The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Colorado

By JOHN CHRONIC

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Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in Colorado

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THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—COLORADO

By JOHN CHRONIC[1]

ABSTRACT

Carboniferous rocks of Colorado have two contrasting facies, which roughly correspond to the Mississippian and the Pennsylvanian.

The Mississippian was a time of widespread and uniform carbonate deposition, which originally covered almost all the State; most carbonate beds are referred to as the Leadville Limestone. Later, most of Colorado, especially the central part, was domed above the sea, a karst surface and residual soil formed, and, in some places, Mississippian strata were completely removed by erosion.

Slight subsidence at about the beginning of Pennsylvanian time brought marginal coal-swamp deposition and then shallow-marine conditions in the basins. These basins bordered two elongate ranges of the rising ancestral Rockies, one roughly parallel to but west of the present Front Range, and the other extending northwest from what is now the San Luis Valley to beyond the present Uncompahgre Plateau.

Until about the middle of Pennsylvanian time, these mountains rose intermittently, shedding coarse alluvium into the adjacent basins in a series of complex marine and nonmarine cycles; deposits reached a maximum thickness of much more than 3,000 m (10,000 ft). In central and western Colorado, 29 evaporite cycles, including several deposits of potash, are present along the Utah-Colorado border. A multitude of names are used for the complex Pennsylvanian sequence.

The later part of the Pennsylvanian is poorly dated in Colorado because the strata lack fossils and datable igneous rocks; therefore, the upper boundary is poorly defined. Other evidence suggests that late in the period the two uplifts and three basins slowed in their differential movement and that the entire central part of the State was broadly domed and raised above sea level; nonmarine red beds, composed largely of debris from the ancestral Rockies, were deposited.

Carboniferous rocks of Colorado yield significant amounts of oil and gas; uranium has been precipitated in economic quantities in the carbonaceous shale. Many of the richest mines for gold, silver, lead, and zinc in Colorado are in Carboniferous rocks enriched during Laramide intrusive and tectonic mountain-building activity. Building stone and evaporitic minerals are produced from Carboniferous rocks as well, but no economic coal of that age is present.

INTRODUCTION

Carboniferous rocks in Colorado were first reported on the maps of Jules Marcou and Edward Hitchcock in 1853, but not until 1870 were they documented along the Front Range by F. V. Hayden. By about 1900, geologists knew that the Carboniferous of Colorado represented two very different regimes, the earlier one, Mississippian, consisting of a very widely distributed but thin limestone sequence deposited in shallow open-marine conditions without reefs or reefing, and the later one, Pennsylvanian, a highly variable and tectonically complex thick sequence of cyclic marine and continental sedimentary rocks.

Now, after 125 years of study, we know that, after deposition, Carboniferous rocks blanketed the State. Since then, however, they have been extensively eroded from the mountains and have been almost entirely covered by later deposition on the plains and plateaus; their present outcrops are "more or less discontinuous areas exposed along the flanks of mountain ranges or sometimes in the channels of rivers" (Girty, 1903, p. 27).

To paraphrase Girty, the most conspicuous feature in the distribution of Carboniferous rocks outcropping in Colorado is their occurrence in a discontinuous band stretching from the northwestern corner of the State to the center of its southern border. The northwestern part of the band is at the eastern end of the Uinta Mountains, where thick fossiliferous strata of Carboniferous age are present.

Southeast of the Uinta Mountains is an isolated fault block, Juniper Mountain, of extremely fossiliferous Pennsylvanian strata. Southeast of this block is a large area of Carboniferous outcrops having a very irregular outline, exposed chiefly along the White and Colorado Rivers and their tributaries and around the White River Plateau. Continuous with this to the south, and really forming a part of it, is the area produced by the upturned beds of the Sawatch and Elk Mountains, including Maroon Bells southwest of Aspen.

East and southeast of these areas, east of the Sawatch Range, a narrow linear area of outcrop ex-

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tends from near Vail south through Leadville to the Arkansas River valley and along the west side of South Park. Continuous with this to the south, but widening in exposure, is the Sangre de Cristo Range, extending to the southern border of the State and composed mostly of Carboniferous and Permian strata.

Another well-defined area of Carboniferous exposure is in southwestern Colorado, in the San Juan Mountains, and northwestward along the Dolores River to Gypsum Valley on the Utah line.

A last outcrop is the strip of sedimentary rocks upturned along the eastern margin of the Front Range. Carboniferous rocks are discontinuous along this belt; they extend from the Wyoming line southward to near the Huerfano River at the southern end of the Wet Mountains.

All the outcrops of Carboniferous rocks in Colorado were exposed by Cenozoic mountain building, and many thousands of square miles of Carboniferous strata have been eroded from the State in the last 60 million years. Many miles of truly outstanding Carboniferous outcrops are in the Colorado mountains, and notable caverns, some well above timber line, have been cut into the massive limestones of this age.

In most places, Carboniferous rocks are exposed at altitudes of 1820 m (6,000 ft) to more than 4,250 m (14,000 ft). Steep drainage basins are normal in these areas, and outcrops are well exposed in canyons and cliffs. Probably the best exposures are in central Colorado, from the McCoy area on the Colorado River southeast along the Mosquito Range and the Sangre de Cristo Range. An outstanding and very accessible exposure of Pennsylvanian strata also is present at Molas Pass south of Silverton. Most of the red arkose and coarse sandstone along the Front Range, from Garden of the Gods northward to the Flatirons at Boulder, are probably of Carboniferous age, although they are generally unfossiliferous.

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomenclature used here conforms with the current usage of the Colorado Geological Survey.

HISTORY

U.S. Government geologists have made many of the studies of Carboniferous rocks of Colorado. In addition to and overlapping the extensive activities of the Hayden survey (Hayden, 1870), were investigations of the Wheeler, King, and Powell surveys, all contributing information on the strata, principally in the central and western parts of the State. The U.S. Geological Survey, established in 1879, began studies in Colorado, especially in and around Leadville. One of the first and most significant reports was by S. F. Emmons in the U.S. Geological Survey Second Annual Report published in 1882. Emmons' final report on this area, in 1886, was U.S. Geological Survey Monograph 12. Then followed several folios and monographs that included details of local occurrence of the Carboniferous System without containing anything generally significant.

In 1903, George H. Girty published "Carboniferous Formations and Faunas of Colorado," U.S. Geological Survey Professional Paper 16. All known occurrences and all fossils collected by the earlier surveys were described and summarized, and an excellent chronologic bibliography was included. This work is the most important reference on the subject of the present report, even though many of the names of formations and fossils have been changed by subsequent research.

Since Girty's classic work, many papers have been published on Carboniferous strata of Colorado, only the most significant of which can be mentioned here. Most of the authors in the early 1900's still used the term Carboniferous, but by 1930, most Colorado Carboniferous rocks were called either Mississippian or Pennsylvanian, and, as in the rest of the United States, the name Carboniferous fell into disuse.

In 1930, Roth and Skinner published the first descriptions of Colorado Pennsylvanian fusulinids and microfossils from the McCoy area, calling the containing rocks the McCoy Formation. In 1934, Read and Johnson described rocks and fossils of Pennsylvanian age from the Mosquito Range, and Brainerd and Johnson summarized the Mississippian of Colorado. Vanderwilt (1935) described the stratigraphy of Pennsylvanian strata in the Elk Mountains, and Johnson (1940, 1944, 1945) continued his long series of publications on the Paleozoic of central Colorado and the algae of the Carboniferous.

Arnold, in 1940 and 1941, called attention to the early Pennsylvanian floras of central Colorado, and in 1945, Thompson described the fusulinids and strata of northwestern Colorado. Brill (1944, 1952) studied the Pennsylvanian and Permian of central Colorado and named the two principal Pennsylvanian stratigraphic units the Belden and Minturn Formations.

McLaughlin (1952) and Lehman (1953) published descriptions of microfossils from the Glen Eyrie Formation near Manitou. Wengerd and Strickland, in 1954, described the varied stratigraphy of the Pennsylvanian in the Paradox salt basin in southwestern Colorado and adjacent areas after oil was discovered there.

The Rocky Mountain Association of Geologists (RMAG) held a field conference and published an excellent "Symposium on Pennsylvanian Rocks of Colorado and Adjacent Areas" (Curtis, 1958). The 22 articles in this symposium represent a comprehensive summary of knowledge on the Pennsylvanian to the date of publication. In 1961, another RMAG field conference resulted in the "Symposium on Lower and Middle Paleozoic Rocks of Colorado" (Berg and Rold, 1961), in which the Mississippian strata of the State are dealt with in a reasonably complete series of articles.

In 1962, Stevens summarized and illustrated the brachiopods of the McCoy area, and, in 1965, Murray and Chronic published the results of a study on conodonts from the Minturn Formation in western Colorado.

Finally, in 1972, Mallory summarized the Pennsylvanian System (p. 111–127) and Craig (*in* Mallory, 1972, p. 100–110) summarized the Mississippian System in "Geologic Atlas of the Rocky Mountain Region." Much of the stratigraphic information and many of the maps presented here are from this masterful volume; the paleontologic data are from the RMAG Symposiums (Curtis, 1958, and Berg and Rold, 1961).

The Colorado Geological Survey has had two periods of active existence. During the earlier period, work was done at the University of Colorado, and publications were mostly summaries, bibliographies, and reports in bulletin form on the geology of various mining areas. In the first report, published in 1909, Junius Henderson summarized information on "The Foothills Formations Of North Central Colorado," revising and adding to this report in 1920. Other early Survey reports document the occurrence of Carboniferous rocks and fossils in mining districts of the State, but the rocks were not seriously studied.

After a hiatus of 35 years, a newly organized Colorado Geological Survey began work in 1969 and has published reports, maps, and other geologic information since. Most data presented to date have been of practical nature, emphasizing oil, coal, gas, minerals, and geologic hazards. No contributive general information on the Carboniferous has been published, and none is now being prepared, although data on economic products from Carboniferous rocks are being gathered and are available at the Survey offices.

GEOLOGIC SETTING

Carboniferous rocks of Colorado lie on strata ranging in age from Precambrian to Late Devonian (fig. 1). In the eastern part of the State, Devonian rocks are generally absent, and Precambrian, Cambrian, and Ordovician beds underlie the Carboniferous rocks; in the west, the Late Devonian Ouray or Chaffee Formations underlie the Carboniferous rocks.

In eastern Colorado, the lower contact is unconformable, but there is little or no angularity between the underlying beds and the Carboniferous and no marked evidence of erosion, even though much time passed between deposition of the two sets of strata. Indeed, data on fossils from diatremes in the northern Front Range, indicate that Silurian marine strata were deposited over at least that part of the State and then completely removed by erosion before Carboniferous deposition.

On the west, deposition appears to have been continuous during Devonian and Carboniferous time; the Ouray Formation of the San Juan Mountains contains fossils of both Devonian and Mississippian age. The exact contact between Devonian and Carboniferous is impossible to determine in many places because no angular relationship or weathered zone is present. In many places, a darker gray zone of carbonate, some of which is soft, is found at about the contact level, but in other places, the Upper Devonian Ouray or Chaffee Formations appear stratigraphically continuous with the massive Leadville Limestone above.

Rocks overlying the Carboniferous in Colorado are generally red beds of continental origin, except in the subsurface of southeastern and southwestern Colorado where, in a few wells, Early Permian limestones have been found that contain fusulinids, suggesting a marine origin (fig. 2). In most places, except very near the Front Range and Uncompahgre uplifts, red beds, whose age is known or strongly suspected to be Permian, are composed of sandstone or shale, indicative of the sharp weakening of tectonism in these areas toward the end of Carboniferous time. In the subsurface of southeastern Colorado, a large area known as the Apishapa uplift contains no known Carboniferous rocks. There, Precambrian

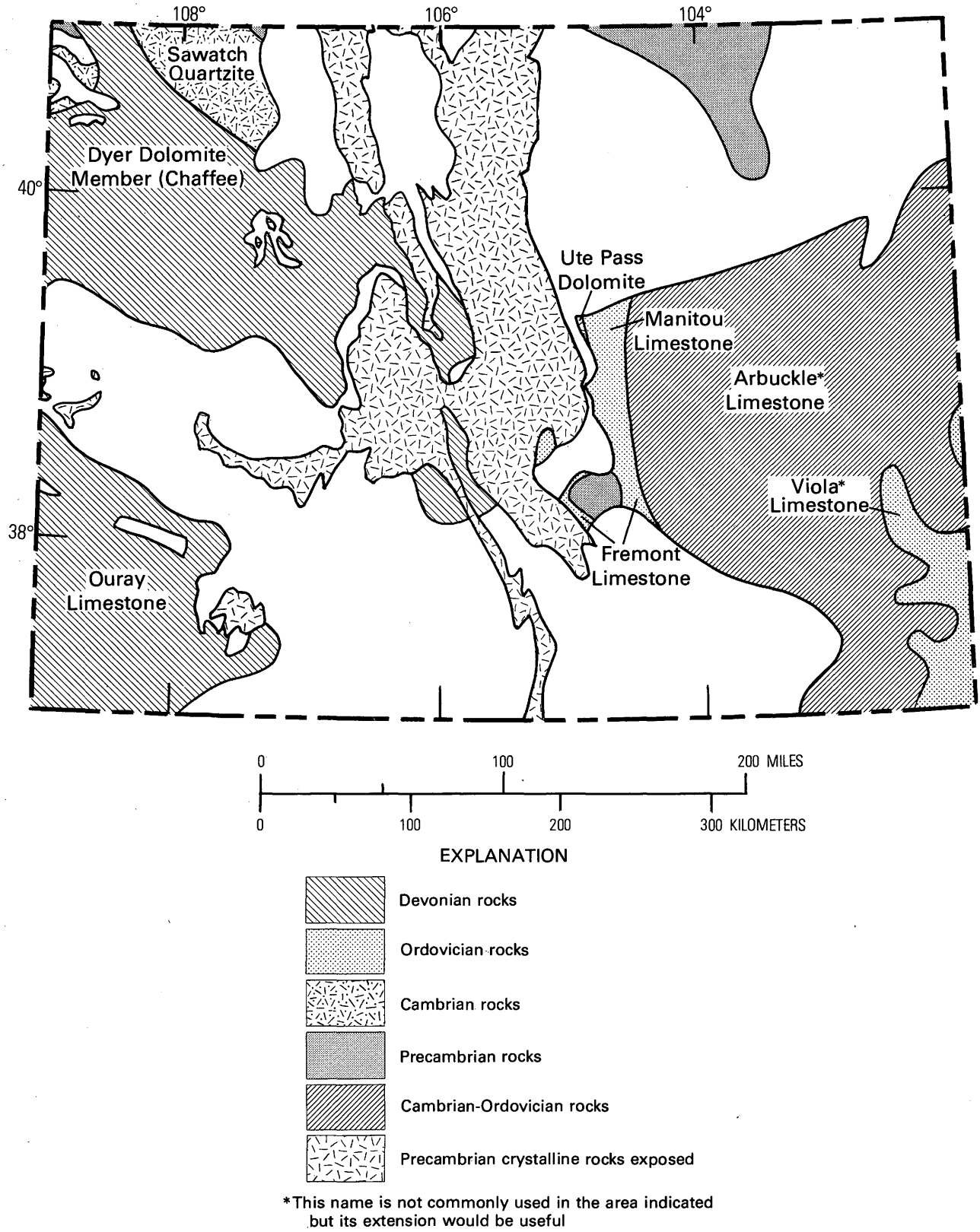


FIGURE 1.—Sub-Mississippian paleogeology (modified from Mallory, 1972, p. 102).

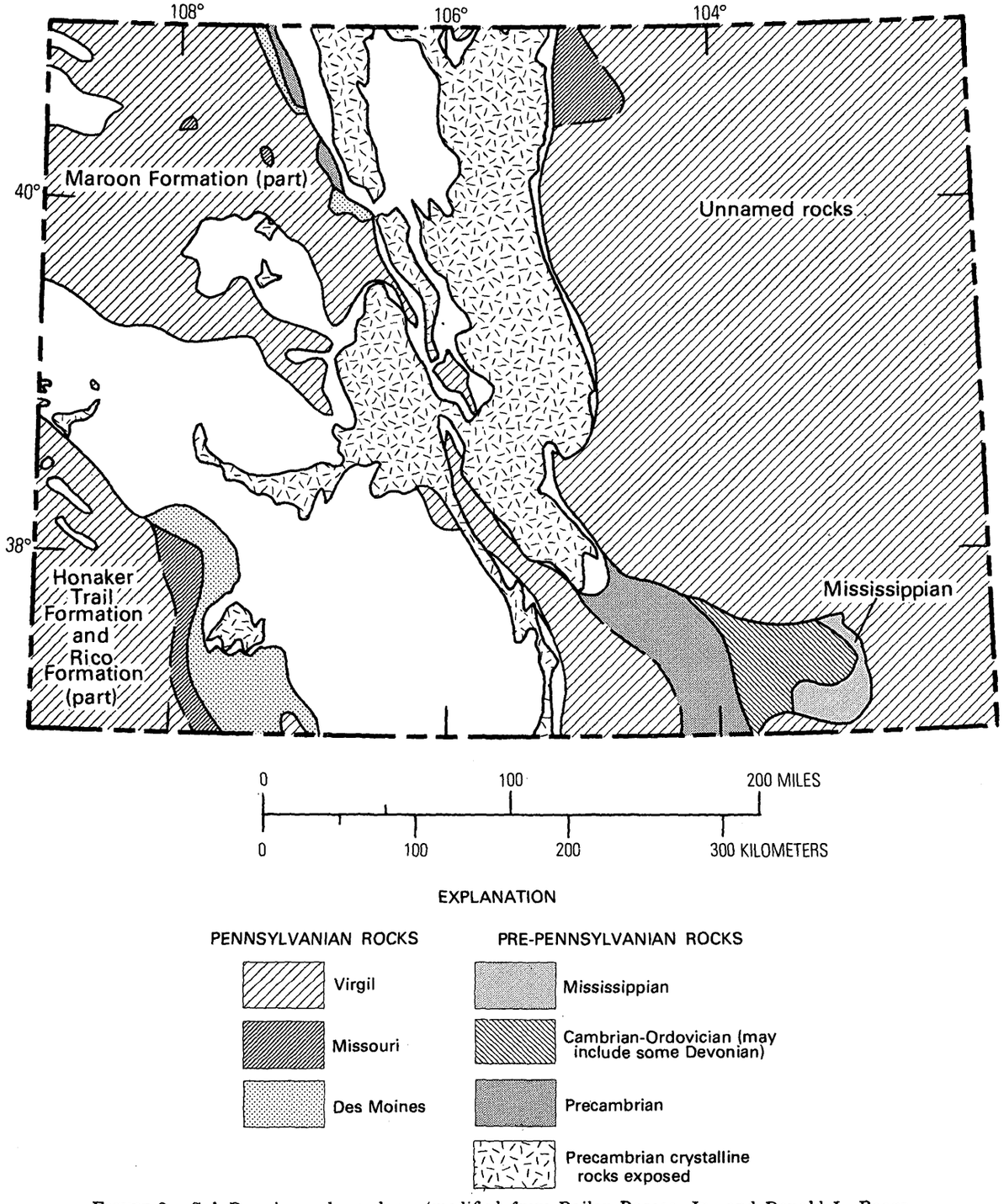


FIGURE 2.—Sub-Permian paleogeology (modified from Bailey Rascoe, Jr., and Donald L. Baars, *in* Mallory, 1972, p. 149).

and earlier Paleozoic strata are in contact with those of Permian age.

The upper surface of the Carboniferous in Colorado cannot be determined accurately because it is unfossiliferous and unsuited for radioactive age dating. Because most of the State was a lowland area receiving alluvial clastic sediments from the residual hills of the Front Range, Uncompahgre, and Apishapa uplifts, much of the upper surface will probably be found to be irregularly unconformable, when and if suitable means of age determination are established.

From the beginning of the Paleozoic Era until about the end of the Mississippian Period, Colorado was relatively stable and had almost no relief and little tectonic movement, except for regional uplift and subsidence. Mississippian strata are not well dated in Colorado, but the early and late parts of the period were apparently times of relative positive movement, whereas the middle part was a time of submergence.

Some evidence indicates that local graben and horst formation took place along the south side of the Uncompahgre uplift during middle Mississippian time, possibly the first signal of later violent Carboniferous events in Colorado.

Late in Mississippian time, Colorado slowly rose above the sea and became a lowland on which the recently deposited carbonate rocks were deeply eroded, almost entirely by solution. Many caves and a widespread karst surface formed at this time.

In Early Pennsylvanian time, the seas readvanced locally into basins between the Front Range and Uncompahgre uplifts, which were in an incipient stage of uplift.

As vertical uplift in these elongate regions, as well as in the Apishapa uplift, accelerated, and deep basins formed between them and at their sides, erosion moved great masses of sediment into the basins, resulting in the great quantity and variable character of Middle and Upper Pennsylvanian strata.

Orogenic movements must have ceased by about the end of Middle Pennsylvanian time, and the entire State was regionally uplifted above sea level. As Middle Pennsylvanian seas receded from the central part of the State, widespread continental deposition took place, and seas remained only in the southeastern and southwestern corners. Tectonic stability must have prevailed by the end of Carboniferous time, for the land was gradually flattened by erosion during the Permian and Triassic Periods.

The cyclic nature of sedimentation in much of the Pennsylvanian Period in Colorado reflects to a remarkable extent the general cyclicity of deposition throughout the world at this time. Few cycles in Colorado rocks contain coal, but most are highly variable units in which red beds, conglomerates, and arkoses alternate with marine limestone, which is usually gray or greenish gray. More than 60 cycles have been recorded in the probable Pennsylvanian rocks of the Arkansas River valley, and at least 40 in many other central Colorado sections. Most of these cycles whose ages have been determined are of Early and Middle Pennsylvanian age; later cycles are completely unfossiliferous.

For probably 100 million years after the Carboniferous Period, Colorado was extremely stable tectonically, but almost always somewhat above sea level. Then, in Early Cretaceous time, the sea invaded the State and covered it completely for about 40 million years.

Along with the surrounding Rocky Mountain area, the State was uplifted locally, and the present mountain ranges formed about 50 to 60 million years ago. Intervening areas, the present intermontane basins, remained slightly above sea level. Then, about 20 million years ago, in Miocene time, the whole State was regionally uplifted to about its present altitude. Violent volcanic activity took place, especially in the southwest, and finally, during the last few million years, glacial erosion and deposition gave the State its present topography. Carboniferous strata that formerly covered the entire State were almost completely eroded away from the mountainous area.

LITHOSTRATIGRAPHY

Carboniferous stratigraphy in Colorado is a study in contrasts. Almost all Mississippian rocks are called Leadville Limestone. Because of the many isolated outcrops and, in the Pennsylvanian System, the abrupt lateral and vertical facies changes, a number of stratigraphic units are in use for Colorado Carboniferous rocks (figs. 3 and 4).

On the east, in subsurface, Kansas terminology is generally used, but along the Front Range, the outcrop names Glen Eyrie and Fountain are used for the 150- to 1,250-m (500- to 4,000-ft)-thick Pennsylvanian section, a marine and continental cyclic sequence overlain by colorful arkosic red beds that form the Garden of the Gods near Colorado Springs, the Redrocks west of Denver, and the Flatirons at Boulder.

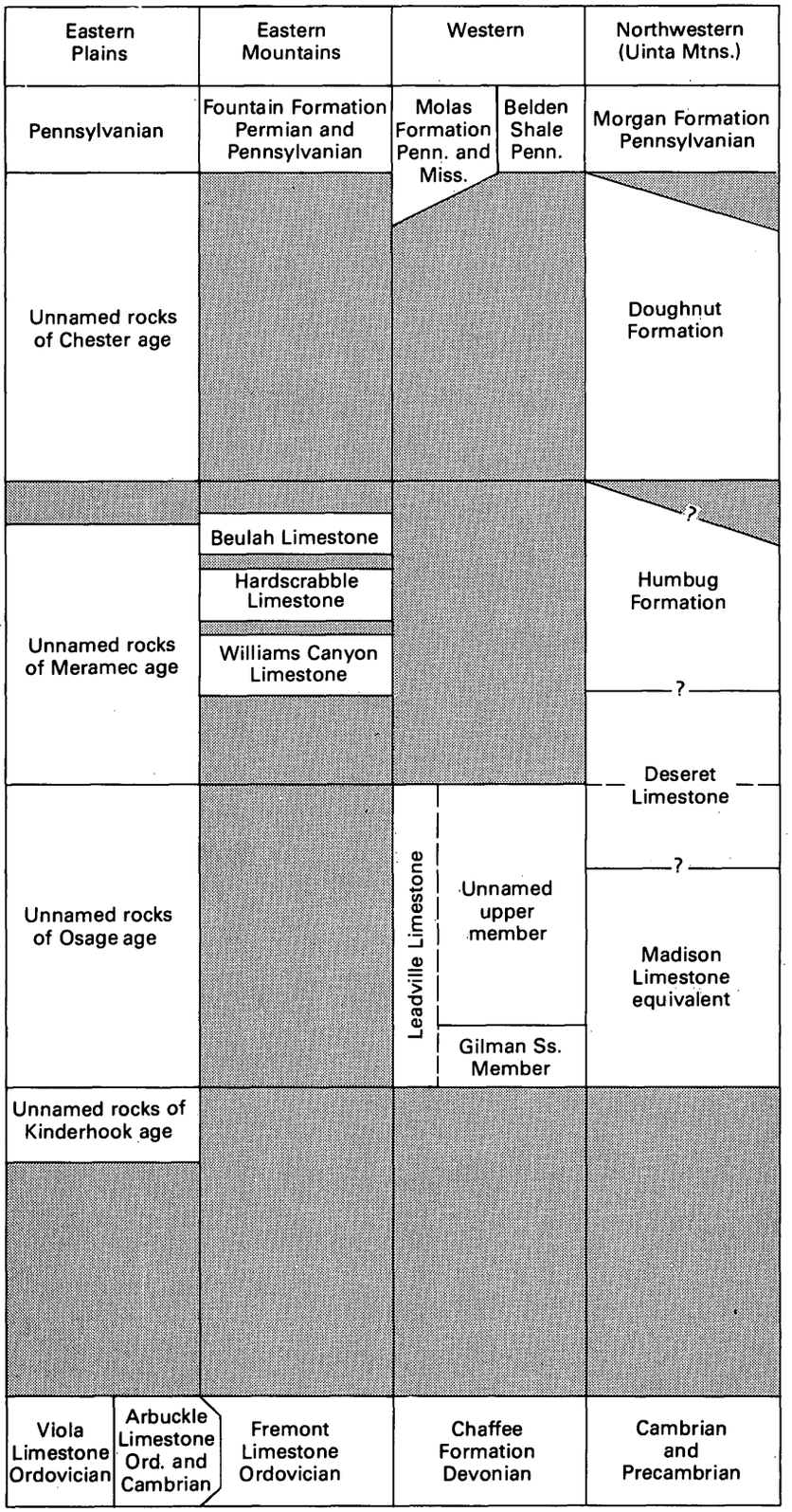


FIGURE 3.—Mississippian correlation chart (modified from L. W. Craig, *in* Mallory, 1972, p. 101).

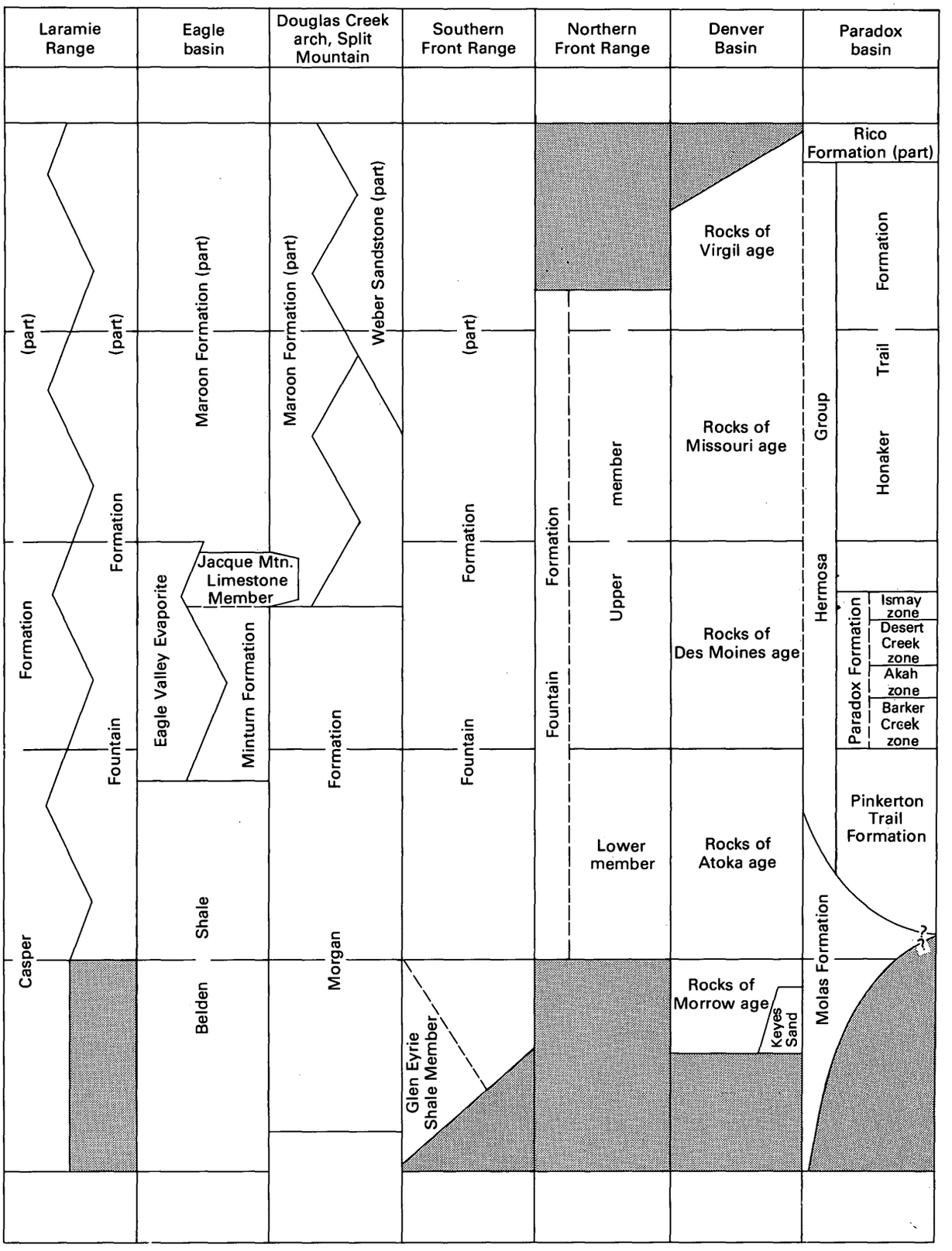


FIGURE 4.—Pennsylvanian correlation chart (modified Mallory, 1972, p. 113).

In the Maroon basin of central Colorado, the sequence of Kerber, Belden, Minturn, and Maroon Formations is used for Pennsylvanian strata. In the south-central part of the State, terminology of New Mexico is used, and in the northwest, that of Utah.

In southwest Colorado, other names have come into use because of the physical separation of the area from the Maroon basin. Molas, Pinkerton Trail, Paradox, Hermosa, and Honaker Trail are usually used for the sequence of Pennsylvanian strata in the Paradox basin, but other names for larger and smaller units are also used.

Figures 5–17, from the "Geologic Atlas of the Rocky Mountain Region" (Mallory, 1972), convey more clearly than any other way the nature of the Carboniferous rocks of Colorado.

In general, the contact between the Mississippian and Pennsylvanian in Colorado represents an erosion surface that has karst characteristics in many places (fig. 11). Commonly, there is an iron-rich, red soil zone, which contains chert in many places

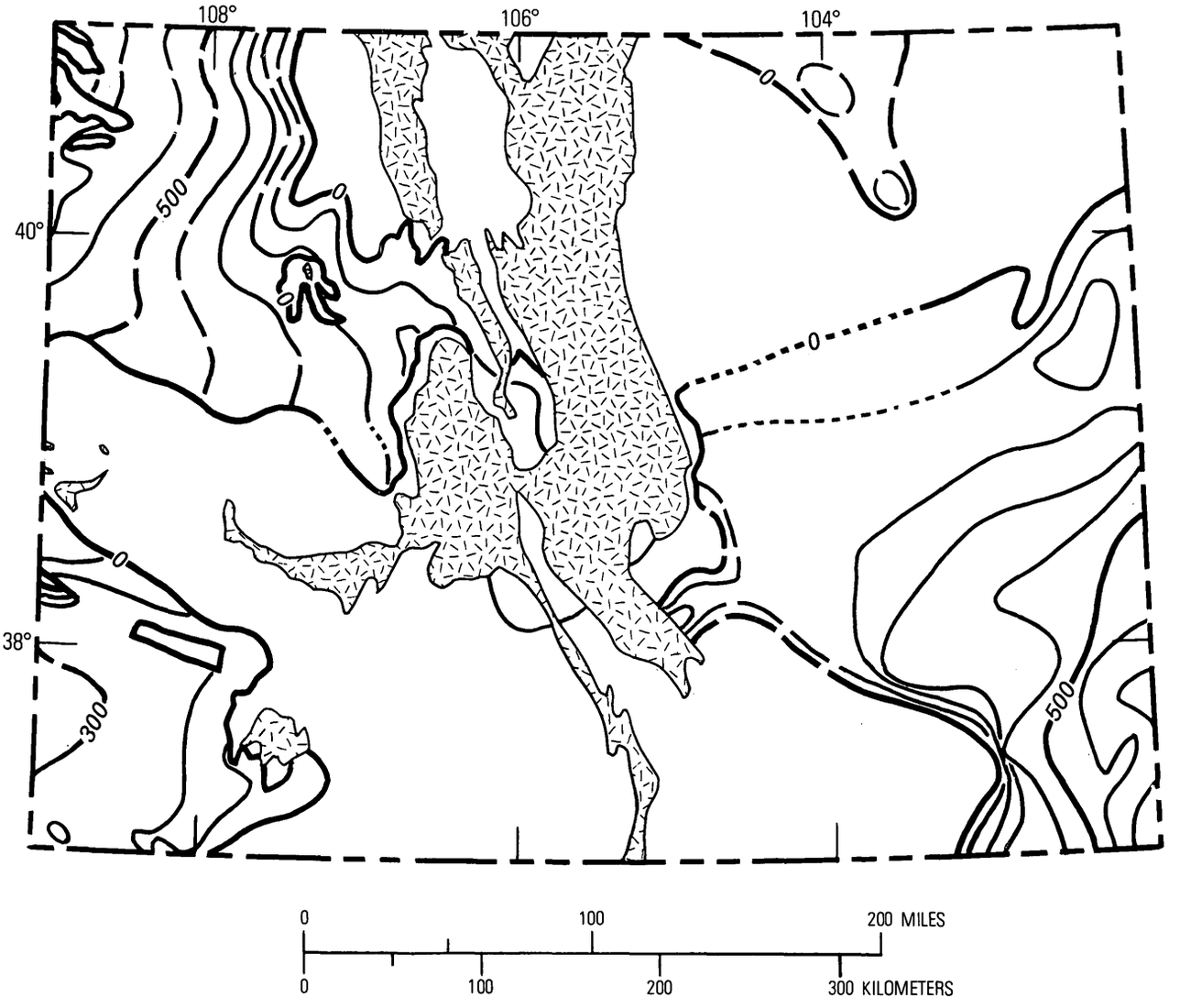


FIGURE 5.—Thickness of the Mississippian System (modified from L. W. Craig, *in* Mallory, 1972, p. 103). Isopach interval 100 feet, dashed where distant from control, dotted where conjectural. Precambrian crystalline rocks are patterned. Note the extensive areas in north-central, northeastern, southern and western Colorado where no Mississippian rock now exists; also note the thickening of the system to the southeast and west, toward the State margins, and the faulted graben on the western state line.

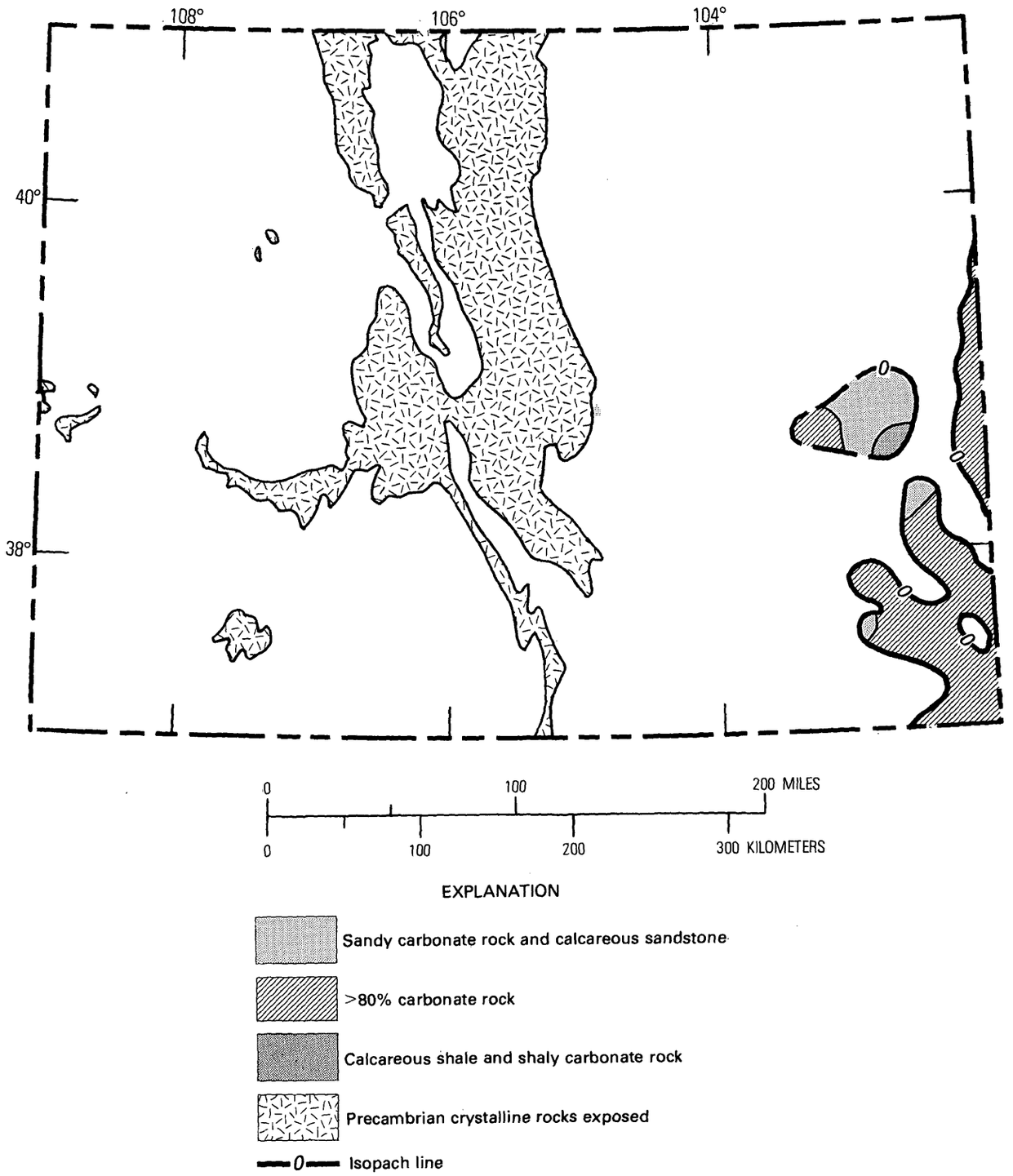


FIGURE 6.—Thickness and lithofacies of rocks of Kinderhook age (modified from L. W. Craig, *in* Mallory, 1972, p. 104).

and may be fossiliferous and of Mississippian age. This deposit is called the Molas Formation in central and western Colorado; in some places, the contact zone and the Molas may be enriched with ores because of its unusual physical and geochemical nature.

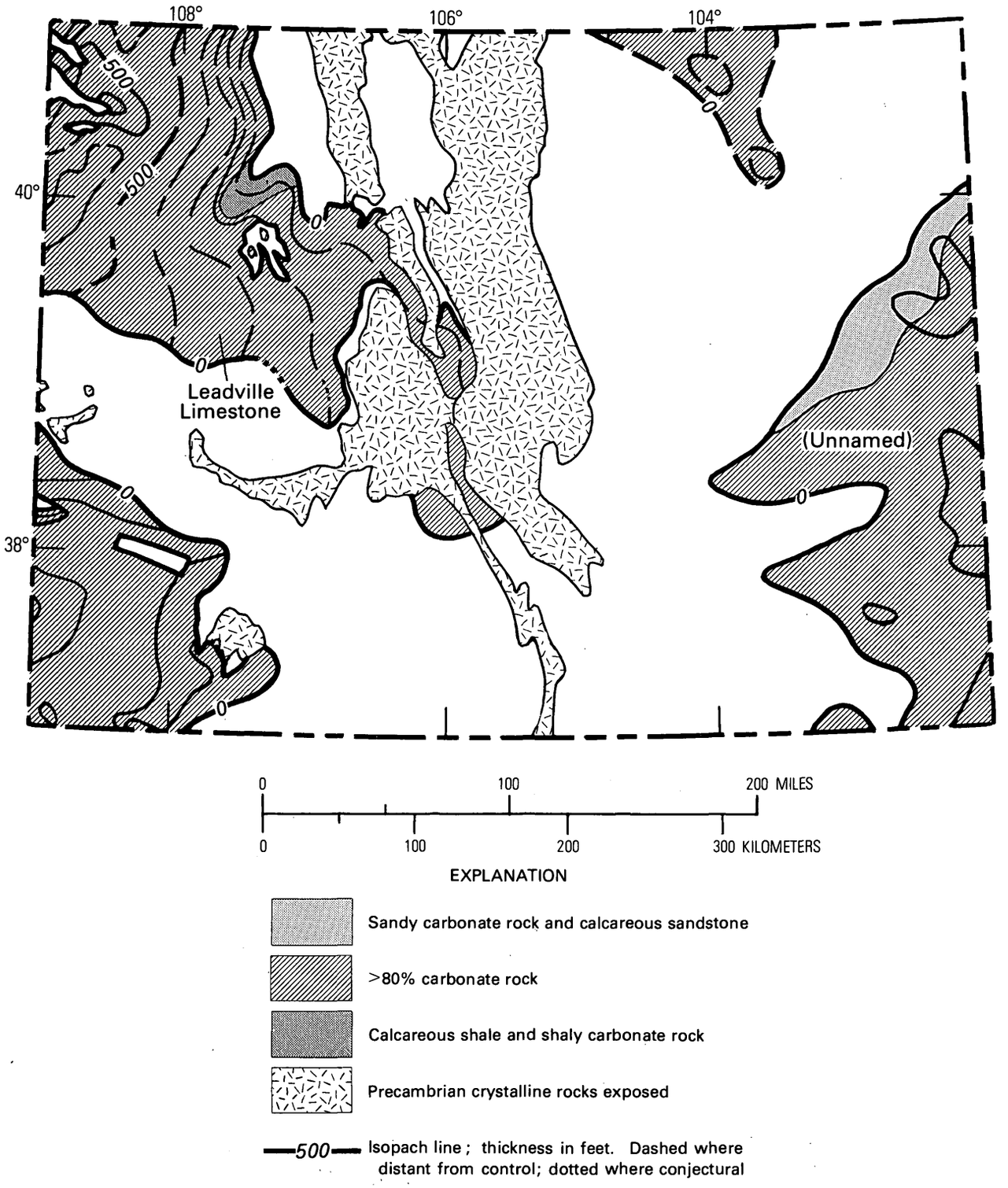


FIGURE 7.—Thickness and lithofacies of rocks of Osage age (modified from L. W. Craig, *in* Mallory, 1972, p. 105).

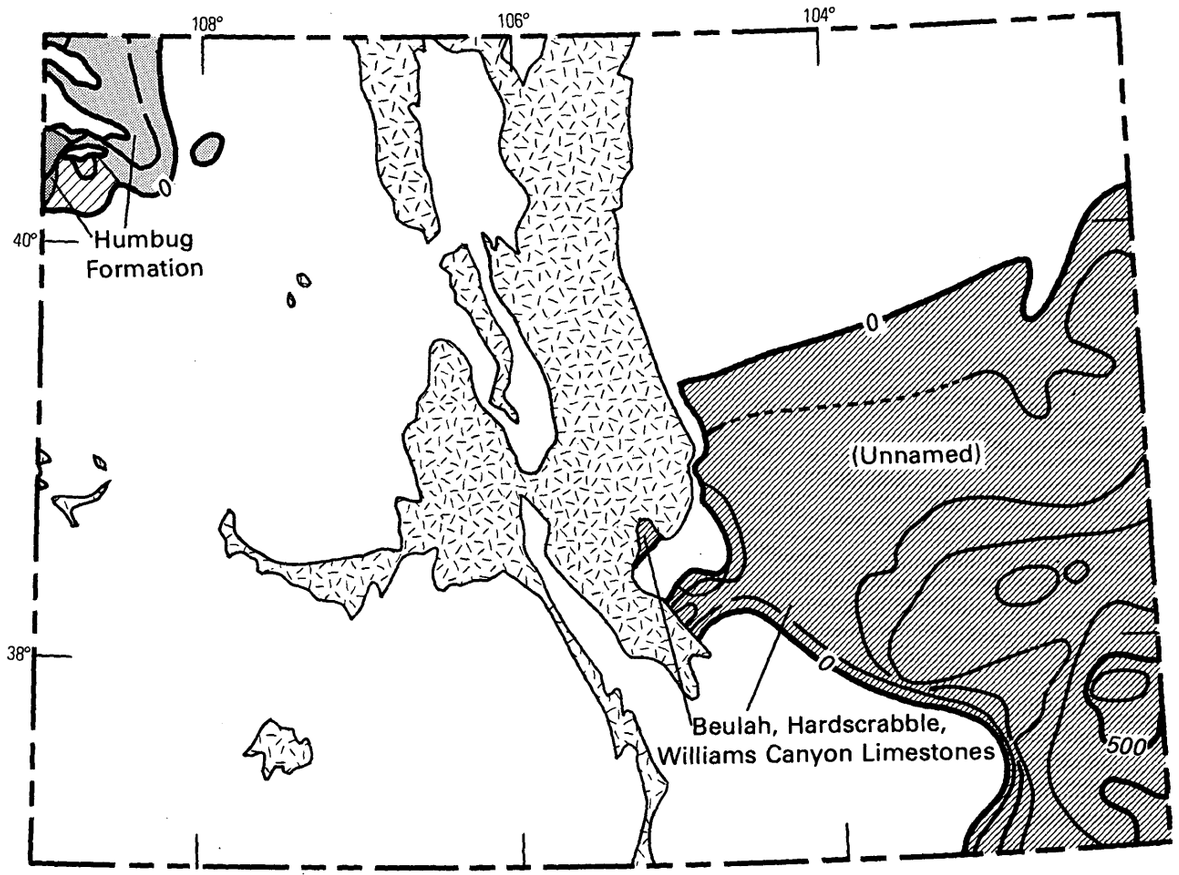


FIGURE 8.—Thickness and lithofacies of rocks of Meramec age (modified from L. W. Craig, *in* Mallory, 1972, p. 107).

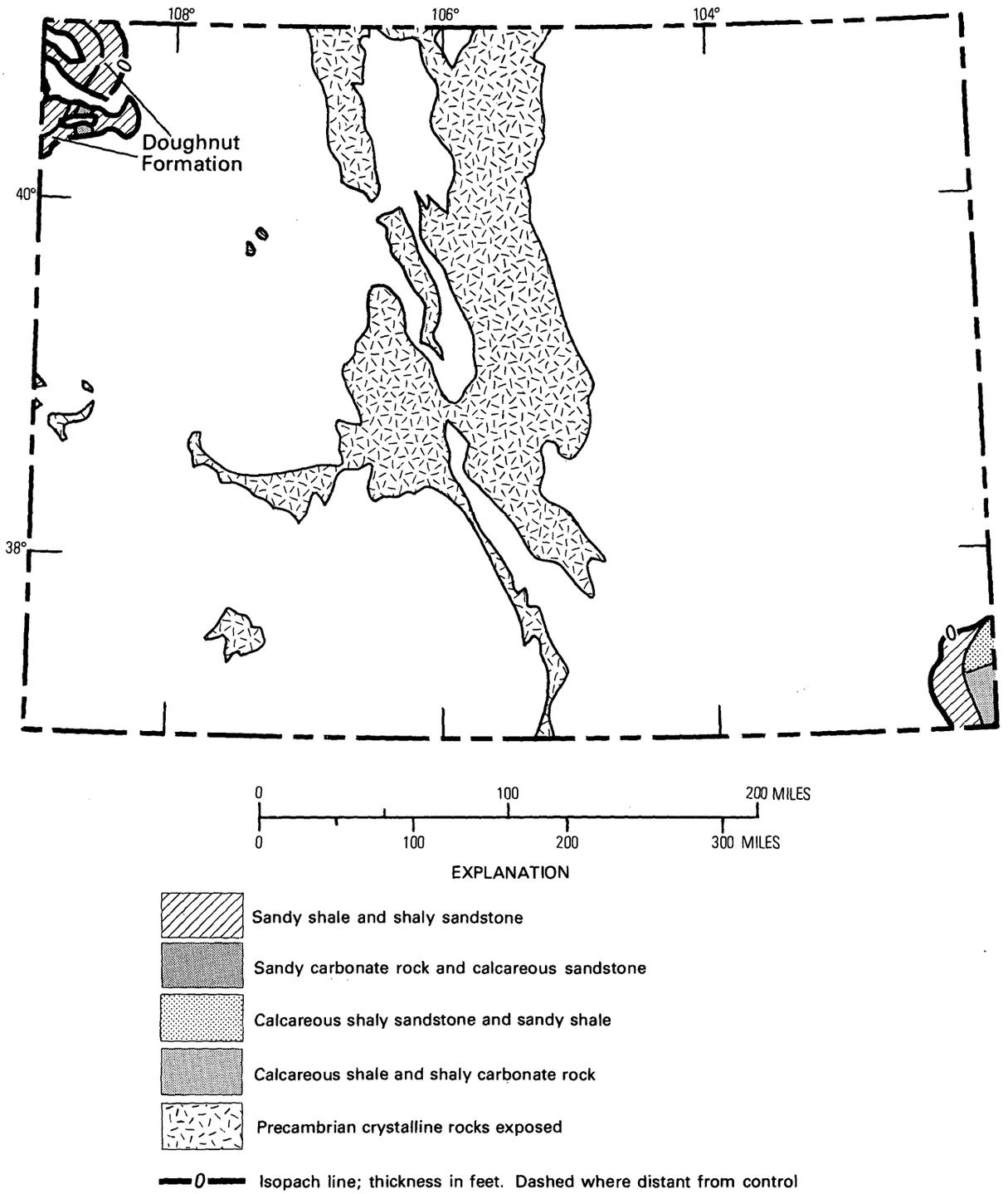


FIGURE 9.—Thickness and lithofacies of rocks of Chester age (modified from L. W. Craig, *in* Mallory, 1972, p. 108).

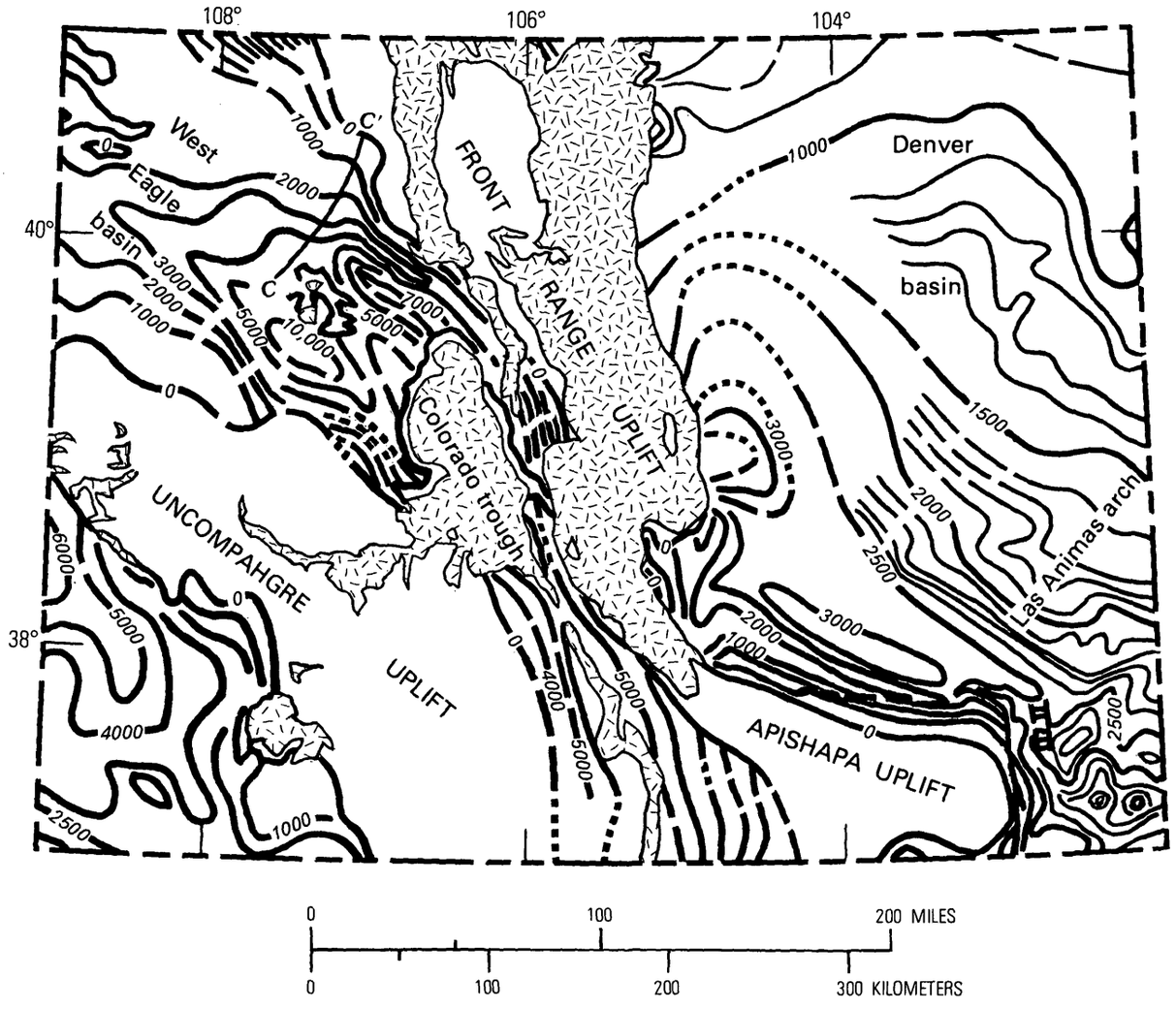


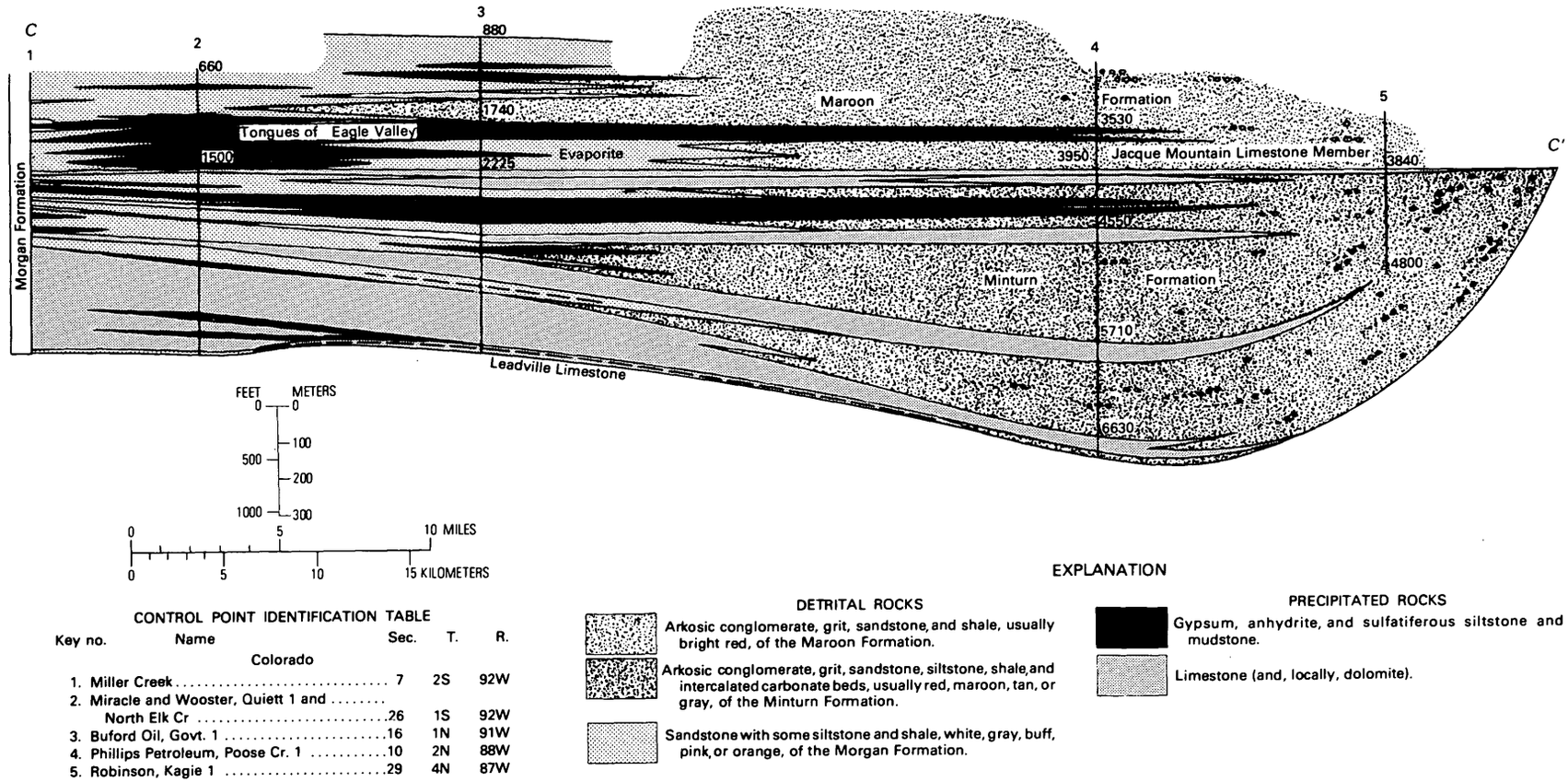
FIGURE 10.—Thickness of the Pennsylvanian System (modified from Mallory, 1972, p. 115). Isopach interval 100 feet, dashed where distant from control, dotted where conjectural. Precambrian crystalline rocks are shaded. Cross section *C–C'* in northwest, across central Colorado trough, is shown in figure 11. The Front Range, Uncompahgre, and Apishapa uplifts were above sea level and at times were mountains during the Pennsylvanian Period. Location of fig. 11 shown by line *C–C'*.

In some areas, especially along the northern Front Range, Mississippian rocks were undoubtedly present but were completely eroded away before Pennsylvanian clastic deposition, as some chert pebbles contain Mississippian fossils, especially the brachiopod *Eumertia* sp. and the bivalve *Conocardium* sp., in the basal Pennsylvanian red beds.

Every known class of sedimentary rock can be found in the Carboniferous strata of Colorado. The principal rocks exposed, however, are the massive gray limestone of the Mississippian and the coarse reddish-gray conglomeratic arkose of the Pennsylvanian. The Pennsylvanian, as indicated in figures 13 to 17, is extremely variable; the very coarse conglomerate of the Minturn and Sangre de Cristo Formations of south-central Colorado contrast strongly with the massive reef and offshore limestones of northwestern Colorado and the thick cyclic salt beds of the Paradox basin.

In Mississippian time, facies changes were scarce and slight and consisted mostly of minor textural changes in the almost pure carbonate. The lower beds of the Mississippian tend to be very fine grained; the overlying beds are commonly oolitic and contain endothyrid foraminifera.

* Fig. 11



CONTROL POINT IDENTIFICATION TABLE

Key no.	Name	Sec.	T.	R.
	Colorado			
1.	Miller Creek	7	2S	92W
2.	Miracle and Wooster, Quiett 1 and North Elk Cr	26	1S	92W
3.	Buford Oil, Govt. 1	16	1N	91W
4.	Phillips Petroleum, Poose Cr. 1	10	2N	88W
5.	Robinson, Kagie 1	29	4N	87W

EXPLANATION

DETRITAL ROCKS

Arkosic conglomerate, grit, sandstone, and shale, usually bright red, of the Maroon Formation.

Arkosic conglomerate, grit, sandstone, siltstone, shale, and intercalated carbonate beds, usually red, maroon, tan, or gray, of the Minturn Formation.

Sandstone with some siltstone and shale, white, gray, buff, pink, or orange, of the Morgan Formation.

PRECIPITATED ROCKS

Gypsum, anhydrite, and sulfatiferous siltstone and mudstone.

Limestone (and, locally, dolomite).

FIGURE 11.—Stratigraphic section through the Pennsylvanian System in the Eagle basin, northwest Colorado (modified from Mallory, 1972, p. 125). Location given on fig. 10.

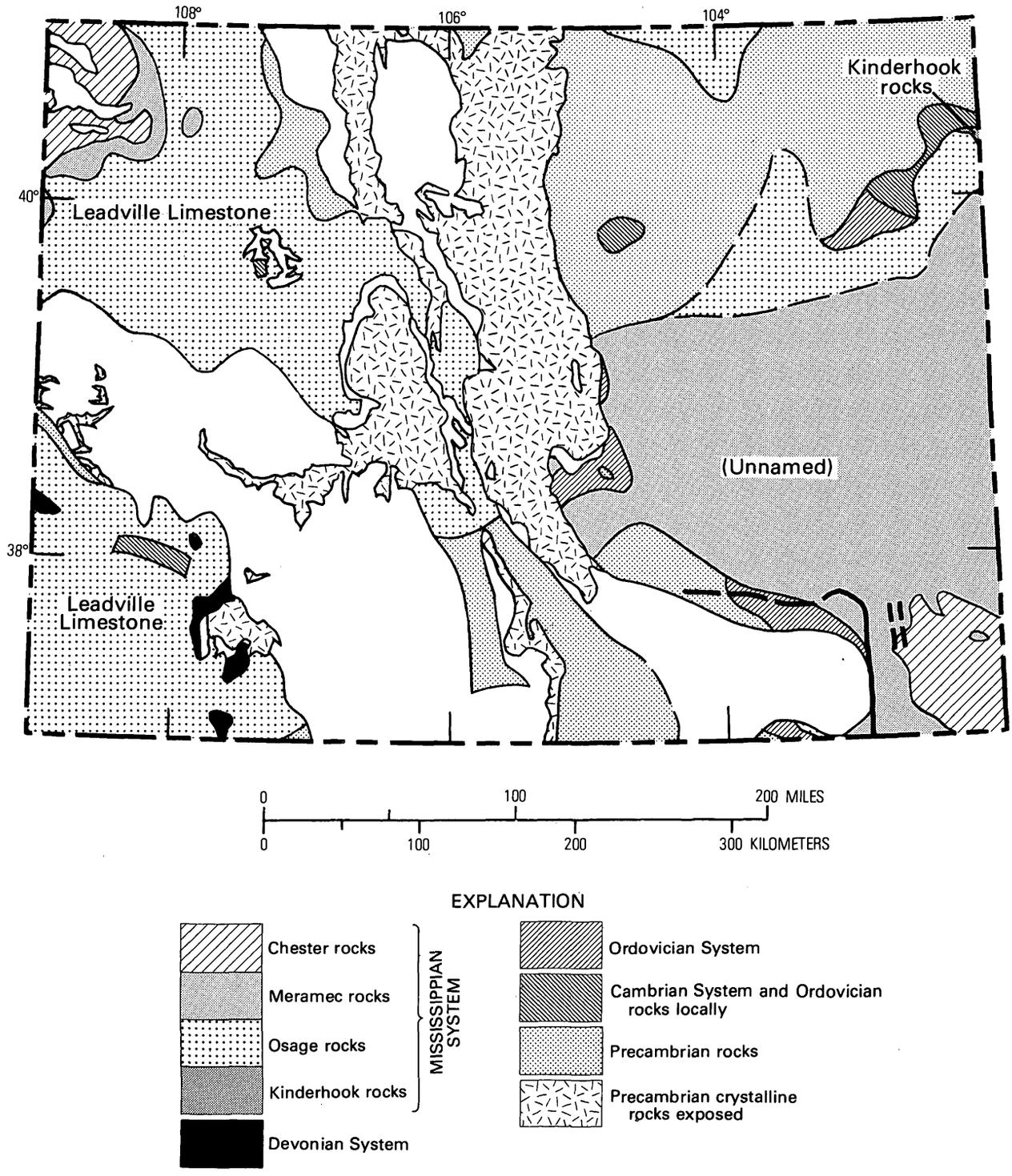


FIGURE 12.—Sub-Pennsylvanian paleogeology (modified from Mallory, 1972, p. 114).

Abrupt facies changes are the rule in the Pennsylvanian of central Colorado. Outcrops, roughly following the edges of Pennsylvanian highlands, may change within a very few miles from continental coarse conglomerates to marine limestones, alternating in cyclic repetition with red shales and sandstones. In many places, correlation of the beds in the clastic strata for more than a few feet is difficult,

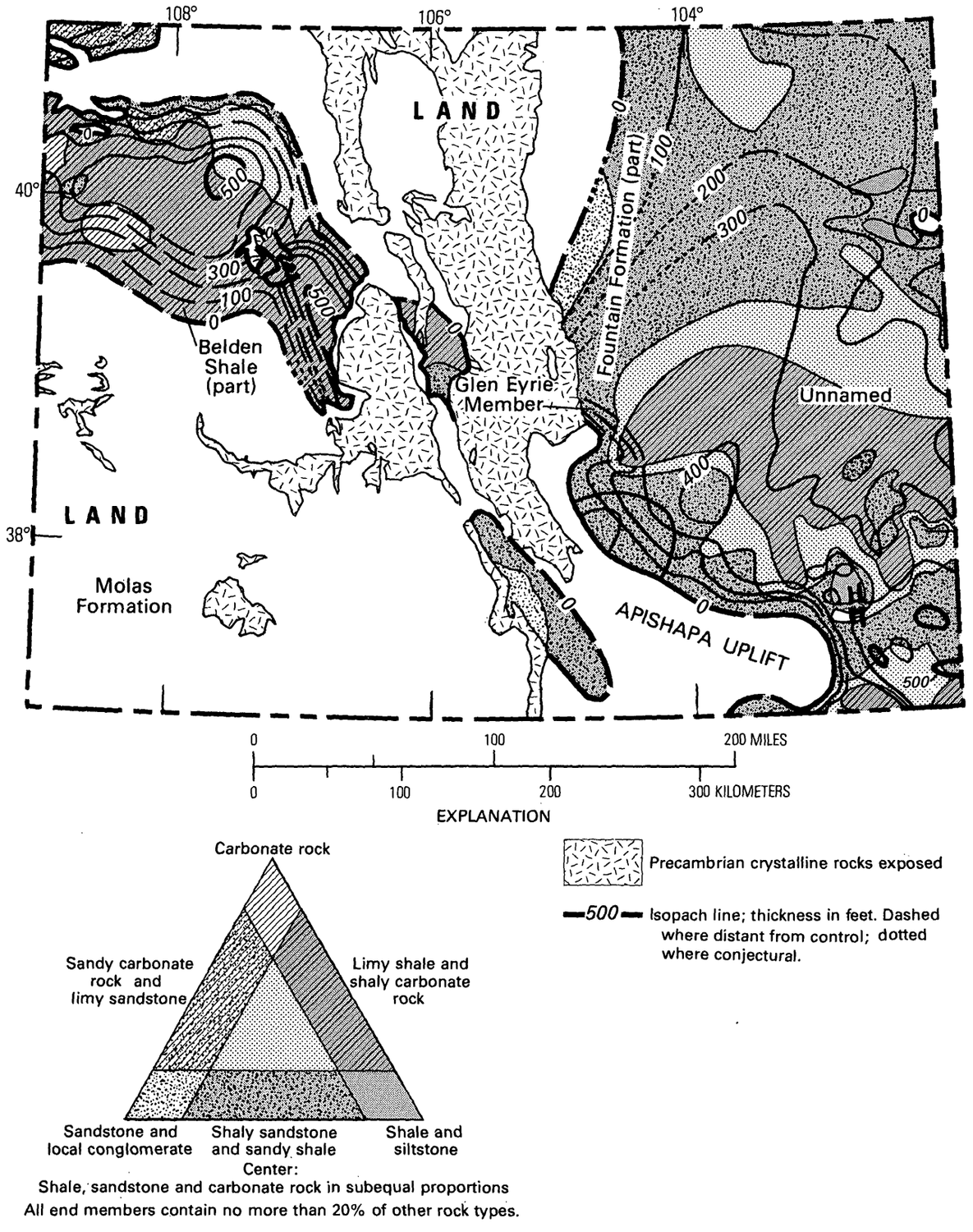


FIGURE 13.—Thickness and lithofacies of rocks mostly of Morrow age (modified from Mallory, 1972, p. 116).

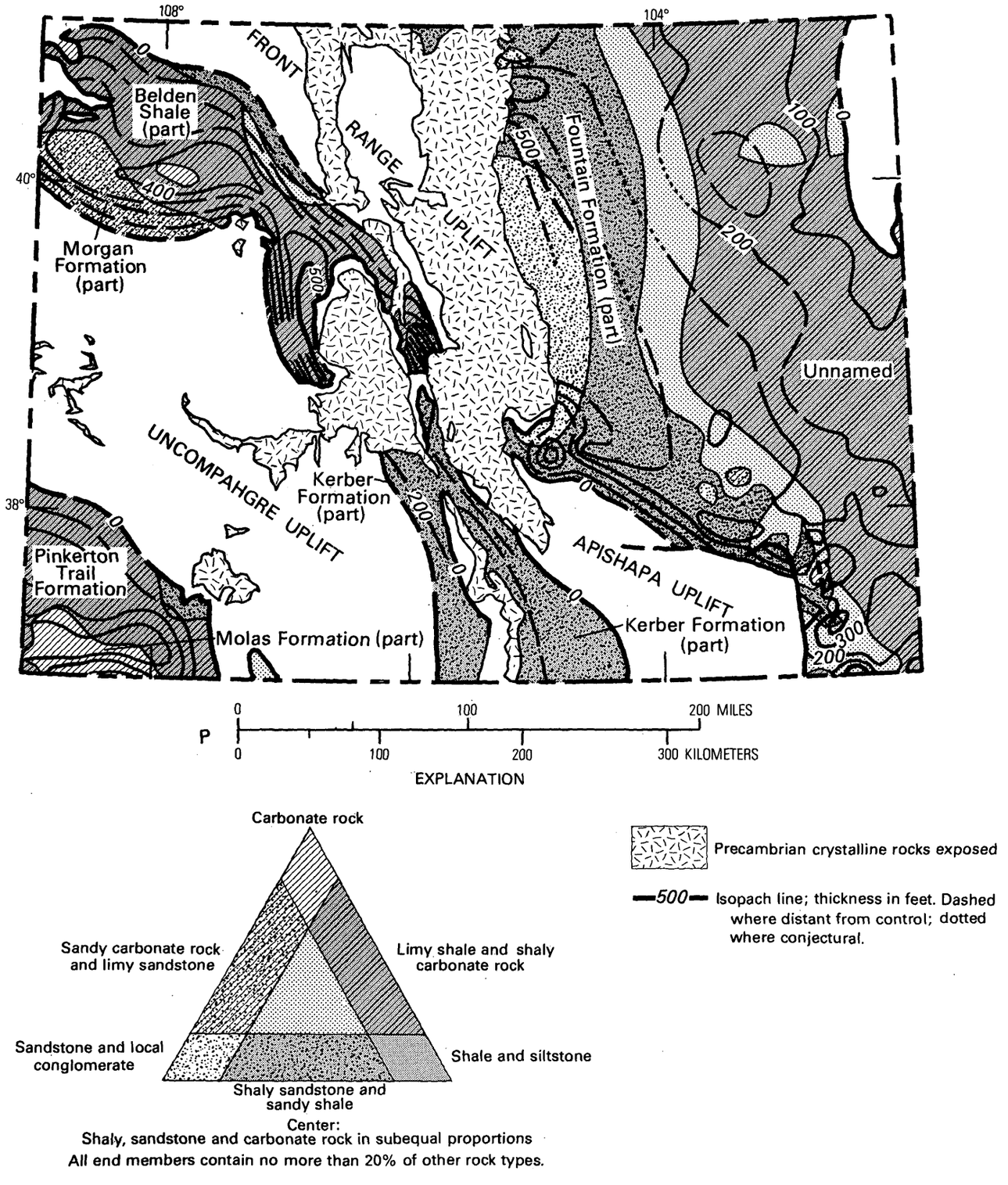


FIGURE 14.—Thickness and lithofacies of rocks mostly of Atoka age (modified from Mallory, 1972, p. 117).

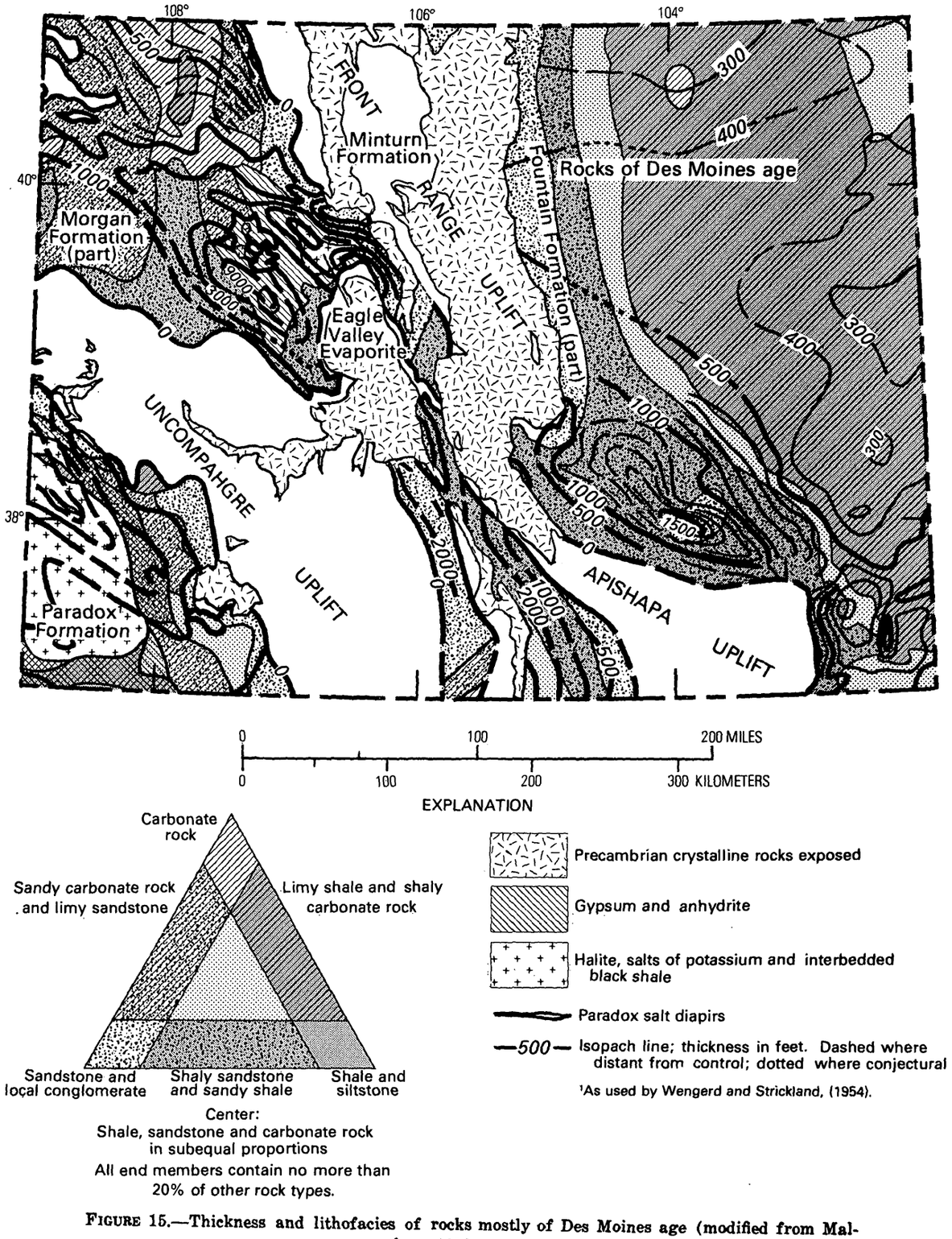


FIGURE 15.—Thickness and lithofacies of rocks mostly of Des Moines age (modified from Mallory, 1972, p. 119).

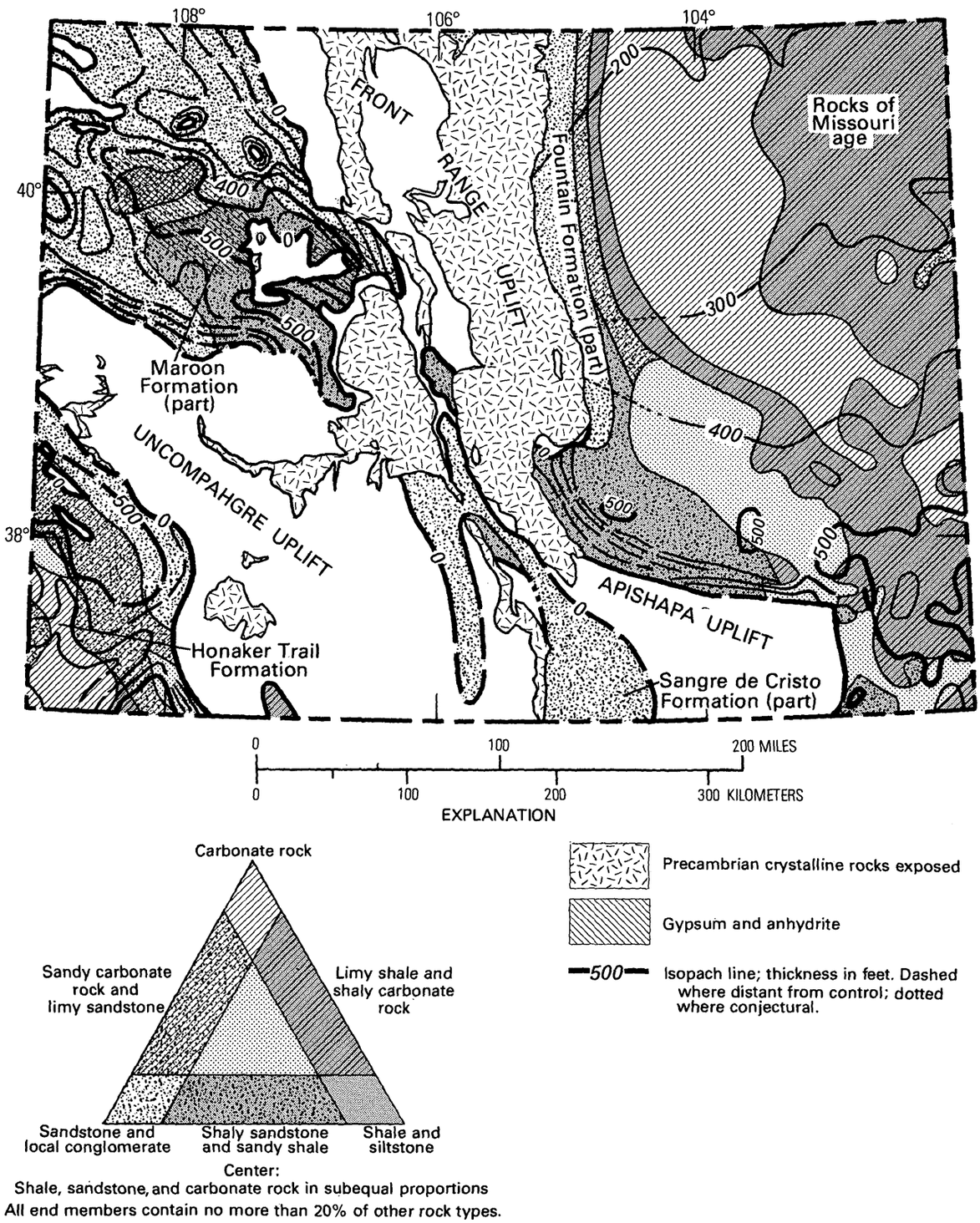


FIGURE 16.—Thickness and lithofacies of rocks mostly of Missouri age (modified from Mallory, 1972, p. 120).

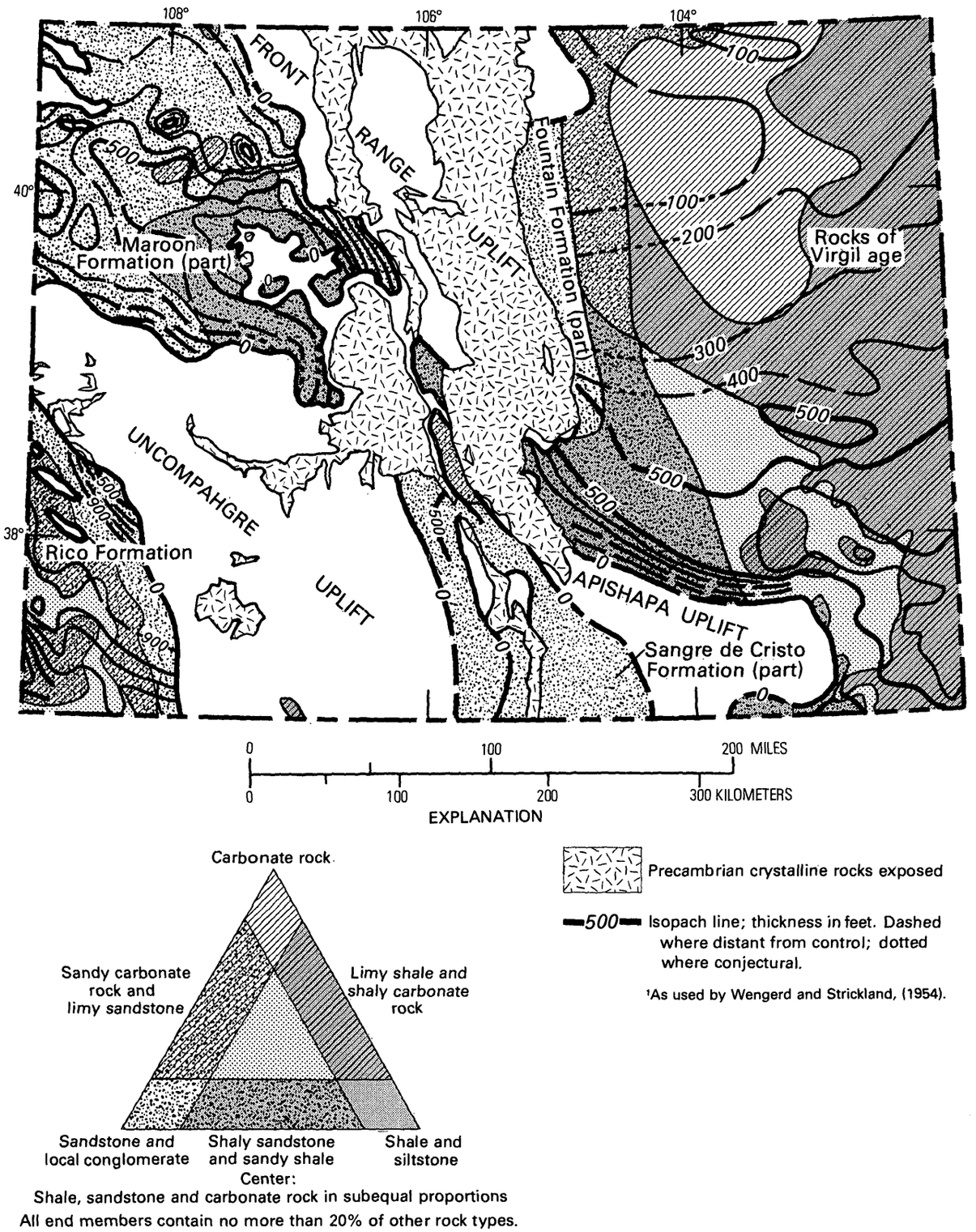


FIGURE 17.—Thickness and lithofacies of rocks mostly of Virgil age (modified from Mallory, 1972, p. 121).

although great lateral continuity exists in some marine beds. The Jacque Mountain Limestone of the Minturn Formation, a bed approximately 6 m (20 ft) thick, is present from the White River Plateau north of Glenwood Springs to the southern Sangre de Cristo Mountains, a distance of more than 300 km (about 200 miles) (fig. 11).

The depositional environment of the Mississippian in Colorado was that of an open unrestricted sea, which was receiving almost no clastic sediments. Present paleogeographic studies suggest that Colorado was at or near the Equator during Carboniferous time, so there can be little doubt that the entire State was in tropical latitudes. The lack of reefs and the rather limited marine fauna, in what are believed to have been tropical conditions, suggest that the depth of water was too great for reef and abundant, varied shallow-water faunas.

Much of the time in the Mississippian Period is not now represented by deposits (figs. 6, 7, 8, and 9). During the latter part of the period, which must have been warm and moist, an extensive karst formed, most of the earlier marine deposits were eroded away, and the residual Molas Formation was deposited.

The *Lepidodendron* forests of central and northwestern Colorado, which formed at about the boundary between Mississippian and Pennsylvanian time, suggest that a brief interval of tropical coal-swamp environment covered at least part of the State before the great upheaval of the Middle Pennsylvanian began.

Early Pennsylvanian environments were of transgressing seas from east and west over a land of low relief, where local uplifts were beginning. The dark-gray muddy deposits, the rather sparse faunas, and the lack of reefs suggest that the turbidity of the seas may have stifled marine growth; limited evaporite deposition at this time may also have prevented abundant life in some areas and certainly suggests that adjacent land areas were arid.

Middle Pennsylvanian environments, in contrast, varied from those of great aridity to those where broad evaporite basins were formed and flanked by massive reef growth. The climate must have been tropical and there appear to have been intermittent dry and moist periods, caused by simple climatic variation through time or by tectonic events, or both. In some localities, particularly the Sangre de Cristo Mountains, the Minturn area, and the Paradox basin, large reef masses formed at the edges of the marine basins. The Weber Sandstone of northwestern Colorado appears to have been deposited as dunes and beaches and suggests an arid climate for that area during Late Pennsylvanian time.

BIOSTRATIGRAPHY

Outcropping Mississippian strata in Colorado, although not very completely dated, are now considered to be mostly of Osage age, but deposits of Kinderhook, Meramec, and Chester age occur in the subsurface, mainly east of the mountains. At the east end of the Uinta Mountains in northwestern Colorado, Meremac and Chester deposits are present in facies unknown elsewhere in the State.

Pennsylvanian rocks whose age can be determined by fossils are mostly of Des Moines age, but the Atoka and Morrow are well documented in central Colorado outcrops, as well as in subsurface occurrences both east and west of the mountains. Missouri strata probably were deposited extensively over the State, but in all outcrops they are unfossiliferous. Documented strata of Missouri age are restricted to the subsurface of the Paradox basin and southeastern Colorado. Virgil rocks have a similar distribution, but marine facies are somewhat more widely distributed than those of Missouri, and occur in the subsurface in the Paradox basin and southeastern Colorado, as well as in strata at the northern end of the Front Range.

As figures 13–17 show, rocks of each of the series of the Pennsylvanian are probably extensively distributed over the State, but most are completely unfossiliferous, and their specific age assignments are based on inferences and probabilities.

The Mississippian faunal succession is very simple in outcrop: a lower, probably Osage brachiopod and coral fauna and a few gastropods and nautiloid cephalopods, mainly in central Colorado, and an upper, very restricted Meramec outcrop on the east side of the Wet Mountains, oolitic in facies and containing endothyrid foraminifera. Rocks of the other Mississippian series are poorly represented or known in the State because they are mostly in subsurface and have been drilled in only a few places for oil and gas. The Chester deposits of northwestern Colorado are dated from plant remains whose age may be in some doubt.

The Pennsylvanian faunal succession is complex in outcrop and in subsurface. The Morrow fauna is limited to a rather poorly defined zone that extends from the northwest corner of the State to near the southeast corner. *Millerella,* a primitive fusulinid, is abundant in most occurrences, along

with other foraminifers, bryozoans, brachiopods, and ostracodes.

The Atoka and Des Moines faunas generally are easily recognized by their abundant fusulinids and by a much more diverse biota, especially algae, corals, echinoderms, and trilobites. Within the Des Moines, most of the fossiliferous strata are of the older Cherokee part, and few, if any, late Des Moines faunas are known. An excellent succession of fusulinids is known within Des Moines rocks, and these have been reasonably well documented in northwestern Colorado by Thompson (1945).

Missouri and Virgil faunas are known only from subsurface and have been recognized by their fusulinid content in well cuttings and cores.

A few vertebrates and plants have been found in Pennsylvanian rocks of Colorado, but they have not yet been thoroughly studied.

Girty (1903) included extensive descriptions of Carboniferous fossils from Colorado, differentiating 55 invertebrates from the Mississippian and 170 from the Pennsylvanian.

Of the Mississippian species, 7 were corals, 5 bryozoans, 23 brachiopods, 5 bivalves, 10 gastropods, 3 arthropods, and 2 echinoderms. These, Girty believed, came from two faunal realms, one in central and southwestern Colorado containing corals, bryozoans, gastropods, and productid brachiopods, and a second along the east edge of the Front Range containing bivalves, bryozoans, large ostracodes, and five distinctive brachiopods: *Orthotetes inequalis* Hall, *Spirifer centronatus* Winchell, *Punctospirifer solidirostris* (White), *Cranaena subelliptica* var. *hardingensis* Girty, and *Eumetria woosteri* (White). Girty suggested that, although they are distinct in nature, both faunas represented an early Mississippian (Osage) age for the enclosing Leadville Limestone.

Since Girty's time, a Meramec fauna has been recognized in the Hardscrabble and Beulah Limestones, mainly consisting of endothyrid foraminifera, productid brachiopods, and corals.

In the Pennsylvanian Period, faunas were much more diverse and abundant. Girty described 170 species of invertebrates, including only 2 foraminifers (both fusulinids), 2 sponges, 9 corals, 21 bryozoans, 41 brachiopods, 45 bivalves, a single scaphopod, 34 gastropods, 2 cephalopods, 6 arthropods, and 7 echinoderms from his scattered collections.

The earliest Pennsylvanian rock units in Colorado, the Kerber, Glen Eyrie, and Belden Formations, commonly have two biofacies. At the base, a coaly cyclic sequence of beds contains *Lepidodendron* and closely related plants; above, a marine, usually cyclic series of beds contain a varied assemblage of algae, foraminifera including *Millerella*, bryozoans, brachiopods, mollusks, arthropods including both trilobites and ostracodes, and echinoderms, mostly echinoid parts and crinoid stem segments. Small fish teeth and conodonts are evidence of vertebrate life at this time.

The Belden Formation also contains an Atokan fauna in many localities, particularly in northwestern Colorado, where several species of *Fusulinella* have been described. Other foraminifera, rhomboporoid bryozoa, productid brachiopods, ostracodes, and echinoid fragments are typical of the Atokan part of the Belden.

Minturn Formation faunas are very diverse, depending on sedimentary facies, and their ages are difficult to determine unless they contain fusulinids because most of the faunas are long ranging. Either with or without the fusulinids, which, in many places, are *Fusulina rockymontana* Roth and Skinner and a species of *Wedekindellina*, the faunas normally are composed of brachiopods, bryozoans, corals, echinoderms, and mollusks. In some localities, extremely varied faunas of gastropods, often diminutive, are present, closely resembling the profuse early Des Moines faunas of Central United States. Some beds of the Minturn in central Colorado are made of crinoid stem fragments or coarse monaxon sponge spicules, and nonfusulinid foraminifera are locally very abundant.

Post-Des Moines faunas, rare in Colorado, are mostly fusulinids. Ingleside Formation limestones containing fusulinids similar to *Triticites cullomensis* Dunbar and Condra are characteristic in the northern Front Range and in the subsurface of eastern Colorado.

Mississippian fossils are not common in Colorado, and those that are present are not easily collected. On Fossil Ridge, however, northeast of Gunnison, corals are well preserved and abundant, and near Meredith, east of Basalt, brachiopods, usually species of *Spirifer* or productid forms, and large horn corals may be easily collected.

Pennsylvanian fossils, by contrast, are very abundant and diverse and can be found weathered from shale beds at many places in the State. From the many localities, four may be selected as outstanding and easily accessible: (1) At Molas Pass, near Silverton, great numbers of corals and brachiopods are present in the limestone beds of the cyclothems. (2)

At McCoy in central Colorado, Roth and Skinner (1930) described *Fusulina rockymontana*, as well as many other microfossils. The limestones east and west of Rock Creek at this locality have yielded great numbers of these and other Des Moines fossils. (3) At Wellsville, southeast of Salida on the south side of the Arkansas River, are excellent outcrops of abundantly fossiliferous early Pennsylvanian faunas. (4) On Juniper Mountain, west of Craig, are many well-exposed and excellently preserved invertebrates and fusulinids.

IGNEOUS AND METAMORPHIC ROCKS

No igneous or metamorphic rocks of Carboniferous age are found in Colorado, although some of the Carboniferous strata were metamorphosed by Laramide mountain building.

ECONOMIC PRODUCTS

Although a few feeble attempts have been made to mine coaly beds of the Kerber and Belden Formations in south-central Colorado, no production of Carboniferous coal is known.

However, oil from Carboniferous beds in the State is big business, especially if production from the Weber Sandstone at Rangely is included. In 1976, about 900,000 barrels of oil were produced along the eastern border of the State; although some of this oil came from beds that may be either Mississippian or Pennsylvanian, most of the total amount was from Mississippian beds.

If we assume that the Weber Sandstone is at least partly Carboniferous, then Pennsylvanian production in 1976 was 21,619,918 barrels (State of Colorado Oil and Gas Conservation Commission, 1976). The Weber, however, produced 20,781,123 barrels of this, and a small part of the total may have come from the Lyons Sandstone, which is probably of Permian age.

Gas production is also of importance to the State; in 1976, probable Carboniferous production was about 13 billion cubic feet.

Excellent prospects for Carboniferous oil and gas production probably still exist in the eastern plains, in the Paradox basin, and in the northwestern part of the State.

A large part of Colorado's lead, zinc, gold, and silver has come from Laramide replacement of the Leadville Limestone. In 1976, more than $24 million in zinc was produced, and lead production was about $9 million. Production of gold and silver was $5,459,111 and $14,292,695, respectively; most of it was from Leadville and Gilman.

Many years ago, iron for the furnaces of the Colorado Fuel and Iron Co. was produced from replacement in the Leadville Limestone of the northern Sangre de Cristo Mountains, but the volume was limited and mining ceased long ago. Some copper has been produced from Carboniferous red beds at several localities, but none is now being mined.

Many localities have produced uranium, mostly in small amounts, from Carboniferous rocks of the Belden Formation in central Colorado. Most uranium from the Belden Formation is produced from the Pitch mine in the Monarch Pass-Marshall Pass district, where the uranium has been precipitated in and around carbonaceous beds of cyclothems. The Pitch mine is along a reverse fault on the southwest corner of the Sawatch Range; the Belden is faulted against the granite and is highly brecciated. Ore valued at several million dollars was produced in the early 1960's, after which the mine lay dormant until the recent revitalization of the uranium industry. The Homestake Mining Co. now owns the mine and has drilled its rocks extensively. They are planning production from an open pit and have about 20 years' production now on reserve.

The famous Yule Marble, used in the Lincoln Memorial and the Tomb of the Unknown Soldier, is Leadville Limestone metamorphosed by a Laramide intrusion in an area south of Glenwood Springs. About $7 million worth of this snow-white marble was produced between about 1900 and 1940, but the remoteness of the area has led to the closing of the quarry.

Many limestone quarries are in Carboniferous strata along the Front Range, but there is little production elsewhere at present, except east of Monarch Pass, where the Colorado Fuel and Iron Co. quarries Leadville Limestone as flux for its smelters in Pueblo.

Lyons Sandstone of the Front Range, at one time considered to be of Carboniferous age, is now thought to be Permian and so is not included in this discussion.

Gypsum is produced in considerable quantities from Pennsylvanian rocks, particularly at Gypsum in west-central Colorado and at Coaldale on the Arkansas River. Potash, from evaporitic beds of the Paradox basin, is produced just over the State border in Utah; it is not yet being mined in Colorado, although it has economic potential.

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The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States

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ON THE COVER

Swamp-forest landscape at time of coal formation: lepidodendrons (left), sigillarias (in the center), calamites, and cordaites (right), in addition to tree ferns and other ferns. Near the base of the largest *Lepidodendron* (left) is a large dragonfly (70-cm wingspread). (Reproduced from frontispiece in Kukuk, Paul (1938), "Geologie des Niederrheinisch-Westfälischen Steinkohlengebietes" by permission of Springer-Verlag, New York, Inc.)

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GEOLOGICAL SURVEY

H. William Menard, *Director*

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FOREWORD

The year 1979 is not only the Centennial of the U.S. Geological Survey—it is also the year for the quadrennial meeting of the International Congress on Carboniferous Stratigraphy and Geology, which meets in the United States for its ninth session. This session is the first time that the major international congress, first organized in 1927, has met outside Europe. For this reason it is particularly appropriate that the Carboniferous Congress closely consider the Mississippian and Pennsylvanian Systems; American usage of these terms does not conform with the more traditional European usage of the term "Carboniferous."

In the spring of 1976, shortly after accepting the invitation to meet in the United States, the Permanent Committee for the Congress requested that a summary of American Carboniferous geology be prepared. The Geological Survey had already prepared Professional Paper 853, "Paleotectonic Investigations of the Pennsylvanian System in the United States," and was preparing Professional Paper 1010, "Paleotectonic Investigations of the Mississippian System in the United States." These major works emphasize geologic structures and draw heavily on subsurface data. The Permanent Committee also hoped for a report that would emphasize surface outcrops and provide more information on historical development, economic products, and other matters not considered in detail in Professional Papers 853 and 1010.

Because the U.S. Geological Survey did not possess all the information necessary to prepare such a work, the Chief Geologist turned to the Association of American State Geologists. An enthusiastic agreement was reached that those States in which Mississippian or Pennsylvanian rocks are exposed would provide the requested summaries; each State Geologist would be responsible for the preparation of the chapter on his State. In some States, the State Geologist himself became the sole author or wrote in conjunction with his colleagues; in others, the work was done by those in academic or commercial fields. A few State Geologists invited individuals within the U.S. Geological Survey to prepare the summaries for their States.

Although the authors followed guidelines closely, a diversity in outlook and approach may be found among these papers, for each has its own unique geographic view. In general, the papers conform to U.S. Geological Survey format. Most geologists have given measurements in metric units, following current practice; several authors, however, have used both metric and inch-pound measurements in indicating thickness of strata, isopach intervals, and similar data.

This series of contributions differs from typical U.S. Geological Survey stratigraphic studies in that these manuscripts have not been examined by the Geologic Names Committee of the Survey. This committee is charged with insuring consistent usage of formational and other stratigraphic names in U.S. Geological Survey publications. Because the names in these papers on the Carboniferous are those used by the State agencies, it would have been inappropriate for the Geologic Names Committee to take any action.

The Geological Survey has had a long tradition of warm cooperation with the State geological agencies. Cooperative projects are well known and mutually appreciated. The Carboniferous Congress has provided yet another opportunity for State and Federal scientific cooperation. This series of reports has incorporated much new geologic information and for many years will aid man's wise utilization of the resources of the Earth.

H. William Menard
Director, U.S. Geological Survey

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