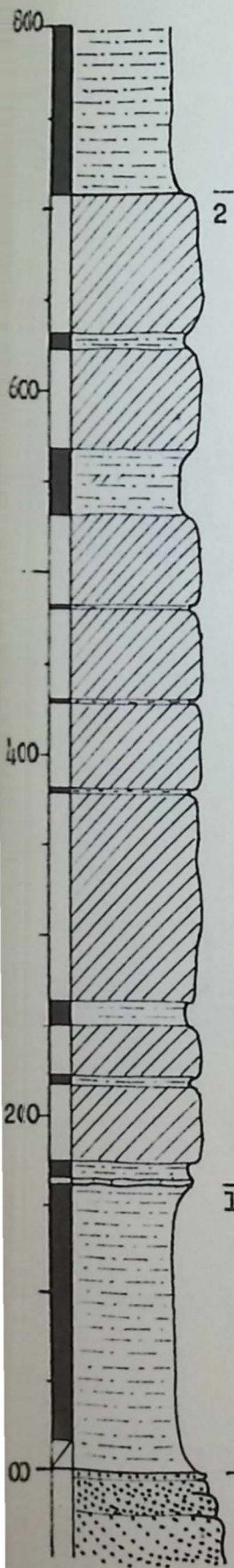


FIG. 80. Location of Sheep Mountain (27) and Gypsum Creek (28) sections.

Section 1, Noble ranch, 17 miles southeast of Lander, Wyoming,
in center of Sec. 13, T. 31 N., R. 98 E., B. H. M.



Feet



2. Gypsum: coarse-crystalline, porous, white, interbedded with red siltstone, a 0.5-foot bed of coarse-crystalline dolomitic limestone at base (Figs. 27 and 28) 54.5

1. Siltstone: red-brown, mottled green in basal 1.5 feet 15.5

Nugget formation.
 Sandstone: resistant, frosted quartz grain, yellow-brown, in sharp contact with overlying siltstone 137.0

Section 2, Derby anticline, 13 miles southeast of Lander, Wyoming, in SW $\frac{1}{4}$, Sec. 33, T. 32 N., R. 98 W., B. H. M.

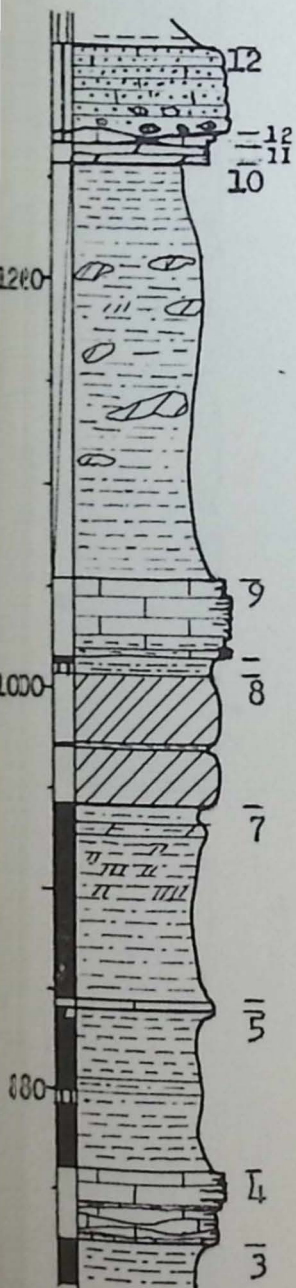
Feet

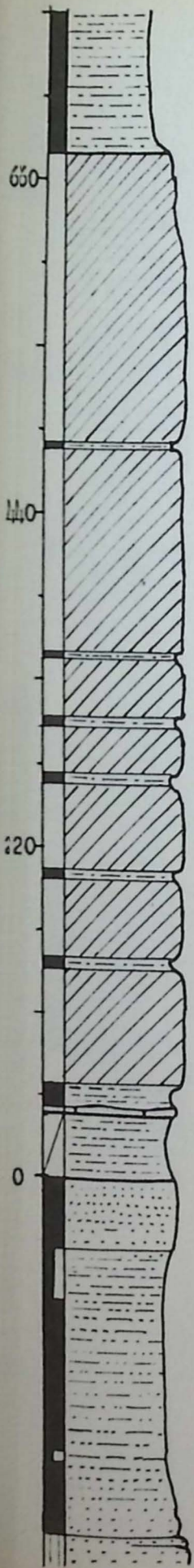
Sundance formation.

- 13. Conglomerate: limestone-pebble, brown, quartz and calcite matrix (Figs. 65 and 66) 4.0

Gypsum Spring formation. Total thickness, 127 feet.

- 12. Limestone: laminated, gray, silty; contains 0.1 mm calcite plates; laminae are contorted (Figs. 64 and 68) 1.0
- 11. Dolomite: silty, gray weathers white blocky, contains a small amount of gypsum 1.3
- 10. Siltstone: red-brown; variegated with yellow, green and brown-red in bottom and top 5-foot intervals; gypsum lenses in central portion . 20.2
- 9. Limestone: thinly laminated, medium-gray, argillaceous in lower foot 3.5
- 8. Gypsum: white, coarse-crystalline, contains red and yellow-brown shale near center and at top 7.8
- 7. Shale: variegated maroon, red-brown and green; gypsiferous, silty 9.6
- 6. Limestone: laminated, brown-gray, poorly bedded 0.5
- 5. Shale: red-brown and silty, green shale in top foot, hard siltstone near center 8.0
- 4. Limestone: laminated, white; poor, wavy bedding and shaly at base; massive at top 3.8
- 3. Siltstone: red-brown, nongypsiferous 11.0



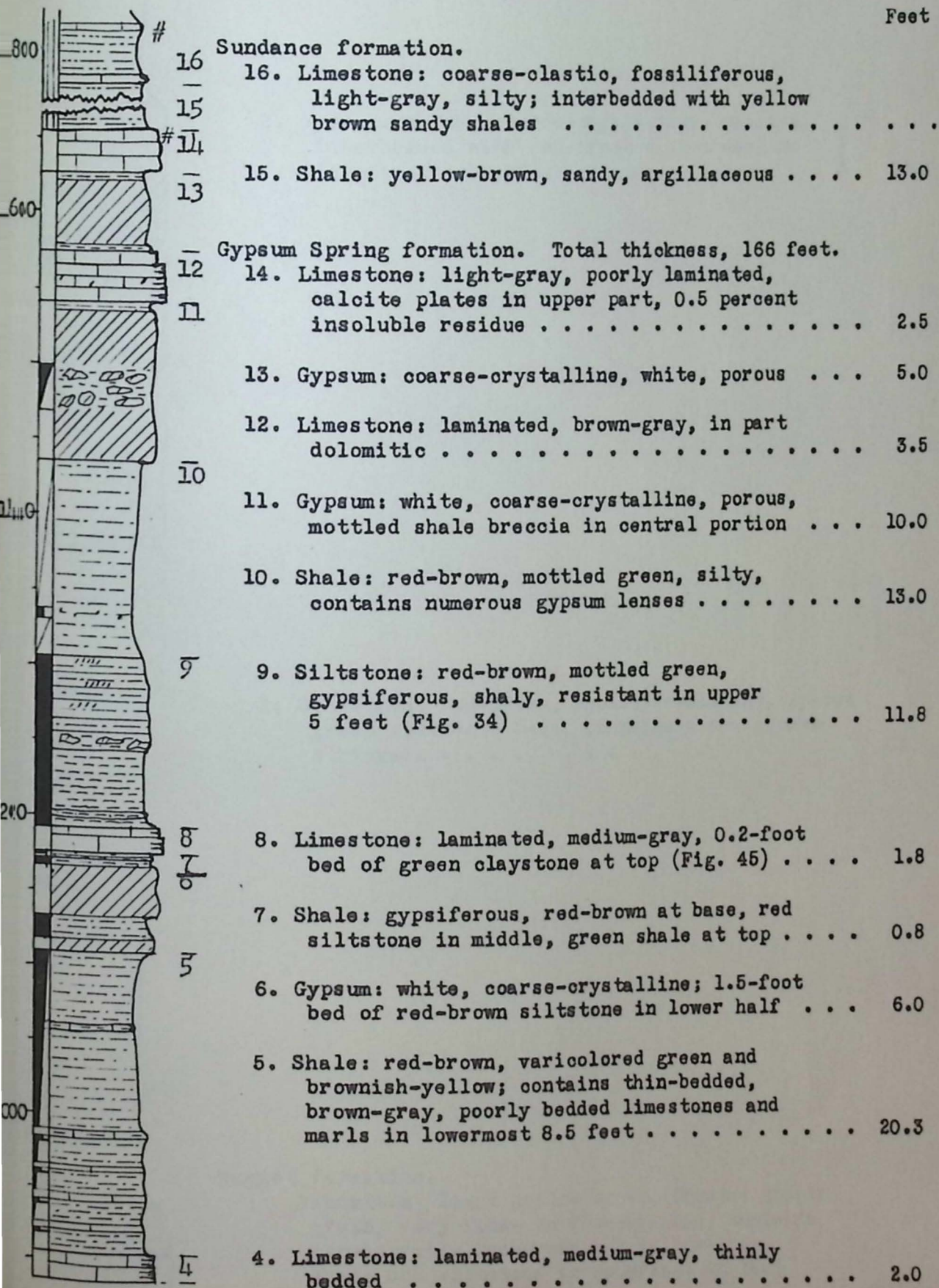


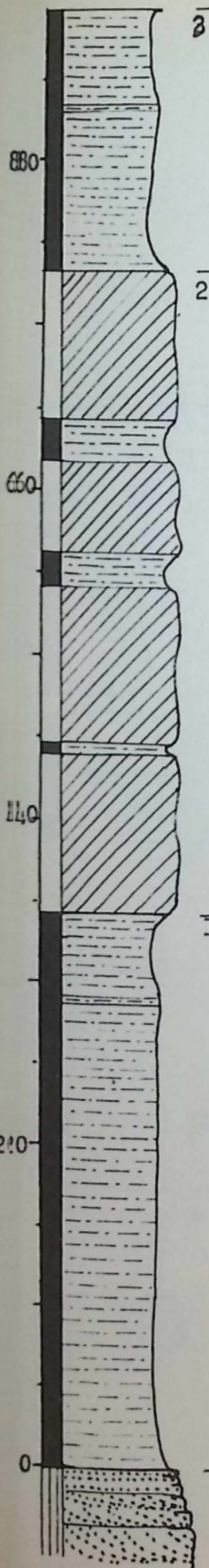
2. Gypsum: white, coarse-crystalline, porous, interbedded with siltstone, contains a coarse-grained recrystallized limestone, 0.3 foot thick at the base of the unit 56.0

1. Siltstone: red-brown, shaly, loosely cemented, a small amount of interbedded green siltstone . . . 4.0

Nugget formation.
 Sandstone: yellow-brown, frosted quartz grain, resistant, cross-bedded. Upper 24 feet is nonresistant and interbedded with green-gray sandy siltstone 420

Section 3, East Flank of Dallas anticline, 7 miles southeast of Lander, Wyoming, in NW $\frac{1}{4}$, Sec. 11, T. 32 N., R. 99 W., B. H. M.





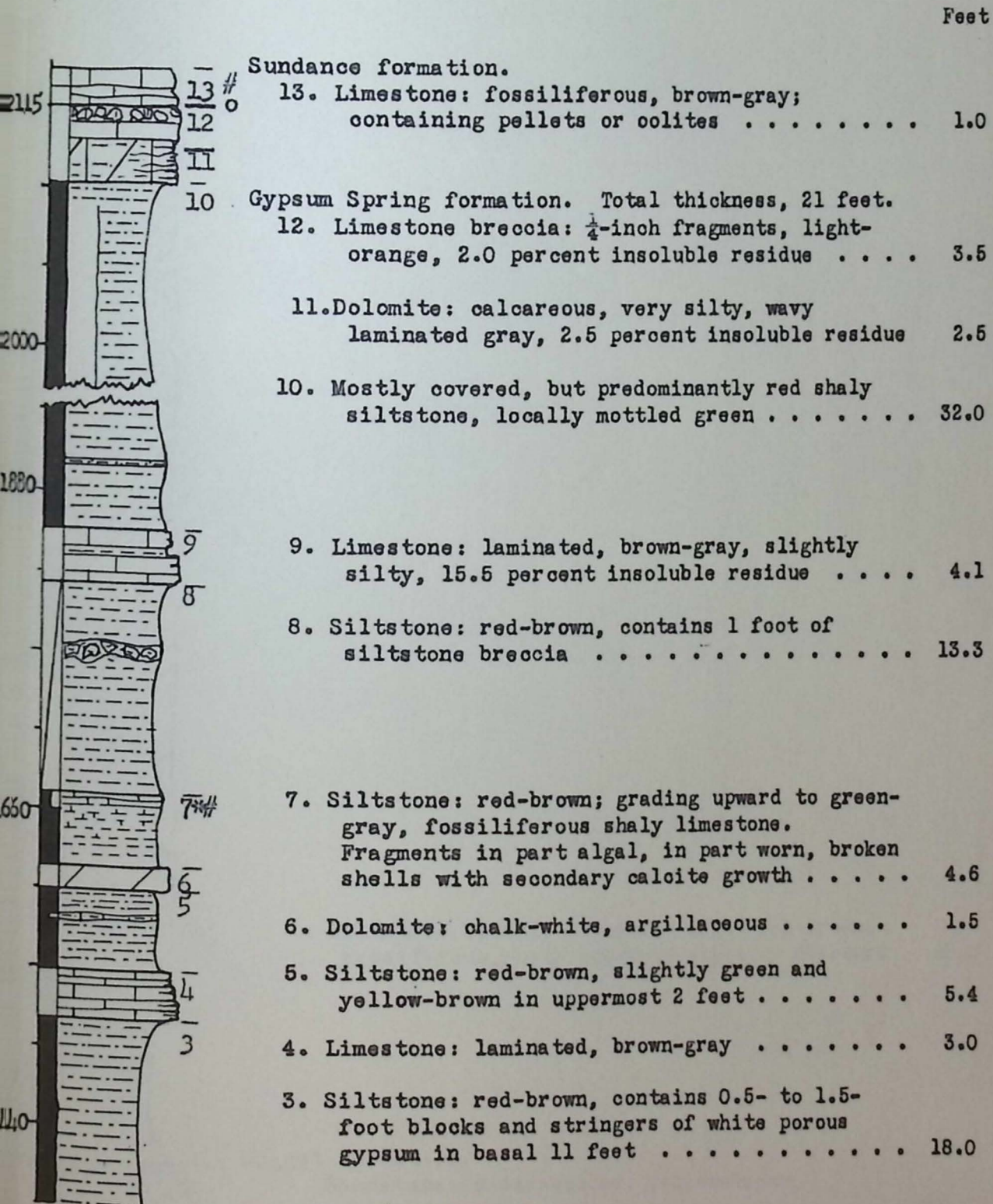
3. Siltstone: locally resistant, brownish-red in lower half, red-brown in upper half, apparently no gypsum present 15.5

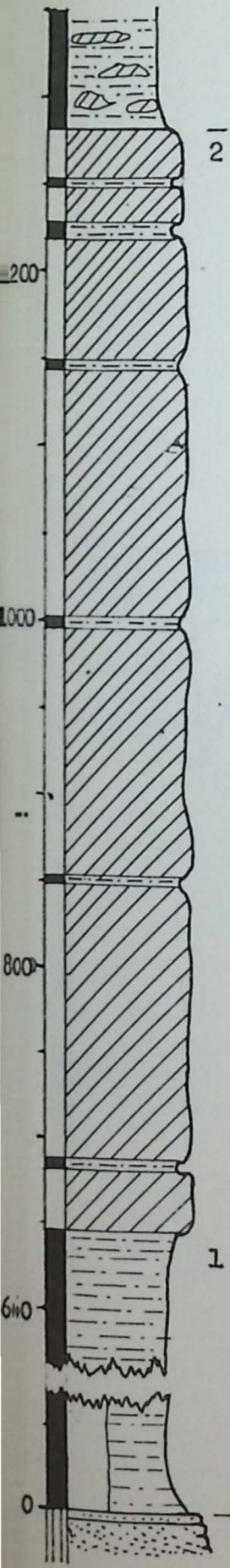
2. Gypsum: white, coarse-crystalline, massive, interbedded with red-brown siltstones, no dolomites exposed 39.0

1. Siltstone: red-brown, locally resistant, sparse green siltstone beds, contains a few gypsum stringers 34.3

Nugget formation.
 Sandstone: light yellow brown, frosted quartz grain, very fine- to fine-grained, contains considerable red-brown and yellow-brown shale and siltstone in uppermost 40 feet (Fig. 5) 374.

Section 4, Squaw Creek, 3 miles southwest of Lander Wyoming,
 in SW $\frac{1}{4}$, Sec. 27, T. 33 N., R. 100 W., B. H. M.





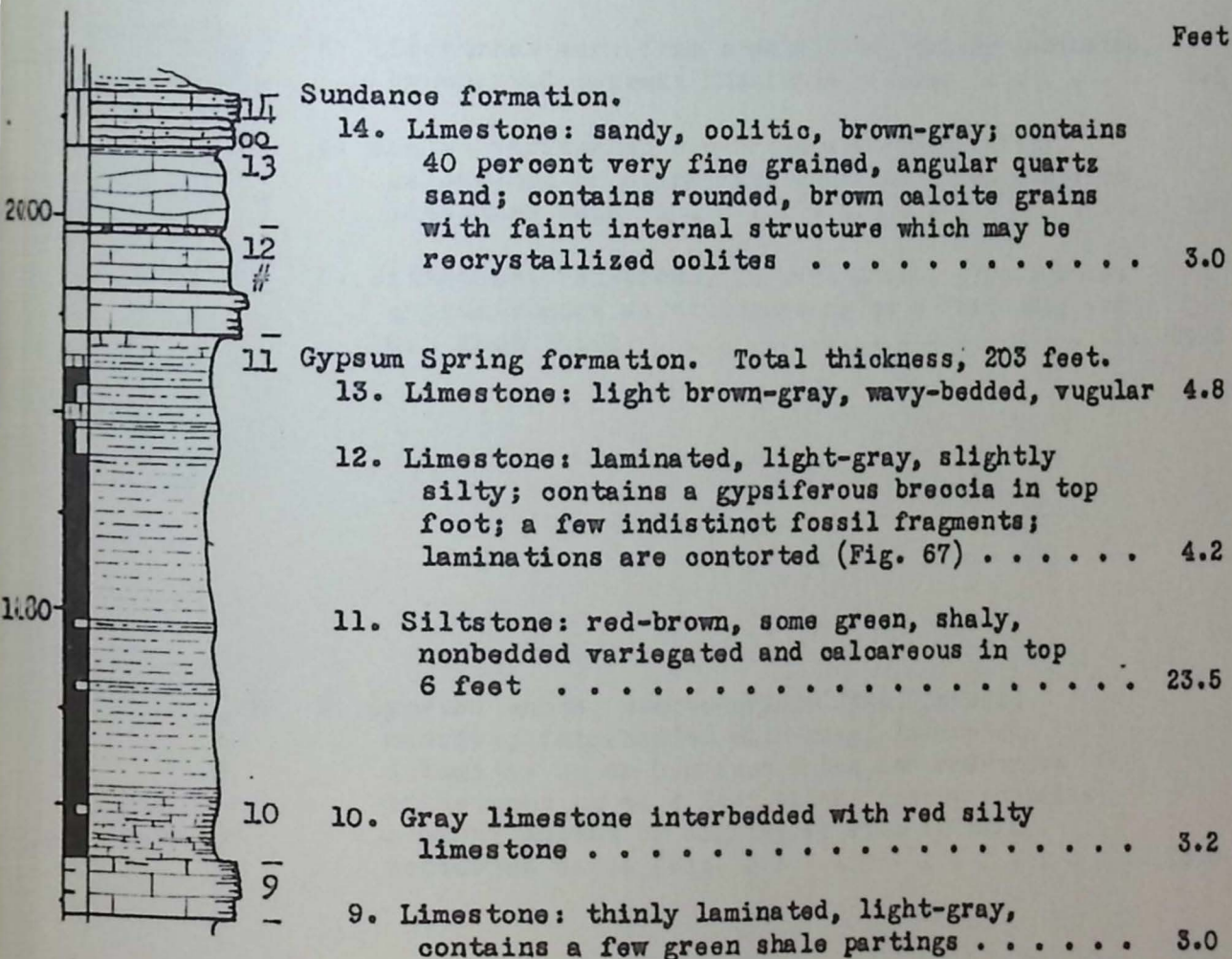
Feet

2. Gypsum: white, coarse-crystalline, massive,
 a few interbedded red-brown siltstones 63.0

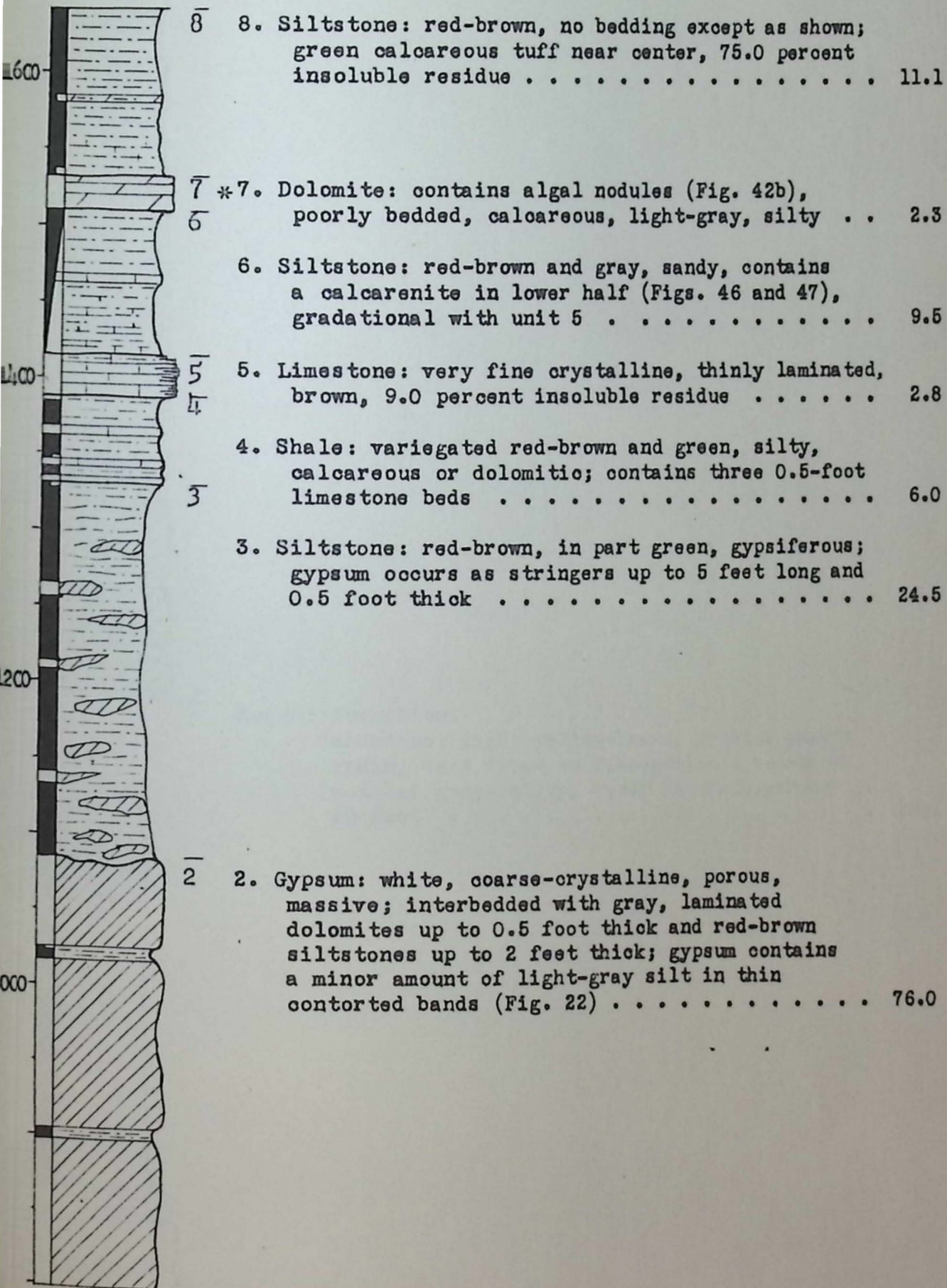
1. Siltstone (poorly exposed): light red-brown,
 gypsiferous, both contacts slightly obscured . 65.0

Nugget formation.
 Sandstone: cross-bedded, yellow-brown,
 frosted quartz grain 361.

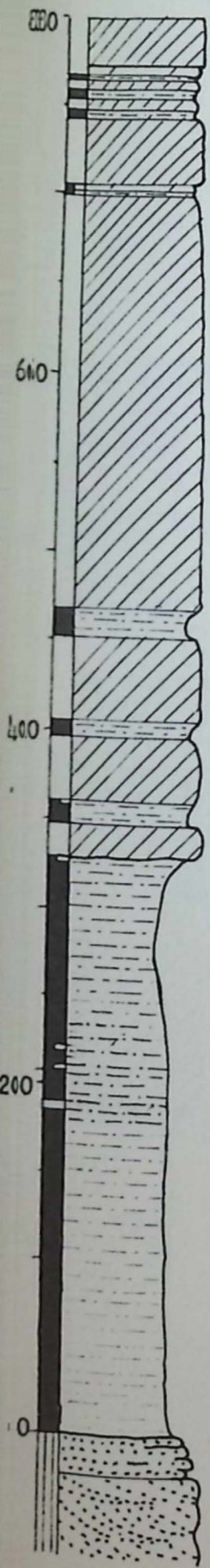
Section 5, East flank of Lander, Anticline, 5 miles northeast of Lander, Wyoming, in E $\frac{1}{2}$, Sec. 13, T. 2 S., R. 1 E., W. R. M.



Feet

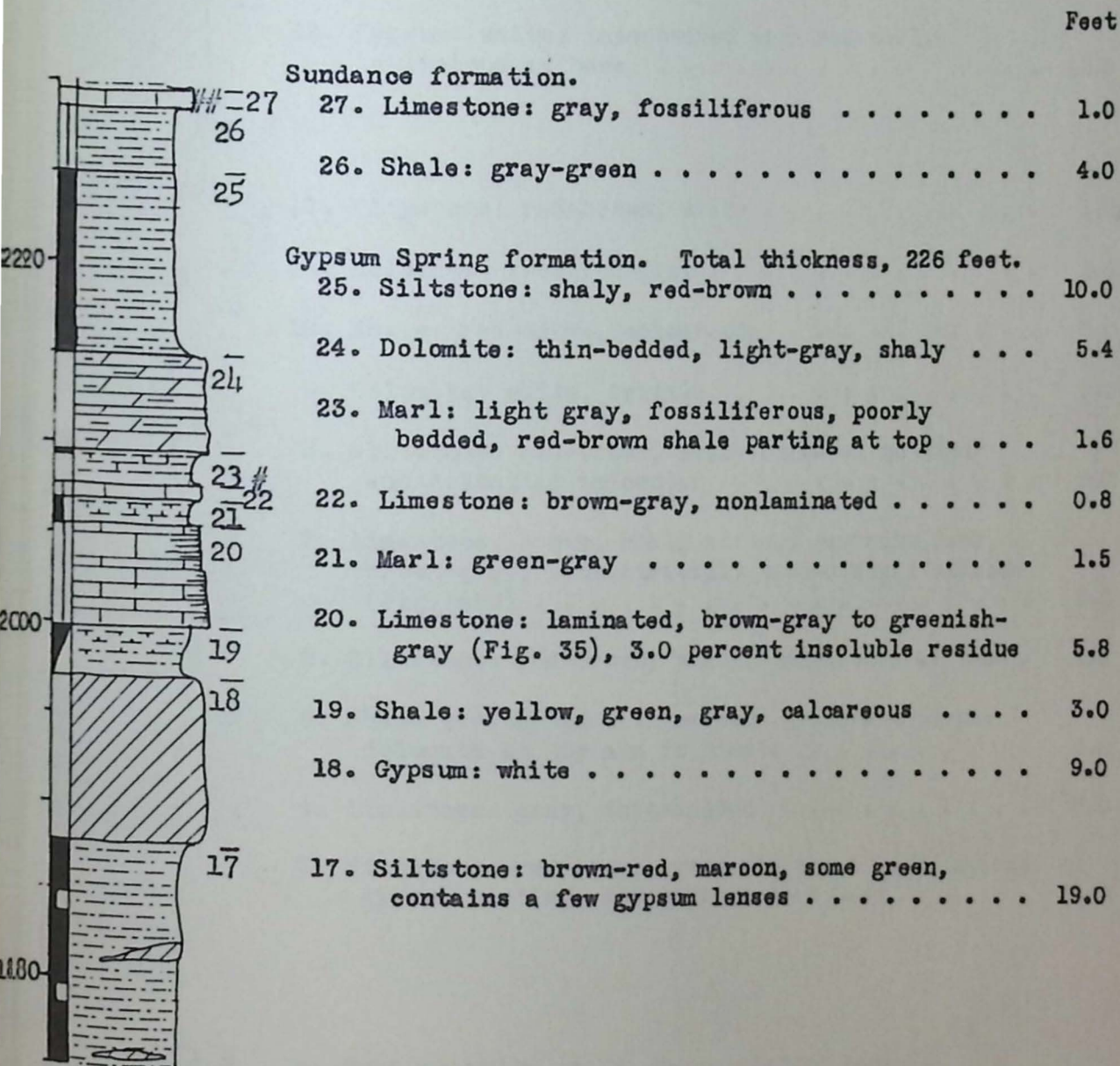


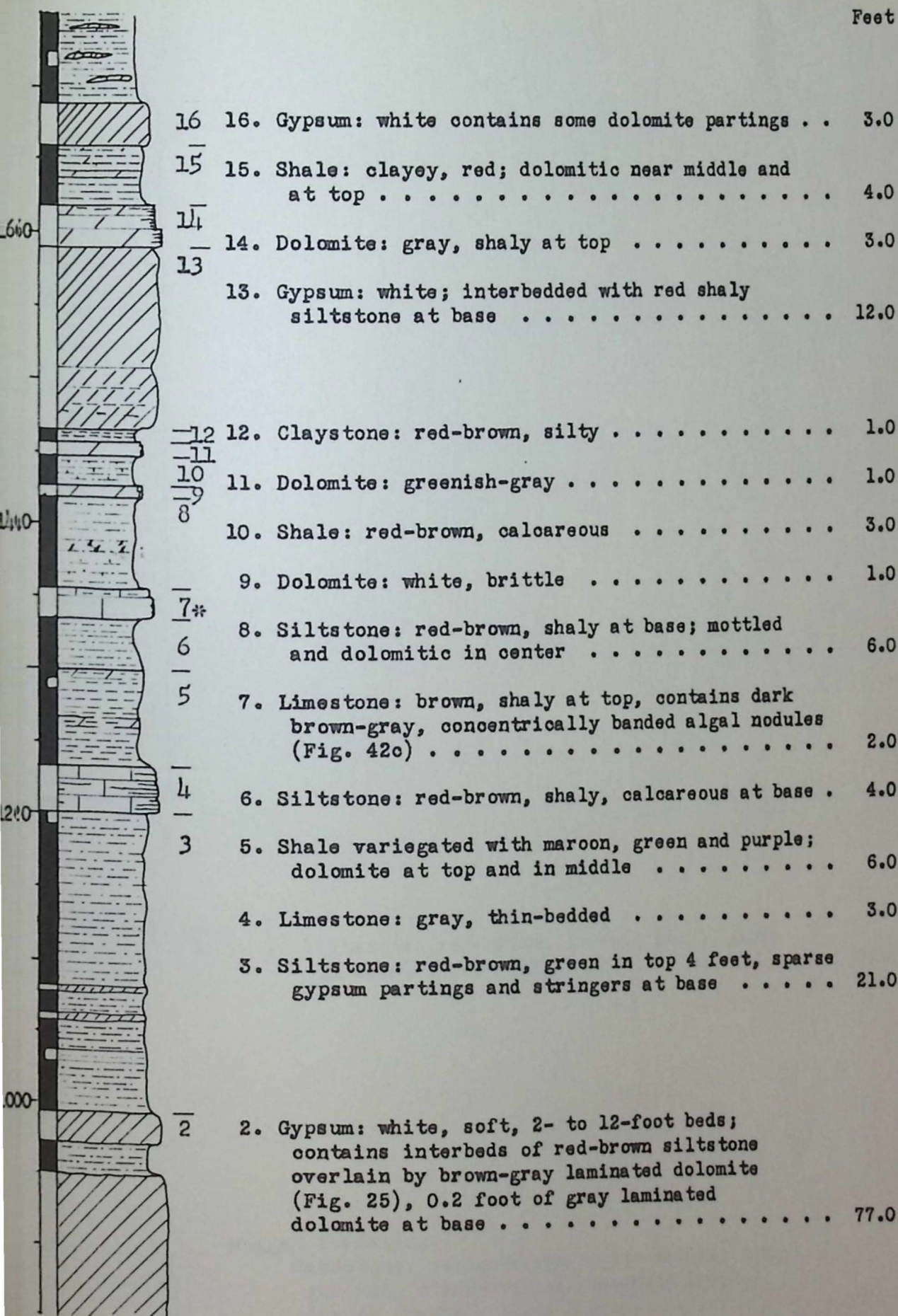
Feet



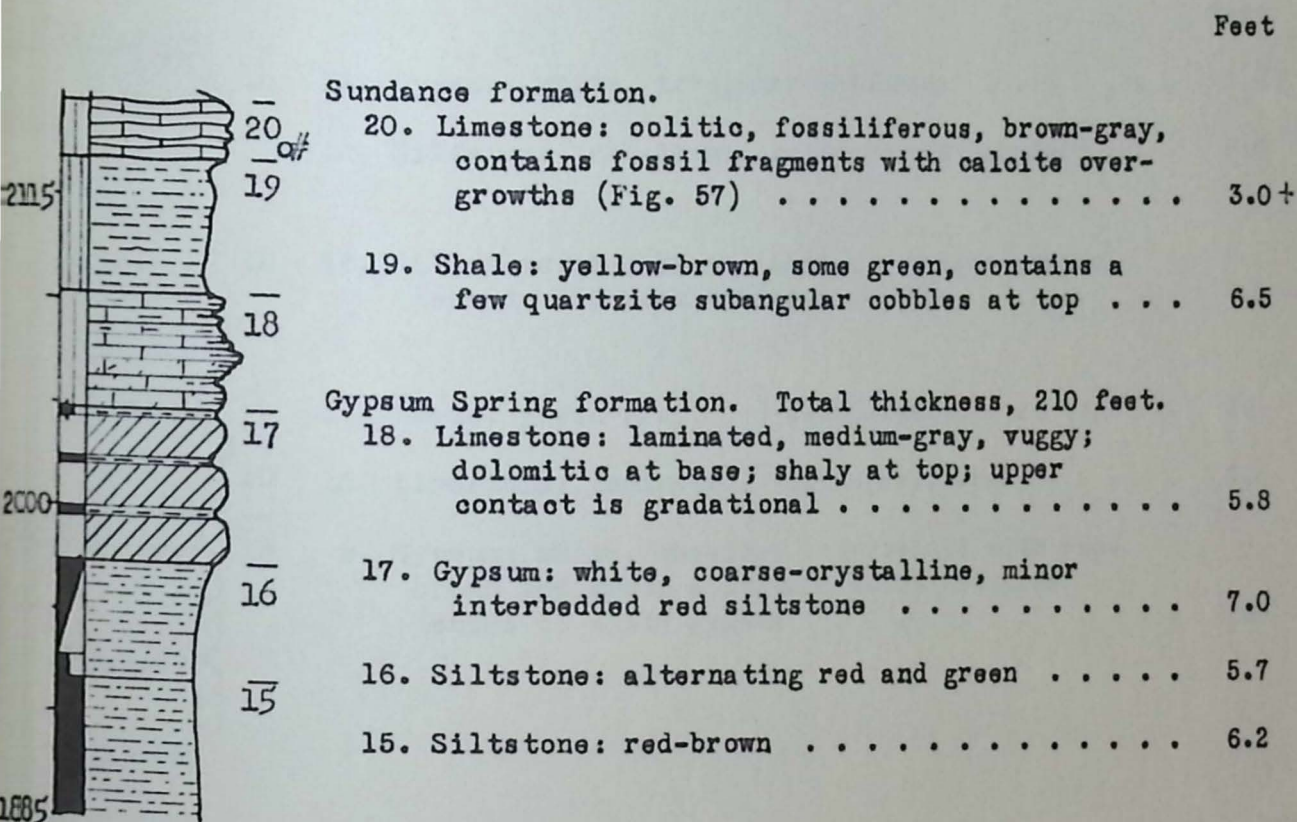
1 Nugget formation.
 Sandstone: light yellow-brown, frosted quartz grain, very fine- to fine-grained; red-brown, mottled gray, silty, sandy in the uppermost 15 feet 280.

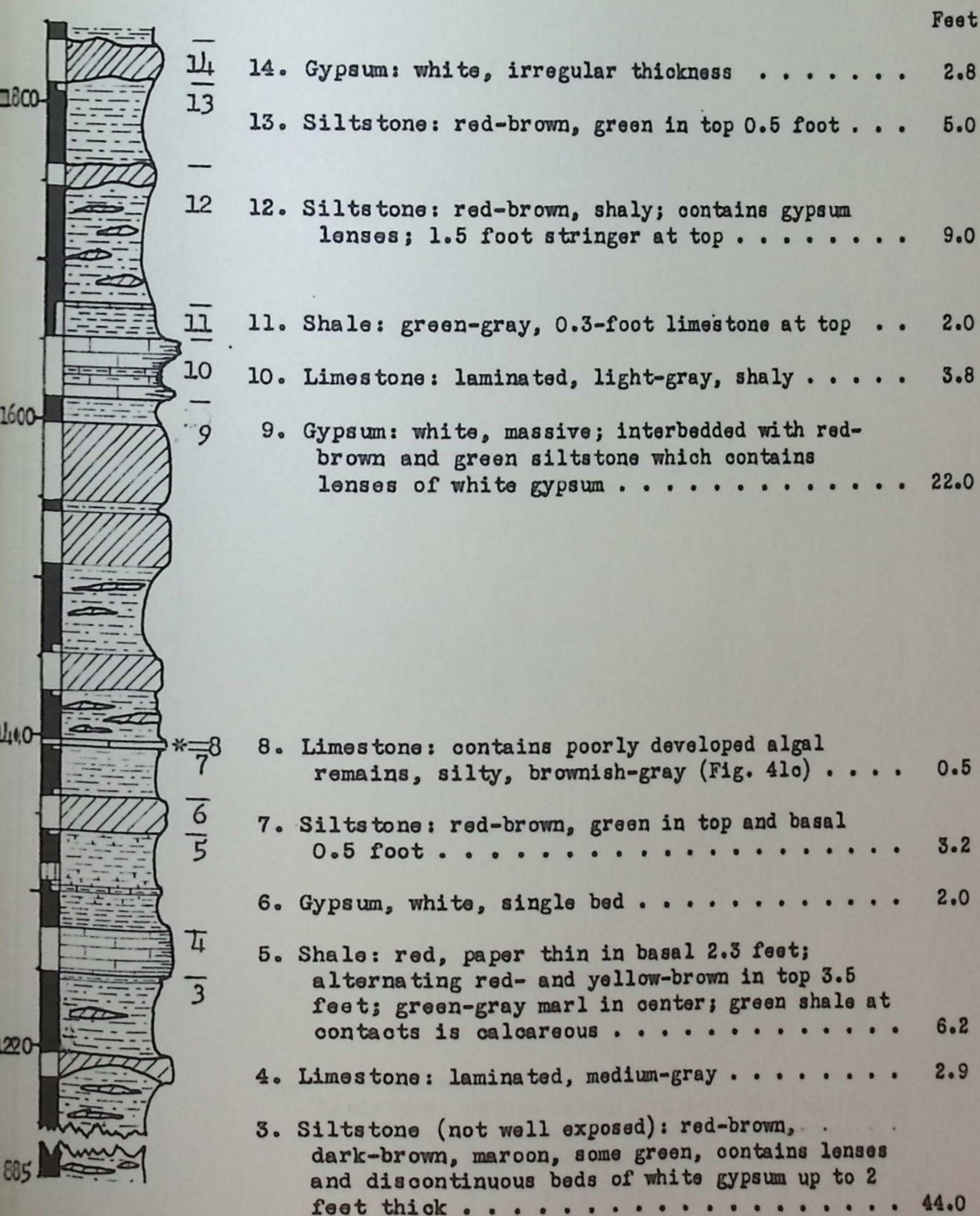
Section 6, Mill Creek, 11 miles northwest of Lander, Wyoming,
 in NE $\frac{1}{4}$, Sec. 6, T. 2 S., R. 1 W., W. R. M.



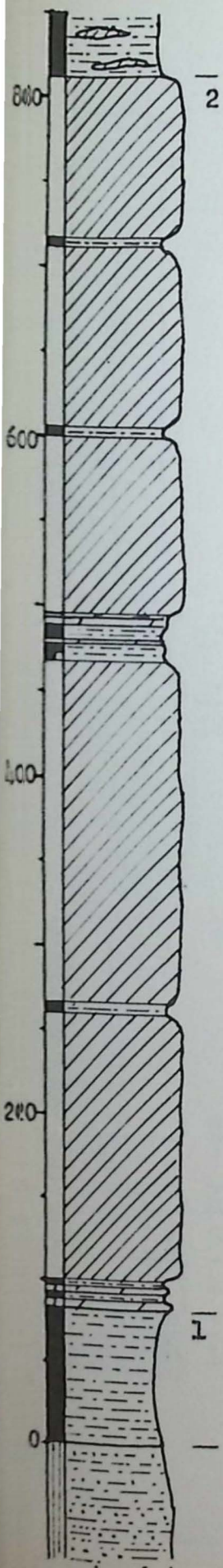


Section 7, South end of Sage Creek Anticline, 13 miles north of Lander, Wyoming in S $\frac{1}{2}$, Sec. 6, T. 1 S., R. 1 E., W. R. M.





Feet

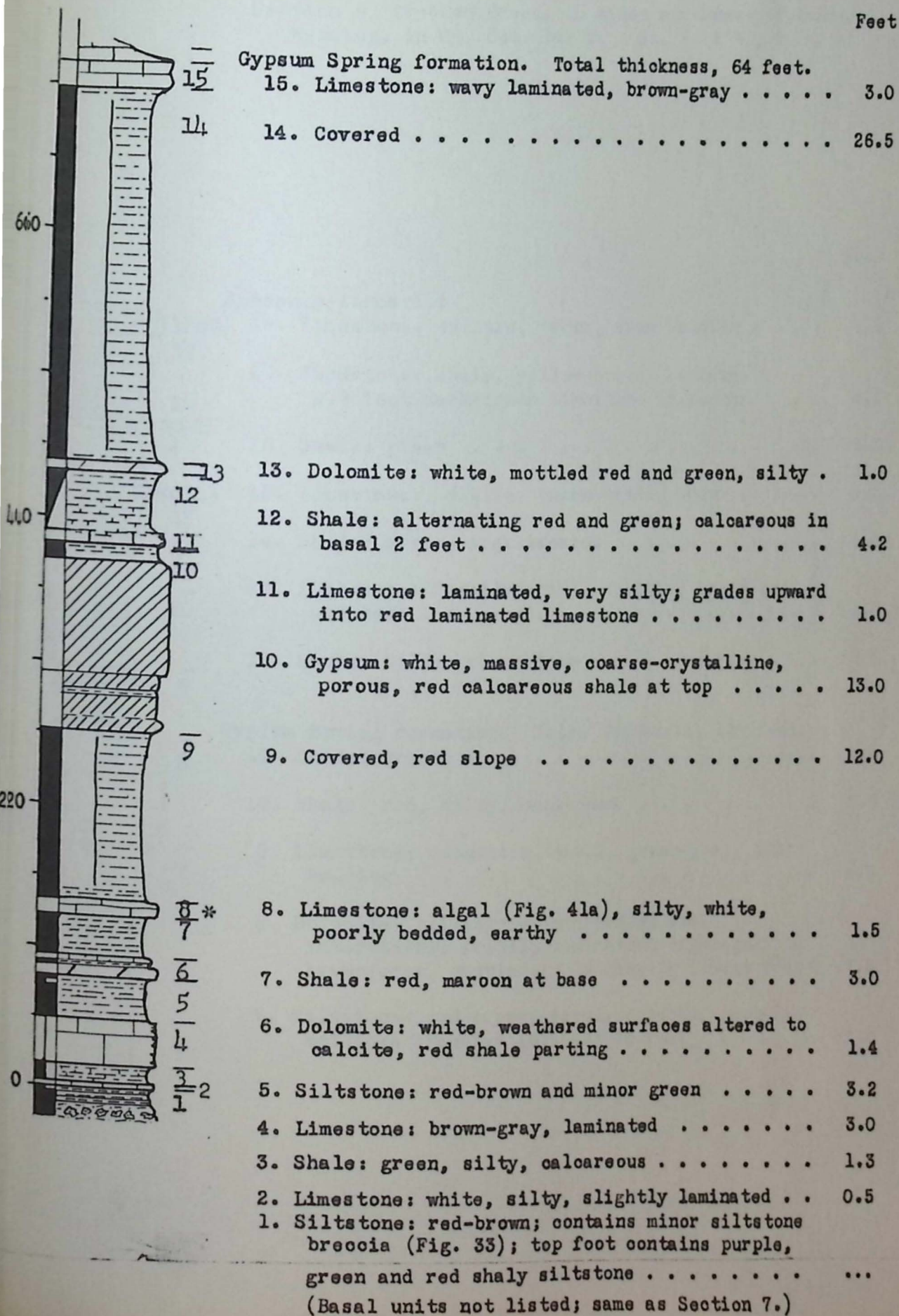


2. Gypsum: white, coarse-crystalline; contains interbedded red shale and brown-gray laminated dolomites 73.0

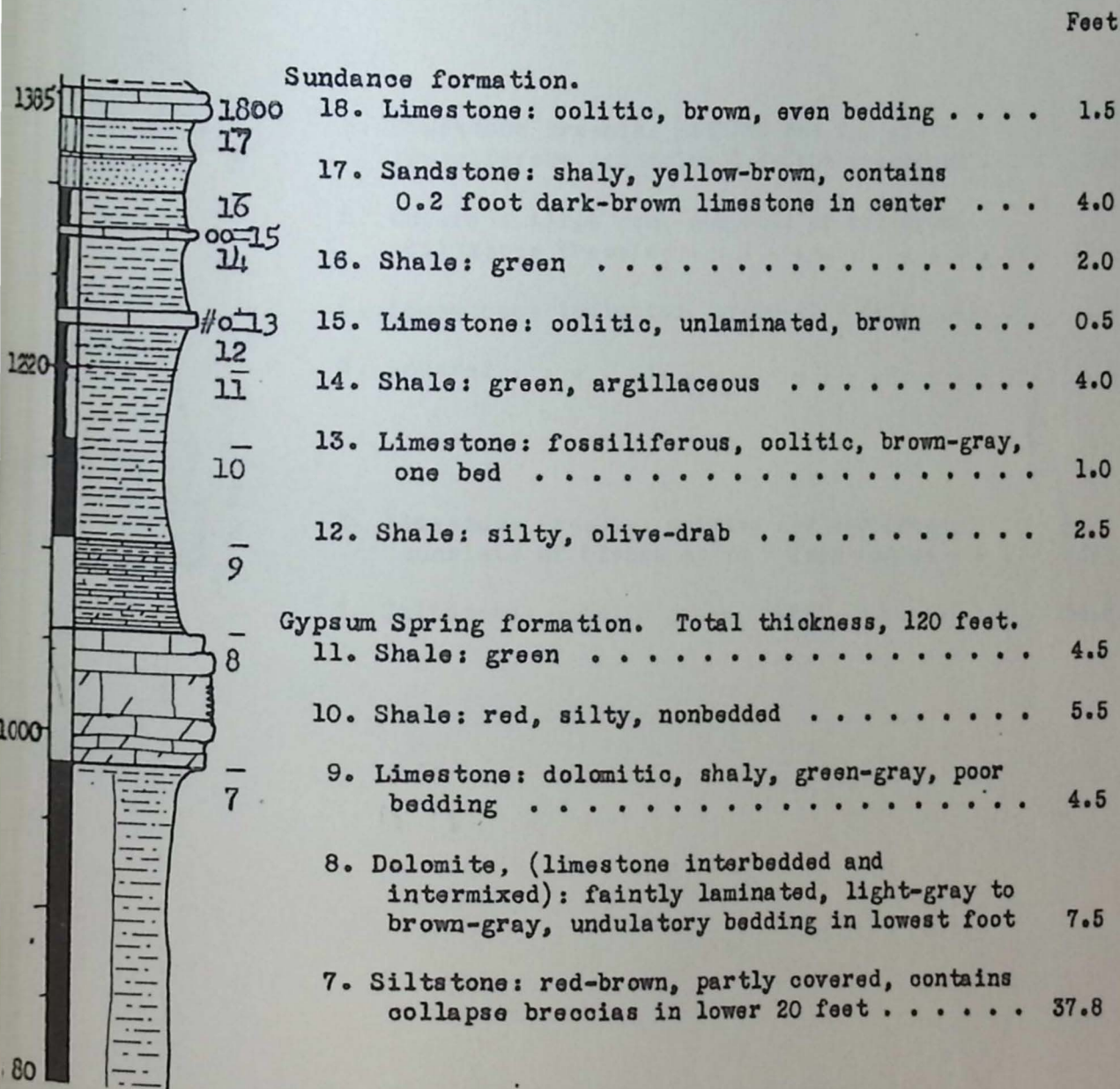
1. Siltstone: shaly, red-brown, mottled green . . . 9.0

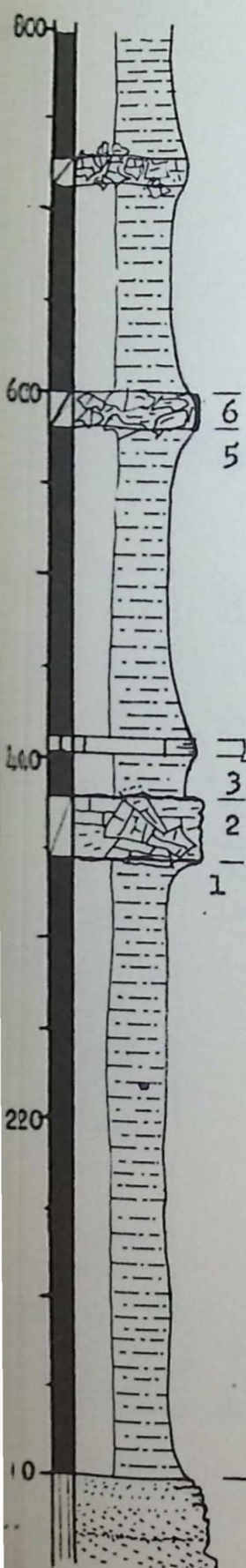
Nugget formation.
 Sandstone: yellow-brown, cross-bedded, cliff-forming, calcareous; increasing quantities of red-brown shale and siltstone in uppermost 29 feet

Section 8, Mill Creek, 12 miles northwest of Lander, Wyoming,
 in NW $\frac{1}{4}$, Sec. 31, T. 1 S., R. 1 W., W. R. M.



Section 9, Crooked Creek, 15 miles northwest of Lander,
Wyoming, in W $\frac{1}{2}$, Sec. 14, T. 1 S., R. 2 W., W. R. M.



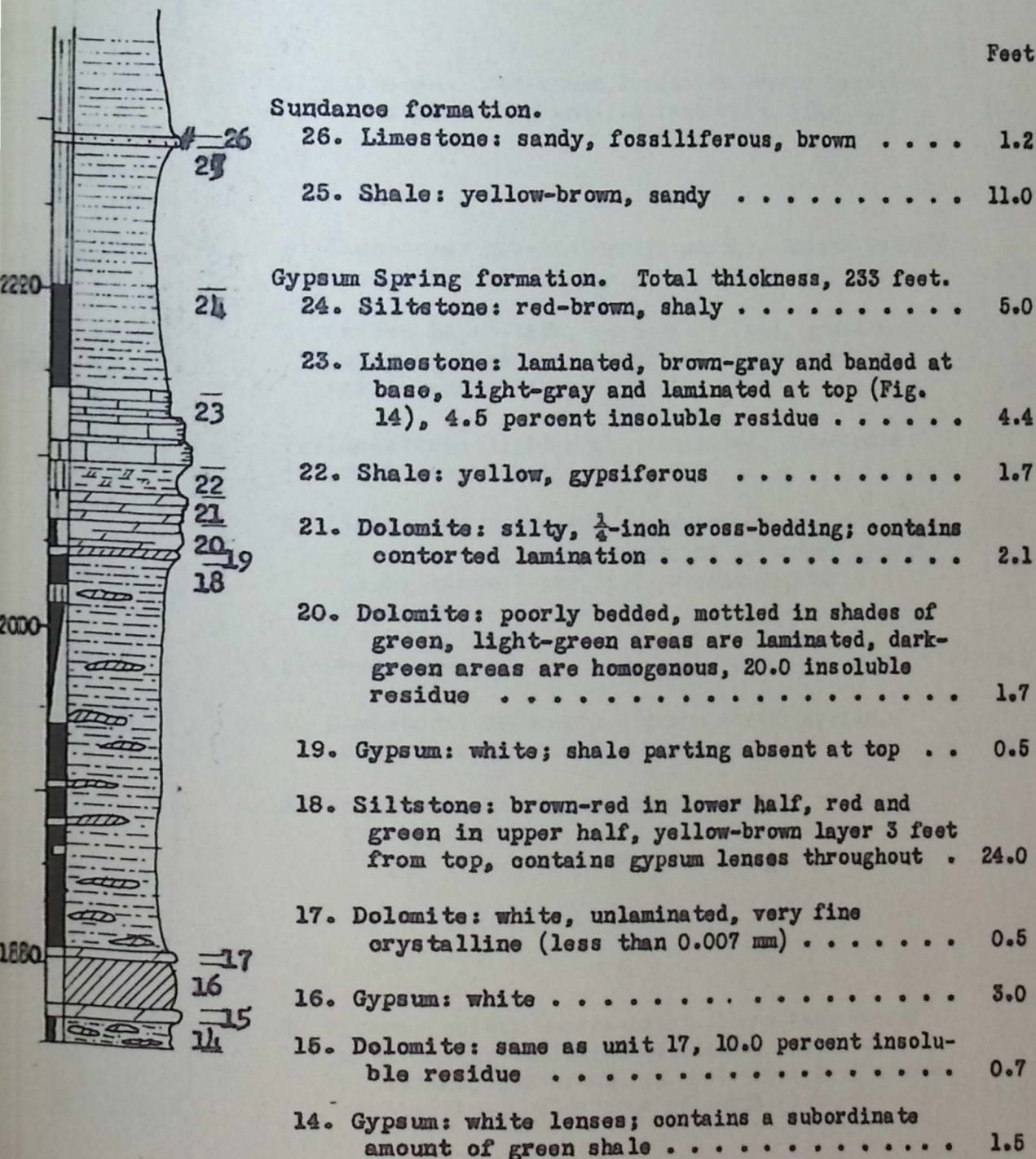


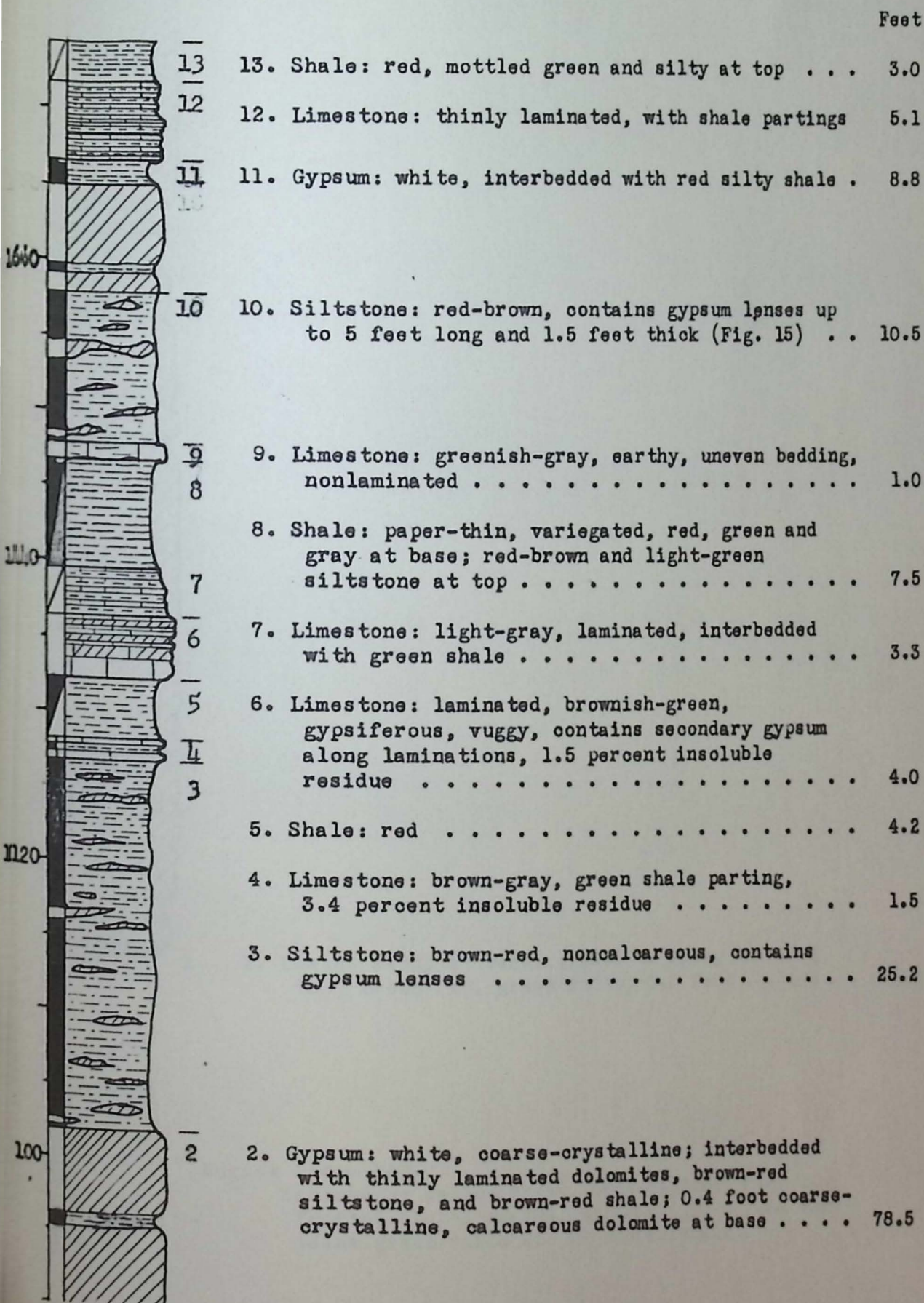
Feet

- 6. Limestone breccia: mottled red and green, gypsiferous, contains 0.2-foot fragments . . . 2.0
- 5. Covered: slope rock composed of red-brown siltstone breccia 17.0
- 4. Limestone: laminated, brown-gray (Fig. 36) . . 1.0
- 3. Covered 2.0
- 2. Limestone breccia: mottled red and green, consists of blocks up to 3 feet across 3.5
- 1. Siltstone: mottled green, partly covered . . . 34.5

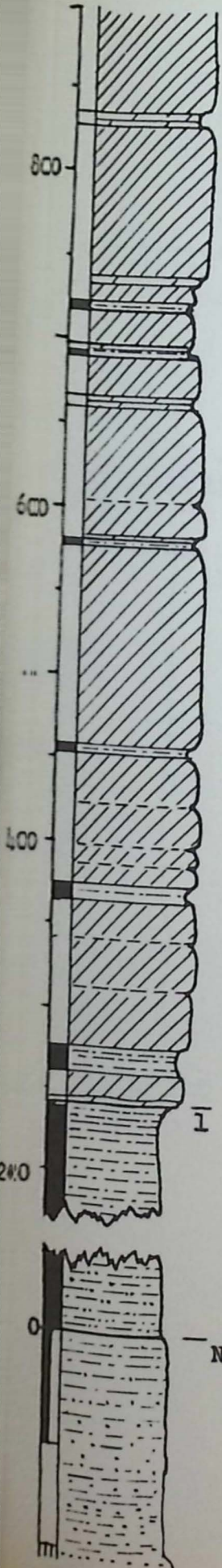
Nugget formation.
 Sandstone: yellow-brown, frosted quartz grain, cross-bedded; mottled and silty in upper 20 feet 317.

Section 10, North end of Sage Creek anticline,
17 miles north of Lander, Wyoming, in SW $\frac{1}{4}$,
Sec. 15, T. 1 N., R. 1 W., W. R. M.





Feet

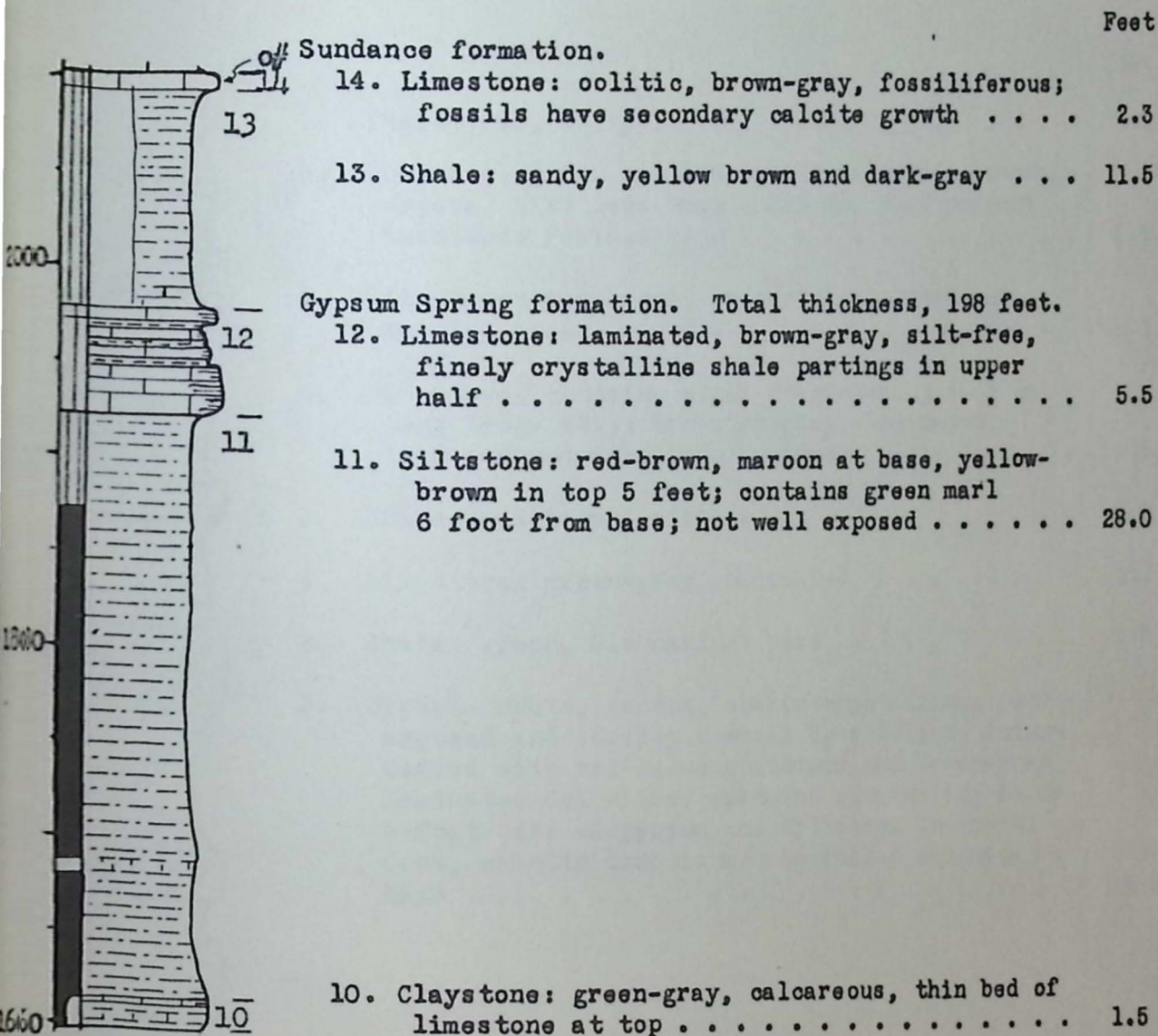


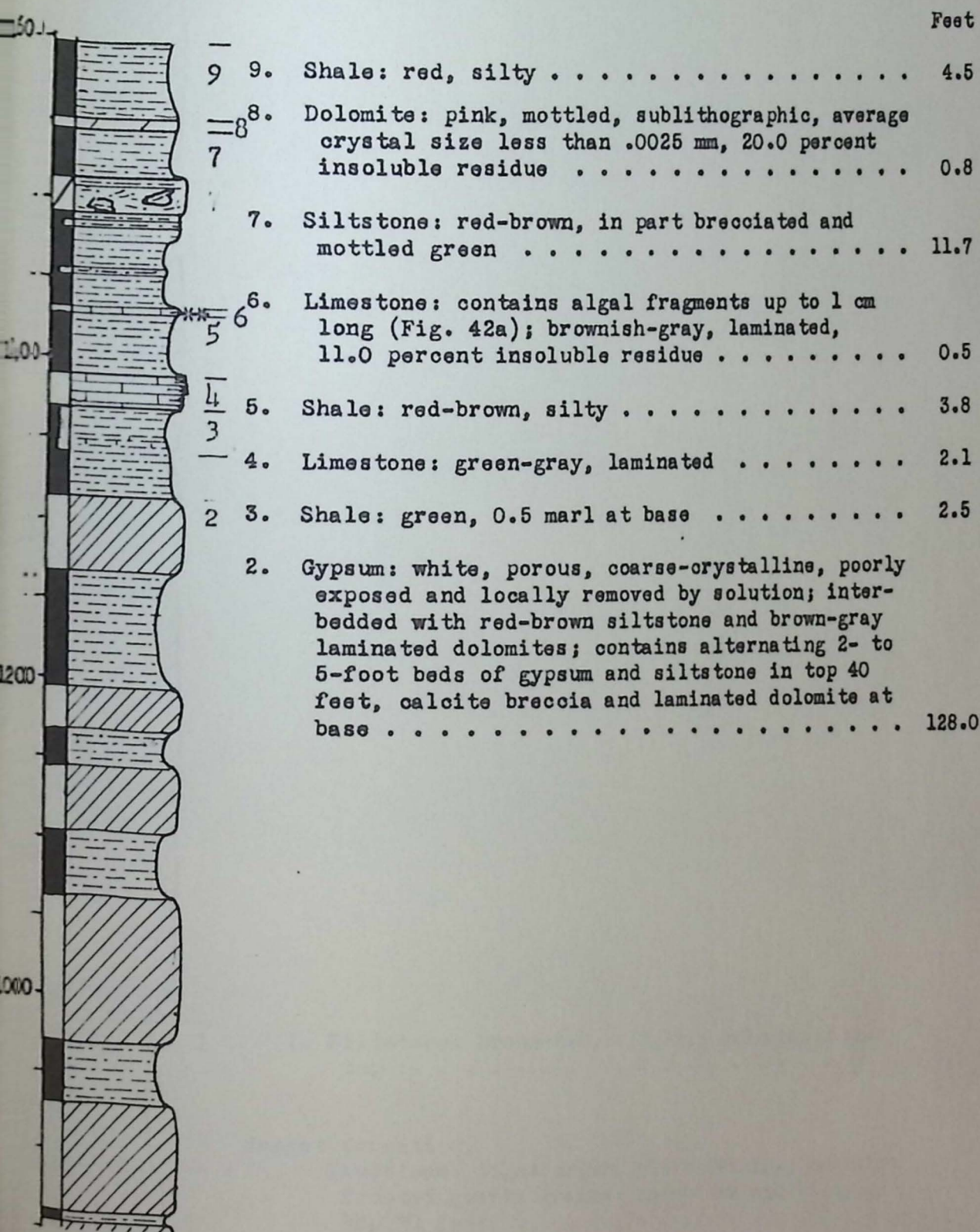
1. Shale: sandy at base, grades to silty shale at top, brown-red, green in top 0.2 foot 24.0

Nugget formation.

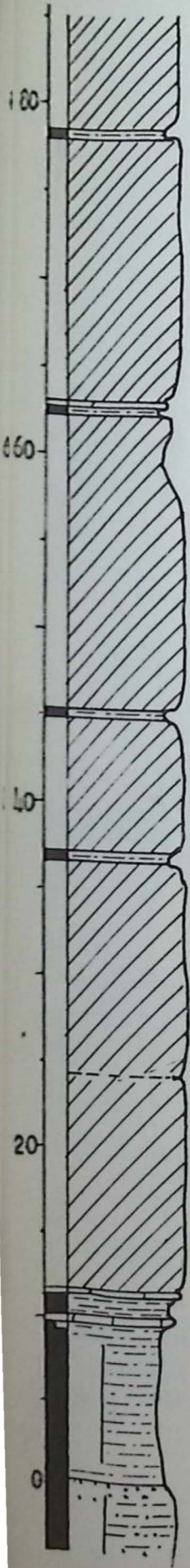
Sandstone: yellow-brown, cross-bedded, resistant, frosted quartz grains, uppermost 12.5 feet contains green shale and is nonresistant

Section 11, Perah Creek, 25 miles northwest of Lander,
Wyoming, in SW $\frac{1}{4}$, Sec. 12, T. 1 N., R. 3 W., W. R. M.





Feet



1. Siltstone: brown-red, slightly calcareous near top 9.3

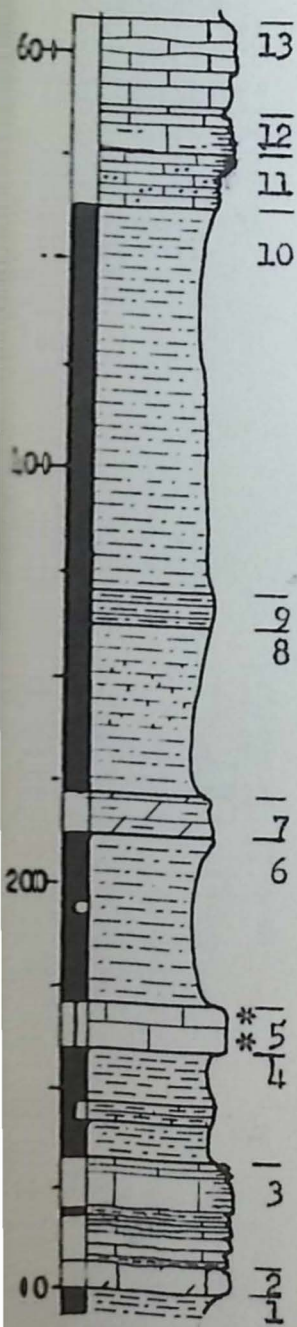
Nugget formation.
 Sandstone: light brown, cliff forming; contains frosted quartz grains; red-brown and silty in top 30 feet

Section 12, North fork Sage Creek, 29 miles northwest of Lander, Wyoming, in SE $\frac{1}{4}$, Sec. 17, T. 2 N., R. 3 W., W. R. M.

Feet

Gypsum Spring formation. Partial thickness, 61 feet.

- 13. Limestone: light brownish-gray; mottled red and green; wavy bedded in top 2.5 feet 4.4
- 12. Limestone: red, laminated, silty at top, red-gray at base; contains thin shale partings . . 1.3
- 11. Limestone: laminated, greenish brown gray, well bedded; no shale partings; contorted laminae and sand at base; quartz sand has secondary overgrowths 3.4
- 10. Siltstone: red-brown; brown in basal 10 feet; variegated with red, green, brown and yellow in uppermost 8 feet 18.7
- 9. Shale: red-brown, mottled green, silty, calcareous, poorly bedded 2.5
- 8. Siltstone: variegated with red, brown, purple, greenish-gray; poorly bedded; in part calcareous 7.5
- 7. Dolomite: white, shaly, thin-bedded and laminated in top bed 2.0
- 6. Shale: silty, brownish-red, a few green beds . 8.0
- 5. Limestone: gray, even bedded; contains ellipsoidal, banded, dark-brown algal nodules up to 3 cm across (Figs. 39 and 40) 2.0
- 4. Shale: red-brown; silty at base; green limestone in center 5.6
- 3. Limestone: laminated, green-gray, thick-bedded; contains red shale partings, 3.5 percent insoluble residue 4.9
- 2. Limestone: dolomitic, light-gray, coarser crystalline than usual 1/45 mm 1.0
- 1. Shale: silty, maroon and reddish-brown

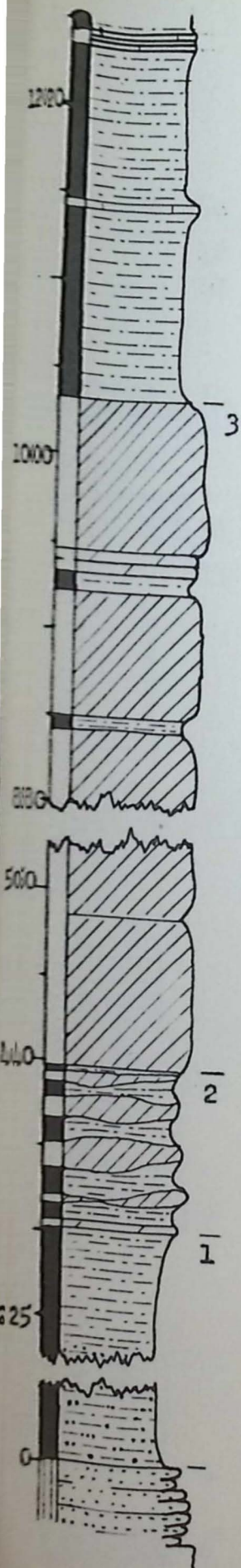


(Underlying units not exposed)

Section 13, Bull Lake, 31 miles northwest of Lander, Wyoming,
in SW $\frac{1}{4}$, Sec. 32, T. 3 N., R. 3 W., W. R. M.

	Feet
Sundance formation.	
21. Limestone: sandy, porous, brown	0.5
20. Shale: sandy, yellow-brown	5.0
Gypsum Spring formation. Total thickness, 198 feet.	
19. Limestone: slightly laminated, light-gray; contains rounded fragmental calcite grains . .	5.4
18. Limestone: dolomitic, light-brown, nonlaminated; contains subrounded dolomite grains 1 mm in diameter and 1/50 mm calcite crystals	3.7
17. Limestone: thin-bedded, laminated, interbedded with green marl	0.8
16. Limestone: poorly laminated, thick-bedded . .	1.2
15. Dolomite: calcareous, laminated, alternating light-red and brown, silty in brown lamina, coloring is secondary (Fig. 54), 7.5 percent insoluble residue	2.7
14. Shale: red-brown, in part siltstone; uppermost 10 feet contains lenses of limestone (in part brecciated)(20%), green shale (25%), brown- yellow shale (10%), red-brown shale (45%) . .	22.9
13. Marl: poorly bedded; mottled red, green and gray	2.2
12. Shale: silty, purplish-red	2.5
11. Limestone: gray, irregularly bedded; contains 1.5-foot lens of purple marl in center	2.5
10. Siltstone: brown-red, shaly; contains light- green, silty dolomite lenses	2.5
9. Dolomite: chalk-white, single bed	1.1
8. Siltstone: variegated with purple, brown-red, red and green; in part calcareous	13.8
7. Limestone: thin-bedded, laminated; interbedded with red shale	2.5
6. Limestone: laminated, gray, 0.2 foot green shale parting at base	3.3
5. Dolomite: poorly bedded, white, splintery fracture	2.1
4. Siltstone: red-brown; contains red-brown fine-crystalline limestone in center; green, sandy and calcareous at top	27.0

Feet



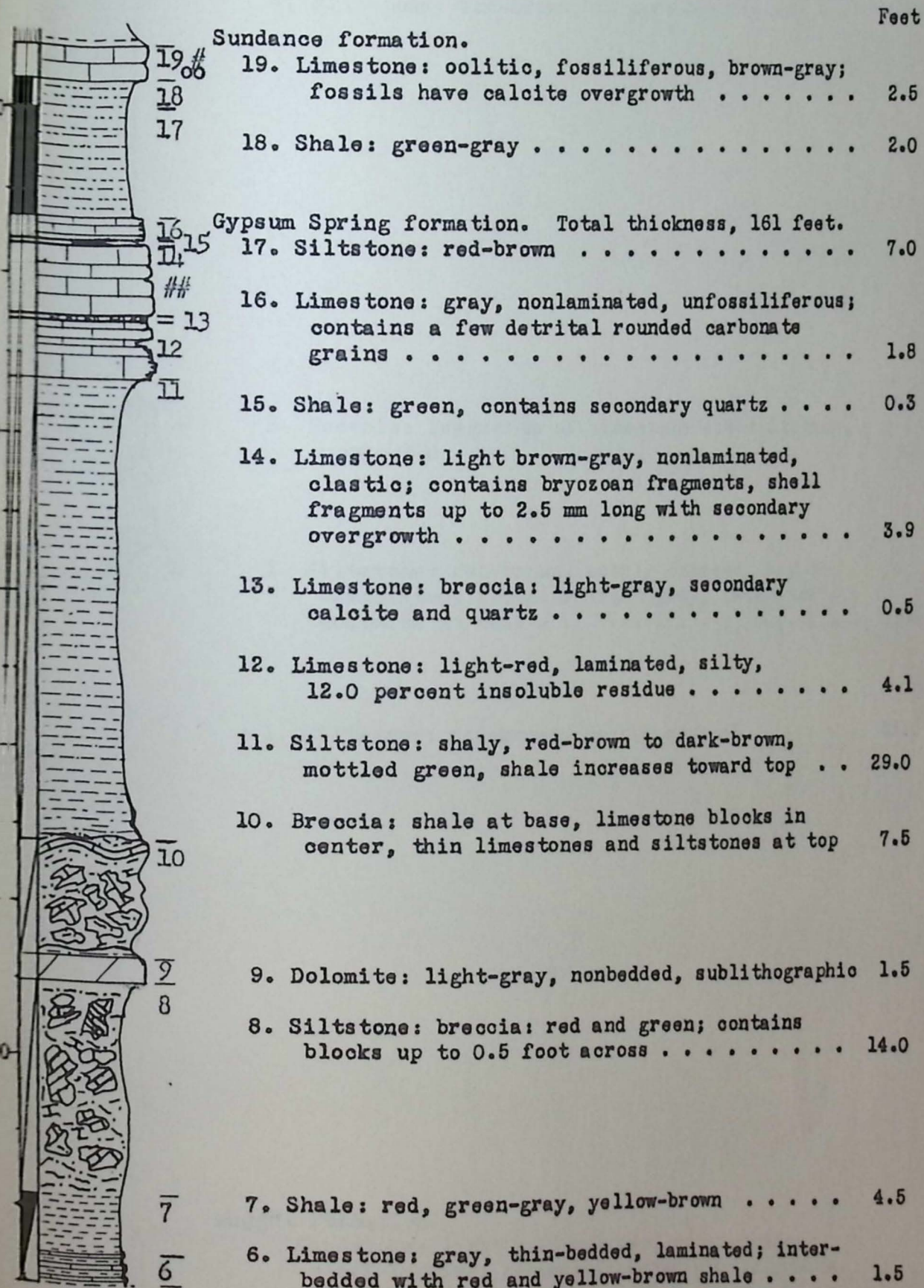
3. Gypsum: white, dense, cliff-forming, massive-bedded; weathers to large joint blocks (Fig. 20); contains thin irregular laminae of gray dolomitic shale (Figs. 23 and 24); contains 2.5-foot bed of red shale and thin-bedded dolomite 9 feet from top 65.5

2. Gypsum: white, non-uniformly bedded; interbedded with gypsiferous red shale; contains brown-gray, silty laminated dolomite at base 8.5

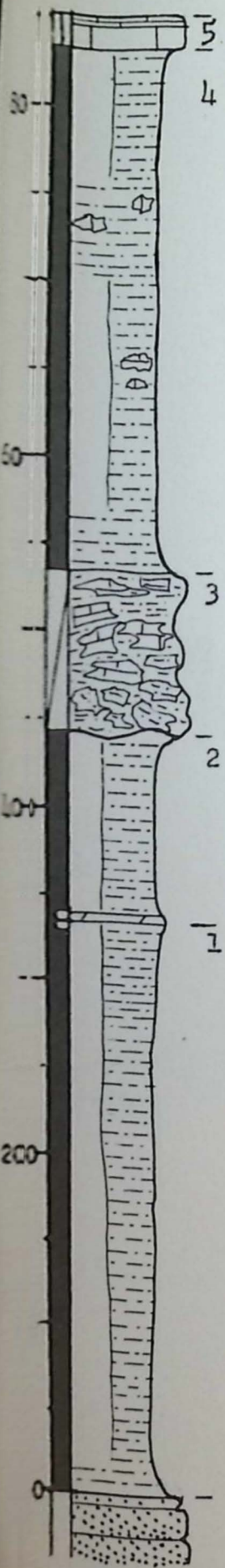
1. Siltstone: brown-red, some green at top, some sand present except in top 8 feet 29.5

Nugget formation.
 Sandstone: yellow-brown, cross-bedded, cliff-forming; contains frosted quartz grains.

Section 14, Willow Creek, 5 miles southwest of Crowheart,
Wyoming, in NW $\frac{1}{4}$, Sec. 16, T. 3 N., R. 4 W., W. R. M.



Feet



5. Limestone: brown-gray, homogenous; contains styolites, 0.7 percent insoluble residus . . . 2.0

4. Siltstone: red-brown, in part brecciated . . . 30.0

3. Breccia: fragments of limestone and siltstone, nonbedded 9.0

2. Siltstone: red-brown, poorly exposed, may be brecciated; contains light-gray, laminated dolomite at base 11.0

1. Siltstone: red-brown, poorly exposed 33.0

Nugget formation.
Sandstone: light yellow-brown, cross-bedded, cliff-forming; contains frosted quartz grains.

Section 15, Bob Creek, 5 miles west of Crowheart, Wyoming,
 in NE $\frac{1}{4}$, Sec. 31, T. 4 N., R. 3 W., W. R. M.

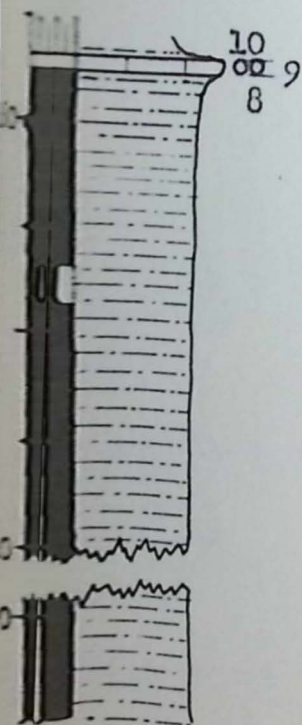
Feet

Sundance formation.

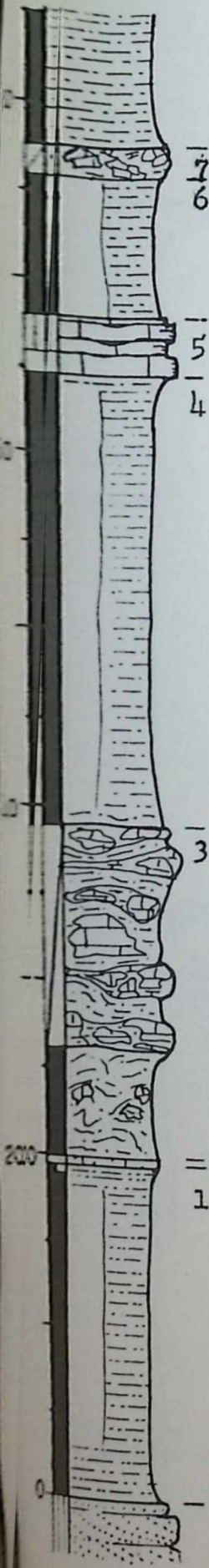
- 10. Shale: yellow brown sandy
- 9. Limestone: oolitic, gray, fossiliferous
 (Fig. 58) 1.0

Gypsum Spring formation. Total thickness, 162 feet.

- 8. Siltstone: red-brown, shaly, yellow-brown, in
 top foot, green shale 8 feet from top. 85.5



Feet

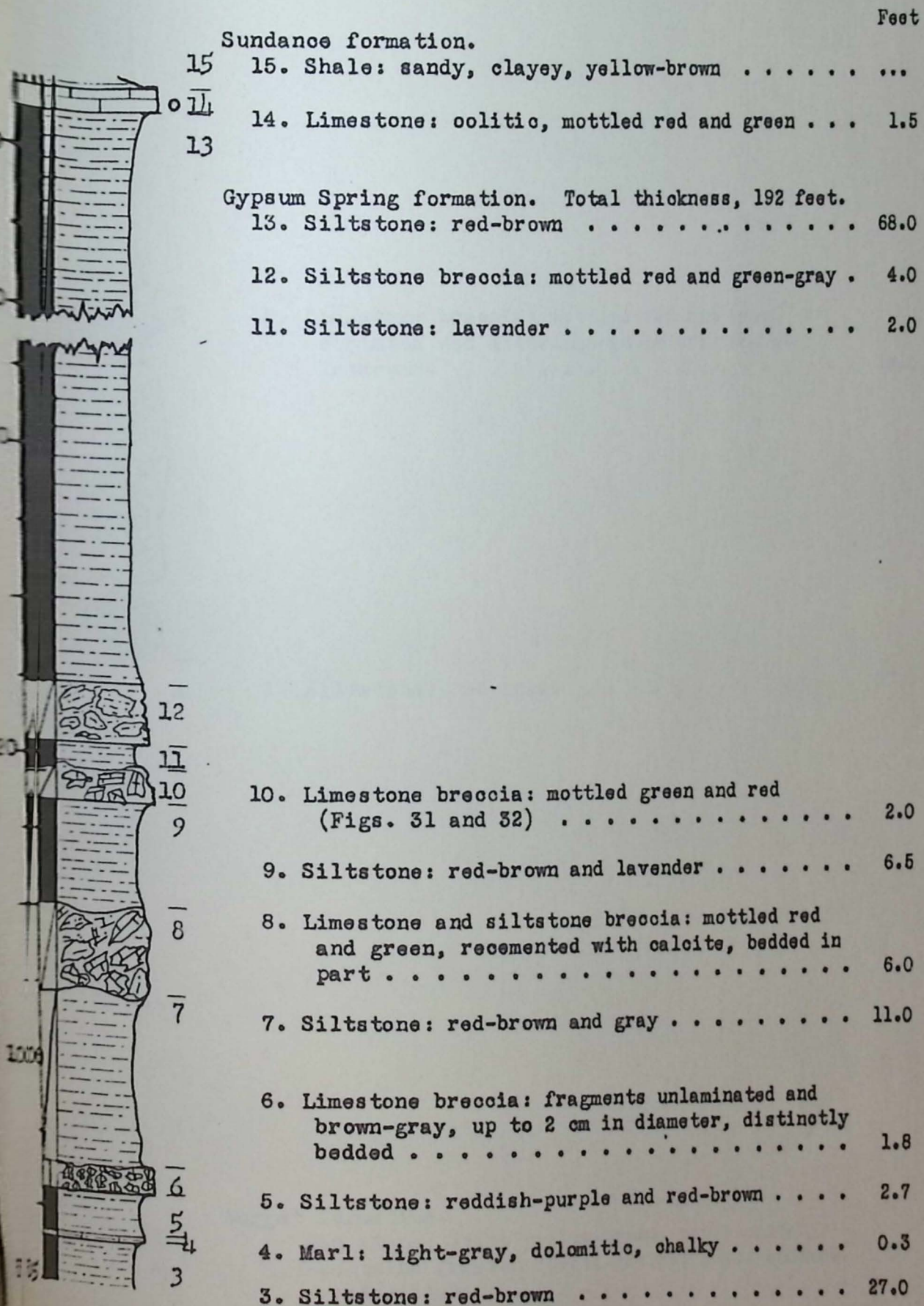


7.	Limestone breccia	1.3
6.	Siltstone: red-brown, not well exposed	8.0
5.	Limestone: brown-gray, laminated	3.2
4.	Siltstone: not well exposed, red-brown, dark-brown, purple	25.5
3.	Limestone breccia: mottled red and gray, blocks of siltstone and gray marl at base	19.0
2.	Limestone: light-gray, laminated, dolomitic	0.4
1.	Siltstone: red-brown, sandy, poorly exposed; green silty shale at top	19.5

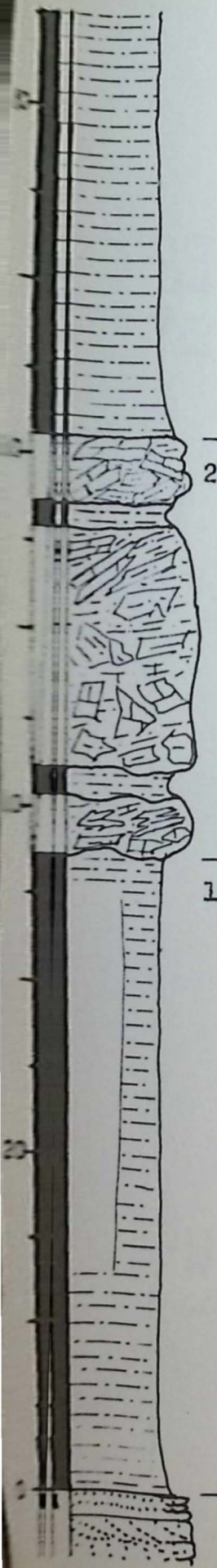
Nugget formation.

Sandstone: light yellow-brown, cross-bedded, cliff forming; contains frosted quartz grains; top 20 feet nonresistant and poorly exposed

Section 16, Cottonwood Draw, 3 miles south of Burris, Wyoming,
in SW $\frac{1}{4}$, Sec. 14, T. 4 N., R. 5 W., W. R. M.



Feet



2. Limestone breccia: mottled red and gray,
 contains red siltstone in matrix and as
 interbeds 24.0

1. Siltstone: red-brown 37.0

Nugget formation.
 Sandstone: light yellow-brown, cross-bedded;
 contains frosted quartz grains; upper contact
 gradational

Section 17, Red Grade, 14 miles southeast of Dubois, Wyoming,
 in SE $\frac{1}{4}$, Sec. 13, T. 5 N., R. 6 W., W. R. M.

Feet

Sundance formation.

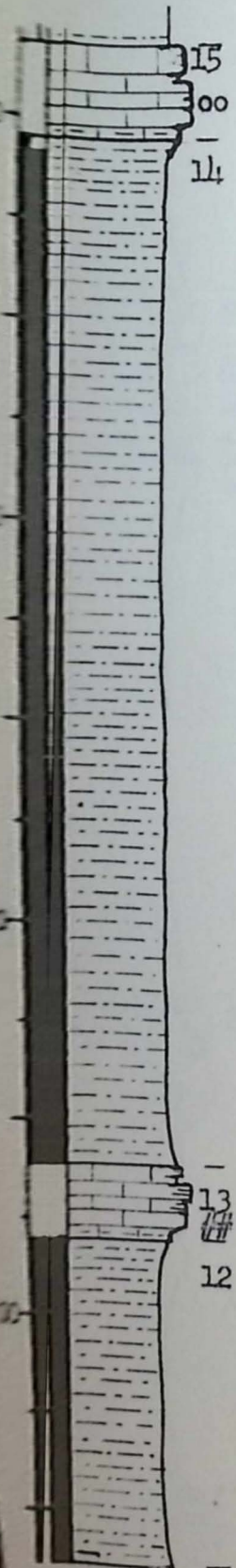
15. Limestone: oolitic, dark-gray, clastic,
 unlaminated, even-bedded 4.7

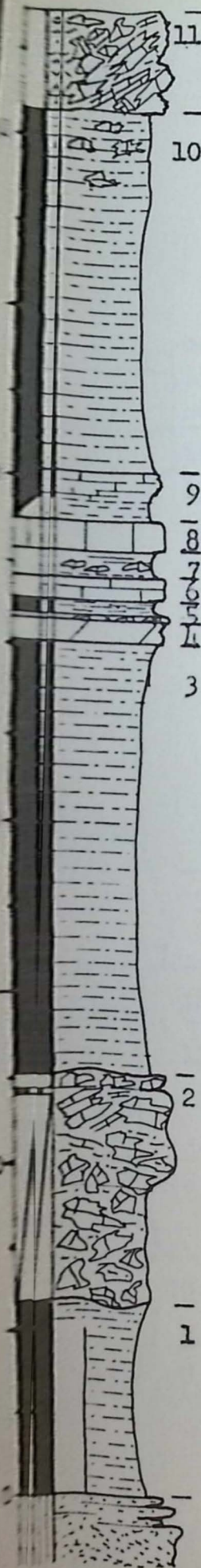
Gypsum Spring formation. Total thickness, 164 feet.

14. Siltstone: red-brown, shaly; contains 1.1 feet
 of green shale at top 50.0

13. Limestone: contains bryozoan fragments, lami-
 nated in upper half, reddish gray (Fig. 52) 3.4

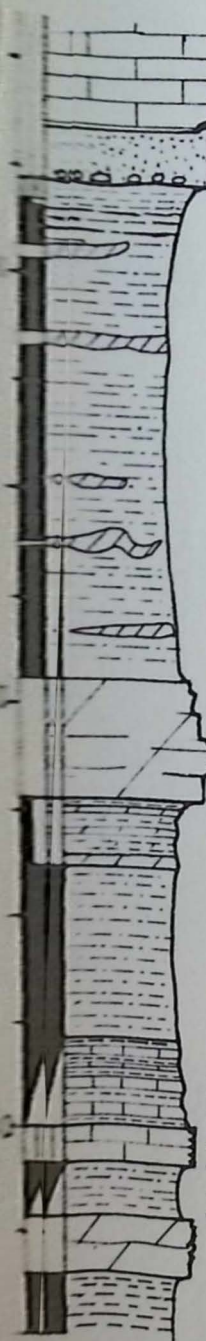
12. Siltstone: shaly, red-brown 17.0

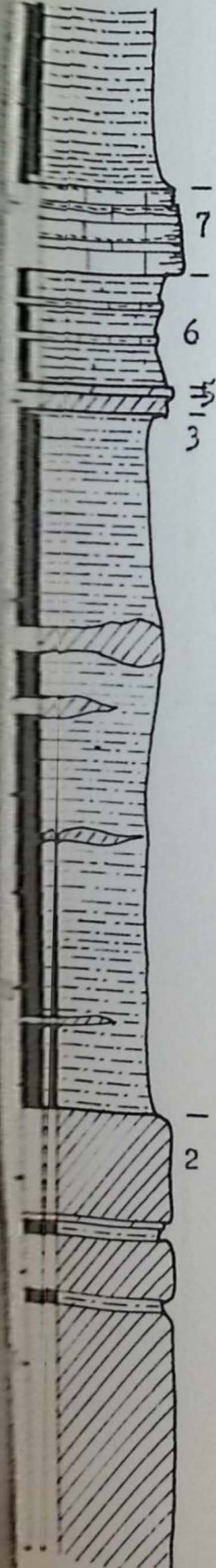




- 11. Limestone breccia: calcite and gray shale matrix, mottled red and gray, maximum fragment size 0.5 foot 5.9
 - 10. Siltstone: red-brown, shaly, limestone and siltstone breccia fragments in uppermost 6 feet 21.0
 - 9. Limestone: light-red, silty; gray, maroon, paper-thin shale at base, calcareous at top 2.7
 - 8. Limestone: un laminated, gray with a few brown streaks, thick-bedded; contains angular to subangular calcite fragments, 1.0 percent insoluble residue 1.8
 - 7. Limestone: red, silty, thin-bedded, interbedded with red-brown shale and a limestone breccia 1.6
 - 6. Limestone: white, porous, even bedded; probably an altered dolomite 1.3
 - 5. Shale: silty, red-brown, contains 0.4 foot bed of quartz and limestone breccia at base 1.3
 - 4. Dolomite: chalk-white, faintly laminated, splintery fracture 1.2
 - 3. Siltstone: brownish-red, shaly 25.5
 - 2. Limestone breccia: fragments up to 1.5 feet in diameter, gray, mottled red and green. Matrix consists of siltstone, limestone and altered dolomite fragments stained red-brown and yellow-brown. Nonbedded except in uppermost 5 feet 13.7
 - 1. Siltstone: shaly, red-brown, grades into limestone breccia at top 12.0
- Nugget formation.
 Sandstone: yellow-brown, frosted quartz grain, cross-bedded, cliff-forming 135.

Section 18, Thermopolis, Wyoming, adjacent to hot springs resort, in SW $\frac{1}{4}$, Sec. 31, T. 43 N., R. 94 W., B. H. M.

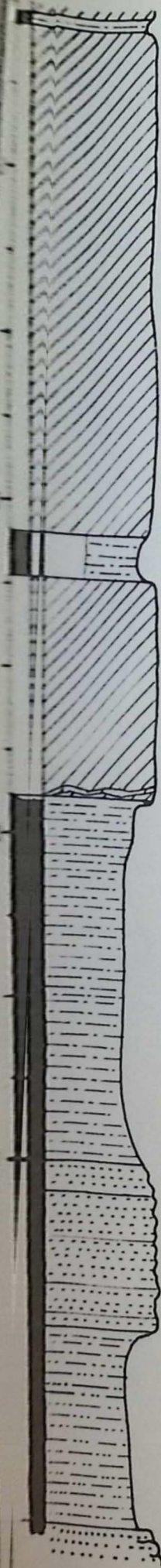
	Feet
	
oo Sundance formation.	
19 Limestone: oolitic, brownish-gray; ooliths have angular quartz and calcite grain nuclei	20 +
oo	
18 Sandstone: fine-grained, conglomeratic, contains subangular quartzite pebbles	2.5
17	
16 Tuff: green, fine-crystalline; contains $\frac{1}{4}$ mm flakes of biotite, and euhedral and angular grains of quartz	2.3
Gypsum Spring formation. Total thickness, 202 feet.	
16 Siltstone: red-brown, shaly; contains stringers and lenses of gypsum	21.
15 Dolomite: chalk-white, splintery fracture, poorly bedded	5.6
14 Dolomite: shaly, white; interbedded with calcareous green shale	3.4
13 Siltstone: red-brown	7.6
12 Limestone: thin-bedded, gray; interbedded with yellow-brown, red-brown and gray shale	4.0
11 Limestone: brown-gray, laminated	1.7
10 Shale: silty, dark blue-gray, and red-brown	2.6
9 Dolomite: dull-white, poorly bedded	2.4
8 Shale: red-brown; contains 0.5-foot bed of green to yellow-brown bentonitic quartz siltstone at base	12.3



Feet

- | | | |
|---|--|------|
| 7 | 7. Limestone: brownish-gray, laminated; contains shale partings in upper half | 4.3 |
| 6 | 6. Shale: green, calcareous; contains two 0.3-foot beds of brown-gray limestone and one bed of bentonitic clay | 5.6 |
| 5 | 5. Dolomite: chalk-white, 11.5 percent insoluble residue | 0.5 |
| 4 | 4. Gypsum: white, 0.2 green shale and white dolomite at base | 1.2 |
| 3 | 3. Siltstone: red-brown; contains stringers and lenses of white gypsum | 35.0 |
| 2 | 2. Gypsum: white, coarse-crystalline; contains interbedded red siltstone and gray dolomite; basal 0.5 feet of gypsum contains inter-laminated dolomite (Fig. 21) | 71.0 |

Feet



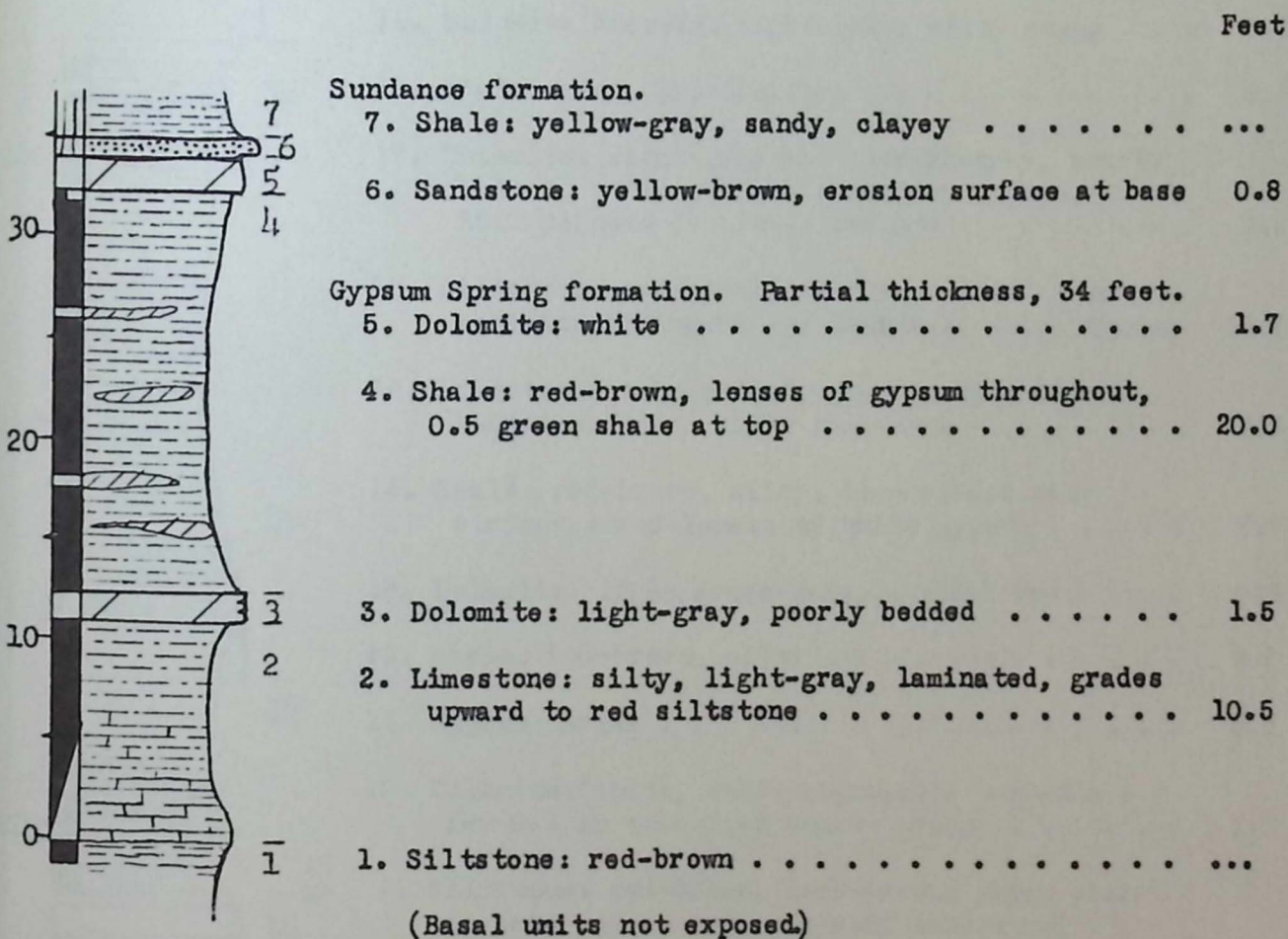
1

1. Siltstone: red-brown, nonresistant; 0.3 foot
 of green siltstone at top 22.0

Chugwater formation.

Alternating 10-foot beds of brownish-red
 siltstones and sandstones, 80.0 percent
 insoluble residue

Section 19, Hart ranch, 6 miles west of Thermopolis, Wyoming,
 in NW $\frac{1}{4}$, Sec. 7, T. 42 N., R. 95 E., W. R. M.



Section 20, Mud Creek, 14 miles west of Thermopolis, Wyoming,
in NW $\frac{1}{4}$, Sec. 27, T. 8 N., R. 3 E., W. R. M.

Feet

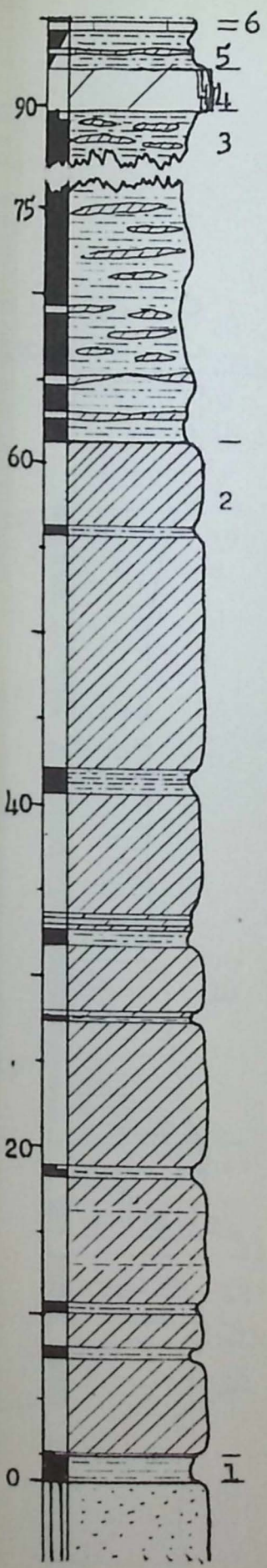
Sundance formation.

1180	22	22. Shale: yellow-brown, sandy	
	210		
	#		
	19	21. Sandstone: conglomeratic, oolitic, contains pelecypod fragments	3.0
	17		

Gypsum Spring formation. Total thickness, 178 feet.

1160	20	20. Shale: green	2.0
	19	19. Dolomite breccia: light-gray, silty vuggy . . .	0.5
	16	18. Shale: gray, gypsiferous	0.5
	17	17. Dolomite: light-gray and reddish-gray, poorly bedded, contains much secondary gypsum, 16.0 percent insoluble residue	9.2
	16	16. Siltstone: red-brown, maroon, mottled green, contains stringers and lenses of white gypsum	30.4
1140	15	15. Limestone: thin-bedded, gray to red; inter- bedded with red silty limestone	9.9
	14	14. Shale: red-brown, silty; interbedded with stringers and lenses of white gypsum	6.7
	13	13. Dolomite: light green-gray, mottled red	0.6
	12	12. Shale: red-brown, silty	2.7
	11	11. Gypsum: white	0.8
120	10	10. Dolomite: white, sublithographic; contains a few 0.1 mm subhedral quartz grains	1.7
	13		
	12		
	10	9. Siltstone: red-brown, dark-brown; green shale at base and at top, contains lenses and stringers of white gypsum	10.6
	9		
	8	8. Limestone: brown-gray, laminated, gypsum and red shale partings; contains rounded, $\frac{1}{4}$ mm calcite grains with indistinct boundaries; 0.6 foot white dolomite at base	4.8
100	7	7. Shale: red-brown, silty, gypsiferous	3.9

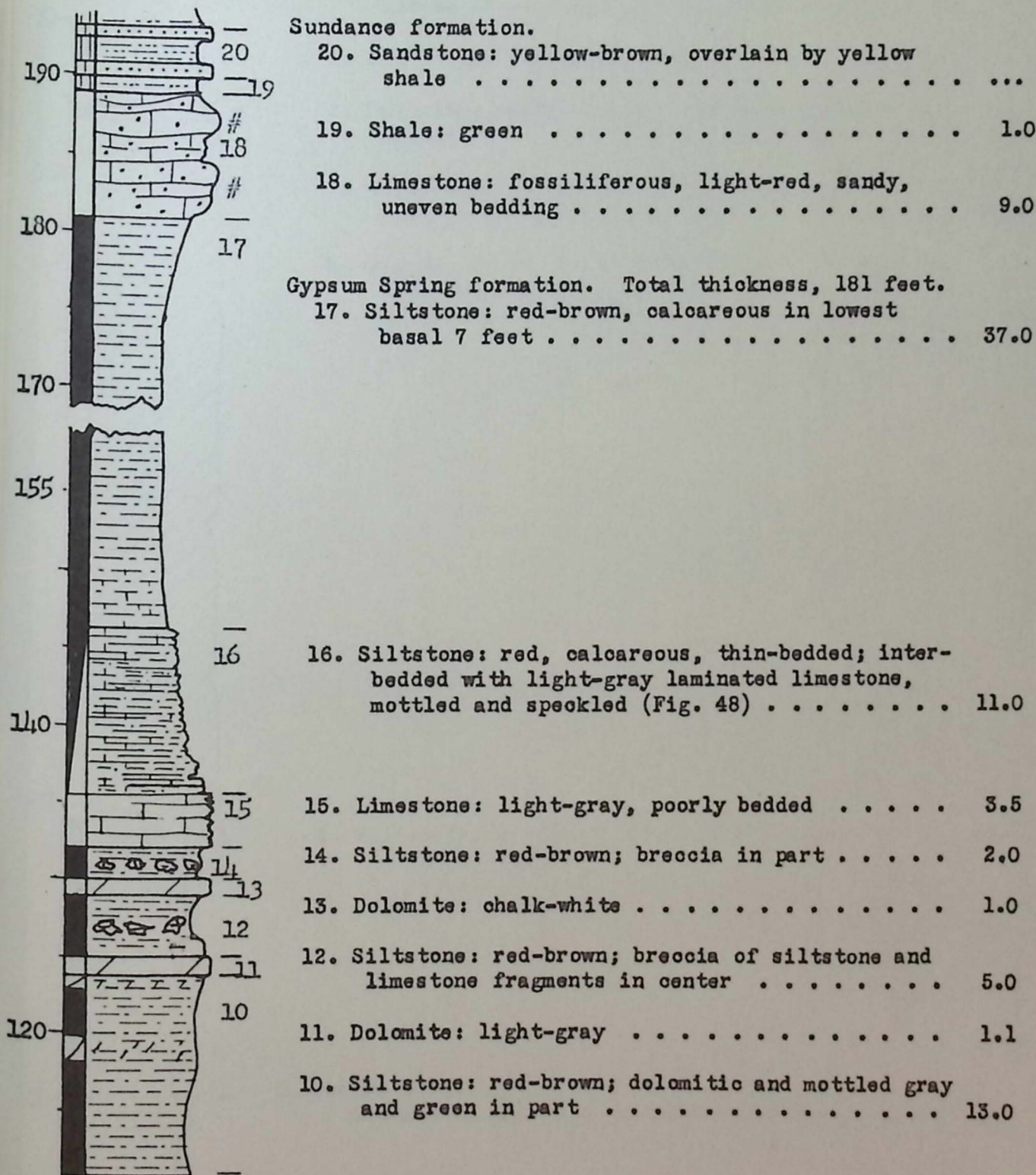
Feet



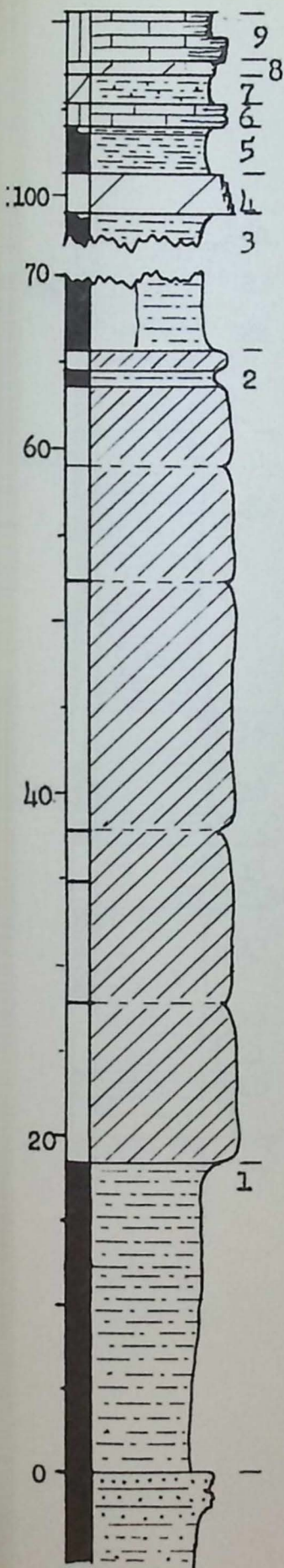
- 6. Limestone: brown-gray, wavy laminated 0.7
 - 5. Shale: maroon and greenish-gray, 0.5 gypsum stringer in center 1.8
 - 4. Dolomite: light-gray; weathers to vertical splinters 2.2
 - 3. Siltstone: red-brown; contains white gypsum stringers and lenses in basal 20 feet 28.5
 - 2. Gypsum: white, coarse-crystalline, 2- to 8-foot beds; interbedded with red-brown siltstone, green silty shale and gray laminated dolomites; reddish-gray, gypsiferous dolomite at base (Fig. 26) 59.5
 - 1. Siltstone: red-brown, gypsiferous, mottled green 1.3
- Chugwater formation.
 Siltstone: red-brown, nonresistant;
 5.7 feet of mustard-yellow oolitic sandstone

Section 21, East fork of Sheep Creek, 22 miles west of
Thermopolis, Wyoming, in Sec. 10
T. 6 N., R. 2 E., W. R. M.

Feet



Feet



- 9. Limestone: brown-gray, thin-bedded, sublithographic 3.2
- 8. Dolomite: chalk-white 0.5
- 7. Siltstone: red-brown, mottled green, calcareous 0.7
- 6. Limestone: light-gray to greenish-gray, thin-bedded 1.3
- 5. Siltstone: red-brown, green at top 2.5
- 4. Dolomite: white, chalky, weathers in vertical splinters 2.2
- 3. Siltstone: red-brown, no gypsum exposed, 0.3 foot green siltstone at top 32.0
- 2. Gypsum: white, 3- to 7-foot beds; interbedded with red siltstone but interbeds not well exposed 47.0

1. Siltstone: dark-red, sandy in lower part . . . 18.0

Chugwater formation.
Sandstone: dark-red, in part siltstone

Section 22, South Fork Owl Creek, 25 miles west of Thermopolis,
Wyoming, in N $\frac{1}{2}$, Sec. 1, T. 8 N., R. 5 E., W. R. M.

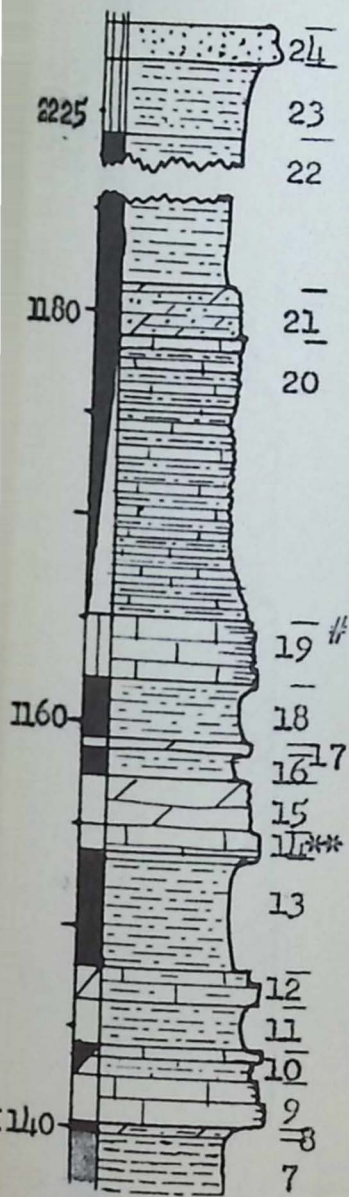
Feet

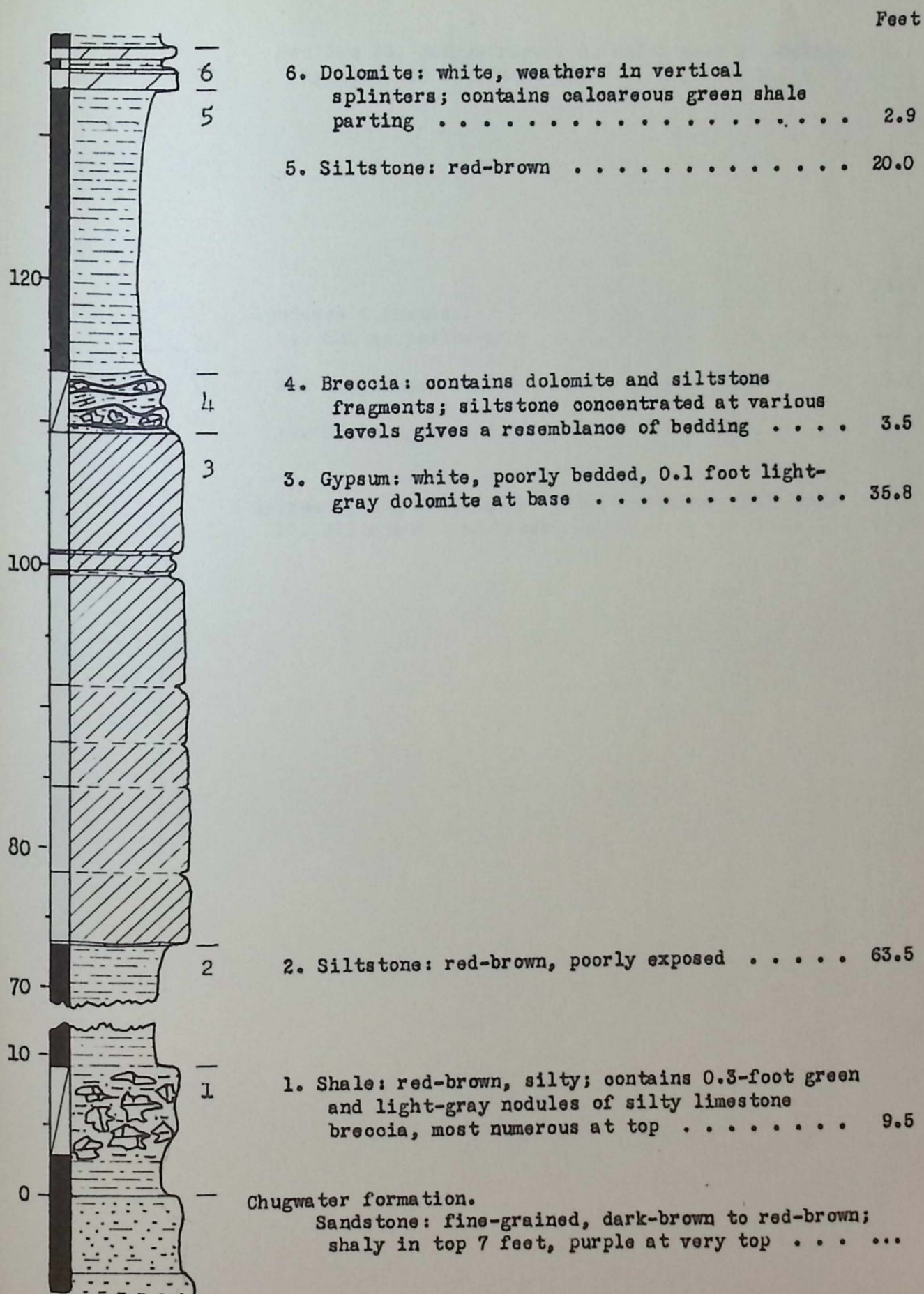
Sundance formation.

- 24. Sandstone: yellow-brown, fine-grained,
overlain by yellow shale 2.0
- 23. Shale: yellow-brown, sandy 3.5

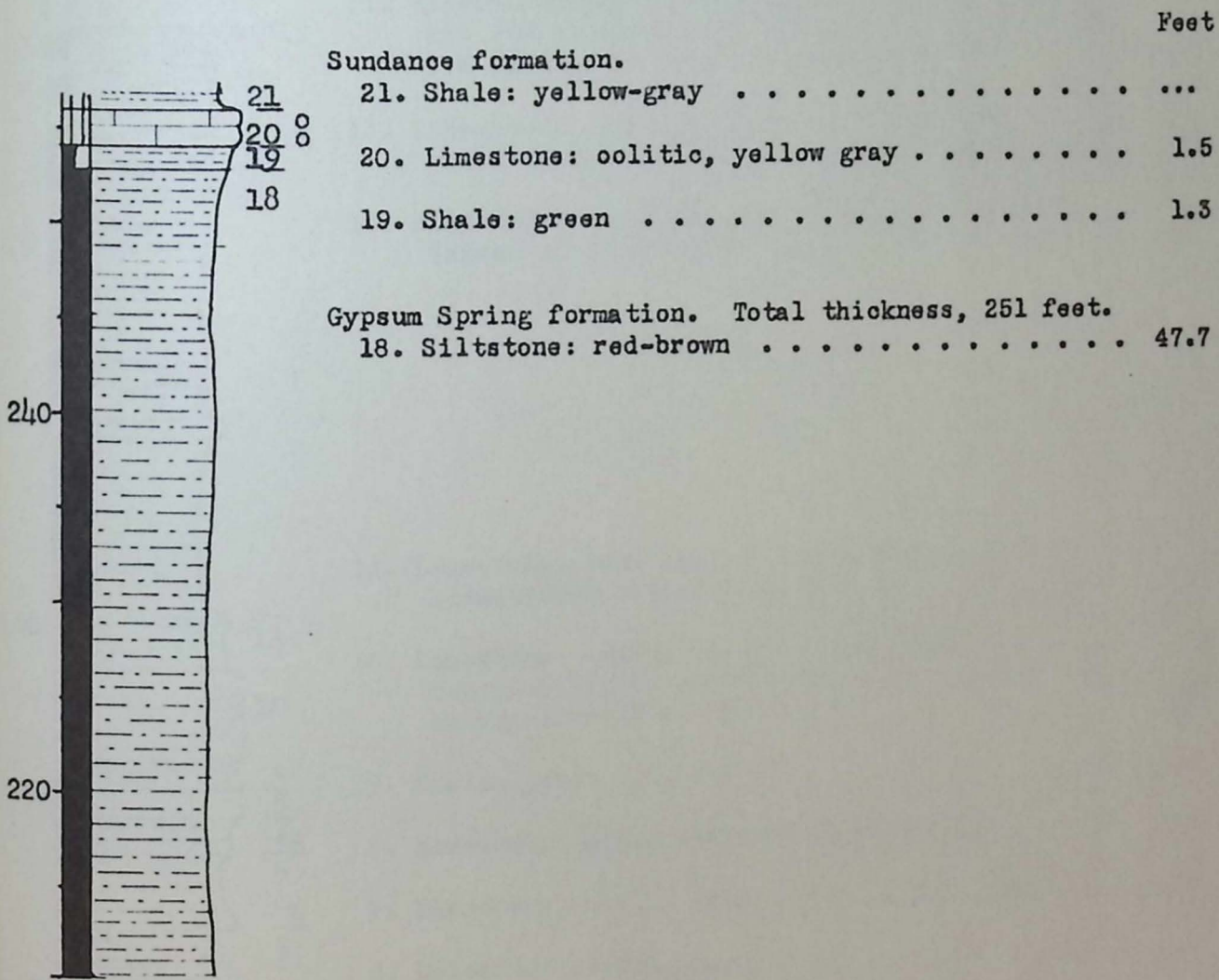
Gypsum Spring formation. Total thickness, 214 feet.

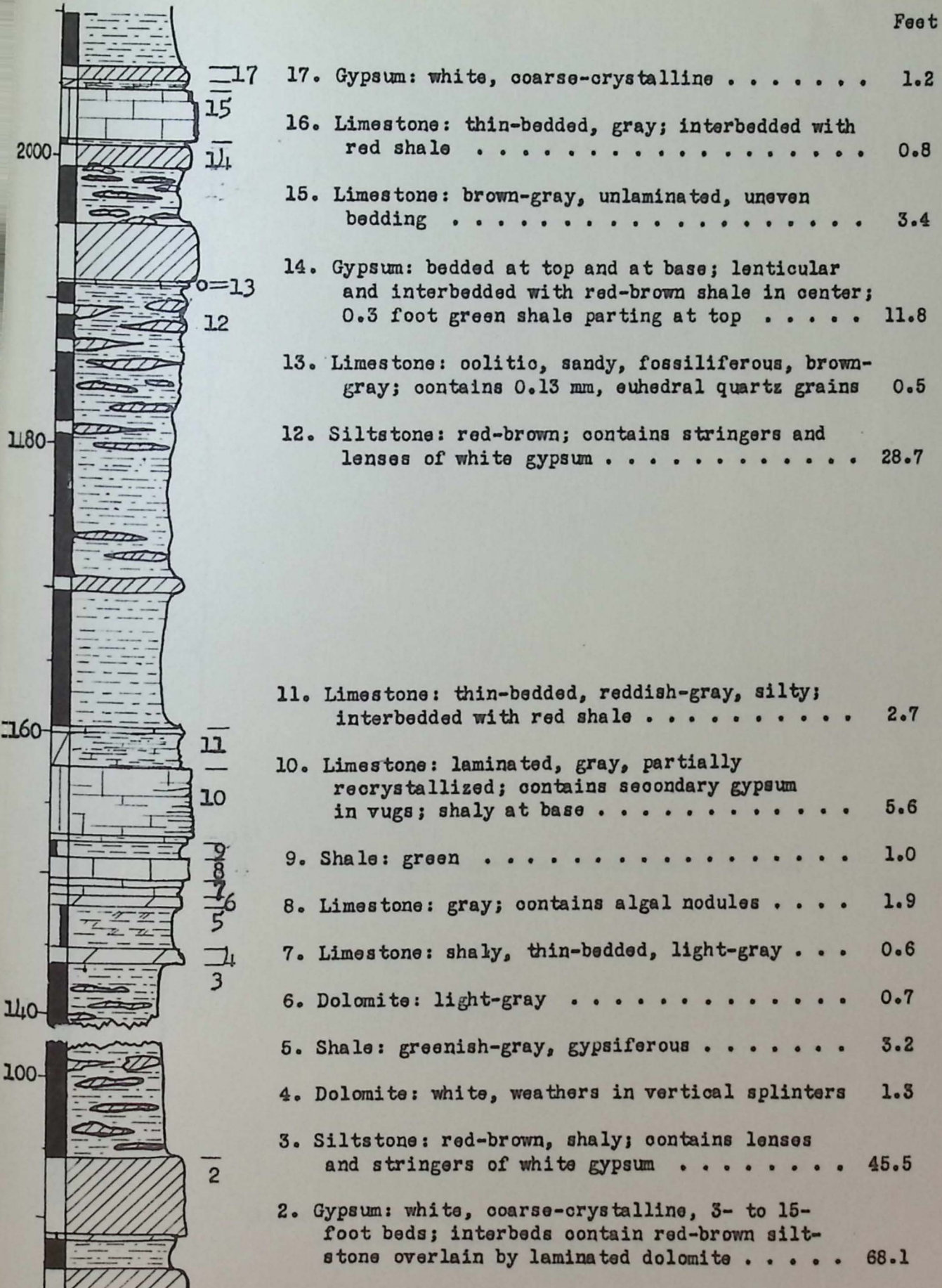
- 22. Siltstone: red-brown 43.0
- 21. Dolomite: sandy, reddish-brown, mottled gray;
contains .1 mm quartz sand grains 2.5
- 20. Siltstone: red, calcareous; interbedded with
gray silty limestone, locally mottled 14.0
- 19. Limestone: gray, laminated, undiagnostic
fossil fragments in top 0.5 foot 3.2
- 18. Siltstone: red-brown 2.8
- 17. Dolomite: light-gray, single bed 0.6
- 16. Shale: red-brown, silty 1.2
- 15. Dolomite: poorly bedded, light-gray, conchoidal
fracture 2.7
- 14. Limestone: even bedded, brown-gray, olastic;
contains brown, concentrically banded algal
nodules and fragments, maximum size is 1 cm 1.2
- 13. Siltstone: red-brown 5.3
- 12. Limestone: red, mottled green-gray, silty
(Fig. 41), 25.0 percent insoluble residue 1.5
- 11. Siltstone: red-brown 1.8
- 10. Siltstone: thin-bedded, calcareous, red-brown;
interbedded with thin-bedded silty red
limestones 1.6
- 9. Limestone: green-gray, laminated 2.5
- 8. Dolomite: reddish-gray, silty 0.6
- 7. Shale: red-brown, no silt 3.7



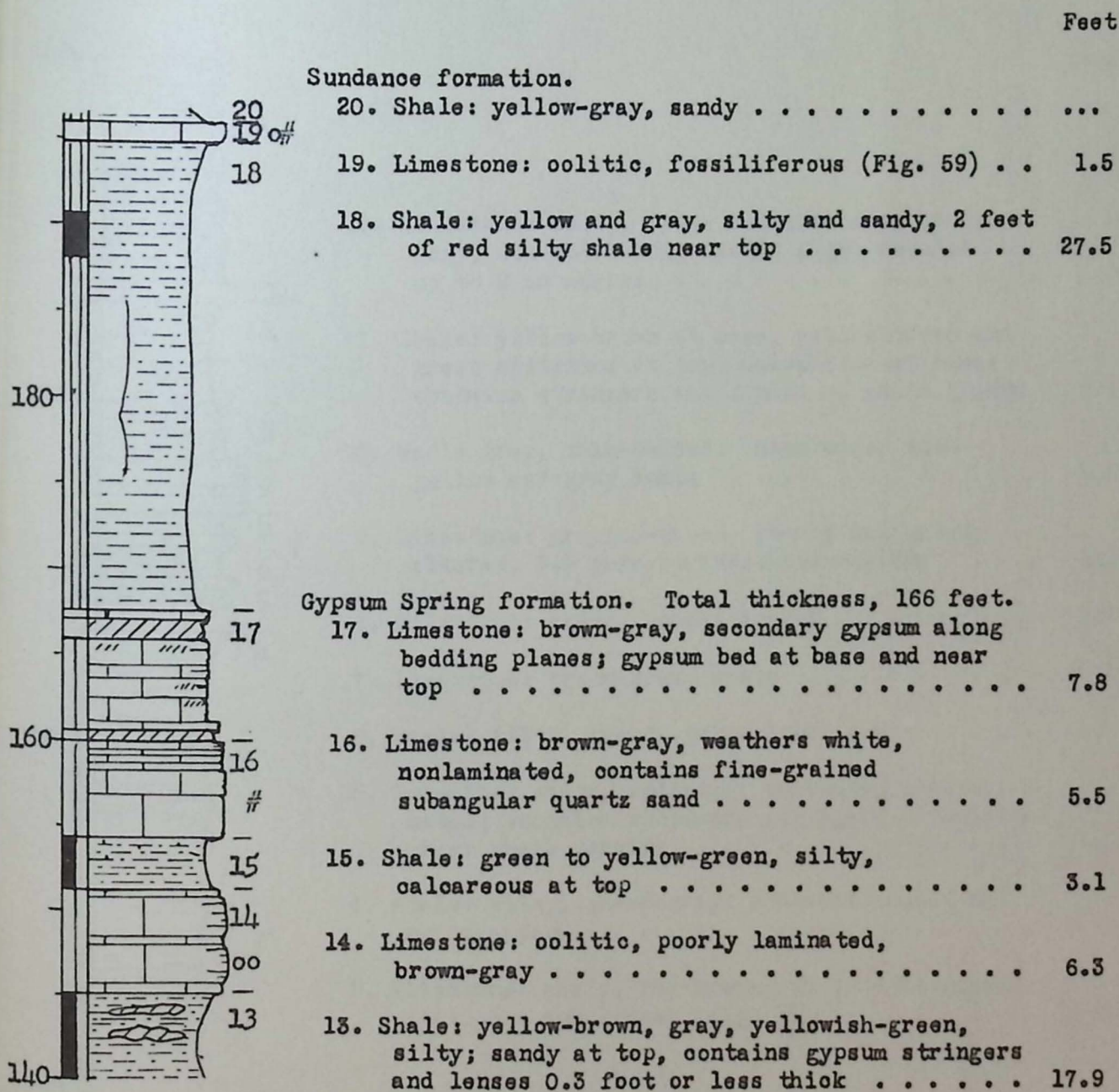


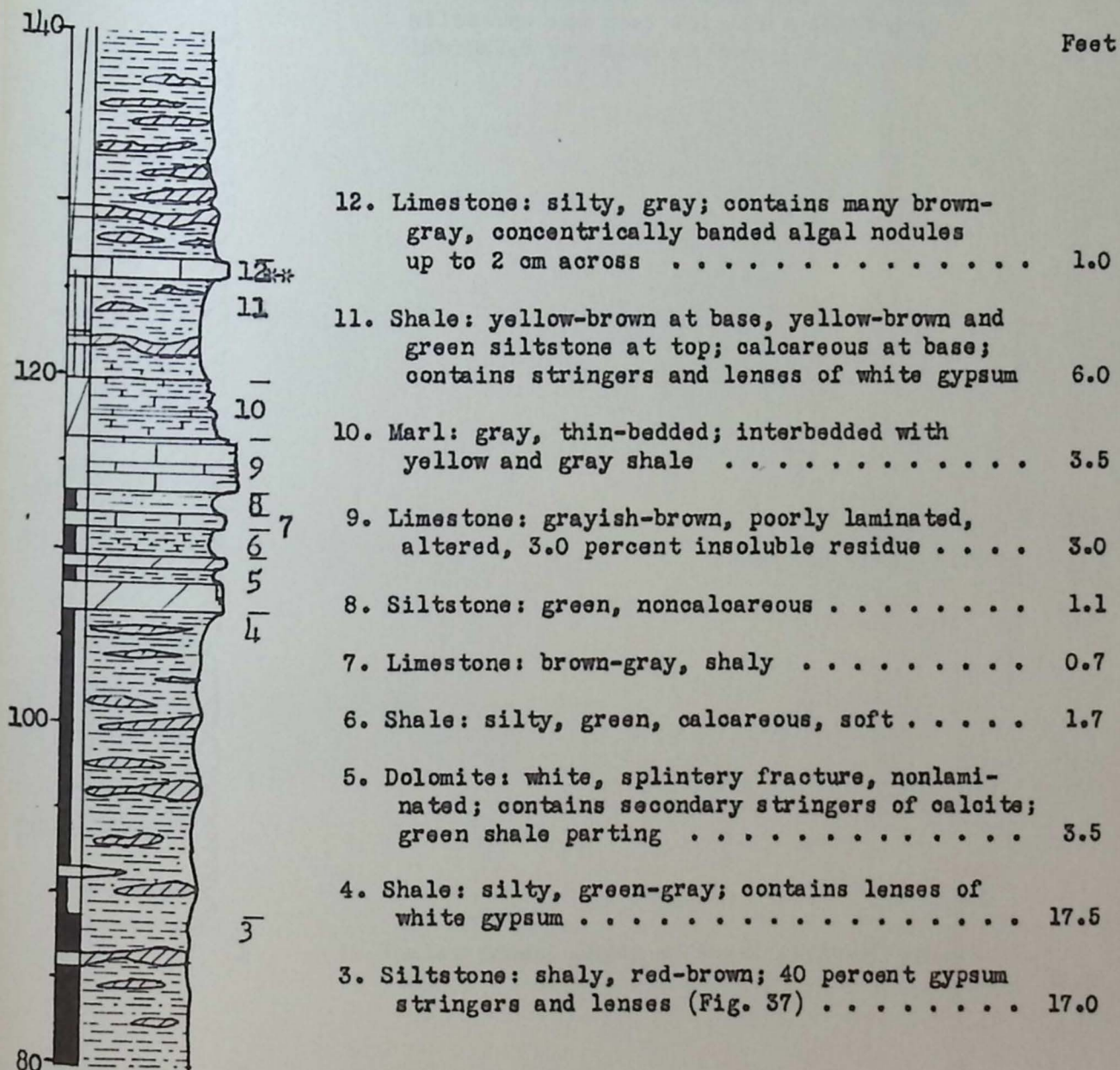
Section 23, Bargee ranch, 32 miles west of Thermopolis,
Wyoming, in SW $\frac{1}{4}$, Sec. 24, T. 7 N., R. 1 W., W. R. M.



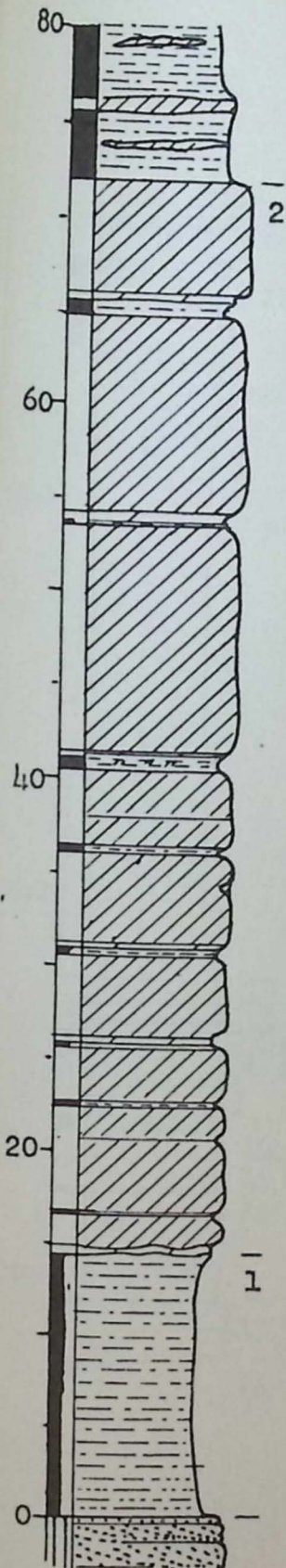


Section 24, Maverick Spring anticline, 34 miles east of
Dubois, Wyoming, in W $\frac{1}{2}$, Sec. 23,
T. 6 N., R. 2 W., W. R. M.





Feet

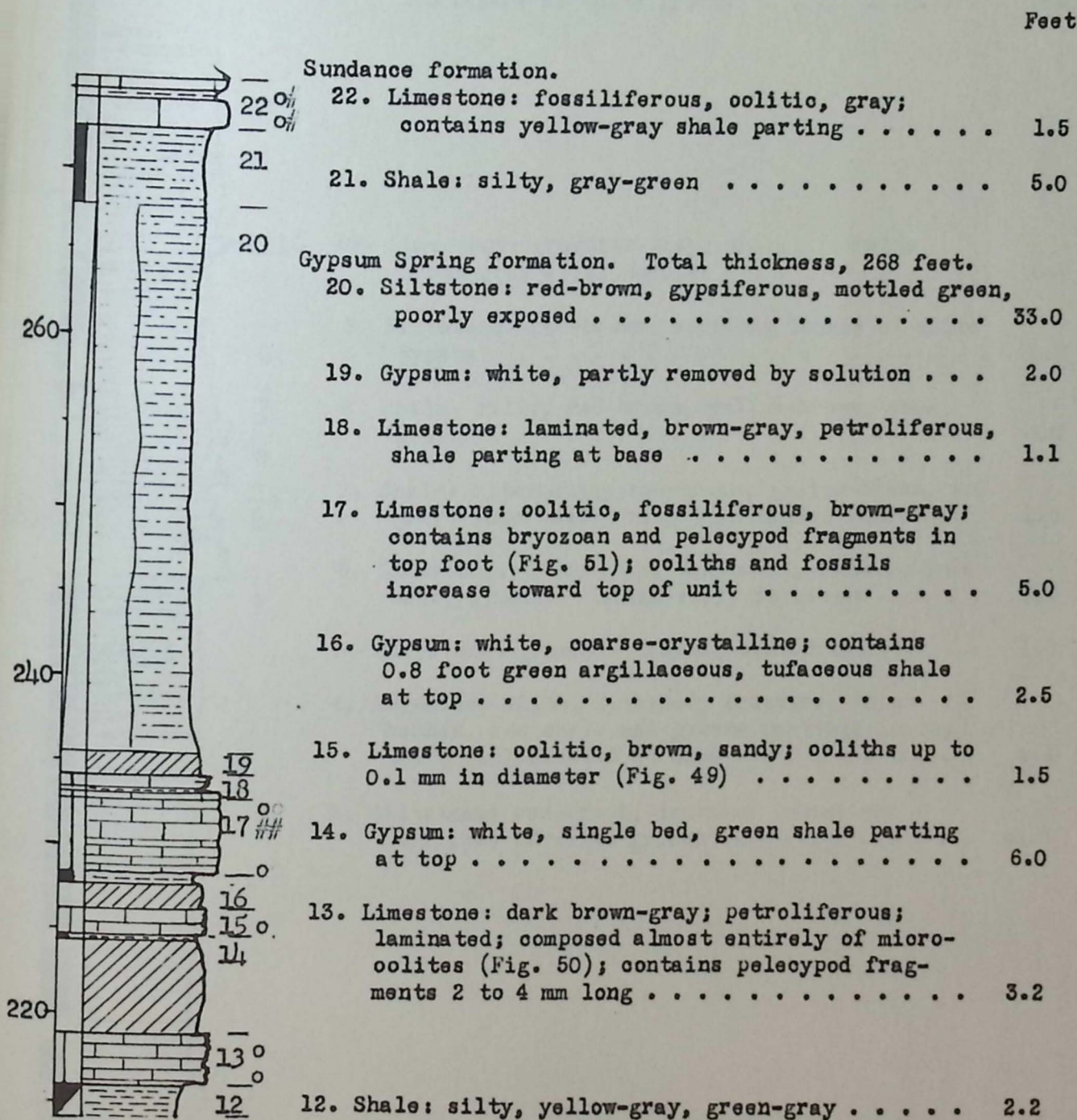


2. Gypsum: white, coarse-crystalline, in beds 2 to 8 feet thick; contains interbedded red siltstone and gray dolomite; light-gray laminated dolomite at base 57.0

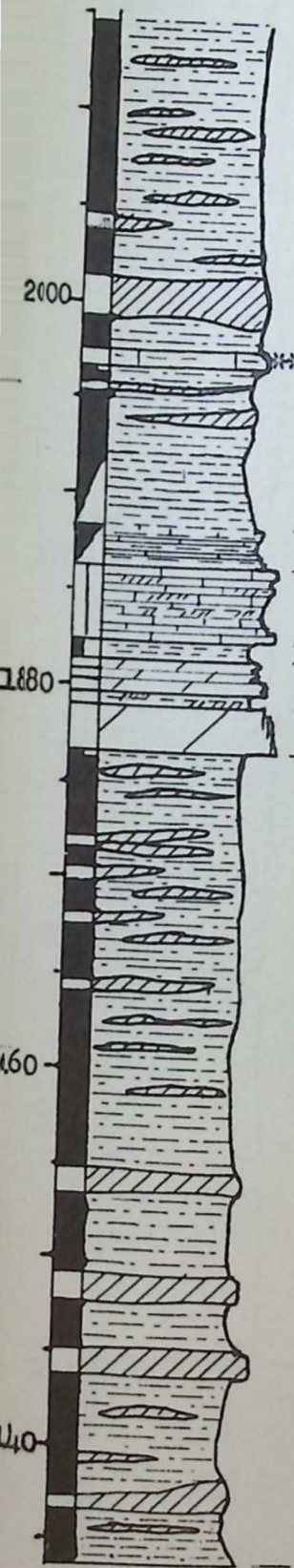
1. Shale: green, sandy at base, yellow-brown at top 13.8

Nugget formation.
 Sandstone: light-brown, shaly; grades into green shale at top

Section 25, Circle Ridge anticline, 29 miles east of Dubois,
Wyoming, in NW $\frac{1}{4}$, Sec. 6, T. 6 N., R. 2 W., W. R. M.



Feet



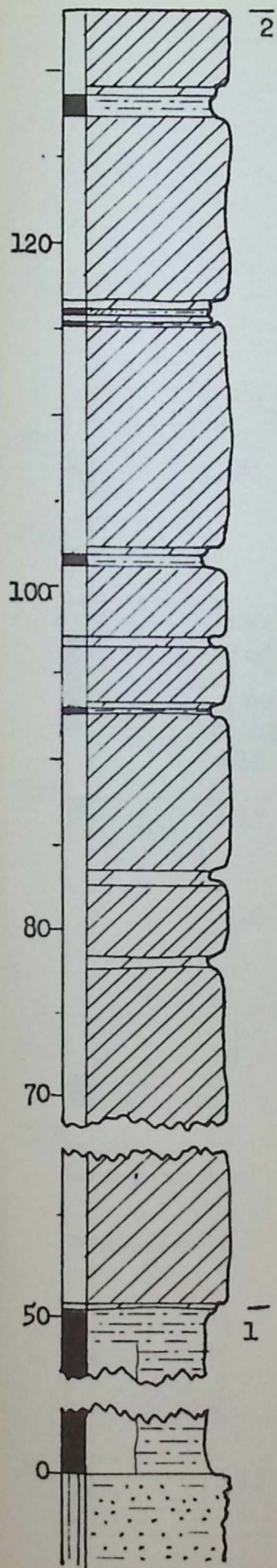
- 11. Siltstone: red-brown; contains lenses and stringers of white gypsum 17.0
- 10. Limestone: greenish-gray, shaly; contains brown-gray algal nodules 0.9
- 9. Siltstone: red-brown; contains lenses of white gypsum 4.3
- 8. Shale: silty, red-brown, yellow-brown, some green 4.0
- 7. Shale: alternating red-brown, yellow-brown, and gray; interbedded with thin-bedded limestone 2.0
- 6. Limestone: brown-gray, laminated, dolomitic at base, gypsiferous and shaly in center 3.9
- 5. Claystone: green, vitreous, bentonitic (?) 1.0
- 4. Dolomite: white, splintery fracture; thin-bedded, red shale and gypsum partings in top half; nonlaminated at base 4.4
- 3. Siltstone: red-brown; contains lenses and stringers of white gypsum 41.8

Feet

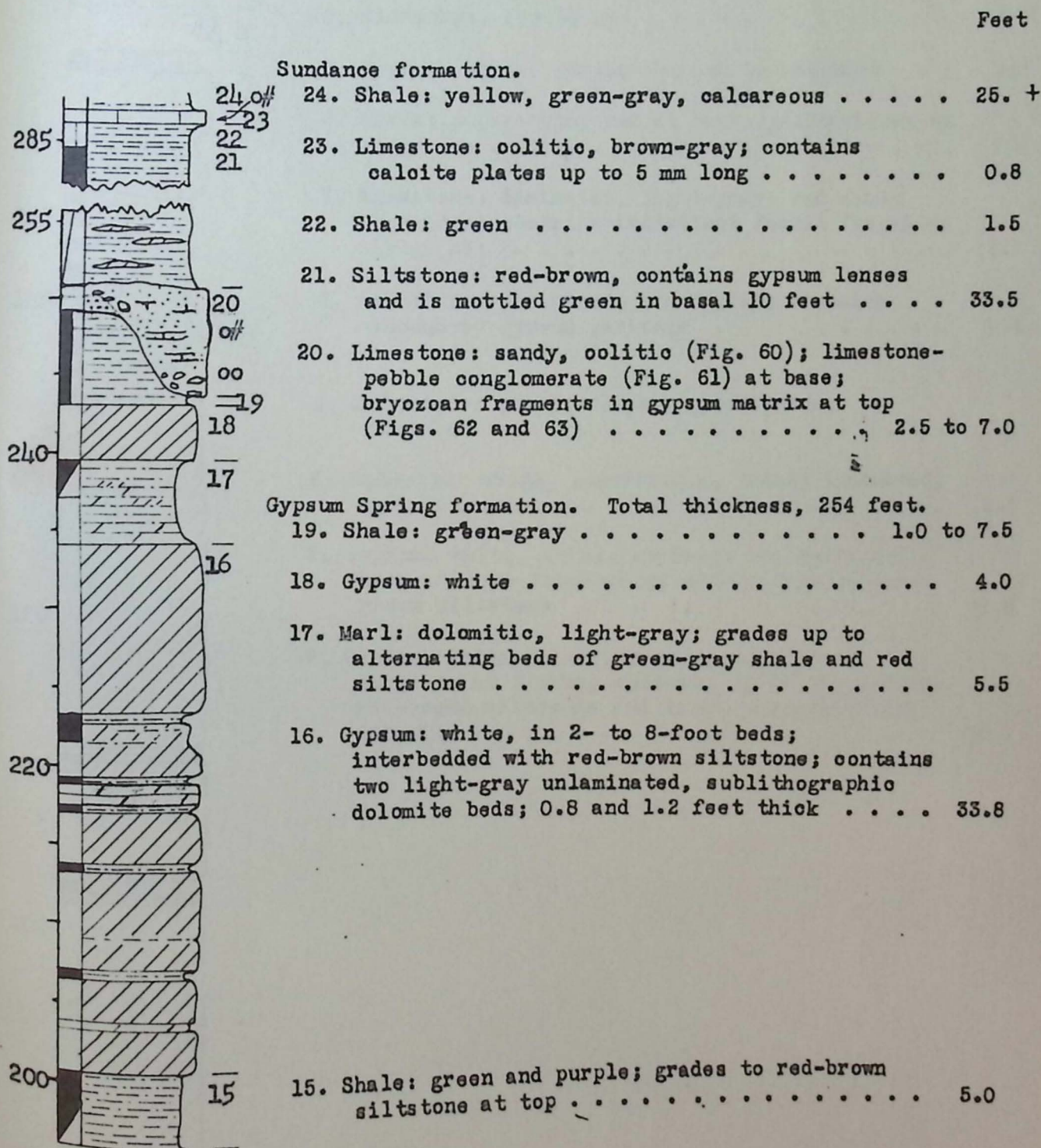
2. Gypsum: white, coarse-crystalline, 2- to 13-foot beds; interbedded with red-brown and green siltstone and brown-gray dolomite . . . 81.4

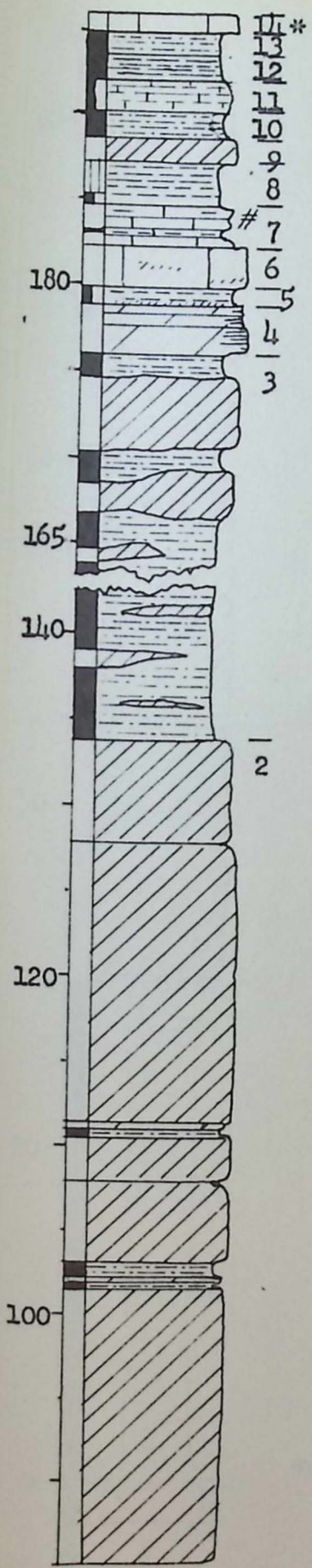
1. Covered, red slope 50.4

Chugwater formation.
Sandstone: medium-grained, dark yellow-brown . . .



Section 26 (locality of type section), Red Creek,
24 miles east of Dubois, Wyoming, NE $\frac{1}{4}$, Sec. 7,
T. 6 N., R. 3 W., W. R. M.

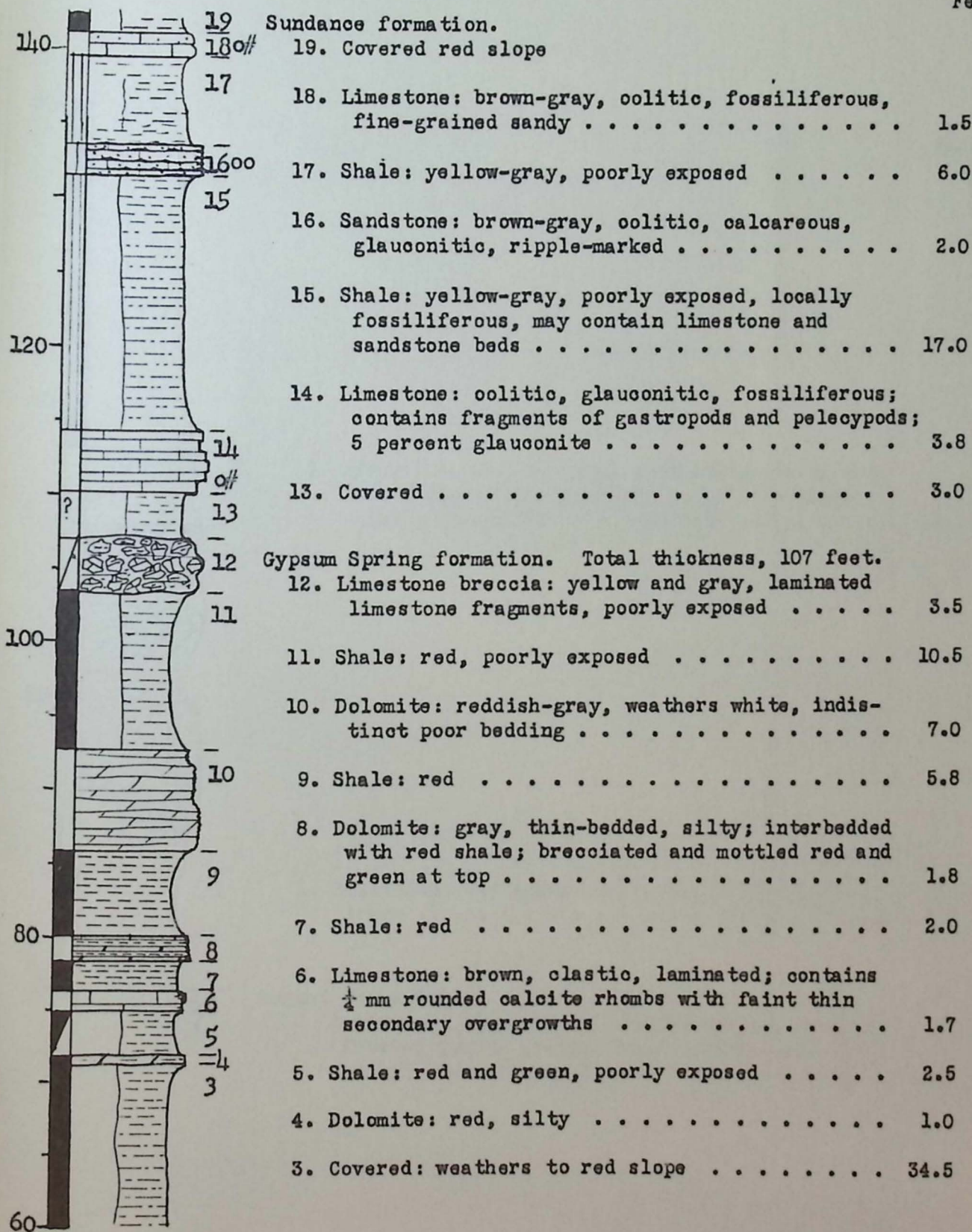


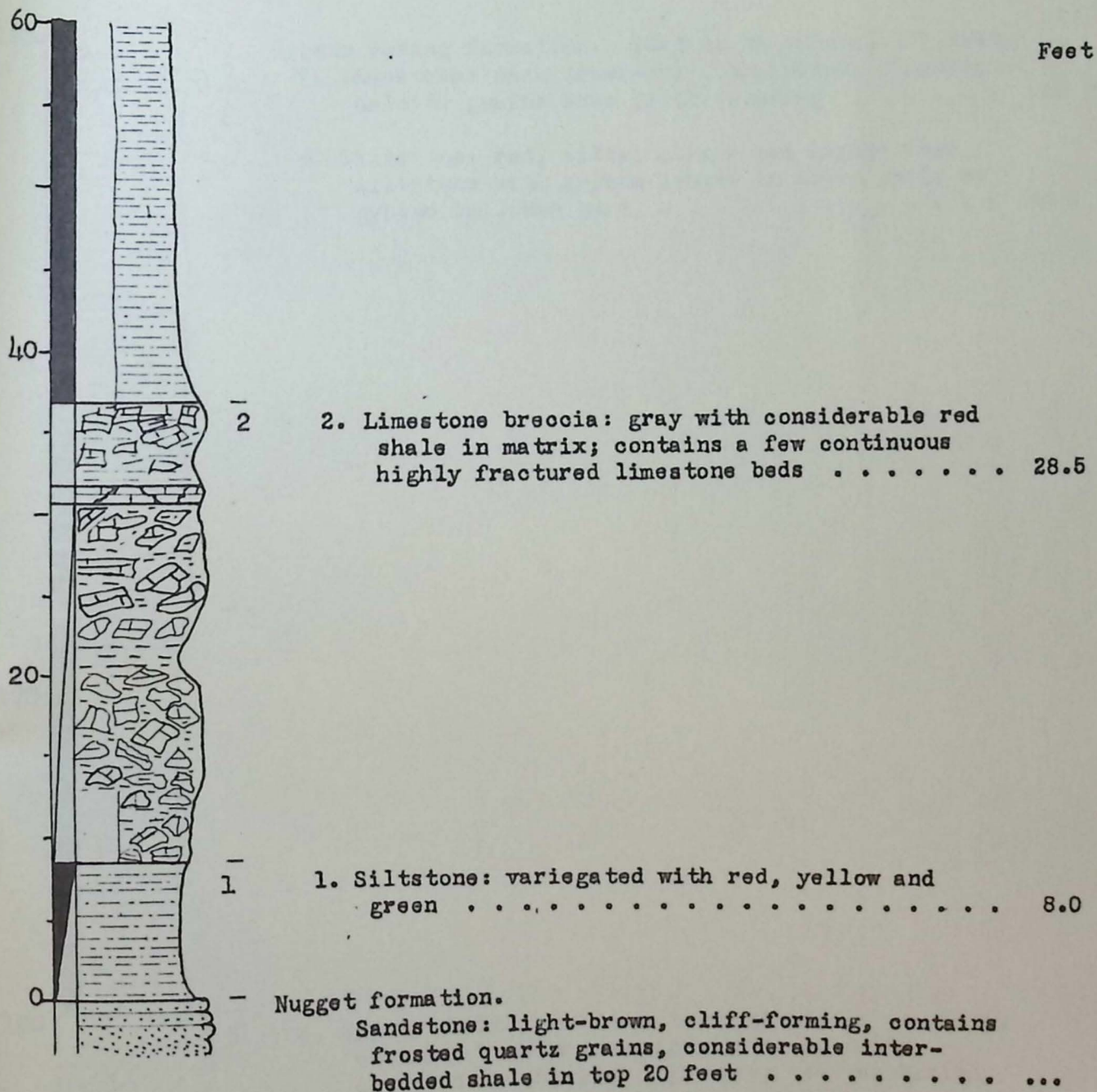


14. Limestone: green-gray, silty; contains dark-brown banded algal nodules (1 to 5 cm) in diameter (Fig. 41b)	1.1
13. Siltstone: red-brown	1.4
12. Shale: red	1.3
11. Marl: green-gray, nonbedded	1.8
10. Siltstone: red-brown	1.7
9. Gypsum: white, partly removed by solution . . .	1.0
8. Shale: paper-thin, red at base, yellow-brown at top	2.8
7. Limestone: laminated, light-gray, red shaly partings; contains indistinct fossil fragments (Fig. 38)	2.7
6. Limestone: laminated, brown-gray; contains secondary gypsum partings	2.4
5. Siltstone: green, clayey, gypsiferous, noncalcareous	1.0
4. Dolomite: white, gypsiferous, thinly laminated, uneven bedding	2.5
3. Gypsum: white, lenses at base, stringers and beds at top; interbedded with red-brown and green siltstone	42.5
2. Gypsum: white, cliff-forming, weathers to large joint blocks; contains minor interbedded red-brown siltstone and light-gray laminated dolomite	106.0

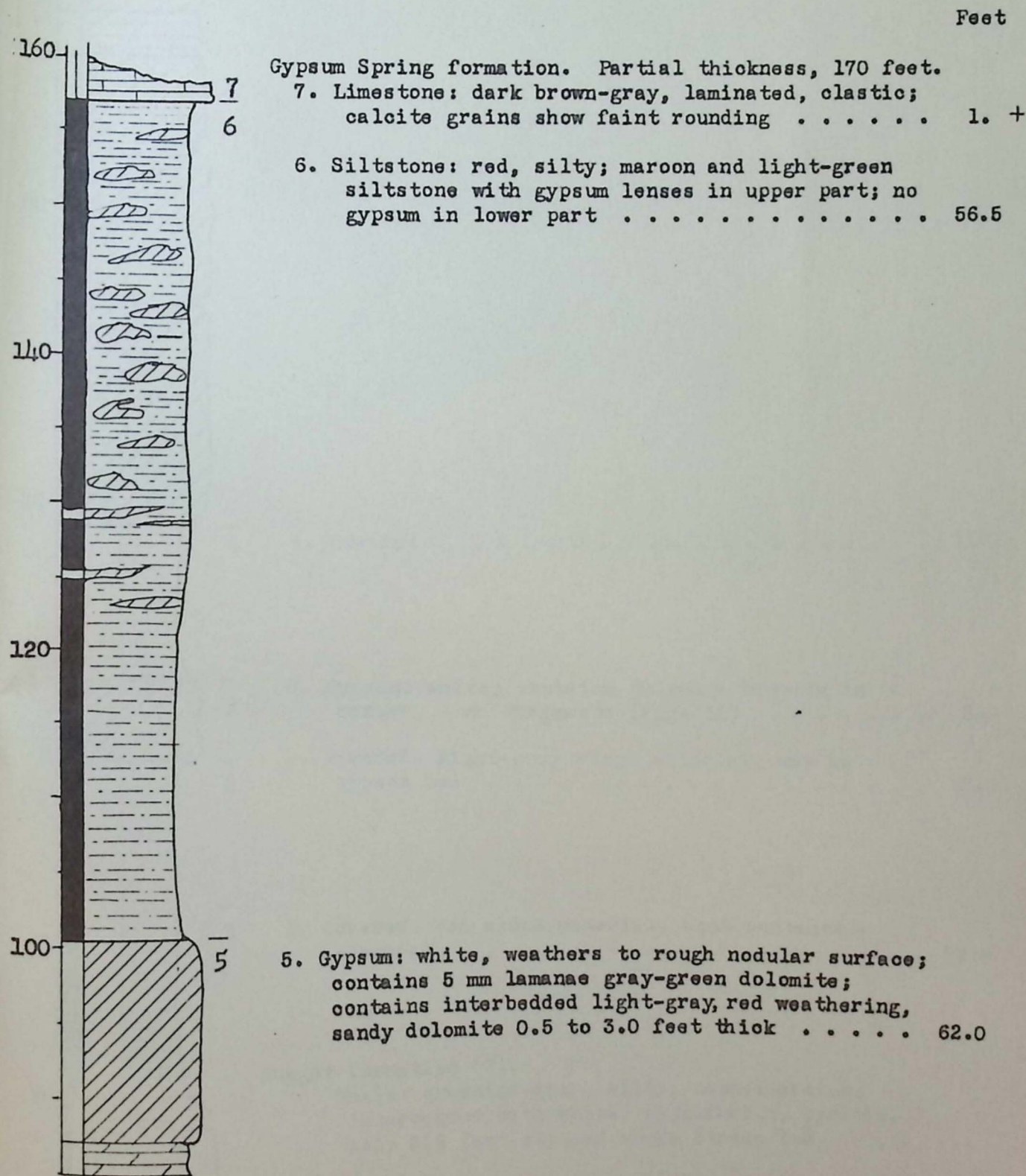
Section 27, Sheep Mountain, 30 miles north of Pinedale,
Wyoming, in SW $\frac{1}{4}$, Sec. 25, T. 39 N., R. 109 W., B. H. M.

Feet

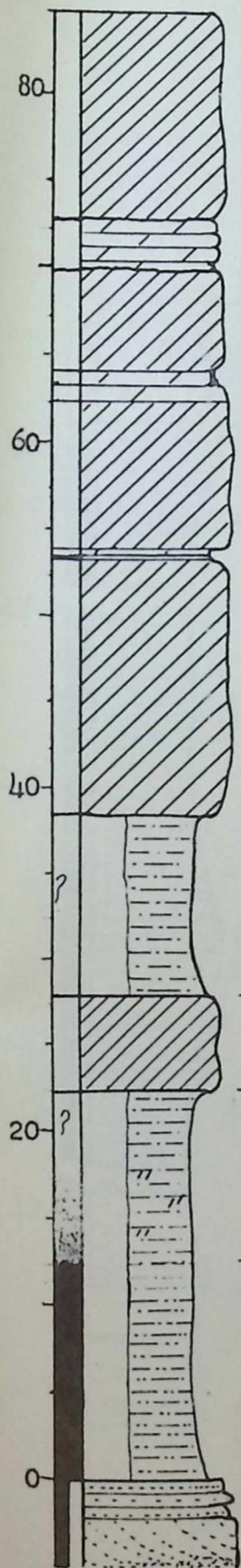




Section 28, Gypsum Creek, 27 miles north of
Pinedale, Wyoming, in SW $\frac{1}{4}$, Sec. 30,
T. 38 N., R. 109 W., B. H. M.



Feet



- 4. Covered 11.0
 - 3. Gypsum: white; contains dolomite breccia in center, 1 mm fragments (Fig. 30) 5.0
 - 2. Covered: light-gray slope material, may be gypsum bed 13.0
 - 1. Covered: red slope material, both contacts obscured 22.0
- Nugget formation (?).
 Shale: greenish-gray, silty, noncalcareous;
 interbedded with white, gypsiferous, pyritic,
 only 3.5 feet exposed above stream bed.

Section 29, Grow Ventre slide, 19 miles northeast
of Jackson, Wyoming, in NE $\frac{1}{4}$, Sec. 4
T. 42 N., R. 114 W., B. H. M.

