UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

STRATIGRAPHIC AND SEDIMENTOLOGIC STUDIES OF LATE PALEOZOIC STRATA IN THE EAGLE BASIN AND NORTHERN ASPEN SUB-BASIN, NORTHWEST COLORADO

by

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ABSTRACT

This report summarizes stratigraphic and sedimentologic data collected during the 1985 and 1986 field seasons from Late Paleozoic strata in the Eagle Basin and northern Aspen sub-basin, west-central Colorado. Strata investigated include the Eagle Valley Evaporite (upper part), the Maroon Formation, the Schoolhouse Tongue of the Weber Sandstone, and the sandstone of the Fryingpan River. These rocks crop out in structurally low areas and on the margins of the Laramide White River uplift.

The Eagle Valley Evaporite (above the lower evaporitic interval) was examined in one section only from the central part of the basin where it predominantly consists of shallow- and marginal-marine clastic deposits of the Eagle Basin seaway. This seaway was gradually filled in by prograding (mainly from the west) nonmarine deposits of the Maroon Formation. The contact between the Eagle Valley Evaporite and Maroon Formation is markedly time transgressive.

The Maroon Formation consists of 300 m (in the center of the basin) to 1000 m or more (on the basin margins) of mixed fluvial and eolian sand-sheet deposits. Fluvial sediments were deposited in braided river channels, in sheetfloods, and on floodplains. Facies and paleocurrent data indicate that climate was arid to semi-arid and that the axis of the Eagle Basin was strongly skewed to the east during Maroon time. Eolian sand-sheet deposits consist mainly of plane- and low-angle bedded very fine grained sandstone with abundant scattered coarse sand grains and granules interpreted as deflation lags. Eolian sediment transport was to the south-southeast. Silt eroded from the Maroon sand sheets was deposited as loess along the northwest margin of the ancestral Sawatch uplift. This loess is well exposed in the Ruedi Reservoir area where it forms one of few described pre-Quaternary loess deposits, also the thickest known loess accumulation.

The Schoolhouse Tongue of the Weber Sandstone (as much as 70 m thick) overlies and interfingers with the Maroon Formation over much of the Eagle Basin. The Schoolhouse Tongue is also an eolian sand-sheet deposit and represents an integral part of the Maroon depositional system. It is differentiated from the Maroon Formation mainly on the basis of its distinctive yellowish-gray color and characteristic hydrocarbon staining; the contact between the Maroon and the Schoolhouse Tongue is largely diagenetic in origin.

The sandstone of the Fryingpan River, previously designated the lower part of the State Bridge Formation, is also considered here to have been an integral part of the Maroon depositional system. This unit has a restricted occurrence along the margin of the ancestral Sawatch uplift and consists mainly of eolian dune deposits. It probably represents an ancient basin-margin dune field analogous to the modern Great Sand Dunes in south-central Colorado.

Climate change, associated with fluctuations in Gondwana glaciers, almost certainly controlled the mixed fluvial-eolian depositional style of the Maroon Formation. The stratigraphic distribution of both eolian and marine deposits in the Maroon Formation and correlative strata in the Eagle Basin argue for at least 30 separate glacio-eustatic-climatic cycles.

PURPOSE AND SCOPE

This report presents preliminary results of stratigraphic and sedimentologic field studies conducted in the late Paleozoic strata in the Eagle Basin and in the northern part of Aspen sub-basin, northwest Colorado. The Eagle Valley Evaporite, Maroon Formation, Schoolhouse Tongue of the Weber Sandstone, and the sandstone of the Fryingpan River were examined. Stratigraphic sections measured during the 1985 and 1986 field seasons comprise the bulk of the report. Sedimentologic and paleogeographic data and interpretations are summarized.

GEOLOGIC SETTING

Pennsylvanian and early Permian tectonism in the western United States resulted in development of the ancestral Rocky Mountains (Curtis, 1958; Mallory, 1972; Tweto, 1977; Kluth and Coney, 1981, Kluth, 1986). Orogenic highlands in Colorado included the ancestral Uncompaghre and Front Range uplifts, which bound the northwest-trending central Colorado trough, and the ancestral Sawatch uplift (DeVoto, 1972), which subdivided this trough into several sub-basins (Fig. 1). The Eagle Basin, generally regarded as the area in the central Colorado trough north of the northern margin of the Sawatch uplift, is one of these sub-basins. The Aspen sub-basin forms the area west of the Sawatch uplift and is a southern extension of the Eagle Basin. Deposition in the Eagle Basin and associated sub-basins was strongly controlled by local tectonics, relative sea-level changes, and climate (Mallory, 1971, 1972; Bartleson, 1972; Walker, 1972).

The Belden Formation, mainly a dark-gray or black shale of deltaic and marine origin, comprises the Early Pennsylvanian fill of the Eagle Basin (Fig. 2; Mallory, 1972). In the Middle Pennsylvanian, the effects of local tectonism were more pronounced and alluvial-fan and fan-delta deposits of the Minturn, Gothic, and Maroon (lower part) Formations accumulated adjacent to basin margins. These basin-margin facies include shallow-marine limestones that pass laterally into evaporite and clastic deposits of the Eagle Valley Evaporite (Mallory, 1971; Schenk, in press). Nonmarine rocks of the upper part of the Maroon Formation comprise the Late Pennsylvanian and Early Permian part of the basin fill.

The Maroon Formation is largely a sequence of nonmarine, red beds. It may be as thick as 4600 m in the Aspen sub-basin (Fig. 1; Freeman and Bryant, 1978), whereas to the north in the Eagle Basin the thickness of the Maroon is considerably less, about 300 to 1000 m. The contact between the Maroon Formation and underlying strata is transgressive, which in part explains the major thickness variations. In the Vail area (Fig. 3), Tweto and Lovering (1977) placed the lower Maroon contact at the top of a prominent marker horizon, the Jacque Mountain Limestone, however elsewhere in the basin the contact is generally placed at a color change between underlying brown and gray rocks and overlying red beds.

The nonmarine Schoolhouse Tongue of the Weber Sandstone (Brill, 1952) overlies the Maroon Formation over most of the Eagle Basin, and consists mainly of yellowish-gray sandstone that is extensively oil stained. The Schoolhouse Tongue has a maximum exposed thickness of about 65 to 70 m, but is locally much thinner and is absent in the eastern portion of the Eagle Basin (Freeman, 1971a). The contact between the Maroon Formation and the Schoolhouse Tongue is generally gradational and placed at the upper limit of red beds. Data presented in this report suggest that this contact is primarily of diagenetic origin.

The sandstone of the Fryingpan River is a pale reddish-orange sandstone

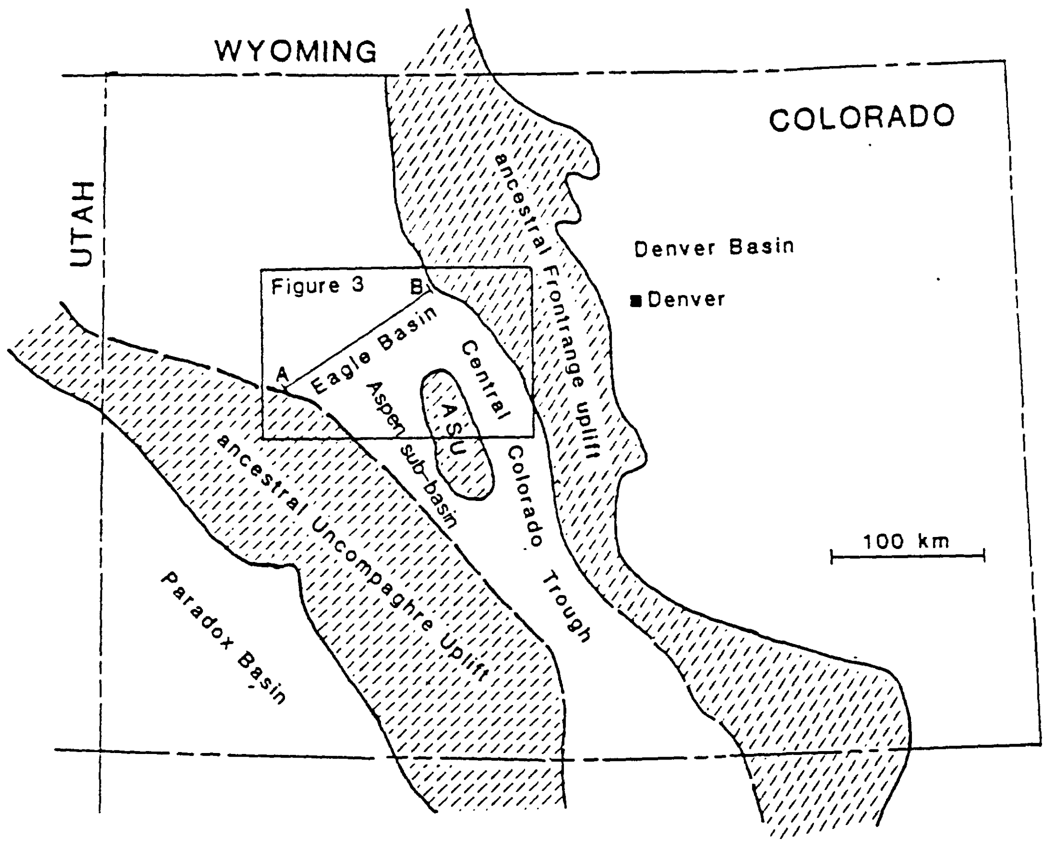


Figure 1. Schematic map showing the location of the ancestral Rocky Mountain highlands and basins in Colorado. ASU = ancestral Sawatch uplift; A-B is line of section for Figure 2. Adopted from Mallory (1972).

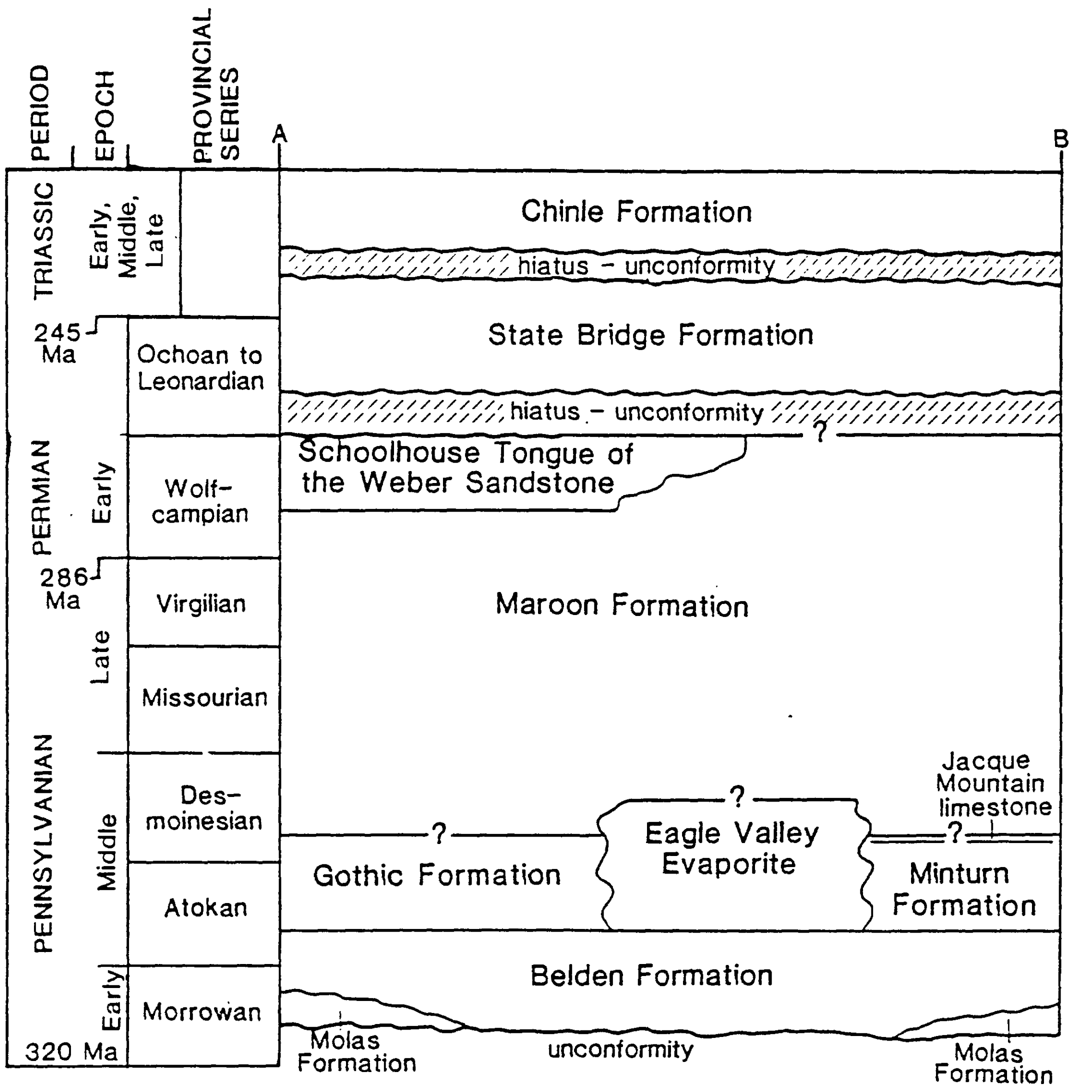


Figure 2. Schematic diagram showing stratigraphy of Pennsylvanian to early Mesozoic strata in the Eagle Basin. Line of section A-B is shown in Figure 1.

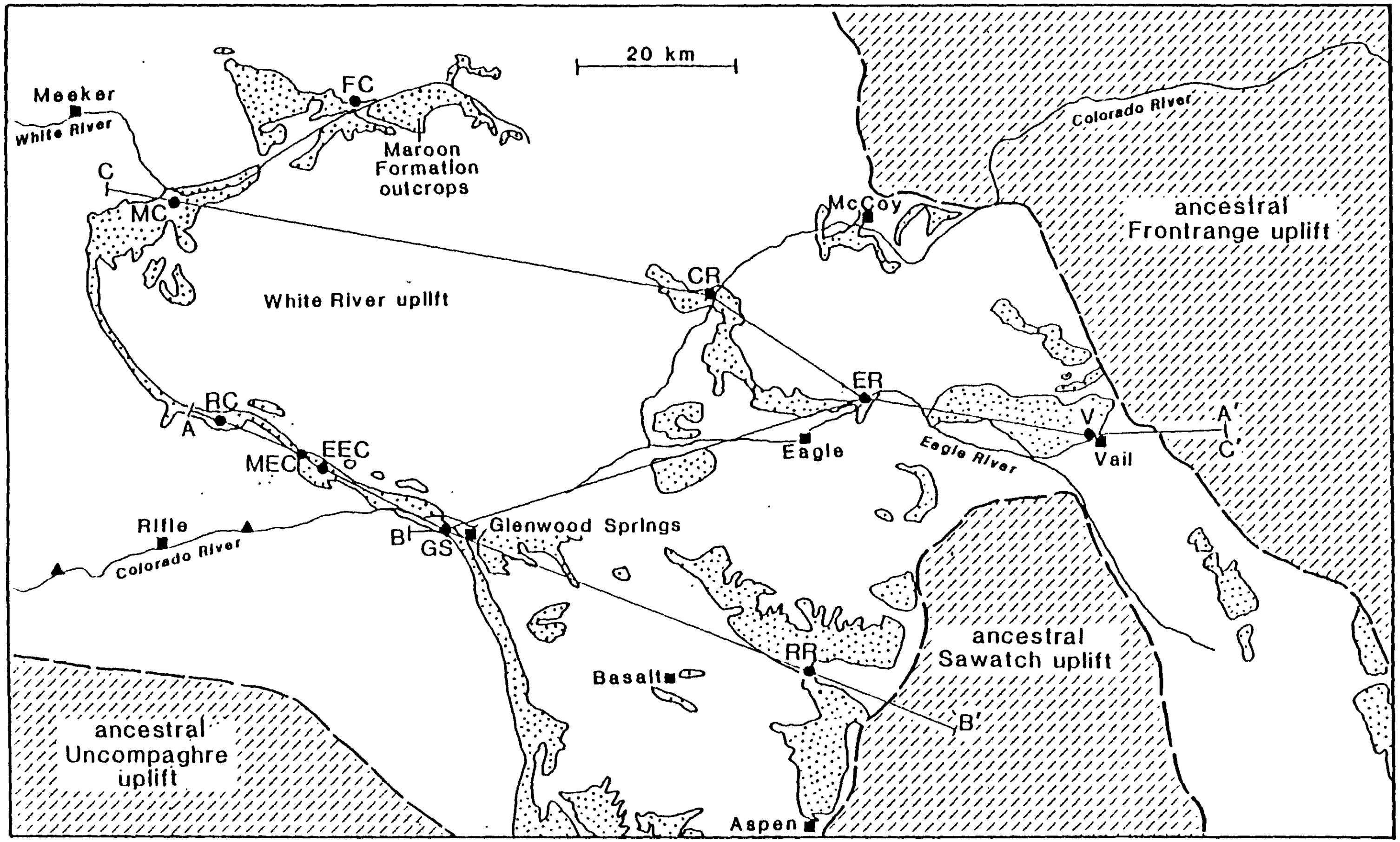


Figure 3. Map showing location of outcrops of the Maroon Formation. Dots show locations of stratigraphic columns shown in Figures 4-12: CR = Colorado River; EEC = East Elk Creek; ER = Eagle River; FC = Fawn Creek; GS = Glenwood Springs; MEC = Main Elk Creek; MC = Miller Creek; RC = Rifle Creek; RR = Ruedi Reservoir; V = Vail. A-A', B-B', and C-C' show locations of the lines of restored stratigraphic cross sections in Figures 15-17. Triangles (along Colorado River near Rifle) show location of faults on seismic lines of Waechter and Johnson (1985, 1986).

of eolian origin (Freeman, 1971b) with a maximum thickness of about 120 m. It is restricted to the Ruedi Reservoir area (Fig. 3) where it gradationally (over about 1 m) overlies the Maroon Formation. Freeman (1971a) defined the sandtone of the Fryingpan River as the lowest member of the overlying State Bridge Formation, however data presented in this report suggest that this unit was probably deposited as an integral part of the Maroon-Weber depositional system and is older than the State Bridge Formation.

The Maroon Formation, the Schoolhouse Tongue of the Weber Sandstone, and the sandstone of the Fryingpan River lack fossils that yield diagnostic ages. Limestones in the underlying Minturn and Gothic Formations, and the Eagle Valley Evaporite contain Middle Pennsylvanian (Desmoinesian) fossils (Tweto, 1949; Boggs, 1966; Mallory, 1971 Bartleson, 1972), and a limestone bed in the lower part of the overlying State Bridge Formation yielded Early Permian (Leonardian) fossils (Bass and Northrop, 1950; M. E. Maclachlan, personal communication, 1987). A Middle Pennsylvanian to Early Permian age has therefore been assumed for the Maroon. However, the contact between the Maroon Formation or the Schoolhouse Tongue of the Weber Sandstone and the State Bridge Formation is locally unconformable (Freeman, 1971a) and may represent a significant hiatus. If this is the case, then the units described here might be solely of Pennsylvanian age.

Many Pennsylvanian faults in northwest Colorado were reactivated in the Laramide orogeny (Tweto, 1977). Pennsylvanian rocks in this region now crop out mainly in structurally low areas and on the margins of the Laramide White River uplift.

STRATIGRAPHY

The Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone in the Eagle Basin form scattered outcrops in structurally low areas and on the margins of the Laramide White River Uplift (Fig. 3). The locations of the stratigraphic sections were selected for their geographic distribution and for the quality of exposure. Continuous sections of well-exposed rocks are lacking at most locations; as a result many of the sections are composite or incomplete.

Glenwood Springs

A continuous, well-exposed section of the Maroon Formation is not present in the vicinity of Glenwood Springs. Mapping of a poorly exposed, but complete section of the Maroon on slopes due west of Glenwood Springs indicates a thickness of 921 m. This thickness was assumed in compiling the composite stratigraphic section of Figure 4. In comparison, Bass and Northrop (1963) measured a stratigraphic thickness of 901 m for the Maroon along Main Elk Creek, approximately 24 km west-northwest of Glenwood Springs. The measured section in Figure 4 includes 38 percent cover.

The lower 98 m of the Maroon Formation section was measured on slopes about 600 m northwest of Valley View Hospital in Glenwood Springs (NW 1/4, sec. 15, T. 6 S., R. 89 W.). The contact with underlying gypsiferous beds of the Eagle Valley Evaporite is well exposed, abrupt, and parallel. Beds strike northwest and dip 40° to the southwest.

The interval between 98 m and 282 m in the section (Fig. 4) was measured in road cuts along Red Canyon Road (an unpaved eastern spur off Highway 82, approximately 2.5 km south of Glenwood Springs) and on the slopes on the north

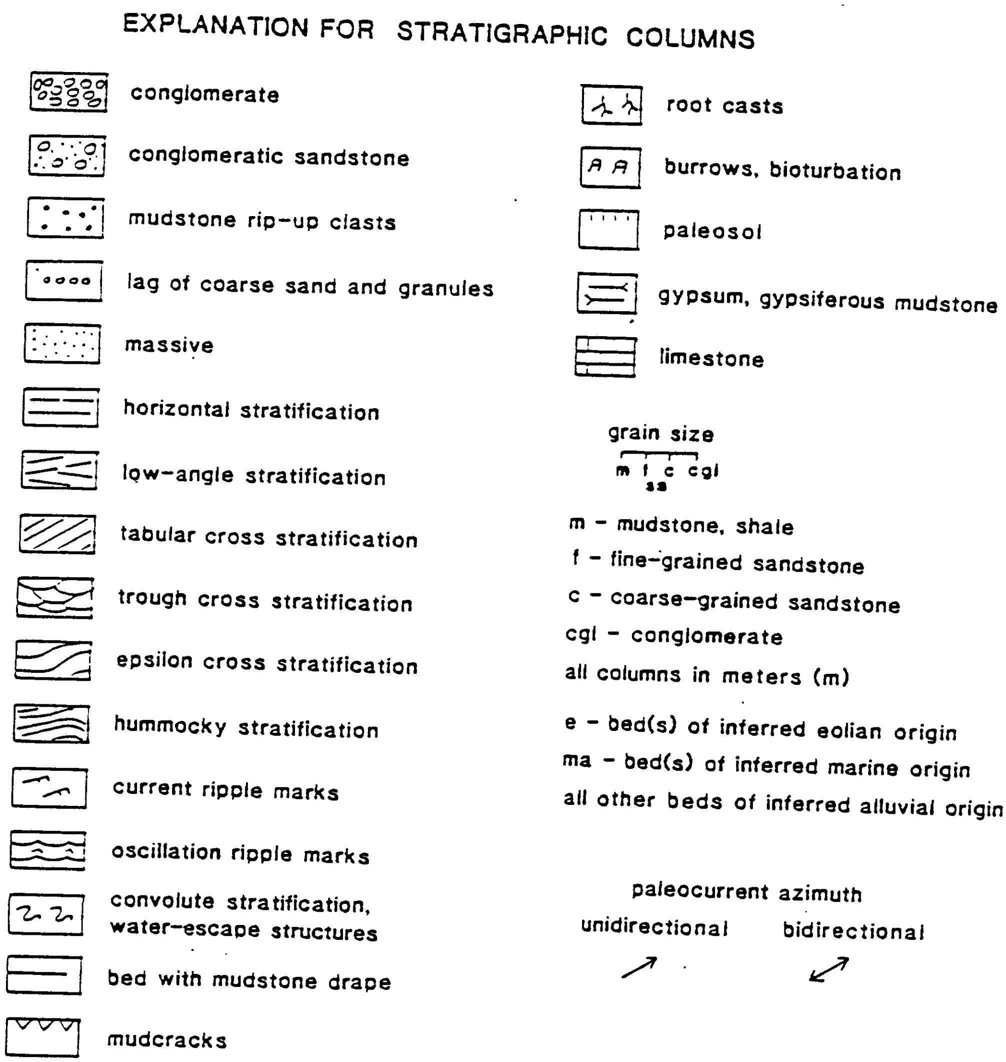
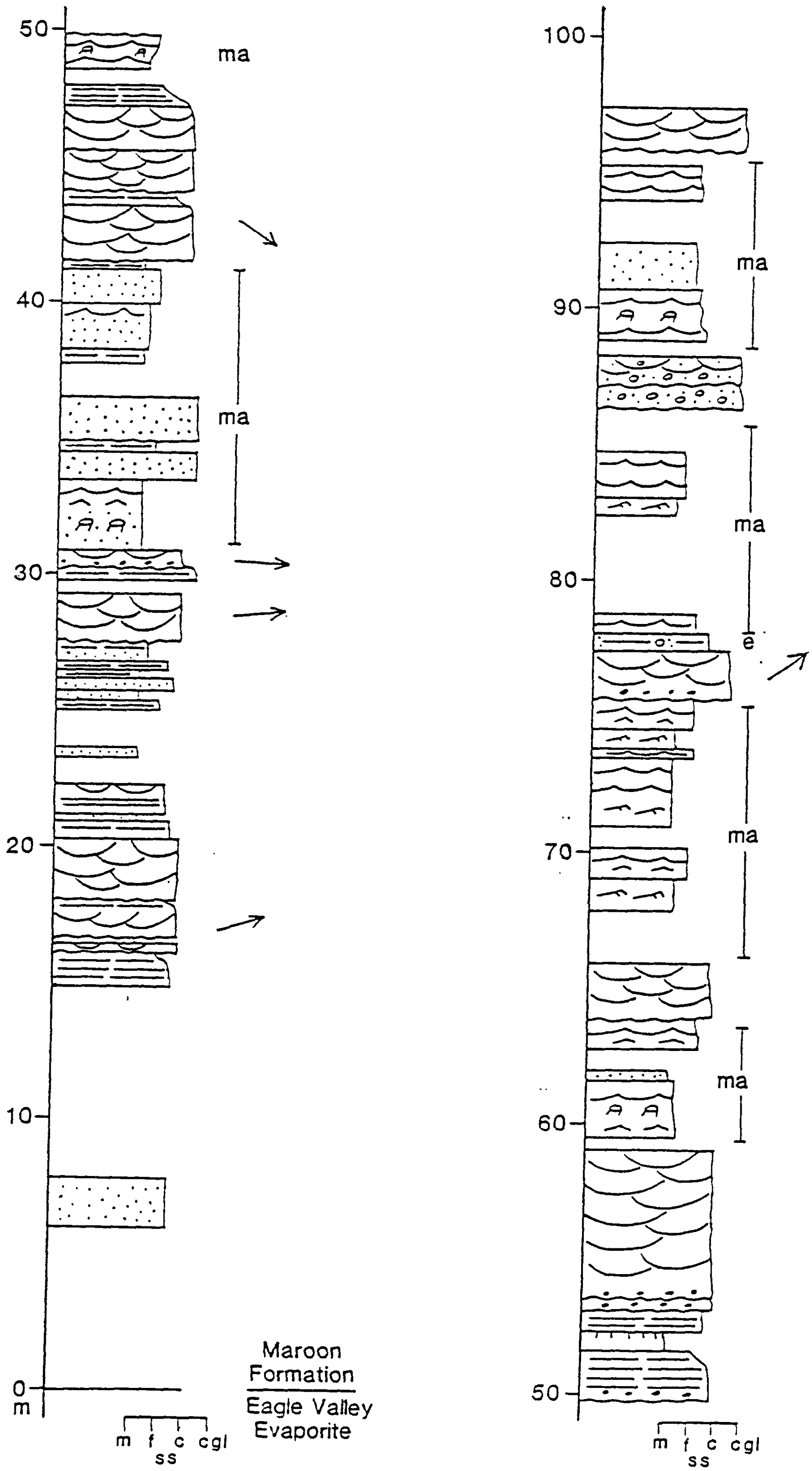


Figure 4. Stratigraphic column of the Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone in the Glenwood Springs area (Fig. 3).



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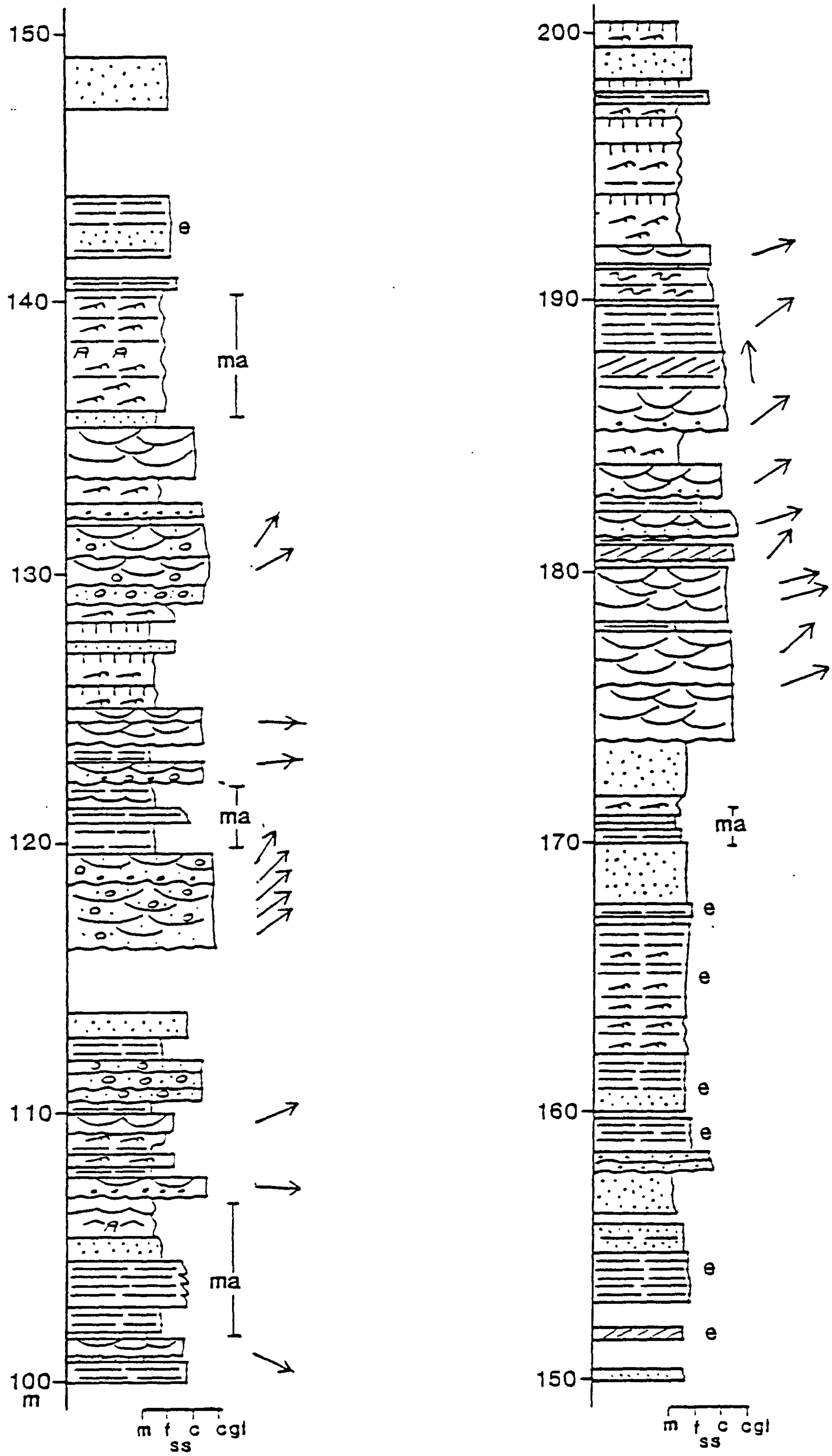

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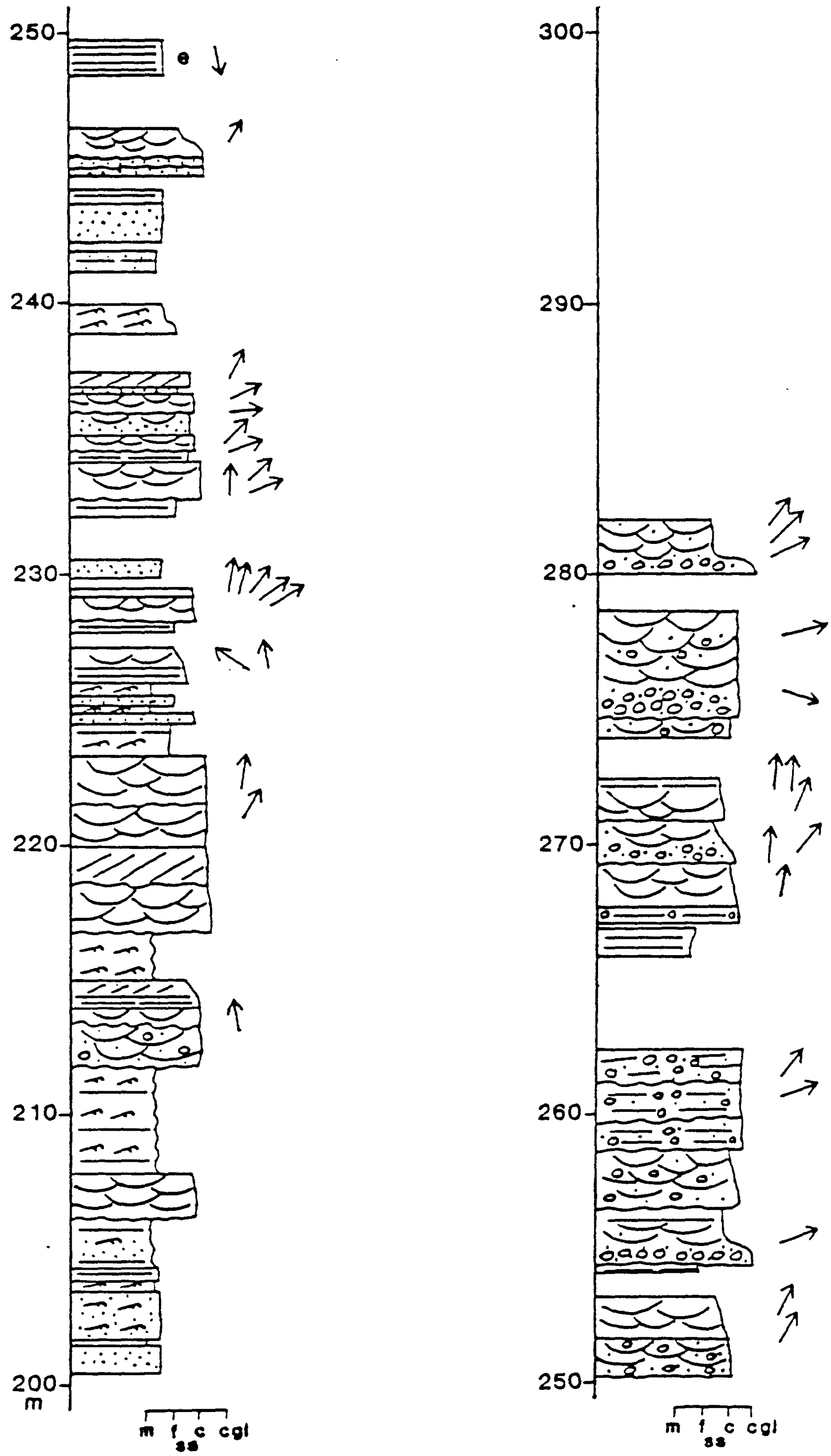

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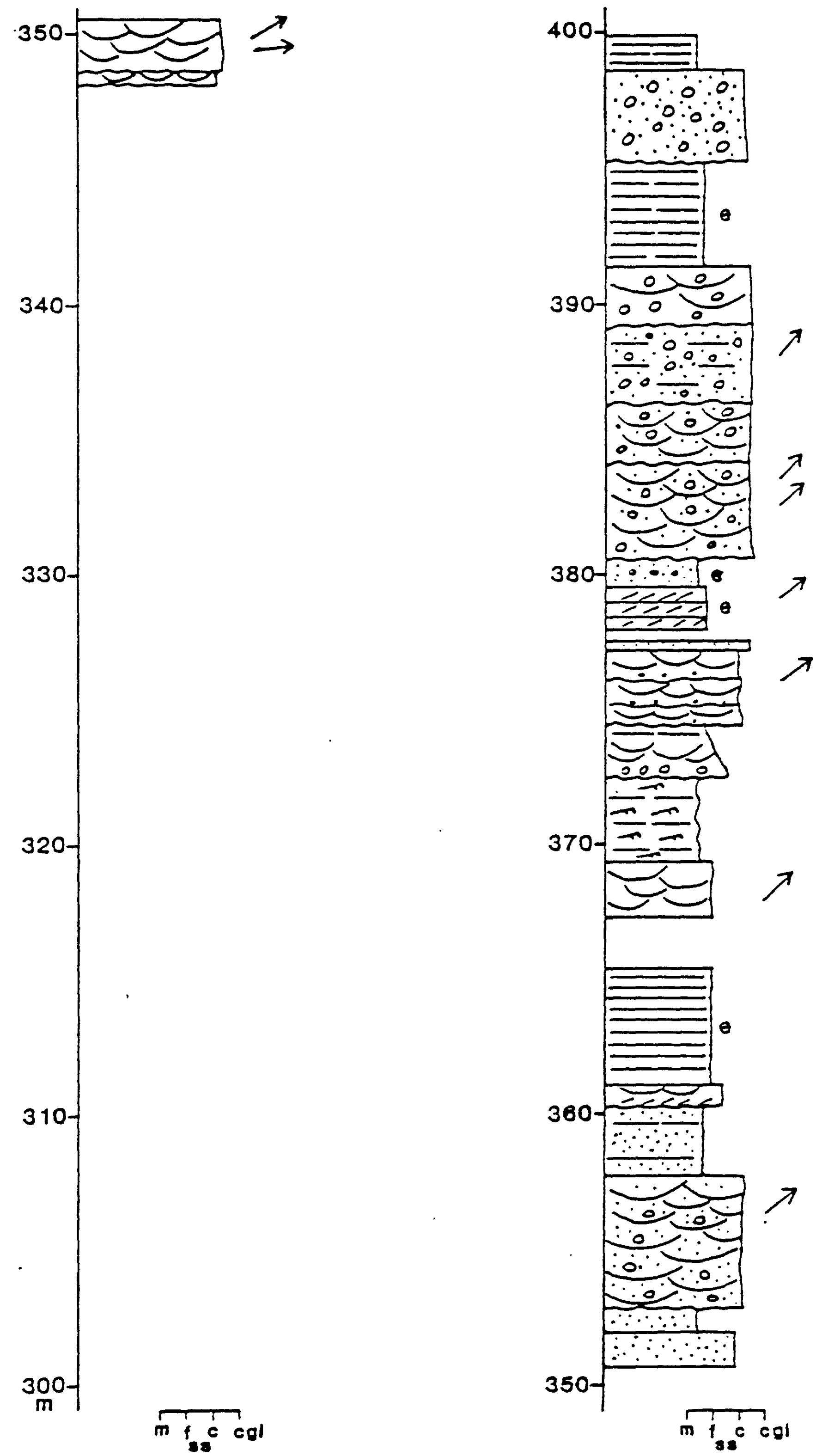

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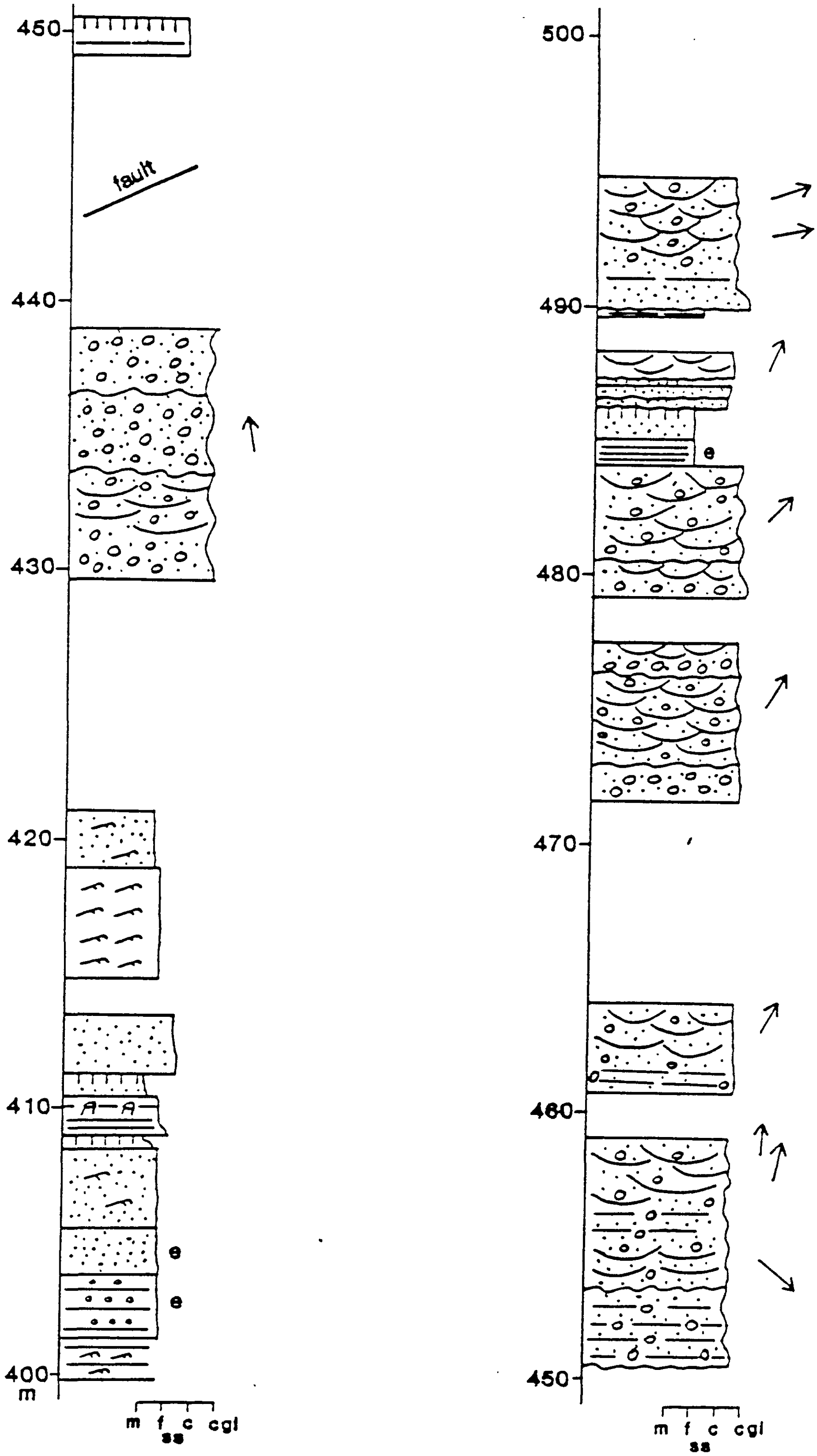

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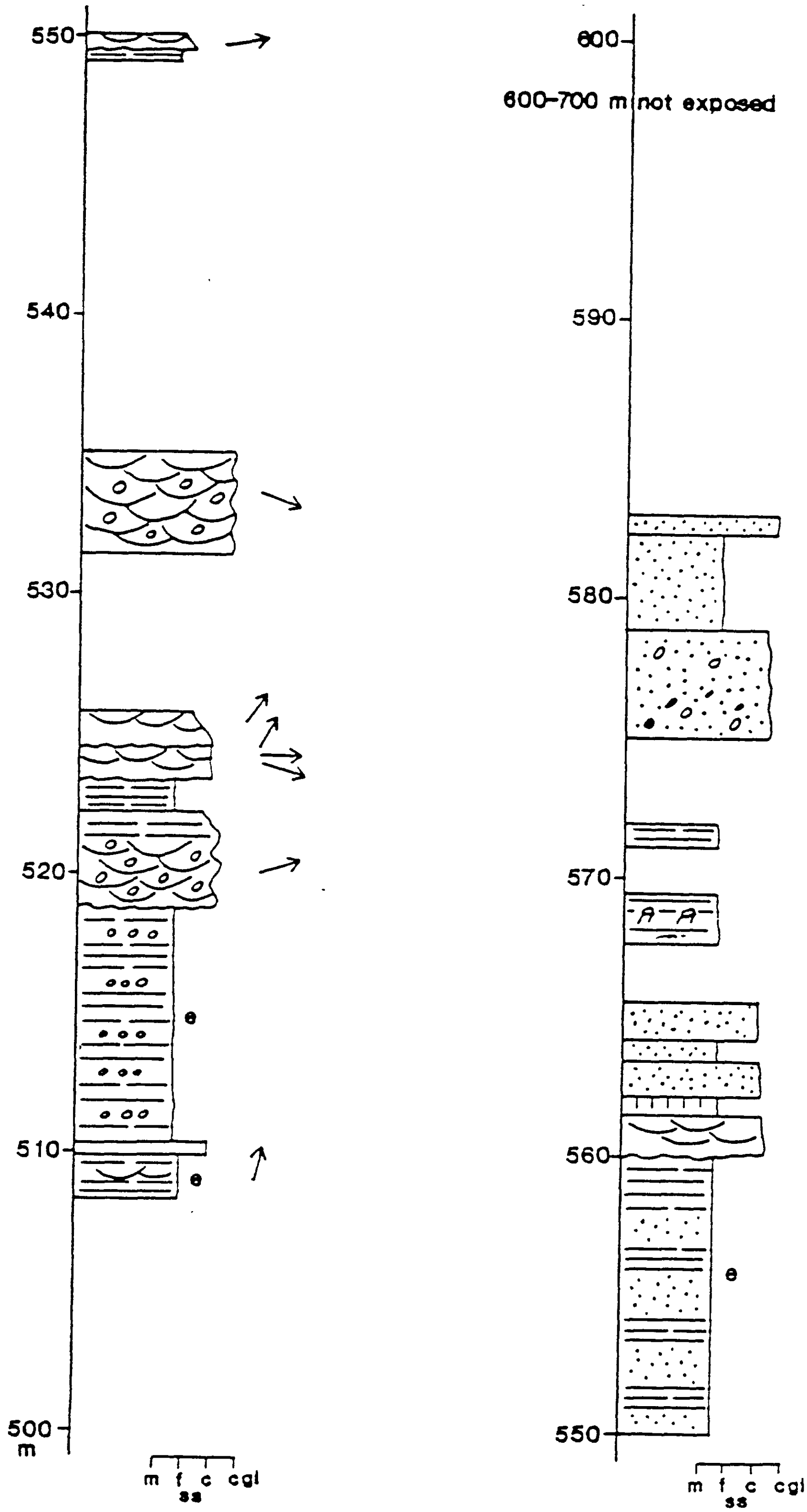

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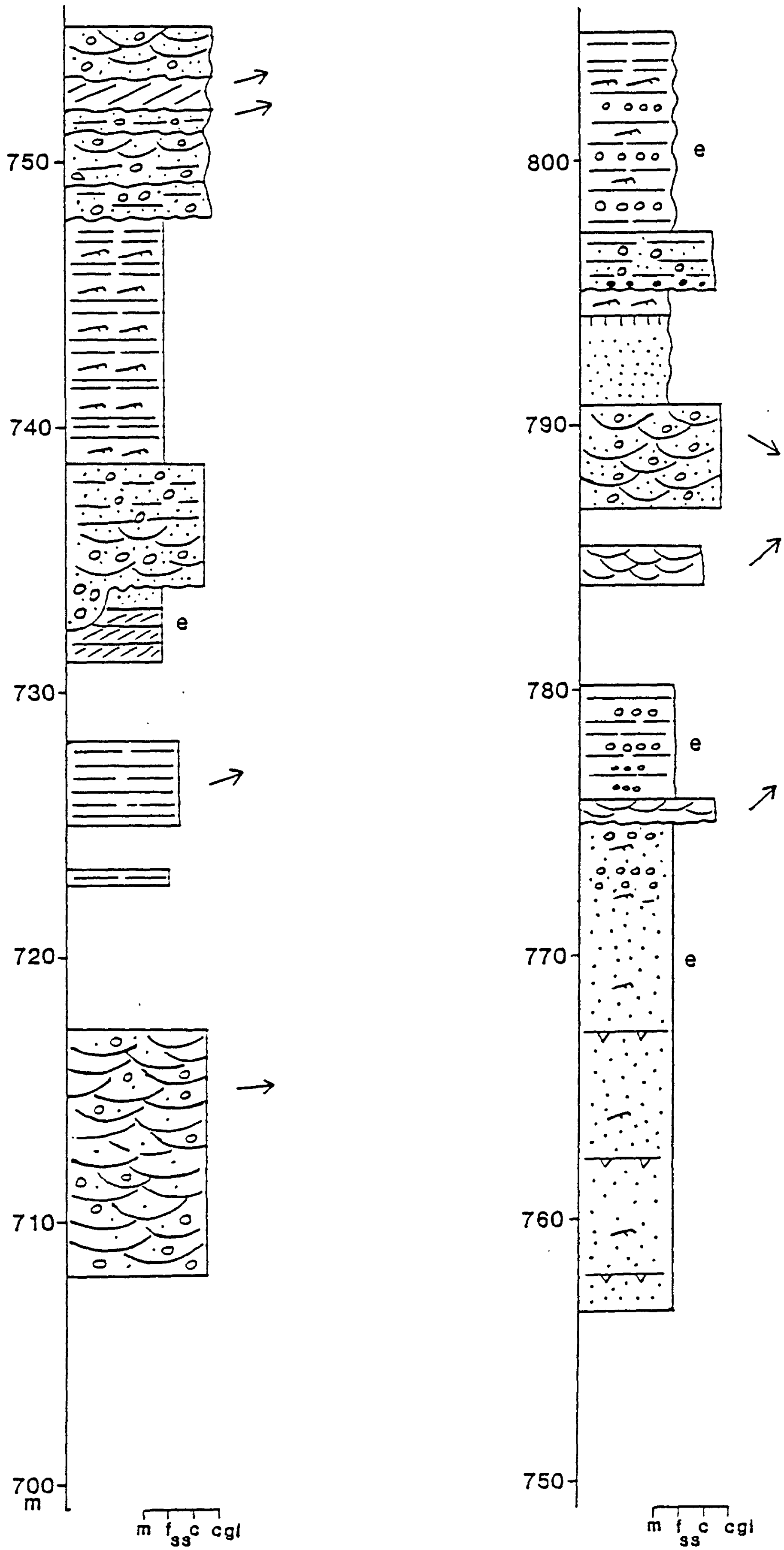

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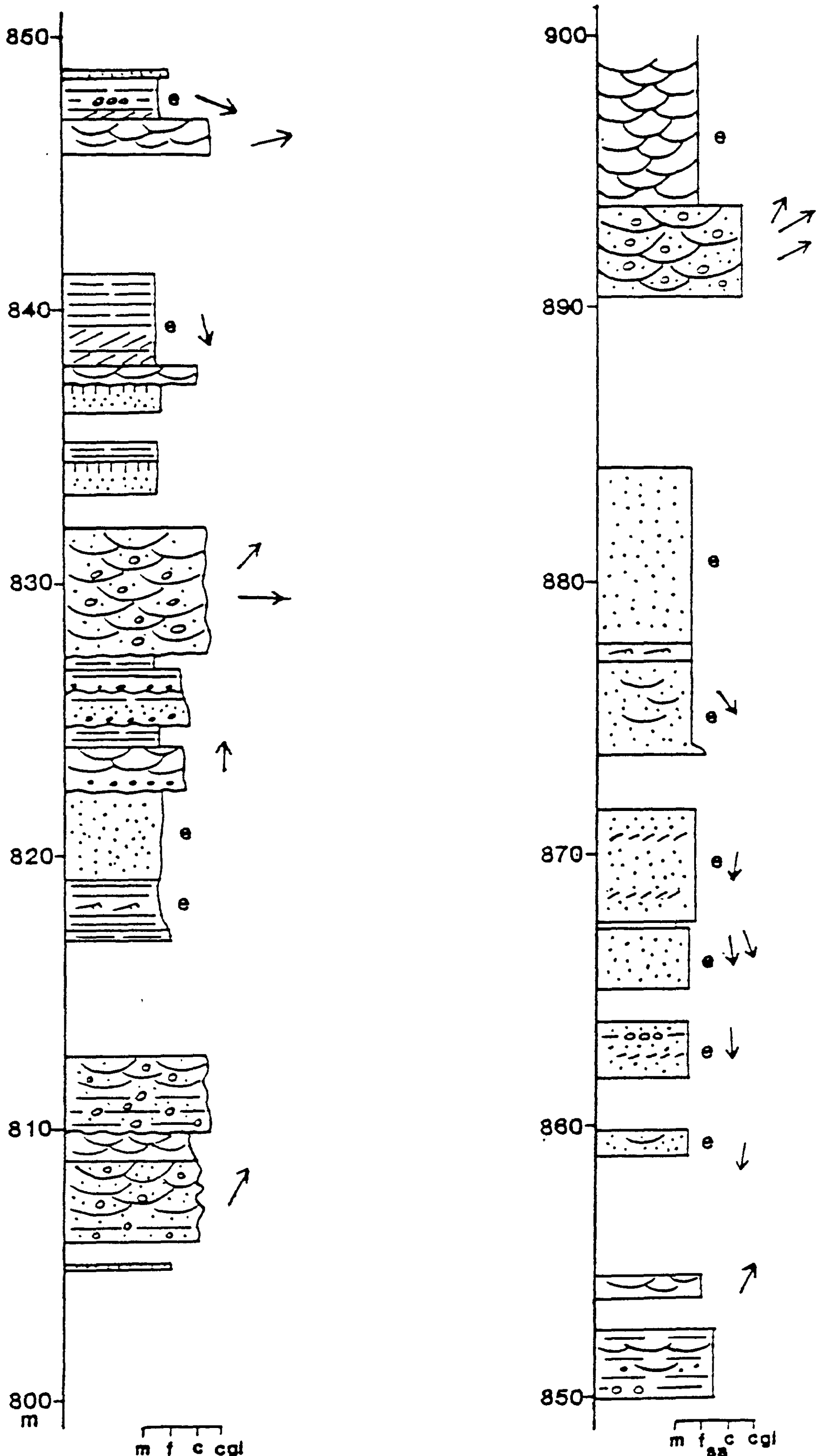

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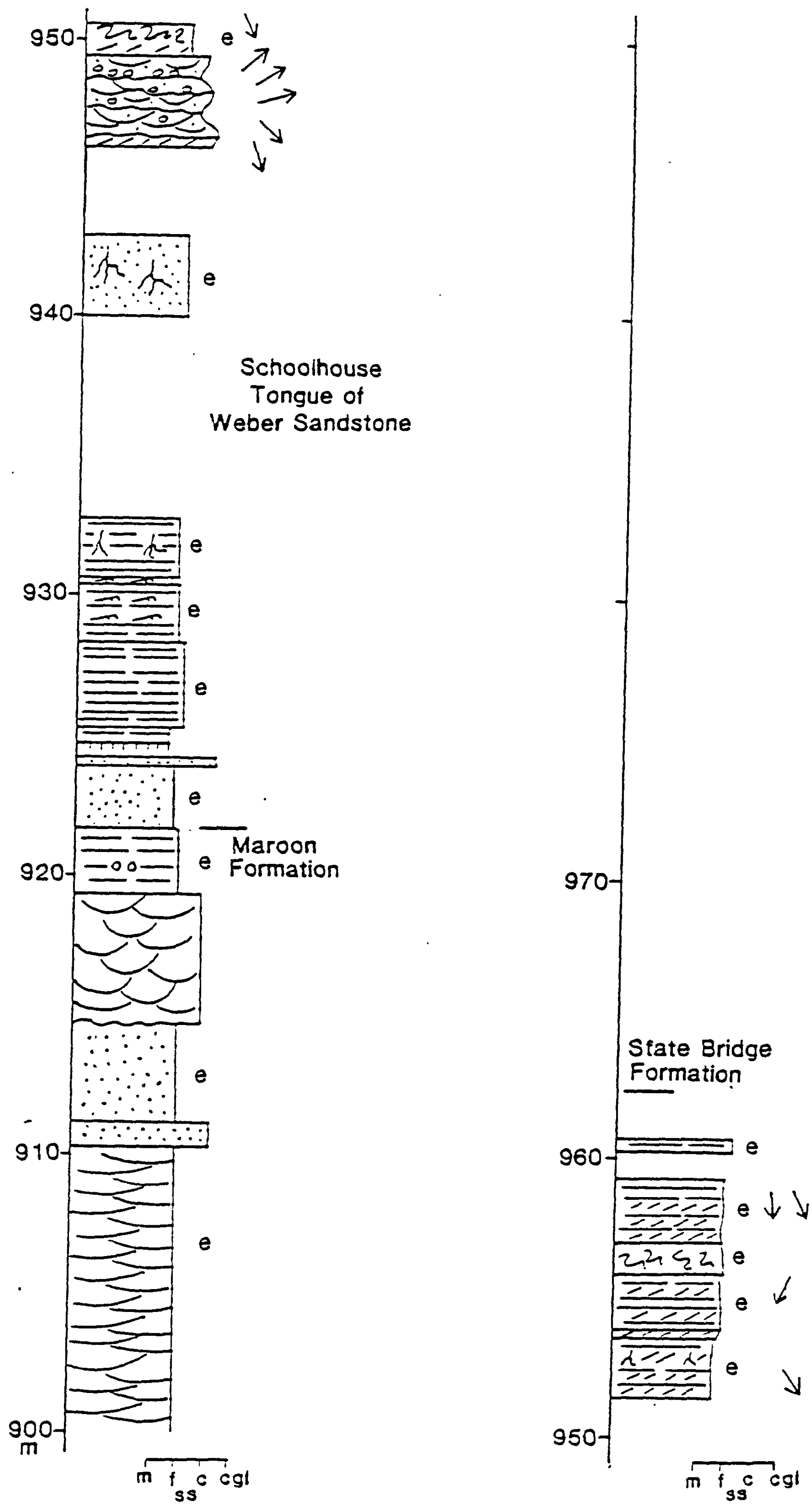


Figure 4 (cont.).

side of Red Canyon (NW 1/4 sec. 26, T. 6 S, R. 89 W). Beds strike north-northwest and dip 5° to 30° to the east.

The remainder of the section was measured on opposite sides of Highway 70, about 7 to 10 km west of Glenwood Springs. The interval from 348 to 583 m was measured on the west slopes of a small drainage and along the slopes that parallel and lie north of Highway 70 and the Colorado River (SW 1/4 SE 1/4 sec. 31, T. 5 S, R. 89 W.). Beds strike west-northwest, dip south-southwest 50° to 70°, and are cut by a few small faults with inferred minimal stratigraphic displacement.

The covered interval in the section from 583 m to 708 m represents the gap between strata measured on opposite sides of Highway 70 and the Colorado River. The interval between 708 and 902 m in the section was measured in the bed of a small drainage and on the crest of a small ridge on the west flank of the drainage (NW 1/4 sec. 36, T. 5 S., R. 90 W.). Beds strike northwest and dip 30° to 40° to the southwest.

The top of the section (the uppermost 19 m of the Maroon Formation and the 42-m-thick Schoolhouse Tongue of the Weber Sandstone) was measured on slopes west of South Canyon Creek, also on the south side of the Colorado River (NW 1/4 sec. 2, T. 6 S., R. 90 W.). Beds strike northwest and dip about 60° to the southwest. The contact between the reddish-brown Maroon Formation and the yellowish-gray Schoolhouse Tongue is placed at the top of the highest red beds and is well-exposed and gradational. The contact between the Schoolhouse Tongue and the overlying reddish-brown to greenish-gray State Bridge Formation is covered by a few meters of float, but is parallel and appears abrupt.

East Elk Creek

A 39.5 m thick section (Fig. 5) of the uppermost part of the Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone was measured along East Elk Creek (NW 1/4 sec. 24, T. 5 S., R. 91 W.) on the south flank of the White River Uplift. The lower 20.3 m of the section was measured on slopes on the west side of East Elk Creek, directly opposite the KOA campground. The remainder of the section was measured on slopes east of East Elk Creek Road opposite the campground entrance. The contact between the Maroon and the Schoolhouse Tongue is at 6.3 m and placed at the upper limit of redbeds. Below this contact, there is a mixed zone of red beds and yellowish-gray beds more than 10 m thick. The Schoolhouse Tongue is overlain unconformably (with about 5° angularity) by quartz-pebble conglomerate and conglomeratic sandstone of the Garta Member of the Chinle Formation (best exposed on the west side of East Elk Creek). The State Bridge Formation, which occurs between the Schoolhouse Tongue and the Chinle Formation over most of the Eagle Basin, is missing. Outcrops in this section are poor to good, the section is 24 percent covered. Beds strike to the southeast and dip 55° to the southwest.

Main Elk Creek

A continuous, 43-m-thick section of the Schoolhouse Tongue of the Weber Sandstone (Fig. 5) was measured on slopes west of Main Elk Creek (SE 1/4 sec. 15, T. 5 S., R. 91 W.). The contact with the underlying Maroon Formation is placed at the upper limit of red beds. A mixed zone of red beds and yellowish-gray beds more than 20 m thick forms the uppermost Maroon Formation at this locality. The Schoolhouse Tongue is overlain by quartz-pebble conglomerate and conglomeratic sandstone of the Gartra Member of the Chinle

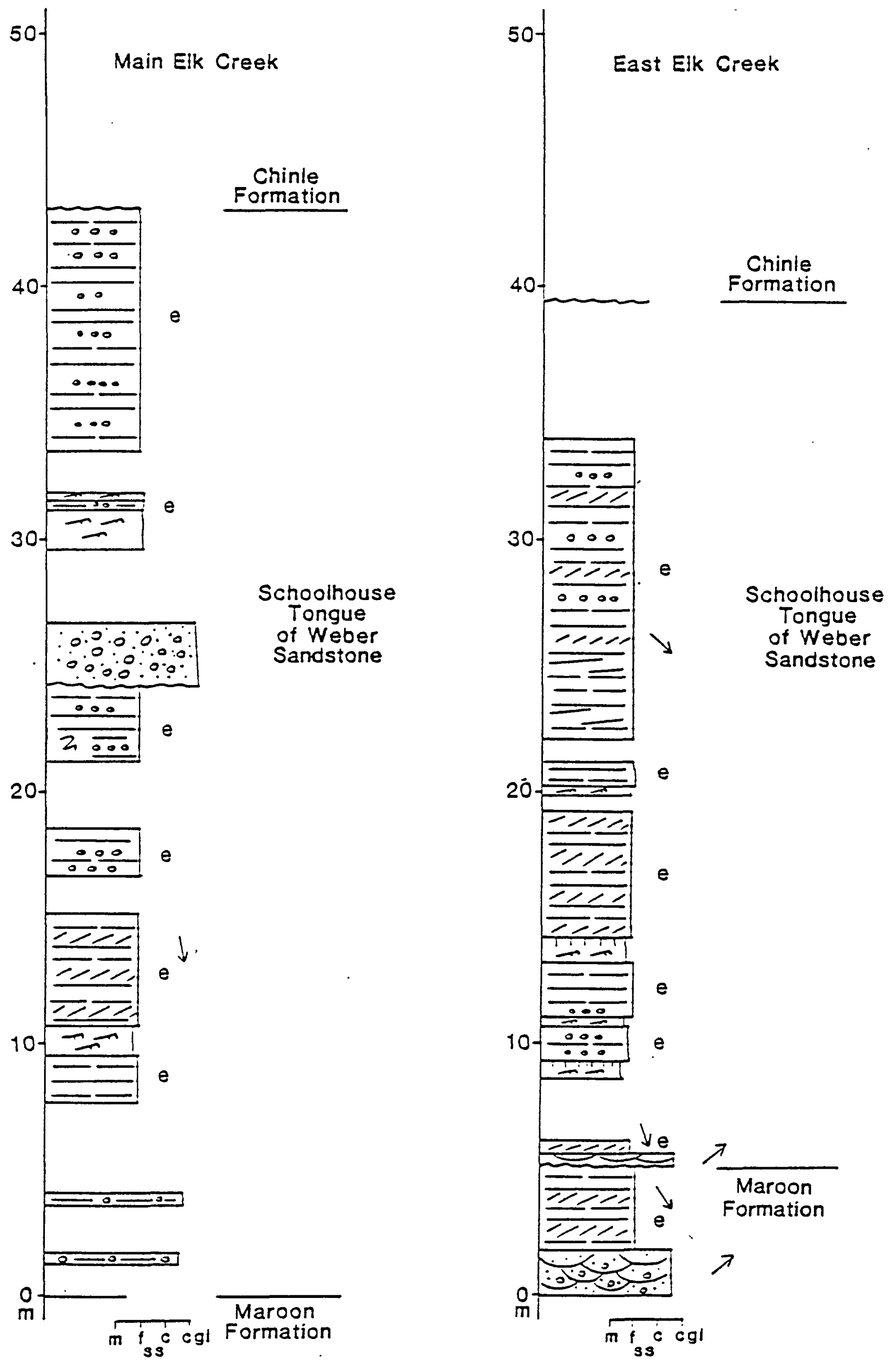


Figure 5. Stratigraphic columns of the Schoolhouse Tongue of the Weber Sandstone along East Elk Creek and Main Elk Creek (Fig. 3). Explanation is the same as in Figure 4.

Formation with slight angular unconformity. The State Bridge Formation, which occurs between the Schoolhouse Tongue and the Chinle Formation over most of the Eagle Basin, is missing. Outcrops are fair to good, the section is 32 percent covered. Beds strike southeast and dip 40° to the southwest. Bass and Northrop (1963) measured a 901-m-thick section of the Maroon Formation at this locality.

Rifle Creek

A complete section of the Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone is exposed on the south flank of the White River Uplift in the Rifle Creek area. The section shown in Figure 6 was measured on the slopes of the valley of Rifle Creek (E 1/2 sec. 22; E 1/2 sec. 27; E 1/2 sec. 34; T. 4 S., R. 92 W.). The Maroon Formation and the Schoolhouse Tongue of the Weber Formation comprise the lower 463 m and the upper 66 m of the 529-m-thick section, respectively. The contact between the gently dipping Maroon and the underlying, moderately dipping gypsum and clastics of the Minturn Formation is poorly exposed and discordant, either a fault or an angular unconformity. The presence of brownish-gray strata of inferred marine origin in the lower part of the Maroon section, characteristic of the lower Maroon throughout the basin, suggests that if the basal contact is a fault, it did not cut out part of the Maroon section. The basal 35 m of the section were measured on the west flank of the valley opposite the Rifle Falls Fish Hatchery. The remainder (35 to 463 m) of the Maroon section was measured on the east flank of the valley. As in other sections, the contact between the Maroon and the Schoolhouse Tongue was placed at the upper limit of red beds in the section. It should be noted, however, that the yellowish-gray color and oil staining which is characteristic of the Schoolhouse Tongue is also common throughout most of the Maroon Formation section in the Rifle Creek area.

The Schoolhouse Tongue of the Weber Sandstone was measured on the west flank of the valley. The contact between the Schoolhouse Tongue and the overlying yellowish-gray (also oil stained) quartz pebble conglomerate and conglomeratic sandstone of the Gartra Member of the Chinle Formation is an angular unconformity. The State Bridge Formation, which occurs between the Schoolhouse Tongue of the Weber and the Chinle Formation in most of the Eagle Basin, is missing. Exposures are poor to excellent, approximately 20 percent of the section is covered. Beds strike approximately east-west and dip south 0 to 30°.

Miller Creek

There is not a well-exposed continuous section of the Maroon Formation on the northern flank of the White River Uplift. The best exposures are in the vicinity of Miller Creek, along Highway 132 and the White River. Mapping of the section along Miller Creek, across a covered interval in the White River valley, and in cliffs along the north side of the White River, suggest a stratigraphic thickness for the Maroon Formation-Schoolhouse Tongue of the Weber Sandstone section of 339 m. This thickness was assumed in compiling the stratigraphic section shown in Figure 7. For comparison, Brill (1944) measured a stratigraphic thickness of 354 m in the same area (However, Brill did not differentiate between the Maroon and the underlying Minturn Formation - the thickness quoted above is based on my interpretation of his section, placing the Maroon-Minturn contact at the top of his unit 26). The measured section shown in Figure 7 includes 22 percent cover.

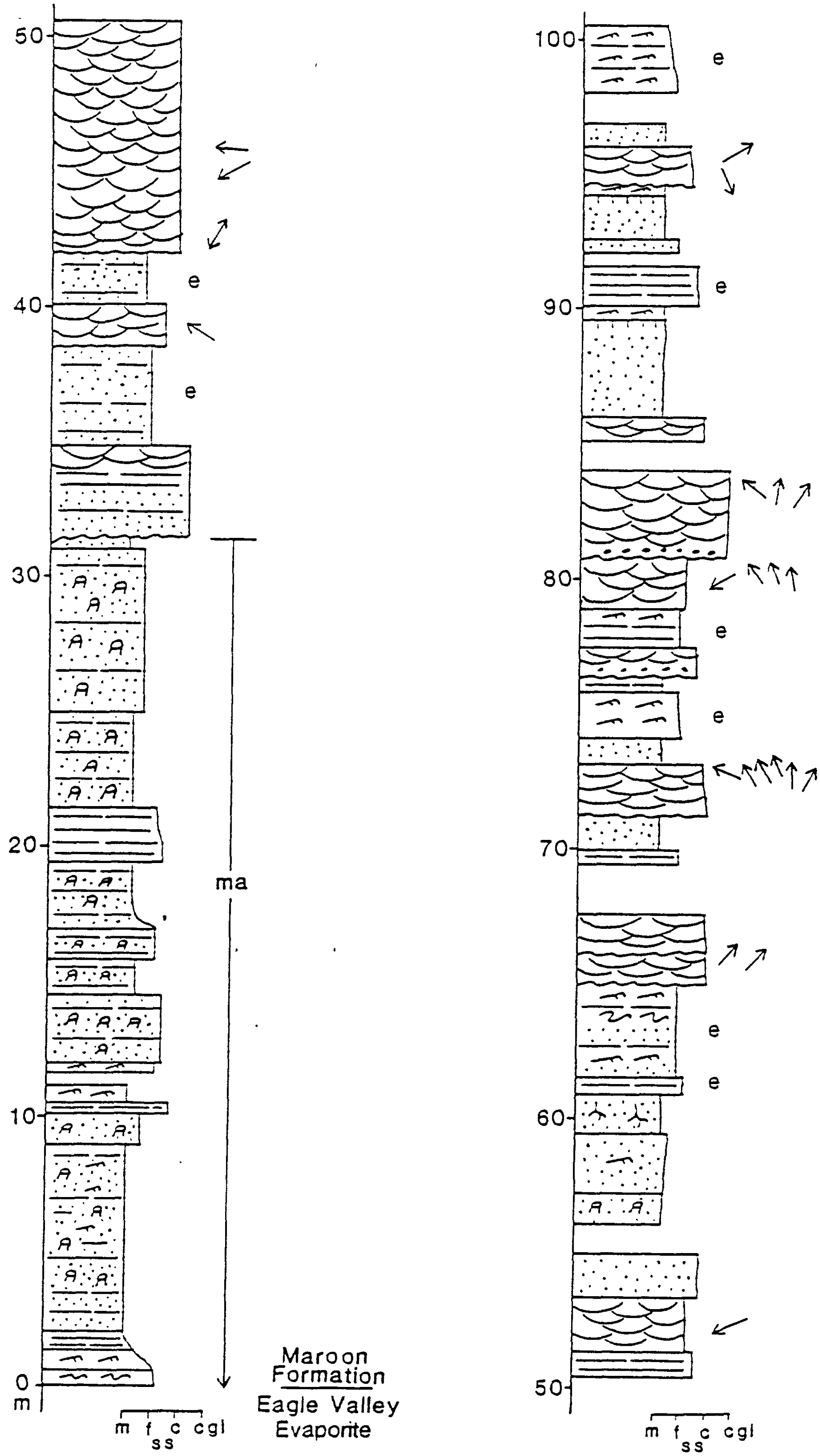
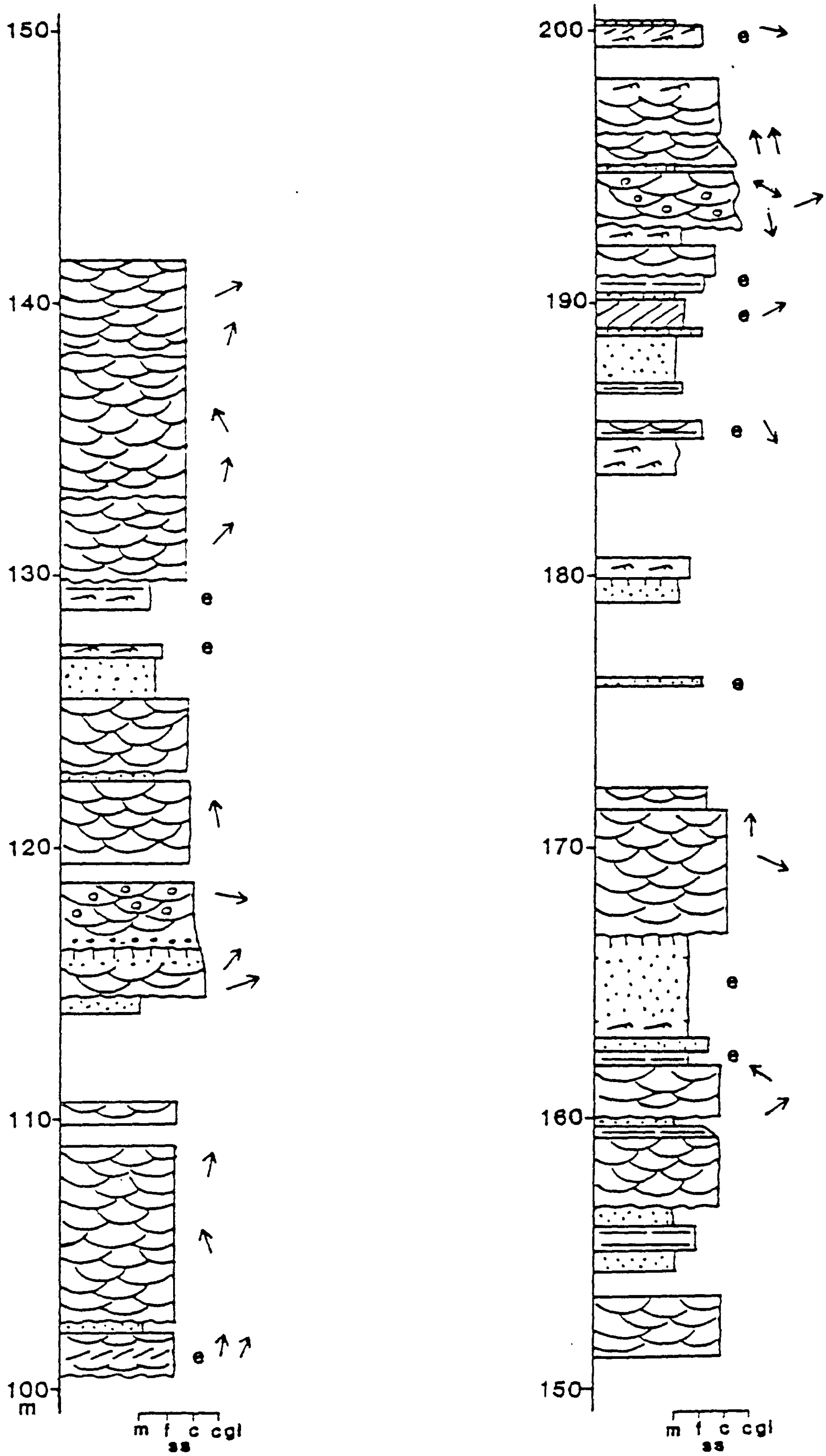


Figure 6. Stratigraphic column of the Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone along Rifle Creek (Fig. 3). Explanation is the same as in Figure 4.



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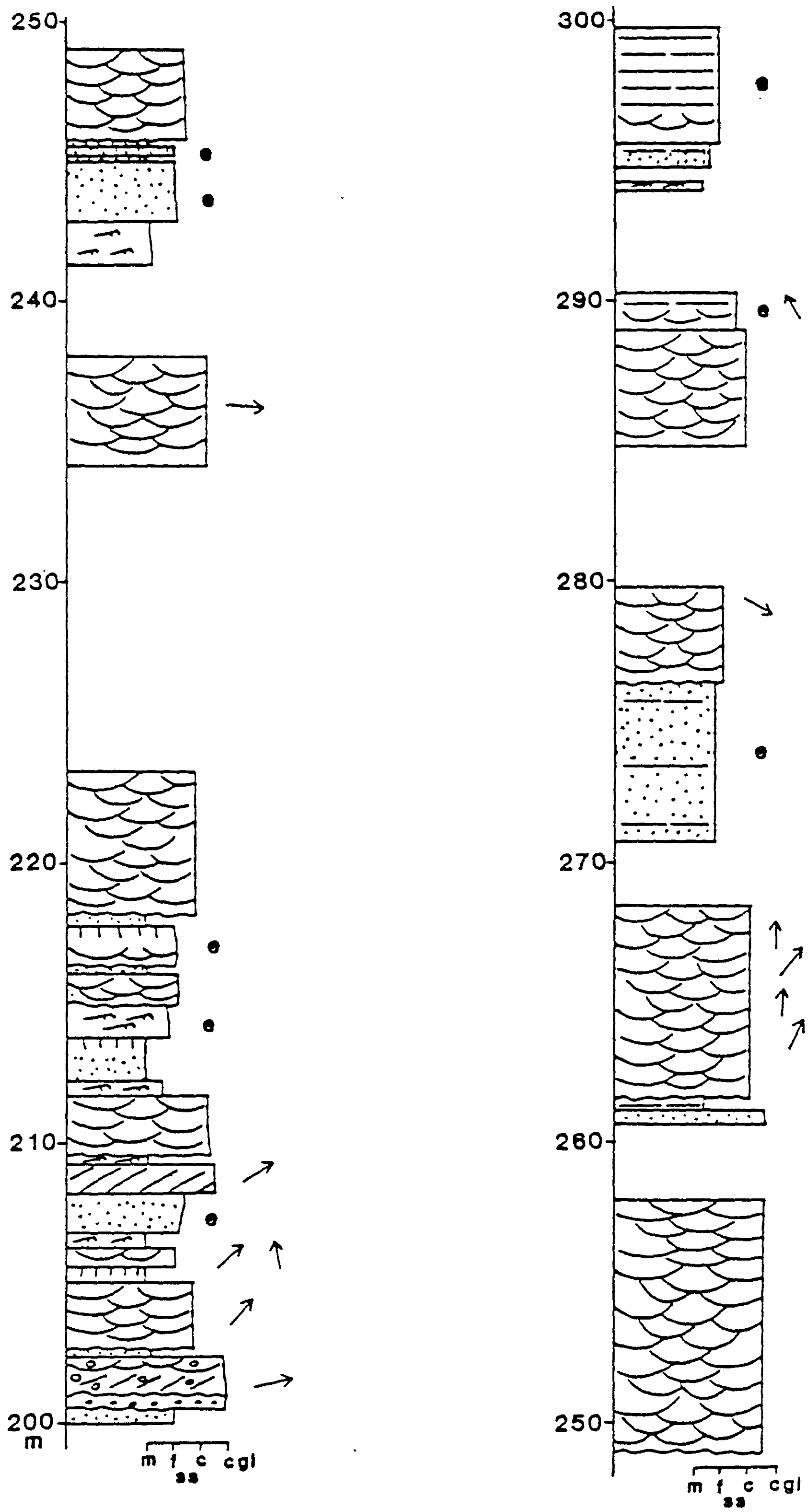

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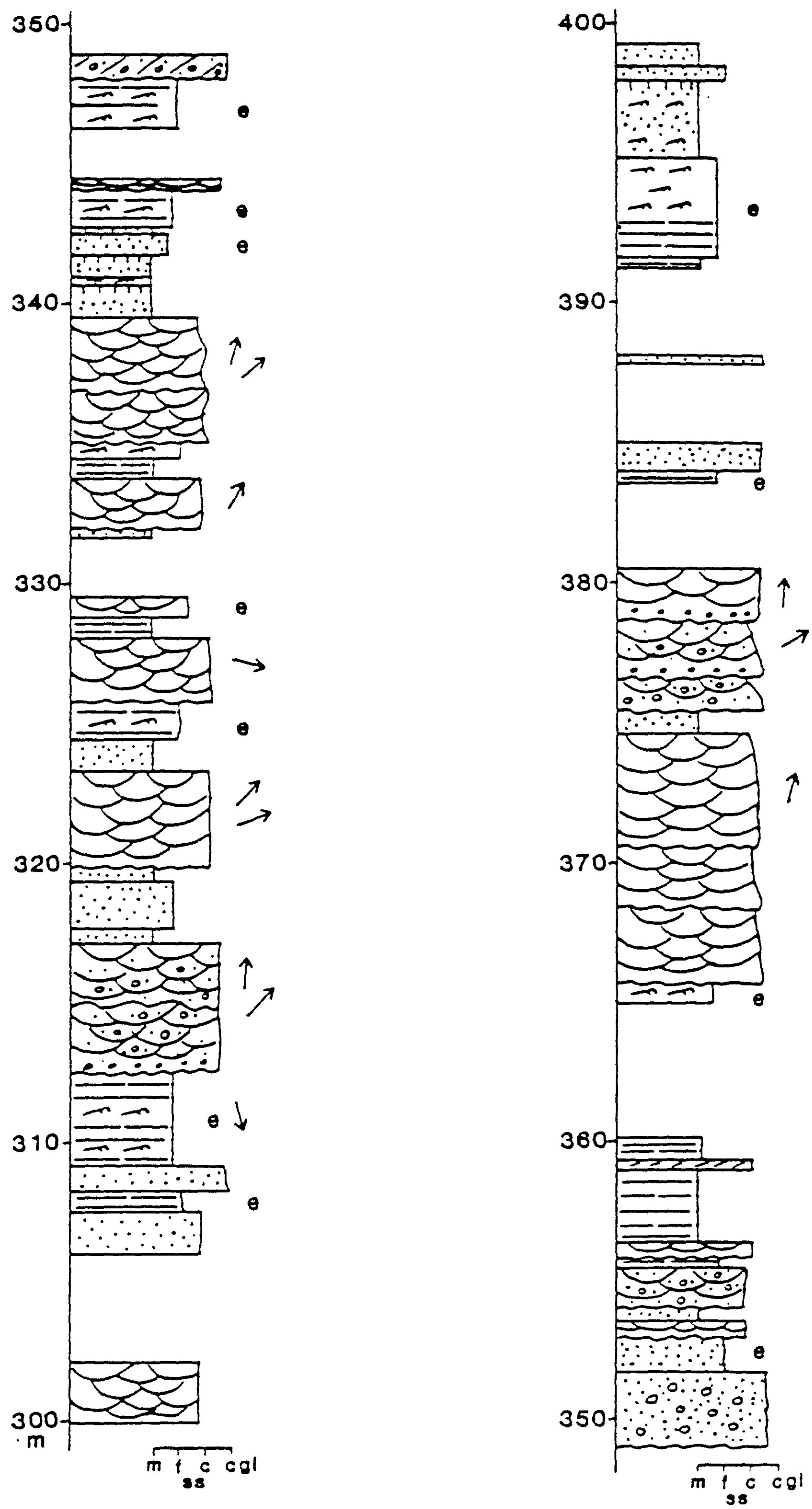

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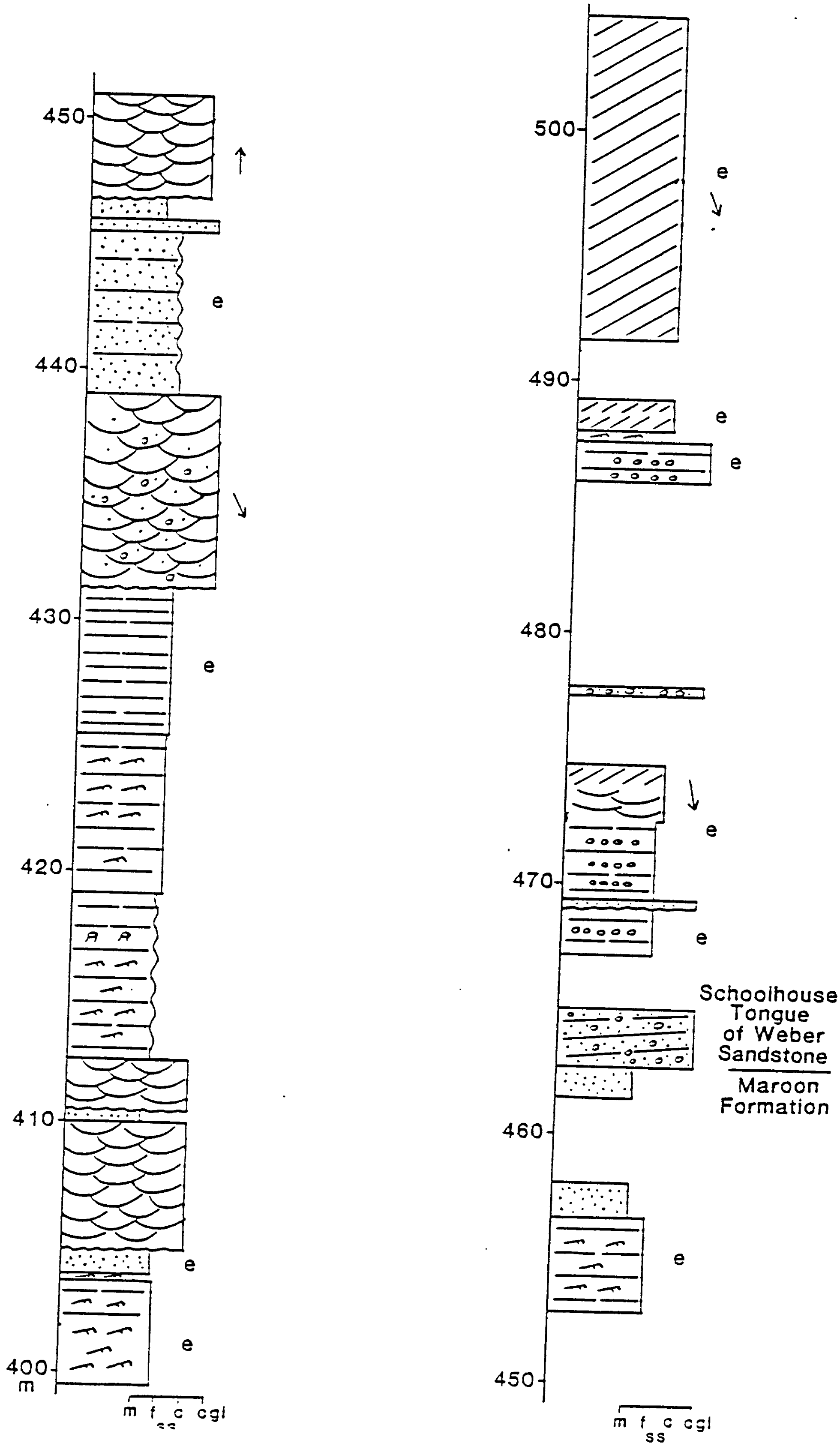

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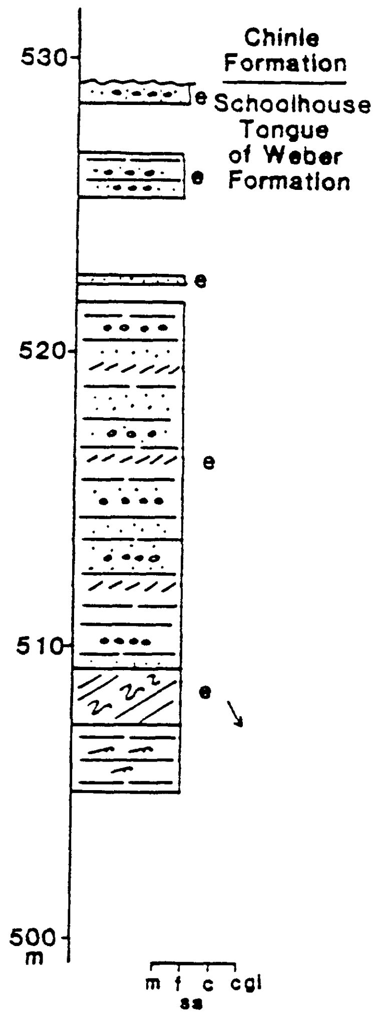

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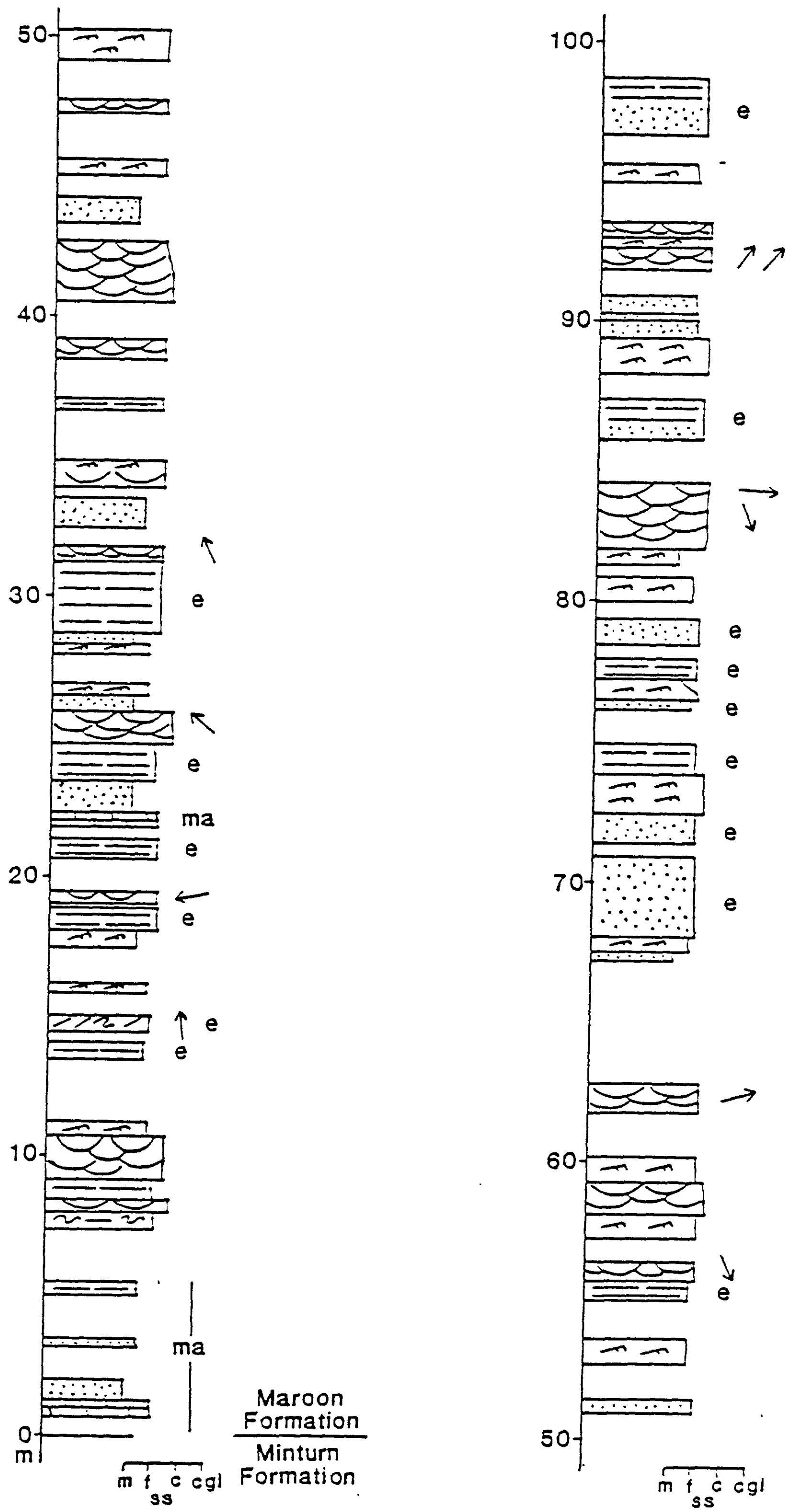
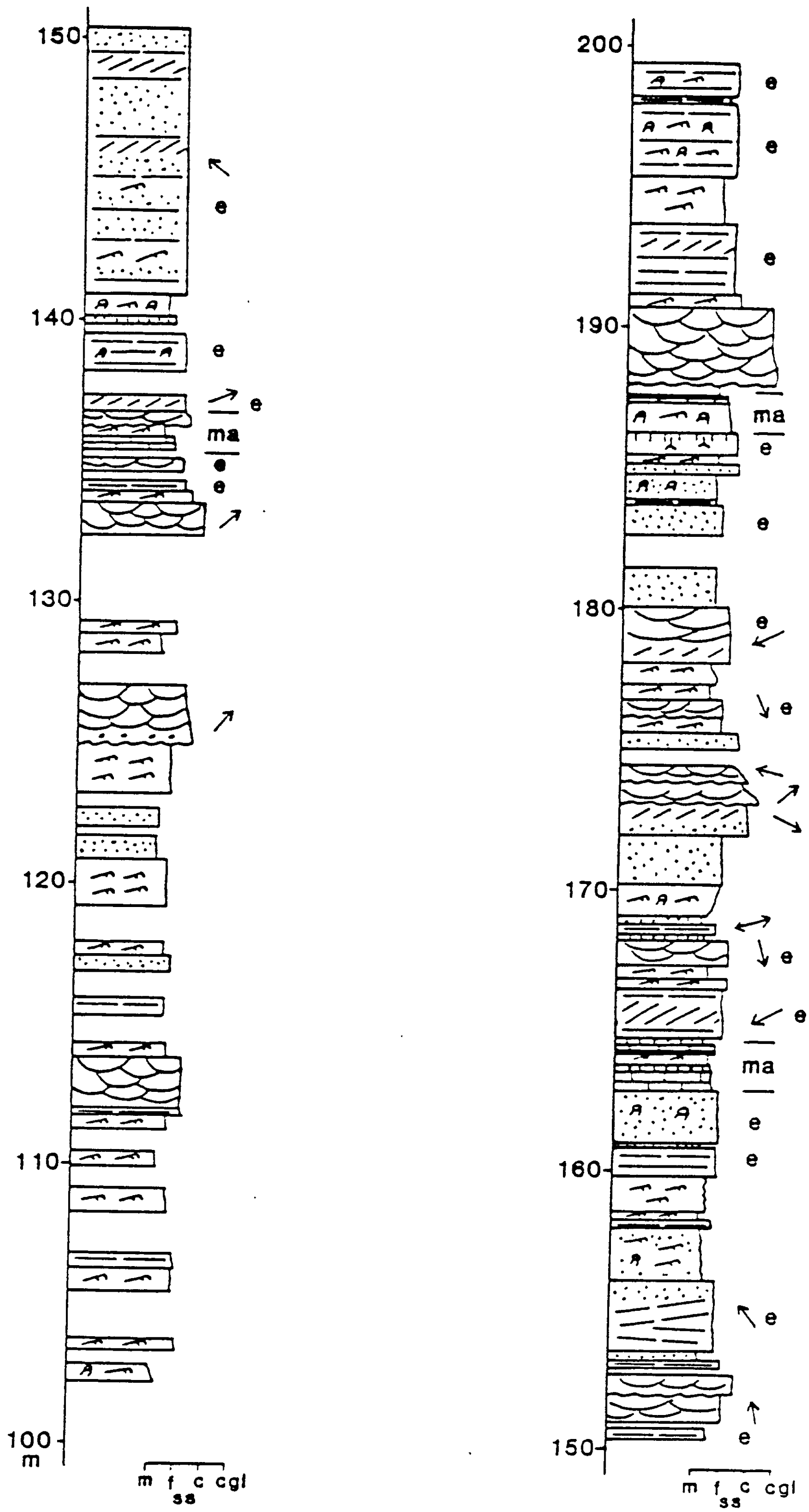


Figure 7. Stratigraphic column of the Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone in the Miller Creek area (Fig. 3). Explanation is the same as in Figure 4.



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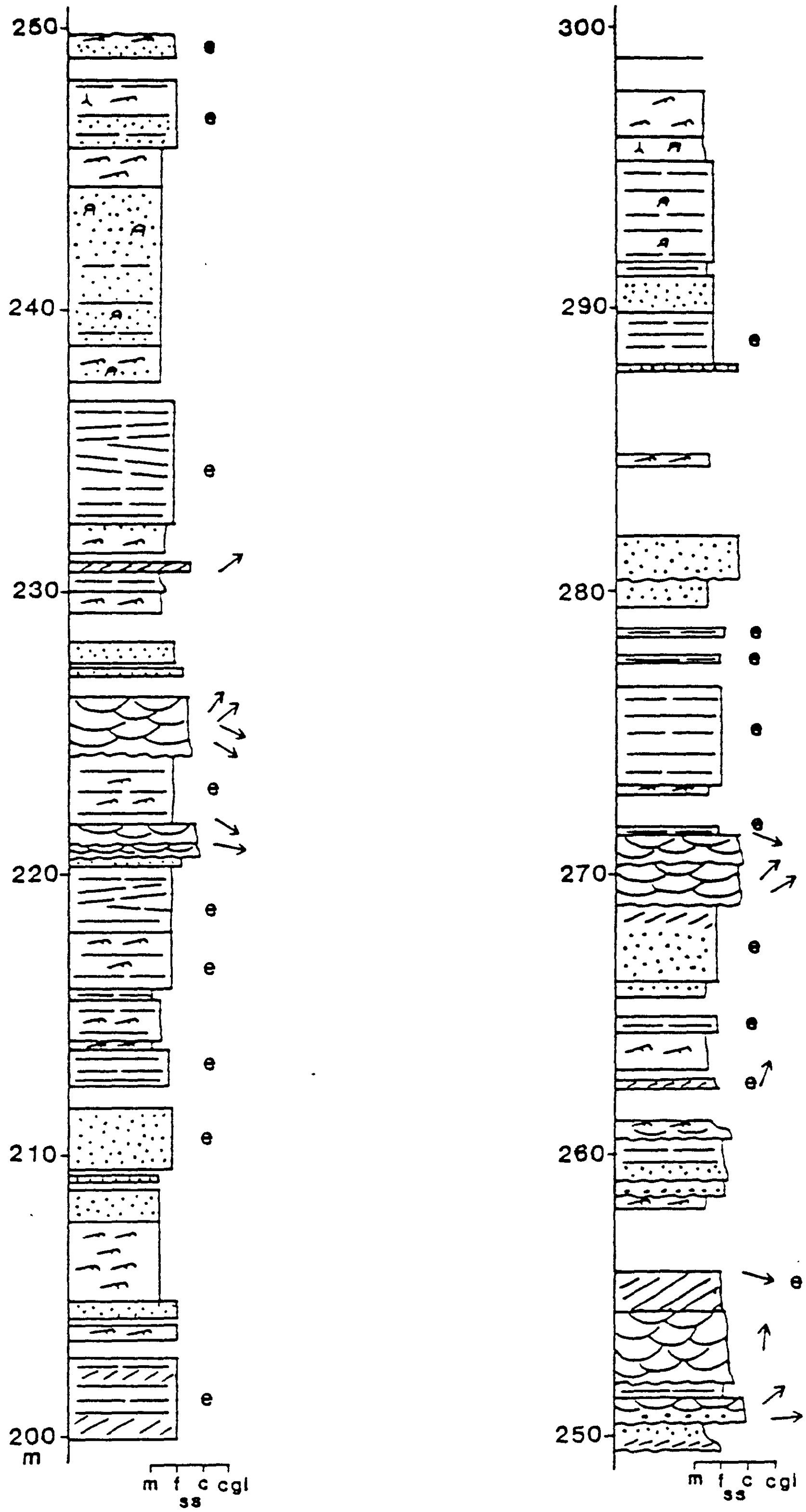

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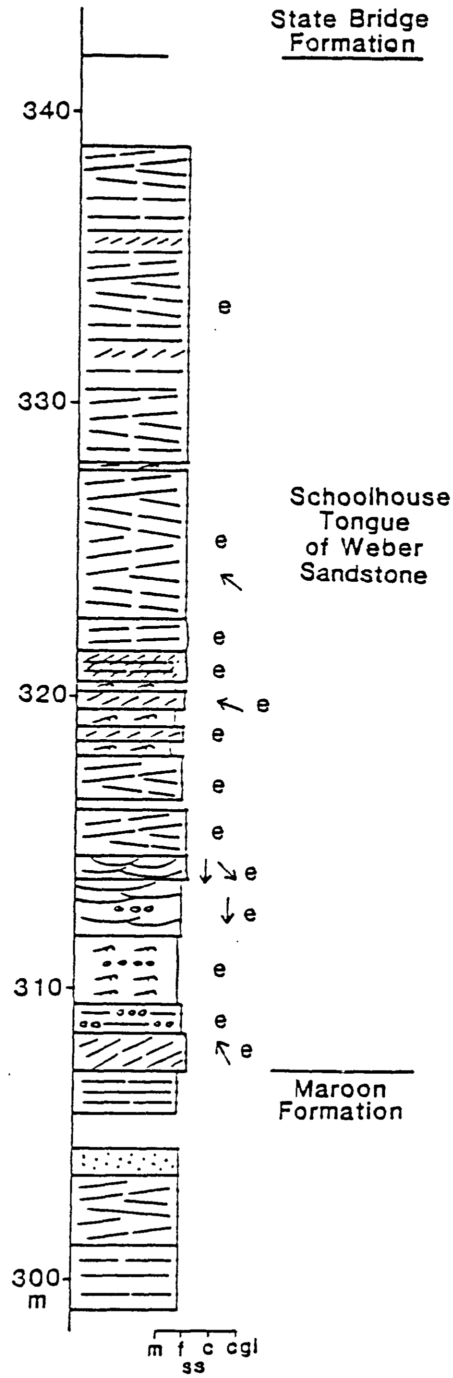


Figure 7 (cont.).

The lower 132 m of the Maroon Formation was measured on slopes on the west side of Miller Creek to the mouth of the first gulch north of Moog Gulch, then up the axis of that gulch to an elevation of 2164 m (NE 1/4 sec. 1, T. 2 S., R. 93 W.; SE 1/4 SW 1/4 sec. 36, T. 1 S., R. 93 W.). The contact with the underlying Minturn Formation is gradational and was placed at the top of the highest limestone bed more than 1 m thick. Exposures in this part of the section are poor to fair, and beds dip gently (< 10°) north.

The interval in the section from 132 m to the top of the Maroon Formation (307 m) was measured about 4.5 km east of Miller Creek in slopes and cliffs on the east side of Warners Point, north of Highway 132 and the White River (SE 1/4 sec. 21, T. 1 S., R. 92 W.). A 40-cm-thick limestone bed at 135 m in this part of the section was noted in the same stratigraphic position in the Miller Creek area, supporting the inferred correlation between the two areas. Exposures in this part of the section are excellent, beds strike northeast and dip gently to the northwest. The contact with the overlying Schoolhouse Tongue of the Weber Sandstone is placed at the upper limit of red beds. Below the contact for about 10 m is a mixed zone of beds of both yellowish and reddish hues.

The Schoolhouse Tongue of the Weber Sandstone (307 to 339 m in the section) was measured in cliffs about 500 m west of the junction of Highway 132 and the Miller Creek Road, north of the White River (SW 1/4 sec. 24, T. 1 S., R. 93 W.). This is the type section of the Schoolhouse Tongue (Brill, 1952). Exposures are excellent, beds dip gently to the north. The contact with overlying reddish-brown beds of the State Bridge Formation is covered by a few meters of float, but is parallel and appears abrupt.

Fawn Creek

A complete, 67-m-thick section (Fig. 8) of the Schoolhouse Tongue of the Weber Sandstone was measured in cliffs north of the North Fork of the White River on the northern flank of the White River Uplift (Fig. 3; NE 1/4 sec. 20, T. 1 N., R. 89 W.). The section was previously measured by Sharps (1962, p. 264-266) who reported a thickness of 65 m (214 ft). The contact with the underlying, poorly exposed Maroon Formation is placed at the top of the highest red beds. Sharps (1962) reported that a 27-m-thick interval below this contact was characterized by lithologies of mixed reddish-brown and yellowish-gray color. The upper contact with beds of greenish-gray and reddish-brown mudstone and very fine grained sandstone is abrupt and parallel. Tweto (1976) mapped these overlying beds as the State Bridge Formation, whereas Sharps (1962) considered them the Park City Formation. Exposures of the Schoolhouse Tongue are fair to good, the section is about 12 percent covered. Beds strike northwest and dip 22° to the northwest.

At Ripple Creek, about 15 km east-northeast of Fawn Creek, Sharps (1962) measured a 55-m-thick section of the Schoolhouse Tongue and a total section of Pennsylvanian to early Permian strata (Belden Formation, Minturn Formation, Maroon Formation, Schoolhouse Tongue) of 1534 m. I visited the locations of Sharps (1962) sections (see Johnson, in press, a) but found that due to considerable cover, it would be difficult to impossible to remeasure them.

Colorado River

A complete section of the Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone (Fig. 9) was measured in slopes on the northwest side of

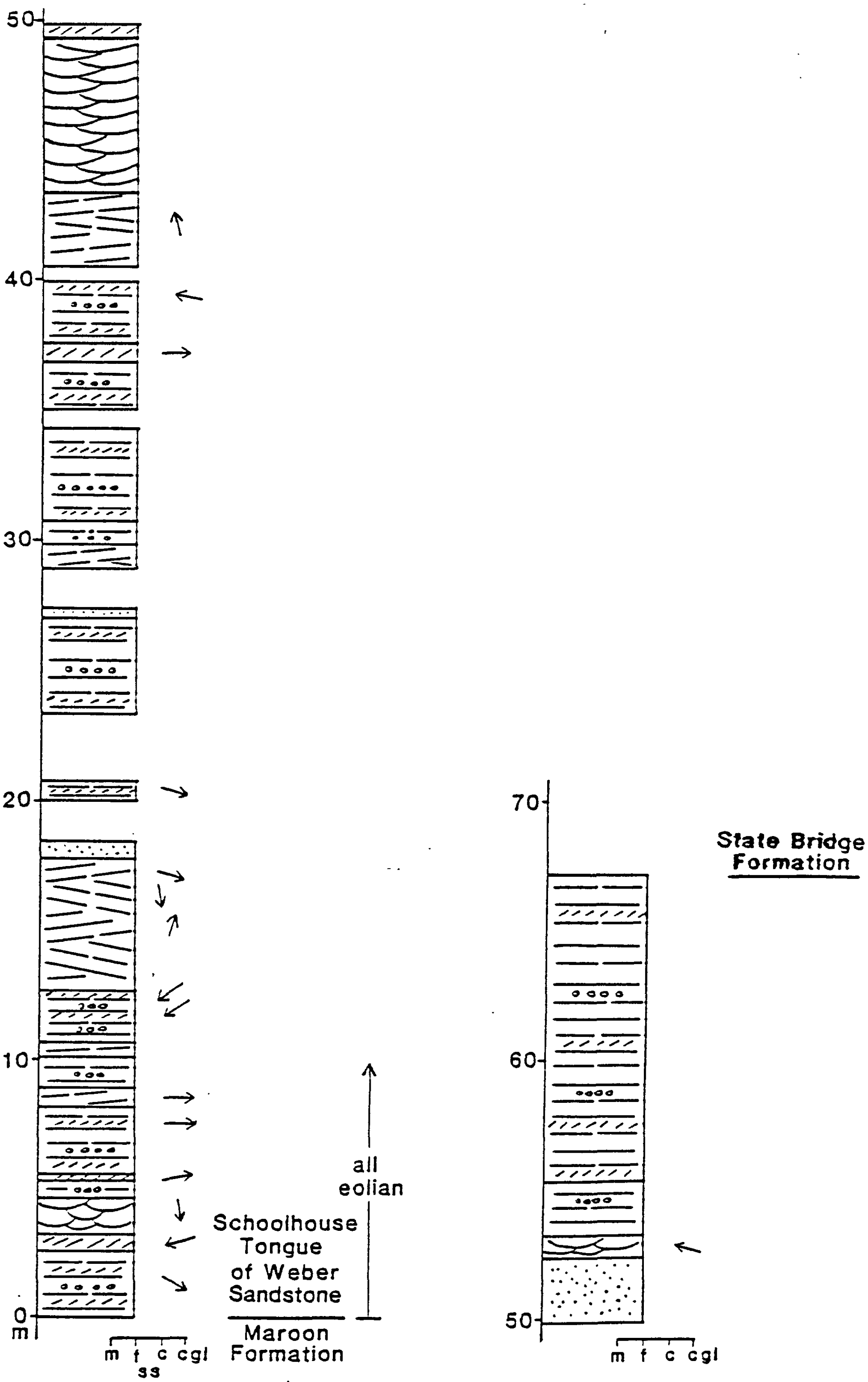


Figure 8. Stratigraphic column of the Schoolhouse Tongue of the Weber Sandstone in the Fawn Creek area (Figure 3). Explanation is the same as in Figure 4.

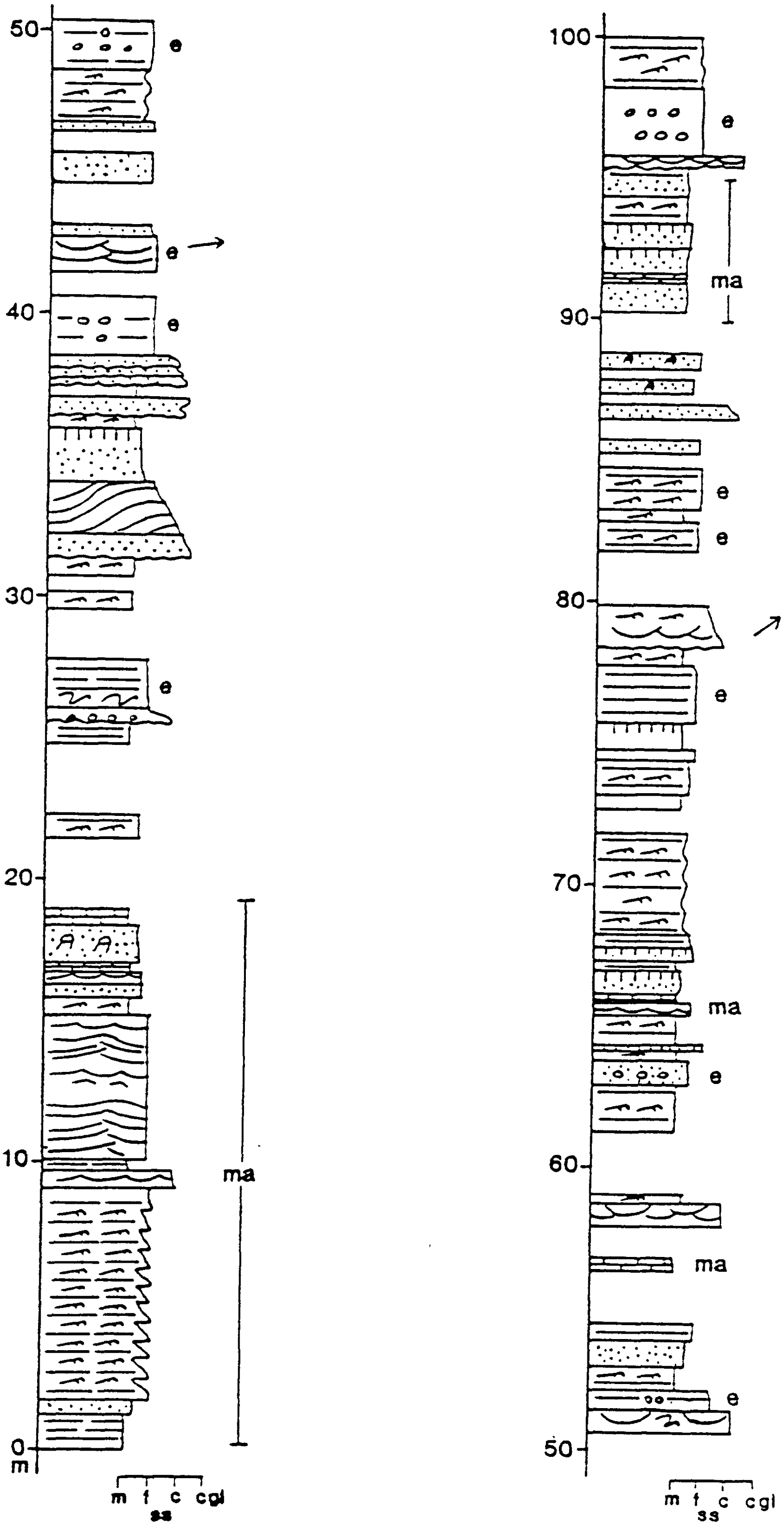
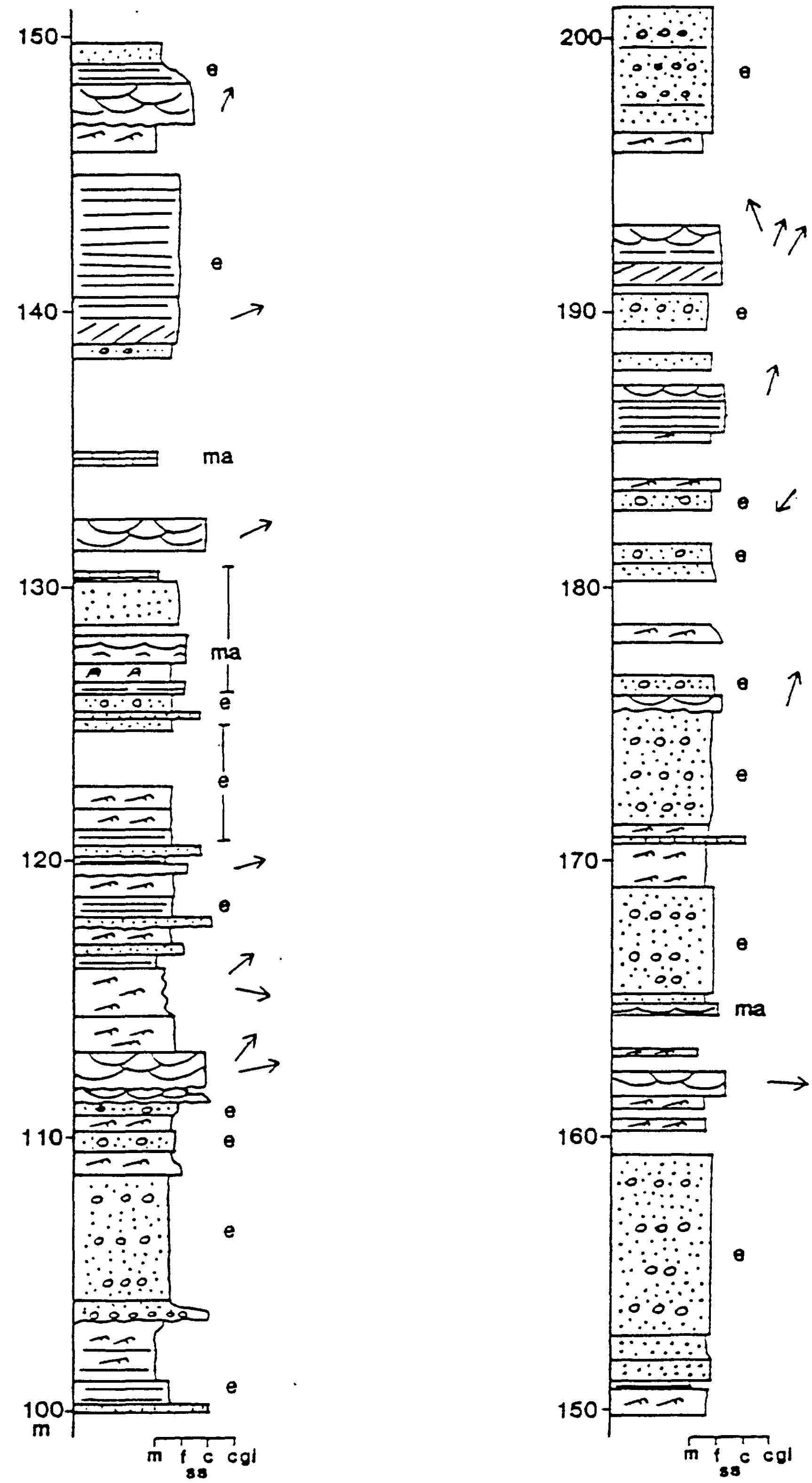


Figure 9. Stratigraphic column of the Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone along the Colorado River (Figure 3). Explanation is the same as in Figure 4.



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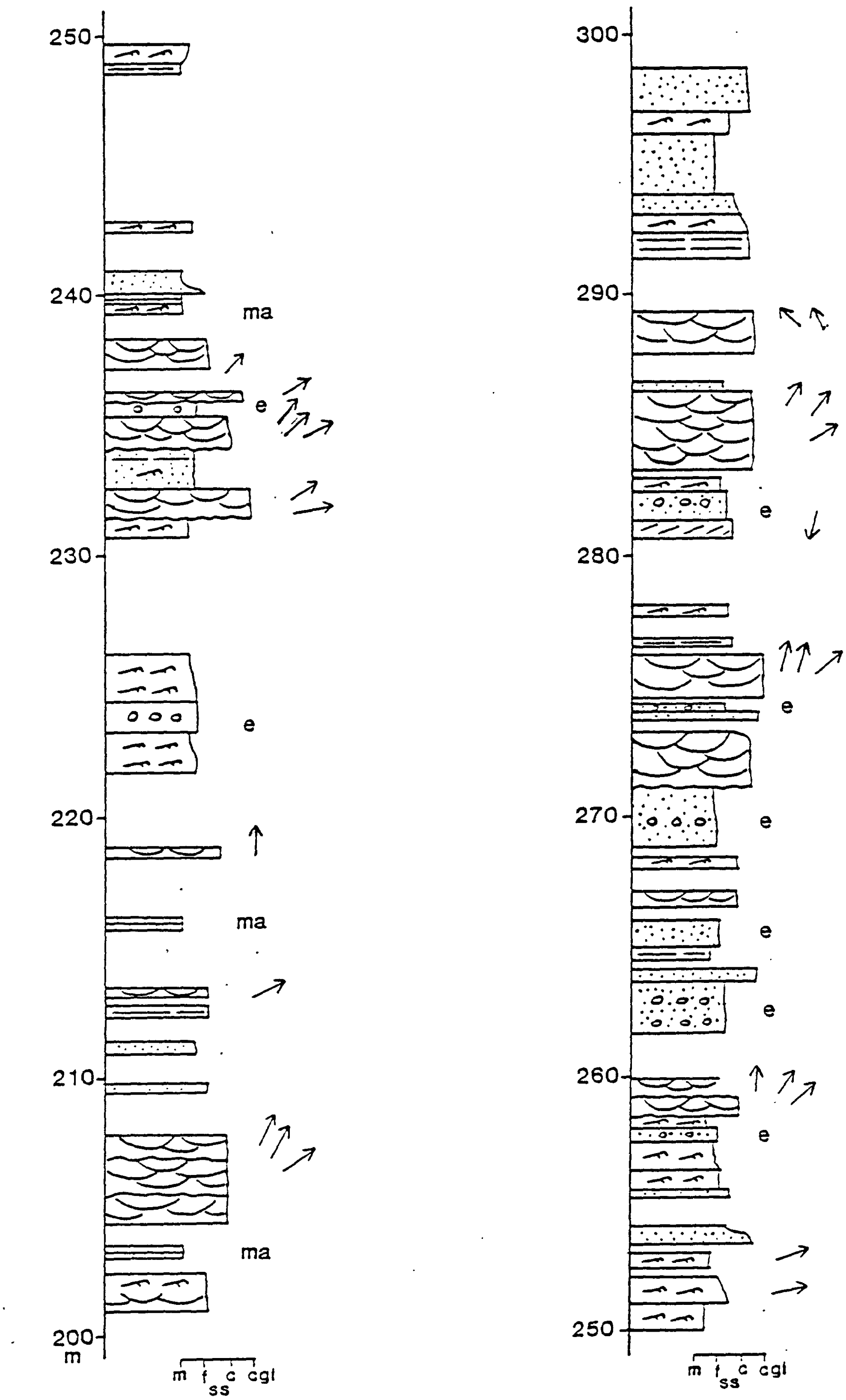

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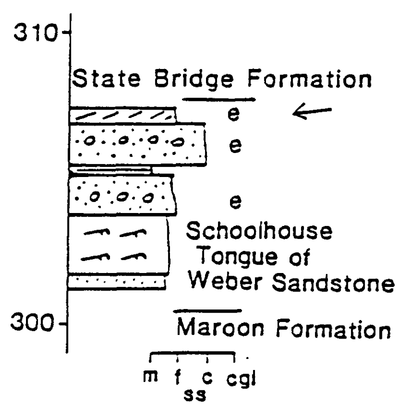


Figure 9 (cont.).

the Colorado River, about 6 to 8 km southwest of the townsite of Burns (Fig 3; NW 1/4, sec. 5, T. 3 S., R. 85 W.; SE 1/4, sec. 31, T. 2 S., R. 85 W.). The Maroon Formation comprises the lower 301 m of the 307-m-thick section (Fig. 9). Exposures are poor to excellent, the section is about 27 percent covered. Beds strike east-southeast and dip 12° to 24° to the north-northeast.

The underlying rocks of the Minturn Formation consist of brownish-gray mudstone to very fine grained sandstone, and gray limestone. The contact with the overlying Maroon Formation is marked by a gradational color change (over about 30 m) from the brownish and grayish hues of the Minturn to reddish-brown and reddish orange hues of the Maroon. For the measured section, the contact was placed at the approximate midpoint of this color change. This contact also represents a change from dominantly marine to dominantly nonmarine facies. The contact between the Maroon Formation and the Schoolhouse Tongue of the Weber Sandstone is covered by float but is parallel and appears abrupt. The contact between the Schoolhouse Tongue and overlying reddish-brown mudstones of the State Bridge Formation is also covered by a few meters of float, but is parallel and appears abrupt.

Eagle River

The 987-m-thick stratigraphic section of Figure 10 shows the stratigraphy of the Eagle Valley Evaporite, the Maroon Formation, and the Schoolhouse Tongue of the Weber Sandstone measured on slopes and cliffs north of the Eagle River and U.S. Highway 70, 5.3 to 6.8 km east of Eagle (SW 1/4, SE 1/4, NE 1/4, sec. 24; SE 1/4, sec. 13, T. 4 S., R. 84 W.). Beds strike to the northeast and dip 20° to 35° to the northeast.

The Eagle Valley Evaporite comprises the lower 600 m of the section and was measured in order to continue a stratigraphic section measured by C. J. Schenk (in press) through the underlying evaporite-rich interval in the same area. The measured section of Eagle Valley Evaporite begins at the top of the highest, thick (about 60 m) gypsum bed in the Eagle Valley section. Exposures of the Eagle Valley are poor to fair. Approximately 62 percent of the section is covered, including the thick interval between 316 and 518 m (calculated from map patterns). It is possible that part of the Eagle Valley Evaporite section has been repeated or cut out by faults in the thick covered intervals, but there is no field evidence to support this hypothesis. The Eagle Valley mainly consists of pale brown, brownish-gray, and yellowish-gray mudstone to very fine grained sandstone, and minor limestone; no evaporites were measured.

The contact between the Eagle Valley Evaporite and the red-brown and red-orange strata of the Maroon Formation occurs in the covered interval between 571 m and 607 m, and the base of the Maroon Formation was placed (somewhat arbitrarily) at 600 m. The Maroon Formation extends from 600 to 981 m in the section. Maroon exposures are fair to excellent, the section includes about 25 percent cover. As in other sections, the contact between the Maroon Formation and the overlying Schoolhouse Tongue of the Weber Sandstone is defined as the upper limit of red beds. Less than 3 km to the east, the yellowish-gray beds of the Schoolhouse Tongue pass laterally into red beds (Freeman, 1971a). The contact between the Schoolhouse Tongue and the overlying red beds of the State Bridge Formation is abrupt and parallel. Freeman (1971a) described a gray, chert-pebble conglomerate at the base of the State Bridge in this area, but this conglomerate bed was not found in this study.

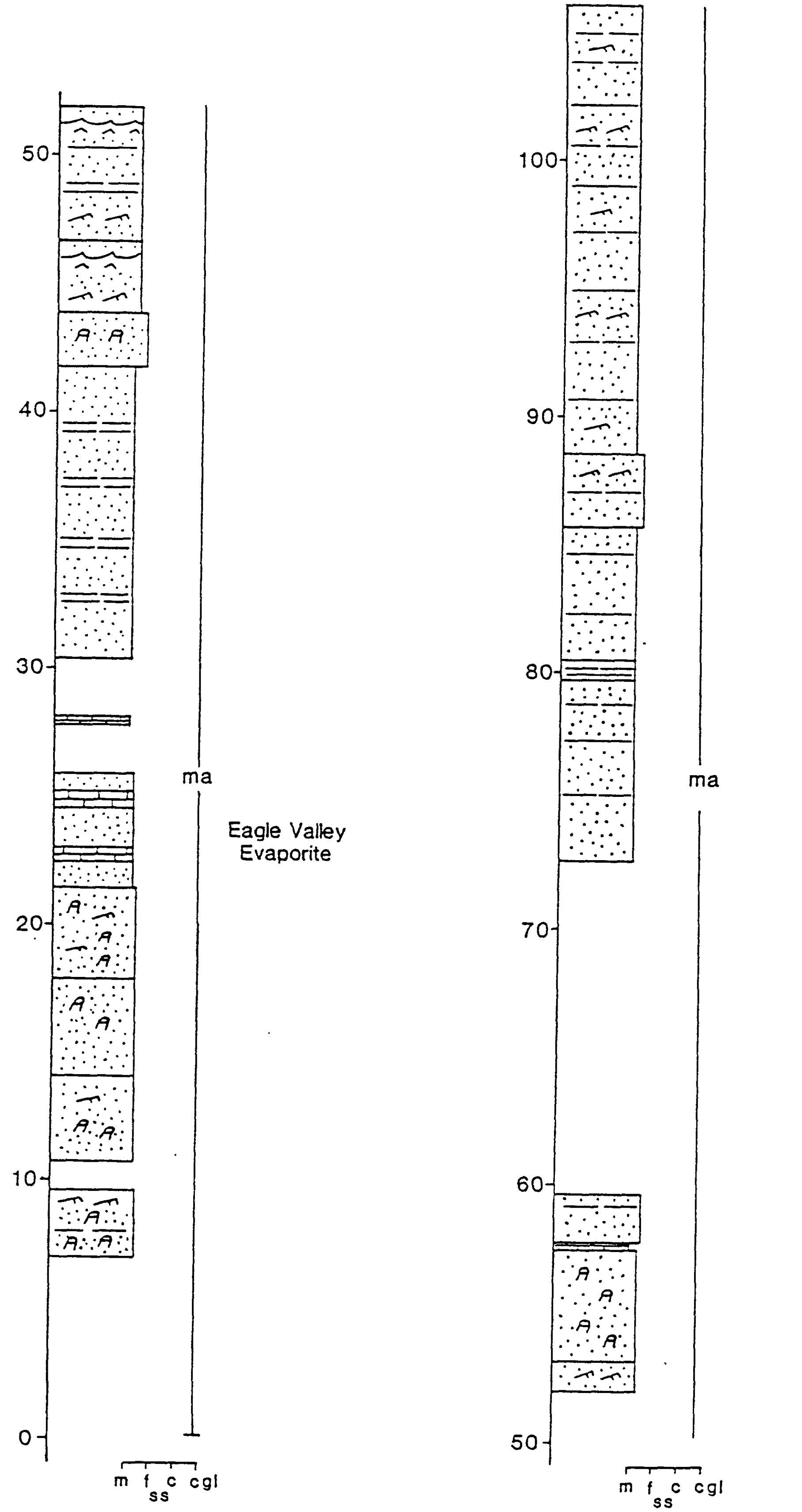
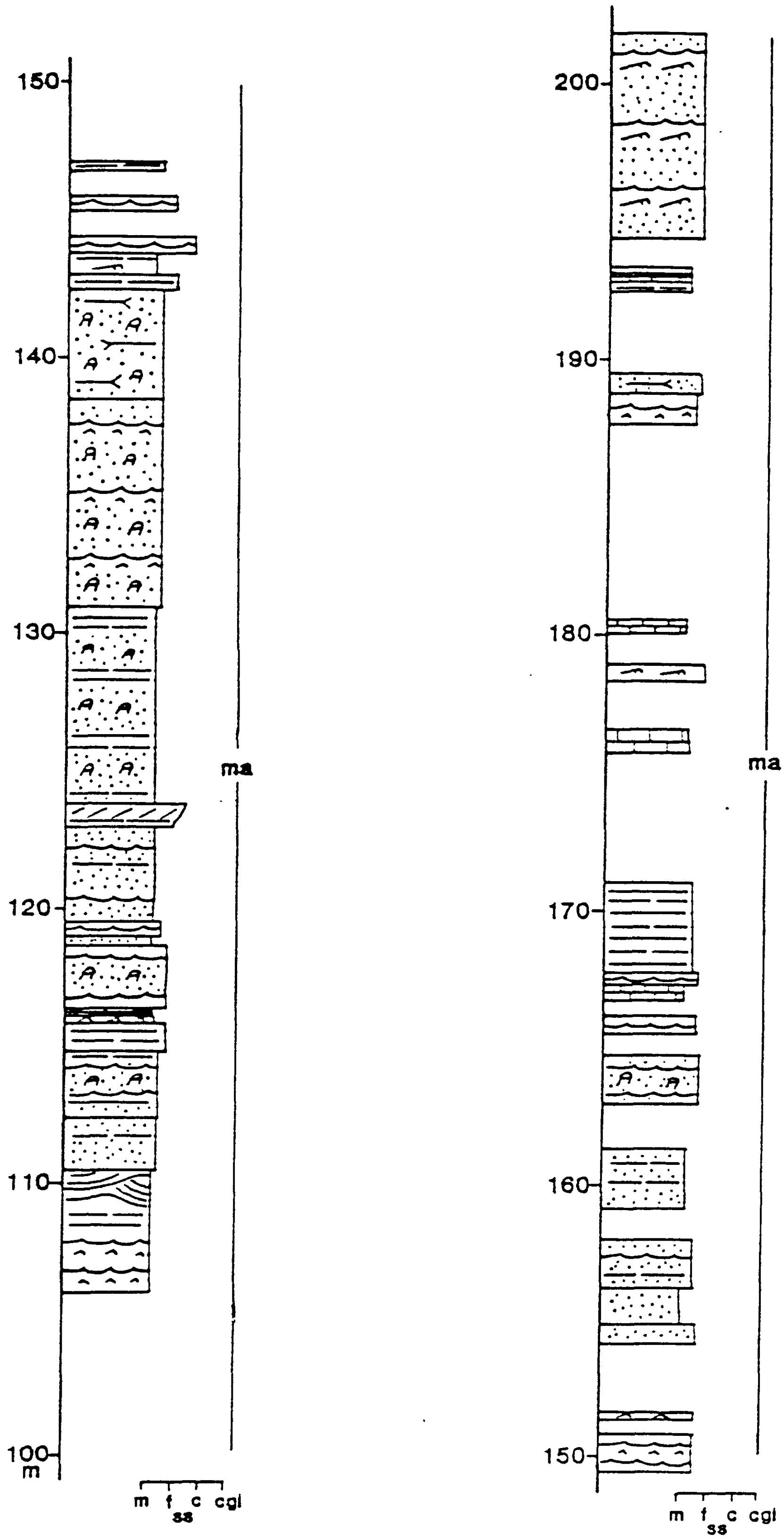


Figure 10. Stratigraphic column of the upper part of the Eagle Valley Evaporite, the Maroon Formation, and the Schoolhouse Tongue of the Weber Sandstone along the Eagle River (Figure 3). Explanation is the same as in Figure 4.



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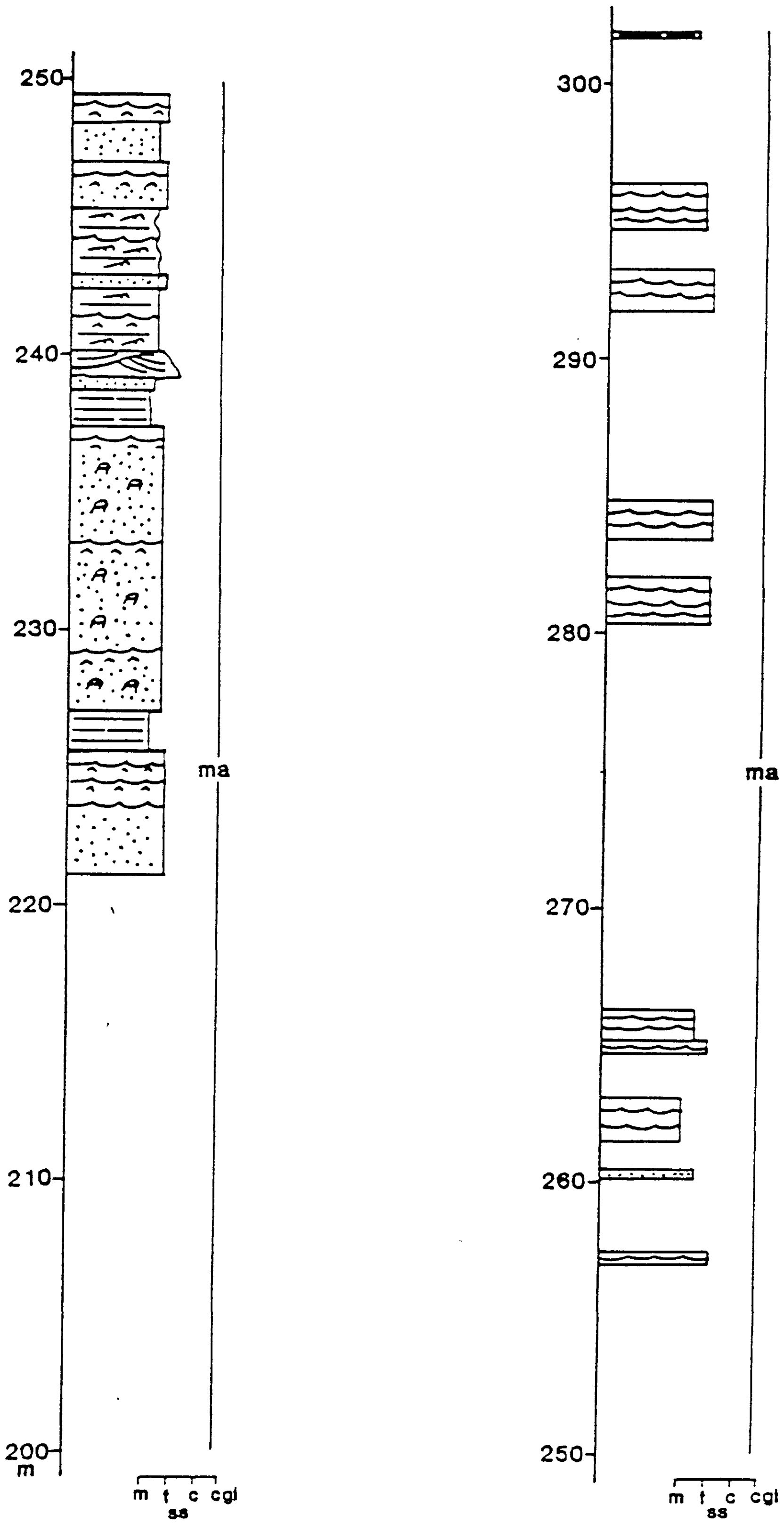

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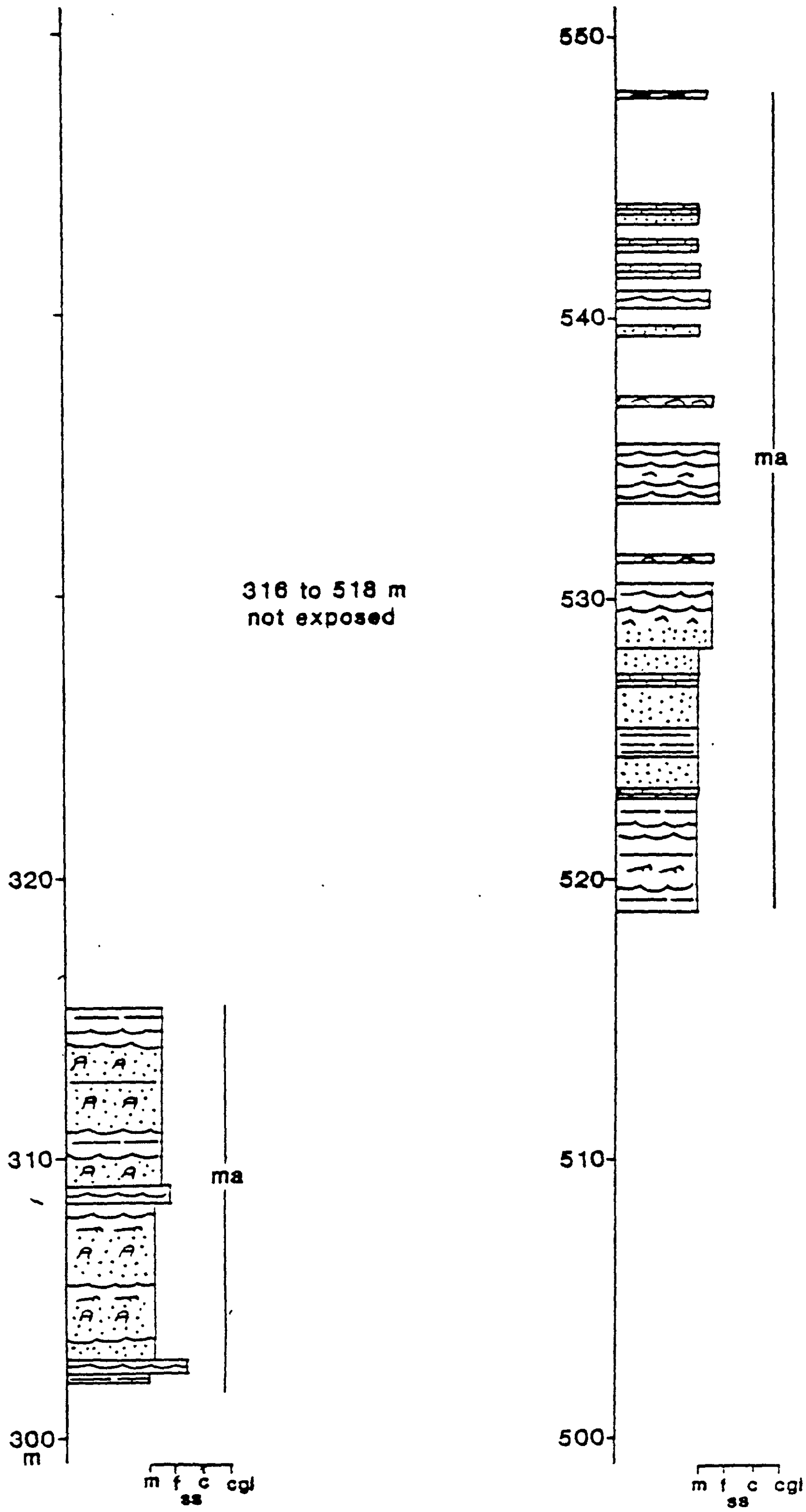

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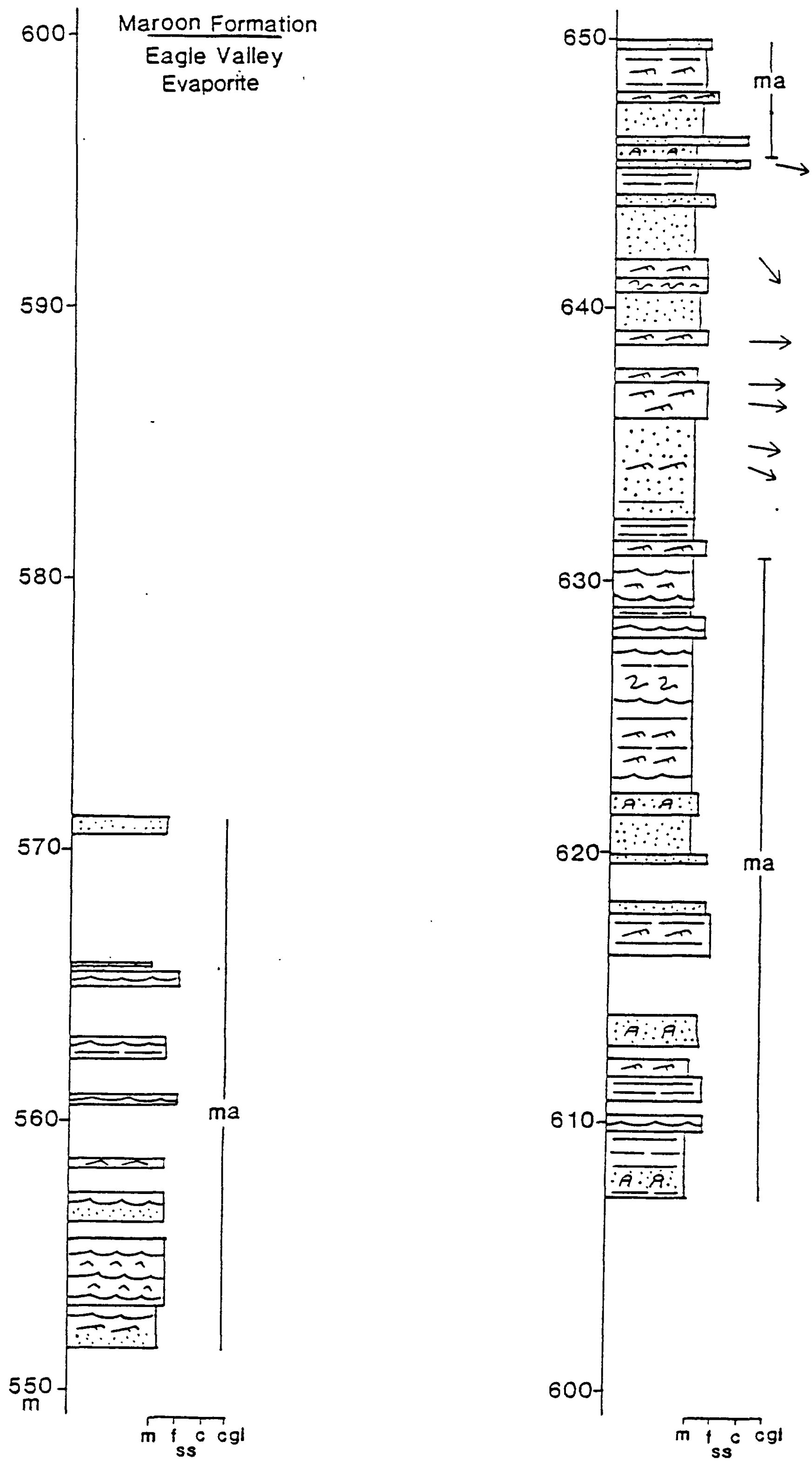

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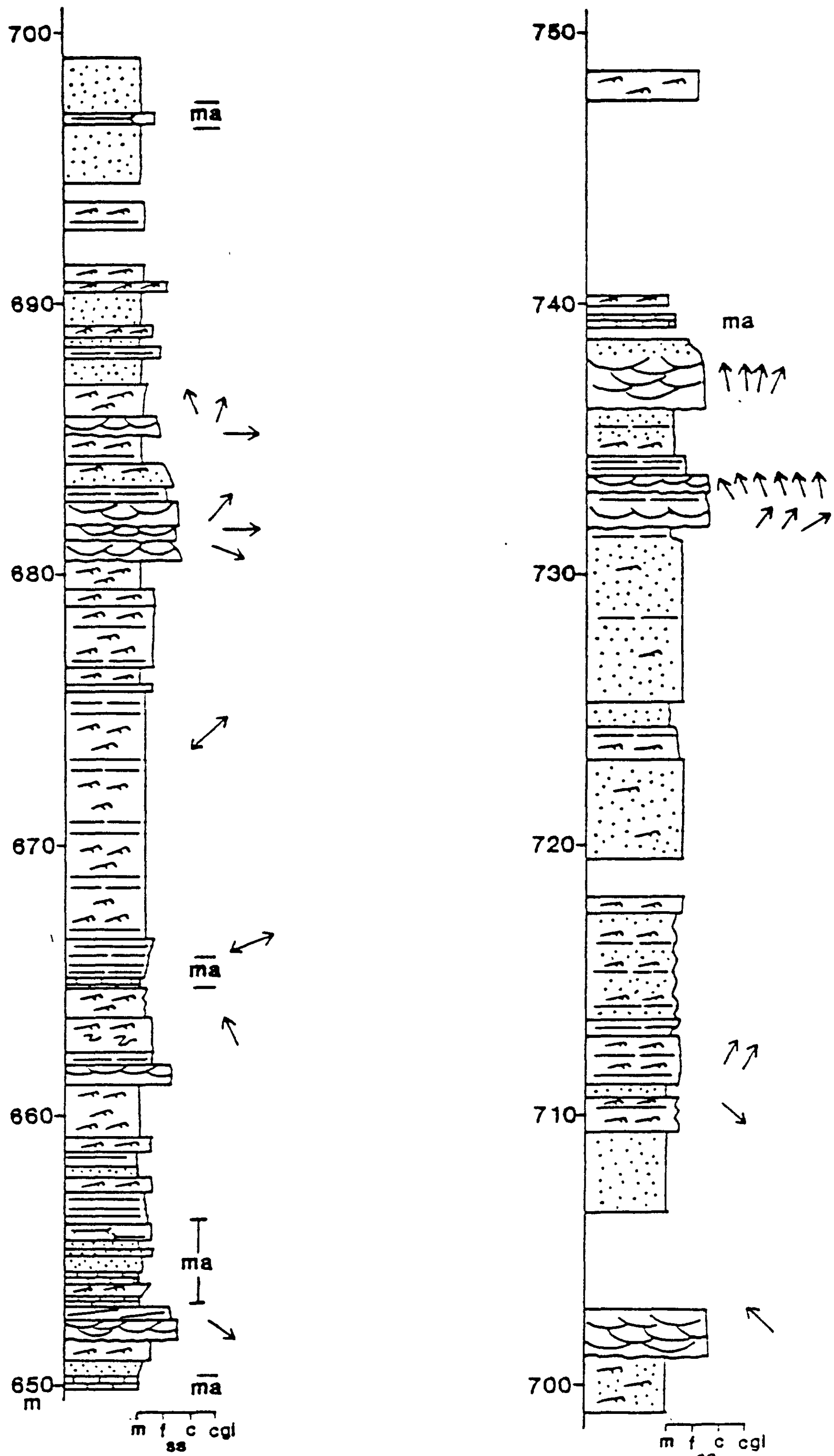

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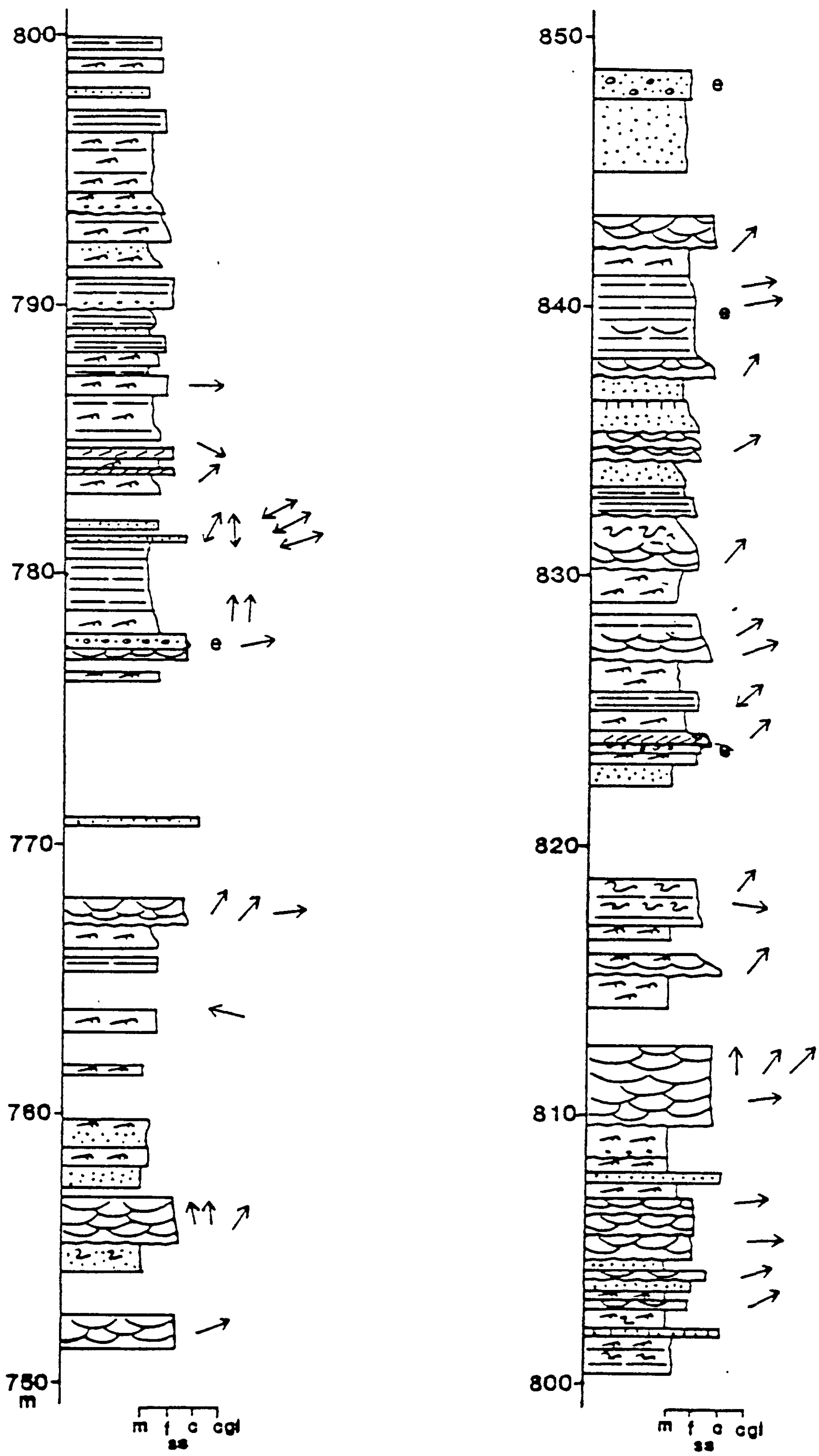

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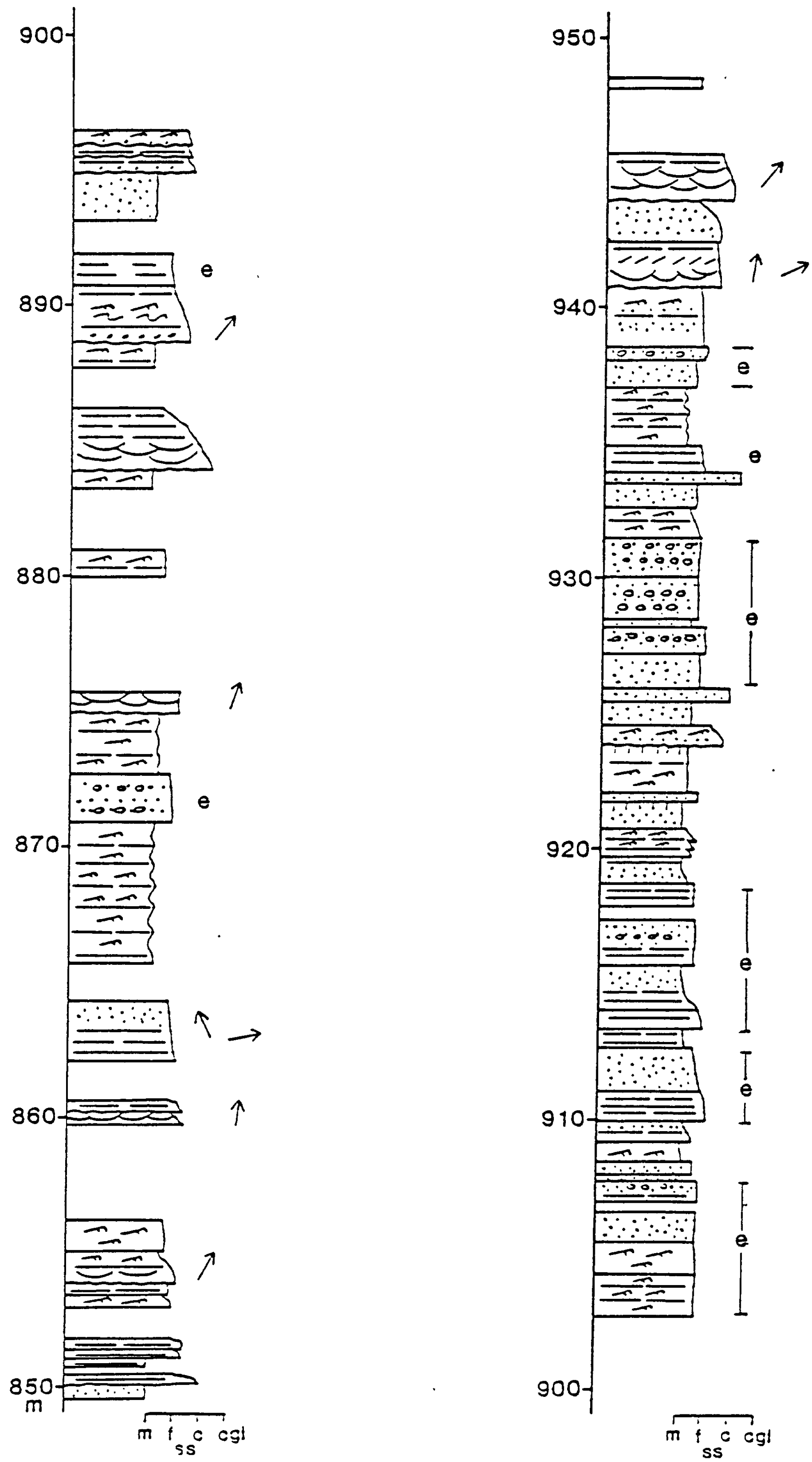

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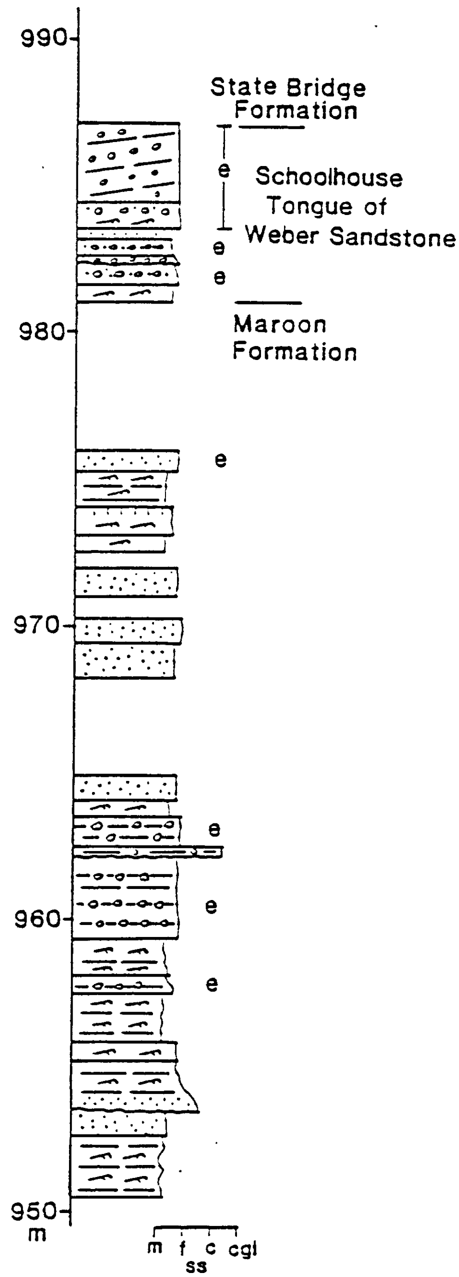

Figure 10 (cont.).

Vail

No well-exposed and(or) complete sections of the Maroon Formation were found on the eastern flank of the Eagle Basin. The 323-m-thick section of the Maroon Formation shown in Figure 11 probably represents the best partial section of the Maroon that can be measured. This section was measured on prominent red slopes overlooking the town of Vail (SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 1, T. 5 S., R. 81 W.). Exposures are poor to good, and about 43 percent of the section is covered. Beds strike east-west and dip to the north (20° to 25°).

In the Vail-Minturn area, Tweto and Lovering (1977) defined the contact between the Maroon Formation and the overlying Minturn Formation as the top of a prominent limestone marker horizon, the Jacque Mountain limestone (Fig. 2). This limestone is 6 to 7.6 m thick in its type area to the southeast in the Kokomo district. Tweto and Lowering (1977) mapped the Jacque Mountain Limestone across the Minturn 15' Quadrangle (which includes the location of this section), Boggs (1966) carried it 20 km west of the Vail section to Squaw Creek (although this correlation was later questioned by Mallory, 1971), and C. J. Schenk (oral communication, 1987) recognized a Jacque Mountain Limestone equivalent still farther west below the Eagle River section of this study. As the Jacque Mountain extends westward, it becomes thinner and is commonly interbedded with clastic detritus (Boggs, 1966). Tweto and Lovering (1977) mapped the Jacque Mountain Limestone on the slope where the Vail section was measured, however in several traverses up, down, and across the slope, the limestone could not be found. This may reflect cover (although limestrike east-west and dip to the north (20° to 25°).

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Ruedi Reservoir

A 1046-m-thick section that includes the sandstone of the Fryingpan River and part of the Maroon Formation (Fig. 12) was measured near the Ruedi

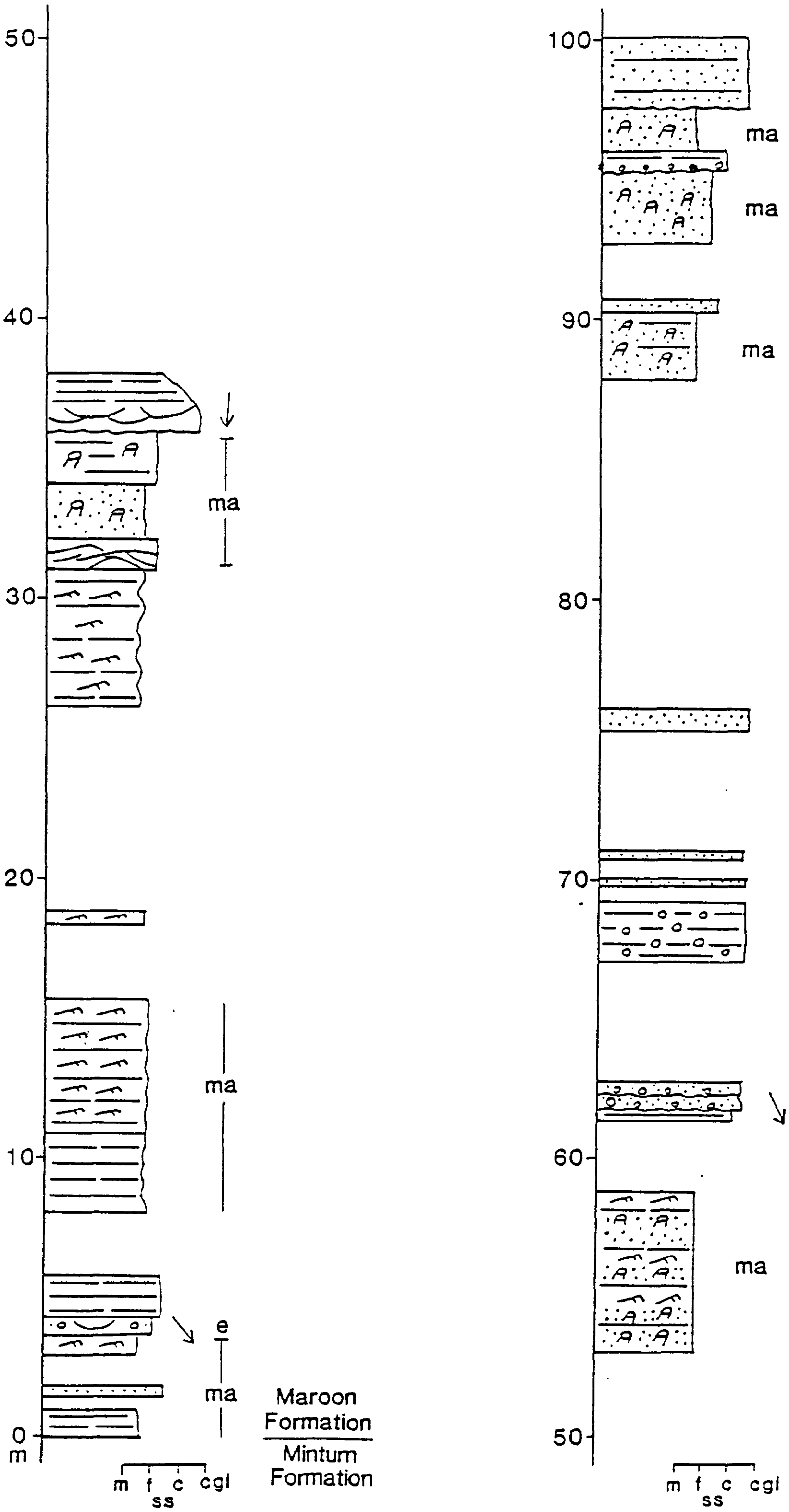
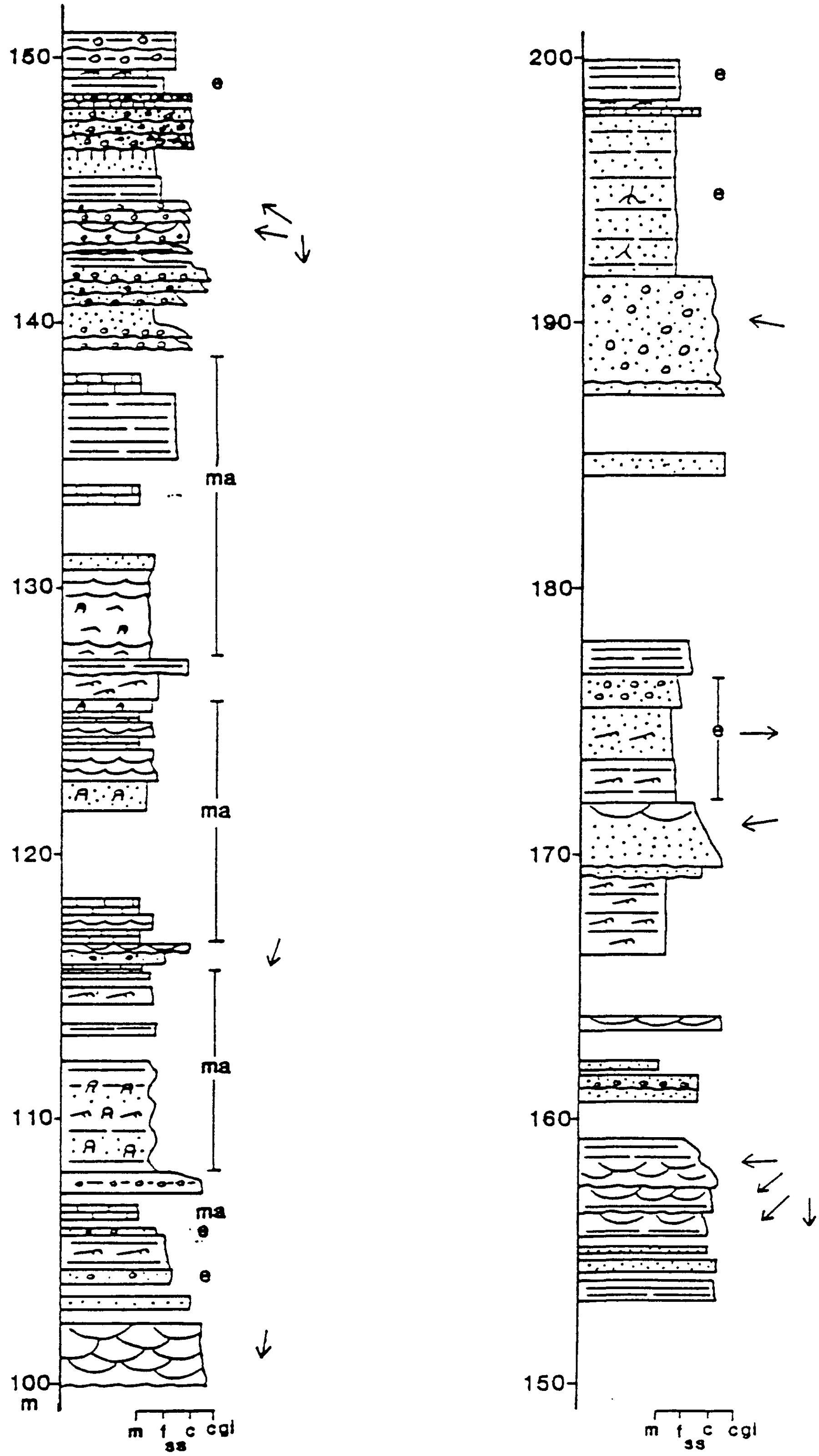


Figure 11. Stratigraphic column of the lower part of the Maroon Formation in the Vail area (Fig. 3). Explanation is the same as in Figure 4.



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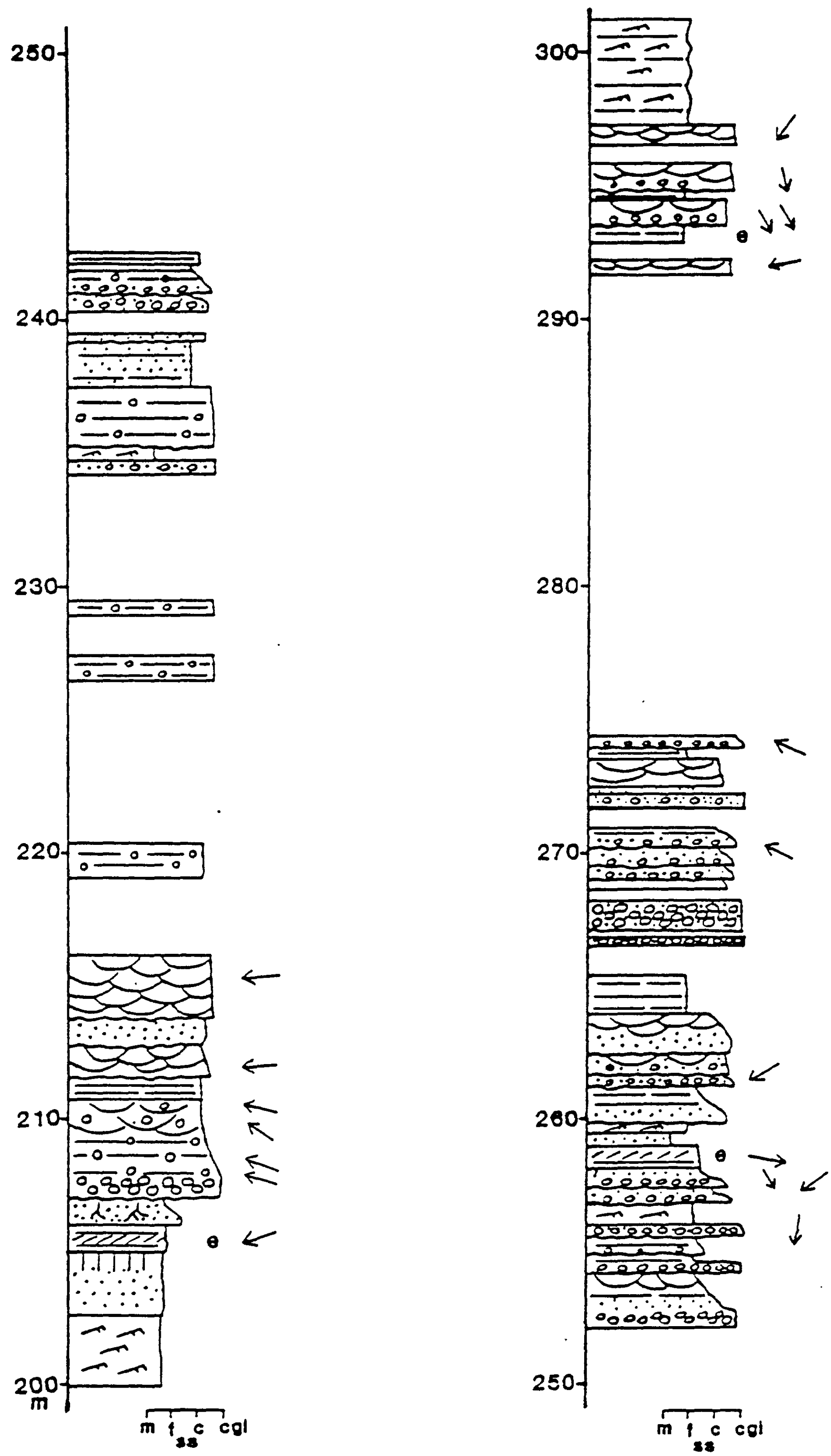

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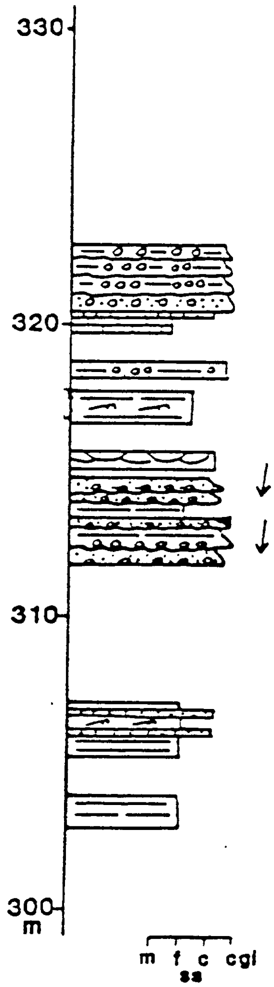

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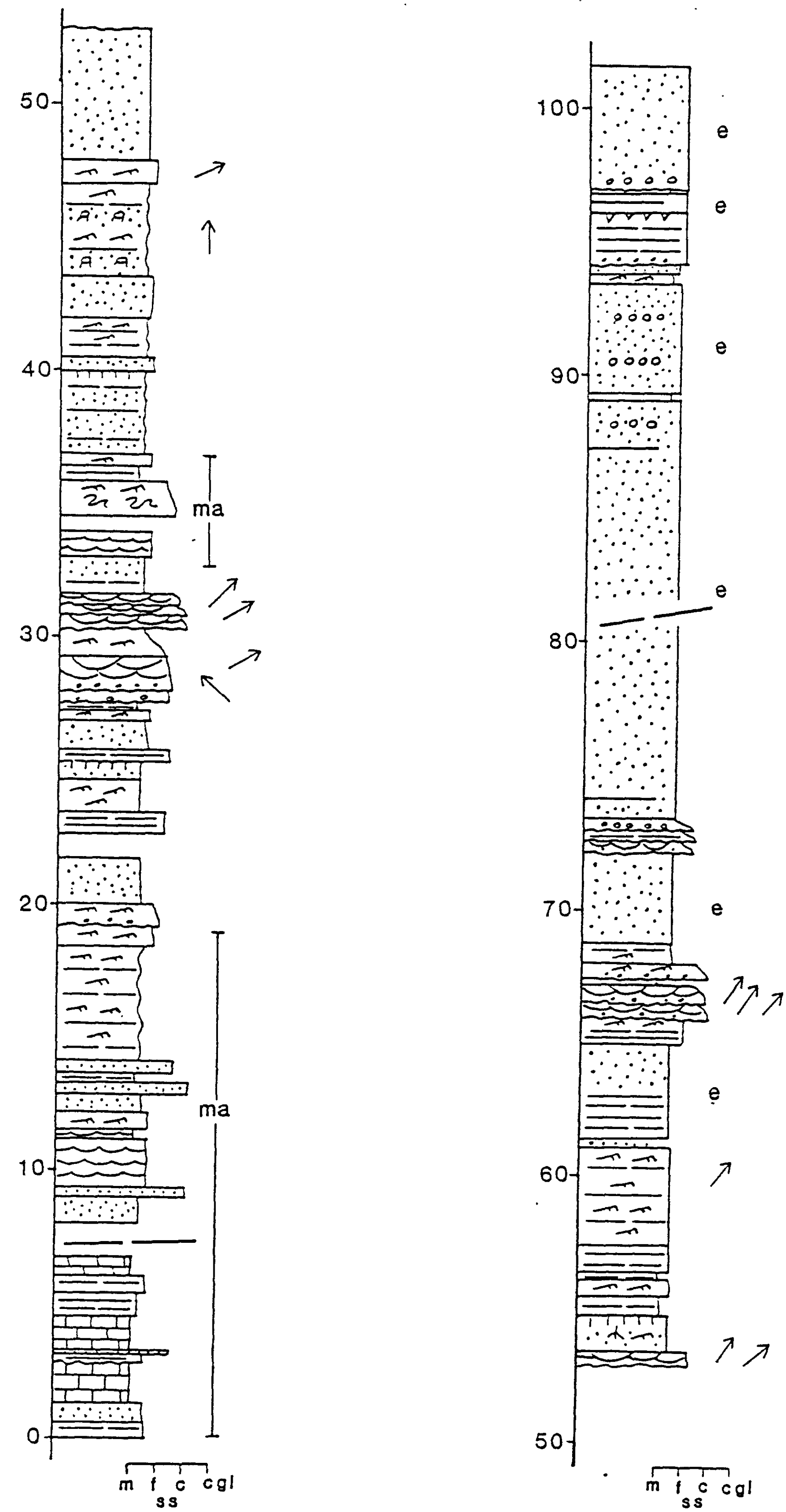
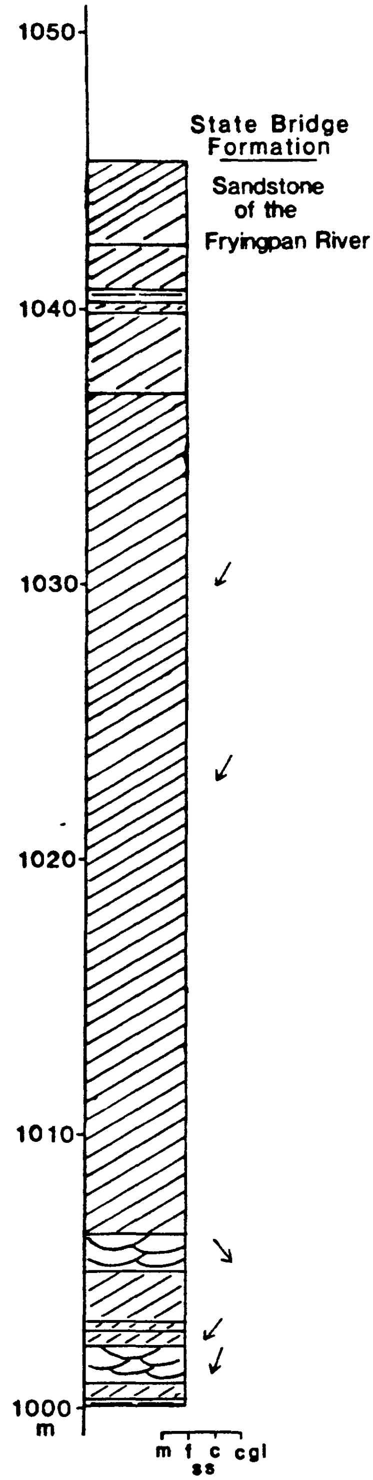


Figure 12. Stratigraphic column of the Maroon Formation and the sandstone of the Fryingpan River in the Ruedi Reservoir area (Fig. 3). Explanation is the same as in Figure 4.



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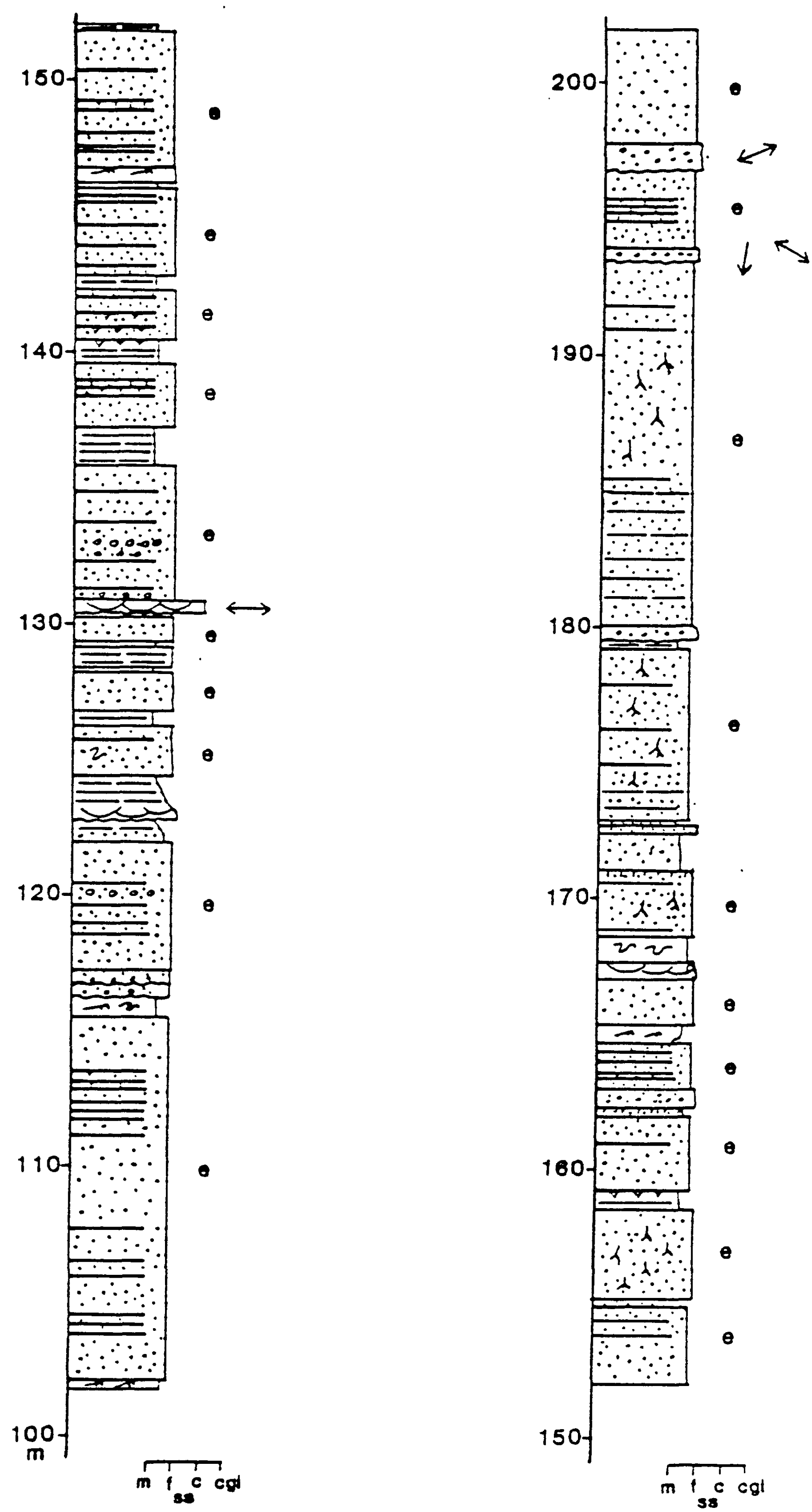

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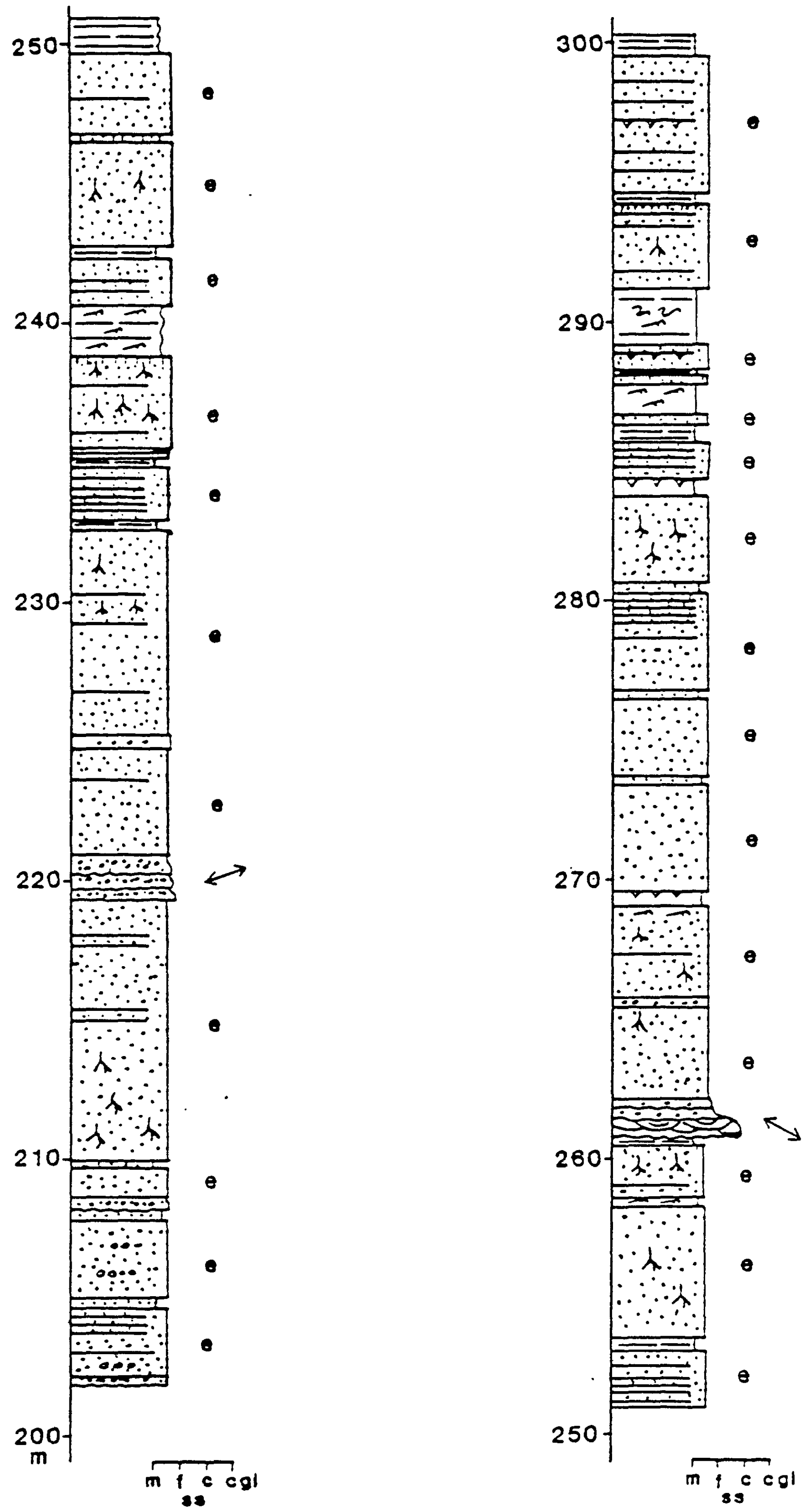

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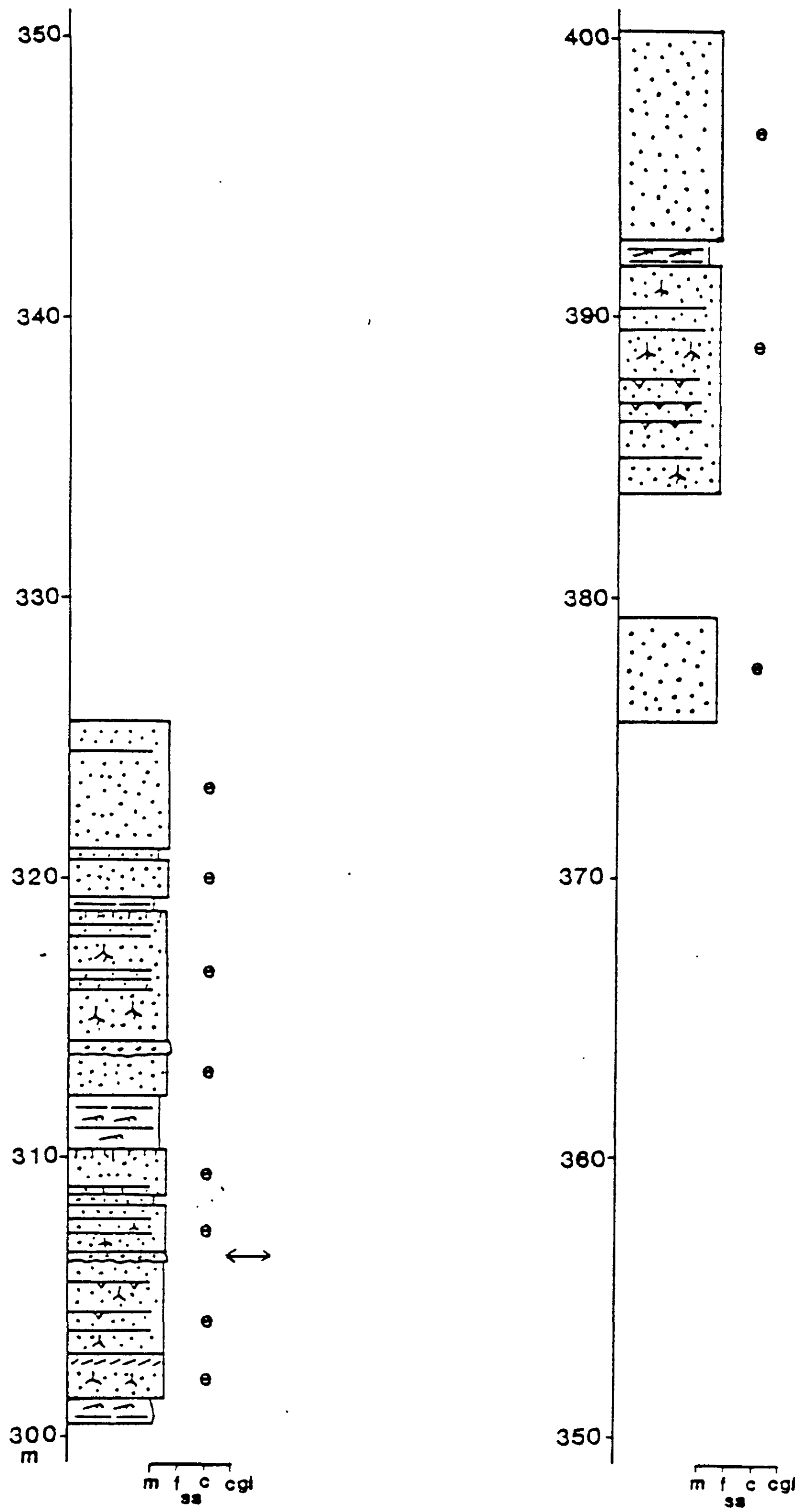

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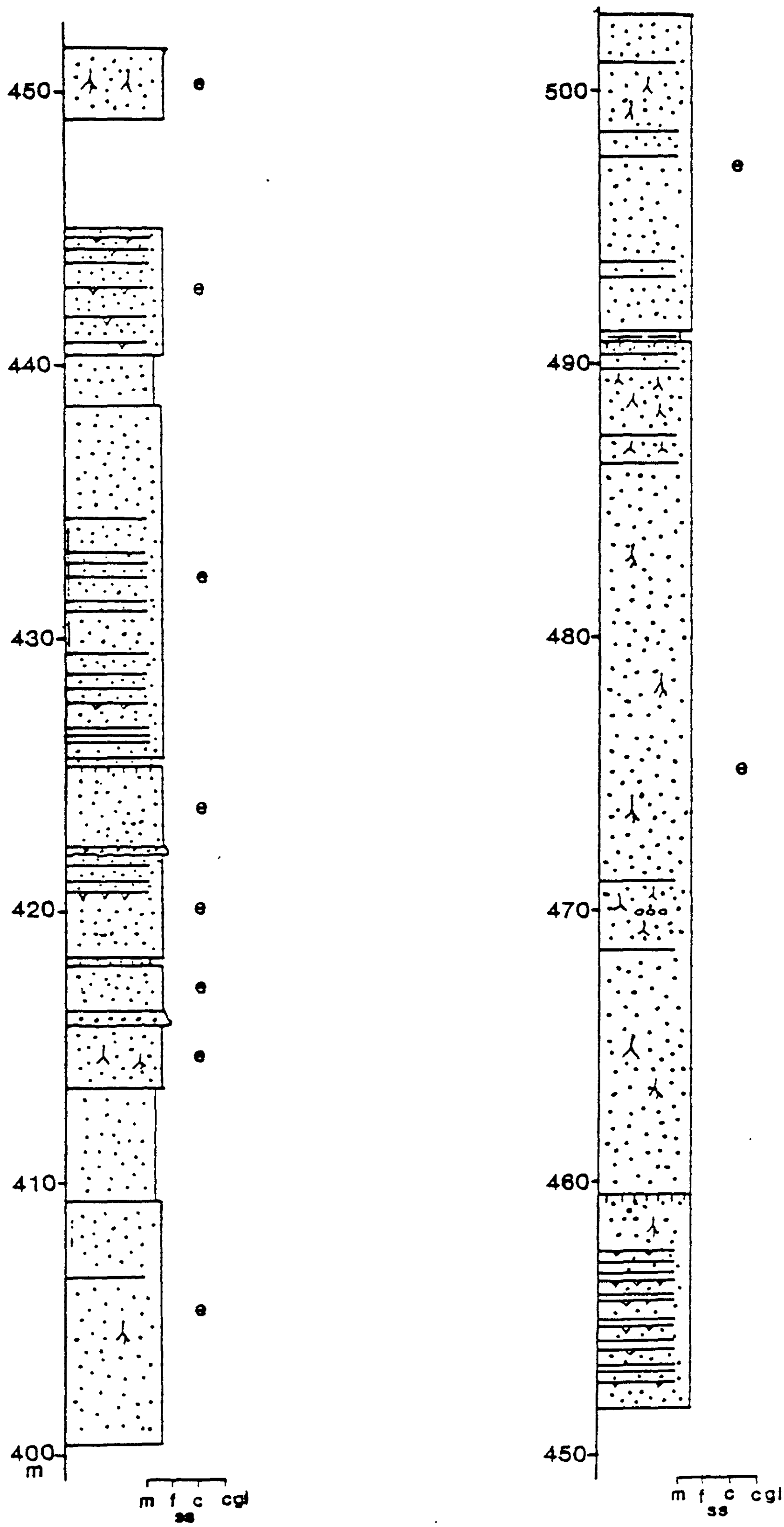

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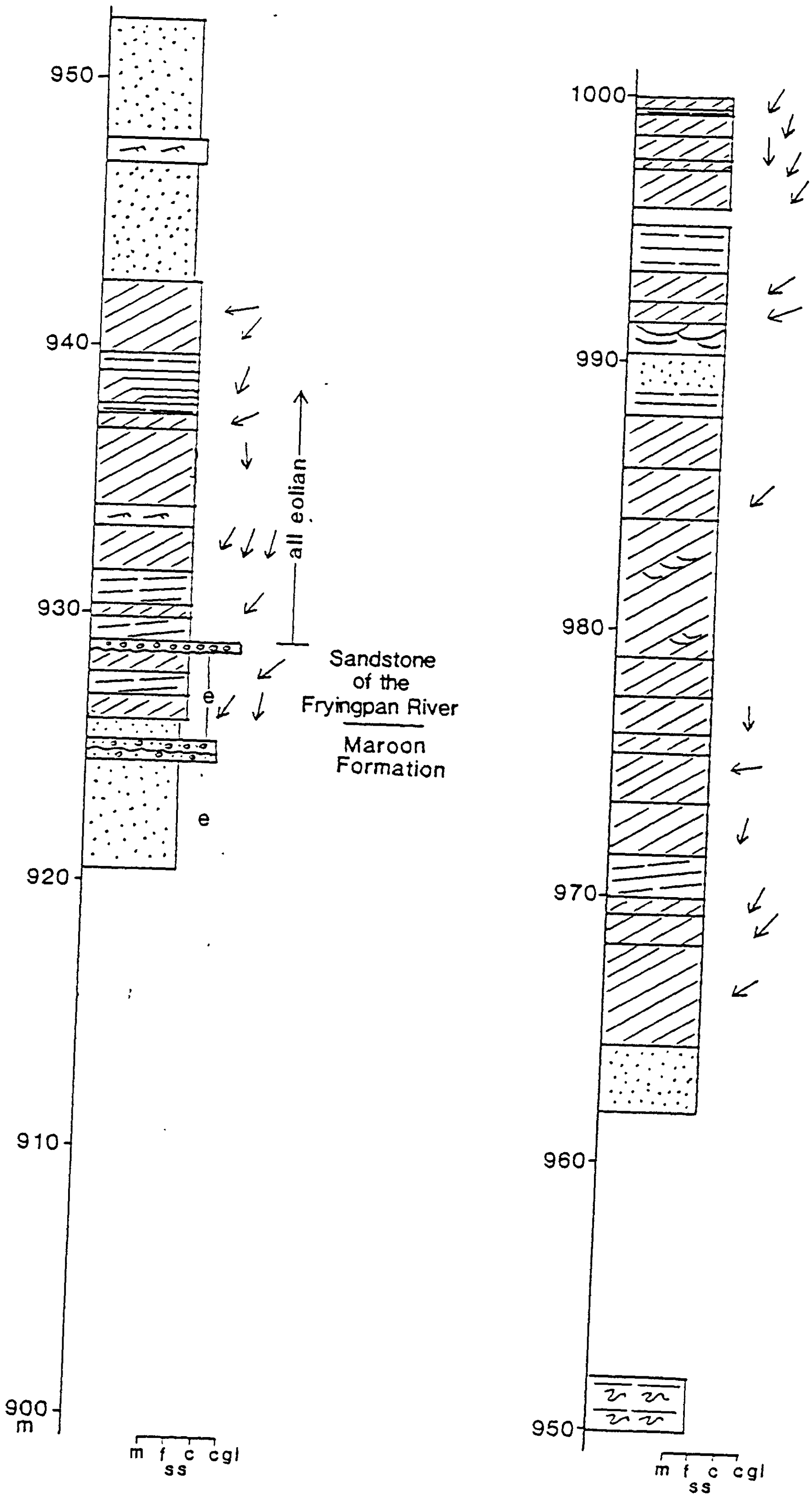

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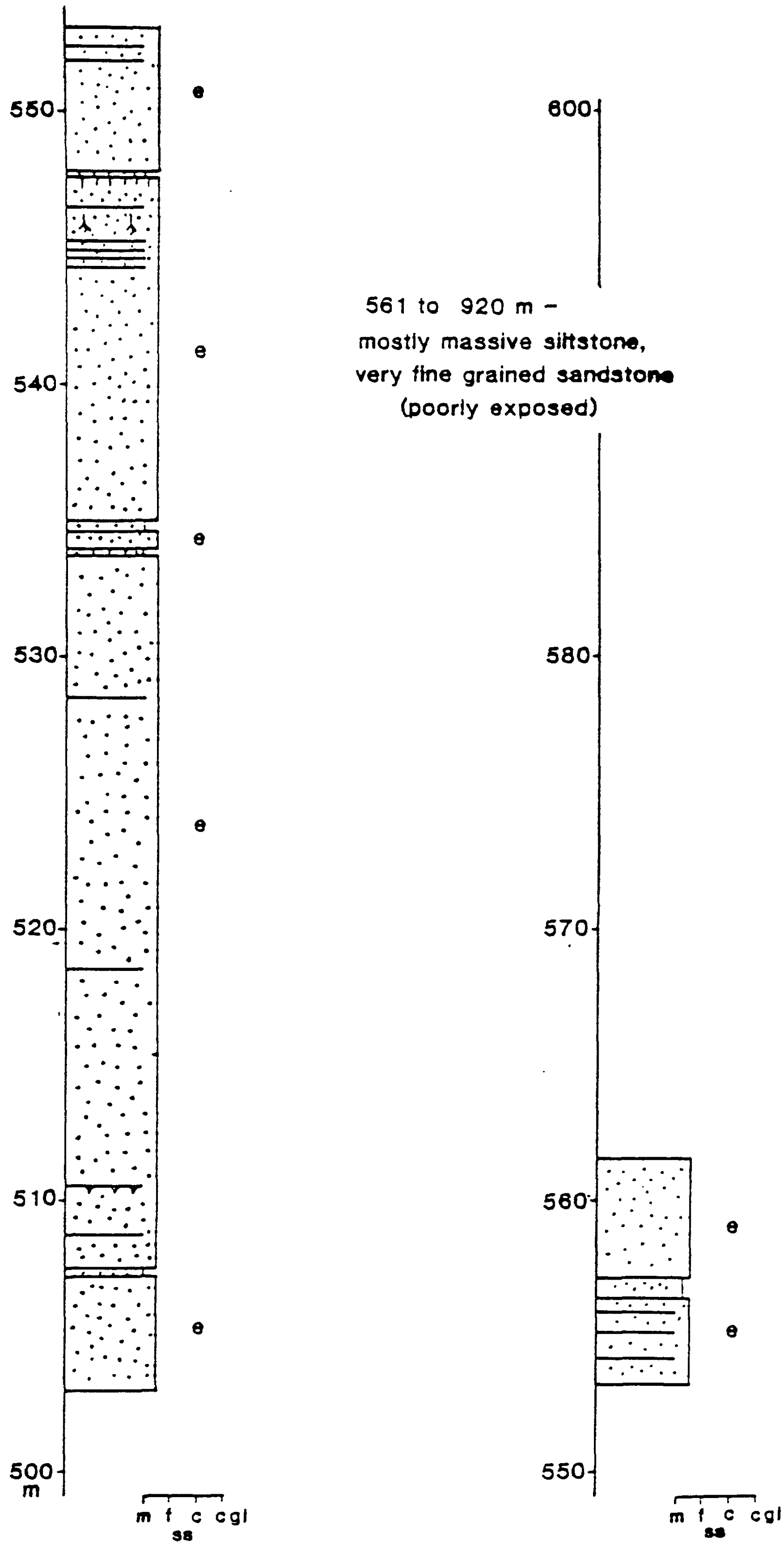

Figure 12 (cont.).

Reservoir in the northeastern portion of the Aspen sub-basin (Fig. 3). Most of this section was measured in roadcuts and in cliffs on and above the Fryingpan River Road (SW 1/4, sec. 7, NW 1/4, sec. 18, T. 8 S., R. 84 W.; SE 1/4, sec. 12, T. 8 S., R. 85 W.) near the western end of the reservoir. The upper part of the sandstone of the Fryingpan River (1007 m to 1046 m) was measured in a small quarry north of the Fryingpan River Road (SE 1/4, sec. 11, T. 8 S., R. 85 W.) about 1200 m west-northwest of the bulk of the section. The inferred thickness of the sandstone of the Fryingpan River is based on map patterns. Strata strike to the southeast and dip southwest 25° to 35°.

The contact between the Maroon Formation and the underlying Eagle Valley Evaporite is not exposed, and Freeman (1972) inferred that the two units were in fault contact at this locality. The amount of missing strata at the base of the Maroon Formation is not known. The base of this section represents the first, well-exposed redbeds in the nearly continuous section above the Ruedi Dam. A few small faults with inferred minimal stratigraphic displacment cut the lower 100 m of the section. Roadcut exposures of the lower 561 m of the section above the reservoir and then below the dam north of the Fryingpan River are good to excellent and nearly continuous. The section from 561 m to 920 m represents the interval between the last good Maroon outcrops along the road and the uppermost 6 m of the Maroon and the overlying sandstone of the Fryingpan River, exposed in the cliffs high above the road. The Maroon Formation in this interval is only partly exposed and was described in reconnaissance only. It consists mainly of massive, reddish-brown, siltstone and very fine grained sandstone, very similar to underlying well-exposed strata. The thickness of this interval was determined from map measurements.

The contact between the Maroon Formation and the sandstone of the Fryingpan River is undulating and characterized by gentle, constructive (i.e., non-erosional) relief. Cliff outcrops of the lower 81 m of the sandstone of the Fryingpan River are well exposed but steep and difficult to work with; the quarry outctrops of the upper 39 m of the section are excellent. The contact between the sandstone of the Fryingpan River and the overlying State Bridge Formation is not exposed but appears abrupt and is probably parallel.

SEDIMENTOLOGY

This section summarizes sedimentologic data and interpretations for the rocks described in the stratigraphic columns (Figs. 4-12). These data are and will be discussed in more detail in Johnson (1986, 1987, in press a, b) and in subsequent publications.

Eagle Valley Evaporite

The dominant lithology in the 600-m-thick Eagle River section of the Eagle Valley Evaporite is greenish-gray, pale brown, yellowish-brown, or less commonly yellowish-orange siltstone to very fine grained sandstone. There is a continuum from massive beds to beds with well preserved primary stratification. Massive beds are commonly several meters thick and are characterized by relict lamination, irregular cementation and weathering, burrows, and mixed zones containing sediment of variable grain size. These characteristics suggest that most primary stratification was destroyed by bioturbation. Well-stratified beds are also as thick as several meters and are characterized by plane bedding or lamination, current- and wave-ripple lamination, and less commonly flaser and lenticular bedding. A few of the plane-bedded units have slightly curved laminae and are bounded by low-angle truncation surfaces, resembling the "micro-hummocky" stratification of Dott and Bourgeois (1982). Plane-laminated and ripple-laminated units are commonly interstratified. Ripple heights are generally 0.5 to 3 cm, and there is no discernible statistical orientation to the crests of ripple axes or the dip directions of ripple foresets. Medium-grained and coarser sandstones comprise only about 1 percent of exposed strata, and consist mainly of plane beds bounded by low-angle truncation surfaces. A single set of cross beds (height = 15 cm) is exposed at 125 m in the section.

The uncommon yellowish-orange sandstones are calcite cemented and contain small (millimeter to centimeter sized), irregular pods and lenses of carbonate and uncommon, randomly distributed, irregular, millimeter-sized voids or fenestrae. Rare mudcracks on bedding planes were also observed in this facies.

Very thinly laminated, grayish-black micritic limestone and lime mudstone forms beds up to 150 cm thick and comprise about 5 percent of exposed strata in the section. Most lamination is horizontal, however curved lamination is also present and suggests an algal origin. The laminations enclose a minor amount of silt, pellets, and intraclasts. These grayish-black, thinly laminated, limestone units occur at 14 different horizons in the stratigraphic section.

Sedimentologic interpretation of the Eagle Valley Evaporite in the Eagle River section is limited by the amount (38 percent) and the quality of exposure. Exposed strata indicate a predominantly shallow marine and marginal marine origin. The presence of wave-ripple lamination and uncommon "micro-hummocky" stratification indicates deposition above wave base. In that the Eagle Basin seaway was geographically restricted (Fig. 1), this probably corresponds to depths of a few meters to tens of meters. Much of the primary stratification in the these shallow marine deposits is inferred to have been destroyed by bioturbation. Rare crossbedded and low-angle bedded fine- to coarse-grained sandstone provide the only evidence of wave-influenced shoreline deposition. The presence of flaser and lenticular bedding suggests a tidal depositional environment of variable energy (Reineck and Singh, 1980). Limestones of inferred algal origin and limy clastic units with uncommon fenestrae and mudcracks also support tidal-flat deposition. In that wave-influenced shoreline deposits are rare and no river-influenced shoreline deposits were recognized, shoreline sedimentation was probably dominated by tidal processes.

The quality and amount of outcrop are insufficient to determine whether there is a regular (or cyclic) pattern to the distribution of shallow marine and shoreline facies. The repeated occurrence of the grayish-black limestone beds of inferred tidal origin suggests several fluctuations in relative sea level. Strata in this section are overlain by fluvial deposits of the Maroon Formation with easterly paleocurrent directions (Fig. 13), suggesting that the noted shoreline deposition occurred on the west side of the seaway in the Eagle Basin.

Maroon Formation

Marine facies

Marine deposits form a minor part of the Maroon Formation and occur primarily at or near its base where they are intimately interbedded with nonmarine deposits. Facies are predominantly the same as those described from the Eagle Valley Evaporite in the preceding section, and are likewise interpreted as shallow and marginal marine in origin. Massive to well-stratified siltstone and very fine grained sandstone predominates, with common evidence of bioturbation. Although generally gray or brown, many beds of inferred marine origin have been oxidized to reddish-brown colors. These red rocks would be indistinguishable from nonmarine facies were it not for the presences of wave-ripple lamination and generally thin (< 30 cm) interbeds of very thinly laminated, grayish-black limestone (similar to those described in the preceding section). Gypsiferous mudstone is present in minor amounts in the Eagle River section (between 650 and 700 m).

Above the transitional zone at the base of the Maroon, marine facies are most abundant in the three sections (Miller Creek, Colorado River, Eagle River) in the central part of the basin. In the Colorado River section, there are at least seven discrete marine intervals above the transition zone (Table 1). Throughout the basin, these marine intervals are commonly abruptly overlain by fluvial channel deposits. This suggests that each interval of marine deposition may have been terminated by a rapid drop in sea level. As discussed in the next section, the marine intervals may have limited utility as marker horizons.

Fluvial facies

Fluvial deposits of the Maroon Formation consist of channel and floodplain deposits. Using architectural element analysis (Allen, 1983; Miall, 1985), Johnson (1986, in press, a) has previously described and interpreted the fluvial channel deposits of the Maroon in detail. A brief summary of this study is presented below.

Proximal fluvial channel deposits occur closest to the basin margins and characterize strata in the Glenwood Springs and Vail sections of this report. Proximal fluvial sandstone bodies consist mainly of channel architectural elements of crossbedded and low-angle bedded sandstone and conglomeratic sandstone, and are interpreted as the deposits of low-sinuousity, bedload-dominated, mobile-channel, braided rivers. Medial fluvial channel sandstone bodies characterize the Maroon Formation in the Rifle Creek, Miller Creek, Colorado River, and Eagle River sections. Medial sandstone bodies consist mainly of crossbedded and plane-bedded foreset-macroform and sand-bedform architectural elements of fine- to coarse-grained sandstone, and are interpreted as the deposits of sandy, braided fluvial systems of low to intermediate sinuousity. Distal fluvial channel deposits were described from the northernmost outcrops in the basin (Fig. 1). These distal deposits consist mainly of sand-sheet architectural elements of ripple-laminated and plane-laminated fine and very fine-grained sandstone and have an inferred sheetflood origin.

Paleocurrent data from fluvial deposits in the measured sections and other areas are shown in Figure 13. These data indicate that the Eagle Basin was markedly asymmetric during Maroon time. Rivers draining the western basin margin flowed well across the geometric center of the basin before entering the Eagle Basin seaway or merging with rivers draining the eastern basin margin (Johnson, in press, a). Facies changes in fluvial channel deposits derived from the western basin margin suggest progressive decreases in flow depth, flow strength, and discharge in the downstream direction. These characteristics typify many fluvial systems in arid to semi-arid basins (Friend, 1978; Johnson, in press, a).

The most common floodplain facies is massive to poorly stratified mudstone to very fine-grained sandstone. The loss of primary stratification is mainly due to pedogenic alteration, as indicated by common 1) irregular

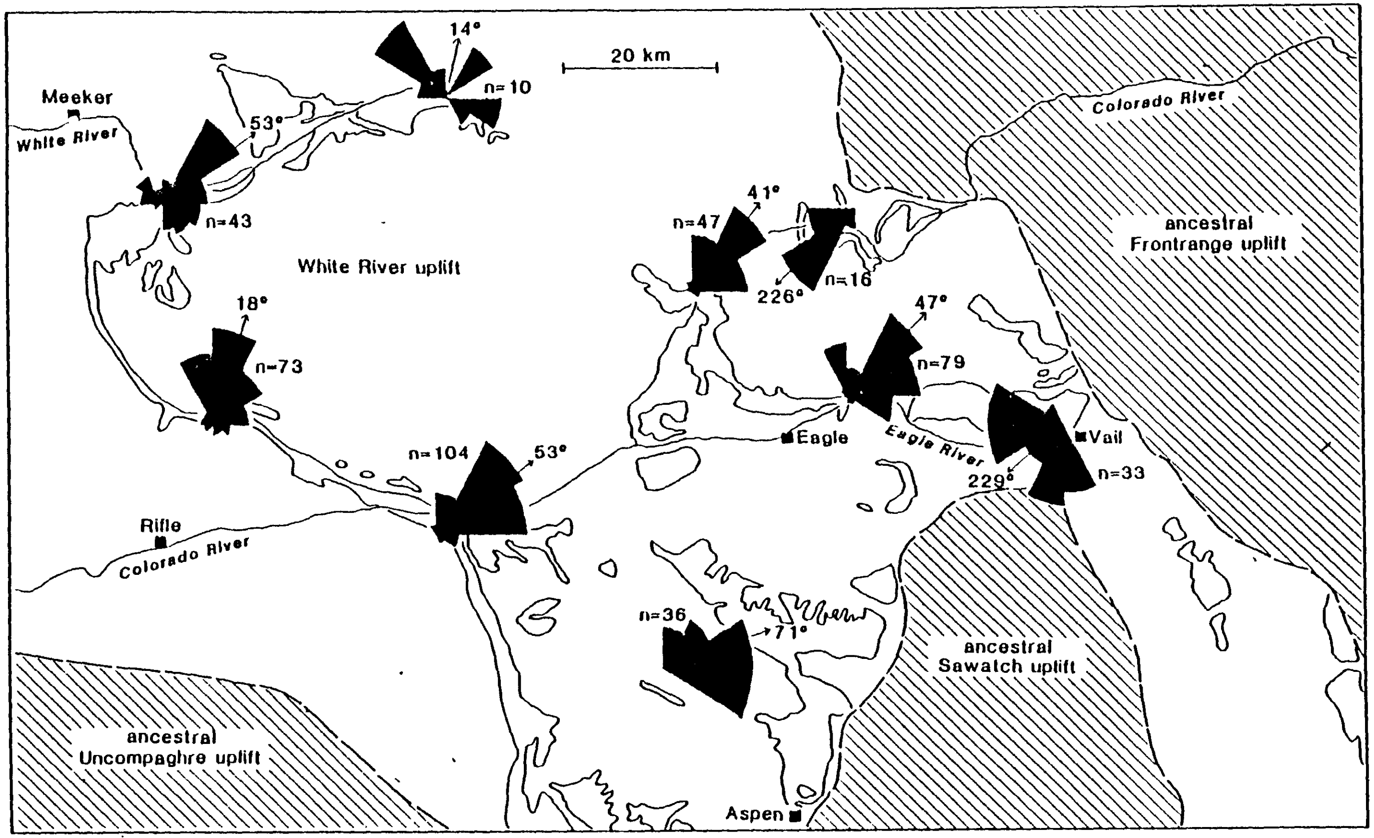

Figure 13. Paleocurrent directions for fluvial deposits in the Maroon Formation. Rose diagrams show dispersion of data, vector mean, and number of observations (n). Data mainly obtained from cross beds and scour marks.

TABLE 1

Stratigraphic position (in meters) of marine limestone beds below contact with State Bridge Formation

Section

Eagle River		Colorado River		Miller Creek
		68		
		93		
		143		
				154
		175	-----------?-----------	177
				205
		215		
		242		
248	-----------?------------	251		
290	-----------? -----------	288		
322	--------------------------	?	------------------------	319
333				
339	--------------------------	?	------------------------	338
356				

mottling and cementation, 2) rootlets, 3) spheroidal weathering, and 4) horizons of carbonate nodules that in some cases form pseudo-anticlines (Allen, 1974). Plane-laminated and ripple-laminated (including climbing ripples) very fine to fine-grained sandstone are a less common floodplain facies. Sandstone beds are generally less than 30 cm thick and are typically bounded by the more massive floodplain facies. Some of the sandstone beds can be traced laterally for ten meters or more and probably formed as overbank sheetflood deposits. Other thin beds of stratified sandstone are lenticular, have erosional bases, and probably formed as floodplain channels. The proportion of exposed fluvial floodplain deposits to fluvial channel deposits increases dramatically from about 0.5 in the Colorado River section in the center of the basin to 2.0 at Glenwood Springs nearer the western sediment source and the basin margin.

Eolian facies

Eolian deposits are widespread in the Maroon Formation and comprise two principal types. Sand-sheet deposits are common in the six sections measured in the Eagle Basin, loess deposits dominate the Ruedi Reservoir section measured in the northern part of the Aspen sub-basin (Fig. 3).

Strata of inferred eolian sand-sheet origin consist mainly of well-sorted, plane-bedded and low-angle bedded, very fine grained sandstone. Thin (< 1 cm) lenses and laminations of coarse sand and granules are common in this facies, and are interpreted as deflation lags. These lags are particularly abundant in the sections that are closest to the basin margins. Some low-angle bedded units drape irregular underlying topography and are probably eolian grainfall deposits. A smaller proportion of this facies is characterized by very thin planar lamination. The planar laminations enclose low-angle ripple foresets and are interpreted as eolian ripple deposits. Portions of plane-bedded and low-angle bedded intervals are commonly partly (in some cases mostly) massive, probably a reflection of pedogenic and phytogenic modification. Root traces are present but uncommon. Rare sets of planar and(or) trough crossbeds, interpreted as eolian dune deposits, are interbedded with the plane- and low-angle bedded facies in all sections. Crossbed heights are generally less than about 30 cm but range up to 2 m. Paleowind directions obtained from crossbeds indicate sediment transport to the southwest (Fig. 14), markedly different from sediment dispersal directions in interbedded fluvial deposits.

The facies described above are intimately interbedded and cumulatively support an eolian origin. The dominance of plane-bedded and low-angle bedded deposits and the relative absence of dune deposits support a sand-sheet origin (e.g., Glennie, 1970; Ahlbrandt and Fryberger, 1984; Kocurek and Nielson, 1986). These inferred sand-sheet deposits form intervals ranging in thickness from several tens of centimeters to 18 m (at 760 m in the Glenwood Springs section). The thickest intervals commonly include rare mudstone laminations (drapes) and asymmetric ripple marks, suggesting minor subaqueous reworking. The inferred sand-sheet deposits also commonly have a distinctive orangish-brown color that subtly contrasts with the more reddish-brown fluvial floodplain deposits and reddish-brown or purplish-gray fluvial channel deposits. This color contrast probably reflects differential early diagenetic histories related to grain size and the postion of the water table relative to the environment of deposition.

Because of poor exposures, distinguishing between eolian sand-sheet deposits and fluvial-floodplain deposits was difficult in parts of many sections. For the most part, poorly exposed fine-grained beds that lacked

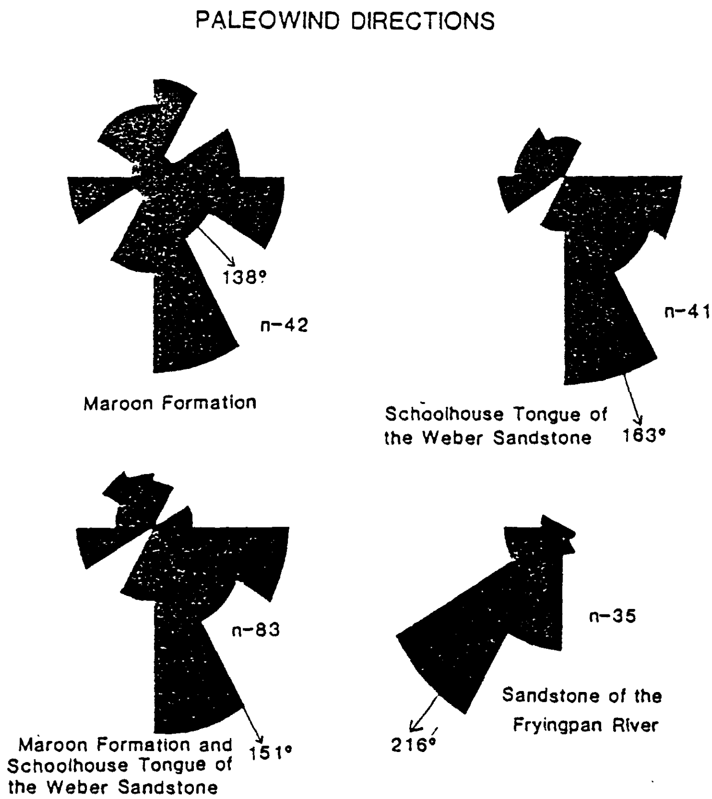

Figure 14. Paleowind directions for the Maroon Formation, Schoolhouse Tongue of the Weber Sandstone, and the sandstone of the Fryingpan River. Rose diagrams show dispersion of data, vector mean, and number of observations (n). Data are from cross beds.

positive criteria for eolian deposition were assigned a subaqueous (fluvial) origin. Additionally, intervals of inferred eolian origin are characteristically not resistant and do not form bold outcrops. The net result is that the proportion of eolian deposits shown in the sections (Figs. 4-12) and described below may be underestimated.

In the Glenwood Springs section (Fig. 4), inferred eolian sand-sheet deposits more than 1 m thick occur at more than 21 discrete intervals and comprise 23 percent of the exposed section above 171 m (above the part of the section typified by fluvial-marine interaction), and 40 percent of the exposed section above 700 m. In the Rifle Creek section (Fig. 6), inferred eolian sand-sheet deposits occur at 27 discrete intervals and comprise 18 percent of the exposed section. In the Miller Creek-Warners Point section (Fig. 7), inferred eolian sand-sheet deposits occur at 20 discrete intervals and comprise 34 percent of the exposed section. In the Burns-Colorado River section (Fig. 9), inferred eolian sand-sheet deposits occur at 22 discrete intervals and form 32 percent of the exposed section. In the Eagle River section (Fig. 10), inferred eolian sand-sheet deposits occur at 13 discrete intervals and comprise 12 percent of the stratigraphic section. In the incomplete section at Vail (Fig. 11), inferred eolian sand-sheet deposits occur at 5 discrete stratigarphic sections and comprise 9 percent of the measured section. The proportion of eolian deposits appears to increase upward in all of the complete Maroon sections.

The Ruedi Reservoir section of the Maroon Formation consists predominantly of massive beds (a few tens of centimeters to 25 m thick) of red-orange and reddish-brown siltstone and less common very fine grained sandstone intepreted as loess and loessoidal (Pye, 1984) sediment. Relict lamination is almost absent and most massive beds appear to have been deposited without primary stratification. Lower contacts of massive beds are generally planar and in most cases horizontal. Upper contacts are planar to undulatory and may be characterized by as much as a meter of gentle relief. Discolored moderate brown horizons are present at the tops of several beds, indicating pedogenic modification. Root casts are common but not widespread.

Massive beds are generally bounded by thin (< 5 mm) mudstone laminations (drapes) or less commonly by as much as 3 m of thinly bedded mudstone and siltstone. Mudcracks and adhesion warts and ripples (Kocurek, 1982) are common features of the mudstone drapes, and current-ripple marks are present on a few mudstone drape surfaces. The thin-bedded mudstone-siltstone intervals are also extensively mudcracked, and many mudstone laminae are discontinuous and curled. The thin-bedded facies is also characterized (to varying degree) by current ripple marks, mudcracks, water-escape structures, convolute lamination, and burrows. In several cases, these thin-bedded interbeds onlap irregular topography on the tops of the massive siltstone beds.

Thin (< 30 cm) fluvial channel deposits form a small proportion (< 1-2 percent) of the section dominated by massive siltstone. Channel deposits are lenticular and generally pass laterally within several meters into massive siltstone beds. Channel fills are dominantly trough crossbedded or plane-bedded fine- to coarse-grained sandstone in their lower part, and ripple-laminated or massive siltstone to very fine grained sandstone in their upper part. Several thin (< 20 cm) horizons of rip-up clasts dispersed in a massive siltstone matrix also occur in the section. These horizons clearly indicate sediment reworking but are not associated with recognizable channels.

An eolian loess origin for the very dominant massive siltstone beds in the Ruedi Reservoir section of the Maroon Formation is supported by (1) the dominance and uniformity of the silt grain size, (2) the absence of distinct stratification, (3) the planar to gently undulating bedding contacts, (4) the relative absence of channel deposits, and (5) the presence of adhesion structures in associated strata. The Ruedi Reservoir area is located downwind from the mixed eolian-fluvial plain of the Maroon Formation (Figs. 3, 14), which undoubtedly served as its sediment source. Deflationary southerly winds carried the silt southward, probably by saltation and short-term suspension (Tsoar and Pye, 1987). Deposition was probably promoted both by the topographic obstruction presented by the ancestral Sawatch uplift, and by the surface roughness effects of vegetation along the basin margin. The loess of the Ruedi Reservoir section comprises the thickest recognized loess deposit and is also one of a very small number of pre-Quaternary loess deposits to be described (Edwards, 1979).

Some of the loess was reworked and redeposited as loessoidal sediment. The intervals of thin-bedded siltstone and mudstone that onlap loess topography indicate that ponds were periodically present on the irregular loess surface. The relative absence of fluvial channel deposits reflects the high primary porosity of loess, which dramatically inhibits precipitation runoff.

Schoolhouse Tongue of the Weber Sandstone

The Schoolhouse Tongue of the Weber Sandstone is predominantly an eolian sand-sheet deposit that varies in character and thickness throughout the Eagle Basin. At all of the section localities, the most abundant facies is low-angle bedded (0° to 15°) very fine to fine-grained sandstone. Beds are commonly parallel or are truncated by low-angle erosion surfaces of inferred deflationary origin. In many cases, the irregular topography above the low-angle erosion surfaces is draped by overlying low-angle beds. Thin, parallel lamination (probably of both grainfall and eolian ripple origin) is preserved in some beds, although more commonly primary lamination is indistinct. Thin lenses of coarse sand and granules, intepreted as deflation lags, are common in the low-angle facies. In several sections (Main Elk Creek, Rifle Creek, Colorado River, Eagle River), particularly in the uppermost part of the unit, there are horizons up to 165 cm thick where the coarse sand-granule horizons are concentrated to the extent that they almost form homogneous, structureless beds.

In most sections, low-angle facies are interbedded with and grade laterally into less common planar-tabular, planar-wedge, and trough crossbedded strata. Crossbeds are typically bounded by low-angle erosional or bedding surfaces, and have concave upward foresets with thin or indistinct laminae. Crossbed set thicknesses are generally less than 50 cm, however a 13-m-thick set is present in the Rifle Creek section and a 3-m-thick set is exposed at the Miller Creek type locality lateral to the measured section. The relatively small scale of most crossbeds and their lateral relationship with low-angle deposits suggest that they formed by migration of small dunes across a low-relief surface. The two larger sets of crossbeds must have formed by migration of larger dunes but appear to be an aberration.

There are interbedded subaqueous deposits in all of the sections except Fawn Creek. In the Glenwood Springs section, there is a 330-cm-thick complex of interbedded fluvial channel deposits of conglomeratic sandstone (maximum clast diameter = 6 cm) and low-angle to crossbedded strata of inferred eolian origin. Thick fluvial channel deposits are also present in the sections at Main Elk Creek, East Elk Creek, and Rifle Creek. Intervals of current-ripple-laminated sandstone (10 cm to more than 1 m thick) are present in all sections except Fawn Creek. Further indication of periodic damp conditions during deposition of the Schoolhouse Tongue include the presence of (1) thick (> 125 cm) intervals of highly deformed crossbeds in the Glenwood Springs and Rifle Creek sections, and (2) bioturbation and phytoturbation(?) traces in several sections.

The abundance of low-angle bedded eolian deposits, the relative absence of large eolian dune deposits, and the intercalation of fluvial and other subaqueous facies support the eolian sand-sheet interpretation. It should be noted that except for its thickness in some parts of the basin, the eolian sand-sheet deposit of the Schoolhouse Tongue is not significantly different from the previously described sand-sheet deposits in the underlying Maroon Formation. The Schoolhouse Tongue therefore appears to have been an integral part of the Maroon depositional system in the Eagle Basin, and is probably best construed as the uppermost and thickest sand-sheet deposit in this system. If it were not bleached and oil stained, the Schoolhouse Tongue would almost certainly not be correlated with the sand sea deposits of the Weber Sandstone (Fryberger, 1979) to the northwest, as has been done repeatedly in the literature. The contact between the two units is primarily diagenetic in character (it juxtaposes bleached and unbleached rocks), not depositional. Paleowind directions obtained from crossbeds in the Schoolhouse Tongue indicate sediment transport to the southeast (Fig. 14), consistent with regional patterns (Driese and Dott, 1984) and that observed in the Maroon Formation.

Sandstone of the Fryingpan River

The sandstone of the Fryingpan River consists almost entirely of well-sorted, moderate reddish-orange, very fine to fine grained sandstone. The section is dominated (82 percent of exposed strata) by thick sets of planar and trough crossbeds, interpreted as eolian dune deposits. Sets are typically 50 cm to 250 cm thick, however a 31-m-thick(?) set of cross beds occurs near the top of the section. When this thick crossbed set is not considered, the mean set thickness is 165 cm. Dips are typically 20° to 30°. Trough widths are as much as 3 m to 5 m, and sets are as thick as 1 m. Foreset laminae of eolian grainflow, ripple, and grainfall origin (Hunter, 1977) were all observed, however the mixed quality of outcrop precludes accurate determination of the relative proportions of these stratification types.

The remaining 18 percent of exposed strata are plane-bedded to -laminated or massive, and are interpreted as interdune deposits. Plane laminations are generally very thin and inversely graded, suggesting they formed as eolian ripples. The rare presence of convolute lamination, bioturbation traces, and current ripples indicate that the interdune areas were periodically wet. Finally, a 30-cm-thick discontinuous lense of intraformational conglomerate near the base of the unit (at 929 m in the Ruedi Reservoir section) probably formed in a small fluvial channel.

The sandstone of the Fryingpan River has a restricted occurrence in the upper part of the Fryingpan River drainage. It pinches out to the north, west, and south (Freeman, 1972a, b), whereas its stratigraphic level has been eroded to the east toward the nearby ancestral Sawatch uplift. The unit therefore must have formed as a small dune field adjacent to the basin margin, a setting analogous to that of the modern dune field at Great Sand Dunes in southcentral Colorado (Andrews, 1981). In addition to comparable basin-margin location, dimensions and facies of the two dune fields are also similar. The dune field at Great Sand Dunes (Province III of Andrews) consists of deposits 100 m to 180 m thick and occupies about 85 km^2. The sandstone of the Fryingpan River is 120 m thick and it likely originally covered 100 to 200 km^2 (extending its mapped northern and southern boundaries eastward to the contact with basement rocks of the modern Sawatch uplift). At both Great Sand Dunes and in large parts of the sandstone of the Fryingpan River section, there is a relatively low proportion of interdune deposits. Andrews (1981) attributed this phenomena to close spacing of the dunes, which in turn resulted from proximity to the topographic obstacle presented by the Sangre de Cristo Mountains.

Paleowind patterns for the sandstone of the Fryingpan River as recorded by crossbed foresets (Fig. 14) are, however, parallel to the inferred trend of the flanking basin margin uplift, whereas Andrews (1981) reported that cross beds in the dune field at Great Sand Dunes dipped east toward the basin margin. In that in each case the topographic obstacle provides (or is inferred to have provided) the obstruction needed for sand concentration and dune development, the paleowind directions for the sandstone of the Fryingpan River are somewhat perplexing. The exact relief and configuration of the ancestral Sawatch uplift are not known, however, and the modern Sawatch uplift protrudes westward directly south of the Ruedi Reservoir area. If this protrusion is relict, it may have restricted transport of eolian sediment. There may also have been a complex local wind cell surrounding the ancestral uplift that created conditions suitable for the sand to accumulate in south-facing dunes. Importantly, C.J. Schenk (personal commun., 1987) has observed thick sets of south-facing crossbeds in trenches cut in the modern dune field at Great Sand Dunes, suggesting that sand transport in that setting might be more complex than previously reported.

As discussed, the sandstone of the Fryingpan River overlies the loessite of the Maroon Formation and was no doubt an integral component of the Maroon depositional system. The termination of loess deposition and the initiation of dune deposition was probably forced by a cessation or slowing of subsidence in the basin to the north. Rather than being rapidly buried beneath the Maroon alluvial-eolian plain, sands were exposed at the surface and made subceptible to eolian erosion and transport for longer time intervals. The sandstone of the Fryingpan River is therefore probably correlative with the top of the Maroon Formation and the Schoolhouse Tongue of the Weber Formation. Signficantly, thick deflationary horizons are present at these inferred correlative stratigraphic horizons to the north.

Freeman (1971b) defined the sandstone of the Fryingpan River as the lowest member of the State Bridge Formation and was the first to infer its eolian origin. However, at the time he pursued this study, the eolian history of the Maroon Formation was not known. The unit clearly has much closer affinity with the Maroon Formation than it does with the overlying marginal-marine red mudstones of the State Bridge Formation and more properly should be made a member of the former.

Discussion

Styles of sedimentation of the Late Paleozoic deposits in the Eagle Basin are consistent with glacio-eustatic-climatic controls suggested by Crowell (1978). Repeated sea-level fluctuations are indicated by the repeated occurrence of inferred tidal deposits (mainly grayish-black algal limestones) in sections of nonmarine rocks (e.g., Miller Creek, Colorado River, Eagle River), and in sections of predominantly shallow marine rocks (e.g., the Eagle Valley Evaporite in the Eagle River section). Alternating deposition of fluvial and eolian deposits throughout the Maroon Formation suggests cyclic climatic control, also no doubt associated with expansion and contraction of Gondwana ice sheets.

Many workers in adjacent basins have noted marked cyclicity to late Paleozoic deposition. For example, Heckel (1986) recognized 55 cycles of marine inundation and withdrawal in Middle and Late Pennsylvanian deposits of the Midcontinent Basin, Hite and others (1984) recognized 29 cycles in Middle Pennsylvanian rocks of the Paradox Basin, and Driese and Dott (1984) recognized 17 cycles in Middle Pennsylvanian deposits of the Wyoming Shelf. Heckel (1986) inferred a cycle periodicity of 400,000 years, whereas Hite and others (1984) suggest a 100,000 year periodicity.

There is no question that the Late Paleozoic rocks described in this report are similarly cyclic, but the number and distribution of the cycles is difficult to determine. The eolian intervals represent arid climatic periods and no doubt correlate with lowered sea level. Therefore when marine conditions were dominant in the middle of Eagle Basin, the eolian deposits would correlate with the inferred tidal deposits represented by the grayish-black algal limestones. However, in upper Maroon time when the basin had mostly filled in, the grayish-black algal limestones would represent sea-level highstands, and would correlate with fluvial deposits and a more humid climate. Considering (1) the number of eolian intervals (> 1 m thick) in the thickest sections of the Maroon Formation on the the basin margins, (2) the number of algal limestones in both the marine and nonmarine rocks in the central part of the basin, and (3) the amount of cover in all sections, there are probably at least 30 separate glacio-eustatic-climatic cycles represented by the rocks described in this study. Limited exposure, the lack of fossils with biostratigraphic utility, and the likelihood of considerable erosion associated with deposition of fluvial sediments, will make correlation of these cycles within and outside the basin very difficult.

CORRELATION

Four principal factors make correlating the stratigraphic section of Figs. 4-12 difficult: (1) the units are dominantly nonmarine clastic deposits that lack fossils suitable for biozonation; (2) facies changes are rapid, as a result there are presently no recognizable lithologic marker horizons that can be traced across the basin and few marker horizons that can be traced between any two sections; (3) the lower contact of the Maroon Formation is time transgressive; and (4) there is strong evidence from seismic data (Waechter and Johnson, 1985, 1986) and lithofacies distributions (DeVoto and others, 1986; Bartleson and Dodge, 1986) for syndepositional normal faulting in the basin. Given these difficulties, the strategy for correlation used here was to hang all sections on the upper contact between the Maroon-Weber-Fryingpan River units and the State Bridge or Chinle Formation. This strategy generally provided satsifactory "fits" between most sections, and also pointed out aspects of the basin geology that required further explanation.

Section 1: Vail to Rifle Creek

Figure 15 is a restored (i.e., the modern level of erosion is not shown) stratigraphic section that extends across the Eagle Basin from Rifle Creek to Vail. At Vail, Tweto and Lovering (1977) estimated a Maroon Formation thickness from geologic contacts of 1147 m using the Jacque Mountain Limestone as the lower Maroon contact (Fig. 2). C. J. Schenk (1987, personal communication) recognized the Jacque Mountain limestone just below a 60-m-thick gypsum bed that underlies the 987-m-thick Eagle River section of Figure 10. Thus, the thickness of the Maroon-Weber section above the Jacque Mountain datum in the two localities is roughly the same, 1050 to 1150 m. The entire measured section of the Maroon at Vail (Fig. 11) is therefore equivalent to the lower part of the Eagle Valley Evaporite section measured along the Eagle River (Fig. 10).

At Glenwood Springs, the Maroon-Weber section is 963-m-thick and, as in the Eagle River section, begins at the top of the stratigraphically highest thick gypsum bed in the underlying evaporitic sequence. The highest gypsum beds in the two sections might be correlative, however C. J. Schenk (personal commun., 1987) favors correlation of the Glenwood Springs gypsum with a gypsum bed about 260 m lower than the top of the highest gypsum in the Eagle River section. If this is correct, then the amount of subsidence in the Eagle Basin during Maroon time would be larger (by about 300 m) at Eagle River then at Glenwood Springs, consistent with the inferences of Johnson (in press, a) based on paleocurrent and facies patterns in Maroon fluvial deposits. In either case, nonmarine facies in the lower part of the Glenwood Springs section are correlative with marine deposits of the Eagle Valley Evaporite in the Eagle River section. Tweto and Lovering (1977) measured a cumulative thickness of 1986 m of pre-Maroon Pennsylvanian rocks at Vail whereas C. J. Schenk (personal commun., 1987) measured only about 380 m of pre-Maroon Pennsylvanian rocks at Glenwood Springs. These thickness variations indicate that the asymmetric subsidence just noted was much more pronounced in pre-Maroon time.

Using the Maroon Formation section of Bass and Northrop (1963) and the Schoolhouse Tongue of the Weber Formation section in Figure 5 of this report, the thickness of the Maroon-Weber section at Main Elk Creek (Fig. 3) is 944 m. This is approximately the same as the 963-m-thickness reported here from Glenwood Springs. At Rifle Creek only 10 km to the west, however, the Maroon-Schoolhouse Tongue section is only 529 m thick, and the entire Pennsylvanian section is only about 920 m thick (Brill, 1944, p. 628). At both Glenwood Springs and Rifle Creek, the pre-Maroon section is about 380 to 390 m thick, so the noted thinning of the section takes place here entirely within the Maroon (in marked contrast to the pronounced pre-Maroon thinning of the section between Vail and Glenwood Springs). The Maroon Formation does thin dramatically across the basin from Glenwood Springs to the Eagle River locality by a facies change, but since Main Elk Creek and Rifle Creek are so near one another and essentially parallel the basin margin, it seems very unlikely that the noted thinning between the two localities reflects a facies change. Rather, it seems likely that there was an active Pennsylvanian fault between the Rifle Creek and Main Elk Creek localities.

Waechter and Johnson (1986) have previously argued that there was a northeast-trending paleo-horst below this portion of the White River Uplift. They further argue for the presence of a major basin-wide unconformity at the contact betwen the Maroon Formation and the underlying rocks, coincident with uplift on this inferred structure and other related faults. As was discussed

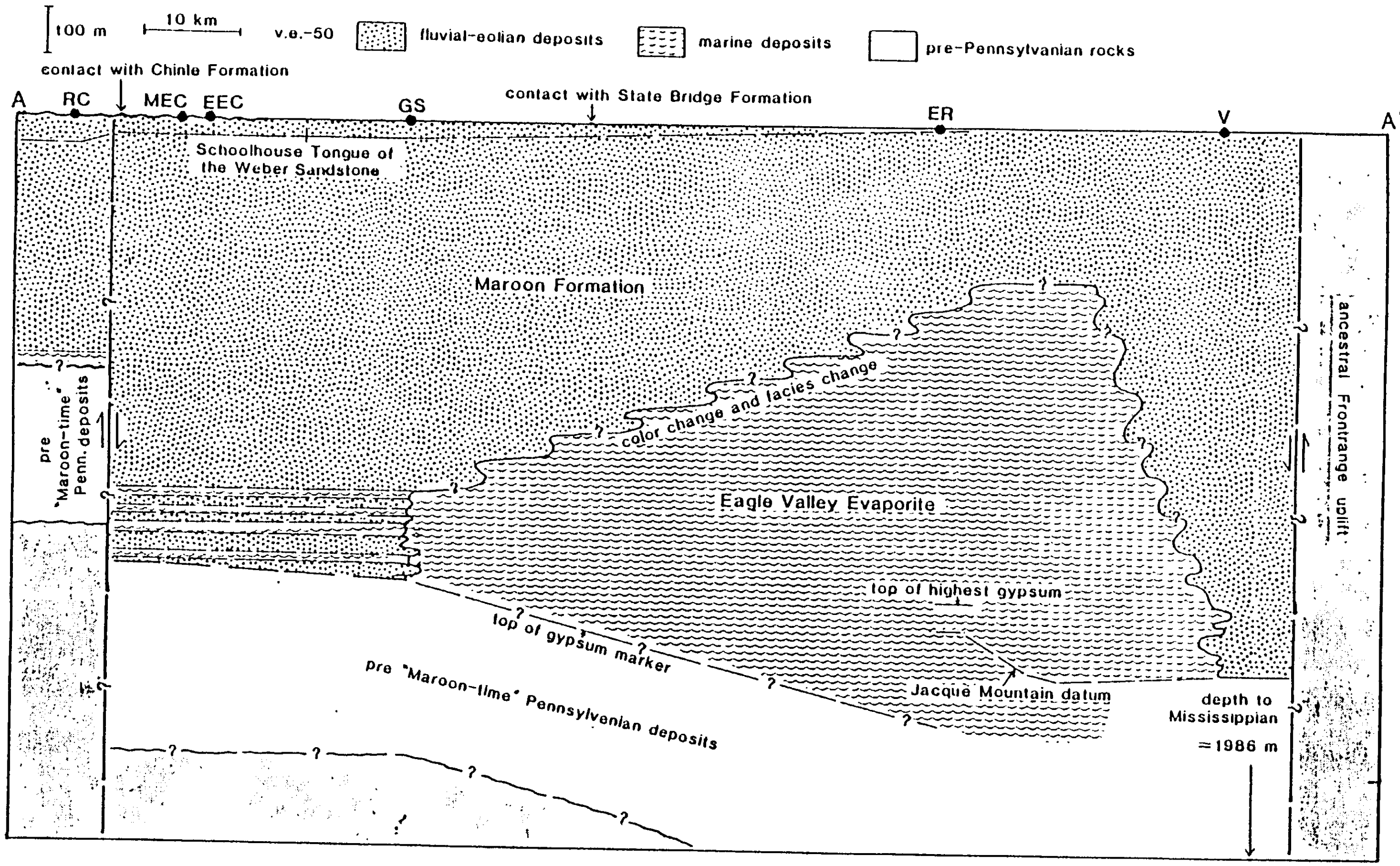

Figure 15. Schematic restored stratigraphic cross section from Vail to Rifle Creek. Line of section is shown on Figure 3. Fluvial-eolian deposits include a minor amount of marine deposits. Abbreviations are the same as in Figure 3. See text for discussion.

earlier, the contact between the Maroon Formation and the Eagle Valley Evaporite at Rifle Creek might be an unconformity, consistent with their hypothesis. This unconformity is definitely not basin-wide however, as evidenced by the transgressive nature of the Maroon-Eagle Valley contact between the Glenwood Springs and Eagle Valley Evaporite sections in this report (Fig. 15). Rather, if (and this seems likely) the unconformity is present on the upthrown side of a fault block at Rifle Creek, it passes to the east off the horst block into a conformity. The lower part of the Maroon Formation section at Glenwood Springs and Main Elk Creek might therefore not have correlatives in the Rifle Creek section (Fig. 15). There are no recognizable surfaces of unconformity or major changes in the depositional style of the Maroon Formation at either Glenwood Springs or Rifle Falls, suggesting that the inferred fault may never have been characterized by significant relief.

The data presented here therefore generally support the paleo-horst model of Waechter and Johnson (1986), however it should be noted that the geometry of the faulted boundary of the horst in the Rifle Creek-Elk Creek area must have had a far more northerly trend (> 330°) than they proposed (about 285°). This inferred fault might be a continuation of the more northerly trending boundary of the ancestral Uncompaghre uplift to the south (Fig. 1). The horst block and related structures may have been reactivated in the Upper Triassic, or continued to have been active through the Upper Triassic. This is the only portion of the basin (the Rifle Creek-Elk Creek area) where the Permian to Triassic State Bridge Formation is missing and the Gartra Member of the Upper Triassic Chinle Formation rests unconformably on the Schoolhouse Tongue of the Weber Sandstone. The fault may have served a major conduit for migration of hydrocarbons and the paleo-horst may have facilitated hydrocarbon trapping. As noted earlier, by far the thickest section of oil-stained rock occurs at the Rifle Creek locality. Given this concentrated local occurrence, derivation of the oil in the Maroon Formation and Schoolhouse Tongue of the Weber Sandstone from a local basinal source such as the Belden Shale (Nuccio and Schenk, 1986; Waechter and Johnson, 1986) seems likely.

Section 2: Glenwood Springs to Ruedi Reservoir

Figure 16 shows a restored cross section from Glenwood Springs to Ruedi Reservoir. The thickness of the complete Maroon-Schoolhouse Tongue section at Glenwood Springs (963 m; Fig. 4) is similar to that of the Maroon-sandstone of the Fryingpan River section at Ruedi Reservoir (1047 m; Fig. 12), where the base of the Maroon is not exposed. Given that the Maroon and correlative strata do not thicken dramatically eastward between the Glenwood Springs and the Eagle River sections (Fig. 15), and that the Ruedi Reservoir and Eagle River localities are approximately the same distance east of Glenwood Springs (Fig. 3), it seems likely that the Maroon Formation at Ruedi Reservoir is at most a few hundred meters thicker than was measured. In both the Glenwood Springs and Ruedi Reserovir sections, the transition from marine to nonmarine facies occurs at about the same stratigraphic position.

The transition between loess deposits and fluvial/sand-sheet deposits is shown as abrupt in the stratigraphic cross section. Where the Maroon is exposed along the Fryingpan River (10 km west of the Ruedi Reservoir section, 3-5 km east of Basalt; Fig. 3), it consists of fluvial channel deposits of conglomeratic sandstone with east-northeast directed paleocurrent indicators (Fig. 13). Presumably these rivers were diverted to more northerly courses by the noted loess accumulation.

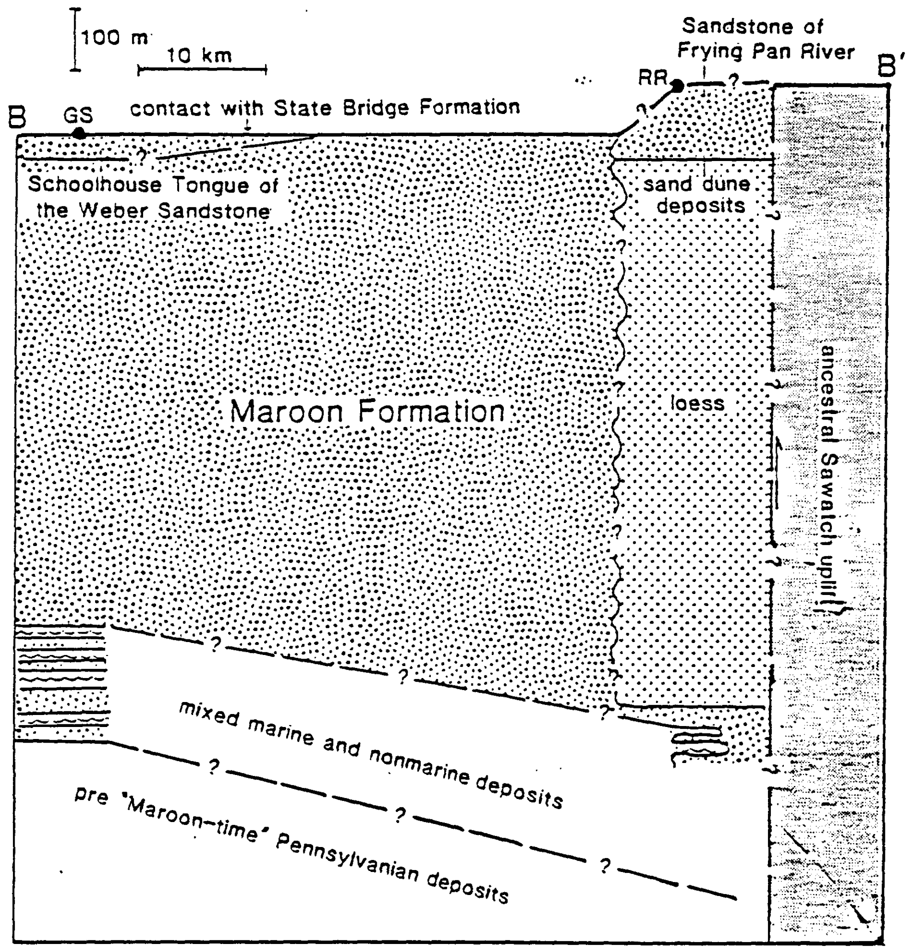

Figure 16. Schematic restored stratigraphic cross section from Glenwood Springs to Ruedi Reservoir. Line of section is shown on Figure 3. Fluvial-eolian deposits include a minor amount of marine deposits. Abbreviations are the same as in Figure 3. See text for discussion.

Section 3: Vail to Miller Creek)

Figure 17 is a restored stratigraphic cross section extending from Vail to Miller Creek. Relationships between the Vail and Eagle River sections were discussed previously for section 1. The Eagle River-Colorado River sections are about 23 km apart and occupy roughly equivalent position in the uniformly subsiding central portion of the Eagle Basin. The initiation of nonmarine deposition came lower in the Eagle River section than in the Colorado River section (356 vs. 288 m below the contact with the State Bridge Formation), indicating that the basin probably filled in from the south as well as from the east and west. The two highest marine intervals in the Eagle River section probably correlate with the two lowest marine intervals in the Colorado River section (Table 1). The two lowest marine intervals in the Miller Creek section (below 338 m and at 319 m) might correlate with marine deposits at a comparable level in the Eagle River section, and there is a marine interval in both the Miller Creek and Colorado River sections that occupies a position 177 m below the State Bridge contact. Marine deposits are also more prevalent at higher levels in the Colorado River Section than at Miller Creek, providing additional data on the geometry of basin infilling.

The lack of a better fit between the marine intervals in the different sections might have several causes: (1) The marine intervals are transgressive deposits that might have been locally eroded by overlying nonmarine regressive deposits. (2) Fluvial systems filling in the basin might have created an irregular and variable shoreline topography over which marine deposition was not uniform. (3) The marine intervals are most readily recognized by the presence of the grayish-black marine limestones. Where these limestones are not present (i.e., the marine deposits are entirely clastic), marine deposits would be harder to identify and might not have been recognized. (4) Cover and poor exposures in the sections precluded identification of each marine interval. (5) Like the Rifle Creek section, the Miller Creek section sits on an uplifted horst block or has been otherwise affected by faulting so that relative rates of deposition vary between it and the Eagle River-Colorado River sections.

In that the contact between the Maroon Formation and the underlying Minturn Formation at Miller Creek is conformable and there is no known considerable thickening or thinning of the Pennsylvanian section in the Miller Creek area, this latter hypothesis (no. 5) seems unlikely. Rather, it seems probable that a combination of the first four hypotheses is responsible for the relatively poor fit. If so, then it can be argued that each stratigraphic level in the three sections where one or more marine intervals is present represents a transgression. The three stratigraphic sections probably cumulatively record at least 13 transgressions.

Because the Maroon section between the Miller Creek and Eagle River sections has a nearly uniform thickness, the Jacque Mountain limestone datum is very tentatively inferred to be relatively flat across this area. The estimate of depth to the underlying Mississippian strata in the area between the Miller Creek and Colorado River sections is based on extrapolation from Sharps (1962) work in the Pagoda Quadrangle to the north.

PALEOGEOGRAPHY

Figure 18 shows four paleogeographic maps, compiled for different

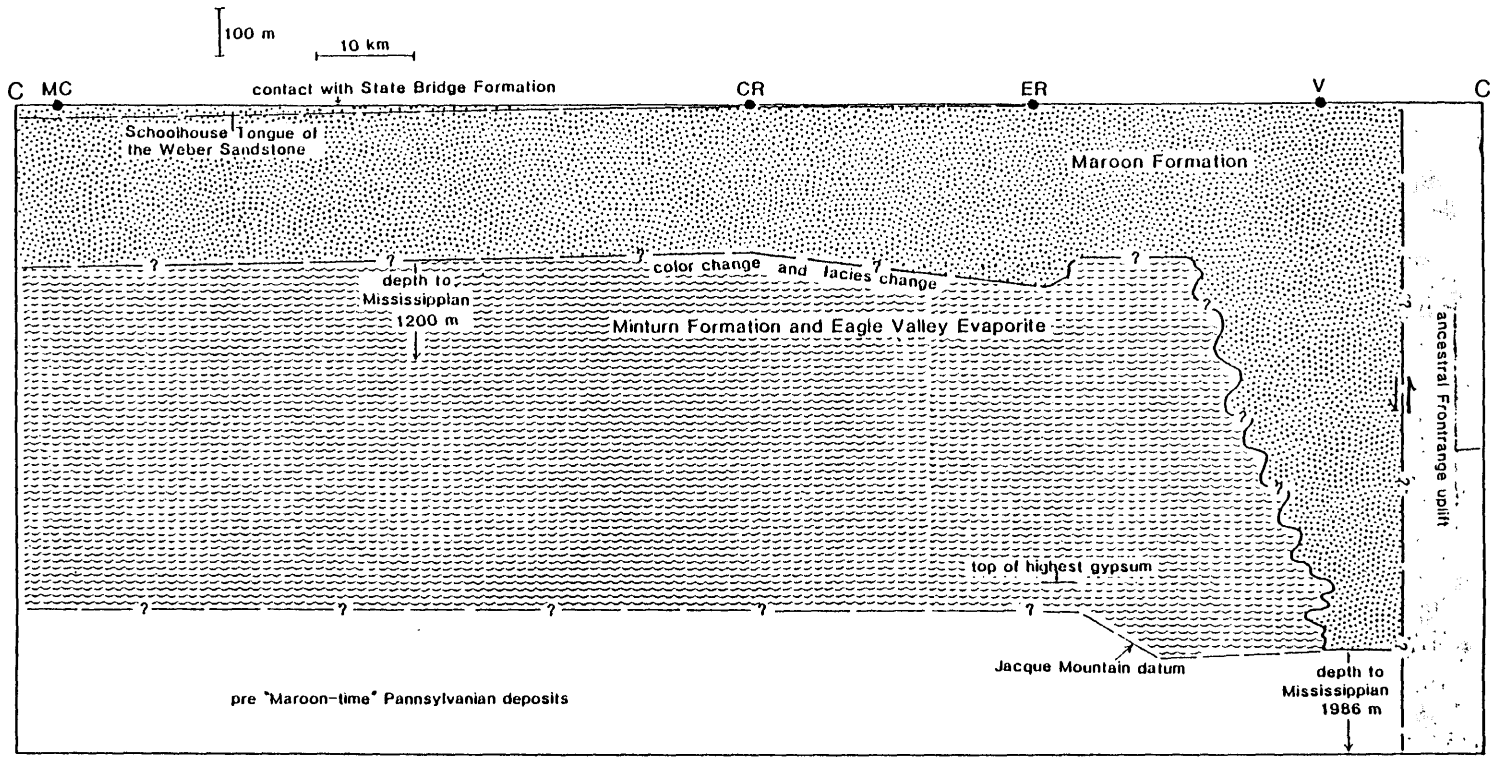

Figure 17. Schematic restored stratigraphic cross section from Vail to Miller Creek. Line of section is shown on Figure 3. Fluvial-eolian deposits include a minor amount of marine deposits. Abbreviations are the same as in Figure 3. See text for discussion.

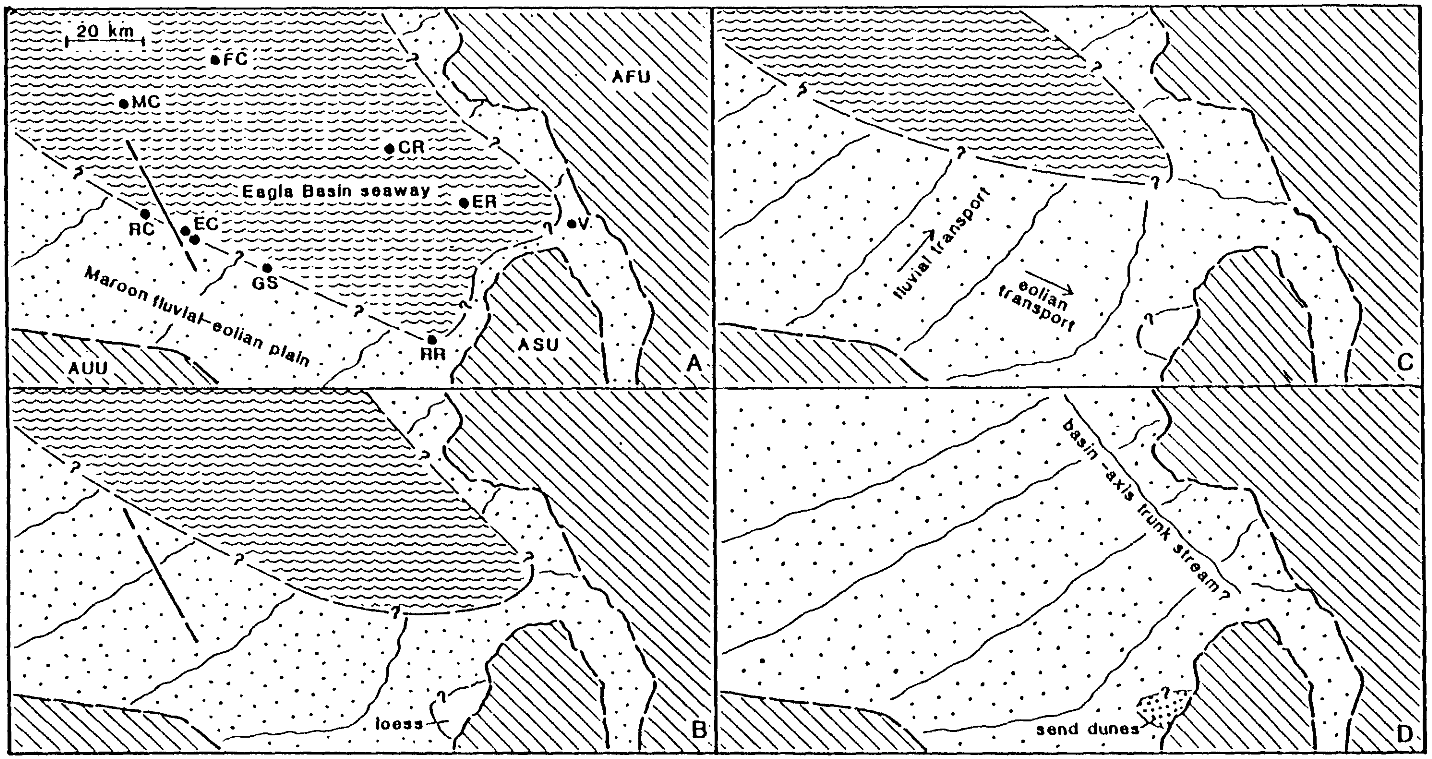

Figure 18. Schematic paleogeographic maps showing basin asymmetry and geometry of basin infilling. AUU = ancestral Uncompaghre uplift; AFU = ancestral Frontrange uplift. Other abbreviations are the same as in Figures 1 and 3.

stratigraphic levels below the contact between the State Brdiye Formation and the Maroon Formation-Schoolhouse Tongue of the Weber Sandstone-sandstone of the Fryingpan River, as outlined in the previous section. In general, the maps show shoreline migration and contraction of the Eagle Basin seaway.

Panel A (representing a stratigraphic level equivalent to the base of the Glenwood Springs section) shows marginal marine conditions on the margins of the basin at Glenwood Springs, Ruedi Reservoir, and Vail. Marine deposition in the Aspen sub-basin had probably ceased at this time. Mostly clastic facies of the Eagle Valley Evaporite and correlative units were being deposited in the Eagle Basin seaway. The seaway was shoaling, this period postdates the time of deposition of subaqueous evaporites (Schenk, in press). The inferred north-northwest trending fault between Rifle Creek and Main Elk Creek and other related faults (Waechter and Johnson, 1986) were probably active at this time, and there may have been minor relief on horst blocks.

In Panel B (representing a stratigraphic level about 600 to 700 m below the State Bridge contact at Glenwood Springs), mixed fluvial-eolian conditions dominate in the western and southern parts of the basin. The Rifle Creek-Main Elk Creek fault and associated structures may have continued to be active but probably had minimal relief. Deflationary winds eroded silt from fluvial deposits and deposited their load along the margin of the ancestral Sawatch uplift as loess. Rivers coming off the Front Range and Uncompaghre uplifts drained into a contracting seaway in the east-central part of the basin. The Colorado River, Eagle River, and Miller Creek areas were characterized by deposition of mainly marine clastics.

Panel C represents a stratigraphic level about 300 to 350 m below the State Bridge contact at Glenwood Springs. The Eagle Basin seaway continued to contract although marine deposition still characterized the Miller Creek and Colorado River localities. Deposition at the Eagle River locality was mostly nonmarine, but the area was submerged during eustatic high stands. Filling of the basin was mostly from east-flowing fluvial sytems. Loess continued to accumulate on the margin of the ancestral Sawatch uplift.

Panel D represents an interval 5 to 50 m below the State Bridge contact. By this time, the seaway had contracted and probably disappeared, and the basin was mostly a low-relief eolian-fluvial plain. It should be noted, however, that there is a marine interval in the Colorado River section only 68 m below the contact, so there was probably still a small seaway in the basin almost until the end of Maroon deposition. Contraction of the seaway led to progressively more asymmetric drainage patterns. Rivers draining the Uncompaghre uplift flowed northwestward well across the center of the basin, where they either dissipated or fed a major trunk stream draining the basin to the northwest (Johnson, in press, a). Unfortunately, outcrops needed to document this trunk stream and the last stages of deposition in the seaway are not present. As basinal subsidence slowed, eolian erosion of fluvial deposits became more effective. Wind-transported sands piled up in dunes along the ancestral Sawatch uplift as the sandstone of the Fryingpan River.

SUMMARY

This report summarizes stratigraphic and sedimentologic data collected during the 1985 and 1986 field seasons in the Eagle Basin and northern Aspen sub-basin, west-central Colorado. Late Paleozoic units investigated include the Eagle Valley Evaporite, the Maroon Formation, the Schoolhouse Tongue of

the Weber Sandstone, and the sandstone of the Fryingpan River. The Eagle Valley Evaporite was examined in one section only from the central part of the basin where it mainly consists of shallow and marginal deposits of the Eagle Basin seaway. This seaway was gradually filled in by prograding (mainly from the west) nonmarine deposits of the Maroon Formation. The contact between the Maroon Formation and the Eagle Valley Evaporite is markedly time transgressive.

The Maroon Formation consists of mixed fluvial and eolian sand-sheet deposits. Paleocurrents and facies patterns in Maroon fluvial deposits indicate that the axis of subsidence of the Eagle Basin was strongly skewed to the east during Maroon time. Eolian sediment transport was mainly to the south-southeast. Silt eroded from the Maroon sand-sheets was locally deposited as loess along the northwest margin of the ancestral Sawatch uplift.

The overlying Schoolhouse Tongue of the Weber Sandstone is also an eolian sand-sheet deposit and represents an integral part of the Maroon depositional system. It is differentiated from the Maroon Formation mainly on the basis of its distinctive yellowish-gray color and related characteristic hydrocarbon staining; the contact between the Maroon and the Schoolhouse Tongue is largely of diagenetic origin.

The sandstone of the Fryingpan River, previously designated the lower part of the State Bridge Formation, is also considered here to have been an integral part of the Maroon depositional system. This unit has a very local occurrence along the margin of the ancestral Sawatch uplift and consists mainly of eolian dune deposits. It probably represents an ancient basin-margin dune field analogous to the modern Great Sand Dunes in south-central Colorado.

Climatic change, associated with expansion and contraction of Gondwana glaciers, almost certainly controlled the mixed fluvial-eolian depositional style of the Maroon Formation. The stratigraphic distribution of both eolian and marine deposits in the Maroon Formation and correlative strata in Eagle Basin argue for at least 30 separate glacio-eustatic-climatic cycles.

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