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By BETTY SKIPP *and* L. W. McGREW

CONTRIBUTIONS TO STRATIGRAPHY

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THE MAUDLOW AND SEDAN FORMATIONS OF THE UPPER CRETACEOUS LIVINGSTON GROUP ON THE WEST EDGE OF THE CRAZY MOUNTAINS BASIN, MONTANA

By Betty Skipp and L. W. McGrew

ABSTRACT

The Sedan Formation and the Maudlow Formation are names adopted in this report for two formations in the lower part of the Livingston Group. The Sedan crops out for a distance of about 64 km (40 mi) from south to north along the western edge of the Crazy Mountains basin in Gallatin, Meagher, and Park Counties, Mont. The Maudlow is restricted to the Maudlow area in Gallatin County, just west of the Sedan outcrops.

The Sedan Formation (a new name) comprises 915–1,370 m (3,000–4,500 ft) (1,076 m (3,528 ft) in the type section) of epiclastic volcanic sandstone, mudstone, and conglomerate, interbedded with volumetrically less important mudflow conglomerate, welded tuff, devitrified, silicified vitric tuff, bentonite, and lignitic coal, which lie above the Eagle Sandstone and below the Billman Creek Formation. The Sedan Formation correlates with the Cokedale and Miner Creek Formations in the type locality of the Livingston Group near Livingston, Mont., and is divided into four informally named members and two formally named members. These members were used in the mapping, during 1964-69, of five 7½-minute quadrangles and one 15-minute quadrangle. In ascending order, the members are as follows: lower sandstone member, welded tuff member, middle sandstone member, mudstone member, Bearpaw Shale Member, and Lennep Sandstone Member. The Bearpaw and Lennep remain of formation rank outside the report area. In addition, the Parkman Sandstone equivalent is recognized in the type section of the Sedan but was mapped with the welded tuff and middle sandstone members. A type section for the Sedan Formation and reference sections for the Bearpaw and Lennep Members are established along Cottonwood Creek in secs. 6, 7, 17, and 18, T. 4 N., R. 8 E., Park County.

The age of the formation is Late Cretaceous, Campanian, and latest Santonian (approximately 83–70 m.y.).

The Maudlow Conglomerate Lentil of the Livingston Formation of McMannis (1955, after Klemme, 1949) is redefined and raised in stratigraphic rank to the Maudlow Formation. This name is proposed for the thick, 1,525–1,675+ m (5,000-5,500+ ft), sequence of volcaniclastic rocks of intermediate composition, including flows, breccias, welded tuffs, vitric, vitric-crystal and vitric-lithic tuffs, interbedded with epiclastic volcanic sandstone, conglomerate, mudstone, and minor lignitic coal, which crop out exclusively within an area of about 65 km² (25 mi²) near Maudlow, Mont., in northeastern Gallatin County. The formation has been subdivided into eight informal members, A through H, in ascending order. Lithologic correlatives of members B, D, F, and H have been recognized in places within the Sedan Formation and permit correlation of the volcaniclastic members of the Maudlow Formation with the largely epiclastic volcanic facies of the Sedan Formation. The Maudlow Conglomerate Lentil is approximately equivalent to members B and C of the Maudlow of this report.

The Maudlow Formation unconformably overlies both the Telegraph Creek Formation and the Virgelle Sandstone Member of the Eagle Sandstone; it is overlain unconformably by Tertiary rocks of the Dunbar Creek Formation and by Quaternary gravels. Pollen and spore assemblages, potassium-argon ages, and lithologic correlations suggest that the Maudlow Formation is also entirely Late Cretaceous in age—Campanian, and probably latest Santonian in part.

The Elkhorn Mountains Volcanics and the Sedan and Maudlow Formations are eroded parts of an extensive volcanic pile which may have covered as much as 26,000 km^2 (10,000 mi^2) of southwestern Montana. In a general way, the Elkhorn Mountains Volcanics are the near vent facies of the pile, the Maudlow Formation is a remnant of the coarse reworked alluvial facies, and the Sedan and related formations are the fine-grained distal alluvial facies.

Potassium-argon ages on hornblende phenocrysts from rhyodacite flows and breccias of members B and F bracket the time of active rhyodacitic volcanism in the Maudlow area as being from about 75 to 79 m.y. ago, a time span which includes the estimated cooling time of the Butte Quartz Monzonite, a major part of the Boulder batholith, which is believed to be comagmatic with the volcanics.

Member D of the Maudlow Formation and the welded tuff member of the Sedan Formation are compositionally like welded tuffs in the lower unit of the Elkhorn Mountains volcanics and may indicate that those tuffs were originally very extensive.

INTRODUCTION

Weed (1893) named the Livingston Formation for a thick sequence of epiclastic volcanic sedimentary rocks in the vicinity of Livingston, Mont. From then until the last decade, the term appeared in the geologic literature attached to a wide variety of concepts of stratigraphy and age. Roberts (1963, p. B86–B92) summarized the most significant of these concepts in an important paper in which he limited the term "Livingston" to those rocks above the Eagle Sandstone and below the Fort Union Formation, raised the Livingston to group rank, and then subdivided the group into four formations, which are, in ascending order, Cokedale, Miner Creek, Billman Creek, and Hoppers. The type sections for these formations are all near Livingston, Mont., some 40 km (25 mi) east of Bozeman. Roberts (1964a–h) used these formations in his mapping of eight quadrangles between Bozeman and Livingston.

Mapping along the east side of the Bridger Range north to Ringling, Mont. (fig. 1), which we completed during the period 1964–69, has shown that the upper two of Roberts' formations, the Billman Creek and Hoppers, can be mapped throughout the area. The Sulphur Flats Sandstone Member at the base of the Miner Creek Formation, however, cannot be recognized a few kilometers north of Roberts' mapping, and it is not possible to differentiate the

Cokedale and Miner Creek Formations in the area east of the Bridger Range.

We propose here to use the name Sedan Formation for this general stratigraphic interval; its type section is along Cottonwood Creek in the northern Wallrock quadrangle and southern Sixteen NE quadrangle, Park County. The Sedan Formation is subdivided into four informal and two formal members (figs. 2, 3), which have been used singly and in combination as map units in parts of the area.

We also propose to raise the volcaniclastic rocks of intermediate composition in the Maudlow area (Skipp and Peterson, 1965) to formation rank, the Maudlow Formation of the Livingston Group. The Maudlow Formation thus defined includes the Maudlow Conglomerate Lentil of the Livingston Formation of McMannis (1955, p. 1410, after Klemme, 1949).

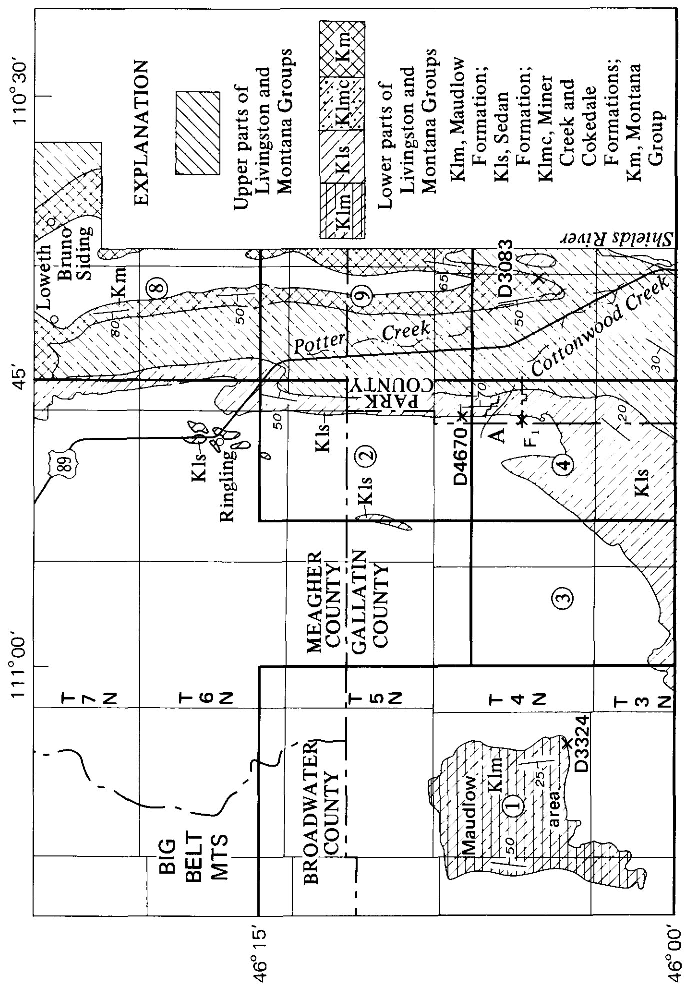
Several authors (Robinson and others, 1968; Gwinn and Mutch, 1965) have assigned the Upper Cretaceous volcaniclastic rocks of the Maudlow area to the Elkhorn Mountains Volcanics—emphasizing the presence of primary volcanic rocks. Inasmuch as the sequence is 50 percent or more epiclastic volcanic rocks and is separated geographically from the main body of the Livingston Group by only 8 km (5 mi), the Livingston Group assignment is preserved here, though the genetic relationship to the Elkhorn Mountains Volcanics is emphasized.

Stratigraphic correlations between the two new formations and the Cokedale and Miner Creek Formations in the type area of the Livingston Group are given. In addition, correlations are made with sections at Loweth and Bruno Siding that are assigned to the Montana Group on the northern edge of the Crazy Mountains basin.

LIVINGSTON GROUP

SEDAN FORMATION

The Sedan Formation is named for the hamlet of Sedan on the east flank of the Bridger Range and is the basal formation of the Livingston Group in this area. Sedan lies 37 km (23 mi) north-northeast of Bozeman, Mont., and about 21 km (13 mi) south-southwest of the Cottonwood Creek area, which contains the type section of the Sedan Formation (figs. 1–3). The type section is located in secs. 6, 7, 17, and 18, T. 4 N., R. 8 E., Park County, Mont., in the southeastern corner of the Sixteen NE quadrangle and in the northeastern corner of the Wallrock quadrangle. The new formation has been mapped for a distance of about 65 km (40 mi) along the western edge of the Crazy Mountains basin in the Sedan (Skipp and McMannis, 1971), Hatfield Mountain (Skipp and Hepp, 1968), Wallrock (Skipp, 1977), Sixteen, Sixteen NE, and Ringling quadrangles (McGrew, 1977a–c). On the southern edge of the


EXPLANATION
Upper parts of Livingston and Montana Groups
Klm
Kls
Klmc
Km
Lower parts of Livingston and Montana Groups
Klm, Maudlow Formation; Kls, Sedan Formation; Klmc, Miner Creek and Cokedale Formations; Km, Montana Group
110°30′
45′
111°00′
46°15′
46°00′
Loweth
Bruno Siding
Shields River
Potter Creek
Cottonwood Creek
PARK COUNTY
MEAGHER COUNTY
GALLATIN COUNTY
BROADWATER COUNTY
BIG BELT MTS
Ringling
89
Maudlow area
D3083
D4670
D3324
A
F1
T 7 N
T 6 N
T 5 N
T 4 N
T 3 N

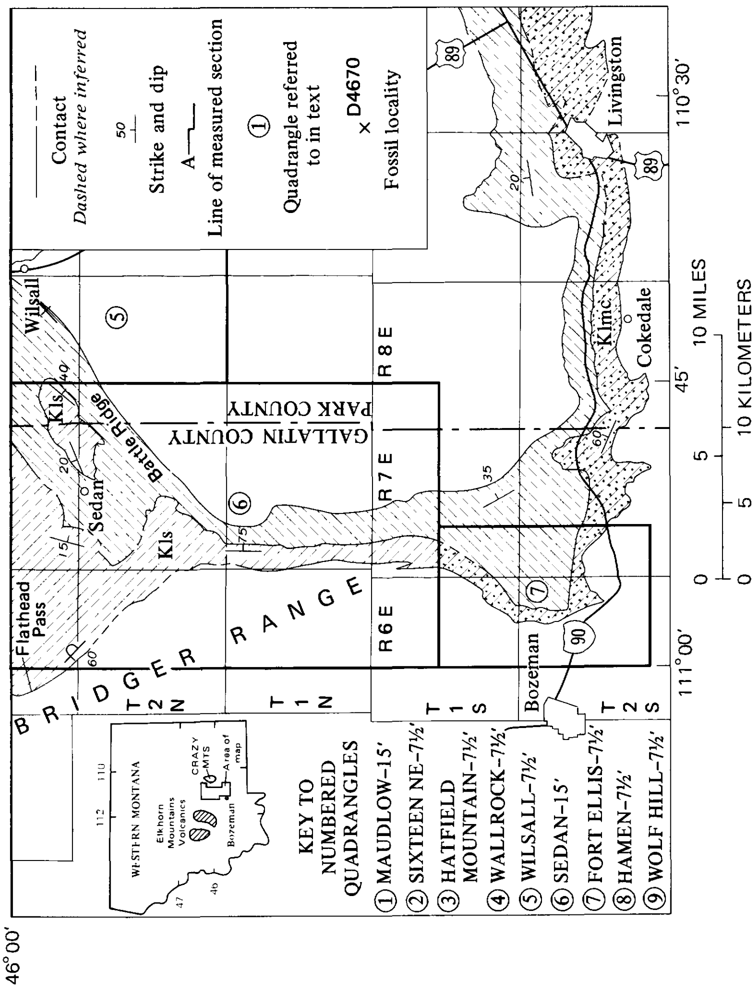


FIGURE 1.—Simplified geologic map and index map of the western edge of the Crazy Mountains basin, Montana, showing distribution of formations in lower part of Livingston Group. Only Livingston rocks are shown; older and younger rocks are not differentiated.

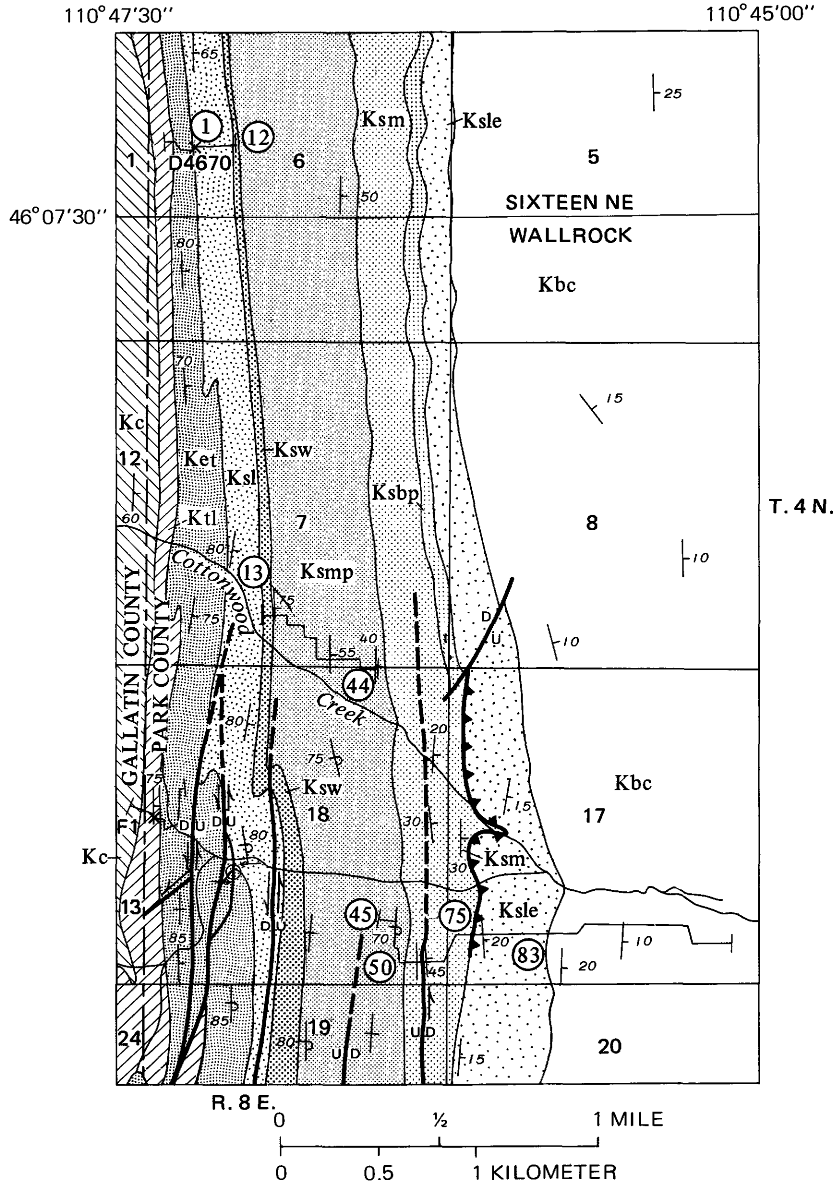


FIGURE 2.—Simplified geologic map of northeast corner of Wallrock quadrangle and southeast corner of Sixteen NE quadrangle showing location of type section of Sedan Formation, distribution of members within the formation, and fossil localities. Geology by Betty Skipp and L. W. McGrew, 1965–66. Base from U. S. Geological Survey, 1951, 1:24,000.

Sedan quadrangle, the Sedan Formation becomes the combined Miner Creek and Cokedale Formations of Roberts (1964f, 1965, 1972). To the northeast the formation grades into the marine and nonmarine formations of the Montana Group.

The Montana Group has been used in central Montana by Gill, Cobban and Schultz (1972, p. 92), by Gill and Cobban (1973), and by Gill and Vaughan (in McMannis and others, 1968). In the northern part of the Crazy Mountains basin (fig. 1), the Montana Group includes nonmarine rocks of the Judith River Formation. In the Ringling-Bruno area, Sims (1967) divided the nonmarine part of the sequence between the Bearpaw Shale and the Virgelle Sandstone Member of the Eagle Sandstone into three parts (col. 6,

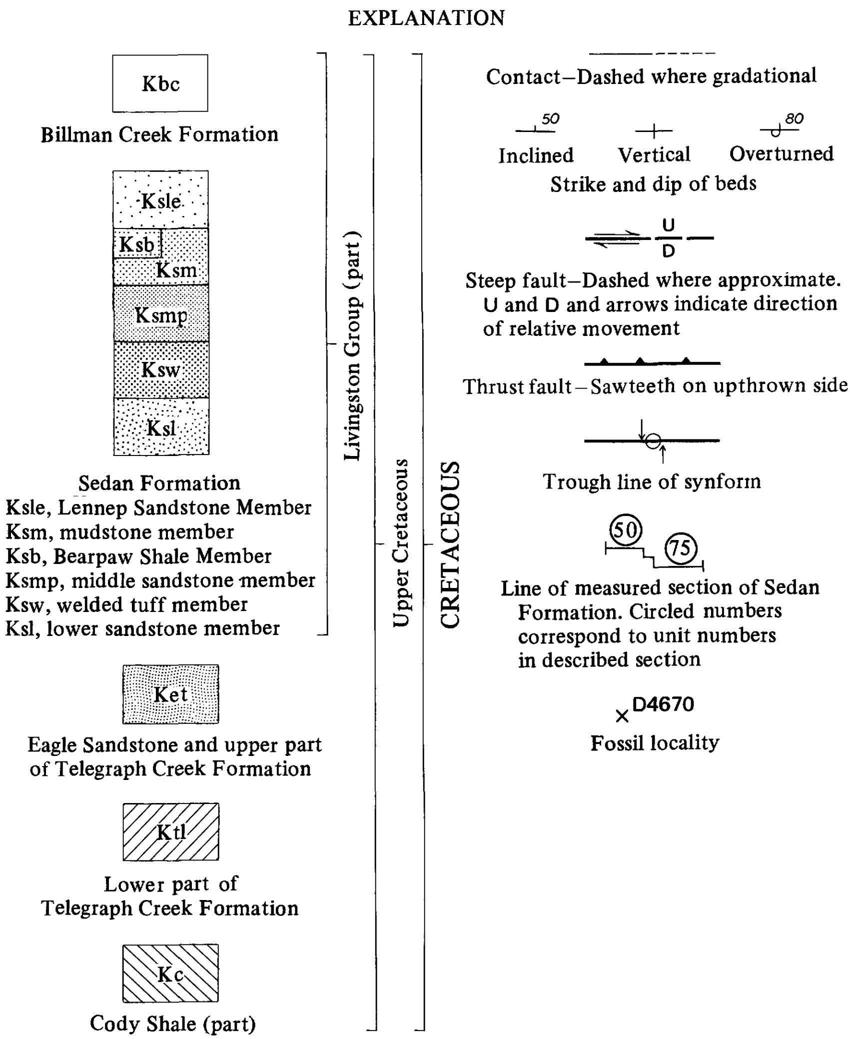
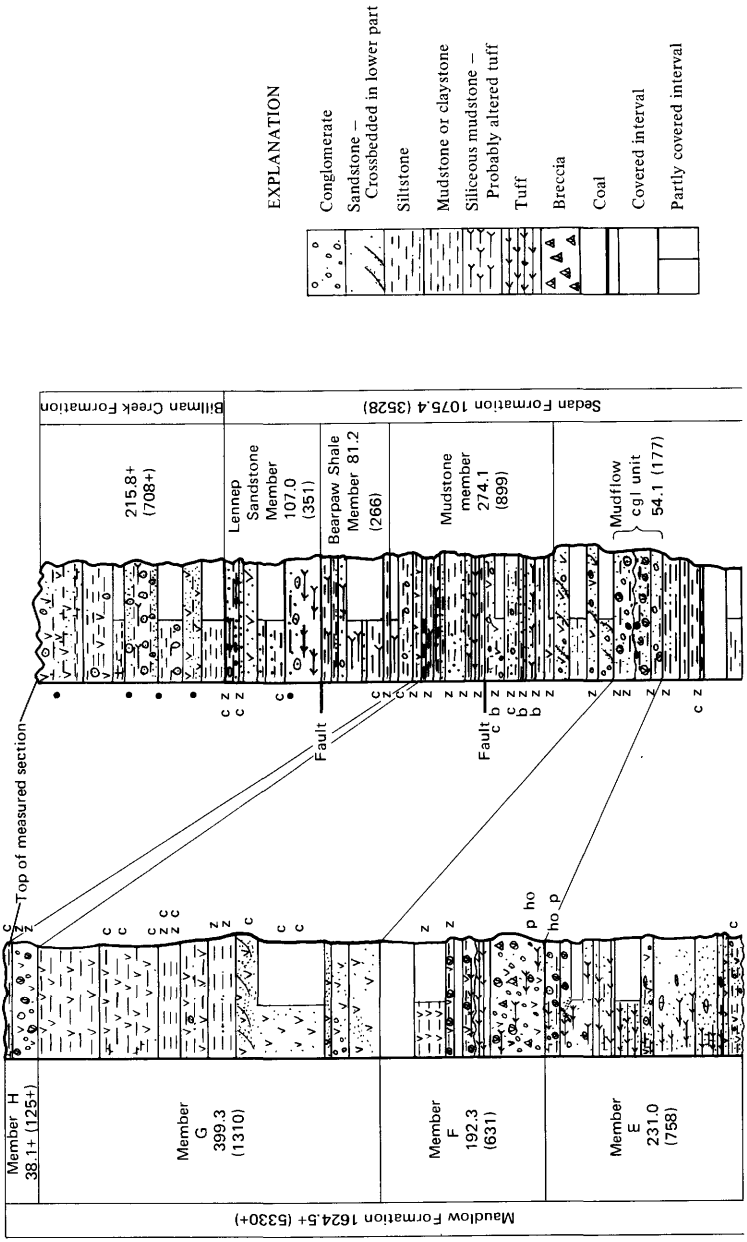


FIGURE 2.—Continued.

fig. 4). He assigned the entire sequence to the Livingston Group. His basal formation of South Fork has been included in the Eagle Sandstone at Bruno Siding by Gill (in Gill and others, 1972), a correlation suggested earlier by Sims (1967, p. 27, fig. 8a), and has been correlated with the upper part of the Eagle Sandstone, the


EXPLANATION
Conglomerate
Sandstone – Crossbedded in lower part
Siltstone
Mudstone or claystone
Siliceous mudstone – Probably altered tuff
Tuff
Breccia
Coal
Covered interval
Partly covered interval
Billman Creek Formation
Sedan Formation 1075.4 (3528)
215.8+ (708+)
Lennep Sandstone Member 107.0 (351)
Bearpaw Shale Member 81.2 (266)
Mudstone member 274.1 (899)
Mudflow cgl unit 54.1 (177)
Top of measured section
Fault
Fault
Member H 38.1+ (125+)
Member G 399.3 (1310)
Member F 192.3 (631)
Member E 231.0 (758)
Maudlow Formation 1624.5+ (5330+)

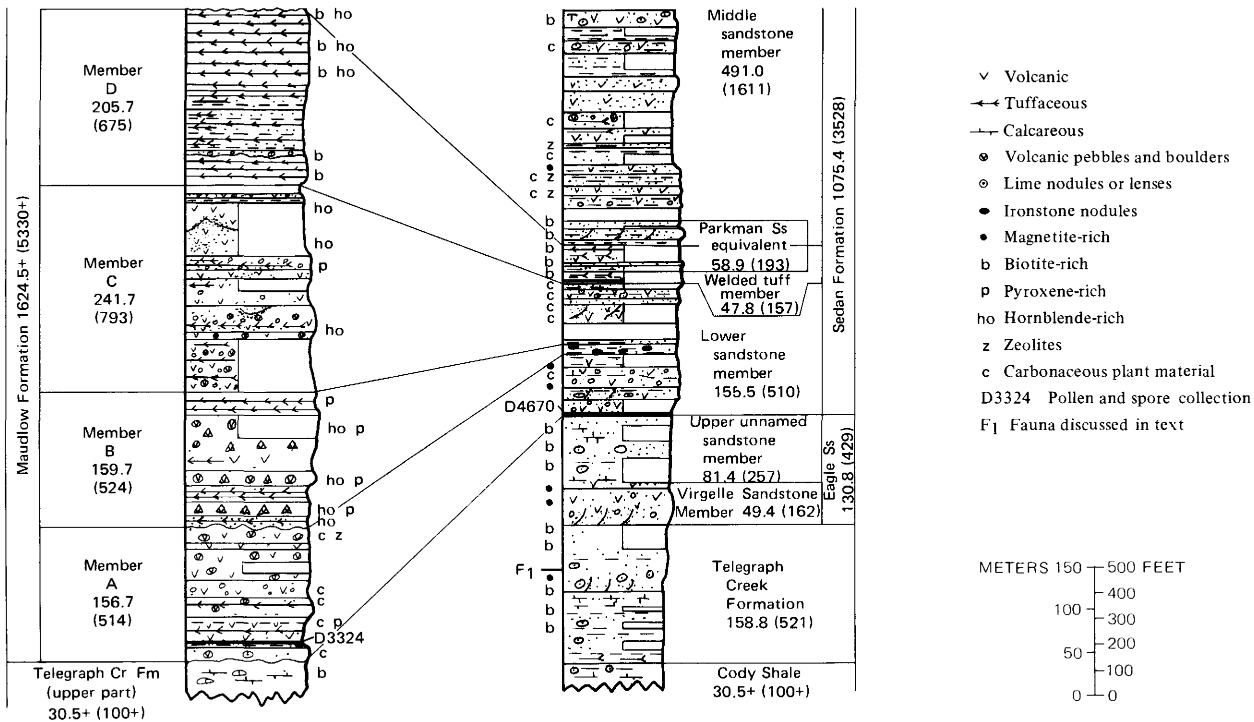


FIGURE 3.—Composite columnar sections showing projected lines of correlation measured in meters (feet) of the Upper Cretaceous Sedan and Maudlow Formations of the Livingston Group and associated rocks in the west-central Crazy Mountains basin. Cody Shale (part) through Billman Creek Formation (lower part) measured near Cottonwood Creek in sec. 13, T. 4 N., R. 7 E., and secs, 6, 7, 17, and 18, T. 4 N., R. 8 E., Park and Gallatin Counties, Montana (see fig. 2). Maudlow Formation measured in T. 4 N., R. 4 E., and R. 5 E. (see fig. 8).

Claggett Shale, and the Parkman Sandstone in another interpretation of the same area (Gill and Cobban, 1973). Sims' formation of Hamen and formation of Bruno are local map units in the Hamen and Wolf Hill quadrangles (Sims, 1967), and a lithologic correlation with the members of the Sedan Formation is suggested (fig. 4).

The Sedan Formation is 915–1,372 m (3,000–4,500 ft) thick, 1,076 m (3,528 ft) in the type section, and consists primarily of nonmarine epiclastic volcanic sandstone, mudstone, and conglomerate interbedded with volumetrically less important mudflow conglomerate, welded tuff, devitrified, silicified, vitric tuff, bentonite, and lignitic coal. McMannis (1955, p. 1407–1408) first recognized these beds as a unit and described in some detail "a lower 4,500-foot unit of tuffaceous or andesitic sandstones" of the Livingston Formation east of the Bridger Range. The volcanic detritus that composes the epiclastic facies is intermediate in composition and represents the mechanical breakdown of rhyodacitic, dacitic, and andesitic volcanic rocks of the same general composition as the primary intermediate volcanic rocks of the Maudlow Formation to the west and of the Elkhorn Mountains Volcanics farther west (Roberts, 1963, p. B87; 1972, p. C39–C47; Skipp and Peterson, 1965) (fig. 1).

Throughout the area of outcrop, the Sedan Formation is underlain by the upper unnamed member of the Eagle Sandstone, which consists of thin-bedded, slope-forming, yellowish-gray, fine-grained, calcareous biotitic, quartzose, nonmarine to brackish-water sandstone. The contact between the two formations is sharp and disconformable along most of the western edge of outcrop but is gradational in the southern part of the Sedan quadrangle.

The Sedan is overlain conformably by the Billman Creek Formation of the Livingston Group, which is characterized by grayish-red and olive-gray volcanic-rich mudstone interbedded with lesser amounts of volcanic sandstone and conglomerate (Skipp and McGrew, 1972).

Within the mapped area (fig. 1), the Sedan Formation has been subdivided into four informally named members and two formally named members which are, in ascending order, lower sandstone, welded tuff, middle sandstone, mudstone, Bearpaw Shale and Lennep Sandstone (figs. 2, 3). The Bearpaw and Lennep are reduced from formation to member rank in the report area; they remain of formation rank east of the report area. In addition, the Parkman Sandstone equivalent is recognized within the type section of the Sedan but has not been mapped separately.

The Sedan Formation is essentially the same unit as "The Leaf Beds" of Weed (1893, p. 22), who said of this lower part of the Livingston sequence, "it consists of a series of sandstones, conglomerates and shales composed largely of angular or but slightly water-worn debris of volcanic eruptions and ash showers."

Recent work supports these early observations and suggests that the Sedan Formation is analogous in mode of origin to the fine alluvial volcanic facies described by Parsons (1965, 1969) in the Absaroka volcanic field, which consists of well-bedded reworked volcanic sedimentary rocks, mainly volcanic conglomerate, sandstone, siltstone, and air-fall tuff, having primary dips of less than 5° and of the same age as the vent facies rocks from which they were derived (Smedes and Prostka, 1972, p. C4–C7).

LOWER SANDSTONE MEMBER

The lower sandstone member ranges in thickness from 152 to 305 m (500 to 1,000 ft) throughout the area. At Cottonwood Creek it is 156 m (510 ft) thick and forms low ridges and moderately steep slopes above the Eagle Sandstone. Epiclastic volcanic sandstone, siltstone, mudstone, porcelanite, and silicified devitrified crystal lithic tuff interbedded with minor granule and pebble conglomerate and lignitic coal make up the member. The sandstone is dark olive gray, greenish gray, and yellowish gray; it weathers brown and is fine grained to conglomeratic, medium bedded, locally crossbedded, and calcareous. Calcareous concretions are present throughout. Ironstone nodules, lenses, and beds of magnetite-rich sandstone are common in the lower part of the measured section (fig. 3). Volcanic detritus ranges in composition from andesite to rhyodacite and, east of Flathead Pass, consists in part of dacite of member B of the intermediate volcanic and volcaniclastic rocks of the Maudlow quadrangle (Skipp and Peterson, 1965). Carbonaceous films on bedding planes and abundant leaf, needle, twig, and cone imprints are characteristic of this member. A lignitic coal bed 0.6 m (2 ft) thick is present at the base of the type section and at other localities. The contact with the light-colored biotitic sandstone of the underlying Eagle Sandstone is abrupt and locally disconformable.

Palynomorphs identified by R. H. Tschudy (written commun., 1971) from the lignitic coal at the base of the type section (figs. 1, 2, 3—loc. D4670) are the following:

Proteacidites 2 sp.
Araucariacites
Gleicheniidites
Plicapollis
Tricolpites reticulatus
Eucommiidites
Complexiopollis (*Latipollis* type)
Anemia 1
Appendicisporites
Polypodiumsporites
C3-rt (cf. C3-rt14)
C3-sm (deep colpi)
C3-r (colpi enlarged)
P3-sm

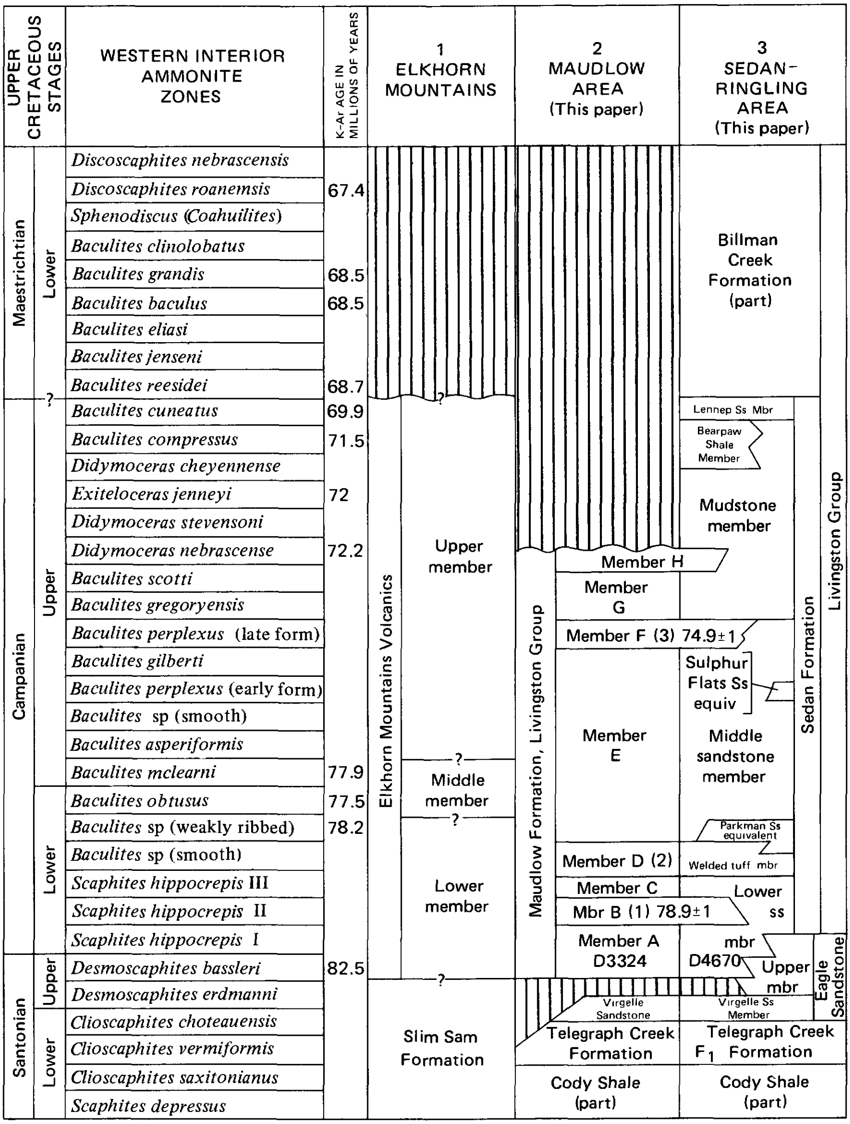


FIGURE 4.—Correlation chart showing relationships of rocks of the Sedan and Maudlow Formations of the Livingston Group along the western edge of the Crazy Mountains basin with the type locality of the Livingston Group, a partial section of the Montana Group at the north end of the Crazy Mountains, and the Elkhorn Mountains Volcanics in the Elkhorn Mountains. Boundaries of stages of the Late Cretaceous, western interior ammonite zones, and potassium-argon ages are adapted from Obradovich and Cobban (1975) and Gill, Cobban, and Schultz (1972). Column 1 is adapted from Smedes (1966), Robinson, Klepper, and Obradovich (1968), Roberts (1972) and Gill and Cobban (1973). Column 4 is adapted from Roberts (1965, 1972). Column 5 is adapted from Gill and Vaughan (in McMannis and others, 1968), Gill, Cobban, and Schultz (1972), and Gill and Cobban (1973). Column 6 is adapted from Sims (1967). (1), (2), and (3) are potassium-argon ages discussed in text; D3324 and D4670 are pollen and spore collections; F_1 is a faunal collection.

Tschudy stated that the assemblage is "from an interval above the *Scaphites despressus* zone and from below the *Scaphites hippocrepis* zone *** [and] probably represents the upper part of the Niobrara Formation."

WELDED TUFF MEMBER

The welded tuff member forms prominent ridges through the Sedan, Hatfield Mountain, and Wallrock quadrangles. It pinches out to the north in the Sixteen NE quadrangle and has not been traced south of the middle of the Fort Ellis quadrangle (fig. 1). The

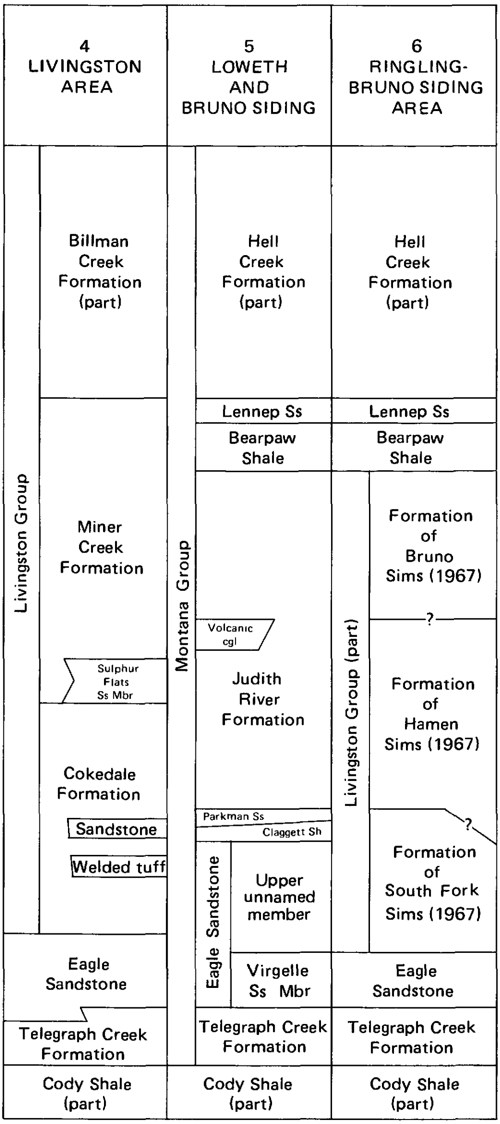


FIGURE 4.—Continued.

unit ranges in thickness from 0 to about 210 m (0 to about 700 ft). It is thickest in the general area of Flathead Pass on the east side of the Bridger Range and in the Maudlow area to the west (fig. 1; Skipp and Peterson, 1965). In the measured section at Cottonwood Creek, it is 48 m (157 ft) thick.

The welded tuff member consists of pale-yellowish-green, light-greenish-gray, grayish-red, and pale-reddish-brown welded tuff in three sheets (each sheet 0–92 m (0–300 ft) thick) and welded tuff conglomerate, separated by olive-gray to light-gray volcanic and quartzose sandstone, dark-colored conglomerate and mudstone, and dark-greenish-gray to gray porcelanite and altered vitric tuff. The welded tuff is fine grained and contains locally abundant (7 percent) phenocrysts of golden-weathering biotite, crystals of labradorite, andesine, augite, and hypersthene, and small clasts of altered volcanic rock. Shards and pumice fragments are less than 1 mm long. The glass is mostly devitrified, but thin (1–1.5 m (3–5 ft) thick) zones of perlitic glass are present in places near the base of flows along the northwestern edge of the Sedan quadrangle. Conglomerate composed of welded tuff pebbles and cobbles marks both the base and top of the unit in some places. Wood is present throughout. The welded tuff member lies on the eroded surface of lower sandstone member.

Skipp (1969) suggested that interbedded tuffs and sandstones of the Sulphur Flats Sandstone Member (at its type section) of the Miner Creek Formation (Roberts, 1963) might be a distal facies of the welded tuff member. However, mapping in the northern part of the Fort Ellis quadrangle (fig. 1) shows that the Sulphur Flats lies about 153 m (500 ft) above the welded tuff member and more likely is related to tuffaceous sandstone beds in the middle part of the middle sandstone member (fig. 3) (units 29 and 30 of measured section).

The welded tuff member and the lower sandstone member below it probably correlate (fig. 4) with volcanic sandstone, mudstone, and tuff, which have been variously assigned to the upper unnamed member of the Eagle Sandstone and the Claggett Shale (Gill and Vaughn, in McMannis and others, 1968, fig. 6; Gill and Cobban, 1973; this paper), to just the upper part of the Eagle Sandstone (Gill and others, 1972, p. 92), and to the formation of South Fork of Sims (1967). Palynomorphs collected from near Bruno Siding were identified by K. R. Newman (cited in Sims, 1967, p. 26–27) as "Upper Cretaceous-Campanian (probably early Campanian)."

PARKMAN SANDSTONE EQUIVALENT

In the western Crazy Mountains basin, the Parkman Sandstone equivalent is present in the upper part of the welded tuff member and the lower part of the middle sandstone member and includes the contact between these two members. The Parkman has not been mapped separately in this area. In the measured section at Cottonwood Creek (fig. 3), the Parkman is 59 m (193 ft) thick and consists of light-gray and olive-gray, fine-grained, thin-bedded, crossbedded, mottled in places, biotitic, noncalcareous and calcareous, quartzose sandstone, interbedded with greenish-gray siliceous mudstone, minor orange-weathering volcanic sandstone and conglomeratic volcanic sandstone, and one 6-m (20-ft)-thick bed of biotite-rich welded tuff. The uppermost light-gray sandstone is characterized by contorted bedding in the measured section, probably a result of contemporaneous slump deformation. Leaf and twig imprints are common in some of the mudstone beds.

This unit is thought to be the rock-stratigraphic equivalent of the thin marine sandstone placed at the top of the Eagle Sandstone at Bruno Siding (figs. 1, 4) by Gill (Gill and others, 1972, p. 92), who earlier had called it Parkman Sandstone (Gill and Vaughn, in McMannis and others, 1968; and then again in Gill and Cobban, 1973, p. 16).

Roberts (1972, p. C43) suggested that a thin calcareous quartzose sandstone 156 m (510 ft) above the base of the Cokedale Formation at Cokedale might be a western tongue of the Parkman Sandstone.

MIDDLE SANDSTONE MEMBER

The middle sandstone member comprises a thick (305–503 m (1,000–1,650 ft)) ridge-forming series of epiclastic volcanic sandstones interbedded with epiclastic volcanic conglomerate, mudflow conglomerate, and minor volcanic siltstone and mudstone (fig. 5). The member is 491 m (1,611 ft) thick in the type section of the Sedan Formation at Cottonwood Creek. The sandstones are light olive green, olive gray, and dark greenish gray; range from fine grained to conglomeratic, but are commonly medium to coarse grained; are calcareous; are mottled in places; and are crossbedded; they weather brown. They are composed largely of feldspar and volcanic rock fragments with subordinate hornblende, augite, quartz, iron oxide minerals, and clays. Carbonaceous material and zeolites—clinoptilolite, mordenite, stilbite, and laumontite (A. J. Gude 3d, written commun., 1974)—are common accessories, and wood is sparse. A mudflow conglomerate, having minor breccia and sandstone (figs. 2 and 6) and 54 m (177 ft) thick in the measured section, is locally present near the top of the middle sandstone member throughout the northern part of the area and south into the northern part of the Sedan quadrangle. It is lithologically like the coarse alluvial facies of member F of the Maudlow Formation.

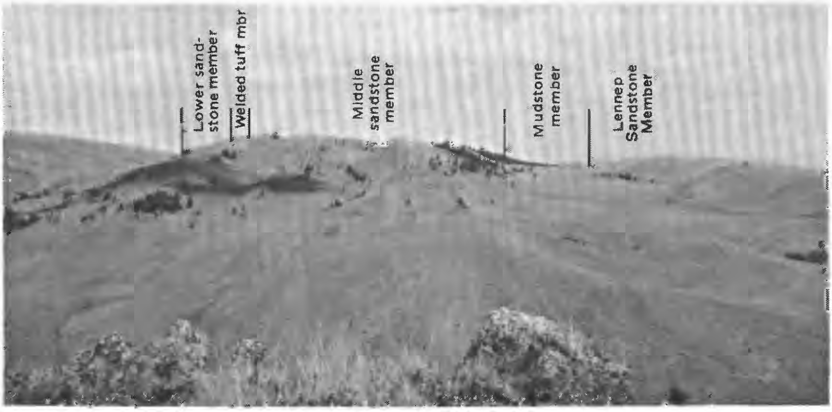


FIGURE 5.—A view of the type section of the Sedan Formation northward across Cottonwood Creek. (See figure 2.) Base of the measured section is in valley to left. Beds dip steeply eastward. Ridge in middle of picture is top of the middle sandstone member. Mudstone member forms valley on right side of picture. Lennep Sandstone Member forms ridge on far right.

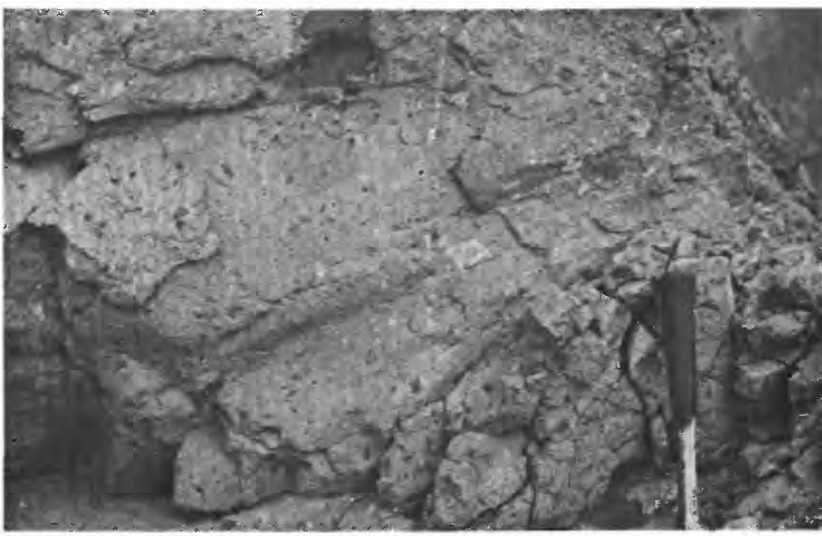


FIGURE 6.—Mudflow conglomerate unit near top of middle sandstone member in Sedan Formation on north side of Cottonwood Creek. Outcrop forms light band on left side of middle ridge in figure 5.

(See section "Member F" and Skipp and Peterson, 1965.) Above the mudflow conglomerate, lenses of polylithologic volcanic conglomerate containing fragments as much as 0.3 m (1 ft) in diameter and conglomeratic sandstone make up the uppermost resistant ledge of the unit (fig. 5). A similar mudflow conglomerate about 37 m (120 ft) thick occurs in the middle of the Judith River Formation at Bruno Siding (Gill and Vaughn, in McMannis and others, 1968, fig. 6).

In the southernmost part of the area, a sandstone equivalent to the Sulphur Flats Sandstone Member of the Miner Creek Formation (Roberts, 1963) is present about 150 m (500 ft) above the top of the welded tuff member in the middle of the middle sandstone member, where it enters the Sedan quadrangle from the Fort Ellis quadrangle (Roberts, 1964f), but it can be mapped northward with certainty for a distance of less than 5 km (3 mi). However, a sequence of sandstone and tuffaceous sandstone 46 m (150 ft) thick, which is about 150 m (490 ft) above the base of the middle sandstone member at Cottonwood Creek, may correlate with the Sulphur Flats Sandstone Member (fig. 3).

In the northern part of the area, light-gray calcareous sandstone of the Parkman Sandstone equivalent is present at the base of the middle sandstone member (fig. 3).

Throughout that part of the area where the welded tuff member is present, the base of the middle sandstone member is placed at the top of the stratigraphically highest welded tuff bed or, in some places, coarse conglomerate composed of welded tuff clasts.

The part of the middle sandstone member above the Parkman equivalent and below the mudstone member probably is equivalent to the formation of Hamen (Sims, 1967, p. 30–33).

Silicified wood and scattered plant impressions are the only fossils found in the unit.

MUDSTONE MEMBER

The mudstone member is a valley-forming interval about 180-300 m (600–1,000 ft) thick, which lies below the Lennep Sandstone Member or locally the Bearpaw Shale Member, and above the middle sandstone member (fig. 2). At Cottonwood Creek, the member is 274 m (899 ft) thick and consists of poorly bedded varicolored—gray, green, brown, red and yellow—volcanic mudstone, much of it siliceous, some bentonitic or sandy, and calcareous in places. The mudstone is interbedded with green and gray, fine-grained to conglomeratic, tuffaceous, partly calcareous, epiclastic volcanic sandstone. Thin beds of yellowish-gray bentonite and gray-and white-weathering vitric tuff are common in the upper part but sparse in the lower part.

A prominent ridge-forming unit in the northern part of the area, about 46 m (150 ft) thick, of light-gray-weathering silicified crystal vitric tuff interbedded with dark-colored volcanic sandstone occurs near the middle of the mudstone member. This unit has been mapped as far south as the Wallrock quadrangle and extends through the entire area, though it ceases to be a ridge former in the southern part.

Lenses of conglomerate containing boulders as much as 1 m (3 ft) in diameter that consist of coarsely porphyritic augite andesite, a vent facies rock found in the conglomerates of member H of the Maudlow Formation (see section "Member H" and Skipp and Peterson, 1965), are present in the middle part of the mudstone member in the southern part of the Wallrock quadrangle and the northern part of the Sedan quadrangle. The conglomerates are interpreted to be eastward-pointing tongues of member H of the Maudlow Formation of the Livingston Group.

Clinoptilolite is common in the mudstones and sandstones as discrete orange specks. Other zeolites, mordenite and laumontite, are present as disseminated masses, and stilbite is common in veins and along fracture planes in the mudstone unit (A. J. Gude 3d, written commun., 1974). Calcite veining is also common. Freshwater limestone nodules are scarce in the upper beds.

Freshwater mollusks, wood, and dinosaur bones were recovered from several localities within this stratigraphic inteval. A large carnosaurian femur found by W. J. McMannis in this unit in the northern part of the Sedan quadrangle is referred to cf. *Gorgosaurus* by Nicholas Hotton III (written commun., 1971).

Contact with the underlying middle sandstone member is everywhere gradational and is placed at the base of the lowest, thick, valley-forming mudstone sequence.

The mudstone member below the Bearpaw Shale Member and above the middle sandstone member probably is equivalent to the formation of Bruno (Sims, 1967, p. 33–34).

BEARPAW SHALE MEMBER

A unit about 76 m (250 ft) thick, above the mudstone member, is equivalent to the marine and brackish-water Bearpaw Shale. This unit is designated the Bearpaw Shale Member in the report area. The member has been mapped separately in the northern part of the area, where it consists of poorly exposed valley-forming mudstone (fig. 3), which is gray, green, and brown, interbedded with a few thin beds of gray and green sandstone and yellowish-gray bentonite. The member cannot be mapped easily in the area south of the Sixteen NE quadrangle (fig. 1).

LENNEP SANDSTONE MEMBER

The Lennep Sandstone was named by Stone and Calvert (1910,

p. 746–747) for exposures at the north end of the Crazy Mountains. It was described as consisting "of dark-colored tuffaceous sandstone intercalated with dark shale" from 250 to 460 feet (76–140 m) thick. The outcrop was described as dark brown, and Stone and Calvert noted (1910, p. 747) that "fossil shells found in this formation are about equally fresh, brackish water, and marine; the fresh water and marine forms occurring in separate horizons."

In recent years, the Lennep Sandstone in the type locality has been determined to be a regressive marine sandstone containing the diagnostic *Baculites cuneatus* or *B. compressus* ammonite zone faunas (Gill and Vaughn, in McMannis and others, 1968; Gill and Cobban, 1973, p. 21).

Roberts indicated that the basal beds of the Miner Creek Formation correlated with the Lennep Sandstone (1963, 1965, 1972), but mapping of the ridge formed by the Lennep equivalent on the western side of the Crazy Mountains (fig. 6) shows that it can be traced nearly continuously from near Loweth (fig. 1) southward to the south edge of the Sedan quadrangle, where it becomes the upper 120–150 m (400–500 ft) of the Miner Creek Formation. These beds comprise hill-forming siltstone, sandstone, and minor conglomerate (Roberts, 1964g, 1972; Roberts, in McMannis and others, 1968, fig. 3).

The Lennep is reduced in rank in the report area to the Lennep Sandstone Member. It is 107–152 m (350–500 ft) thick along the western edge of the Crazy Mountains basin and is 107 m (351 ft) thick at Cottonwood Creek (fig. 3). Marine beds are present in the northern and eastern parts of the area, but elsewhere ridge-forming brackish-water or nonmarine sandstone, conglomerate, minor mudstone, and zeolitized (laumontite) vitric tuff make up the unit. The sandstones, which are olive gray, greenish gray, light gray, and pale orange, commonly weather a distinctive yellowish brown. The brown-weathering characteristic is not as pronounced in the southern part of the Sedan quadrangle, where slopes are heavily forested, as in the remainder of the region. The sandstones are made up largely of fragments of volcanic rocks of intermediate composition; they are fine grained to conglomeratic, generally calcareous, poorly bedded to crossbedded; they contain much carbonaceous material and are commonly iron stained. Crossbedding indicates a general western source. Red-brown-weathering calcareous "cannonball" concretions are most common in the upper beds but locally are present throughout. Epiclastic volcanic pebble and cobble conglomerate is present in lenses in the southern part of the area, and a few pebbles are of Paleozoic limestone and quartzite. Altered vitric tuff and siliceous mudstone are common in the lower 30 m (100 ft) and occur locally in the upper beds.

The top of the member is marked by a thick, 30 m (100 ft), coarse-grained calcareous sandstone that is overlain by 60–90 m (200–300 ft) of gray and brown volcanic mudstone and friable, crossbedded, magnetite-rich sandstone and conglomerate lenses of the lower part of the Billman Creek Formation.

The lower part of the Lennep Sandstone Member is marked by a series of thin medium- to coarse-grained sandstone lenses interbedded with siliceous mudstone and devitrified vitric tuff, which commonly form the lower part of a steep slope or the top of a low ridge above the valley-forming mudstone member.

A few dinosaur bone fragments, freshwater and brackish-water mollusks (W. A. Cobban, written commun., 1967), and burrows of a marine crustacean, *Ophiomorpha* (J. R. Gill, oral commun., 1971), were recovered from this member. The presence of *Ophiomorpha* indicates that at least part of the unit was deposited in a marine environment.

Palynomorphs recovered from the Lennep in the northern part of the Wolf Hill quadrangle were reported by K. R. Newman (in Sims, 1967, p. 38) to be suggestive of a probable late Campanian age.

AGE AND CORRELATION

The Sedan Formation is of Late Cretaceous (latest Santonian and Campanian) age. Palynomorphs recovered from the lignitic coal at the base of the measured section (fig. 3, fossil colln. D4670) were identified by R. H. Tschudy (written commun., 1971) as representing "an interval above the *Scaphites depressus* zone and below the *Scaphites hippocrepis* zone *** [which correlates with] the upper part of the Niobrara Formation." The assemblage is older than any recovered from the type section of the Cokedale Formation (Roberts, 1972, p. C38, C42). *Clioscaphites* sp. (either *vermiformis* or *choteauensis*), identified by W. A. Cobban (written commun., 1971), was collected by the authors from the Telegraph Creek Formation below the Eagle Sandstone (figs. 2, 3, fossil colln. F_1) in the type section of the Sedan Formation, and thus the stratigraphic interval of the lignitic coal at the base can be narrowed to above the *Clioscaphites choteauensis* zone and below the *S. hippocrepis* zone. From the estimated dates for the Late Cretaceous ammonite sequence (Obradovich and Cobban, 1975; Gill and Cobban, 1966, p. A35), the base of the Sedan Formation and the Livingston Group in this area falls at about 82–83 m.y. (million years) (latest Santonian). This age agrees well with the 82-m.y. base of the Livingston in the Livingston area, reported by Roberts (1972, p. C6). Roberts (1972, p. C45, C48) reported several palynomorph assemblages from the Cokedale and Miner Creek Formations, which indicate correlation with the Blair Formation of Wyoming, the type Claggett Shale, the type Judith River Formation of Montana, and the upper part of the Pierre Shale. A collection from the lower part of the Lennep Sandstone in NE¼ sec. 25, T. 4 N., R. 8 E., near Wilsall, Mont., from an original Stanton locality (cited in Stone and Calvert, 1910, p. 765), is reported by Roberts (1972, p. C47, 48) to represent the *Baculites compressus* or *Baculites cuneatus* zone (fig. 1, fossil colln. D3083). Roberts correlated this zone with the Sulphur Flats Sandstone Member at the base of the Miner Creek and hypothesized that the top of the Miner Creek is as young as Maestrichtian (1972, p. C6). Mapping between the type Sulphur Flats Sandstone Member and the Lennep Sandstone at Loweth shows that the Lennep Correlates instead with the upper ridge-forming beds of the Miner Creek Formation. The potassium-argon age of the *Baculites cuneatus* and *Baculites compressus* ammonite zones proposed by Obradovich and Cobban (1975, p. 36) is about 70 m.y.; thus, the lower part of the Livingston Group, the Sedan Formation, is bracketed by an 82–83-m.y. age at the base and a 70-m.y. age at the top; hence it was deposited within a span of about 12–13 m.y.

Some uncertainty remains regarding the assignment of beds above the Lennep Sandstone at Loweth, at the northwestern edge of the Crazy Mountains basin. J. R. Gill reported 240 m (785 ft) of Miner Creek Formation above the Lennep Sandstone (in Roberts, 1972, p. C46). These beds are probably the same as the 216 m (708 ft) of the lower part of the Billman Creek Formation above the type Sedan Formation in the measured section at Cottonwood Creek (fig. 3), and we consider them to be lithologic correlatives of the Billman Creek. The criteria for the formation assignment are as follows: the presence of a zone of brown-weathering, spherical, calcareous sandstone concretions about 75 m (250 ft) above the Lennep Sandstone; a marker bed in the lower beds of the type section of the Billman Creek Formation (Roberts, 1972, p. C49); the preponderance of mudstone and siltstone over sandstone; and the lenslike nature of the sandstone beds in the section.

The top of the Eagle Sandstone appears to become progressively younger in the northern and eastern parts of the map area (fig. 4). At Bruno Siding, east of Loweth, the base of the volcanic detritus (the base of the Judith River Formation) is estimated to occur at about 78 m.y. (Obradovich and Cobban, 1975, p. 36; Gill and others, 1972, p. 92), though the upper part of the Eagle Sandstone in this interpretation is dominantly nonmarine volcanic mudstone and shale overlain by an upper thin marine shale and sandstone. Gill and Vaughn (in McMannis and others, 1968, fig. 6) and Gill and Cobban (1973) earlier called the upper marine sandstone, the Parkman Sandstone. The interval between the top of the Virgelle Sandstone Member of the Eagle and the top of the marine sandstone (Parkman) was called the formation of South Fork by Sims (1967), who suggested a possible correlation with the Eagle Sandstone. These interpretations and suggested relations to the Sedan Formation are shown in the correlation chart (fig. 4).

MAUDLOW FORMATION

In the 10th census report of 1880, Waldemar Lindgren (1886, pl. 53 and p. 736) published a map of the "Lower Sixteen-mile Creek Cretaceous Basin" and noted the presence of sandstone belonging "to the Laramie formation" and "volcanic conglomerate of dark, often glassy eruptives and red liparite [welded tuff]." The volcanic rocks, later referred to the Livingston Formation by Peale (cited in Weed, 1893, p. 21) form the central part of the Maudlow structural basin located between the Bridger Range to the south and the Big Belt Mountains to the north (fig. 1). Stone and Calvert (1910, pl. 7) showed the Maudlow area to be a westward extension of the Crazy Mountains basin, and Billingsley (1915, p. 35) described "the coarse andesitic conglomerate at Maudlow ***" as having been derived "from no other source than the lavas of the Elkhorn Mountains."

These general views were supported by the later work of Klemme (1949), who used the name Livingston Formation for the volcanic series, mapped the geographic extent of the outcrop, described in some detail a 1,220-m (4,000-ft) measured section at Maudlow, and proposed the name "Maudlow conglomerate lentil" (fig. 7) for a series of lensing "volcanic conglomerates with interbedded tuffs" (members B and C of the Maudlow Formation of this report) strikingly exposed near the town of Maudlow. The name Maudlow was first published in a report by McMannis (1955). The conglomerates and tuffs are undoubtedly those examined earlier by Billingsley. Klemme, and later, McMannis (1955, p. 1410), and Klepper, Weeks, and Ruppel (1957, p. 39) reiterated Billingsley's assertion that the sequence was derived from the Elkhorn Mountains Volcanics. Fossil plants identified by Erling Dorf for Klemme from the "Maudlow conglomerate lentil" suggested the possibility of a Paleocene age for this part of the Livingston Formation. The name Maudlow is redefined and raised to formation rank in this report. Certain measured sections in T. 4 N., R. 5 E., (p. B56) are designated the type section, because no type section was selected in any of the earlier reports.

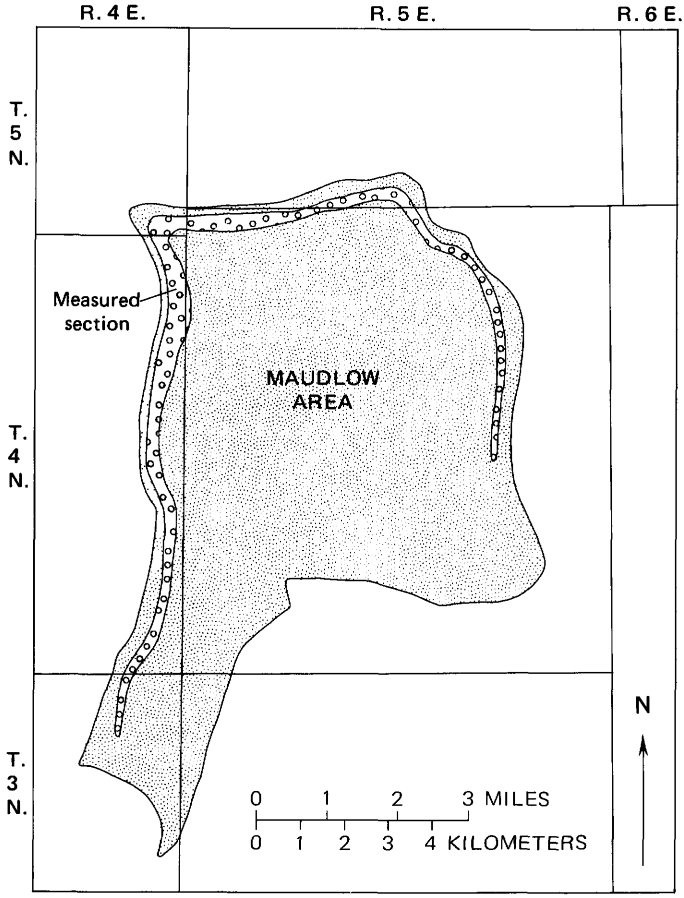


FIGURE 7.—Simplified geologic map modified from Klemme (1949) showing outline of area of outcrop of his Livingston Formation (stippled) and areal distribution of his Maudlow Conglomerate Lentil of the Livingston Formation (patterned). Stratigraphic position of the lentil is discussed under members B and C (see sections "Member B" and "Member C").

Detailed mapping of the Upper Cretaceous volcaniclastic and volcanic rocks near Maudlow by Skipp and Peterson (1965) showed that the sequence is divisible into eight map units—three of them largely of primary volcanic origin, the others dominantly epiclastic. These units constitute members A through H of the Maudlow Formation, which total about 1,677+ m (5,500+ ft) along the west edge of the outcrop and about 1,525+ m (5,000+ ft) along the eastern edge (fig. 8). Faulting in the vicinity of Maudlow has repeated members A, B, and C, and so earlier measurements of the thickness of conglomerates in that area are too large. Member D contains several fine-grained biotitic dacitic welded tuff sheets, the "red liparite" of Lindgren. The tuffs resemble ash-flow tuffs of the lower unit of the Elkhorn Mountains Volcanics (Smedes, 1966, p. 32–33). Members B and F contain thick primary hornblende-augite, augite-rhyodacite, and dacite flows. Facies changes and

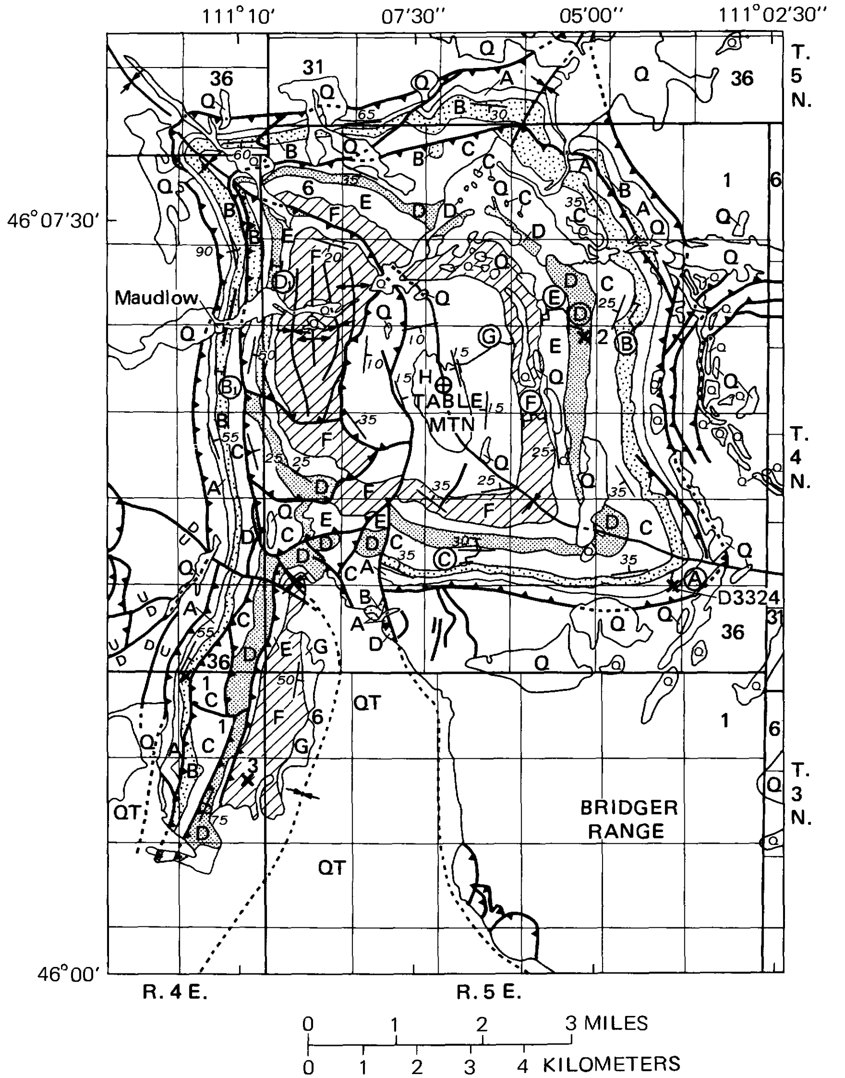


FIGURE 8.—Simplified geologic map of the Maudlow area (adapted from Skipp and Peterson, 1965) showing distribution of members H through A of the Maudlow Formation of the Livingston Group, location of measured sections of members, fossil locality D3324, and localities of samples which yielded potassium-argon ages.

wedging out of these units and of lithic and lithic crystal tuffs of members F and G from west to east across the basin indicate western or southwestern sources for all of the primary volcanic material. The remainder of the members contain much epiclastic material—fragments of altered volcanic rocks as much as 2 m (6 ft) in diameter—which was derived in part from the Elkhorn Mountains Volcanics to the west, though some of the material is clearly of local origin. The size of included boulders, the presence of volcanic breccias, the massive bedding, and the generally dark color indicate that the Maudlow Formation is an example of the coarse alluvial volcanic facies of Parsons (1969), which grades eastward into the fine alluvial facies of the Sedan Formation.

The Maudlow Formation unconformably overlies either the upper part of the Telegraph Creek Formation or the Virgelle Sandstone Member of the Eagle Sandstone (Skipp and Peterson, 1965; it

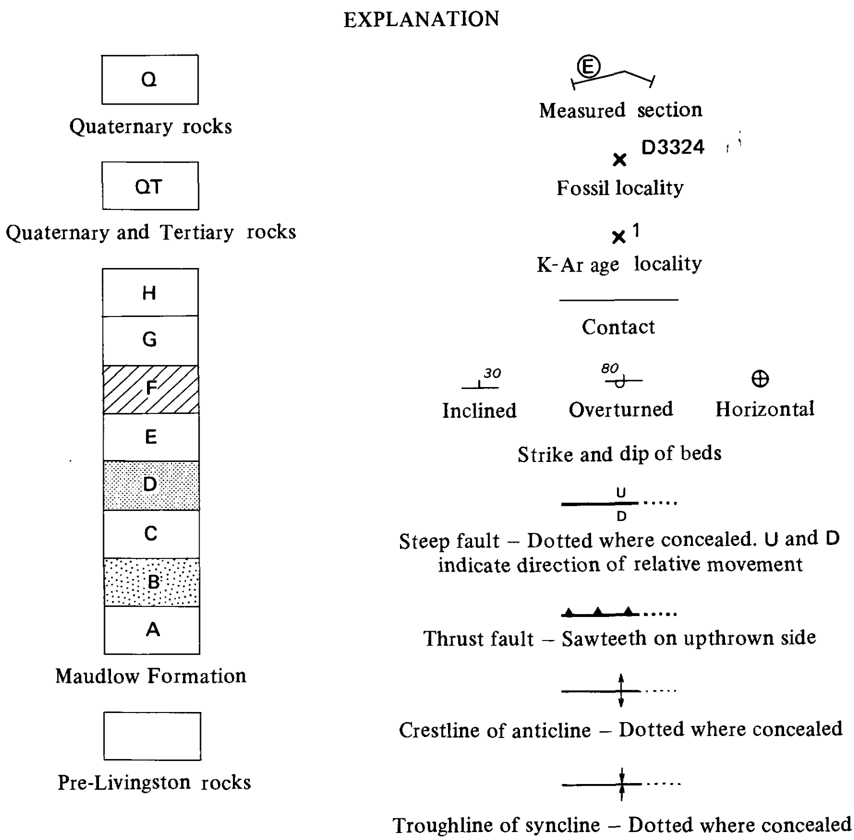


FIGURE 8.—Continued.

is unconformably overlain by tuffaceous beds of the Oligocene Dunbar Creek Formation of the Bozeman Group, or by Quaternary gravels in the southwest part of the map area.

The eight members shown in the composite columnar diagram of figure 3 are described here in ascending order.

MEMBER A

Member A unconformably overlies the Telegraph Creek Formation (upper part) at the type section (measured section A) in the southeast corner of the area of outcrop (fig. 8). It is 157 m (514 ft) thick at this locality and is about 90± m (300± ft) thick elsewhere. On the southwest and west sides of the Maudlow area, member A overlies magnetite-rich sandstone of the Virgelle Sandstone Member of the Eagle Sandstone. Member A consists of epiclastic volcanic sandstone, conglomerate, and mudstone with some lithic tuff and a few beds of lignitic shales near the base. Conglomeratic sandstone and conglomerate make up almost 50 percent of the unit in the type section. Plant fossils are abundant in this member.

The unconformity at the base of member A is characterized by an abrupt and persistent change in mineral constituents. The beds below the unconformity, the Telegraph Creek Formation (upper part) or the Virgelle Sandstone Member, are composed of abundant quartz, some feldspar, and varying amounts of biotite, sphene, and magnetite in a calcite matrix, whereas the basal sandstones and mudstones of member A appear to be slightly reworked crystal tuffs with abundant plagioclase, minor quartz, moderate hornblende, and pyroxene in a clay-rich zeolite or calcite matrix. These lithologies are not interbedded in the Maudlow area but show interbedding in the lower parts of the type sections of the Sedan Formation and the Cokedale Formation (Roberts, 1972; Skipp and McGrew, 1972). A thin zone of yellow ochre clay, possibly an ancient soil zone, has been observed at the contact at the base of member A in the measured section.

The sandstones and conglomerates of member A are generally olive gray, greenish gray, and brownish gray, are made up of fragments (as much as 46 cm (18 in.) in diameter) of altered porphyritic rocks ranging in composition from basaltic to rhyodacitic, and are well indurated and ridge forming. Crossbedding is common in several places and is emphasized by heavy-mineral concentrations. The phenocrysts in the volcanic rock fragments are largely kaolinized plagioclase and augite, a little hornblende, some secondary opaque iron ores, and relict olivine. A few fragments of impure sandstone and single euhedral or subhedral crystals of plagioclase, augite, and hornblende are also present.

The sandstones are cemented with clay minerals (nontronite and montmorillonite), zeolite (clinoptilolite), and calcite. Finely laminated claystones, ranging in color from pale yellowish brown to dark greenish gray, are found interbedded with the sandstones in several places. They contain leaf, needle, grass, and twig impressions and silicified wood fragments. J. A. Wolfe (written commun., 1960, 1962) and R. A. Scott (written commun., 1961) identified the following flora from several localities in the map area:

Ferns:
- *Anemia elongata* (Newberry) Knowlton
- *Dryopteris* sp.
- *Gleichenites* sp., cf. G. *kurriana* Heer

Conifers:
- *Sequoia reichenbachi* (Geinitz) Heer
- *Araucarites* sp.
- *Araucarioxylon* sp.
- *Glyptostrobus?* sp.

Dicots:
- *"Cissus"*[1] *marginata* (Lesquereux) Brown

[1]Quotes indicate the uncertainty of generic assignments (J. A. Wolfe, written commun., 1975).

The presence of *Sequoia reichenbachi,* known also from the type locality of the Livingston, from the type Judith River Formation, and from the Elkhorn Mountains Volcanics, places member A in the Cretaceous. The fern *Anemia elongata* is known only from several Late Cretaceous formations in the Rocky Mountains (J. A. Wolfe, written commun., 1960).

Erling Dorf identified the following Late Cretaceous flora from beds "300 feet above the Eagle Sandstone—Livingston Formation contact" (Klemme, 1949, p. 58, 186) in sec. 12, T. 4 N., R. 4 E., in the northeastern part of the Maudlow area:

Fern:
- *Asplenites tenellum* Knowlton

Dicots:
- *"Salix" lancensis* Berry
- *Apeibopsis? laramiensis* Knowlton

A sample of lignitic shale 19 m (63 ft) above the base of the Maudlow Formation, from unit 3D of measured section A (p. B64; fig. 8), was examined by Robert H. Tschudy (written commun., 1964, 1968), who reported the following palynomorphs (USGS Paleobot. loc. No. D3324, figs. 3, 8):

Appendicisporites (App 5)
Klukisporites (TT-rt3)
Proteacidites
Araucariacites
Schizaea (M-stl)
Gleicheniidites (Gleich 5)

Minorpollis (Pa_3-sm18B)
Taxodiaceaepollenites (Tax-r5)
Eucommiidites (C_3-sm15)
Complexiopollis
TO-p8
Callialasporites
CP_3-rt10?
C_3-sm7?
S_1-rt new sp
C_3-rt14
C_3-sm16

This flora, like that reported from the base of the Sedan Formation, appears to be older than assemblages previously obtained from the Cokedale Formation (Roberts, 1972, p. C37–C39) and "can be no younger than early Claggett [type section] and no older than Telegraph Creek [type section] " (Tschudy, written commun., 1968). This places the assemblage in the latest Santonian to earliest Campanian age range.

MEMBER B

Member B disconformably overlies member A. This unit comprises the resistant consistently grayish red purple "andesitic" beds noted by Billingsley (1915, p. 35) and included by Klemme in his "Maudlow conglomerate lentil" in 1949. In the vicinity of Maudlow, the member consists of volcanic breccias (fig. 9), tuff, dominantly monolithologic mudflow conglomerate, and rudely laminated monolithologic volcanic sandstone topped by a ledge-forming massive red-purple vitric crystal tuff. Measured section B (p. B61; fig. 8) in this area is 159.8 m (524 ft) thick. To the south the member thins and consists mostly of autobrecciated and unbrecciated flows. Two chemical analyses of these flows (table 1, columns 1 and 2) and thin section examination show them to be hornblende dacites with phenocrysts of zoned plagioclase (calcic andesine-sodic labradorite) and hornblende as much as 5 mm long, accessory magnetite, minor apatite, and sparse sphene, all in an uneven microcrystalline mosaic of feldspar, quartz, and minor zeolite (clinoptilolite). In some places augite and diopsidic augite are important constituents of these flows and flow breccias, though nowhere was the augite:hornblende ratio observed to be greater than 1:2.

Fragments in the flow breccias are angular to rounded and are as much as 0.6 m (2 ft) in diameter. In places the breccias have incorporated a few loose cobbles and boulders of older rocks (fig. 9). From a distance the brecciated nature of the flows is quite striking; at the outcrop it is difficult to delineate (fig. 9), but it is visible in thin section. In some places the interstices of the flow breccias are

FIGURE 9.—Outcrop of hornblende dacite volcanic breccia of member B of Maudlow Formation. Fragments and matrix are of same material. Note single rounded quartzite pebble (circled) caught up in the breccia. Locality is just east of town of Maudlow in NE¼ sec. 13, T. 4 N., R. 4 E.

filled with a brecciated felsitic matrix of the same material as the boulders. In others the interstices are lined with zeolites, largely clinoptilolite (Anna Shepard, written commum., 1962).

The massive altered vitric crystal tuff at the top of the member (measured section B) near Maudlow consists of chalcedonized glass, much of it with relict shard outlines; 20–25 percent altered plagioclase and lithic fragments; and 3 percent diopsidic augite.

Member B thins to 94 m (309 ft) on the eastern side of the area (measured section B) and consists largely of sandstone and crystal lithic tuff with thin beds of conglomerate. The sandstones that retain the distinctive grayish-red color of the weathered dactite are largely monolithologic and appear to be slightly reworked crystal lithic tuffs.

A small remnant of member B was found in a streambed just east of Flathead Pass, in the lower sandstone member of the Sedan Formation, but it was not found farther east. Changes in lithology and thickness of the member (fig. 10), from vent facies in the

TABLE 1.—*Chemical and normative compositions of igneous rocks of the Maudlow Formation and an associated sill*

[0, looked for but not found; —, not looked for]

	Maudlow Formation			Sill
Sample No	1	2	3	4
Laboratory No	156295	156296	157753	157755
Rapid rock analysis (Analysts: P. L. Elmore, I. H. Barlow, Gillison Chloe, and S. D. Botts)				
SiO_2	64.6	62.0	64.6	53.9
Al_2O_3	16.4	17.4	13.8	13.0
Fe_2O_3	3.7	3.9	1.4	3.1
FeO	1.2	1.4	.88	4.9
MgO	1.6	2.3	.70	9.0
C_2O	5.0	5.2	5.6	7.6
Na_2O	3.5	4.2	1.2	2.4
K_2O	2.1	1.7	.58	3.1
H_2O	1.3	1.7	10.3	2.0
TiO_2	.43	.46	.45	.62
P_2O_5	.27	.31	.08	.46
MnO	.12	.14	.05	.16
CO_2	$<.05$	$<.05$	$<.05$	.23
Sum	100.0	101.0	100.0	100.0
CIPW norms				
Quartz	24.18	17.34	42.54	1.38
Orthoclase	12.23	10.01	3.34	18.35
Albite	29.34	35.63	9.96	20.44
Anorthite	23.07	23.63	27.80	15.85
Enstatite	4.00	5.60	1.70	20.40
Magnetite	3.02	4.87	1.62	3.27
Ilmenite	.76	.91	.91	1.22
Apatite	.67	.67	0	1.34
Hematite	1.60	.48	.32	0
Diopside				14.36
Normative plagioclase	An_{48}	An_{38}		An_{43}
Semiquantitative spectrographic analysis [Analyst: H. W. Worthing]				
Si			Major	Major
Al			7.0	3.0
Fe			1.5	3.0
Mg			.3	3.0
Ca			3.0	7.0
Na			.7	1.5
K			.7	3.0
Ti			.3	.3
P			0	0
Mn			.03	.15
Ag			0	0
An			0	0

TABLE 1.—*Chemical and normative compositions of igneous rocks of the Maudlow Formation and an associated sill—Continued*

	Maudlow Formation			Sill
Sample No	1	2	3	4
Laboratory No	156295	156296	157753	157755
Semiquantitative spectrographic analysis—Continued (Analyst: H. W. Worthing)				
Au	...	...	0	0
B	...	...	.003	.003
Ba	...	...	.15	.07
Be	...	...	.0003	.00015
Bi	...	...	0	0
Cd	...	...	0	0
Ce	...	...	0	0
Co	...	...	.0003	.007
Cr	...	...	.0015	.015
Cs	...	...	0	0
Cu	...	...	.0007	.007
Dy	...	...	0	0
Er	...	...	0	0
Eu	...	...	0	0
F	...	...	...	...
Ga	...	...	.0007	.0007
Gd	...	...	0	0
Ge	...	...	0	0
Hf	...	...	0	0
Hg	...	...	0	0
Ho	...	...	0	0
In	...	...	0	0
Ir	...	...	0	0
La	...	...	.003	0
Li	...	...	0	0
Lu	...	...	0	0
Mo	...	...	.0003	0
Nb	...	...	0	0
Nd	...	...	0	0
Ni	...	...	.003	.03
Os	...	...	0	0
Pb	...	...	.0007	0
Pd	...	...	0	0
Pr	...	...	0	0
Pt	...	...	0	0
Rb	...	...	0	0
Re	...	...	0	0
Rh	...	...	0	0
Ru	...	...	0	0
Sb	...	...	0	0
Sc	...	...	.0007	.0015
Sn	...	...	0	0
Sr	...	...	.3	.15
Sm	...		0	0
Ta	...	...	0	0
Tb	...	...	0	0
Te	...	...	0	0

TABLE 1.—*Chemical and normative compositions of igneous rocks of the Maudlow Formation and an associated sill—Continued*

	Maudlow Formation			Sill
Sample No	1	2	3	4
Laboratory No	156295	156296	157753	157755
Semiquantitative spectrographic analysis—Continued (Analyst: H. W. Worthing)				
Th	....	....	0	0
Tl	....	....	0	0
Tm	....	....	0	0
U	....	....	0	0
V	....	....	.0015	.003
W	....	....	0	0
Y	....	....	.003	.0007
Yb	....	....	.0003	0
Zn	....	....	0	0
Zr	....	....	.03	.007

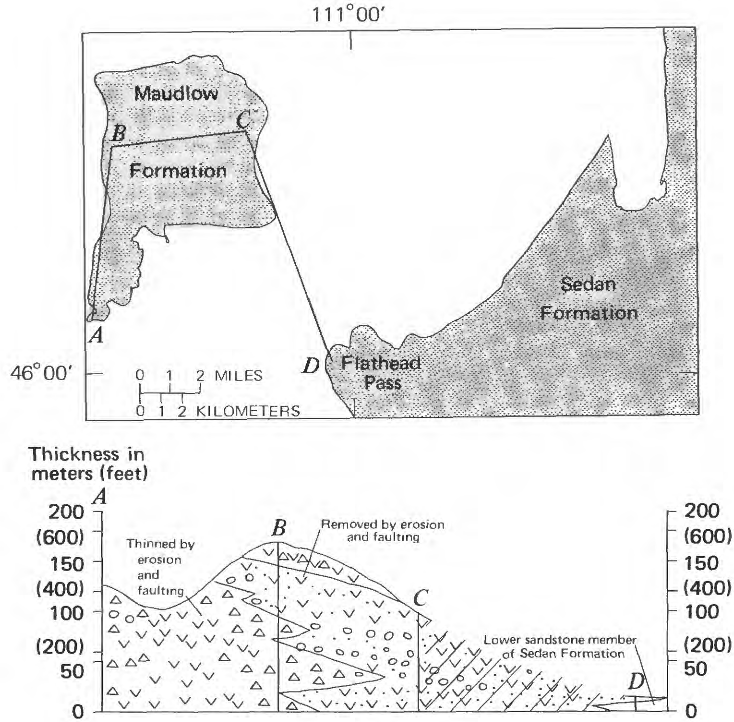
1. Dacite; grayish-purple porphyritic hornblende dacite lava flow from member B on west side of Maudlow area center E½ sec. 25, T. 4 N., R. 4 E. Collected by Marjorie MacLachlan.
2. Dacite; grayish-purple porphyritic hornblende dacite lava flow from member B on southwest side of Maudlow area NW¼NW¼ sec. 1, T. 3 N., R. 4 E. Collected by Betty Skipp.
3. Altered dacitic welded tuff; grayish-black perlite of member D on southeast corner of Maudlow area SW¼NW¼ sec. 26, T. 4 N., R. 5 E. Collected by Betty Skipp.
4. Shoshonite; brownish-black augite-olivine shoshonite sill in member G in southern part of Maudlow area SW¼SE¼ sec. 31, T. 4 N., R. 5 E. Collected by Betty Skipp.

southwest to alluvial facies (Parsons, 1969) in the east, indicate a western or southwestern source.

Hornblende from the dacite flow of sample No. 2 (table 1) yielded a potassium-argon age of 78.9±1 m.y. (J. D. Obradovich, written commum., 1974; referred to as sample No. 1 on figs. 4 and 8).

MEMBER C

Member C disconformably overlies member B and consists of polylithologic volcanic conglomerate, sandstone, and some tuff, which total 242 m (793 ft) on the south side of the outcrop area (measured section C). A thick ridge-forming conglomerate (fig. 11) containing some boulders of member B is present at the base of the member in most places. This conglomerate was included in "the Maudlow conglomerate lentil" (fig. 7) of Klemme (1949). Near Maudlow, where the basal conglomerate is repeated, it is about 60 m (200 ft) thick. It consists of dacitic and rhyodacitic volcanic rocks as much as 0.9 m (3 ft) in diameter, well-rounded and loosely cemented by finer volcanic debris; altered shards; plagioclase; hornblende and augite crystals; and hematite. Many of the



EXPLANATION

Vent facies – Porphyritic hornblende-augite dacite flows, breccias, and vitric-crystal tuffs

Fine to coarse alluvial facies – Epiclastic volcanic sandstone and conglomerate interbedded with crystal-lithic and vitric-crystal tuff of hornblende-augite dacite composition

FIGURE 10.—Diagram of facies and thickness relationships of member B of Maudlow Formation in the type section and eastward to the small outcrop near Flathead Pass in the lower sandstone member of the Sedan Formation. Hachured area has been removed by erosion.

boulders have deeply oxidized banded rims as much as 2.5 cm (1 in.) thick. Hornblende and augite porphyries make up most of the basal conglomerate, but a few pebbles of altered welded tuff are also present. No cobbles or boulders of sedimentary rocks were seen in any of the deposits.

Somber colors, mostly gray or olive gray, dominate the member, which, above the basal conglomerate, consists of sandstone, siltstone, claystone, conglomerate, and some thin tuff beds. The sandstones are fine-grained to conglomeratic, calcareous, crossbedded, volcanic microbreccias. In many places the crossbedding

FIGURE 11.—Outcrop of coarse epiclastic polylithologic volcanic conglomerate at base of member C of Maudlow Formation near Maudlow. This conglomerate and the breccia of figure 9 were included in the Maudlow Conglomerate Lentil of the Livingston Formation of Klemme (1949). Boulders and cobbles have weathered rinds up to 2.5 cm (1 in.) thick. Outcrop is located 0.4 km (0.25 mi) northeast of Maudlow in center SE¼ sec. 12, T. 4 N., R. 4 E.

is accentuated by concentrations of detrital iron oxide minerals and subhedral crystals of hornblende and pyroxene. Calcite, clay, and zeolites (clinoptilolite and stilbite) are cementing materials.

The member is, in general, a coarse alluvial volcanic facies, but it is transitional into fine alluvial facies along the eastern edge of the outcrop.

Some parts of the fine-grained sandstone and mudstone of the member are highly fossiliferous; J. A. Wolfe (written commun., 1960) identified the following flora from a locality northwest of Maudlow above the basal conglomerate:

Ferns:
- *Dryopteris carbonensis* Knowlton
- *Asplenites tenellum* (Knowlton) Dorf

Conifers:
- *Sequoia dakotensis* Brown

Dicots:
- *"Cinnamomum"*[1] *affine* Lesquereux
- *"Ficus" impressa* Knowlton?
- *Grewiopsis saporteana* Lesquereux
- *"Zizyphus" cretaceus* (Dawson) Bell?

[1]The quotes indicate the uncertainty of generic assignments (J. A. Wolfe, written commun., 1975).

Mr. Wolfe stated that the flora is of Late Cretaceous age.

Klemme (1949, p. 58, collns. 1, 3, and 4) listed a flora that Erling Dorf originally thought might be Paleocene from beds interpreted to belong to member C. Subsequently Dorf (oral commun., 1960) decided the fossils were not diagnostic.

MEMBER D

Member D disconformably overlies member C. It varies in thickness in the Maudlow region from about 122 m (400 ft) in the northeastern part to 206 m (675 ft) on the east side (measured section D) and 142 m (467 ft) on the west side (measured section D_1) of the area of outcrop (fig. 8). The member consists of three groups (cooling units?) of dacitic welded tuff flows separated by thick volcanic sandstones and conglomerates. The welded tuffs range from 0 to 98 m (0–320 ft) in thickness and are extremely varied in color. Hydrated, fresh, or partly devitrified glass or perlite is black or dark brownish gray. Completely devitrified glass is light orange pink, pale brown, pale yellowish brown, pale reddish brown, grayish red, and pale green. The brown and red colors are caused by finely disseminated iron oxide in the chalcedony or quartz alteration; the pale orange results from small amounts of additional green nontronite, and the green, from a dominance of nontronite (or celadonite). Sandstone and conglomerate interbedded with the welded tuff sheets contain many fragments of welded tuff, as much as 36 cm (14 in.) in diameter, mixed with other volcanic debris of intermediate composition. Fossil coniferous wood is found in the sandstones.

The rock is difficult to classify. It contains 65 percent SiO_2, 5–10 percent H_2O, and 3–10 percent phenocrysts—plagioclase, calcic andesine to sodic labradorite in composition; golden-weathering biotite; augite and hypersthene in decreasing order of abundance; and altered volcanic rock fragments. Pumice and ash fragments are small, most less than 0.5 mm in length, and densely packed; the rock is poorly to moderately welded (fig. 12). In thin section the glass is completely isotropic and has a refractive index of 1.505 ± 0.002. A chemical analysis of a perlite from member D was published by Robinson and Marvin (1967, p. 604) and is repeated in table 1 (sample No. 3). Moderately high silica content (64.6 percent) and the moderately calcic nature of the plagioclase phenocrysts suggest a dacitic composition for the magma.

Internally inconsistent potassium-argon ages on biotite (83±2 m.y.) and plagioclase (71±7 m.y.) from a sample of the welded tuff (sample No. 2 of figs. 4 and 8) were reported by Robinson and Marvin (1967, p. 607). These numbers have not been considered on the correlation chart (fig. 4).

The chemical composition of these welded tuffs precludes cor-

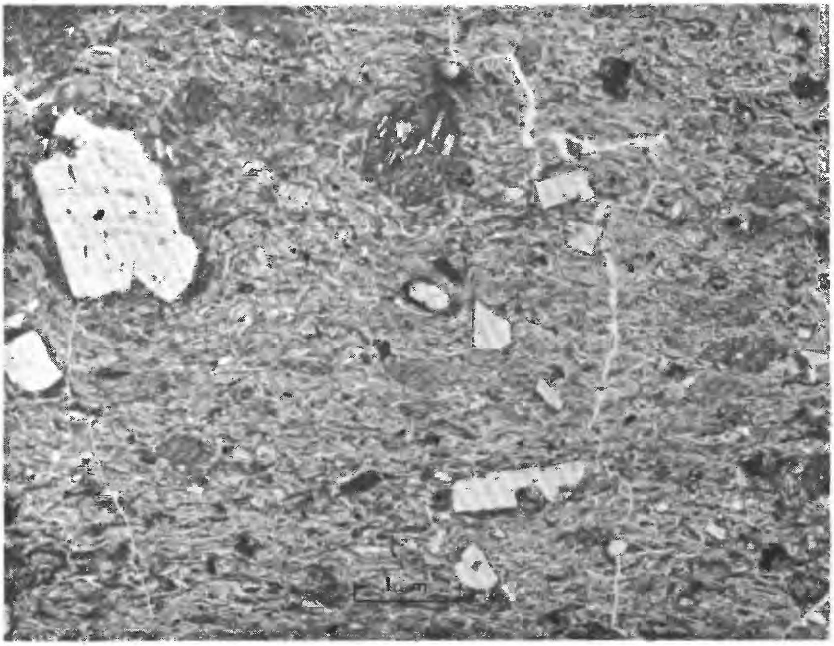


FIGURE 12.—Photomicrograph in plain light of glassy zone in lower sheet of welded tuff in member D of Maudlow Formation showing small size of shards, moderate welding, and crystals of andesine and augite and numerous fragments of altered volcanic rocks. Sample comes from southeast corner of Maudlow Formation outcrop in NW¼ sec. 26, T. 4 N., R. 5 E.

relation with the rhyolite ash flows of the middle unit of the Elkhorn Mountains Volcanics, which are characterized by 69–71 percent SiO_2, porphyroblastic clusters of quartz and K-feldspar, and plagioclase of andesine composition (Smedes, 1966, p. 22, 33–34). The Maudlow welded tuffs are compositionally more like the "quartz latite ash flows" from the lower unit of the Elkhorn Mountains Volcanics, which contain 60.7 percent SiO_2 and plagioclase phenocrysts of calcic andesine to sodic labradorite composition (Smedes, 1966, p. 22, 32–33). The welded tuffs of the Maudlow Formation are the first recognized indication that the ash flows of the lower unit of the Elkhorn Mountains Volcanics may have been areally extensive.

MEMBER E

Member E is a series of nonresistant, well-bedded, crossbedded, dark-colored, generally fine-grained, calcareous, volcanic sandstones, mudstones, and tuffs, typical of the fine alluvial volcanic facies. Conglomerate and breccia are rarely present. The beds are commonly grayish green to olive gray on fresh surfaces and weather various shades of brown. Brown-weathering limy concretions as much as 2 m (6 ft) in diameter are common. Cross-bedded volcanic sandstone is interbedded with massive devitrified and silicified vitric-lithic, vitric-crystal, or lithic tuffs. The member is 231 m (758 ft) thick in the reference section on the east side of the outcrop area and commonly forms a valley between the resistant ridges of members D and F.

One thin section of a dusky blue-green altered vitric-lithic tuff consists of more than 50 percent angular to subrounded altered volcanic lithic fragments as much as 1 mm across. The lithic fragments contain fresh zoned plagioclase (andesine), iron oxide minerals, and a few unaltered clinopyroxene crystals in an altered matrix with relict shard outlines. Green sheafs of celadonite (or nontronite) and a little "chlorophaeite" (a mineral or mixture of minerals closely related to chlorite in composition) make up the matrix.

Silicified logs were the only fossils found.

MEMBER F

Member F is a ridge-forming thick (183–244 m (600–800 ft)) massive sequence of varicolored, largely gray, grayish-green, and grayish-red, flows, flow breccia, lithic tuff, mudflow conglomerate, and epiclastic volcanic conglomerate and sandstone. Porphyritic hornblende and hornblende-augite dacite and rhyodacite flows, flow breccias, and lithic tuffs make up more than 50 percent of the interval in the western areas of outcrop, forming a vent facies. The vent facies grades eastward into the coarse alluvial facies of measured section F, which consists of volcanic conglomerate, containing boulders as much as 1.5 m (5 ft) in diameter, with interbedded volcanic sandstone, tuff, and claystone.

Breccia fragments in the abundant flow breccias range in size from crystal fragments to angular pieces of volcanic rocks as much as several centimeters across (fig. 13); they are set in a felsitic or cryptofelsitic groundmass much the same as, though less abundant than, the groundmass of the enclosed rock fragments. The boundaries of the rock fragments are indistinct under the microscope, and many show incipient brecciation. Rock and crystal fragments make up about 50 percent of the whole. The cryptofelsitic groundmass has a low birefringence and interstitial fillings of celadonite, nontronite, quartz, and the zeolites mordenite and clinoptilolite (A. J. Gude 3d, written commun., 1974), in about that order of abundance.

Of four thin sections of the breccia from various locations, two had phenocrysts of only andesine plagioclase and green horn-

FIGURE 13.— Outcrop of porphyritic dacite breccia of member F of the Maudlow Formation. Large coarsely porphyritic angular fragments with large andesine phenocrysts are surrounded by much finer material of the same dacitic compositions. Crops out along north side of road northeast of town of Maudlow in the E½ SW¼ sec. 7, T. 4 N., R. 5 E.

blende in both rock and crystal fragments and two had phenocrysts of the above plus augite showing oscillatory zoning. In these latter two, the hornblende is about twice as abundant as the augite. In places, however, augite is the dominant mafic mineral. Magnetite is a common accessory mineral; sphene and apatite are present in small amounts. Kaolinitic alteration is common in the feldspars in both the enclosed rock fragments and the separate crystals.

Lithologic correlatives of the breccias and conglomerates of member F are present east of Flathead Pass in the upper part of the middle sandstone member of the Sedan Formation (fig. 14). Also, the coarse volcanic conglomerate in the Judith River Formation at Loweth (Gill and Vaughan, in McMannis and other, 1968) is thought to be a distant alluvial facies of member F of the Maudlow Formation (fig. 4). Similar lithologies and consistent decrease in size of clasts across the mapped area support this interpretation.

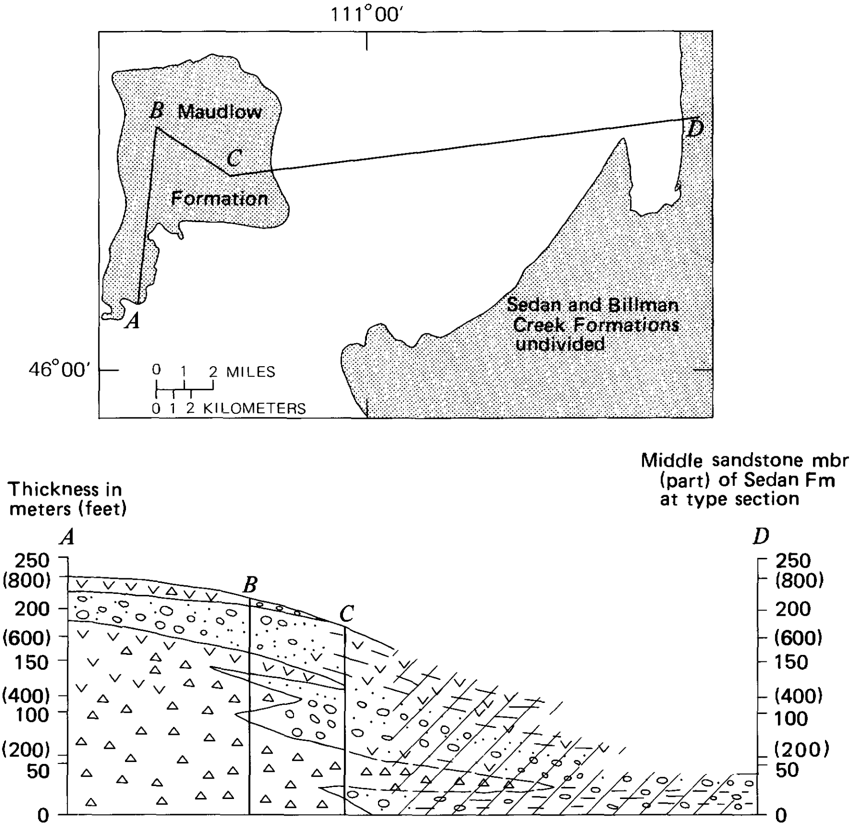
A few silicified tree trunks were the only fossils found in the fine epiclastic beds of the member.

A potassium-argon age determined on hornblende phenocrysts from the southwestern area of outcrop is 74.9±1 m.y. (J. D. Obradovich, written commun., 1974) (sample No. 3 of figs. 4 and 8). Because member F is the stratigraphically highest member of the Maudlow Formation which contains primary volcanic rocks, this radiometric age indicates the time of cessation of active rhyodacitic volcanism in the Maudlow area.

MEMBER G

Member G conformably overlies member F and constitutes a thick (400 m (1,310 ft) in measured section G) sequence of slope-forming, moderately well bedded, epiclastic, volcanic sandstone, siltstone, and claystone, and lithic and crystal-lithic tuffs that weather a characteristic yellowish brown and support very little vegetation. A few of the tuffs are conglomeratic, with pebbles as much as 1.3 cm (0.5 in.) long. No boulder conglomerates were seen in the unit. Bedding is visible in many places and ranges from 2.5 cm (1 in.) to a meter or more (several feet) in thickness. Beds of coarse-grained sandstone weather out in relief. Crossbedding is present but is not a prominent feature. The lithologies are typical of a fine alluvial volcanic facies.

Two thin sections from a reworked lithic-crystal tuff from the upper part of the member consist of about 40 percent angular to rounded lithic fragments as much as 4 mm in length, 15 percent unaltered augite and partly altered hypersthene, 5 percent altered



EXPLANATION

Vent facies – Porphyritic dacite and rhyodacite: breccias, flows, and lithic tuffs (fig. 13)

Coarse alluvial facies – Mudflow conglomerate, volcanic sandstone, and minor mudstone composed exclusively of member F detritus

FIGURE 14.—Diagram of facies and thickness relationships of member F of Maudlow Formation in the Maudlow area and eastward to the tongue of mudflow conglomerate of member F in the middle sandstone member of the Sedan Formation in the type section.

plagioclase, and accessory magnetite in a matrix of clay and zeolite. The lithic fragments are largely devitrified vitric volcanic rocks.

An unbrecciated body of grayish-black shoshonite or trachybasalt, which weathers grayish-brown, crops out in the southwestern part of the area in sec. 6, T. 3 N., R. 5 E., within member G. A chemical analysis is given in table 1 (sample No. 4). In thin section the rock contains 40 percent euhedral to subhedral phenocrysts as much as 5 mm long, consisting of augite and olivine altered to iddingsite and magnetite, with the augite slightly more abundant; 30 percent subhedral phenocrysts of altered, twinned, and zoned plagioclase (calcic andesine to labradorite) and accessory magnetite and apatite in a granular intergrowth of clear untwinned subhedral to anhedral alkali feldspar (some as crystal overgrowths on laths of plagioclase); subordinate subhedral plagioclase; and anhedral quartz with devitrified intersertal glass.

Merrill (1895, p. 638) reported similar rock in the Cretaceous about 4 km (2.5 mi) southeast of Bozeman on the east side of Bozeman Creek; similar rocks have been reported by Klepper, Weeks, and Ruppel (1957, p. 51), which they termed augite lamprophyre mafic orthoclase-clinopyroxene gabbro, and porphyritic olivine-augite-anorthoclase, and by Smedes (1966, p. 51–53), termed augite-trachybasalt in composite intrusives and sills, dikes, and laccoliths in the Elkhorn Mountains Volcanics.

Member G contains many plant remains. Fossil wood resembling sycamore *(Platanus)* is very common and was identified by R. A. Scott (written commun., 1961) from several stratigraphic positions within the member. A few freshwater clams and the following spores and pollen were collected from the base of the member in sec. 9, T. 4 N., R. 5 E., and identified by R. H. Tschudy (written commun., 1962):

Proteacidites P_3-rt 1A
Tricolpate pollen
Trilete fern spores TT-Sm 4?
Monolete fern spores M-Sm 3 M-Sm 4
Zlivisporis VOT-rt 1
Rugubivesiculites VOT-rugl? fragment

Tschudy concluded that the assemblage is of Late cretaceous age.

Lithologic correlatives occur in the mudstone member of the Sedan Formation.

MEMBER H

Member H is a ledge of boulder and cobble conglomerate 38+ m (125+ ft) thick, which forms Table Mountain, the synclinal center of the Maudlow structural basin (fig. 8). The coarse volcanic conglomerate contains abundant cobbles and boulders as much as 2 m (6 ft) in diameter, of various altered volcanic rocks of intermediate composition, including distinctive coarsely porphyritic pyroxene andesite that is not recognized lower in the sequence. Boulders of this distinctive lithology also have been recognized in conglomerate lenses in the middle part of the mudstone member of the Sedan Formation and are used here for lithologic correlation of these two horizons.

Fragments in the conglomerate range from subangular to well-rounded and characteristically make up less than 50 percent of the rock. The matrix contains numerous brecciated crystals of ferromagnesian minerals, iron oxide minerals, two varieties of augite, and albitized and laumontized feldspars; the matrix is made up of the zeolite, laumontite, and plagioclase, and clay, as determined by X-ray (A. J. Gude 3d, written commun., 1961).

The conglomerate on Table Mountain is overlain by a thin layer of leaf-bearing fine-grained brownish-weathering sandstone and siltstone that forms the eroded top of the formation. The Oligocene Dunbar Creek Formation and Quaternary gravels unconformably overlap the Maudlow Formation in the southern part of the area.

AGE AND CORRELATION

Palynomorphs and leaves from the Maudlow Formation all indicate a Cretaceous age for the formation. Palynomorphs from member A are of latest Santonian or early Campanian age. Radiometric ages calculated on hornblende from dacite breccias of members B and F are 78.9±1 and 74.9±1 m.y., respectively (J. D. Obradovich, written commun., 1974).

The upper part of the formation is dated through the lithologic correlation of member H with lenses of similar volcanic conglomerate in the middle part of the mudstone member of the Sedan Formation below the dated Lennep Sandstone Member. Thus, the maximum age range of the Maudlow Formation is similar to that of the Sedan Formation—latest Santonian to Campanian—though the present eroded outcrop of the Maudlow Formation does not include beds as young as those of the upper part of the Sedan Formation.

The igneous rocks of members B, D, F, and H all have stratigraphic counterparts in the Sedan Formation farther east and have been used to make the correlations shown in figure 4.

RELATIONS TO ELKHORN MOUNTAINS VOLCANICS

The Maudlow and Sedan Formations probably are time equivalents of the Elkhorn Mountains Volcanics. Radiometric ages determined on hornblende phenocrysts from the lower member of the Elkhorn Mountains Volcanics in its type locality have a mean of about 78 m.y. (Robinson and others, 1968; Roberts, 1972). The mean agrees well with the 78.9±1 m.y. radiometric age determined on hornblende from member B of the Maudlow Formation. The volcanic conglomerates and sandstones of member A and of the lowest part of the Sedan Formation, however, indicate that western volcanism of the Elkhorn Mountains type commenced earlier, probably about 82–83 m.y. ago, as suggested by the palynomorph assemblages at the base of these eastern assemblages. The upper part of the Elkhorn Mountains Volcanics has been recognized as being the time equivalent of the Judith River Formation (Smedes, 1966, p. 27; Klepper and others, 1957, p. 38). Robinson, Klepper, and Obradovich (1968, p. 574) extrapolated this correlation to an estimated age of 72–73 m.y., and Roberts (1972, p. C6) indicated a possible cessation of volcanism at about 74 m.y. The new radiometric ages of Obradovich and Cobban (1975) suggest that the *Baculites cuneatus* zone (fig. 4) is about 70 m.y. old. This zone is correlated with the top of the Lennep Sandstone Member of the Sedan Formation, which contains several tuff beds. Thus, it seems probable that the last eruptions of the Elkhorn Mountains volcanic field may have occurred about 70 m.y. ago, at the same time that the uppermost beds of the Sedan and Miner Creek Formations were deposited.

Active rhyodacitic volcanism in the Maudlow area at the eastern edge of the Elkhorn Mountains volcanic field is neatly bracketed by radiometric ages obtained from members B and F of the Maudlow Formation. These ages indicate that volcanism spanned approximately 5 m.y., from about 75 to 79 m.y. ago. The radiometric age obtained on member F (74.9±1 m.y.) falls right in the middle of the estimated cooling time of the Butte Quartz Monzonite (~ 76–74 m.y. ago; Tilling and others, 1968; Tilling, 1974) of the Boulder batholith, suggesting that at least along the eastern margin of the Elkhorn Mountains volcanic field, volcanism was contemporaneous with the emplacement of that volumetrically major part of the batholith. Tilling (1974, p. 1927) suggested that major volcanism ceased before the emplacement of the Butte mass and that radiometric ages obtained on adjacent volcanics may have been affected by reheating. The volcanic rocks of the Maudlow Formation are too distant from the Boulder batholith to have been reheated by it.

The original thickness of the Elkhorn Mountains Volcanics "may well have been at least 15,000 feet" (Smedes, 1966, p. 24). Near Maudlow, the volcanic rocks of this age have a thickness in excess of 1,525 m (5,000 ft). Near Wilsall, 32 km (20 mi) east of the Maudlow area, 1,075 m (3,528 ft) of section is present. At Livingston, 48 km (30 mi) to the southeast, and near Loweth, 40 km (25 mi) to the northeast, thicknesses are 884 m (2,900 ft) and 777 m (2,550 ft), respectively. The wedging out of coarse volcanic detritus continues to the east across the Crazy Mountains basin (Roberts, 1972, p. C39).

Calc-alkalic rocks dominated by dacite-rhyodacite flows and tuffs characterize the volcanic facies of the Elkhorn Mountains volcanic field and the Livingston Group in the Maudlow area. The variety of rock types present in the Elkhorn Mountains field, however, is not found in the Maudlow sequence. No basalt is present, and the extensive rhyolite ash flows of the middle member of the Elkhorn Mountains Volcanics are not represented. The Maudlow sequence is primarily rhyodacite with related andesite and dacite. The shoshonite sill in member G is the only departure from the rather uniform assemblage. The dacitic welded tuff of the Maudlow Formation is compositionally like welded tuffs present in the lower unit of the Elkhorn Mountains Volcanics and may indicate that those tuffs were originally very extensive areally.

The Elkhorn Mountains Volcanics and the formations that compose the lower part of the Livingston Group are eroded parts of an extensive volcanic pile, which may have covered as much as 26,000 km^2 (10,000 mi^2) of southwestern Montana (Smedes, 1966, p. 21). In a general way, the rocks named the Elkhorn Mountains Volcanics are the vent facies of the pile—the Maudlow Formation, a remnant of the coarse alluvial facies; and the Sedan, Cokedale, and Miner Creek Formations, the fine alluvial facies.

MEASURED SECTIONS

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members

[The six members of the Sedan were measured at the following localities in T. 4 N., R. 8 E.: Lennep Sandstone Member in the S½SW¼ sec. 17; Bearpaw Shale Member and mudstone member in the SW¼ sec. 17 and SE¼ sec. 18; middle sandstone member in the SE¼ sec. 18 and S½ sec. 7; welded tuff member in the S½ sec. 7; lower sandstone member in the S½NW¼ sec. 6]

	Thickness (meters)	Thickness (feet)
Billman Creek Formation:		
Lower part:		
83. Mudstone, gray, grayish-green, and grayish-red, largely calcareous; interbedded with gray sandstone, siltstone, and brown-weathering limestone nodules; contains fossil dinosaur bones and mollusks (Skipp and McGrew, 1972, p. 104)	216+	708+
Gradational contact.		
Sedan Formation:		
Lennep Sandstone Member:		
82. Sandstone, volcanic, and crystal-lithic tuff, medium-light-gray, greenish-gray, and olive-gray, iron-stained, medium-grained to conglomeratic, rudely bedded; contains dark-brown-weathering calcareous nodules, fossil conifer wood, abundant carbonaceous material, and hexagonal columnar structures in tuffaceous sandstone	5.3	17.4

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

Sedan Formation—Continued Lennep Sandstone Member—Continued	Thickness (meters)	Thickness (feet)
81. Sandstone, volcanic, light-olive-gray, medium-greenish-gray, and medium-olive-gray, fine-grained to conglomeratic, thin-bedded, slabby; some rude crossbedding; dark-purple, brown-weathering friable cannonballs common; light-colored breccia near top; greenish-gray and grayish-purple pebble conglomerate at base; contains intermediate volcanic cobbles as much as 8-10 cm (3-4 in.) in diameter; much zeolite cement; forms low-angle slope	6.8	22.4
80. Sandstone, volcanic, and crystal-lithic tuff, light-olive-gray to olive-gray and grayish-orange, mottled; sandstone is mostly fine grained with some mud-pellet conglomerate, crossbedded and slabby with 1.3-cm (0.5-in.) irregular slabs in upper part, poorly bedded in lower part; medium-dark-gray-weathering calcareous cannonball nodules common throughout; some carbonized wood nuclei; abundant carbon; mottled, altered, zeolitic (laumontite), crystal-lithic tuff bed at top	7.3	24.0
79. Sandstone, volcanic, pale-orange to olive-gray, some mottled, iron-stained, very fine grained to fine-grained, poorly bedded, some thin-bedded, mostly noncalcareous; most weathers to moderate brown; abundant carbonaceous material throughout	13.6	44.4
78. Partly covered interval; subcrop is very fine grained volcanic sandstone and mudstone, light- to dark-olive-gray, noncalcareous, massive with spheroidal weathering; weathers brown; forms slope	10.0	32.7
77. Partly covered interval; subcrop is light- to dark-olive-gray fine- to medium-grained, mostly very poorly bedded, generally noncalcareous brown-weathering volcanic sandstone; a few mudstone interbeds; much carbonaceous plant material; a few irregular ledges of light-colored thin-bedded sandstone are exposed, otherwise unit forms gentle slope	20.4	67.0
76. Sandstone, volcanic, greenish-gray to light- to dark-olive-gray, iron-stained, mostly fine-grained, some medium-grained, very poorly bedded, some magnetite-rich; weathers moderate brown; some flat limy nodules; much spheroidal weathering; some very fine grained material breaks into small irregularly shaped chips; some carbonaceous material; forms broad top of ridge	25.0	82.0

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Lennep Sandstone Member—Continued		
75. Mudstone, siliceous, and devitrified vitric tuff, dark-greenish-gray, olive-gray, and grayish-brown; subconchoidal fracture; blocky weathering; some fine-grained grayish-orange volcanic sandstone interbeds; 1.2 m (4 ft) of dark greenish gray medium- to coarse-grained volcanic sandstone at base; forms resistant ledge just below top of ridge	18.6	61.0
Total Lennep Sandstone Member	107.0	350.9
Reverse fault along bedding plane; offset unknown, but presumed small.		
Bearpaw Shale Member:		
74. Mudstone, moderate to dark-greenish gray, sandy, massive, siliceous; probably devitrified vitric-crystal and vitric-lithic tuff in part; 0.6 m (2 ft) of chocolate colored bentonite 4.6 m (15 ft) above base; lower 1.5 m (5 ft) pale olive gray fine- to medium-grained calcareous volcanic sandstone, banded by heavy mineral concentrations along bedding	11.7	38.5
73. Mudstone, olive-gray, greenish-gray and brownish-gray, siliceous; weathers into small polygons; thin bentonitic claystone in center; silty in lower part	10.2	33.5
72. Sandstone, grayish-green, medium- to coarse-grained and conglomeratic, crossbedded, slightly calcareous; medium bedded in beds 1–46 cm (0.5–18 in.) thick; graded bedding common; some mottling; nearly euhedral feldspar crystals abundant; some reworked crystal tuff; forms ledge	8.5	28.0
71. Mostly covered interval; siliceous claystone and (or) devitrified tuff and sandstone in float; forms moderate slope beneath unit 72	24.1	79.0
70. Mostly covered interval; green iron-stained carbonaceous nodular-weathering sandstone exposed on hillside; contains a few mudstone interbeds and bentonitic clay near base	20.7	68.0
69. Mudstone, brownish-gray, siliceous, zeolitic (clinoptilolitic); 31–46 cm (12–18 in.) thick greenish-gray fine-grained volcanic sandstone exposed at base	6.0	19.5
Total Bearpaw Shale Member	81.2	266.5
Mudstone member:		
68. Partly covered interval; devitrified vitric tuff, light-greenish-gray; bentonitic soil zones prominent; grades northward into altered vitric tuff ridge; grayish-red-purple mudstone with pale-pink zeolite (laumontite) veins exposed at base	10.1	33.0

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Mudstone member—Continued		
67. Sandstone and mudstone, volcanic; greenish-gray fine-grained massive upper sandstone has hackly surface; underlain by olive-gray mudstone and sandstone containing limestone nodules 0.9–1.2 m (3–4 ft) long which weather reddish-brown and contain carbonaceous plant debris; basal 4.6 m (15 ft) is greenish-gray medium-grained massive calcareous sandstone, which contains numerous veins of calcium carbonate and forms a ledge	17.5	57.5
66. Mudstone, volcanic, greenish-gray and brownish-gray, siliceous, massive, noncalcareous; contains abundant clinoptilolite and calcium carbonate veins; basal 3 m (10 ft) is greenish-gray massive volcanic sandstone, which forms a ledge	9.5	31.0
65. Partly covered interval; mudstone with minor sandstone, volcanic, olive-gray and brown-gray, siliceous; abundant zeolite and calcium carbonate in subcrop	6.2	20.5
64. Mudstone and siltsone, volcanic; contain abundant flecks of orange clinoptilolite and mordenite; light-brownish-gray soft sandy mudstone at top; thin dark-brownish-gray soft bentonitic clay in middle; basal 3 m (10 ft) is brownish-gray calcite-veined resistant volcanic mudstone and silty mudstone	8.2	27.0
63. Mudstone, volcanic, brownish-gray; interbedded with olive-gray volcanic sandstone; fine grained, massive, siliceous near top; contains abundant flecks of orange clinoptilolite; calcium carbonate in veins; grayish-green and dark-reddish-brown altered zeolitic (stilbite and laumontite) tuff in subcrop near top	8.8	29.0
62. Sandstone, volcanic, light-greenish-gray to olive-gray, fine- to medium-grained, partly conglomeratic; thin veins of zeolite (stilbite); some mudstone interbeds near top; sandstone beds form resistant ridges between mudstone outcrops	5.2	17.0
61. Mudstone, volcanic, olive-gray, partly sandy and silty, massive, mostly siliceous; weathers into small polygons; abundant orange clinoptilolite; some stilbite, mordenite(?), and calcite veins; interbedded with olive-gray fine-grained, argillaceous volcanic sandstone; olive-gray medium-grained massive friable calcareous volcanic sandstone 0.9 m (3 ft) thick in lower part	23.8	78.0
60. Mostly covered interval; subcrop is brownish-gray soft chocolate-like mudstone, interbedded with sandy or silty mudstone; soft mudstone may be bentonitic; flecks of orange zeolite common; calcite veins present in upper, more silty and si-		

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Mudstone member—Continued		
60. Mostly covered interval, etc.—Continued liceous beds; grayish-green medium grained calcareous volcanic sandstone 0.6 m (2 ft) thick at base	7.8	25.5
59. Crystal tuff, greenish-gray, fine- to medium-grained calcareous, 0.9 m (3 ft) thick with conspicuous greenish-black biotite; underlain by brownish-gray mudstone, and pinkish-gray and yellowish-gray soft slope-forming vitric tuff and bentonite; grayish-green medium-grained crossbedded calcareous volcanic sandstone, with zeolites on bedding surfaces, forms basal 0.9 m (3 ft); unit forms ridge and is a persistent marker bed in the northern part of Wallrock and in Sixteen NE and Ringling quadrangles	6.1	20.0
58. Mudstone and siltstone, dark-greenish-gray, massive; with numerous thin zeolite (stilbite) veins	6.9	22.8
Fault (dip changes from 45° east above to 90° below)		
57. Partly covered interval in upper part; mudstone and fine-grained sandstone, volcanic, olive-gray; some carbonaceous material; lower part well exposed dark-olive-gray and dark-yellowish-brown fine- to medium-grained to conglomeratic poorly bedded noncalcareous volcanic sandstone; much iron staining with abundant slickensides and calcite veins in lower part	10.3	33.7
56. Sandstone, volcanic, medium-olive-gray and greenish-gray, medium-grained to conglomeratic, thin- to medium- bedded; disseminated clinoptilolite; weathers to light brownish gray; graded bedding with some crossbedding; some calcite and zeolite (stilbite) veins; forms ridge	2.6	8.4
55. Partly covered interval; sandstone, volcanic, dark-greenish-gray and olive-gray, medium-grained, poorly bedded, friable, partly calcareous; in subcrop and some outcrops; flecks of orange clinoptilolite common; a few conglomeratic lenses; some carbonaceous plant material; forms slope	13.0	42.8
54. Mudstone, dusky-yellow-green and light-olive-gray, noncalcareous; contains abundant calcium carbonate veins and some brownish-gray beds with flecks of orange zeolite; interbedded with greenish-gray medium-grained to conglomeratic thin-bedded volcanic sandstone; a sandstone bed about 3.7 m (12 ft) thick is present in middle of unit	15.2	50.0

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Mudstone member—Continued		
53. Mudstone, varicolored, brownish-gray, greenish-gray, grayish-red and yellowish-gray; zeolite (stilbite) zone at top; thick olive mudstone and friable sandstone in middle; olive-gray medium-grained crystal rich sandstone, 10–15 cm (4–6 in.) thick at base	4.9	16.0
52. Partly covered interval; mudstone, greenish, gray some siliceous, some bentonitic; specks of orange zeolite (clinoptilolite) common, with minor grayish-green and olive-gray fine-grained thin-bedded crossbedded volcanic sandstone and siltstone; a thin devitrified vitric bed is present near the top; sandstone is more abundant in the upper half; a thin bentonite bed is present near the middle of the unit	14.8	48.5
51. Mudstone, dark-olive-gray, massive; abundant orange clinoptilolite, with a thin poorly exposed bentonite bed at top; underlain by greenish-gray medium-grained punky massive volcanic sandstone crossbedded with a thin medium-light gray coarse-grained to conglomeratic pink-weathering sandstone, 8–10 cm (3–4 in.) thick at base	7.8	25.5
50. Partly covered interval; 3.0 m (10 ft) of gray and dark-grayish-green silty siliceous volcanic mudstone, rich in accessory orange zeolite, exposed at top; mudstone float throughout remainder of unit; forms slope	14.2	46.5
Total mudstone member	192.9	632.7
Middle sandstone member:		
49. Sandstone, volcanic, grayish-green and light-brown, medium- to coarse-grained, partly conglomeratic, thin-bedded and crossbedded, noncalcareous, feldspathic; grayish-green beds common in middle of unit; weathers mostly pale brown; forms ridge	19.2	63.0
48. Partly covered interval; alternating sandstone ridges and mudstone intervals exposed to north of measured section; sandstone is volcanic, light-olive-gray, fine- to medium-grained, and weathers with characteristic yellowish-gray rind; fine-grained hard light-orange-pink-weathering sandstone, 20 cm (8 in.) thick, forms small ridge at base	19.2	63.0
47. Covered interval; devitrified vitric tuff, white and yellowish-gray; in float	1.1	3.8
46. Conglomerate, grayish-green; volcanic pebbles and		

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Middle sandstone member—Continued		
46. Conglomerate, etc.—Continued cobbles, most 2.5 cm (1 in.) but some 20–25 cm (8-10 in.) in diameter, subrounded to well-rounded, consisting of welded tuff, rhyodacitic to andesitic flows, and scoriaceous material; gravel is densely packed in crossbedded sandstone matrix with abundant orange zeolite; lenses into sandstone to the north and south; dinosaur bone fragment in float; forms ridge	10.8	35.5
45. Partly covered interval; sandstone, greenish-gray to olive-gray, medium-grained to conglomeratic, thin-bedded and crossbedded; may be some conglomerate like that of unit 46	19.5	64.0
Break in section: offset to S½ SE sec. 7, T. 4 N., R. 8 E.		
Mudflow conglomerate unit:		
44. Mudflow conglomerate, dark-greenish-gray and grayish-red-purple; a few sandy ledges; boulders of hornblende-rich dacitic volcanic rocks as much as 0.3 m (1 ft) in diameter, set in a mudstone matrix; abundant orange zeolite and calcium carbonate, some of which is brecciated; forms steep slope	23.1	76.0
43. Mudflow conglomerate, greenish-gray, brownish-gray, and yellowish-gray; intermediate volcanic rock fragments, generally less than 2.5 cm (1 in.) in diameter, some of hornblende dacite up to 0.3 m (1 ft) in diameter set in a mudstone matrix; some sandy conglomerate; some coarse-grained sandstone; one or two thin light-grayish-red-purple to grayish-green and gray crossbedded sandstone beds; mudstone contains abundant orange zeolite (clinoptilolite), calcite veins, and some chalcedonized wood; well exposed; forms broad top of ridge	18.3	60.0
42. Sandstone, volcanic, light-olive-gray to yellowish-brown, fine-grained to conglomeratic, medium-bedded; crossbedded with heavy mineral concentrations along bedding planes; lenticular; interbedded with a few brownish-gray mudstone beds; forms ledge	6.5	21.5
Disconformity		
41. Mudflow conglomerate, olive-gray; weathers brown; pebbles and cobbles of various intermediate volcanic rocks in upper part; upper 0.6–0.9 m (2–3 ft) contain sub-rounded boulders up to 15.2 cm (6 in.) in diameter in a		

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Middle sandstone member—Continued		
Mudflow conglomerate unit—Continued		
41. Mudflow conglomerate, etc.—Continued fine-grained, green mud matrix; orange zeolite (clinoptilolite) common; large calcite veins; unit grades into gray-green mudstone at base; forms base of resistant cliff; units 44 through 41 resemble member F of the Maudlow Formation, (p. B39, this report)	6.1	20.0
Total mudflow conglomerate unit	54.0	177.5
40. Mudstone and siltstone, olive-gray, structureless, siliceous; weathers brown; abundant orange zeolite and calcite veins; thin olive-gray fine-grained volcanic sandstone, laminated and crossbedded at top; forms slope	20.4	67.0
39. Mudstone and siltstone, olive gray, noncalcareous; abundant calcite veins; medium-dark-gray white-spotted siliceous resistant mudstone, 1.2 m (4 ft) thick at top, forms ledge; olive-gray fine-grained, friable thin-bedded laminated volcanic sandstone at base; forms slope	10.7	35.0
38. Mudstone and siltstone, olive-gray to olive-black, siliceous; interbedded with olive-gray fine-grained thin-bedded nodular-weathering volcanic sandstone; crossbedded in places; some laminae; veins of zeolite (mordenite and clinoptilolite) common; abundant fossil wood and calcium carbonate in float; forms resistant slope	14.2	46.5
37. Mudstone and siltstone, greenish-gray to olive-gray, siliceous; interbedded with olive-gray fine- to medium-grained volcanic sandstone in beds about 5 cm (2 in.) thick; abundant fossil wood and carbonaceous material; forms resistant slope	5.7	18.6
36. Covered interval; creek bed-float is olive-gray blocky-weathering siltstone and mudstone	25.9	85.0
35. Mostly covered interval; mudstone, olive-gray, interbedded with light-olive-gray fine-grained volcanic sandstone in lenticular beds in the lower part	18.6	61.0
34. Sandstone, volcanic, light-greenish-gray to light-olive-gray, fine-grained, thin-bedded, crossbedded, calcareous, partly quartz-rich; contains zones of brown-weathering cannonball-type nodules and abundant calcium carbonate veins; forms small ridge which disappears to the north but persists to the south	18.6	61.0

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

Sedan Formation—Continued Middle sandstone member—Continued	Thickness (meters)	(feet)
33. Mostly covered interval; predominantly fine-grained mudstone, tuff and sandstone; pale-olive mudstone well exposed at base	15.2	50.0
32. Mudstone and siltstone, grayish-olive, massive, calcareous; wood and carbonaceous plant debris in upper part; middle part is olive-gray fine-grained calcareous thin-bedded volcanic sandstone; lower part is olive-gray and brownish-gray massively bedded calcareous sandstone; forms slope	15.2	50.0
31. Mostly covered interval; some olive-gray mudstone outcrop with olive-gray fine-grained volcanic sandstone lenses; about 6 m (20 ft) of well-exposed brown mudstone with concentric weathering patterns at base	27.1	89.0
30. Sandstone, volcanic, dark-greenish-gray and light-olive-gray, very fine- to fine-grained, thin-bedded; breaks into irregular slabs; forms small ridge	17.1	56.0
29. Partly covered interval; float is greenish-gray and olive-gray, fine-grained calcareous volcanic sandstone; outcrop in center of interval is greenish-gray and olive-gray medium- to coarse-grained crossbedded thin-bedded calcareous volcanic sandstone; forms slope	24.4	80.0
28. Mostly covered interval; upper 3 m (10 ft) consists of sandstone and volcanic pebble conglomerate; sandstone is volcanic, greenish-gray to light olive gray, fine to medium grained, calcareous, and contains much organic debris; subcrop of remainder of unit is volcanic sandstone and mudstone	18.9	62.0
27. Mostly covered interval; upper 1.5 m (5 ft) well exposed devitrified tuff and mostly fine grained tuffaceous sandstone; both are light to dark olive gray, thick bedded, and have abundant organic debris; sandstone debris on remainder of slope	18.3	60.0
26. Sandstone, volcanic, olive-gray, conglomeratic, massive; contains numerous clay pebbles and subhedral plagioclase crystals; orange zeolite in irregular pods; matrix is mudstone in part, probably reworked crystal tuff; 0.6 m (2 ft) of grayish-green thin-bedded sandstone at base	3.0	10.0
25. Mostly covered interval; yellowish-gray volcanic mudstone exposed near top; weathers dark yellowish brown; olive-gray fine-grained volcanic		

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Middle sandstone member—Continued		
25. Mostly covered interval, etc.—Continued sandstone with much carbonaceous plant material makes up subcrop on remainder of slope	22.3	73.0
24. Sandstone, volcanic, grayish-olive and light-olive-gray, fine-grained, thin-bedded, crossbedded, noncalcareous, resistant; interbedded with minor dark mudstone; 0.6-7.6 cm (0.25-3 in.) bedding outlined by heavy minerals including magnetite; forms ridge with unit 22	10.1	33.0
23. Sandstone and mudstone, volcanic, grayish-olive and light-olive-gray; fine-grained lenticular sandstone; light-olive-gray zeolite-rich (stilbite, laumontite and clinoptilolite) carbonaceous siltstone near base; unit forms shallow valley between units 24 and 22	14.4	47.1
22. Sandstone, volcanic, olive-green and olive-gray, very fine to medium-grained, thin-bedded, crossbedded, very carbonaceous, zeolitic, noncalcareous; forms ridge with unit 24	8.7	28.5
21. Siltstone, very fine grained sandstone and mudstone, grayish-green and olive-gray; contains abundant silicified wood; medium-dark-gray conglomeratic sandstone breccia, weathers with a very characteristic grayish-orange-pink rind; bed 0.3-0.6 m (1-2 ft) thick at base forms ledge	15.5	51.0
20. Covered interval; float consists of grayish-green soft fine-grained sandstone, siltstone, and mudstone; forms saddle	17.4	57.0
19. Sandstone, volcanic, medium-light-gray to olive-gray, fine-grained, thin-bedded, crossbedded, calcareous, slightly biotitic; ledge forming in upper 3.7 m (12 ft); lower 4.3 m (14 ft) mostly covered; mudstone and very fine grained sandstone in subcrop; both are volcanic, dark greenish gray, and siliceous (Parkman Sandstone equivalent)	8.2	26.8
18. Sandstone, medium-light-gray to light-olive-gray, mottled, fine-grained, crossbedded, contorted-bedded, thin-bedded, friable, calcareous, biotitic; lenses of grayish-olive-green brown weathering siliceous mudstone; forms ledge (Parkman Sandstone equivalent)	12.5	41.0
17. Mudstone, medium-dark-gray, siliceous; twig and leaf imprints (Parkman Sandstone equivalent)	4.8	15.8
Total middle sandstone member	491.0	1,611.1

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Welded tuff member		
16. Mostly covered interval; a few outcrops of welded tuff and pale-yellowish-green and pale-reddish-brown welded tuff, with abundant biotite in upper part; interbedded dark-greenish-gray and olive-gray mudstone and fine-grained volcanic sandstone in lower part (Parkman Sandstone equivalent)	21.6	70.9
15. Sandstone, light-gray, fine-grained, crossbedded, friable, calcareous, biotitic; hard greenish-gray limy sandstone lenses and layers; upper part is very fine- to fine-grained, has contorted bedding in thin layers, and is noncalcareous in part; forms ledges (Parkman Sandstone equivalent)	3.9	12.9
14. Mostly covered interval; greenish-gray sandstone and conglomeratic sandstone; weathers orange at top; middle part is greenish-gray siliceous mudstone in subcrop; light- to medium-gray fine-grained quartzose calcareous sandstone at base (Parkman Sandstone equivalent)	7.9	25.8
Total Parkman Sandstone equivalent	(58.9)	(203.2)
13. Mostly covered interval; light- to dark-gray siliceous mudstone, with carbon markings; weathers pinkish gray and light olive gray at top; light-greenish-gray, light-gray biotitic welded tuff in subcrop throughout and in outcrop at base; greenish-gray fine-grained calcareous volcanic sandstone common in interval to north	14.4	47.2
Total welded tuff member	47.8	156.8
Break in section: offset to S½NW¼ sec. 6, T. 4 N., R. 8 E.		
Lower sandstone member:		
12. Partly covered interval; light olive-gray to grayish-olive fine- to medium-grained noncalcareous volcanic sandstone in upper part just below welded tuff member; grayish olive siltstone in lower part; forms slope	7.0	22.9
11. Sandstone, volcanic, olive-gray, fine- to medium-grained, thin-bedded, calcareous; contains some brown-weathering elongate calcareous concretions about 0.6 m (2 ft) high and 2 m (6 ft) long in upper 7.5 m (24.6 ft); underlain by 0.9 m (3 ft) of dark gray siliceous mudstone containing abundant carbonaceous material and 3 m (10 ft) of greenish-gray medium-grained to conglomeratic		

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Lower sandstone member—Continued		
11. Sandstone, volcanic, etc.—Continued massive slightly calcareous volcanic sandstone, crossbedded and thin-bedded in basal part	11.5	37.6
10. Sandstone, light-olive-gray, olive-gray, and yellowish-gray, fine-grained, thin-bedded, crossbedded; imprints of leaves, needles, wood, and carbon films abundant; forms ridge	6.9	22.5
9. Partly covered interval; olive-gray and greenish-gray fine- to medium-grained thin-bedded cross-bedded noncalcareous to slightly calcareous volcanic sandstone; beds up to 10 cm (4 in.) thick; abundant organic material, leaves, wood, and so forth; forms steep slope below ridge	21.9	72.0
8. Covered interval; slope covered by debris from units 9, 10, and 11; probably interbedded medium-grained volcanic sandstone and mudstone; forms steep slope	18.6	61.1
7. Mudstone, olive-gray; grayish-black ironstone lenses in upper part; yellowish-orange and dusky yellow medium- to coarse-grained calcareous feldspathic volcanic sandstone cross-bedded in lower 1.5 m (5 ft)	4.9	16.2
6. Mudstone, siltstone, and sandstone, volcanic, dark-greenish-gray and light-olive-gray; has minor very-dark-brown to grayish-black-weathering ironstone nodules throughout; forms slope	12.0	39.2
5. Partly covered interval; volcanic, olive-gray, dark-gray, olive-green, calcareous and siliceous; sandstone and siltstone have minor mudstone; a few grayish-black-weathering ironstone nodules; sandstone is mostly fine grained, some medium-grained;upper 0.6 m (2 ft) is medium-grained dark-greenish-gray magnetite-rich sandstone which forms low ledge; whole unit forms slope	15.2	50.0
4. Sandstone, dark-greenish-gray, medium- to coarse-grained, partly conglomeratic; some interbedded mudstone; 2–3-m (7–10-ft) resistant ledge at top is olive-gray crossbedded very calcareous and magnetite-rich sandstone; interval of greenish-gray mudstone next below forms rubbly slope; olive-gray-weathering medium- to coarse-grained calcareous volcanic sandstone forms ledge near middle; lower part consists of a series of ledges of greenish-gray-weathering medium-grained to		

Type section of the Sedan Formation and reference sections of the Lennep Sandstone and Bearpaw Shale Members—Continued

	Thickness (meters)	Thickness (feet)
Sedan Formation—Continued		
Lower sandstone member—Continued		
4. Sandstone, etc.—Continued conglomeratic crossbedded calcareous volcanic sandstone	21.5	70.5
3. Sandstone, olive-gray and dark-greenish-gray, medium- to coarse-grained, crossbedded, thin- to medium-bedded, feldspathic, calcareous, partly magnetite-rich; has some friable lenses; concentric weathering pattterns; forms series of ledges on steep slope; greenish-gray mudstone, with lenses of dark-greenish-gray medium-grained magnetite-rich sandstone, forms rubble-covered slope of upper 9 m (30 ft); lower 6 m (20 ft) is volcanic sandstone, which contains some brown-weathering elongate limy nodules near top and forms ledge; imprints of leaves, needles, and other carbonaceous films abundant throughout interval	15.2	50.0
2. Mostly covered interval; upper part is steep slope covered with volcanic sandstone and conglomeratic sandstone rubble containing some organic debris; lower 0.6 m(2 ft) is grayish-olive medium- to coarse-grained crossbedded thin-bedded feldspathic noncalcareous volcanic sandstone	15.8	52.0
1. Mostly covered interval; light-olive-gray fine- to medium-grained friable feldspathic volcanic sandstone near middle; 0.6 m (2 ft) of lignitic coal (pollen and spore colln. D4670) overlain by light-gray fine- to medium-grained soft volcanic sandstone; weathers orange at base	5.0	16.3
Total lower sandstone member	155.5	510.3
Total Sedan Formation	1,075.4	3,528.3
Conformable contact		
Eagle Sandstone—upper unnamed member	81.4	267.0

Type section of the Maudlow Formation

[The eight members of the Maudlow were measured at the following localities in T. 4 N., R. 5 E. (except member B): (H) northeast side of Table Mountain NW¼ sec. 16; (G) N½ sec. 16; (F) NW¼ sec. 22 and SW¼ sec. 15; (E) S½ sec. 10; (D) NE¼ sec. 15 and SE¼ sec. 10; (C) center sec. 28; (B) center sec. 13 (T. 4 N., R. 4 E.); (A) SE¼ sec. 26]

	Thickness (meters)	Thickness (feet)
Maudlow Formation:		
Member H:		
2. Siltstone, fine-grained sandstone, and claystone, olive-gray, thin-bedded, calcareous; many leaf impressions	7.6+	25+
1. Conglomerate and breccia, volcanic, medium-dark- to light-gray; angular to subrounded fragments of assorted altered intermediate volcanic rocks,		

Type section of the Maudlow Formation—Continued

	Thickness (meters)	Thickness (feet)
Maudlow Formation—Continued		
Member H—Continued		
1. Conglomerate and breccia, etc.—Continued ranging from microscopic to 2 m (6 ft) in diameter, set in an abundant matrix (as much as 50 percent) composed largely of massive zeolite (laumontite) and clay (montmorillonite); caps Table Mountain	30.5	100
Total member H	38.1+	125+
Contact covered; probably disconformable		
Member G:		
9. Claystone and some siltstone, volcanic, brownish-yellow, poorly bedded; forms gentle slope	73.5	241
8. Claystone, volcanic, olive-gray, light-brown, much-silicified, partly calcareous; weathers to pale-yellowish-brown and reddish-brown soil; conchoidal weathering habit; minor medium-grained olive-gray sandstone near base; much silicified sycamore wood	66.8	219
7. Claystone, grayish-green, olive-gray, and light-brown; subconchoidal fracture, breaks into little angular bits; many silicified wood and leaf imprints, largely sycamore; zeolites common; unit weathers into gentle barren slope	26.5	87
6. Claystone, volcanic, dark-grayish-green, olive-gray, medium-gray, commonly siliceous; interbedded with a few ledges of siltstone; rare calcareous cannonball nodules with irregular rounded shapes; weathers to cubes and needles 0.6 cm–0.3 m (0.25 in.–1 ft) across; some indistinct bedding; minor silicified wood	32.0	105
5. Claystone and siltstone, light-brown; breaks into small chips with subconchoidal fracture; secondary zeolites in fractures; forms slope	33.5	110
4. Sandstone, volcanic, olive-gray to yellowish-brown, fine- to coarse-grained, crossbedded; irregularly bedded in 5–15 cm (2–6 in.) beds; large ripple marks; much plant debris, pine needles, leaves carbonized wood; weathers dark yellowish brown; upper 23.7 m (78 ft) forms ledge. Lower 79.6 m (261 ft) forms partly covered slope of grayish-green medium- to fine-grained massive unbedded volcanic sandstone, which weathers dark yellowish brown	103.3	339
3. Sandstone, volcanic, dark-greenish-gray, olive-gray, medium-grained; laminated and crossbedded with heavy mineral concentrations on bedding surfaces; forms ledge	7.9	26
2. Sandstone, volcanic, yellowish-brown, partly grayish-green, fine-grained to slightly conglomer-		

Type section of the Maudlow Formation—Continued

	Thickness (meters)	Thickness (feet)
Maudlow Formation—Continued		
Member G—Continued		
2. Sandstone, volcanic, etc.—Continued atic; indistinct bedding; weathers yellowish brown; forms slope between units 1 and 3	20.1	66
1. Sandstone, volcanic, light-olive-gray, medium- to coarse-grained; rude crossbedding; contains white-weathering feldspars; weathers light brown and pale yellowish brown; forms low ridge	35.7	117
Total member G	399.3	1,310
Base of section covered; steep slope marks contact; unit 7 of member F, represented by purple gray soil, may extend 3–6 m (10–20 ft) into unit 1 of member G.		
Member F:		
7. Covered interval; float is grayish-red-purple very fine grained claystone	42.3	139
6. Claystone, volcanic, grayish-red-purple, brownish-gray, and grayish-blue-green; partly covered, like unit 7; much colluvium on surface of outcrop	34.4	113
5. Mudflow conglomerate, volcanic, largely vivid grayish-red-purple, greenish-gray, and grayish-blue-green, massively bedded; boulders up to 0.6 m (2 ft) in diameter; much zeolitic material (mordenite and clinoptilolite); forms ledge	10.7	35
4. Covered interval; float suggests conglomerate like unit 3	10.7	35
3. Conglomeratic volcanic claystone with interbedded fine-grained sandstone and devitrified crystal vitric tuff, olive gray; boulders up to 0.3 m (1 ft) in diameter, both rounded and angular; not bedded; weathers dark brown; forms ledge; 1.5 m (5 ft) of relief on disconformable surface between units 2 and 3	13.1	43
2. Tuff, crystal-lithic, medium-greenish-gray and grayish-red-purple; has brown limy layers and nodules up to 46 cm (18 in.) in diameter; bedding defined by color changes; fine-grained hackly surface; well exposed in streambed	18.6	61
1. Volcaniclastic conglomerate and breccia; boulders up to 1.5 m (5 ft) in diameter of grayish-red-purple, greenish-gray, and grayish-blue-green augite-hornblende dacite and rhyodacite; boulders mostly fresh, but some weathered; matrix is olive-gray and pale-yellowish-brown medium-grained poorly bedded tuffaceous volcanic sandstone; zeolites common; some silicified conifer wood; forms massive cliff in places, low ridge in others; lower 6 m (20 ft) poorly exposed	62.5	205
Total member F	192.3	631
Disconformable abrupt contact		

Type section of the Maudlow Formation—Continued

Maudlow Formation—Continued Member E:	Thickness (meters)	Thickness (feet)
10. Sandstone, volcanic, and crystal-lithic tuff, olive-gray, light-olive-gray, fine- to medium-grained, massively bedded, calcareous; sandstone conglomeratic in places; 3-m (10-ft)-thick lens of mudflow conglomerate with porphyritic hornblende-augite rhyodacite boulders as much as 1.2 m (4 ft) in diameter 4.6 m (15 ft) above base; silicified conifer wood and brown-weathering lime nodules common; forms slope	17.7	58
9. Sandstone, olive-gray, yellowish-brown, tuffaceous, medium-grained to conglomeratic; contains volcanic pebbles as much as 0.6 cm (0.25 in.) in diameter; crossbedded in upper part; forms steep slope with ledges at top and bottom; partly covered	38.4	126
8. Sandstone, volcanic, and tuff, grayish-green and light-olive-gray, fine- to medium-grained, poorly bedded, slightly calcareous; a few siliceous nodules; weathers olive gray, pale brown, and yellowish brown; forms slope	24.1	79
7. Tuff and sandstone, volcanic; dark-yellowish-brown and medium-olive-gray tuff with interbedded medium-grained poorly bedded sandstone; largely covered; forms slope	32.0	105
6. Sandstone, volcanic light-olive-gray, dark-yellowish-brown, medium- to coarse-grained, calcareous; weathers olive gray; massively bedded with indistinct laminae; some crossbedding; interbedded with minor fine-grained sandstone; some conglomeratic sandstone at base; large lime nodules, as much as 1.2 m (4 ft) in diameter at top; locally forms cliff	15.8	52
5. Sandstone, tuffaceous, gray, grayish-green, dark-yellowish-brown, massively bedded; some weathers pale brown; calcareous veins common; limy nodules present in upper beds; forms low barren slope	48.1	158
4. Sandstone, tuffaceous, grayish-green and olive-gray, indistinctly bedded, calcareous; brown-weathering limy nodules as much as 2 m (6 ft) in largest dimension common; interbedded with minor tuffaceous light-brown calcareous sandstone with plant remains, which forms 1.5-m (5-ft)-thick ledge at base and 0.3 m (1 ft) ledge 15 m (50 ft) above base; unit forms low slope	26.5	87
3. Sandstone, volcanic, tuffaceous, grayish-green, fine-grained, massively bedded, slightly calcareous; contains large olive-gray-weathering limy nodules; forms slope	6.1	20

Type section of the Maudlow Formation—Continued

	Thickness (meters)	Thickness (feet)
Maudlow Formation—Continued		
Member E—Continued		
2. Sandstone, volcanic, light-olive-gray and grayish-green; weathers olive gray; crossbedding emphasized by local concentrations of heavy minerals; forms ridge	4.9	16
1. Claystone, olive-gray, moderately to thin-bedded, siliceous; plant remains; interbedded with light-olive-gray conglomeratic volcanic sandstone; crossbedded with porphyritic dacite pebbles as much as 1.3 cm (0.5 in.) in diameter; forms poorly exposed slope	17.4	57
Total member E	231.0	758
Disconformable contact		
Member D:		
4. Tuff, vitric, welded and unwelded, grayish-green (10GY5/2) and pale-reddish-brown (10R5/4); biotite and hornblende visible accessories; forms ridge	97.5	320
3. Tuff and tuffaceous sandstone, fine- to medium-grained, massively to fine-bedded; interbedded with dark-gray and grayish-brown claystone, some fissile; forms slope	66.1	217
2. Conglomerate and conglomeratic sandstone, volcanic; largely welded tuff pebbles as much as 10 cm (4 in.) in diameter in grayish-green or pale-red matrix, unconformably overlies unit 1	3.7	12
1. Tuff, vitric, welded, pale-yellowish-brown, grayish-yellow-green, olive-gray, dark-gray; much accessory biotite; glassy perlitic zone 1.2 m (4 ft) thick occurs 1.5 m (5 ft) from top of unit	38.4	126
Total member D	205.7	675
Covered contact; probably disconformable		
Member C:		
10. Covered interval; may be sandstone like unit 7. Covered by float from biotitic welded tuff of member D	10.7	35
9. Sandstone, volcanic, light- to medium-olive-gray, medium-bedded, calcareous; weathers light brown; beds as much as 46 cm (18 in.) thick; forms ledge	3.0	10
8. Claystone, and devitrified vitric tuff, grayish-red-purple, massively bedded; cannonball concretions as much as 20 cm (8 in.) in diameter; weathers with suggestion of columnar structure	4.9	16
7. Sandstone, volcanic, olive-gray, fine- to medium-grained, crossbedded; hornblende concentrated on bedding surfaces; largely covered; forms saddle; no evidence of conglomerate	65.2	214

Type section of the Maudlow Formation—Continued

	Thickness (meters)	Thickness (feet)
Maudlow Formation—Continued		
Member C—Continued		
6. Sandstone, tuffaceous, olive-gray, very fine grained to conglomeratic, medium- to thick-bedded; some cross laminations; calcareous in places; weathers light brown; 0.6 m (2 ft) interbedded with pyroxene-rich vitric crystal tuff; rare plant fragments; forms ridge	15.5	51
5. Sandstone, volcanic, gray, fine-grained, generally poorly bedded; small-scale crossbedding in places; forms slope	10.4	34
4. Sandstone, tuffaceous, olive-gray, fine-grained, friable; forms upper 14 m (45 ft) of unit; partly covered with yellowish-brown soil; lower beds are medium-gray and pale-reddish-brown fine-grained to conglomeratic well-bedded volcanic sandstone; forms slope	31.4	103
3. Sandstone, volcanic, light-gray or grayish-yellow-green, medium- to coarse-grained, thick-bedded (up to 0.9 m (3 ft)), crossbedded; surfaces marked by concentrations of heavy minerals; much graded bedding; interbedded with volcanic conglomerate having andesitic boulders as large as 15 cm (6 in.) in a tuffaceous matrix which is common in lower 15 m (50 ft); forms ridge	31.7	104
2. Sandstone, volcanic, dark-gray, conglomeratic, mostly massively bedded; feldspars and hornblendes visible on surface; weathers yellowish brown; some crossbedding	7.9	26
1. Mostly covered; float suggests coarse-grained lithic tuff, volcanic sandstone, and pebble to boulder conglomerate with boulders as much as 15 cm (6 in.) in diameter, some from member B, rounded with weathered rinds; forms slope	61.0	200
Total member C	241.7	793
Disconformable contact		
Member B:		
7. Vitric crystal tuff, grayish-red-purple, grayish-red, dusky-red-purple, massive, pyroxene-rich; forms ridge	32.6	107
6. Volcanic conglomerate and breccia in upper part, grayish-red-purple, massive, monolithologic; contains porphyritic hornblende-pyroxene dacite; conglomerate has subrounded boulders as large as 1.2 m (4 ft) in diameter; mostly covered; forms steep slope for upper 15 m (50 ft); lower part is moderate-red-purple banded tuffaceous volcanic sandstone; some crossbedding at base; forms gentle slope	59.7	196
5. Volcanic conglomerate and breccia, grayish-red-purple, massive, monolithologic; contains por-		

Type section of the Maudlow Formation—Continued

	Thickness (meters)	Thickness (feet)
Maudlow Formation—Continued		
Member B—Continued		
5. Volcanic conglomerate, etc.—Continued phyritic hornblende-pyroxene dacite; subangular to rounded cobbles, and boulders as much as 0.3 m (1 ft) in diameter; most fragments between 1.3–2.5 cm (0.5–1 in.) in diameter	12.5	41
4. Crystal-lithic tuff and sandstone, volcanic, grayish-red-purple, medium- to coarse-grained, thin- to moderate-bedded; 0.9 m (3 ft) bed at base, other beds 2.5–5 cm (1–2 in.) thick; forms steep slope	18.3	60
3. Volcanic breccia, grayish-red-purple; contains monolithologic porphyritic hornblende-pyroxene dacite; indistinct cobbles and boulders up to 15 cm (6 in.); matrix same composition; some sorting; forms ridge	20.7	68
2. Lithic-crystal tuff and sandstone, volcanic, grayish-red-purple, fine- to coarse-grained, rudely bedded; much plagioclase, some hornblende; more resistant than unit 1	9.8	32
1. Lithic crystal tuff and sandstone, volcanic, grayish-red-purple, fine-grained; forms gentle slope above gully; partly covered	6.1	20
Total member B	159.7	524
Contact between member A and member B covered in sec. 13; disconformable, abrupt contact exposed in sec. 26.		
Member A:		
11. Sandstone, volcanic, olive-gray, greenish-gray, gray, pale-brown, fine- to coarse-grained, well-bedded; float suggests some conglomerate; sandstone crossbedded with mafic minerals concentrated on bedding; secondary zeolites (clinoptilolite), carbonaceous films, and plant remains abundant; *"Cissus" marginata* (Lesquereux) Brown identified by J. A. Wolfe (written commun., 1962); partly covered; forms steep slope	16.8	55
10. Sandstone, volcanic, olive-gray, coarse-grained, partly conglomeratic, blocky; feldspars weather white; crossbedding with mafic minerals, concentrated on bedding planes; weathers yellowish gray to pale yellowish brown; forms ridge	7.6	25
9. Mostly covered; upper 9 m (30 ft) made up of medium-gray olive-gray massive tuffaceous volcanic conglomerate and sandstone; conglomerate has rounded boulders with diameters as large as 5 cm (2 in.), intact framework, and some boulders of "spotted" Cretaceous sandstone cemented with analcite; middle part covered; lower 6 m (20 ft) is interbedded conglomerate and sandstone; sandstone is volcanic, tuffaceous, medium gray, olive		

Type section of the Maudlow Formation—Continued

	Thickness (meters)	Thickness (feet)
Maudlow Formation—Continued		
Member A—Continued		
9. Mostly covered, etc.—Continued gray, yellowish gray, and fine grained to conglomeratic; scattered boulders in conglomerate as much as 46 cm (18 in.) in diameter, most 1.3 cm (0.5 in.), all porphyritic volcanics; massive bedding; forms slope	45.7	150
8. Sandstone, volcanic, light-olive-gray, greenish-gray, grayish-orange-pink, fine-grained to conglomeratic, siliceous; color changes accentuate bedding; beds about 46 cm (18 in.) thick; small-scale festoon crossbedding marked by heavy mineral concentrations present in finer grained beds; uppermost bed has calcareous cannonball concretions; thin volcanic conglomerate beds 0.6m (2ft) thick near base, cobbles as much as 2 cm (0.75 in.) in diameter; some light-gray, some dark-yellowish-orange siliceous interbedded mudstone lenses throughout unit; weathers medium dark gray and moderate brown; forms slope	15.2	50
7. Sandstone, volcanic, light-olive-gray, medium- to coarse-grained, massive; weathers olive gray; forms slope	6.1	20
6. Sandstone, volcanic, and lithic-crystal tuff, moderate-olive-gray, light-olive-gray, dusky-yellow-green, some mottled, fine-grained to conglomeratic, mostly coarse-grained, mostly massive, siliceous; some laminations; some clay layers; bedding 1.8–2.4 m (6–8 ft) thick marked by color changes; some plant remains; weathers yellowish gray and pale yellowish brown; forms ledge; upper 3 m (10 ft) forms small cliff	13.7	45
5. Sandstone and mudstone, volcanic, pale-yellowish-brown, olive-gray; sandstone fine to coarse grained; much plant material; calcareous cannonballs at base; thin interbeds of black shaly material; one thin bed of yellowish-gray mostly massive pyroxene-rich tuff in middle forms steep slope below ledges of unit 6	24.4	80
4. Sandstone and dark gray mudstone, volcanic; sandstone is light olive gray with scattered pods of grayish orange, fine grained to conglomeratic, mostly medium to coarse grained	4.6	15
3. Interbedded volcanic sandstone, lignitic or carbonaceous mudstone and shale:		
A. Mudstone, volcanic, grayish-brown, shaly, carbonaceous; plant imprints; white specks, altered feldspars, common	.9	3
B. Sandstone, volcanic, grayish-orange, friable, fine- to medium-grained; limonite staining; much organic material	.3	1

Type section of the Maudlow Formation—Continued

Maudlow Formation—Continued Member A—Continued	Thickness (meters)	Thickness (feet)
C. Mudstone, volcanic, grayish-brown, carbonaceous; white feldspars; plant fragments; weathers pale yellowish brown	.6	2
D. Shale, pale-brown, grayish-black, lignitic; interbedded with very pale orange fine-grained to conglomeratic volcanic sandstone; angular fragments up to 3 mm in diameter; much carbonaceous plant material; pollen and spore colln. D3324	1.5	5
E. Sandstone, grayish-black, lignitic; interbedded claystones, as in B	3.1	10
	6.4	21
2. Sandstone, volcanic, grayish-black, fine-grained, quartzose; weathers moderate yellowish brown; limonitic staining; forms ledge	0.6	2
1. Sandstone, volcanic, moderate-olive-gray, fine-grained to conglomeratic; white feldspars stand out on fresh surfaces; some cannonballs 15–30 cm (6–12 in.) in diameter; much carbonaceous material; weathers olive gray; moderate-olive-gray massive volcanic claystone at base, with many leaf imprints and carbonaceous films; indistinct bedding; fractured outcrop; forms steep slope	15.6	51
Total member A	156.7	514
Total Maudlow Formation	1,624.5+	5,330+

Contact with underlying Telegraph Creek Formation (upper part) disconformable (see text).

Reference section for part (member D) of the Maudlow Formation

[NW¼ sec. 7, T. 4 N., R. 5 E. (fig. 8)]

Maudlow Formation (part) Disconformable contact with member E Member D:	Thickness (meters)	Thickness (feet)
5. Welded tuff, mottled-pale-red and grayish-yellow-green; much black biotite; fine-grained pale-green lithic fragments, in matrix of biotite-rich pale-red tuff form upper part of unit; lower part is dusky-yellow-green pale-olive fine-grained volcanic claystone and sandstone; limonitic staining; forms slope below unit 4	15.2	50
4. Welded tuff, grayish-yellow-green, pale-reddish-brown, pale-yellowish-brown, moderate-red (5R4/4), fine-grained, biotitic; forms vertical ridge	30.5	100
3. Sandstone, volcanic, olive-gray, fine- to medium-grained, calcareous; some calcareous nodules; interbedded with volcanic conglomerate and grayish-green tuff in lower part	33.5	110

Reference section for part (member D) of the Maudlow Formation—Continued

	Thickness (meters)	Thickness (feet)
Member D—Continued		
2. Conglomerate, volcanic, olive-gray; rounded boulders of welded tuff and porphyritic intermediate volcanic rocks up to 8 cm (3 in.) in diameter in volcanic matrix; olive-green fine-grained thin-bedded volcanic sandstone present in lower 1.5 m (5 ft)	5.2	17
1. Vitric tuff, welded and unwelded, grayish-green, greenish-gray, light-greenish-gray, fine-grained, crumbly, biotitic; partly covered; forms slope	27.4	90
Total member D	111.8	367
Contact with member C not exposed		

Reference section for part (member B) of the Maudlow Formation

[SW ¼ sec. 11, NW ¼ sec. 14, T. 4 N., R. 5 E. (fig. 8)]

	Thickness (meters)	Thickness (feet)
Maudlow Formation (part)		
Disconformable contact with member C		
Member B:		
9. Sandstone, grayish-red-purple, partially conglomeratic, medium-bedded, crossbedded; pebbles of hornblende-pyroxene dacite as much as 2 cm (0.75 in.) in diameter form 10–20 percent of sandstone; upper 3 m (10 ft) and basal 8 m (25 ft) form low rounded ledges; middle covered	20.1	66
8. Sandstone, volcanic, grayish-red-purple, fine- to medium-grained, thin-bedded, crossbedded; forms slope between ledges of units 7 and 9	18.6	61
7. Sandstone, volcanic, and crystal tuff, grayish-red-purple, thick- and thin-bedded; 0.6 cm (0.25 in.) laminae of feldspar and hornblende crystals, some crossbedded; interbedded with minor volcanic breccia and conglomerate with fragments as much as 2.5 cm (1 in.) in diameter; forms resistant ledge with basal 5 m (15 ft) cliff	20.7	68
6. Sandstone, volcanic, grayish-red-purple, fine- to medium-grained, thin-bedded; beds 1.3–10 cm (0.5–4 in.) thick with irregular surfaces; some pockets of coarse-grained sandstone; gray sandstone bed in middle; forms slope below unit 7	2.4	8
5. Conglomerate, grayish-red-purple, monolithologic, hornblende-pyroxene-dacite; subangular to subrounded pebbles as much as 5 cm (2 in.) in diameter in upper beds, average about 1.3 cm (0.5 in.), in matrix of similar composition; interbedded with grayish-red-purple fine-grained to conglomeratic thin sandstone; forms irregular ledges or hogbacks	11.8	38.5
4. Sandstone in upper part, volcanic, grayish-red, fine-grained, laminated to thin-bedded, crossbedded;		

Reference section for part (member B) of the Maudlow Formation—Continued

	Thickness (meters)	Thickness (feet)
Maudlow Formation—Continued		
Member B—Continued		
4. Sandstone, etc.—Continued beds 0.6–5 cm (0.25–2 in.) thick; some ripple marks; forms gully below conglomerate of unit 5; in lower part, grayish-red-purple poorly bedded lithic-crystal tuff has angular fragments of intermediate volcanic rocks as much as 1.3 cm (0.5 in.) in diameter, most 0.2 cm (0.1 in.), matrix same; forms rounded dark ledges	5.4	17.5
3. Crystal-lithic tuff, grayish-red-purple, massive; fragments as much as 0.6 cm (0.25 in.) in diameter; forms low area between resistant ledges of units 2 and 4	2.1	7
2. Sandstone, volcanic, and lithic-crystal tuff, grayish-red-purple, mostly fine- to medium-grained; upper 0.6 m (2 ft) lithic-crystal tuff with fragments as much as 0.6 cm (0.25 in.) in diameter, bedding regular; beds 0.6–5 cm (0.25–2 in.) thick in lower part, as much as 0.6 m (2 ft) thick in upper part; forms ledges	6.7	22
1. Crystal-lithic tuff, grayish-red-purple, fine- to medium-grained; feldspar crystals weather white; bedding irregular; graded bedding; lower 0.6 m (2 ft) forms resistant ledge, rest forms slope	6.4	21
Total member B	94.2	309
Disconformable contact with member A		

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