Stratigraphy of Madison Group Near Livingston Montana, and Discussion of Karst and Solution-Breccia Features

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GEOLOGY OF THE LIVINGSTON AREA, SOUTHWESTERN MONTANA

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By Albert E. Roberts

ABSTRACT

The Madison Group (Mississippian) near Livingston, southwestern Montana, is predominantly a marine-carbonate sequence in which limestone, dolomitic limestone, and dolomite alternate cyclically. The group is divided into two formations: the Lodgepole Limestone (in part Kinderhook age and in part Osage age) and the Mission Canyon Limestone (in part Osage age and in part Meramec age). The Lodgepole is subdivided into the Paine Shale and Woodhurst Limestone Members. The Mission Canyon is subdivided into two unnamed members; the upper member is equivalent to the Charles Formation of central and eastern Montana. Karst deposits and solution-breccia beds are both conspicuous features on or within the upper member of the Mission Canyon Limestone.

Karst deposits are on the upper surface of the Madison Group in much of Montana. In late Meramec time the Madison sea withdrew from parts of western Montana: the Mission Canyon Limestone, or its equivalent, was subjected to subaerial erosion; and karst deposits were formed prior to deposition of the Kibbey Formation of Chester age. Residual deposits continued to accumulate in Early Pennsylvanian time in southern Montana, and they are included in the basal part of the Amsden Formation.

One or more solution-breccia beds are found throughout southwestern Montana in the Mission Canyon Limestone. These formed between Late Mississippian and early Tertiary time, probably after the Late Cretaceous and early Tertiary uplifts. They mark the stratigraphic positions of evaporites that leached from surface or near-surface exposures; they do not represent an unconformity. The basal anhydrite in the upper member of the Mission Canyon Limestone or in the Charles Formation is a continuous stratigraphic unit throughout much of Montana and Wyoming. Other evaporite units, however, are discontinuous and occupy different stratigraphic positions within the formation.

The solution-breccia beds and the karst-filled deposits are quite similar in color and clayey-siltstone matrix but different in continuity and clay mineralogy. The solution breccia is a heterogeneous mixture of small angular fragments near the base of the beds but grades upward into slightly fractured limestone and dolomite. The karst-filled deposit generally has more matrix and contains fewer chaotically distributed fragments. The upper and lower surfaces of the karst-filled deposit and the upper surface of the solution breccia are poorly defined and are not stratigraphically controlled. The lower surface of the solution breccia, however, is generally sharp, well defined, and continuous. The karst deposit is laterally discontinuous, whereas the solution-breccia units are relatively continuous along the outcrop. Kaolinite is the chief clay mineral in the matrix of the karst-filled deposit, and illite is the chief clay mineral in the matrix of the solution breccia.

INTRODUCTION

Resistant carbonate rocks of the Madison Group form most of the prominent ridges and peaks near Livingston, southwestern Montana. The group is best exposed and most accessible in the east wall of the lower canyon of the Yellowstone River, 3 miles south of Livingston (fig. 1). The Madison, in this area, is a marine-carbonate sequence in which limestone, dolomitic limestone, and dolomite alternate cyclically; it is divided into two formations: the Lodgepole Limestone (in part Kinderhook age and in part Osage age) and the Mission Canyon Limestone (in part Osage age and in part Meramec age) (fig. 2). The Lodgepole is subdivided into a lower, Paine Shale Member, 334 feet thick, and an upper, Woodhurst Limestone Member, 146 feet thick. The Mission Canyon is subdivided into a lower member, 330 feet thick, and an upper member, 326 feet thick. The Madison Group rests apparently conformably on multicolored shale in the upper part of the Three Forks Formation of Late Devonian and early Kinderhook age and is unconformably overlain by grayish-red shale or argillaceous limestone of the Amsden Formation of Pennsylvanian age.

Karst deposits and solution-breccia beds are widespread in the upper part of the Madison Group in Montana and Wyoming, and interbedded red shale is present locally. As knowledge about the Madison carbonate-anhydrite-shale sequence increased, some confusion arose regarding the distinguishing characteristics of the karst deposits and solution-breccia beds. Few localities better exemplify these features as close together for convenient comparison than that of the Madison sequence near Livingston.

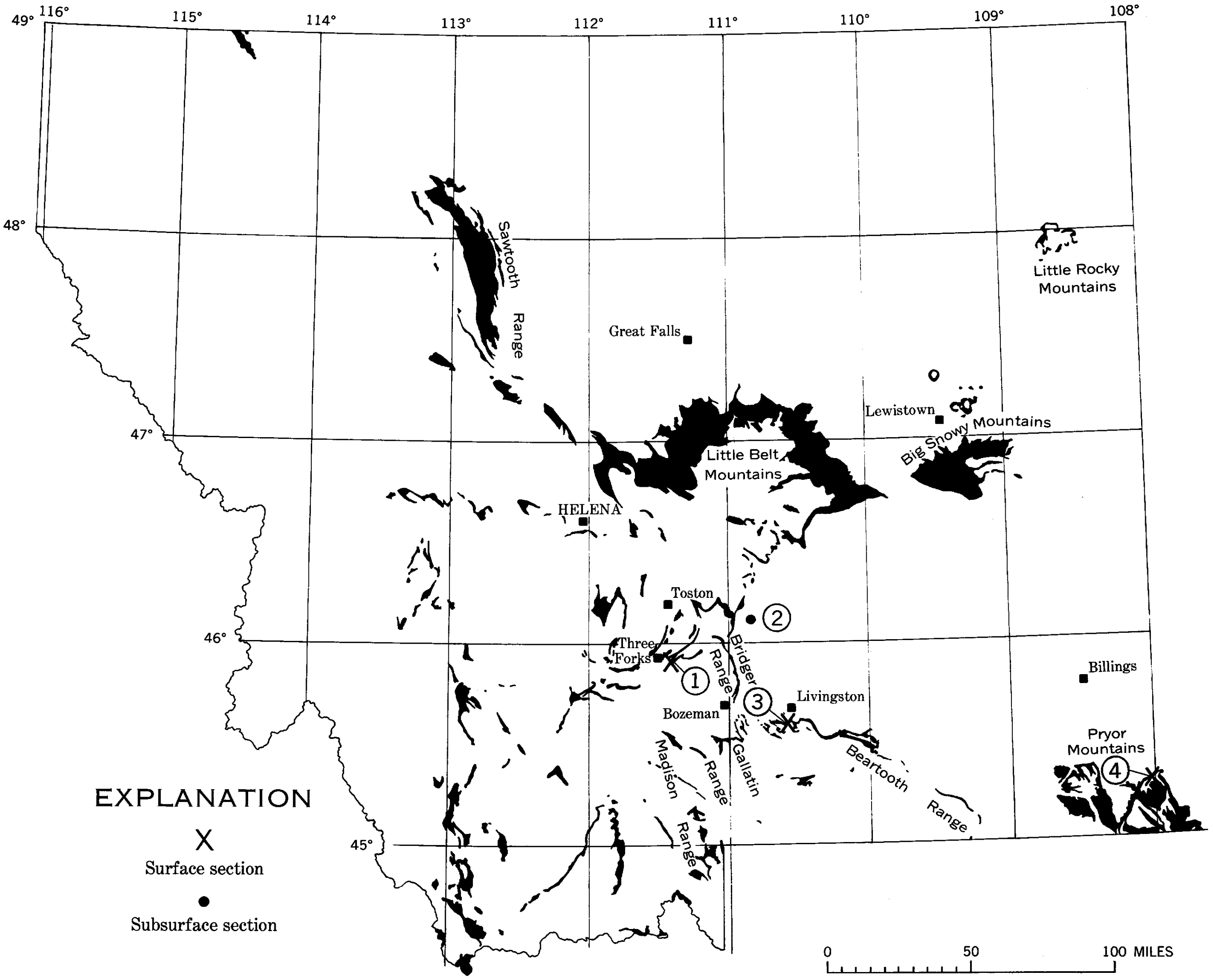

FIGURE 1.—Distribution of major outcrops of Mississippian rocks in western Montana (modified from Ross, Andrews, and Witkind, 1955). Numbered localities refer to measured sections shown in figure 8.

Investigations for this report were made from 1957 through 1961 as a part of the study of the general and economic geology in the area between Livingston and Bozeman, Mont. (Roberts, 1964, a, b, c, d, e, f, g, h; 1966). Some of the conclusions presented here were published earlier (Roberts, 1961), in a preliminary report on the Madison Group near Livingston.

STRATIGRAPHY OF THE MADISON GROUP

DEVELOPMENT OF NOMENCLATURE

Peale (1893, p. 32) divided Carboniferous rocks near Three Forks, Mont. (55 miles northwest of Livingston), into the Madison and Quadrant Formations. He subdivided the Madison Formation, beginning at the base, into "Laminated limestones, Massive limestones, and Jaspery limestones." Iddings and Weed (1894, p. 2) used the name Madison Limestone for the carbonate and shale sequence exposed near Livingston. The Madison Limestone north of Livingston in the Little Belt Mountains was subdivided by Weed (1899, p. 2) into the Paine Shale (for the lower part), the Woodhurst Limestone (for the middle part), and the Castle Limestone (for the upper part); the units are approximate counterparts to Peale's earlier subdivisions. Weed (in Hague, Weed, and Iddings, 1896, p. 4) indicated that the formation was named for the Madison Range, where the limestones are conspicuously exposed. Inasmuch as the report in which Peale (1893) named the Madison Formation was a discussion of the Paleozoic section near Three Forks, acceptance of the Three Forks area as the

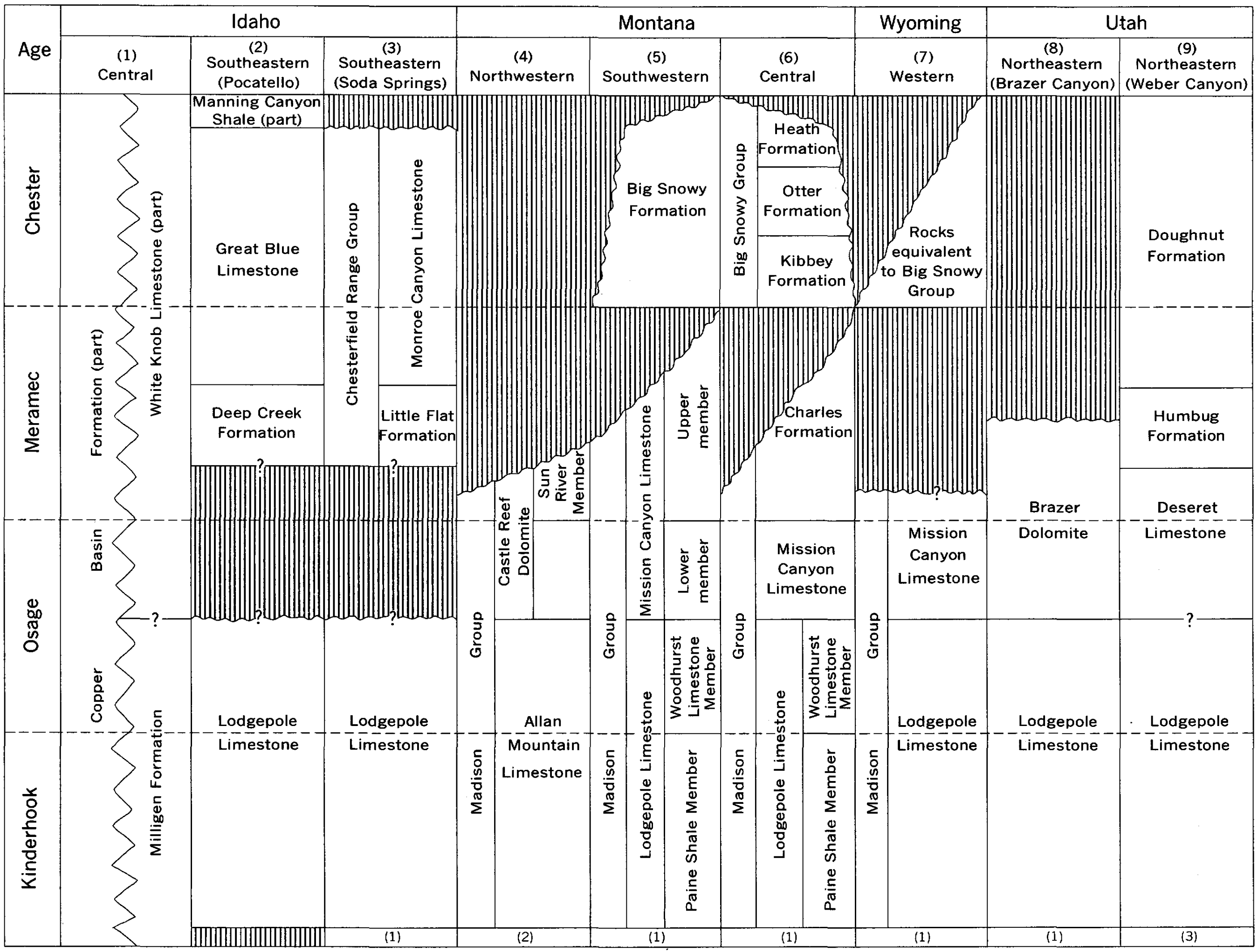

FIGURE 2.—Correlation and stratigraphic relations of the Madison Group in southwestern Montana and other areas in Montana, Idaho, Wyoming, and Utah. Modified from (1) Ross (1962), (2) Carr and Trimble (1961), (3) Dutro and Sando (1963), (4) Mudge, Sando, and Dutro (1962), (5) Roberts (1961), (6) Mundt (1956), (7) Sando and Dutro 1960, (8) Dutro and Sando (1963), and (9) T. E. Mullens (oral commun., 1963). Numbers in parentheses at bottom of chart indicate (1) Three Forks Formation (part), (2) Exshaw Shale (part), and (3) Three Forks(?) Formation (part).

type area seems reasonable, although it was not so designated in Peale's report.

The Madison Formation in the Little Rocky Mountains region in northern Montana was designated a group and divided into the Lodgepole Limestone and the overlying Mission Canyon Limestone by Collier and Cathcart (1922, p. 173). The Lodgepole corresponds approximately to Peale's laminated limestones and his massive limestones, and the Mission Canyon corresponds approximately to Peale's jaspery limestones.

The nomenclature of the Madison in southwestern Montana was integrated by Sloss and Hamblin (1942, p. 314). They proposed retention of group rank for the Madison and adoption of Weed's Paine Shale and Woodhurst Limestone as members of the Lodgepole Limestone. The stratigraphic section of Madison rocks exposed along the north bank of the Gallatin River in secs. 25 and 26, T. 2 N., R. 2 E., Gallatin County, near Logan, Mont., was interpreted by Sloss and Hamblin (1942, p. 313) as the type Madison section (fig. 1, loc. 1). The Paine Shale and Woodhurst Limestone Members are recognizable in this section, but they are best recognized as two distinct lithologic units in the Little Belt Mountains. These two Lodgepole members are much less distinct near Livingston, southeast of the type Madison section.

A carbonate sequence, including interbedded red shale, anhydrite, gypsum, and salt, that is partly a facies of and partly overlies the Mission Canyon Limestone is present in much of Montana. Seager (1942, p. 864) applied the name Charles to this sequence in southeastern Montana. He suggested (1942, p. 864) that the Charles should perhaps be included with the underlying carbonate rocks as part of the Madison, but he also reasoned that the greater porosity of the limestone beds below the Charles indicated a time break. Seager, therefore, included the Charles in the overlying Big Snowy Group and considered it the basal member. Perry and Sloss (1943, p. 1299) also included the Charles in the Big Snowy Group, assigned the Charles to formational rank, and picked contacts in the California Oil Co. Charles 4 (type) well in sec. 21, T. 15 N., R. 30 E., Petroleum County, Mont. Nordquist (1953, p. 73), however, redefined the Charles by lowering its top to the contact between clastic rocks of the Big Snowy Group and carbonate rocks of the Madison Group. The base of the Charles in west-central Montana (including the section in the type well) is placed at the base of the lowest thick anhydrite bed in a sequence of interbedded carbonate and evaporite beds that overlies the Mission Canyon Limestone. In parts of eastern Montana, where this basal anhydrite is missing, the base of the Charles is generally placed at the base of a persistent dark-gray shale—the Richey shale of subsurface usage. This shale is about 200 feet stratigraphically higher than the basal anhydrite.

Many authors have applied the name Brazer to rocks in the upper part of the Madison Group in parts of Idaho, Montana, Utah, and Wyoming. The type Brazer Limestone correlates approximately with the Mission Canyon Limestone at the type section of the Madison at Logan, Mont. (Sando, Dutro, and Gere, 1959, p. 2755–2761). As a result of their studies of the type Brazer section, Sando, Dutro, and Gere (1959, p. 2768) proposed that the term Brazer Dolomite be restricted to the Mississippian dolomite sequence in the Crawford Mountains, northeastern Utah. The Mission Canyon at the type Madison section contains considerable dolomite (Sando and Dutro, 1960, p. 124), as do the Mission Canyon at Livingston (Roberts, 1961, p. B294) and its equivalent, the Castle Reef Dolomite (fig. 2), in northwestern Montana (Mudge, Sando, and Dutro, 1962, p. 2005–2006). Future study will probably reveal widespread dolomite in this part of the Madison Group; however, in Montana, use of the term Brazer for the dolomitic beds is not recommended.

The Madison Group in the Livingston area includes the Lodgepole Limestone and the Mission Canyon Limestone (fig. 2). The Lodgepole is subdivided (with difficulty) into the Paine Shale Member, which here is predominantly a carbonate sequence, and the Woodhurst Limestone Member. The Mission Canyon is subdivided into upper and lower members (Roberts, 1961, p. B294); the upper member correlates with the Charles Formation.

LITHOLOGIC COMPOSITION

GENERAL FEATURES

The Madison Group near Livingston is predominantly a ridge-forming carbonate sequence that contains very little fine-grained clastic material except for the Paine Shale Member of the Lodgepole Limestone. The Madison is a rhythmically bedded, or cyclically deposited, sequence generally of carbonate and fine-grained clastic rocks. The repetitive units are chiefly massive to thick-bedded limestone in the upper part and medium- to thin-bedded dolomite in the lower part. Laudon and Severson (1953, p. 507) described marine cycles, which they interpreted to be alternating shallow and deep-water deposits, in the Madison at Fairy Lake in the Bridger Range. Marine cycles indicated by alternating deposition of calcium and magnesium carbonate rocks in the Madison Group near Livingston were described by Roberts (1961, p. B294).

The limestone units are massive to thick bedded, are light olive gray (5*Y* 5/2), and contain less than 5 percent insoluble residue. In general, they are composed of microcrystalline calcite in part recrystallized to microspar and sparry calcite showing grain-growth texture. Fossils and fossil debris are the predominant allochemical constituents, and oolites and pellets are lesser constituents. Oolites are more abundant in the massive limestone units, rather than in the well-bedded units, and occur only in massive limestones containing very little insoluble residue. The texture, fossils, oolites, and presence of quartz and heavy-mineral intraclasts suggest that most of the limestone units were deposited in a near-shore high-energy environment. The generalized lithology of the group is shown in figure 3.

The dolomite beds weather more rapidly than the limestone beds and form indentations in the outcrop profile. The dolomite is generally microcrystalline, is varied in color but is commonly light olive gray (5*Y* 6/1) to yellowish brown (10*YR* 6/2), is mostly brecciated, and contains more than 5 percent insoluble residue. The very fine grained dolomite was probably deposited in a low-energy environment in which there were some suspended clay minerals, and the medium-grained dolomite is a secondary-recrystallization product. In most dolomite units the color is slightly darker (light olive gray, 5*Y* 5/2) in the upper part than (light olive gray, 5*Y* 6/1) in the lower part, and the upper part has a slightly more fetid odor than the lower part. Only a few dolomite units contain fossils or fossil fragments.

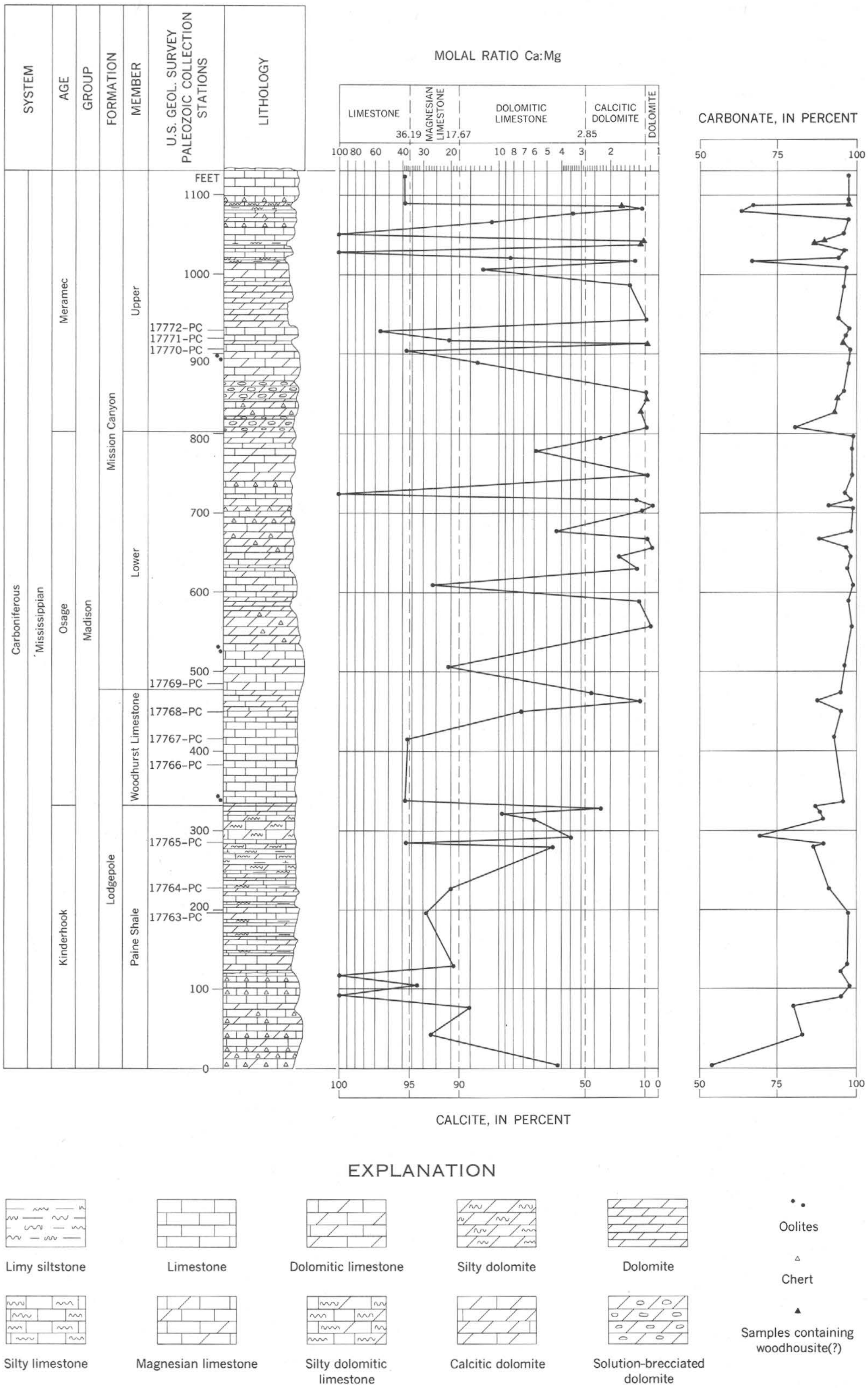

FIGURE 3.—The Madison Group in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., near Livingston, southwestern Montana. Calcium-magnesium analyses by J. A. Thomas.

The Madison Group near Livingston is 1,136 feet thick and is subdivided into four members (fig. 3). From oldest to youngest they are the Paine Shale and Woodhurst Limestone Members of the Lodgepole Limestone (480 ft thick) and the lower and upper members of the Mission Canyon Limestone (656 ft thick). The Paine Shale Member is 334 feet thick and consists mostly of medium-bedded to very thin bedded finely to coarsely crystalline limestone, dolomitic and magnesian limestone, and calcitic dolomite that has intercalations of greenish-gray siltstone. The Woodhurst Limestone Member is 146 feet thick and consists of massive to thin-bedded very finely to coarsely crystalline limestone, dolomitic limestone, calcitic dolomite, and dolomite. The lower member of the Mission Canyon Limestone is 330 feet thick and consists mostly of massive very finely to medium-crystalline cherty limestone, magnesian limestone, dolomitic limestone, calcitic dolomite, and dolomite with some solution breccia of dolomite. The upper member is 326 feet thick and consists chiefly of massive finely crystalline limestone, dolomitic limestone, calcitic dolomite, and dolomite with interbedded solution breccia of dolomite and dolomitic grayish-red siltstone.

The type Lodgepole Limestone in the Little Rocky Mountains of north-central Montana consists of 550 feet of thin-bedded carbonate and shale (W. J. Sando and J. T. Dutro, Jr., written commun., 1962). Thin bedding is a typical feature of the Lodgepole in central and parts of western Montana, and many geologists use thin bedding as the criterion for differentiating the Lodgepole from the massive Mission Canyon. Twenty miles west of Livingston, in Bridger Canyon at the south end of the Bridger Range, the Lodgepole Limestone is excellently exposed and exhibits this thin-bedding characteristic (fig. 4).

The type Mission Canyon Limestone in the Little Rocky Mountains consists of 300 feet of massive carbonate (W. J. Sando and J. T. Dutro, Jr., written commun., 1962). At the type locality, beds equivalent to the upper member at Livingston or to the Charles Formation of central Montana were removed by pre-Jurassic erosion. The characteristic massive feature of the Mission Canyon is also widespread in central and western Montana. The excellent exposure in the west wall of the lower canyon of the Yellowstone River near Livingston shows this distinguishing characteristic of the Mission Canyon Limestone (fig. 5).

The upper member of the Mission Canyon Limestone in the Livingston area contains three conspicuous grayish-red dolomitic siltstone beds that can be traced continuously for many miles. One of the siltstones near the top of the upper member is outlined in figure 6 to emphasize its conformable relation with adjacent strata. The siltstone beds are ferruginous and well laminated, and they weather to form indentations between the more resistant limestone beds. These siltstone beds are probably related to the evaporite zones to the north in the upper member of the Mission Canyon Limestone or in the Charles Formation. The red-siltstone beds have been mistaken for matrix materials of karst-filled deposits, which they resemble in color, lithology, and grain size. At the Livingston Mission Canyon section, the stratigraphic relation of the siltstone units to the adjacent beds (figs. 6, 10) and to the karst deposits (fig. 10) is clearly evident.

Mapping the Mission Canyon-Amsden contact in the Livingston area (Roberts, 1964a, b, e, f, g) indicated less than 10 feet of erosional relief on the upper surface of the Mission Canyon (fig. 7). However, numerous northwest-trending joints or normal faults of small displacement in the lower canyon of the Yellowstone

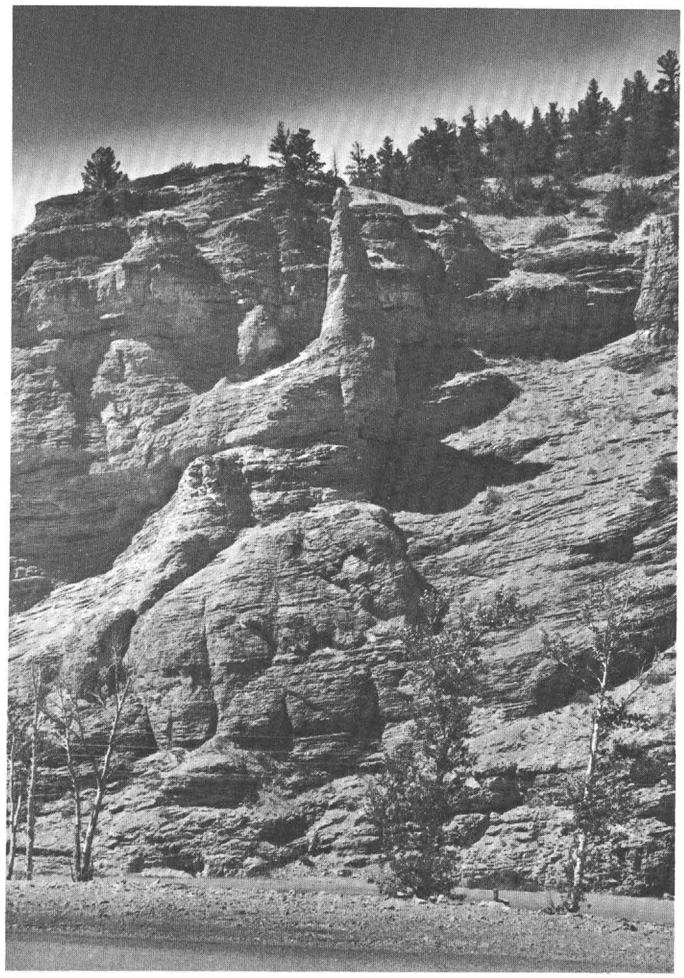

FIGURE 4.—Typical thin-bedded Lodgepole Limestone at the south end of the Bridger Range in Bridger Canyon in sec. 34, T. 1 S., R. 6 E.

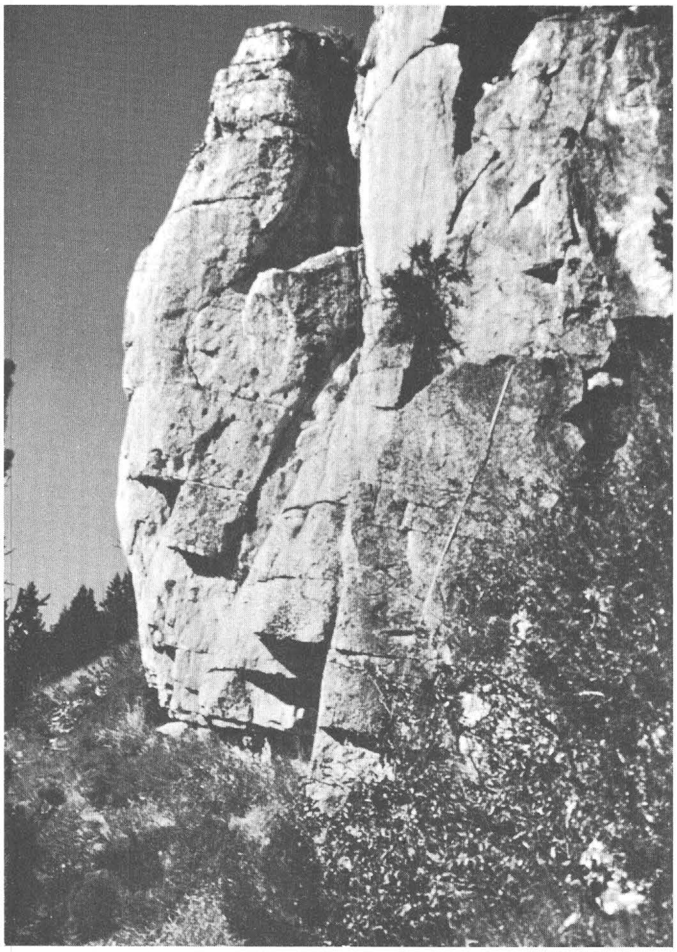

FIGURE 5.—Characteristic massive Mission Canyon Limestone in the south wall of Rocky Creek Canyon in sec. 30, T. 2 S., R. 7 E. Outcrop is approximately 30 feet high.

River cut the beds in the upper member of the Mission Canyon Limestone. Along these joints or faults a karst topography formed (locally to depths of 60 feet) during Early Pennsylvanian time.

Throughout the carbonate sequence at Livingston, chert is common in thin layers along bedding planes or, less commonly, in nodules or lenses. It is particularly abundant in the basal part of the Lodgepole. The thin layers are irregular in cross section and are etched out in relief on weathered surfaces. The proportions of chert and insoluble residue in individual stratigraphic units have no apparent relation. Although chert is particularly abundant in the basal limestone beds, it is also common in dolomite beds higher in this section and does not seem to have been selectively deposited according to rock type.

A dolomitic limestone unit 20 feet thick at the base of the Lodgepole contains about 30 percent brown and yellow chert and is an excellent stratigraphic marker

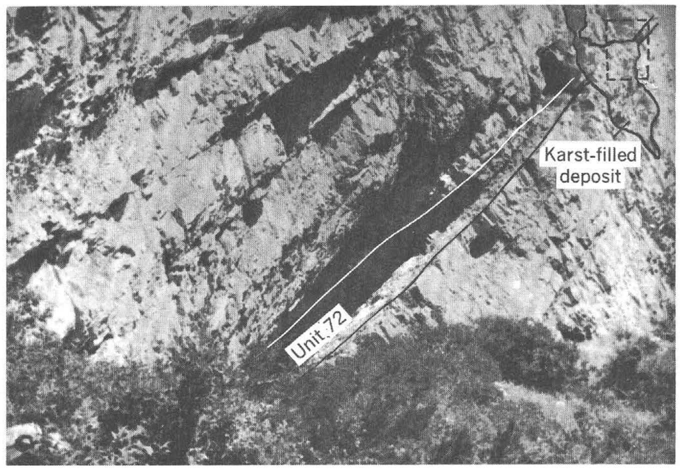

FIGURE 6.—Grayish-red siltstone (unit 72) forming conspicuous indentation between massive limestone 43 feet below the top of the upper member of the Mission Canyon Limestone in SE¼ sec. 35, T. 2 S., R. 9 E. Note outline of karst-filled deposit (shown in fig. 10) in the upper right-hand corner of this photograph.

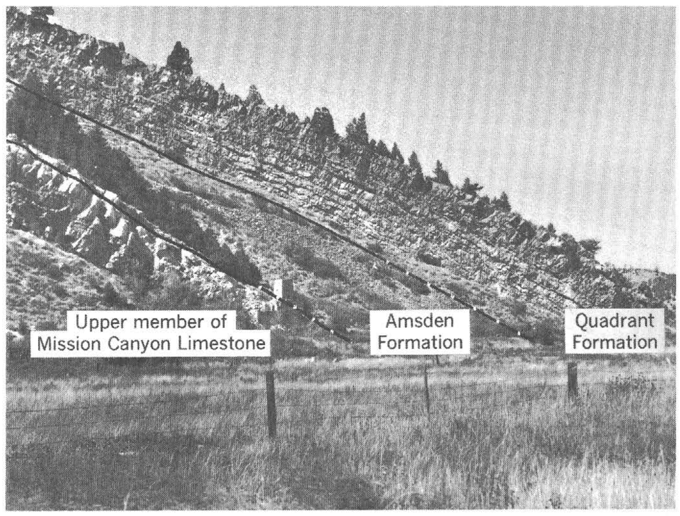

FIGURE 7.—Contact of the upper member of the Mission Canyon Limestone and the overlying Amsden Formation in the S½ sec. 35, T. 2 S., R. 9 E. Note the small amount of erosional relief on the upper surface of the upper member.

in the Livingston area, particularly in structurally complex areas where the Three Forks Formation is faulted or squeezed out. Dark-gray to yellow nodular chert also distinguishes the basal Lodgepole in the Bridger Range (Laudon and Severson, 1953, p. 509). Richards (1957, p. 409) described these basal cherty beds that stand in ledges above the easily eroded Three Forks Shale at Shell Mountain, southeast of Livingston. in ledges above the easily eroded Three Forks Shale Chert is also common in the lower part of the Lodgepole in western Wyoming and northeastern Utah, and in the subsurface of central Montana.

The Mission Canyon Limestone at Livingston contains several laterally continuous breccia beds that I interpret as solution breccia remaining after removal of soluble minerals such as anhydrite or gypsum (see p. B19. Thickness of the upper member of the Mission Canyon Limestone may vary considerably in adjacent surface and subsurface sections. Comparison of thickness, lithology, and fabric on a regional basis suggests that this unit must have been reduced by internal solution during the period of gradual uplift. One example of this change in thickness is shown in figure 8.

DOLOMITE AND DOLOMITIZATION

Dolomite is present throughout the Madison Group at Livingston in amounts that range from a trace to beds composed entirely of layers of dolomite rhombohedra. There are two general groups of dolomite rocks. The larger group has a very finely crystalline (<0.009 mm) matrix with fine- to medium-subhedral to euhedral dolomite crystals dispersed throughout, and the smaller group is varied in crystallinity. In the latter, the dolomite crystals average almost 0.10 mm in diameter and range from very small to 0.20 mm. In comparison, the limestone beds are predominantly microcrystalline-calcite ooze (<0.006 mm in diameter) partially recrystallized to microspar (0.01 mm) and sparry calcite exhibiting grain-growth texture. Dolomitization is confined mainly to the limestone beds of mirocrystalline calcite. Traces of silica, replacing carbonate, are also present; also some dolomite rhombohedrons are partially changed to microcrystalline silica.

The Lodgepole Limestone at Livingston has relatively less dolomite or dolomitic limestone than the Mission Canyon. The calcium: magnesium molal-ratio curve (fig. 3) illustrates a cyclic alternation of carbonate rocks of varied calcium carbonate to magnesium carbonate composition in both formations. The cycles are imperfect or are not apparent in the lower part of the Lodgepole Limestone but are better defined in the younger rocks; in the upper member of the Mission Canyon Limestone, these cycles are conspicuous in the field and are clearly shown in figure 3. Cyclic deposition of limestone and dolomite in Mississippian rocks in the Bridger Range was excellently illustrated by Laudon and Severson (1953, p. 509–512).

The intimate interlayering of thin dolomite and limestone beds, as well as the finer crystallinity of most of the dolomite and the larger content of insoluble residues in the dolomite (fig. 3), suggests that most limestone and uniformly very finely crystalline dolomite were deposited directly from sea water. The nonuniformly medium crystalline dolomite, however, probably recrystallized from a very finely crystalline carbonate. Dolomite rhombohedra transecting fossil and oolite outlines occur in some medium-crystalline dolomite and indicate dolomitization of an original limestone. Hohlt (1948, p. 33) and Chilingar (1956, p. 2492) suggested that the reorientation of calcite crystals facilitates solution migration in carbonate rocks. Hobbs (1957, p. 37) illustrated this point by suggesting a relation between the amount of dolomitization and the types of calcite present. The occurrence of dolomite in the microcrystalline calcite and the absence of trace amounts of dolomite in recrystallized limestone suggest that recrystallization of microcrystalline calcite preceded dolomitization. Dolomitization occurred shortly after lithification and recrystallization but before compaction stresses were great enough to cause reorientation of the microcrystalline calcite. Magnesium-rich solutions were able to penetrate into the microcrystalline calcite but were impeded by decreased porosity and permeability in the coarser grained recrystallized calcite. A few dolomite beds showed gradational enrichment in magnesium coincident with a decrease in size of crystals in some zones or layers.

INSOLUBLE RESIDUES

Differences in insoluble-residue content also characterize the formations and members of the Madison Group, a fact first recognized by Sloss and Hamblin (1942, p. 305). Correlation, based in part on a study of insoluble residues of the Madison Group in north-central Wyoming, was made by Denson and Morrisey (1954, p. 46, 47). Examination of insoluble residues in the Madison at Livingston by Roberts (1961) indicated that the quantity of insoluble residue generally increases as the quantity of magnesium increases. Reports by Roy, Thomas, Weissman, and Schneider (1955), Fairbridge (1957), Dunbar and Rodgers (1957), Bisque and Lemish (1959), and Amsden (1960) discussed or demonstrated this general relation for dolomites.

Insoluble residues in the Madison Group in the lower canyon of the Yellowstone River near Livingston are, mainly, clay minerals, quartz, feldspar (mostly microcline), and chert, and, subordinately, pyrite, magnetite, tourmaline, zircon, garnet, biotite, pyroxene, sphene, barite, hematite, leucoxene, apatite, gold, and marcasite. The most abundant heavy minerals are pyrite and barite, which range from a trace to 90 percent of the total heavy-mineral fraction. Barite was identified by X-ray diffraction. The clay minerals, identified by X-ray diffraction, are illite, kaolinite, and mixed-layer clays. Illite ranges from 60 to 100 percent of the total clay minerals but averages about 90 percent. A few insoluble residues contained as much as 30 percent kaolin-

TABLE 1.—*Grain-size distribution of insoluble residue in carbonate beds of the Lodgepole Limestone and the Mission Canyon Limestone near Livingston, Mont.*

[Analyses by R. F. Gantnier and J. A. Thomas]

Sample	Percent soluble in acid	Percent insoluble for indicated grain size, in millimeters												Heavy minerals in sample (percent)
		4.0	2.0	1.0	0.5	0.25	0.125	0.062	<0.062	0.05	0.005	0.002	<0.002	
MISSION CANYON LIMESTONE														
Upper member														
79	99.3				100.0									0.07
75	99.6								100.0					.12
74	99.1							100.0						.10
73	98.9			0.9	1.3	4.8	11.5	25.6	55.9					.26
72	85.5	[1] 1.3	[1] 0.1			.4	.1	.1		6.2	16.5	10.3	65.0	Trace.
71	[2] 61.1													.04
70	99.7								100.0					
69	99.0						3.4	16.9	79.7					.11
68	99.2						[3] 18.5	[3] 19.7	[3] 61.8					.22
67	92.6									11.0	18.0	21.0	50.0	.04
65	91.3									4.0	17.0	7.0	72.0	Trace.
64	99.3								[4] 100.0					Trace.
62	95.8						.4	6.9	92.7					.02
61	66.8						.2	2.5		11.3	56.4	4.7	24.9	Trace.
59	98.8								100.0					Trace.
53	98.7	[4] 2.2	[4] 2.6	[4] 1.5	6.0	5.2	6.7	15.4	60.3					.12
52	99.4								[3] 100.0					Trace.
50	99.9								100.0					
49	95.9		[1] 36.3		3.3	3.7	[3] 7.3	[3] 13.9	35.5					.61
48	97.6								[3] 100.0					1.86
45	79.3				.04	.1	4.6	12.7	15.3	6.7	41.0	4.7	14.8	Trace.
Lower member														
36	97.3							6.2	93.8					0.06
33	90.4		0.2	1.4	3.2	5.3	11.8	19.1	59.0					.01
LODGEPOLE LIMESTONE														
Woodhurst Limestone Member														
18	89.9									9.0	39.0	1.0	51.0	Trace.
17	95.7	[4] 1.0		[4] 1.2	2.5	2.2	14.3	11.3	67.5					Trace.
16	94.7									9.0	30.0	15.0	46.0	0.01
Paine Shale Member														
12	92.6									14.0	35.0	1.0	50.0	0.01
11	89.8	[4] 0.8	[4] 6.2	[4] 14.3	[4] 12.4	6.5	5.7	11.2	42.8					.01
10 [5]	91.1									8.0	34.0	12.0	46.0	.01
10 [6]	[2] 68.9													Trace.
9	91.1		[4] 10.8	[4] 29.6	[4] 19.7	[4] 4.9	11.0	9.6	14.4					.07
8	90.5									20.0	36.0	15.0	29.0	.01
6 [5]	93.5			.2	.7	2.7	7.5	27.6	61.3					.01
6 [7]	98.3								100.0					.03
4	98.0	[4] 4.0	[4] 3.5	[4] 6.2	[4] 14.7	19.9	17.9	12.7	21.1					.10
3	86.3			4.1	4.0	3.6	10.6	18.6		4.1	34.8	7.1	13.0	Trace.
2	81.0								[1] 100.0					.01
1	50.9	[1] 63.1	[4] 13.1	[4] 6.8	[4] 2.9	1.2	0.8	1.4	10.6					.20

[1] Includes silicified fragments or chert.
[2] Silicified; unable to disaggregate.
[3] Includes petroliferous matter.
[4] Includes fossil fragments.
[5] Near top.
[6] Near bottom.
[7] Near middle.

ite, but most contained 10 percent or less. About half the insoluble residues from the Mission Canyon contained from a trace to as much as 20 percent mixed-layer clay. Only one insoluble residue from the Lodgepole contained mixed-layer clay. Six insoluble residues from the upper member of the Mission Canyon Limestone contained an unidentified hydrous double salt (probably of the beudantite group) very similar to woodhouseite [$Ca\ Al_3(PO_4)(SO_4)(OH_6)$]. This mineral was present in dolomite, calcitic dolomite, and dolomitic siltstone that contained less than 15 percent insoluble residue. Samples containing this mineral were generally rich in illite or mixed-layer clay and poor in kaolinite. Phosphate and sulfate radicals in this mineral suggest incipient deposition of evaporites.

Grain sizes of the insoluble residues range from less than 0.002 mm to 4.0 mm (table 1). The average grain size of detrital particles is less than 0.062 mm. The larger fragments are silicified carbonate particles or fossil debris.

A comparison of the total insoluble residue and the heavy-mineral fraction indicates that, in general, the ratio of insoluble residue to heavy minerals is high when percentage of insolubles is high, and the ratio is low when the percentage of insolubles is low. This relation suggests that chemical precipitation of iron and sulfate minerals was environmentally controlled, and that the balance of the environment was not upset by the introduction of detrital material. Generally the percentage of insoluble residues and the percentage of heavy minerals increased as the magnesium content of the sea water increased. The presence of pyrite and marcasite suggests slightly reducing conditions. Barite formed presumably when oxidation of some sulfides released sulfate in the presence of barium ions (Pettijohn, 1957, p. 150).

STRATIGRAPHIC SECTION NEAR LIVINGSTON

The following detailed stratigraphic section of the Madison Group was measured by tape and Brunton traverse. Representative samples were collected from about the middle of each lithologic unit for laboratory study. Description of the stratigraphic units combines the megascopic and microscopic examinations. Colors are those given by the National Research Council's "Rock-Color Chart" (Goddard and others, 1948). In referring to the bedding of the rocks, the following standard was used: Massive, greater than 4 feet thick; thick bedded, 2–4 feet; medium bedded, 6 inches–2 feet; thin bedded, 2–6 inches; very thin bedded, ½–2 inches; platy, 1/16–½ inch; and fissile, less than 1/16 inch. In referring to the crystallinity of the carbonate rocks, the following standard was used: Very coarsely crystalline, grains or crystals 1–4 mm in diameter; coarsely crystalline, grains or crystals 0.25–1 mm in diameter; medium crystalline, grains or crystals 0.0625–0.25 mm in diameter; finely crystalline, 0.0156–0.0625 mm in diameter; and very finely crystalline, 0.0039–0.0156 mm in diameter. Terms applied to carbonate rocks are modified from Guerrero and Kenner (1955). Fossils from localities given in the measured section are listed in a separate part of this report.

The section was measured along the east wall of the lower canyon of the Yellowstone River and is considered to be typical of the group in this region.

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.

[Measured by Albert E. Roberts and Cyril J. Galvin, in 1957]

Amsden Formation (Pennsylvanian).

Unconformity: About 1–4 ft of relief on the upper surface of unit 79.

Madison Group (Mississippian):

Mission Canyon Limestone:

Upper member:	*Ft*	*in*
79. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); contains endothyrid Foraminifera Plectogyra; forms ridges	22	7
78. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light gray (*N*7); contains lenses and stringers of light-olive-gray (5*Y* 6/1) chert less than 2 in. thick; brecciated locally	4	6
77. Limestone, medium- to thick-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	4	7
76. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); lens 1 ft (or less) thick of mottled chert near top	7	5
75. Limestone, medium-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light gray (*N*7)	1	2
74. Dolomite, calcitic, thin- to medium-bedded, medium-crystalline, pale-red (10*R* 6/2); weathers very pale orange (10*YR* 8/2); silty	2	5
73. Limestone, magnesian, irregularly bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light gray (*N*7)		9

Madison Group measured on the east side of the Yellowstone River in Sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	in
Madison Group (Mississippian)—Continued		
Mission Canyon Limestone—Continued		
Upper member—Continued		
72. Siltstone, dolomitic, thin- to thick-bedded, sandy, grayish-red (10*R* 4/2) and yellowish-gray (5*Y* 7/2); weathers yellowish gray (5*Y* 8/1) to pale yellowish orange (10*YR* 8/6); about 1 in. or less of grayish-yellow-green (5*GY* 7/2) claystone at top; forms conspicuous indentation	3	4
71. Limestone, dolomitic, massive, finely crystalline, silty, light-olive-gray (5*Y* 5/2); weathers medium light gray (*N*6); continuous zone of chert nodules 6½ ft below top	15	6
70. Limestone, dolomitic, thick-bedded, medium-crystalline, pinkish-gray (5*YR* 8/1); weathers pale yellowish brown (10*YR* 6/2); contains several lenses of chert 2–6 in. thick	9	1
69. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); two prominent brown-chert beds generally about 3 in. thick at top of unit	15	9
68. Limestone, medium-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	1	1
67. Siltstone, dolomitic, thin-bedded, brittle, mostly grayish-red (10*R* 4/2); lesser amounts yellowish gray (5*Y* 7/2), weathers pinkish gray (5*YR* 8/1); brecciated at base owing to adjustment along bedding planes during folding; unit squeezed to irregular thicknesses	2	7
66. Limestone, medium-bedded, very finely crystalline, light-olive-gray (5*Y* 6/1); weathers light gray (*N*7); contains fine grains of magnetite		8
65. Dolomite, calcitic, very thin bedded to medium-bedded, argillaceous, very finely crystalline, yellowish-gray (5*Y* 7/2); weathers grayish yellow (5*Y* 8/4)	3	5
64. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); oolitic in upper half	13	7

Madison Group Measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	in
Madison Group (Mississippian)—Continued		
Mission Canyon Limestone—Continued		
Upper member—Continued		
63. Siltstone, irregularly bedded, calcareous, grayish-red (10*R* 4/2), yellow, and pink; fills shallow channels 1–2 ft deep in underlying limestone	1	10
62. Limestone, dolomitic, thick-bedded, finely crystalline, light-olive-gray (5*Y* 6/1); continuous zone of chert nodules near top of unit	2	5
61. Siltstone, dolomitic, medium- to thin-bedded, grayish-red (10*R* 4/2); contains a few thin beds of argillaceous dolomite	2	6
60. Limestone, dolomitic, massive, finely crystalline, arenaceous, mottled grayish-red (10*R* 4/2), pale-red (5*R* 6/2), and pinkish-gray (5*YR* 8/1); weathers grayish pink (5*R* 8/2); contains some silt and fine quartz sand; poorly exposed	28	11
59. Dolomite, calcitic, medium-bedded, finely crystalline, pale-yellowish-brown (10*YR* 6/2); weathers light olive gray (5*Y* 6/1); vuggy; some chert at top of unit	2	0
58. Dolomite, calcitic, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2); very porous—much of the surface resembles a sponge. Many cavities ranging from a few inches to several feet wide; unit generally brecciated	17	5
57. Limestone, dolomitic, medium-bedded, very finely crystalline, light-olive-gray (5*Y* 5/2); weathers light gray (*N*6); several thin lenses of chert in lower half	3	5
56. Dolomite, irregularly bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2)	4	6
55. Dolomite, massive to thin-bedded, fine- to medium-crystalline, fossiliferous, brittle, grayish-orange-pink (5*YR* 7/2); weathers very pale orange (10*YR* 8/2); basal 9 ft oolitic; forms conspicuous slabby talus; locally a sandy pebble to cobble conglomerate in the lower 6–12 ft	26	11

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

Madison Group (Mississippian)—Continued
Mission Canyon Limestone—Continued
Upper member—Continued

	Ft	in
54. Limestone, massive, fine- to medium-crystalline, yellowish-gray 5*Y* 7/2); weathers yellowish gray (5*Y* 8/1); fossil locality 17772–PC is the upper 4 ft and fossil locality 17771–PC is the lower 6 ft of unit; upper surface covered with *Syringopora surcularia* Girty; lower 4 ft is dolomitic and bedded; forms prominent ridges	13	5
53. Dolomite, medium- to thin-bedded, finely crystalline, brittle, light-olive-gray (5*Y* 6/1); weathers yellowish gray (5*Y* 7/2); contains broken fossils and a little chert	4	9
52. Limestone, dolomitic in lower half, massive to poorly bedded, fine- to medium-crystalline, pale-yellowish-brown (10*YR* 6/2) to light-olive-gray (5*Y* 6/1); weathers very light olive gray (5*Y* 7/1); oolitic in upper 8 ft; fossil locality 17770–PC upper half of unit; forms prominent ridges; fetid odor	45	8
51. Solution breccia of calcitic finely crystalline light-olive-gray (5*Y* 5/2) dolomite; weathers yellowish gray (5*Y* 7/2; fetid odor	5	0
50. Dolomite, massive, finely crystalline, fossiliferous, light-olive-gray, (5*Y* 5/2); weathers yellowish gray (5*Y* 8/1); unit generally brecciated—probably a solution breccia. Long stringers of chert 2 ft from base	18	3
49. Dolomite, platy, very finely crystalline, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2)	2	7
48. Dolomite, calcitic, massive to poorly bedded, medium-crystalline, fossiliferous, pale-yellowish-brown (10*YR* 6/2); weathers yellowish gray (5*Y* 7/2); contains many nodules and stringers of chert	20	0
47. Dolomite, irregularly bedded, very finely crystalline, yellowish-gray (5*Y* 8/1); contains interbedded grayish-yellow-green (5*GY* 7/2) siltstone; unit generally brecciated—probably a solution breccia	3	0
46. Dolomite, irregularly bedded, very finely crystalline, argillaceous, light-olive-gray (5*Y* 5/2); weathers light shades of pink, yellow, and green; locally brecciated—probably a solution breccia	9	6
45. Solution breccia of irregularly very finely crystalline yellowish-gray (5*Y* 8/1) dolomite; weathers shades of green, yellow, and pink; contains subangular to subrounded pebbles, cobbles, and a few boulders of dolomite and chert in interbedded grayish-yellow-green (5*GY* 7/2) siltstone; many cavities ranging from a few inches to several feet wide	5	6
Total, upper member	326	0

Lower member:

	Ft	in
44. Dolomite, calcitic, massive, finely crystalline, pale-yellowish-brown (10*YR* 6/2); weathers very pale orange (10*YR* 8/2); brecciated locally	15	7
43. Dolomite, medium- to thin-bedded, very finely crystalline, light-olive-gray (5*Y* 6/1); weathers yellowish gray (5*Y* 7/2); thin interbeds of limestone	7	6
42. Limestone, dolomitic, massive to faintly stratified, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); contains many chert beds 2 in. or less thick and many chert nodules as much as 6 in. wide; fetid odor; forms ridges	31	6
41. Dolomite, massive to poorly bedded, very finely crystalline, very pale orange (10*YR* 8/2); weathers yellowish gray (5*Y* 8/1); contains solution cavities	6	6
40. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 6/1); weathers light gray (*N*7); prominent chert bed 1½ ft from top; fetid odor; forms ridges	15	3
39. Dolomite, extensively fractured, very finely crystalline, argillaceous; olive-gray (5*Y* 4/1); weathers yellowish gray (5*Y* 7/2); contains solution cavities	1	0

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	in
Madison Group (Mississippian)—Continued		
Mission Canyon Limestone—Continued		
Lower member—Continued		
38. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 6/1); weathers light gray (*N*7)	6	2
37. Dolomite, calcitic, massive to medium-bedded, finely crystalline, fossiliferous, pale yellowish-brown (10*YR* 6/2); weathers light gray (*N*7); contains chert nodules; fetid odor	10	5
36. Dolomite, medium-bedded, very finely crystalline, argillaceous, light-olive-gray (5Y 6/1); weathers yellowish gray (5*Y* 8/1); many solution cavities	1	0
35. Dolomite, calcitic, massive to faintly bedded, finely crystalline, light-brownish-gray (5*YR* 6/1); weathers pinkish gray (5*YR* 8/1); contains chert nodules	12	6
34. Limestone, dolomitic, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); sporadic chert nodules and three beds of chert near top of unit; fetid odor	25	8
33. Solution breccia of very finely crystalline light-gray (*N*7) dolomite; weathers very light gray (*N*8); many solution cavities	6	4
32. Limestone, dolomitic, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); contains sporadic chert nodules	5	5
31. Dolomite, medium- to thin-bedded, very finely crystalline, very light olive gray (5*Y* 7/1); weathers yellowish gray (5*Y* 8/1); contains chert lenses and nodules generally 2 in. or less wide; fetid odor	8	1
30. Dolomite, calcitic, massive to thick-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	15	1
29. Solution breccia of calcitic light-gray (*N*7) to light-olive-gray (5*Y* 6/1) dolomite; contains chert nodules	6	0
28. Dolomite, calcitic, medium-bedded to very thin bedded, very finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); very silty in the middle and base of unit; contains chert in upper half of unit; fetid odor	6	2

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	in
Madison Group (Mississippian)—Continued		
Mission Canyon Limestone—Continued		
Lower member—Continued		
27. Limestone, magnesian, massive, fine- to medium-crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); flat-pebble conglomerate 6 ft from top; chert nodules and lenses; forms ridges	32	1
26. Dolomite, calcitic, thin-bedded to very thin bedded, very finely crystalline, pale-yellowish-brown (10*YR* 6/2); weathers yellowish gray (5*Y* 7/2); readily eroded and is locally cavernous; fetid odor	6	3
25. Limestone, dolomitic, medium-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); conspicuous bed of chert at top of unit	2	7
24. Dolomite, thin-bedded, very finely crystalline, pale-yellowish-brown (10*YR* 6/2); weathers yellowish gray (5*Y* 7/2)	1	5
23. Limestone, dolomitic, thick-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); thin zone of chert in middle of unit	3	3
22. Dolomite, thin-bedded, very finely crystalline, yellowish-gray (5*Y* 7/2); continuous bed of chert at top of unit	3	3
21. Dolomite, massive to medium-bedded, finely crystalline, light-olive-gray (5*Y* 6/1); weathers yellowish gray (5*Y* 8/1); chert stringers and thin beds throughout unit; some flat-pebble conglomerates in upper part; forms ridges	41	6
20. Limestone, magnesian, massive to medium-bedded, medium-crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); oolitic throughout, but more oolitic near top of unit; fossil locality 17769–PC in lower 10 ft of unit; forms very prominent continuous ridges	59	6
Total, lower member	330	0
Total, Mission Canyon Limestone	656	0

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	*in*
Madison Group (Mississippian)—Continued		
Lodgepole Limestone:		
Woodhurst Limestone Member:		
19. Dolomite, calcitic, medium- to thin-bedded, coarsely crystalline, fossiliferous (predominantly crinoidal), light-olive-gray (5*Y* 5/2); weathers light gray (*N*7)	4	7
18. Dolomite, calcitic, thin-bedded, very finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	13	4
17. Limestone, dolomitic, thin-bedded, very coarsely crystalline, light-brownish-gray (5*YR* 6/1); contains moderate red (5*R* 5/4) flecks; weathers yellowish gray (5*Y* 8/1); fossil locality 17768–PC; forms ridges	16	6
16. Limestone, generally thin-bedded in upper 35 ft and massive to thick-bedded in lower 10 ft; alternating light-olive-gray (5*Y* 5/2) and pale-red (10*R* 6/2) beds; weathered surfaces yellowish gray (5*Y* 7/2) to grayish orange pink (5*YR* 7/2); finely to coarsely crystalline; at 23 ft below top several lenticular grayish-red (10*R* 4/2) calcareous-siltstone beds as much as 6 in. thick; some tracks and trails on bedding planes; fossil locality 17767–PC	45	0
15. Limestone, missive to medium-bedded, fine- to medium-crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); to yellowish gray (5*Y* 8/1); fossil locality 17766–PC	22	8
14. Dolomite, mostly medium- to thin-bedded, thick-bedded in middle of unit, finely crystalline, fossiliferous, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	24	6
13. Limestone, massive to thick-bedded upper half of unit and medium- to thin-bedded in lower half, finely to coarsely crystalline, oolitic, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1) tains fossil fragments in lower half of unit; forms ridges	19	5
Total, Woodhurst Limestone Member	146	0

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	*in*
Madison Group (Mississippian)—Continued		
Lodgepole Limestone—Continued		
Paine Shale Member:		
12. Dolomite, calcitic, medium-bedded to very thin bedded, very finely crystalline, silty; beds alternately pale yellowish brown (10*YR* 6/2) and pale olive (10*Y* 6/2); weathers mottled to banded light brownish gray (5*YR* 6/1) and yellowish gray (5*Y* 8/1); many thin penecontemporpaneous intraformational breccias; a few fossil tracks and trails	7	3
11. Limestone, dolomitic, thin-bedded, finely to coarsely crystalline, light-olive-gray (5*Y* 6/1); some grayish-red (10*R* 4/2) flecks; weathers light gray (*N*7); contains fossil fragments, tracks, and trails	5	11
10. Limestone, dolomitic, mostly medium- to thin-bedded, locally very thin bedded to platy; finely crystalline, argillaceous, light-olive-gray (5*Y* 5/2) and grayish-red (10*R* 4/2); weathers yellowish gray (5*Y* 7/2) and grayish orange pink (5*YR* 7/2); unit is very conspicuous because of its bedding and weathered color; red beds contain more clay and silt and are slightly more coarsely crystalline than yellowish-gray beds; fossils, tracks, and trails	29	8
9. Limestone, magnesian, thick-bedded, cross-bedded, coarsely crystalline, light-olive-gray (5*Y* 5/2); some grayish-red (10*R* 4/2) flecks; weathers light gray (*N*7); locally contains flat-limestone-pebble conglomerate; fossil locality 17765–PC	3	0
8. Limestone, dolomitic, thin-bedded to platy, finely crystalline, argillaceous, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2) and locally grayish orange pink (5*YR* 7/2), grayish red (10*R* 4/2) and greenish gray (5*GY* 6/1); interbedded calcareous greenish-gray (5*G* 6/1) siltstone; some fossil fragments of crinoids and brachiopods; a few thin stringers of chert; generally partly covered	43	11

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

Madison Group (Mississippian)—Continued Lodgepole Limestone—Continued Paine Shale Member—Continued	*Ft*	*in*
7. Limestone, dolomitic, medium- to thin-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2); interbedded calcareous greenish-gray (5*G* 6/1) siltstone; locally becomes intraformational breccia	3	2
6. Limestone, magnesian, medium- to thin-bedded, finely to very coarsely crystalline, light-olive-gray (5*Y* 5/2); weathers grayish orange (10*YR* 7/4) and grayish yellow (5*Y* 7/2); very thin interbedded calcareous greenish-gray (5*G* 6/1) siltstone; few small chert nodules in upper 1 ft of unit; fossil locality 17764–PC between 3 and 4 ft below top of unit; fossil locality 17763–PC 34 ft below top of unit; tracks and trails on siltstone bedding planes; 2-ft-thick flat-siltstone-pebble conglomerate 35 ft below top	105	6
5. Limestone, magnesian, medium-bedded to very thin bedded, finely crystalline, fossiliferous, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); contains sporadic small chert nodules and some tracks and trails	6	3
4. Limestone, massive to poorly bedded in upper part and thin- to medium-bedded in lower part, medium- to very coarsely crystalline, fossiliferous, pale-yellowish-brown (10*YR* 6/2), weathers light-olive-gray (5*Y* 6/1); sporadic chert lenses and nodules throughout; oolitic in part; forms prominent cliffs (only unit in measured section that forms a barrier to walking at river's edge)	46	6
3. Limestone, dolomitic, medium- to thin-bedded, finely crystalline, fossiliferous, light-olive-gray (5*Y* 5/2); weathers grayish yellow (5*Y* 7/4); argillaceous; some silty partings	10	0

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

Madison Group (Mississippian)—Continued Lodgepole Limestone—Continued Paine Shale Member—Continued	*Ft*	*in*
2. Limestone, magnesian, thick- to thin-bedded, thinner bedded toward base of unit, finely to coarsely crystalline, fossiliferous, pale-yellowish-brown (10*YR* 6/2) to medium-gray (*N*5); weathers light olive gray (5*Y* 6/1) to yellowish gray (5*Y* 7/2); abundant medium-gray (*N*5) chert that weathers medium light gray (*N*6); forms ridges	52	10
1. Limestone, dolomitic, medium- to thin-bedded, mostly fine- to medium-crystalline, basal 3½ ft coarsely crystalline, argillaceous, light-olive-gray (5*Y* 6/1) to medium-dark-gray (*N*4); weathers medium light gray (*N*6), grayish yellow (5*Y* 8/4), grayish orange (10*YR* 7/4), and locally moderate orange pink (5*R* 7/4); many thin shaly partings; abundant crinoidal debris; contains about 30 percent pink, brown, and yellow chert; more chert than any other unit in the Madison Group	20	0
Total, Paine Shale Member	334	0
Total, Lodgepole Limestone	480	0
Total, Madison Group	1,136	0

Three Forks Formation (Mississippian and Devonian).

AGE AND CORRELATION

The Madison Formation, as defined by Peale (1893, p. 33), was assigned by Walcott (in Peale, 1893, p. 39) to lower Carboniferous. Faunas collected from the Madison Limestone in Yellowstone National Park were regarded by Girty (1899, p. 484) as possibly equivalent in age to the major part of the Mississippian but as having their strongest affinities with the Kinderhook. Faunas from the Paine Shale and the Woodhurst Limestone were assigned to the Kinderhook, or Chouteau, by Schuchert and Girty (in Weed, 1900, p. 293).

The Madison of southwestern Montana was summarized by Weller and others (1948, p. 138) as late

Kinderhook and Osage in age. Laudon (1948, p. 295) and Holland (1952, p. 1714) concluded that faunas from the type Madison were indicative of Kinderhook age. Dolomite beds in the upper part of the Mission Canyon in southwestern Montana were assigned by Sloss and Moritz (1951, p. 2157) to the Meramec and tentatively correlated with dolomite beds of the Charles Formation of central Montana. The Lodgepole and Mission Canyon Formations in the Bridger Range represented continuous deposition through all of Kinderhook and perhaps earliest Osage time, according to Laudon and Severson (1953, p. 507). Williams (in Klepper, Weeks, and Ruppel, 1957, p. 18) recognized beds of Meramec age in the upper part of the Mission Canyon in western Montana. The Madison Group, including the type section, was subdivided into faunal zones (Sando and Dutro, 1960, p. 122; Sando, 1960, p. B227); the zones were correlated with late Kinderhook, Osage, and probable Meramec of the type Mississippian.

Mississippian rocks equivalent to the Madison Group (Sando, 1960, p. B226) exposed in the Sawtooth Range of northwestern Montana were named the Hannan Formation by Deiss (1941, p. 1896) and were later described briefly by Deiss (1943, p. 228). He (1933, p. 45) considered this sequence to be almost equivalent in age to the Kinderhook and Osage Series. Sloss and Hamblin (1942, p. 311) concurred with Deiss but recognized that some of the upper limestone beds might be of Late Mississippian age. Sloss and Laird (1945) subdivided the Hannan Formation in northwestern Montana into units MC, MB_2, MB_1, and MA, in ascending order. Unit MC was assigned a Kinderhook age and was considered equivalent to the Paine Shale Member of the Lodgepole Limestone. Unit MB_2 was assigned an Osage age and was considered equivalent to the Woodhurst Limestone Member of the Lodgepole.

Unit MB_1 was assigned an Osage age and was considered equivalent to the Mission Canyon Limestone. Unit MA was assigned a Meramec age and was considered equivalent to the Charles Formation. Mudge, Sando, and Dutro (1962, p. 2003) subdivided the Madison Group in northwestern Montana into the Allan Mountain Limestone (equivalent to the Lodgepole Limestone) and the Castle Reef Dolomite (equivalent to the Mission Canyon Limestone), as shown in figure 2. Unit MA of Sloss and Laird (1945) was named the Sun River Member of the Castle Reef Dolomite by Mudge, Sando, and Dutro (1962, p. 2003).

The Madison Group at Livingston, Mont., is divided into the Lodgepole Limestone, in part of Kinderhook age and in part of Osage age, and the Mission Canyon Limestone, a lower member in part of Osage age and an upper member of Meramec age (fig. 2). Fossils found in the Madison Group in this area include corals, brachiopods, crinoids, and bryozoans. These assemblages are normal-marine benthonic faunas that probably lived in relatively shallow waters on extensive shelves or in epeiric seas (J. T. Dutro, Jr., W. J. Sando, and E. L., Yochelson, written commun., 1958). On the basis of the collections, the Kinderhook-Osage boundary is placed at or near the contact between the Woodhurst Limestone and Paine Shale Members of the Lodgepole (W. J. Sando and J. T. Dutro, Jr., written commun., 1963), and the Osage-Meramec boundary may be placed at the base or at the top of the solution breccia that lies at the base of the upper member of the Mission Canyon Limestone. Inasmuch as the base of the solution breccia is a more consistent stratigraphic horizon than the top, the Osage-Meramec boundary is placed, for convenience, at the base. The solution-breccia units, the grayish-red shale units, the presence in the insoluble residues of minerals that suggest incipient evaporite deposition, and a Meramec fauna seem to establish conclusively the correlation of the upper member of the Mission Canyon Limestone at Livingston with the Charles Formation in central and eastern Montana and unit MA of Sloss and Laird (1945) or with the Sun River Member of the Castle Reef Dolomite in northwestern Montana.

The following fossils, listed in ascending stratigraphic order, were collected from the measured section of the Madison Group near Livingston (see p. B9–B15). Identification of fossil assemblages from this section was made by J. T. Dutro, Jr., W. J. Sando, and E. L. Yochelson (written commun., 1958). Collections from the oldest rocks are listed first. Locality numbers are U.S. Geological Survey upper Paleozoic locality numbers and identify the collections in the measured section (fig. 3; p. B9–B15).

Fossils from the Paine Shale Member of the Lodgepole Limestone:
- Locality 17763–PC:
  - *Orbiculoidea*? sp.
  - *Schuchertella*? sp.
  - *Spirifer* sp. (*centronatus* type) cf. *S. madisonensis* (Girty)
  - *Composita* cf. *C. madisonensis* Girty
  - *Eumetria*? sp.
  - *Platyceras* sp.
- Locality 17764–PC:
  - crinoid arm and fragments, indet.
  - fenestrate bryozoan, indet.
  - *Cystodictya*? sp.
  - *Orthotetes*? sp.
  - *Camarotoechia* cf. *C. herrickana* Girty
  - *Rhynchopora*? sp.
  - "*Productus*" sp. (large)
  - "*Buxtonia*"? sp.
  - "*Productus*" cf. "*P.*" *galletinensis* Girty

Spirifer sp. (*centronatus* type)
Torynifer cf. *T. cooperensis* (Girty)
Punctospirifer cf. *P. solidirostris* (White)
Eumetria cf. *E. verneuiliana* (Hall)
Aviculopinna? sp.
Schizodus? sp.
Bellerophon sp.
Straparollus (*Euomphalus*) sp. cf. *S.* (*E.*) *subplanus* (Hall)
Anematina sp.
Loxonema? sp.

Locality 17765–PC:
crinoidal debris, indet.
platycrinid columnal, indet.
bryozoan fragments, indet.
Schuchertella? sp.
Eumetria sp.

Fossils from the Woodhurst Limestone Member of the Lodgepole Limestone:

Locality 17766–PC:
platycrinid columnals, indet.
Homalophyllites sp.
Vesiculophyllum sp.
Chonetes cf. *C. loganensis* Hall and Whitfield
Linoproductus cf. *L. ovatus* (Hall)
"*Productus*" cf. "*P.*" *gallatinensis* Girty
Spirifer sp. (*centronatus* type)
sp.
Composita? sp.
Platyceras sp.
Straparollus sp.

Locality 17767–PC:
crinoidal debris, indet.
Homalophyllites sp.
Vesiculophyllum sp.
fenestrate bryozoan, indet.
orthotetid brachiopod, indet.
Leptagonia sp.
Chonetes cf. *C. loganensis* Hall and Whitfield
sp. (large form)
productoid brachiopod, indet.
Spirifer sp. (*centronatus* type)
Composita cf. *C. madisonensis* (Girty)
Punctospirifer sp.
Straparollus (*Euomphalus*) sp.

Fossils from the lower member of the Mission Canyon Limestone:

Locality 17768–PC:
Chonetes cf. *C. loganensis* Hall and Whitfield
"*Productus*" cf. "*P.*" *gallatinensis* Girty
Spirifer sp. (*centronatus* type)
cf. *S. madisonensis* Girty
Torynifer? sp.

Locality 17769–PC:
crinoidal debris, indet.
Homalophyllites sp.
Vesiculophyllum? sp.
Spirifer sp.

Fossils from the upper member of the Mission Canyon Limestone:

Locality 17770–PC:
crinoidal debris, indet.
Rhipidomella sp.
Spirifer aff. *S. madisonensis* Girty
sp. (*rowleyi-grimesi* type)
sp. (*centronatus* type)

Locality 17771–PC:
crinoidal debris, indet.
Syringopora surcularia? Girty
Perditocardinia sp. cf. *P. dubia* (Hall)
Rhipidomella? sp.
Spirifer sp. (*rowleyi-grimesi* type)
sp. (*centronatus* type)

Locality 17772–PC:
Syringopora surcularia Girty
aff. *S. surcularia* Girty

SOLUTION BRECCIAS IN THE MISSION CANYON LIMESTONE

A conspicuous solution breccia in the upper member of the Mission Canyon Limestone (fig. 8) throughout southwestern Montana is of great geologic importance in correlation because it is the approximate boundary between rocks of Osage and Meramec age. Near the type locality of the Madison Group, the breccia was first described by Berry (1943, p. 16) as a limestone conglomerate, which he had traced for 10–15 miles. Berry also noted a faunal break and placed an unconformity at the base of the limestone conglomerate, coincident with the base of Peale's (1893) jaspery-limestone unit. This section of Madison rocks, as well as others in the Bridger and Gallatin Ranges, was later described by Leonard (1946), who proposed that the Mission Canyon Limestone be divided into two formations. His division was made at the base of Berry's conglomerate, which Leonard regarded as a basal conglomerate of his Fairy Lake Formation. He noted that the conglomerate contained rounded limestone boulders and angular cherts. Leonard (1946, p. 61) considered the possibility that the conglomerate unit was a solution breccia, but, because of the roundness of the limestone boulders, he preferred the term "conglomerate." Laudon (1948, p. 296) subsequently prepared a diagrammatic sketch illustrating a large unconformity at the base of the conglomerate described by Berry and Leonard. The magnitude of his unconformity was based on his interpretation of the fauna in the lower part of the Mission Canyon as late Kinderhook in age (Laudon, 1948, p. 295).

Laterally continuous collapse-breccia beds in the upper part of the Mission Canyon Limestone in the Elkhorn Mountains were described in Klepper (1950) and Klepper, Weeks, and Ruppel (1957, p. 20). They believed that the breccia formed by penecontemporaneous formation and collapse of solution caverns during a post-Mission Canyon–pre-Amsden erosional period. The stratigraphic persistence of the breccia indicated to them that a widespread withdrawal of seas, due to a slight but uniform uplift, would have exposed a terrain

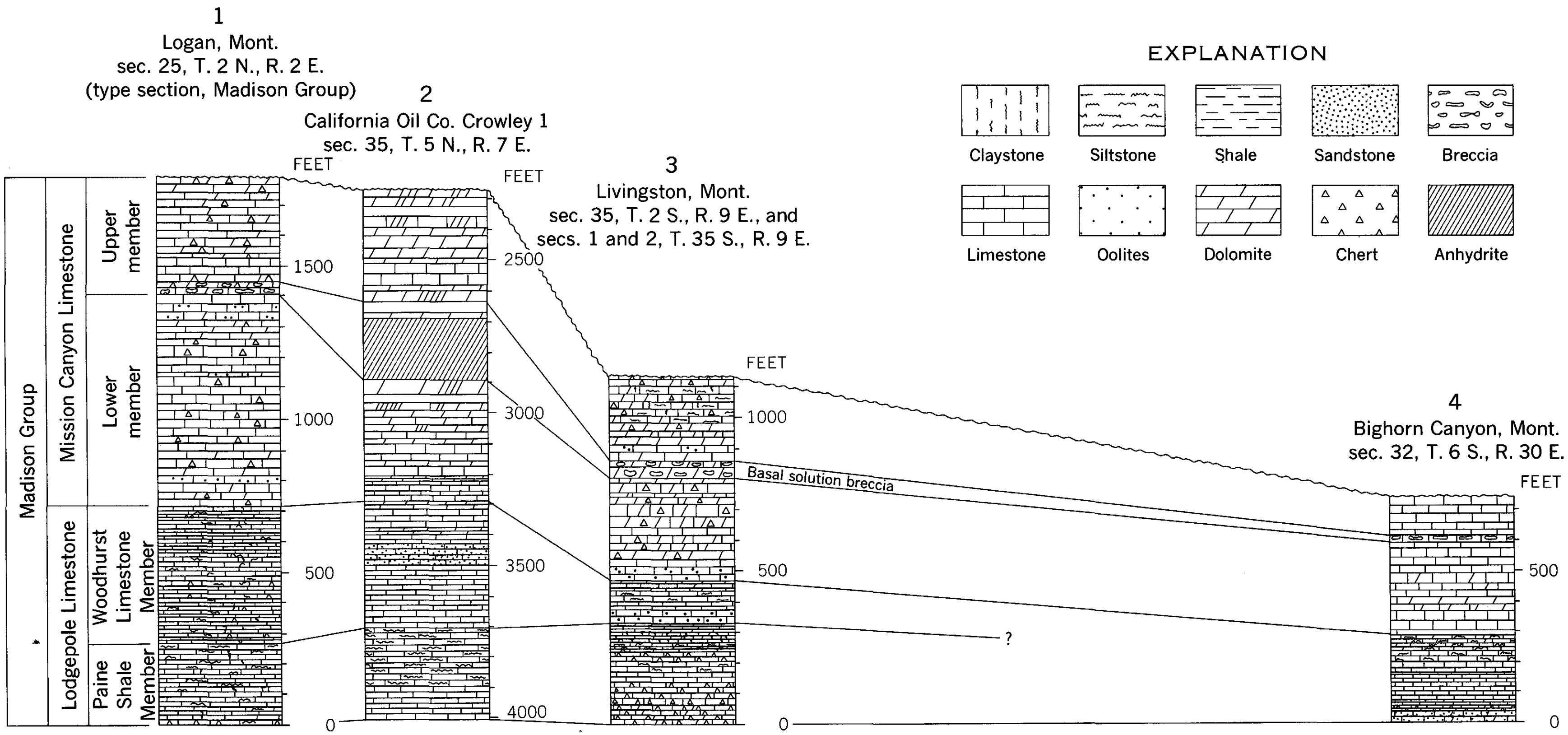

FIGURE 8.—Eastward thinning of the Madison Group and the relations of the basal solution breccia of the upper member of the Mission Canyon Limestone from Logan to Bighorn Canyon, Mont. Localities shown in figure 1.

of negligible relief. They assumed that under such conditions the ground-water level would have been constant and that leaching and ultimate collapse of the roof of the leached zone might have produced a rather continuous breccia zone at about the same stratigraphic horizon.

Severson (1952, p. 33) observed that surface sections of the upper part of the Madison Group in central Montana were thinner than nearby subsurface sections. This difference seemed to indicate that the evaporites in the subsurface sections of the Charles Formation were originally deposited over the mountainous areas but had subsequently been removed by solution. He (1952, p. 37) indicated that the brecciated zones correlated with the anhydrite zones of the subsurface sections and that the subsurface Charles Formation was a correlative of the Mission Canyon Limestone. Sloss (1952, p. 67) briefly summarized the lithology of the Charles Formation and assumed that breccia zones at some localities marked the positions of evaporite beds leached from surface exposures. Laudon and Severson (1953, p. 509–512) remeasured the Fairy Lake section in the Bridger Range and indicated the stratigraphic position of the solution-breccia beds.

In his discussion of the Charles Formation of central Montana, Nordquist (1953, p. 80) pointed out that the basal unit of the formation is generally marked by a massive anhydrite bed that locally is as much as 100 feet thick. In the mountainous areas of central Montana where the upper part of the Madison is exposed, Nordquist observed that the sequence is characterized by several brecciated zones, which he interpreted as having formed by the leaching of evaporite beds.

Denson and Morrisey (1954, p. 46) divided the Mission Canyon Limestone in the Bighorn Basin of Montana and Wyoming and the Wind River Basin of Wyoming into two recognizable members. The base of their upper member is generally marked by a continuous breccia zone, which they (1954, p. 47) could recognize in both the surface and subsurface. They (1954, p. 48) referred to this breccia zone as an intraformational conglomerate.

Andrichuk (1955, p. 2179) correlated the anhydrite beds in the California Oil Co. Crowley 1 well near Ringling, Mont., with solution-breccia beds in the Bridger Range, described by Laudon and Severson (1953, p. 512). In the Fairy Lake section Severson (1952, p. 37) found minor beds of breccia and intraformational conglomerate below the basal breccia of the upper member of the Mission Canyon Limestone. Andrichuk (1955, p. 2173, 2179) identified one of these smaller breccia beds in the lower member of the Mission Canyon as tentatively corresponding to the third evaporite zone in the Mission Canyon of central Montana.

Strickland (1956, p. 54–55) reviewed the work of Mansfield (1927), Love (1939), Berry (1943), Laudon (1948), and Denson and Morrisey (1954) and concluded that the upper member of the Mission Canyon Limestone seems to lie disconformably on the rocks beneath. Later, Norton (1956, p. 54) reviewed the work of Leonard (1946), Laudon and Severson (1953), Denson and Morrisey (1954), and Richards (1955) and concluded that the evidence presented did not substantiate an unconformity but could be explained as collapse brecciation.

Middleton (1961) examined Mission Canyon Limestone sections in the Limestone Hills, on the east flank of the Elkhorn Mountains, and in the Smith River area of the Belt Mountains; reexamined the Fairy Lake section of Leonard (1946), Severson (1952), and Laudon and Severson (1953); and presented a summary description of the solution-breccia beds. He (1961, p. 193) also concluded that the breccia was a solution feature—not formed penecontemporaneously or by metasomatic replacement or by recrystallization.

My recent work supports my earlier conclusions (Roberts, 1961, p. B294) that the laterally continuous breccia beds in the Mission Canyon Limestone at Livingston are solution breccias, and supports my earlier subdivisions (p. B295) of the Mission Canyon Limestone. I (1961, p. B295) subdivided the Mission Canyon into two members, separated at the continuous breccia at the base of the upper member (fig. 9). Several beds of solution breccia are also present in the lower member of the Mission Canyon Limestone, and these should be considered in making regional correlations.

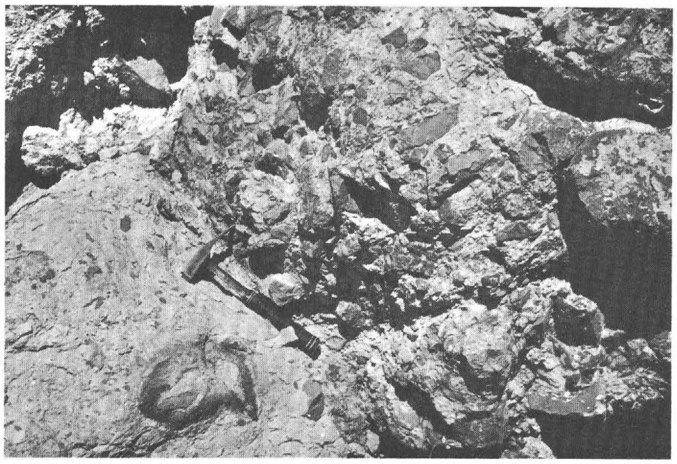

FIGURE 9.—Solution breccia at the base of the upper member of the Mission Canyon Limestone (unit 45) in the SE¼ sec. 35, T. 2 S., R. 9 E.

The solution breccia at the base of the upper member of the Mission Canyon Limestone forms prominent cliffs in the northwestern part of the Yellowstone National Park near Bannock Peak. The breccia, which is continuous throughout the area, is 60 feet thick and 310 feet below the top of the upper member—markedly similar to that in the Livingston section. Similar stratigraphically continuous breccia beds in the Mission Canyon Limestone were observed by Blackstone (1940, p. 594) and by Richards (1955, p. 22) in the Pryor Mountains, Mont., by McMannis (1955, p. 1400) in the Bridger Range, Mont., by Knechtel (1959, p. 735) in the Little Rocky Mountains, and by Robinson (1963, p. 42) in Milligan Canyon near Three Forks, Mont.

KARST DEPOSITS IN THE MISSION CANYON LIMESTONE

Karst deposits are present in the upper part of the Madison Group in southern and western Montana. In south-central Montana, Thom (1923, p. 42) and Thom, Hall, Wegemann, and Moulton (1935, p. 35) discussed the collapsed caverns, or sinkholes, which formed along the joints and bedding planes in the upper part of the Madison prior to the deposition of the overlying Amsden. Karst features at this locality were later illustrated by Richards (1955, pl. 5). Along the north flank of the Beartooth Range, Knappen and Moulton (1930, p. 11) reported a deeply weathered surface and a red residual soil on the top of the Madison. Henbest (1958) briefly described the regional significance of the karst terrane in Upper Mississippian and Lower Pennsylvanian rocks in the Rocky Mountain region.

Sloss and Hamblin (1942, p. 309) stated that in southern Montana the basal sandstones of Chester age (Kibbey Formation) contain fragments of Madison Limestone, and that sandstone of the Amsden Formation fills caverns and solution channels in the Madison. They (1942, p. 318) described the deposits as "a coarse solution breccia formed by the collapse of cavern roofs. These breccias are commonly colored red or maroon by infiltration from the overlying Kibbey or Amsden Formations." Sloss and Hamblin (1942, p. 318) observed that "near Livingston, red Amsden sandstone forms clastic sills and dikes in solution channels cut 200 feet into the Mission Canyon." Laudon (1948, p. 295) referred to these deposits as deep sinkhole-like channels carved into and filled with reworked materials of Mission Canyon. Laudon, Sloss, and Hamblin did not differentiate the red-shale and solution-breccia units in the upper member of the Mission Canyon or the karst deposits of this report.

Scott (1935, p. 1022), Walton (1946, p. 1297), Severson (1952, p. 19), and Miller (1959, p. 13) referred briefly to the erosional unconformity on the upper surface of the Madison in central and southern Montana. Walton (1946, p. 1297) also mentioned pre-Kibbey sinkholes near Riceville, Mont., as evidence of widespread subaerial erosion prior to Kibbey time. Robinson (1963, p. 43) reported a karst topography on the Mission Canyon Limestone near Toston, Mont., where local relief is as much as 100 feet along 300 feet of contact with the basal part of the Big Snowy Group.

Near Livingston the karst deposits (fig. 10) are lithologically very similar to the solution-breccia beds. Both are unstratified fragmental deposits that consist primarily of carbonate rocks and lesser amounts of chert in a matrix that weathers reddish or yellowish gray. The sorting is poor, and the range in size of the fragments is wide. The matrix is composed of in-

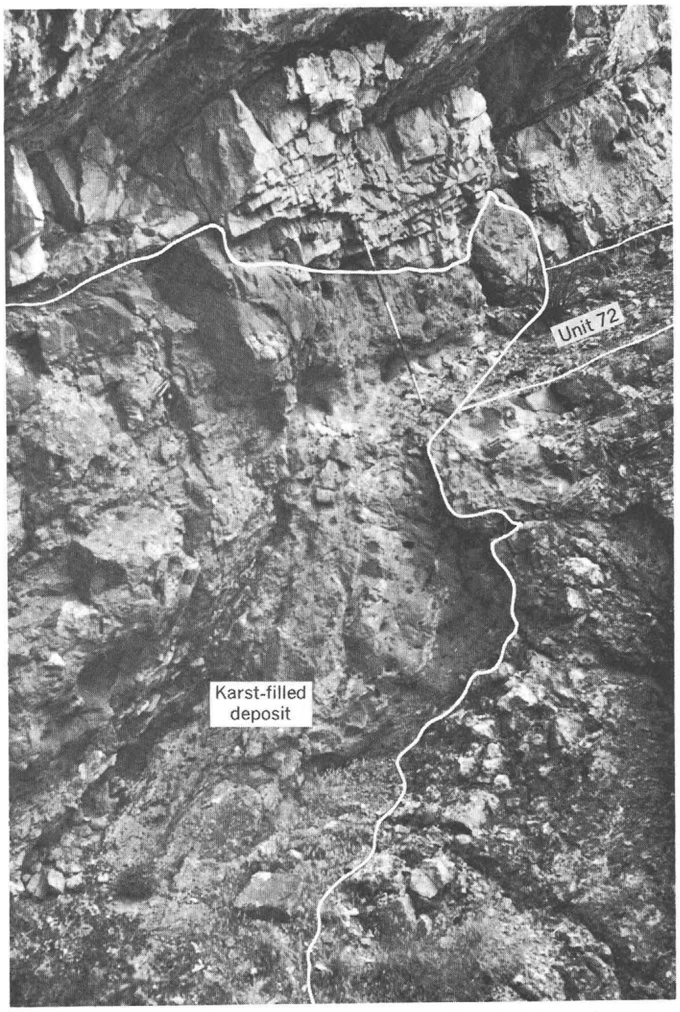

FIGURE 10.—Karst-filled deposit in the upper member of the Mission Canyon Limestone in the SE¼ sec. 35, T. 2 S., R. 9 E. Note the crosscutting relation of the karst-filled deposit to the siltstone (unit 72). Base of stadia rod (painted in 1-ft intervals) is 47 feet below top of the upper member.

durated clayey siltstone containing limestone fragments, calcite, and smaller amounts of quartz. The fragments in both the karst deposits and the solution-breccia beds are mostly angular to subangular, although some carbonate fragments are rounded; these rounded fragments may have been shaped by the action of solutions. The chert in both types of deposits is sharply angular.

In the Livingston area there is a significant difference between clay mineralogy of the karst deposits and that of the solution-breccia and red siltstone beds. Kaolinite is the chief clay mineral in the insoluble residues from the karst deposits, and illite is the chief clay mineral in the insoluble residues from the bedded red siltstones and from the basal solution breccia of the upper member of the Mission Canyon Limestone. Illite was also the chief clay mineral in samples collected from the lower, middle, and upper parts of the overlying transgressive Amsden Formation. Thus, though the Amsden and karst deposits are lithologically similar, the predominance of illite in the Amsden and the predominance of kaolinite in the karst deposits indicate entirely different sources and origins. Kaolinite in the karst deposits may have formed during prolonged weathering of an ancient soil that was developed on the uplifted surface of the Mission Canyon. The illite in the siltstone and solution-breccia beds was deposited, but was not necessarily formed, during marine deposition and was not changed during uplift or brecciation.

Severson (1952, p. 35) observed that in a solution-breccia unit there is a definite progression upward from small heterogeneous unsorted material near the base to breccia that is merely a slightly fractured and displaced roof rock near the top. The karst deposits generally have more matrix and fewer chaotically distributed fragments than do the solution-breccia beds (figs. 9, 10). Also, the karst deposits fill cavities or joints that generally widen upward.

The upper and lower surfaces of the karst cavities and the upper surface of the solution-breccia beds are similar in that they are poorly defined and not stratigraphically controlled. The lower surface of the solution-breccia beds, however, is generally a sharp, well-defined laterally continuous boundary. The karst deposits are discontinuous, whereas the solution-breccia beds can be traced continuously for many miles in surface exposures and appear to be continuous with evaporite zones in the subsurface.

Formation of the karst features occurred during post-Mission Canyon (post-Meramec) and pre-Amsden (pre-Early Pennsylvanian) time. The solution-breccia beds probably formed much later, for they are restricted to areas of Late Cretaceous and early Tertiary uplift. In nearby areas that were not uplifted, the evaporite zones in the Madison Group are generally unaltered. For example, about 25 miles northeast of the Fairy Lake section in the Bridger Range, three evaporite zones were penetrated in the California Oil Co. Crowley 1 well (fig. 8, col. 2). Similar conditions exist in the subsurface less than 10 miles from the Big Snowy Mountains. In some localities there may be a surface expression in the younger rocks that would indicate the presence of underlying solution-breccia beds. Such an example of large sinks or depressions due to collapse over major solution zones was observed near Monarch and Riceville, in the Little Belt Mountains, and was described by Severson (1952, p. 41). He noted that rocks as young as Colorado Shale of Cretaceous age were affected in this area and, accordingly, that solution activity at this locality occurred after deposition of the Colorado Shale. Severson's (1952, p. 43) conclusion that the solution-breccia beds were formed during or after Late Cretaceous and early Tertiary uplift therefore seems most reasonable.

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