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

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

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By JOHN E. WELSH[1] and HAROLD J. BISSELL[2]

ABSTRACT

A late Kinderhookian to Osagean Redwall carbonate bank prograded northwestward from southeastern Utah over a starved phosphatic basin and formed the clinoform Monte Cristo Limestone in southwestern Utah and the Deseret Limestone in central Utah. The interior of the Redwall carbonate bank was extensively dolomitized in southeastern Utah; the same lithofacies in northern Utah is Brazer Dolomite. Later, in late Meramecian and Chesterian time, the Great Blue carbonate bank prograded westward nearly to the present Nevada border and covered Antler flysch deposits. Clastic materials in the Mississippian were derived primarily from two sources. Erosion of the Antler Highlands in central Nevada provided fine clay and silt to the Chainman Formation and fine quartz sand and coarse chert pebbles to the Diamond Peak Formation. Erosion on the craton northeast of Utah provided clay, silt, and sand which were transported westward down the Doughnut trough and then deposited as prograding prodeltaic and deltaic deposits of the Deseret Limestone, Humbug Sandstone, and Manning Canyon Formation.

The Pennsylvanian Oquirrh basin in north-central Utah and the Paradox basin in southeastern Utah were elongated downwarps that received feldspathic sands beginning in the Morrowan and received an increasing volume of clastic material in late Des Moinesian through Virgilian time from the Uncompahgre uplift. Evaporites were deposited during a short period of the early Des Moinesian (Cherokee) time when the southeast inlet to the Paradox basin was barred by algal stratigraphic reefs. The Antler Highlands in central Nevada contributed fine clastic chert and quartz to the Hogan Member of the Ely Limestone on the Ely shelf in western Utah during the Des Moinesian. The Antler Highlands never were a source for the feldspathic sandstones of the Oquirrh Formation. Pre-Wolfcampian erosion stripped all the Pennsylvanian rocks off the Emery high in central Utah and beveled the Pennsylvanian rocks across the entire southwest quarter of the State.

Late Mesozoic (Sevier) structures are strongly influenced by the Carboniferous stratigraphy and paleogeography. The Leamington Canyon tear fault and the Charleston-Nebo allochthon are spatially controlled by the original northwestern edge of the Redwall carbonate bank and the south side of the Doughnut trough. The Chainman decollement of northeastern Nevada and northwestern Utah has caused the overlying Pennsylvanian, Permian, and Triassic sequence to shear into multiple nappes. Now these nappes, consisting of distinctly different parts of the upper Paleozoic and Triassic sequence, rest structurally upon plastically deformed shale of the Chainman Formation or directly upon the footwall of the Devonian carbonate rocks along the flanks of the Mesozoic anticlinoria and gneiss domes. Lower Mississippian limestone, particularly the Joana Limestone, was widely boudinaged by the Chainman decollement.

The Carboniferous rocks of Utah do not contain any economic coal deposits; however, they have yielded more than 361 million barrels of oil, mostly from the Paradox basin. Carboniferous limestones contain ores of copper, lead, silver, gold, zinc, and arsenic. Potash, clay, and limestone are produced from the Carboniferous deposits.

INTRODUCTION

Carboniferous rocks crop out in the fault-block mountains of western Utah, in the asymmetrical overthrust anticlines of the Wasatch Hinge Line, in the deep canyons of the Canyon Lands (fig. 1, locs. 42, 45), in the Paradox salt anticlines (fig. 1, loc. 43), and along the flanks of the Uinta Mountains (fig. 1, loc. 29). The Carboniferous sequence has been densely drilled for oil and gas only in the Paradox basin in southeastern Utah. Widely spaced drilling in the High Plateaus and Uinta Basin has provided useful Carboniferous stratigraphic control for this compilation. A few holes have penetrated the sequence in the Basin and Range province, but samples and logs are incomplete. Excellently exposed sequences of the Carboniferous are found in the tilted ranges in western Utah.

In northeastern Utah, the Lower Mississippian limestone sections crop out either as hogbacks or as near-vertical canyon walls. In southeastern Utah, where no Mississippian outcrops exist, the Pennsylvanian cyclical limestones form ledge and slope topography at Cataract Canyon (fig. 1, loc. 42) of the Colorado River and at the Goosenecks (fig. 1, loc. 45) of the San Juan River. Tilted fault blocks of Pennsylvanian limestone, anhydrite, and black shale form linear ridges in the Paradox salt anticli-

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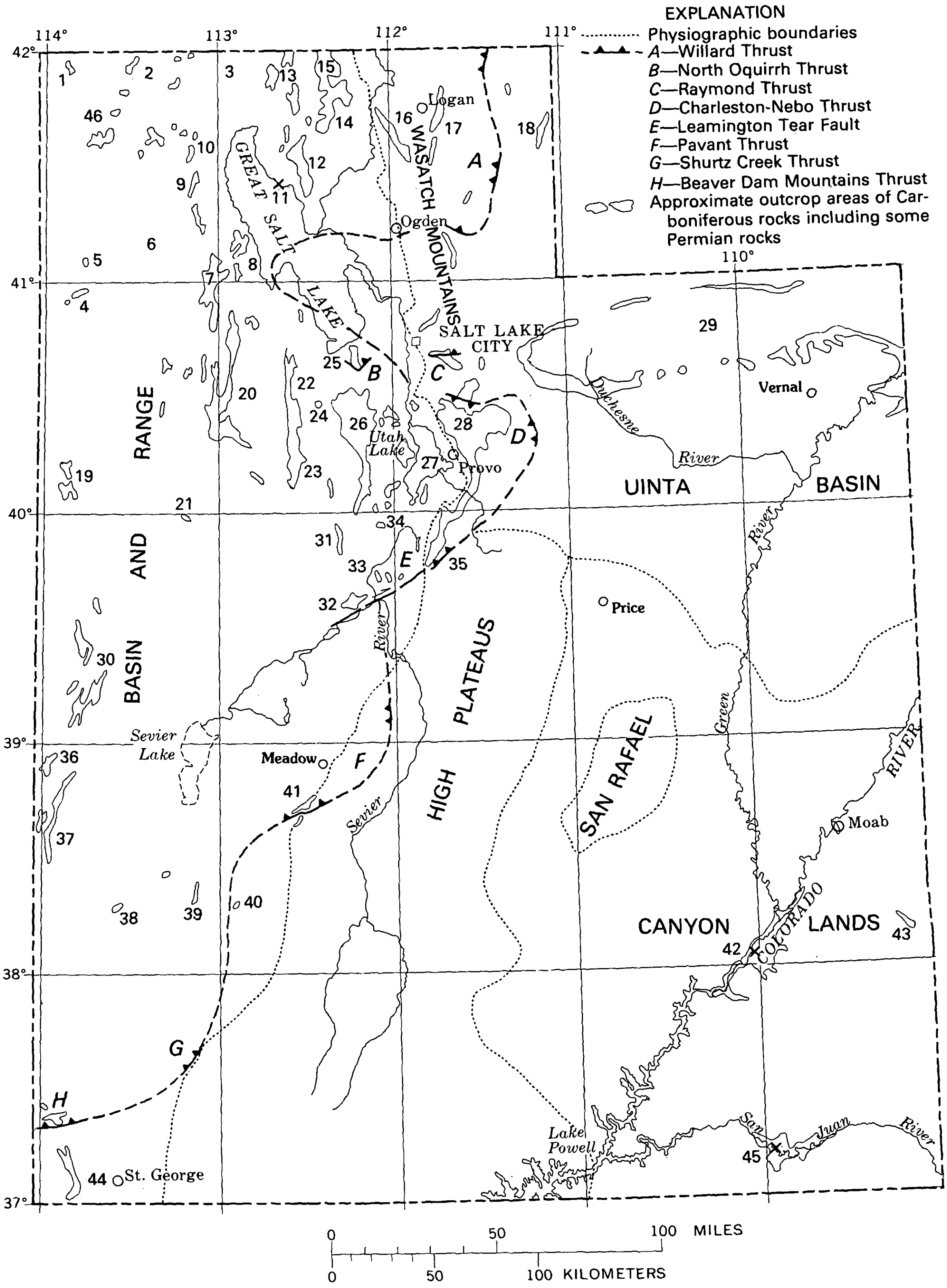


FIGURE 1.—Locations of outcrops of Carboniferous rocks in Utah. Outcrops west of the thrust belt are allochthonous. Numbers refer to locality list. (See locality list on facing page.) Uppercase letters refer to thrust and tear faults recognized along eastern boundary of the Sevier Orogenic Belt. Physiographic boundaries are indicated by a dotted line.

nal valleys near Moab and Lisbon (fig. 1, loc. 43). Salt solution in these anticlines has caused collapse structures to form.

In the Basin and Range province, Upper Mississippian rocks generally crop out as long strike valleys. Where resistant limestones or sandstones are present in the Mississippian sequences, these strike valleys may have a series of parallel minor hogbacks. Cuestas are less common than hogbacks because the dip is generally greater than 10°. Pennsylvanian cyclical limestones and sandstones in the same province give rise to steplike topography which usually extends to the crest of the ranges. Most of the magnificent skyline of Mt. Timpanogos (fig. 1, loc. 28) and Mt. Nebo (fig. 1, loc. 35) in the southern Wasatch Mountains is formed by the Pennsylvanian Oquirrh Formation.

A generalized biostratigraphic zonation of Carboniferous deposits in Utah is shown on figure 2; figure 3 is a lithostratigraphic correlation chart of the Utah Carboniferous. Displacement of allochthonous sequences is recognized in the belt of overthrusting along the Wasatch Hinge Line from southwesternmost Utah to near Logan and in areas of denudation adjacent to the Raft River gneiss dome in northwestern Utah and the Snake Range-Deep Creek gneiss dome in eastern Nevada and western Utah.

The stratigraphic data from the Uinta and Wasatch Mountains and northern Utah were compiled by Bissell; the remaining surface and subsurface information was compiled by Welsh. This paper includes a generalization of much unpublished stratigraphic information originated by Welsh. The writers have attempted to simplify the stratigraphic terminology and to relate it to specific lithostratigraphic facies.

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 Utah Geological and Mineral Survey.

ACKNOWLEDGMENTS

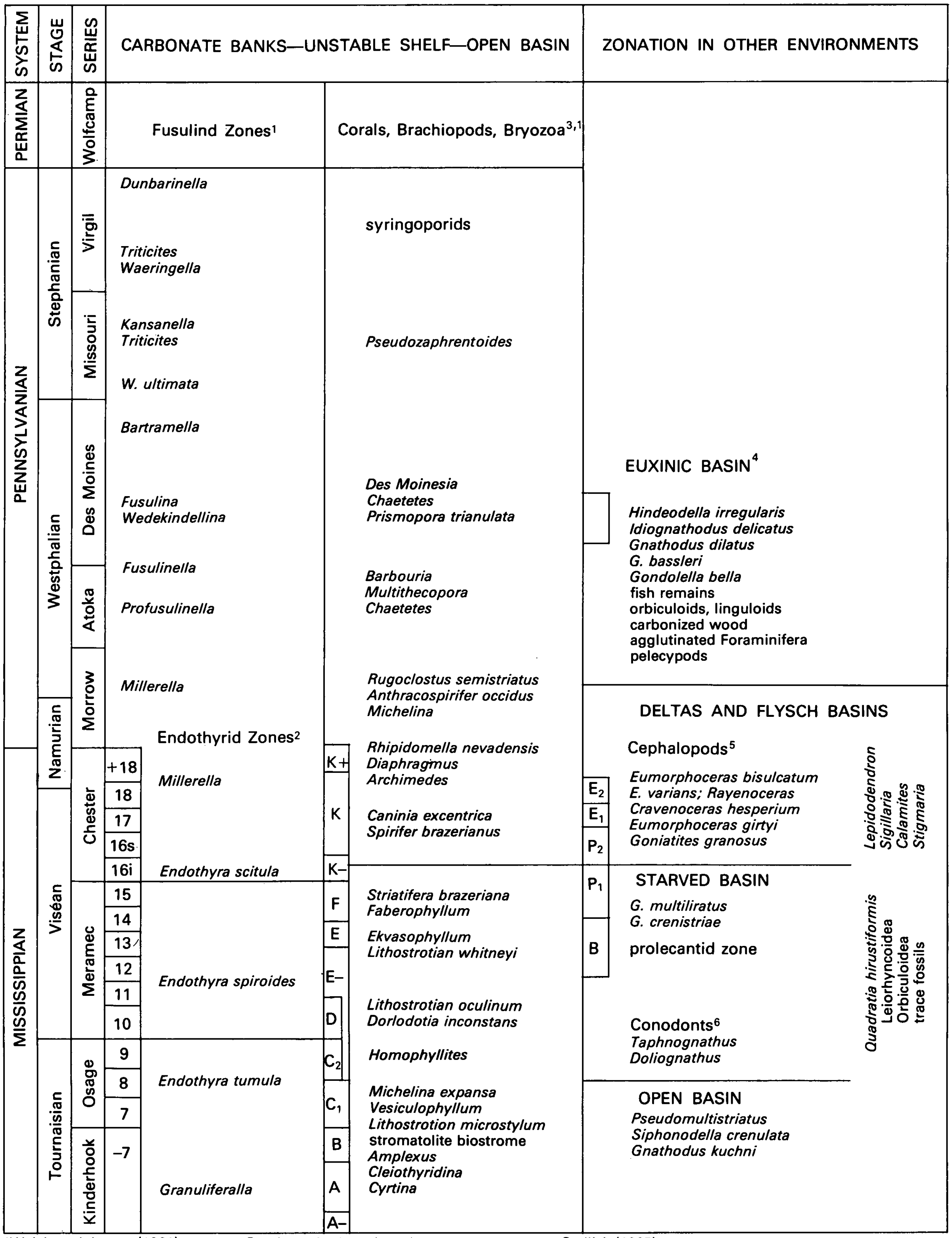
The writers acknowledge the exchange of information with C. A. Sandberg, W. J. Sando, and R. Gutschick concerning the starved-basin concept and paleontological zonation. The writers are, however, wholly responsible for the data presented. Graduate students of many universities deserve credit for undertaking mapping and stratigraphic projects in remote areas which have complex geology.

Welsh is indebted to A. Shaw for a rigorous introduction to paleontology, to R. Spivey for an introduction to fusulinids, and to A. James and W. L. Stokes for an appreciation of the value of stratigraphy in solving geologic problems. Bissell has benefited greatly from source data collected by some of his graduate students and also is grateful to various

FIGURE 1.—Continued

Locality list

1. Goose Creek Mountains
2. Raft River Range
3. Curlew Valley
4. Silver Island Range
5. Crater Island
6. Newfoundland Mountains
7. Grassy Mountains
8. Lakeside Mountains
9. Terrace Mountains
10. Hogup Mountains
11. Rozel Point
12. Promontory Mountains
13. Hansell Mountains
14. Blue Hill Mountains
15. West Mountains
16. Wellsville Mountains
17. Bear River Range
18. Crawford Mountains
19. Gold Hill
20. Cedar Mountains
21. Dugway Range
22. Stansbury Mountains
23. Onaqui Mountains
24. South Mountain
25. North Oquirrh Mountains
26. South Oquirrh Mountains
27. Lake Mountains
28. Timpanogos Mountain
29. Uinta Mountains
30. Confusion Range
31. West Tintic Mountains
32. Gilson Mountains
33. East Tintic Mountains
34. Tintic Mountains
35. Mt. Nebo
36. Burbank Hills
37. Needles Range
38. Southern Wah Wah Mountains
39. Star Range
40. Bradshaw Mountain
41. Pavant Range
42. Cataract Canyon
43. Lisbon Valley
44. Beaver Dam Mountains
45. Goosenecks of San Juan River Canyon
46. Grouse Creek Mountains



1Welsh and James (1961)
2B. L. Mamet and Betty Skipp, *in* Sando and others (1969)
3Sando and others (1969); J. T. Dutro, Jr., *in* Tooker and Roberts (1970)
4Stone (1968)
5Sadlick (1965)
6Sandberg and Gutschick (1977)

FIGURE 2.—Generalized biostratigraphic zonation of Carboniferous deposits in Utah.

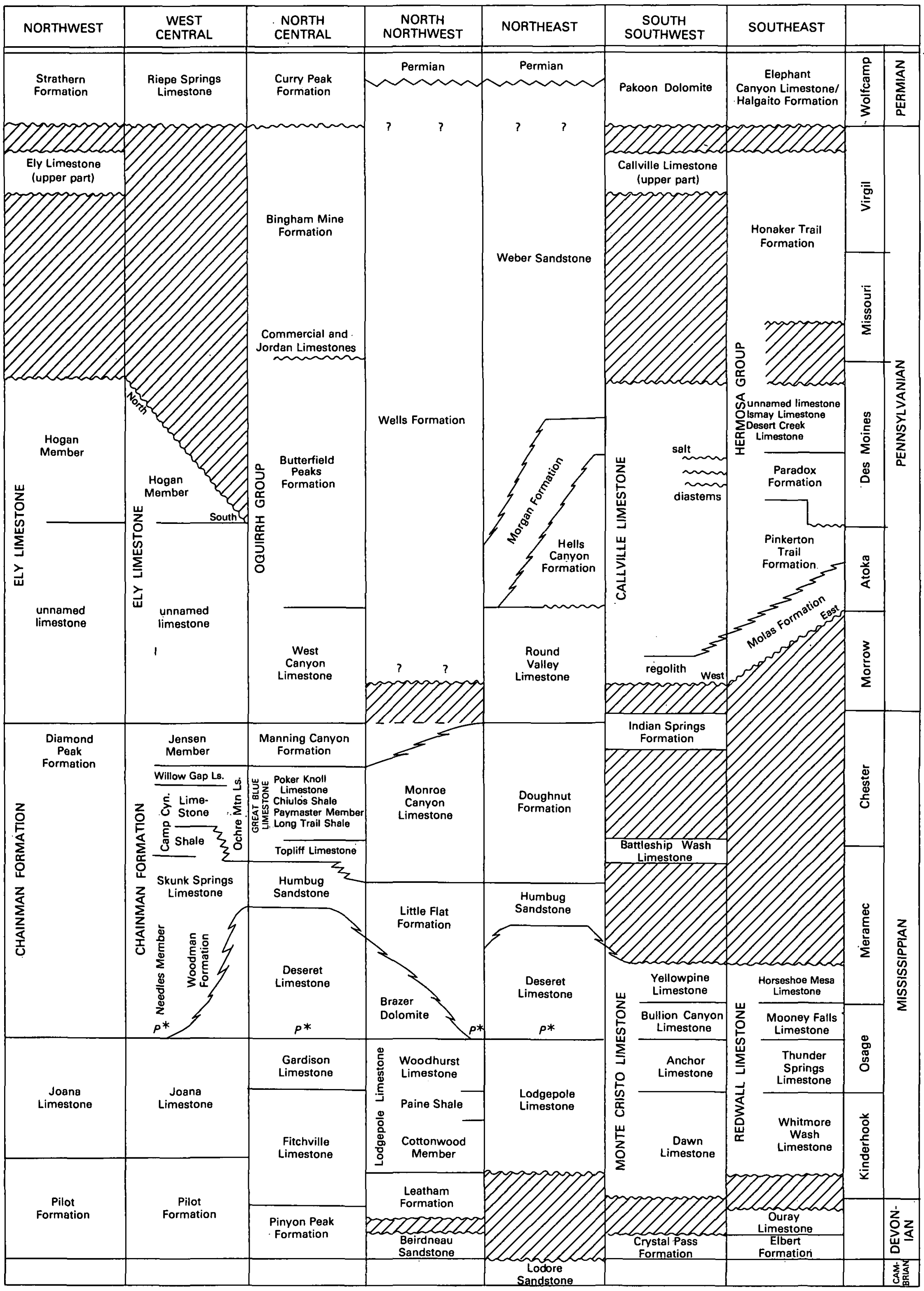


FIGURE 3.—Lithostratigraphic correlation of Carboniferous deposits in Utah. The presence of phosphatic shale is indicated by p*.

oil companies for releasing some data accrued while he was in their employ.

The writers appreciate the cooperation of the Utah Geological and Mineral Survey personnel under the directorship of Don McMillan. Brent Jones supervised the drafting of the illustrations. Martha Smith has immeasurably improved the manuscript by helpful suggestions and editing. Carlton Stowe provided the oil-production data.

HISTORY OF STRATIGRAPHIC NOMENCLATURE

HISTORICAL BACKGROUND

More than a century ago, Clarence King (1876) named the Weber Quartzite in Weber Canyon east of Ogden. Blackwelder, in 1910, separated the red sandstones and shales at the base of the quartzite cliffs as the Pennsylvanian Morgan Formation. Shortly thereafter, in 1912, Richards and Mansfield gave the name Wells Formation to rocks below the Phosphoria Formation in Wells Canyon, Bannock County, Idaho. The Wells Formation is in the same stratigraphic position as the Weber Formation, but their correlation is not well documented, even today.

Discovery of replacement ore bodies of precious and base metals in Carboniferous rocks at Park City, Bingham, Tintic, Ophir, Gold Hill, and other, lesser districts resulted in generalized stratigraphic studies and a proliferation of formation names. Formations were poorly defined because of structural and alteration complications, and names were extended to other areas on the basis of paleontology rather than lithology. This practice has resulted in an imprecise use of lithostratigraphic terms. The nomenclature of the Mississippian sequences has been sufficiently revised, as discussed below, that these sequences represent coherent lithofacies. The Pennsylvanian sequences are still in a state of confusion, particularly in the Oquirrh basin where 9,000 m of Pennsylvanian and Permian section are referred to as the "Oquirrh Formation." Unfortunately, paleontologic extension of formation names continues.

MISSISSIPPIAN NOMENCLATURE

The Mississippian sequences were lithologically divided by Gilluly (1932) in the Oquirrh Mountains (fig. 1, loc. 26) and by Nolan (1935) in the Gold Hill district (fig. 1, loc. 19). The Oquirrh Mountain terminology of the Deseret Limestone, Humbug Sandstone, Great Blue Limestone, and Manning Canyon Formation has been extended as the accepted terminology of the allochthonous sequences west of the Wasatch Hinge Line. The Deseret Limestone and Humbug Sandstone have also been accepted to the east for the autochthonous sequences. The Lower Mississippian sequences, formerly called "Madison," are now called the Gardison and Fitchville Limestones because of correlation with those limestones in the Tintic district (Morris and Lovering, 1961). Equivalent rocks in northern Utah are now called the Lodgepole (Holland, 1952). The Chesterian Manning Canyon Formation of the Oquirrh Mountains has been found in all the allochthonous sections of the proto-Oquirrh basin, whereas the thinner Doughnut Formation includes the late Meramecian to Chesterian rocks on the shelf to the east in the Wasatch and Uinta Mountains. Nolan's Upper Mississippian units of the Woodman Formation and Ochre Mountain Limestone at Gold Hill were extended by Staatz (1972) into the Dugway Range (fig. 1, loc. 21), but these units need to be further defined by larger scale mapping at Gold Hill before they can be correlated regionally.

Williams (1948) and his students measured reconnaissance sections in northern Utah, but the descriptions of the rocks were generalized. Parks (1951) first described the coral zones of the Upper Mississippian section in the Wellsville Mountains (fig. 1, loc. 16). Sando and his colleagues (1959 and 1976) have further revised the lithostratigraphy and biostratigraphy in northern Utah by restricting the name Brazer Dolomite to the Crawford Mountains (fig. 1, loc. 18) and by using the name Little Flat Formation for basinal siltstones equivalent to the Deseret Limestone. Limited stratigraphic studies of the Mississippian in northern Utah were done in conjunction with the U.S. Geological Survey's phosphate program in the late 1940's and early 1950's.

Oil companies initiated regional stratigraphic studies in the early 1950's, but very little critical work was accomplished until oil was discovered in the mid-1950's in the Paradox basin, Utah, and at Eagle Springs, Nevada. These discoveries spurred investigations throughout both States. The U.S. Geological Survey geologists restudied the stratigraphy of the Tintic district in the 1950's, then later initiated an investigation of the northern Oquirrh Mountains (fig. 1, loc. 25) following the completion of the stratigraphic field work in the southern Oquirrhs by Bissell (1959) and in the overall Oquirrh Mountains by Welsh and James (1961). Sadlick, in graduate studies at the University of

Utah (1956, 1957, 1965), contributed substantially to the biostratigraphy in northeastern and western Utah and was the first to describe the flysch facies of the Upper Mississippian sections in western Utah. Sadlick and Mackenzie Gordon, Jr. (oral commun., 1960), did most of the goniatite zonation of the Upper Mississippian sequences. By the late 1950's a geologic mapping program, supervised by Lehi Hintze and Lee Stokes, was initiated and was funded by the Utah State Land Board. Graduate students at Brigham Young University and the University of Utah received partial field expenses for much of the original geologic mapping in remote areas of the State. These mapping and stratigraphic theses resulted in new regional information on the Carboniferous rocks and made possible the compilation of the 1:250,000-scale "Geologic Map of Utah" (Hintze and others, 1962–1964).

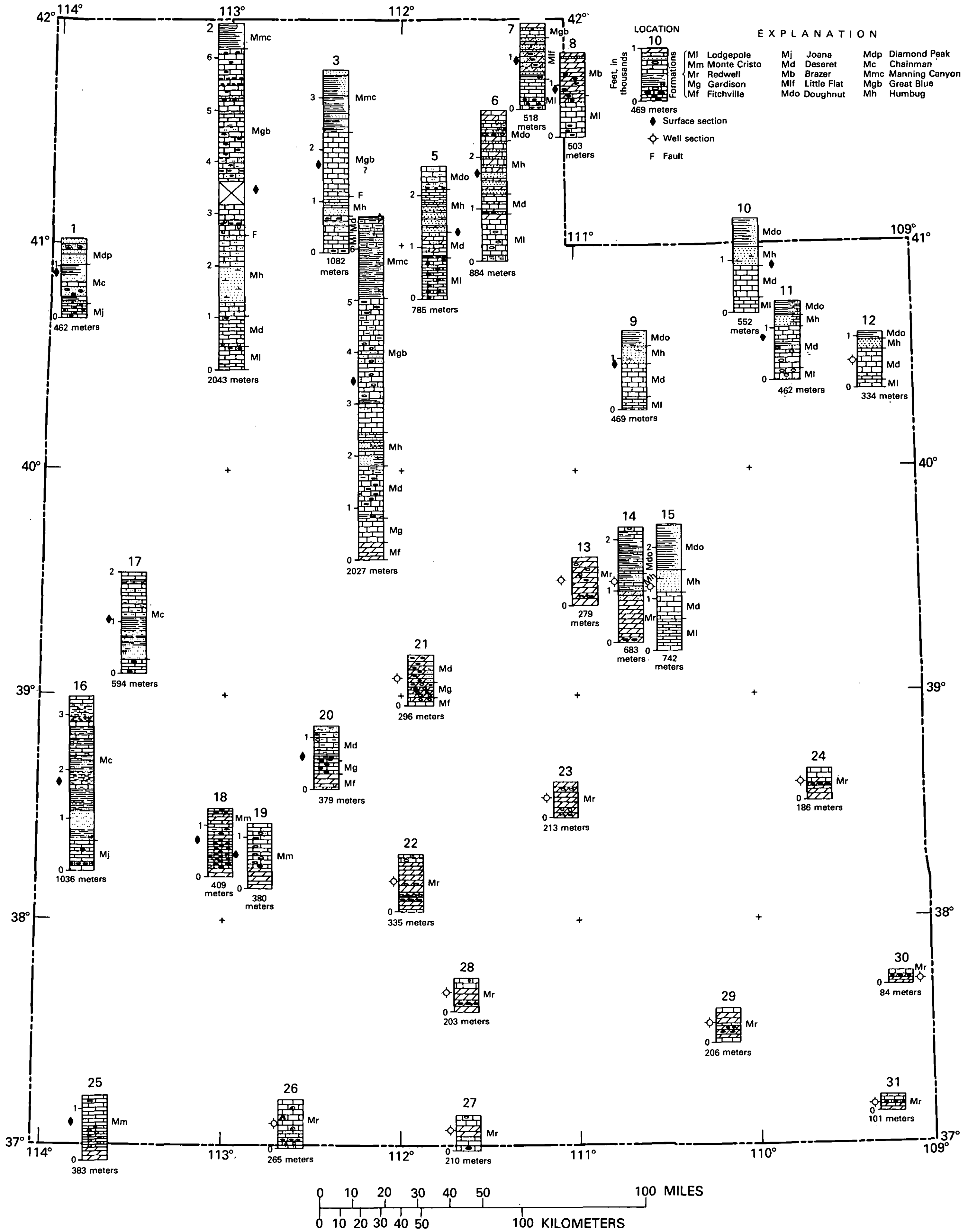
Hose and Repenning (1959) and Langenheim (1963) formally extended the Joana Limestone, Chainman Formation, and Monte Cristo Limestone terminology into western Utah, where oil company geologists had been using the terminology informally since the early 1950's. Parker and Roberts (1966) formally used McKee and others' (1969) members of the Redwall Limestone to designate units in the subsurface of southeastern Utah. The recognition that the Redwall Limestone was the interior carbonate bank deposit and that the Monte Cristo Limestone was the clinoform slope deposit was made in the early 1960's by oil company geologists in southern Nevada. Rose (1976b) found this relationship to extend along the Wasatch Hinge Line across Utah into Idaho. The basinal siltstone facies of the Deseret in the Pavant Range (fig. 1, loc. 41), now known to be equivalent to the Little Flat Formation, was first recognized by Welsh (1972). Several recent oil tests (fig. 4, secs. 13, 21) between Meadow in the Pavant Range and Hiawatha southwest of Price (fig. 1) have provided the control necessary for defining the initial northeast trend of the Osagean Redwall carbonate bank (fig. 5).

Gutschick (1976) and Sandberg and Gutschick (1977) interpreted conodont zones in the phosphatic shales of the lower part of the Deseret Limestone as having been deposited in a starved basin of the early Osagean. The recognition of this starved basin (fig. 5) helped explain the northwest progradation of the Osagean and lower Meramecian limestones. Dolomitization of the interior carbonate bank (fig. 5) was recognized by Sando and others (1959) as the Brazer Dolomite. This same dolomitization had been recognized in outcrops earlier by oil geologists at Frenchman Mountain near Las Vegas. Drilling since the mid-1950's in south-central Utah has shown the universality of dolomitization in the interior Redwall carbonate bank.

Oil geologists in 1954 recognized that the western margin of the Chesterian carbonate bank of the Great Blue and Ochre Mountain Limestones, also called the Great Blue Carbonate Bank (fig. 6), was in the Confusion Range (fig. 1, loc. 30)-Gold Hill (fig. 1, loc. 19) area. This bank margin crops out in the Skunk Springs section (fig. 4, sec. 17) of the Confusion Range. Rose (1976b) first illustrated the regional progradation of this Chesterian carbonate bank almost to the Nevada border. Research on source beds by Sandberg and Gutschick (1977) has renewed interest in Mississippian stratigraphy and we hope that more detailed investigations will result from this economic interest.

PENNSYLVANIAN NOMENCLATURE

The quality of Pennsylvanian stratigraphic data from Utah is directly proportional to the past economic incentive to study the geology of the State. Oil exploration in southeastern Utah, and the resultant discovery of the Greater Aneth field in 1956, stimulated the early synthesis of subsurface data by Wengerd and Strickland (1954), Herman and Sharps (1956), and Herman and Barkell (1957). These investigators assumed lateral facies changes from evaporites to carbonate rocks around the margins of the basin; thus, their correlations cross time–stratigraphic units. In 1958, Welsh showed that in the subsurface of southeastern Utah, an unconformity separates the Des Moinesian and Missourian series and a disconformity separates the lowermost Des Moinesian and Atokan series. Wengerd and Matheny (1958) revised the lithostratigraphy of the Paradox basin and used the top of the Desert Creek Limestone or the equivalent Horn Point Limestone at Honaker Trail (fig. 1, loc. 45) as the top of the Paradox Formation. They included all the superjacent limestone in the Honaker Trail Formation. In 1963, Welsh used fusulinid data to show that the evaporites of the Paradox Formation were equivalent to disconformities on the western margin of the basin and were not equivalent to the fossiliferous marine limestones that overlie and underlie the evaporites. The fact that the contact between the Missourian and Wolfcampian series is unconformable was further documented by fusulinid data. Baars, Parker, and Chronic (1967) reverted


EXPLANATION
LOCATION
10
Feet, in thousands
Formations
469 meters
Ml Lodgepole
Mm Monte Cristo
Mr Redwell
Mg Gardison
Mf Fitchville
Mj Joana
Md Deseret
Mb Brazer
Mlf Little Flat
Mdo Doughnut
Mdp Diamond Peak
Mc Chainman
Mmc Manning Canyon
Mgb Great Blue
Mh Humbug
Surface section
Well section
F Fault
2043 meters
1082 meters
2027 meters
785 meters
884 meters
518 meters
503 meters
462 meters
552 meters
462 meters
334 meters
469 meters
594 meters
1036 meters
279 meters
683 meters
742 meters
296 meters
379 meters
409 meters
380 meters
335 meters
213 meters
186 meters
203 meters
206 meters
84 meters
383 meters
265 meters
210 meters
101 meters
0 10 20 30 40 50 100 MILES
0 10 20 30 40 50 100 KILOMETERS

to the lateral facies concept, ignored time-stratigraphic units, and correlated the evaporites of the Paradox Formation with open-circulation limestones of both Des Moinesian and Missourian ages. Since 1967, many papers have been written on the Paradox basin, but the time-stratigraphic correlation of the facies has not been adequately documented in the literature.

At present, the name Hermosa Group can logically be restricted to the limestone-clastic sequence in the immediate area of the Paradox basin and to the type area in southwestern Colorado. The Pinkerton Trail Formation is the preevaporite carbonate rock of the Atokan and early Des Moinesian; the Paradox Formation is the evaporite sequence; the Desert Creek, Ismay, and unnamed Des Moinesian limestones are the overlying, open-marine formations. The Honaker Trail Formation is restricted to the Missourian and Virgilian limestones. The Callville Limestone as used in this paper is the western platform facies of the Hermosa in south-central Utah. The Wolfcampian Pakoon Dolomite is the western platform facies of the Elephant Canyon Limestone and the red beds of the Halgaito Formation, all of which unconformably overlie Pennsylvanian rocks of either the Callville Limestone or the Hermosa Group.

The Pennsylvanian rocks of the type Oquirrh Formation in the southern Oquirrh Mountains (fig. 1, loc. 26) were not divided by Gilluly (1932). He included approximately 9,000 m of Pennsylvanian and Permian rocks in one map unit and implied complex facies changes within the Stockton and Fairfield quadrangles. Nolan (1930) had earlier applied the Oquirrh name to Pennsylvanian and Permian sequences in the Gold Hill district of western Utah; today the Pennsylvanian part of these sequences is considered to be the Ely Limestone. Nolan's correlation was based upon similar faunal elements, not lithology. Detailed descriptions of the "Oquirrh" sequences at Gold Hill have never been published. Bissell (1959) was the first to publish descriptions of mappable formations in the southern Oquirrh Mountains (fig. 1, loc. 26), and he divided the Pennsylvanian sequence into the Morrowan Hall Canyon Member, the Atokan Meadow Canyon Member, the Des Moinesian Cedar Fort Member, the Missourian Lewiston Peak Member, and the Virgilian Pole Canyon Member. Unquestionably these lithologic units are mappable; however, the youngest rocks in the southern Oquirrh Mountains are Des Moinesian, not Virgilian. Welsh and James (1961) divided the entire Pennsylvanian and Permian sequence of the Oquirrh Mountains into mappable time-strati-

FIGURE 4.—Numbered stratigraphic sections of the Mississippian in Utah. Formational subdivisions and generalized lithologies are shown. Where no section number is supplied, the stratigraphy is a composite of information from more than one section. Stratigraphic sections 13–23 and 25–28 are based on original unpublished data of Welsh; the other sections are modified from published sources as indicated.

1. Silver Island Mountains, T. 1 N., R. 19 W. (modified from Schaeffer, 1960)
2. Lakeside Mountains, T. 6 N., R. 9 W. (modified from Doelling, 1964)
3. Promontory Mountains, T. 7 N., R. 6 E. (modified from Olson, 1960)
4. South Oquirrh Mountains, T. 5 S., R. 4 W. (modified from Gilluly, 1932)
5. Morgan, T. 4 N., R. 3 E. (modified from Nohara, 1966)
6. Causey Dam, T. 7 N., R. 3 E. (modified from Mullens and Izett, 1964)
7. Old Laketown Canyon, T. 13 N., R. 6 E. (modified from Sando and others, 1976)
8. Crawford Mountains, T. 11 N., R. 8 E. (modified from Sando and others, 1976)
9. Duchesne River, sec. 14, T. 1 N., R. 8 W. (modified from Sadlick, 1957)
10. Sols Canyon, sec. 11, T. 2 N., R. 18 E. (modified from Sadlick, 1957)
11. Whiterocks Canyon, T. 2 N., R. 1 E. (modified from Kinney, 1955)
12. Ute Federal, sec. 12, T. 4 S., R. 22 E. (modified from Sadlick, 1957)
13. Hiawatha, sec. 13, T. 15 S., R. 7 E.
14. Miller Creek, sec. 26, T. 15 S., R. 10 E.
15. Mounds, sec. 33, T. 15 S., R. 12 E.
16. Needles Range, T. 25 S., R. 19 W.
17. Skunk Springs, T. 17 S., R. 16 W.
18. Elephant Canyon, T. 28 S., R. 12 W.
19. Bradshaw Mountain, T. 29 S., R. 10 W.
20. Cove Fort, T. 24 S., R. 6 W.
21. Scipio Lake, sec. 14, T. 20 S., R. 2 W.
22. Antimony Canyon, sec. 30, T. 30 S., R. 2 W.
23. South Last Chance, sec. 18, T. 26 S., R. 7 E.
24. Little Valley, sec. 29, T. 26 S., R. 20 E. (modified from Parker and Roberts, 1966)
25. Beaver Dam Mountains, T. 42 S., R. 18 W.
26. Kanab, sec. 2, T. 43 S., R. 8 W.
27. Judd Hollow, sec. 19, T. 43 S., R. 2 E.
28. Upper Valley, sec. 12, T. 36 S., R. 1 E.
29. Moqui, sec. 33, T. 37 S., R. 15 E. (modified from Parker and Roberts, 1966)
30. Coalbed Canyon, sec. 20, T. 35 S., R. 26 E. (modified from Parker and Roberts, 1966)
31. Desert Creek, sec. 2, T. 42 S., R. 23 E. (modified from Parker and Roberts, 1966)

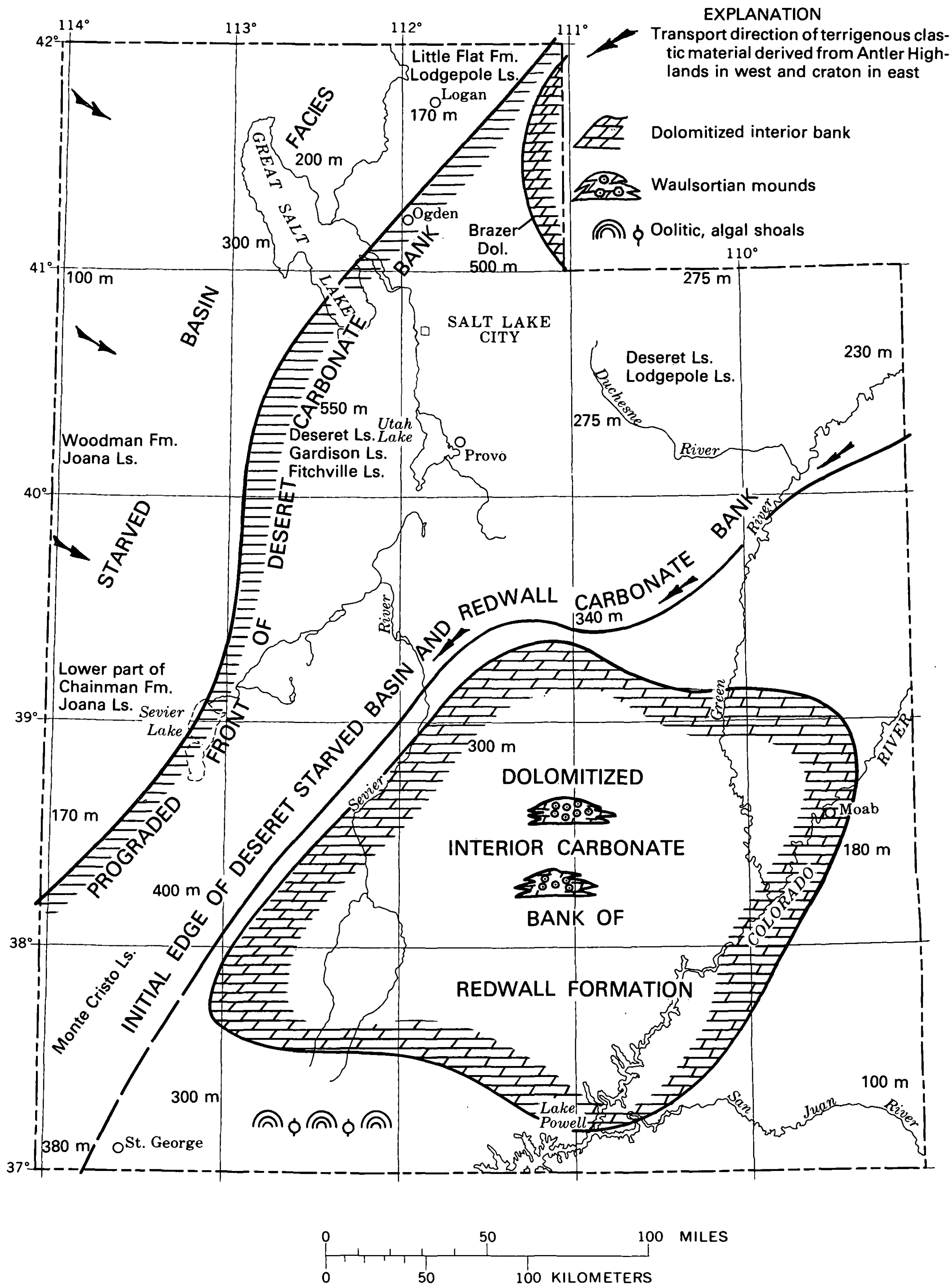


FIGURE 5.—Paleogeographic map of Utah showing approximate present thicknesses in meters of deposits of the late Kinderhookian through Osagean into early Meramecian time.

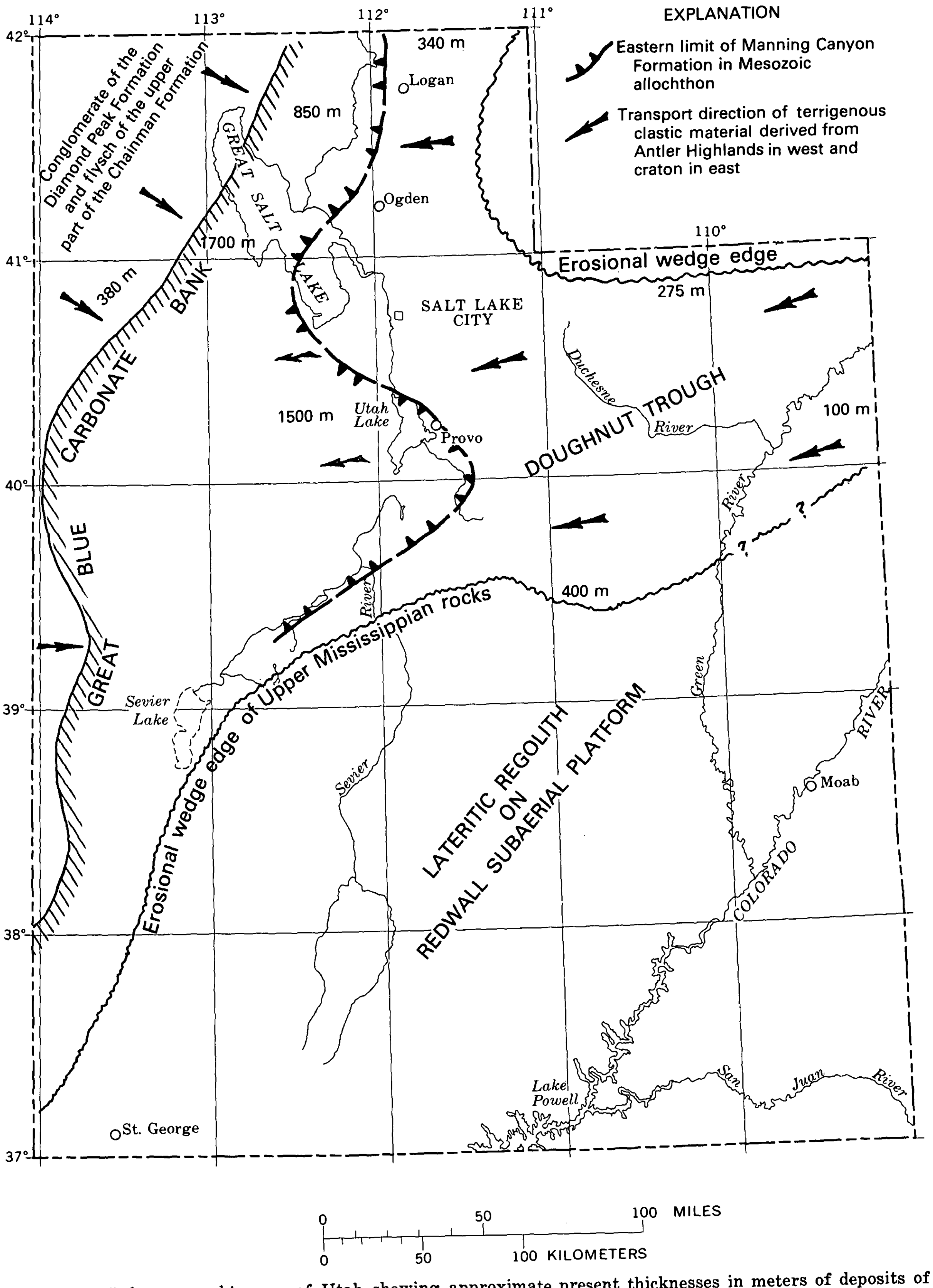


FIGURE 6.—Paleogeographic map of Utah showing approximate present thicknesses in meters of deposits of the late Meramecian to late Chesterian time.

graphic units in conjunction with structural mapping in the Bingham district. Welsh (*in* Welsh and James, 1961) recognized the importance of the South Mountain (fig. 1, loc. 24) section of Des Moinesian through Wolfcampian rocks for understanding the correlation of other structural blocks. He also first recognized the Permian Kirkman Limestone, Diamond Creek Sandstone, and Park City Formation at South Mountain (fig. 1, loc. 24) and in the northern Oquirrh Mountains (fig. 1, loc. 25); these formations completed the sequence. Lateral continuity of Pennsylvanian formations and marker limestone beds throughout the Oquirrh Mountains was demonstrated by Welsh and James (1961). The Oquirrh Group was logically restricted to the Pennsylvanian sequence, and these mappable Permian units in ascending order were established for the first time in the Oquirrh Mountains: Curry Peak Formation, Freeman Mountain or "Clinker" Sandstone, Kirkman Limestone, Diamond Creek Sandstone, and Park City Formation. Tooker and Roberts in 1960 obtained complete access to Welsh's stratigraphic and structural data for the 1961 guidebook (Welsh and James, 1961), and in 1970 published their interpretation of the Oquirrh stratigraphy.

Bissell (1937) and Baker (1947) recognized the usefulness of fusulinids in dividing the Oquirrh Formation in the central Wasatch Mountains (fig. 1, loc. 28). M. L. Thompson and George Verville identified fusulinid collections for Bissell, and Lloyd Henbest identified collections for Baker. Baker's (1972, 1973, 1976) geologic maps of the Charleston-Nebo allochthon (fig. 1, thrust fault D) make it possible to correlate time-stratigraphic units with units in the type section of the Oquirrh Formation in the Oquirrh Mountains. As accurate time-stratigraphic data become available in a few mountains besides the type area, we will be able to synthesize the Oquirrh depositional history.

Chamberlain and Clark (1973) began an environmental interpretation by describing trace fossils in the deeper water environment of the Pennsylvanian and Permian of the Oquirrh basin, but unfortunately they used Bissell's (1959) inaccurate time-rock units of the southern Oquirrh Mountains (fig. 1, loc. 26) for the South Mountain section.

Geologic mapping in isolated mountain ranges by Croft (1956) in the Onaqui Mountains (fig. 1, loc. 23), Rigby (1958) in the Stansbury Mountains (fig. 1, loc. 22), Costain (1960) in the East Tintic Mountains (fig. 1, loc. 33), and Maurer (1970) in the Cedar Mountains (fig. 1, loc. 20) has contributed data about the Oquirrh. Few lithostratigraphic units have been mapped; reliance on time units based on fusulinids has not stimulated structural interpretations or regional lithologic correlations. J. K. Rigby (oral commun., 1977) now suspects that the described onlap of Pennsylvanian Oquirrh Formation on the Mississippian Manning Canyon Formation in the Stansbury Mountains is structural rather than stratigraphic. Many similar structural problems in western Utah await resolution before the Pennsylvanian stratigraphy can be further resolved.

The Callville platform and Ely shelf (figs. 7–9) have been extensively studied by oil company geologists. Hose and Repenning (1959) described in detail the Ely Limestone in the Confusion Range (fig. 1, loc. 30) of western Utah. Bissell (1962) and Brill (1963) presented reconnaissance overviews of the Pennsylvanian in the Cordilleran region. Roberts and others (1965) compiled the Pennsylvanian and Permian data for northwestern Utah, but the critical stratigraphic information was and still is lacking for this region.

Much of the better stratigraphic information gathered by oil company geologists and students is in guidebooks of the Intermountain Association of Geologists, Utah Geological Association, Four Corners Geological Society, and Rocky Mountain Association of Geologists. The Brigham Young University Geology Studies, the Utah Geological Society, and the Utah Geological and Mineral Survey have published many of the graduate theses.

GEOLOGIC SETTING

The lowermost Carboniferous limestones disconformably overlie calcareous siltstones of the Pilot, Pinyon Peak, and Leatham Formations in the miogeosyncline of central and western Utah. The time-stratigraphic boundary between the Famennian and lower Kinderhookian is placed by conodont studies near the top of the Pilot and Leatham Formations and within the Fitchville Limestone that overlies the siltstone of the Devonian Pinyon Peak Formation. In the Colorado Plateau region in southeastern Utah, the Whitmore Wash Member of the Redwall Limestone rests disconformably either upon the siltstone of the middle Famennian Pinyon Peak Formation or upon the Ouray Limestone. In the central Wasatch Mountains (fig. 1, thrust fault C), the Fitchville Limestone rests unconformably upon the Middle Cambrian Maxfield Limestone near the

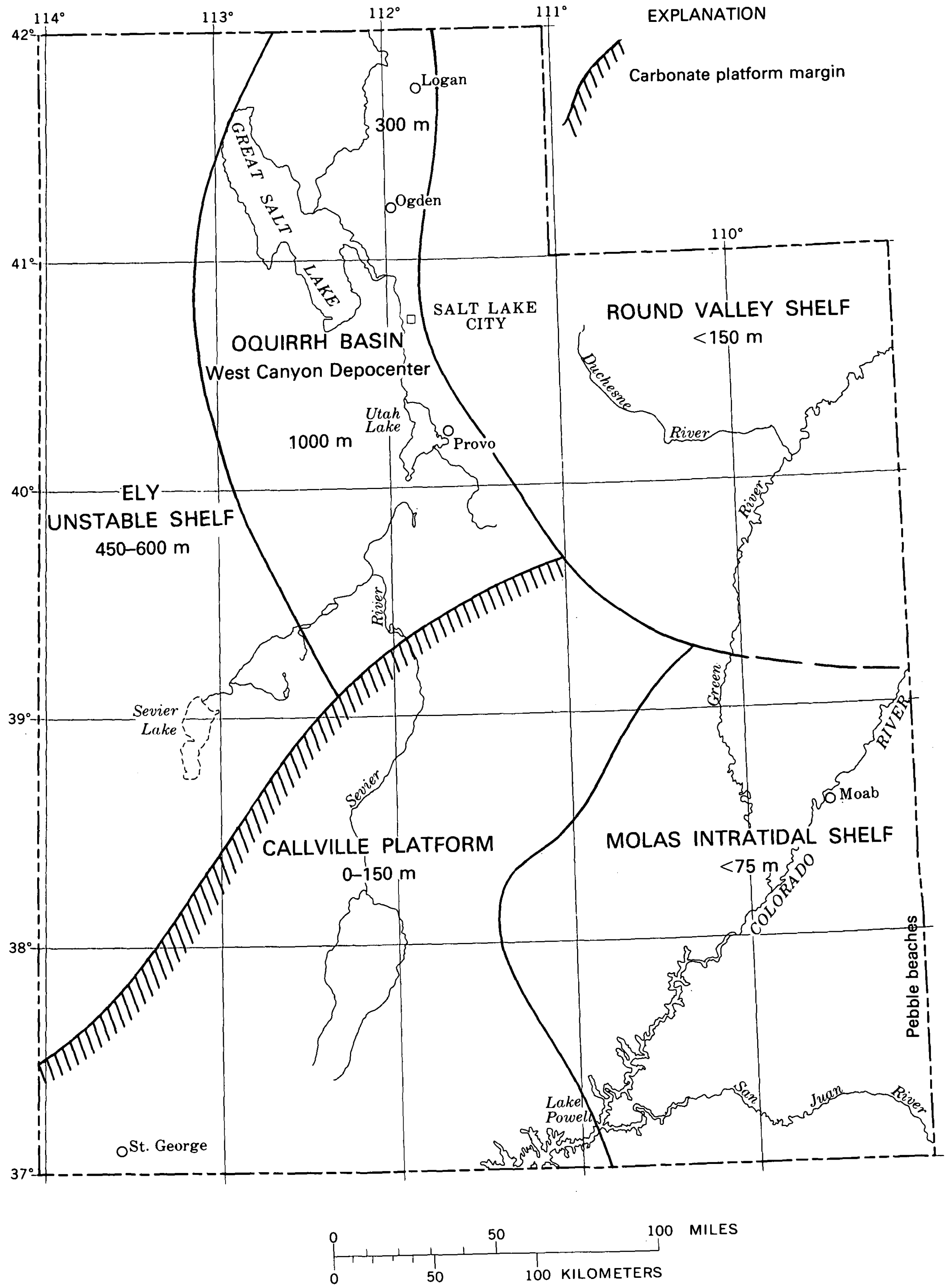


FIGURE 7.—Paleogeographic map of Utah showing approximate present thicknesses in meters of deposits of Morrowan and Atokan time.

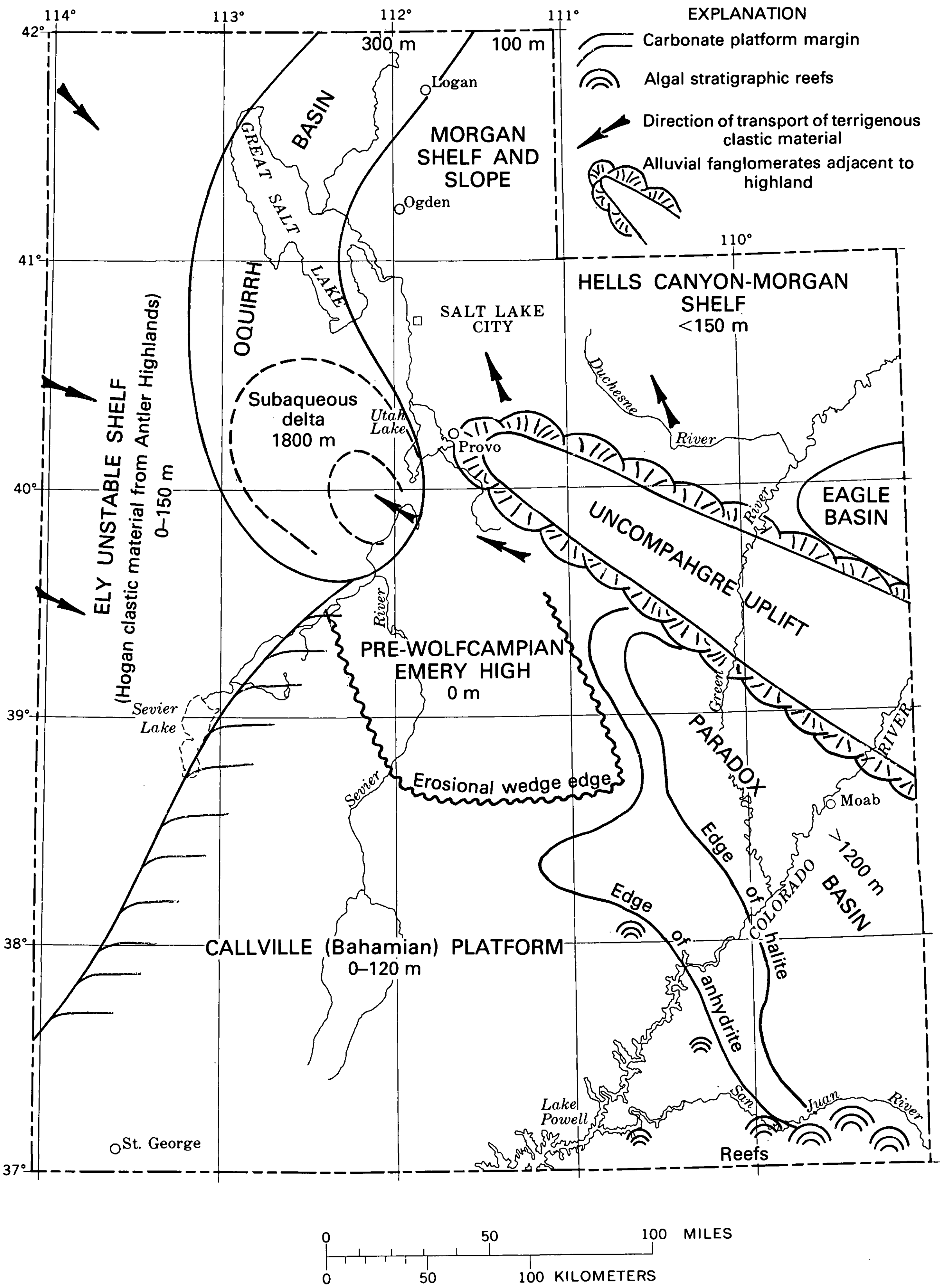


FIGURE 8.—Paleogeographic map of Utah showing approximate present thicknesses in meters of deposits of Des Moinesian time.

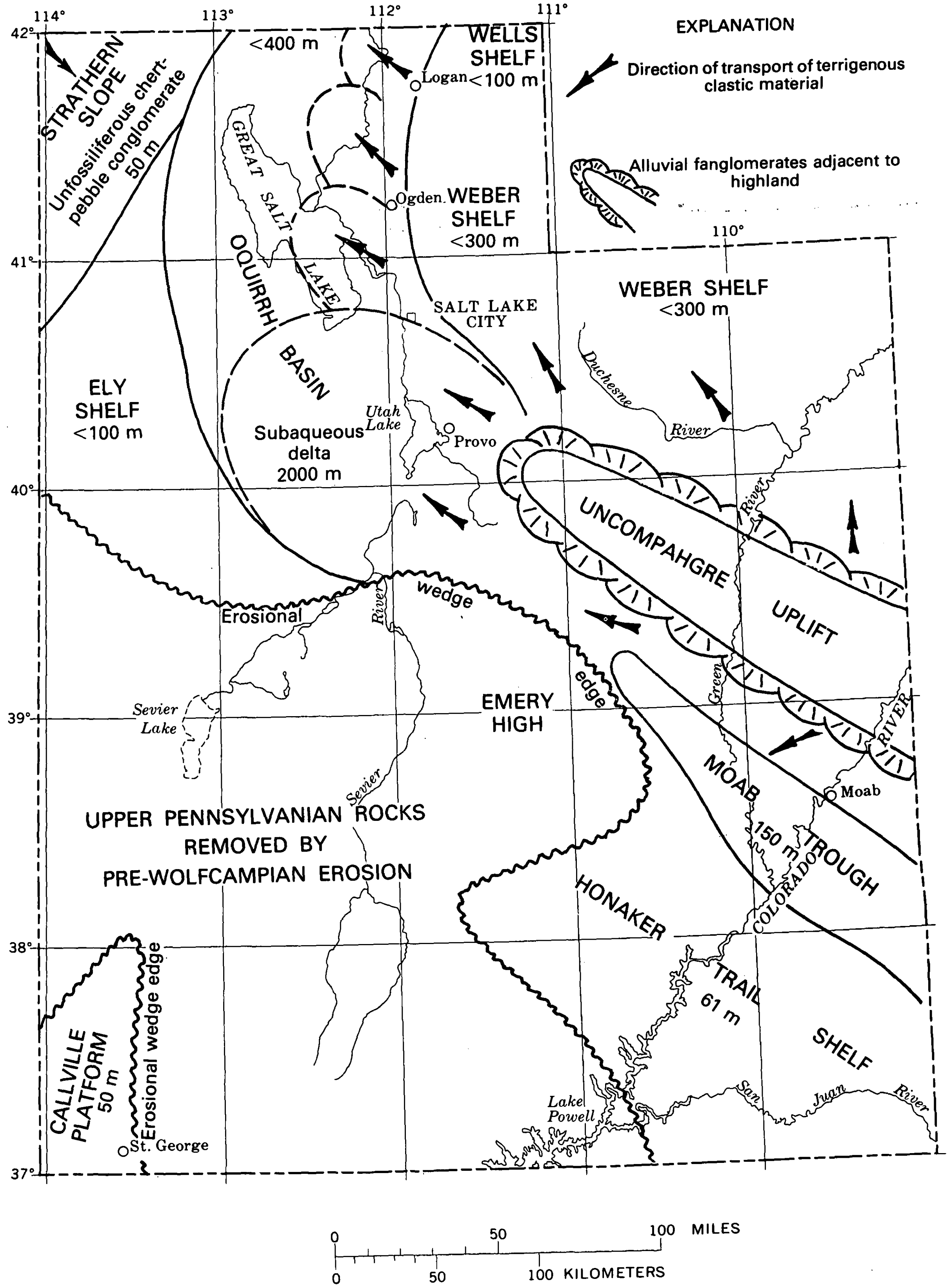


FIGURE 9.—Paleogeographic map of Utah showing approximate present thicknesses in meters of deposits of Missourian and Virgilian time.

site of the Upper Devonian Stansbury uplift; in the Uinta Mountains (fig. 1, loc. 29), the Lodgepole Limestone rests unconformably upon the Cambrian Lodore Sandstone (fig. 3).

Regional depositional breaks within the Carboniferous are (1) a diastem of slow deposition or nondeposition at the top of the Joana, Gardison, Thunder Springs, and Lodgepole Limestones; (2) a lateritic regolith on top of the Horseshoe Mesa Member of the Redwall Limestone in southeastern and southern Utah; (3) an unconformity at the top of the Brazer Dolomite in the Crawford Mountains of northern Utah; (4) a regional disconformity between the Des Moinesian and Missourian series; and (5) an angular unconformity below the Wolfcampian which beveled on a regional scale the Pennsylvanian rocks down to the Mississippian rocks on the Emery high (figs. 8 and 9).

Early Mississippian depositional patterns were affected by the Upper Devonian subaerial highs and restricted basins. This is reflected in the Redwall, Joana, Fitchville, and Lodgepole lithostratigraphic units. Renewed downwarping of local Devonian restricted basins in western and northern Utah produced a regional starved basin in late Osagean and Meramecian time. This downwarping, which began in Late Devonian and continued intermittently through the Chesterian, was east of the central Nevada Antler orogenic belt.

By Late Mississippian, the region of thick carbonate deposition in northwestern Utah of the Deseret and Great Blue Limestones (figs. 5 and 6) became the proto-Oquirrh basin, which extended eastward as a downwarp (known as the Doughnut trough) into the craton. Clastic material was eroded from the Roberts Mountain overthrust sheets of oceanic sediments and lava flows in central Nevada and was redeposited in eastern Nevada and western Utah as flysch. Renewed thrusting or uplift and erosion in the Antler belt during the Des Moinesian provided fine quartzose and chert clastic deposits to the Ely shelf in western Utah (fig. 8).

The Uncompahgre uplift in eastern Utah and southwestern Colorado (figs. 8 and 9) raised the Precambrian basement approximately 6,000 m during Des Moinesian through Early Permian time. The Paradox basin and Oquirrh basin were negative areas at the same time, and both received the clastic material eroded from the Uncompahgre uplift. Other positive elements of the ancestral Rocky Mountains had less influence on Utah depositional patterns but did provide some sand that crossed the carbonate banks. The Weber shelf and the Wells slope contained clastic sediments that were moving toward the Oquirrh basin.

Lower Permian depositional patterns were controlled by renewed uplift of the Uncompahgre in east-central Utah and by influx of chert-pebble conglomerates from the Antler belt in extreme northwestern Utah. Wolfcampian limestones and dolomites unconformably overlie Pennsylvanian carbonate deposits in southern and western Utah. Wolfcampian siltstones unconformably overlie Pennsylvanian sandstones in the Oquirrh basin, but the Permian contact is problematical within the Wells and Weber sandstones of the northeastern shelf. Red beds of the Halgaito Formation disconformably overlie the Pennsylvanian limestones in southeastern Utah.

The Upper Jurassic and Laramide overthrusts of the Sevier belt had a profound effect upon the distribution pattern of the Carboniferous rocks in the eastern Great Basin (fig. 1). The eastward piling of overthrust asymmetrical anticlines onto the Wasatch Hinge Line belt has telescoped lithofacies. Contrastingly, the decollement-type thrusting in the area of denudation associated with gneiss domes in eastern Nevada and western Utah has structurally reduced the thickness of Mississippian sections and scattered Pennsylvanian outcrops in a grandiose chaos of nappes. The one major palinspastic problem is the Oquirrh basin, because the amount of transport on the Charleston-Nebo thrust (fig. 1, D) is unknown. The allochthon is restricted to rocks of the Oquirrh basin and is separated from the thin eastern and southern Carboniferous sections by the Leamington tear fault (fig. 1, E) and the Charleston-Nebo thrust (fig. 1, D). The Leamington fault appears to follow the northeasterly ancestral break between the Redwall platform and the Doughnut trough (fig. 6).

LITHOSTRATIGRAPHY

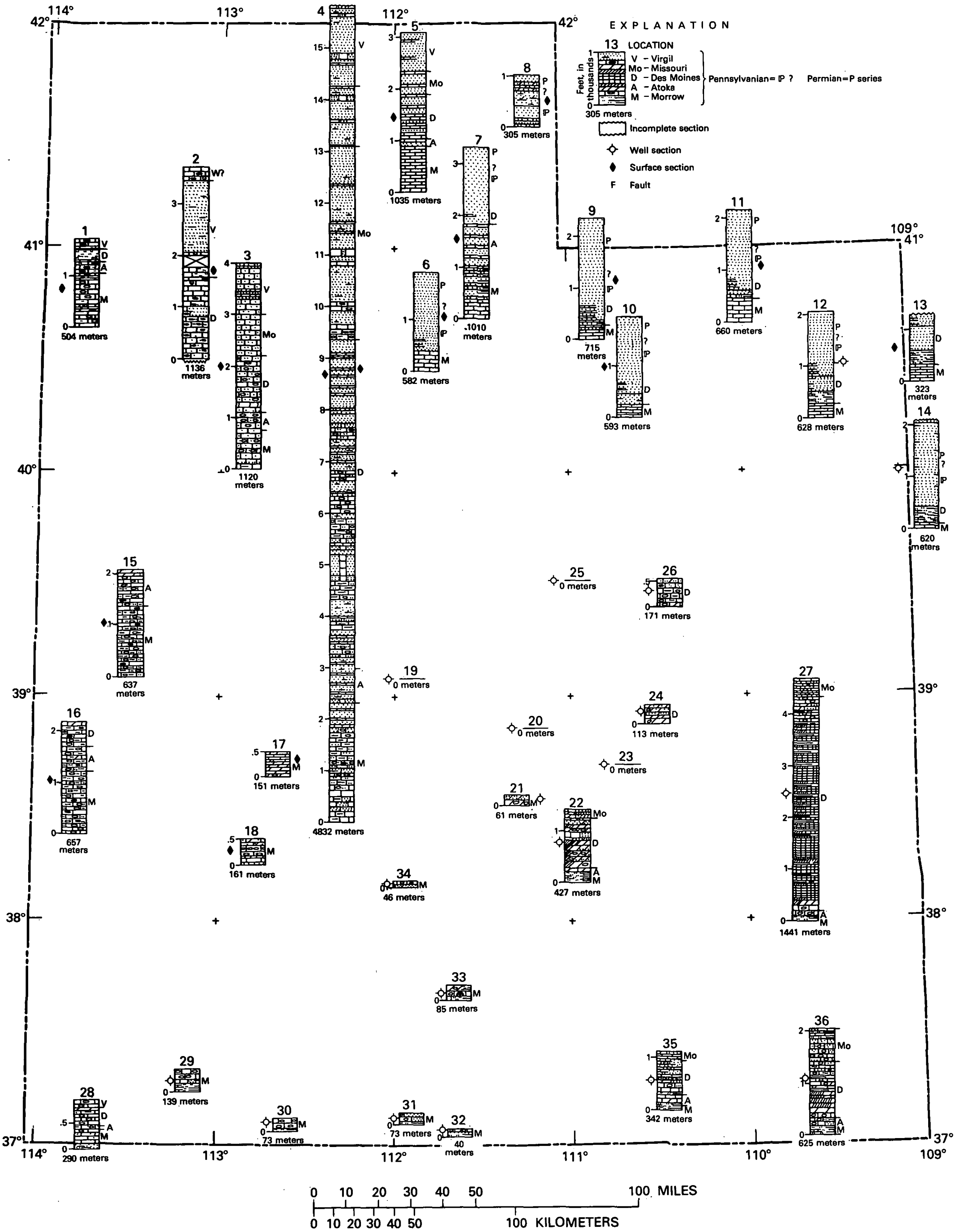
The Utah Carboniferous lithostratigraphic terminology is shown on the correlation chart in figure 3. Rock units and biostratigraphic zones (fig. 2) are shown in relationship to different biofacies and lithofacies. Regional stratigraphic sections of the Mississippian are illustrated in figure 4 and those of the Pennsylvanian, in figure 10. The Mississippian sections are divided into formational units, whereas the Pennsylvanian sections are divided into approximate series units.

MISSISSIPPIAN LITHOSTRATIGRAPHY

The Mississippian depositional history may be summarized as a succession of prograding carbonate banks and adjacent restricted reducing basins (figs. 5 and 6). The earliest Mississippian basins were a continuation of the restricted siltstone deposition in the Devonian Pilot, Pinyon Peak, and Leatham Formations (fig. 3). Carbonate deposition expanded across Utah by late Kinderhookian time, resulting in the time-equivalent limestone units of the Joana in the west, the Fitchville in the central, the Whitmore Wash in the southern, and the Lodgepole in the northern regions (fig. 3). The Whitmore Wash oolitic and algal limestones were deposited on a Bahamian-type platform, whereas the other time-equivalent units were deposited on open-marine shelves. The darker carbonate, gray chert, and widespread stromatolitic "Curley" bed of the Fitchville Limestone indicate deposition in a deeper, lower energy environment than the oolites and oncoliths of the Whitmore Wash Limestone. These differences in the limestones of the late Kinderhookian indicate that the Redwall carbonate bank was already differentiated from the basin to the northwest (fig. 5).

The Thunder Springs Member of the Redwall, Gardison, and upper parts of the Joana and Lodgepole Limestones are lithostratigraphic equivalents (fig. 3). All units are characterized by dark-gray thin-bedded limestones and abundantly bedded and nodular dark chert. These clinoform units were deposited in deeper water than the earlier Mississippian limestones. Thicknesses for this interval range from 15 m at Desert Creek (fig. 4, sec. 31) in the Four Corners area to 134 m at Elephant Canyon (fig. 4, sec. 18) in the Star Range. On parts of this slope, Waulsortian mounds accumulated within the Thunder Springs and the Joana. Where these encrinite mounds were dolomitized in the interior Redwall bank, they are porous petroleum reservoirs in the subsurface at South Last Chance, Ferron, and Big Flat fields (fig. 12, locs. 19, 17, 21).

At the end of the deposition of the Thunder Springs cherty limestones and equivalent units, subsidence in northwestern Utah accelerated, resulting in the sharp differentiation of the starved basin from the Redwall carbonate bank in southeastern Utah. From middle Osagean to early Meramecian, the carbonate bank prograded northwestward over this starved basin (fig. 5). The Mooney Falls and Horseshoe Mesa Limestones of the interior carbonate bank of the Redwall Limestone are equivalent to the prograded slope deposits of the Bullion Canyon and Yellowpine Limestone Members of the Monte Cristo Limestone in extreme southwestern Utah and the Deseret Limestone of central and northern Utah (fig. 3). The original edge of the carbonate bank is defined by fine clastic quartz in the Mooney Falls Member and lower part of the Deseret Limestone. These quartzose clastic deposits directly overlie the phosphatic shales of the starved basin. The phosphatic shales crop out in the basal Deseret Limestone at the Gilson, Tintic, Oquirrh, Wasatch, Pavant, and Wah Wah Mountains (fig. 1). The quartzose clastic deposits are present in the surface sections at Bradshaw Mountain (fig. 4, sec. 19) in the Mineral Range, at Cove Fort (fig. 4, sec. 20) in the Pavant Range, and in the subsurface wells near Meadow, Scipio Lake (fig. 4, sec. 21), North Springs, and Miller Creek (fig. 4, sec. 14). Clastic deposits and gamma-ray logs are the basis for defining the original edge of the starved basin (fig. 5). Biostratigraphic studies by Gutschick (1976) have confirmed the synchronous start of the starved basin in central Utah. Conodont studies by Sandberg and Gutschick (1977) show that the phosphatic shales of the basal parts of the Deseret, Chainman, and Little Flat are the time-stratigraphic equivalents of the late Redwall carbonate bank. The phosphorite beds of the starved-basin facies of the Deseret are overwhelmed by increased deposition of quartzose silt. The surface section at Cove Fort (fig. 4, sec. 20), the Scipio Lake (fig. 4, sec. 21) subsurface section, and the Shell Sunset Canyon subsurface section near Meadow in the Pavant Range (fig. 1, loc. 41) have a predominance of silt over carbonate material in the Deseret Limestone. The similarity of these three sections contrasts with the all-carbonate facies at the Elephant Canyon section (fig. 4, sec. 18) in the Star Range. The subsurface sections at North Springs, Mounds (fig. 4, sec. 15), and Miller Creek (fig. 4, sec. 14) south of Price are also in the basinal siltstone facies, whereas the subsurface section at Hiawatha (fig. 4, sec. 13) is in the dolomitized interior carbonate bank. The surface sections in the allochthon of the Charleston-Nebo thrust (fig. 1, thrust D) contain predominantly limestone above the phosphatic shales, which suggests that the siltstone of the Deseret was deposited parallel to the carbonate bank near the original basin margin by bypassing quartz from the craton to the northeast (fig. 5). No evidence exists for any quartzose source on the Redwall platform to the southeast. The Horseshoe Mesa Limestone, the uppermost member of the Redwall Limestone, progrades north-


EXPLANATION
13 LOCATION
Feet, in thousands
V - Virgil
Mo - Missouri
D - Des Moines
A - Atoka
M - Morrow
Pennsylvanian= IP ? Permian=P series
305 meters
Incomplete section
Well section
Surface section
F Fault
114°
113°
112°
111°
110°
109°
42°
41°
40°
39°
38°
37°
504 meters
1136 meters
1120 meters
4832 meters
1035 meters
582 meters
1010 meters
305 meters
715 meters
593 meters
660 meters
628 meters
323 meters
620 meters
637 meters
657 meters
151 meters
161 meters
0 meters
171 meters
113 meters
61 meters
427 meters
1441 meters
46 meters
85 meters
290 meters
139 meters
73 meters
40 meters
342 meters
625 meters
0 10 20 30 40 50 100 MILES
0 10 20 30 40 50 100 KILOMETERS

westward over the Deseret siltstone facies in the Price area and Pavant Range (fig. 1, loc. 41) sections.

In the interior of the Redwall carbonate bank, reflux dolomitization is common in the subsurface sections (figs. 4 and 5). This dolomitization is also present in outcrop in the Brazer Dolomite of the Crawford Mountains (fig. 4, sec. 8) in northern Utah and in the Redwall Limestone at Frenchman Mountain in southern Nevada. Superposition of imbricate thrusts in southern Nevada has juxtaposed the clinoform limestones of the Monte Cristo against the interior platform dolomite of the Redwall. In southwestern Utah, the Redwall or Monte Cristo Limestones reach their maximum thicknesses of 383 m in the Beaver Dam Mountains (fig. 4, sec. 25) and 409 m at Elephant Canyon (fig. 4, sec. 18) in the Star Range. The Yellowpine, Bullion Canyon, Anchor, and Dawn members of the Monte Cristo Limestone are recognized in these prograded carbonate deposits. From the High Plateau province to the Four Corners region, the Redwall Limestone thins approximately from 300 to 90 m. Parker and Roberts (1966), using the top of the Thunder Springs cherty limestone as a datum, demonstrated that there is both erosional wedging out and depositional thinning of the individual limestone members of the Redwall in a southeasterly direction. At Rockwood quarry, the nearest surface section in LaPlata County, Colorado, the Redwall (Leadville) Limestone is only 30 m thick (Baars and Knight, 1957). All the Mississippian rocks of the Redwall Limestone in southeastern Utah are on the carbonate bank and are oolitic, pelletal, birdseye micritic, stromatolitic, and fossiliferous. Dolomitization is variable and crosscuts lithologies, but it is spatially restricted to the interior of the carbonate bank (fig. 5).

In the Confusion Range (fig. 1, loc. 30) synclinorium of western Utah, there are well-exposed, unfaulted sections of the Carboniferous in the Needles Range (fig. 4, sec. 16), Burbank Hills (fig. 1, loc. 36), and Confusion Range (fig. 4, sec. 17). The Mississippian-Devonian boundary here is determined on the basis of conodont zones to be within the siltstones of the upper part of the Pilot Formation. For mapping, the base of the Joana Limestone is used as the base of the Mississippian. The Joana Limestone is approximately equivalent to the Lodgepole, Fitchville, and Gardison Limestones and the lower half of the Redwall and Monte Cristo Limestones (fig. 3). Most stratigraphers have traditionally placed a

FIGURE 10.—Numbered stratigraphic sections of the Pennsylvanian in Utah. Series subdivisions and generalized lithologies are shown. Where no section number is supplied, the stratigraphy is a composite of information from more than one section. Stratigraphic sections 1 and 15–36 are based on original unpublished data of Welsh; the other sections are modified from published sources as indicated.

1. Rishel Peak, T. 1 N., R. 18 W.
2. Lakeside Mountains, T. 2 N., R. 11 W. (modified from Doelling, 1964)
3. Cedar Mountains, T. 4 S., R. 10 W. (modified from Maurer, 1970)
4. Oquirrh Mountains, T. 4 S., Rs. 3–5 W. (modified from Welsh and James, 1961)
5. Wellsville Mountain, T. 10 N., R. 1 W. (modified from Williams, 1948)
6. Mt. Aire, T. 1 S., R. 2 E. (modified from Crittenden, 1959)
7. Weber Canyon, T. 4 N., R. 3 E. (modified from Bissell and Childs, 1958)
8. Crawford Mountains, T. 11 N., R. 8 E. (modified from Sando and others, 1959)
9. Deadman Mountain, T. 1 N., R. 11 E. (modified from Bissell and Childs, 1958)
10. Duchesne River, sec. 14, T. 1 N., R. 8 W. (modified from Sadlick, 1957)
11. Sols Canyon, sec. 11, T. 2 N., R. 18 E. (modified from Sadlick, 1957)
12. Ute Federal, sec. 12, T. 4 S., R. 22 E. (modified from Sadlick, 1957)
13. Whirlpool Canyon, sec. 27, T. 3 S., R. 25 E. (modified from Sadlick, 1957)
14. Watson, sec. 34, T. 9 S., R. 25 E. (modified from Sadlick, 1957)
15. Skunk Springs, T. 17 S., R. 16 W.
16. Needles Range, T. 25 S., R. 19 W.
17. Cove Fort, T. 24 S., R. 6 W.
18. Bradshaw Mountain, T. 29 S., R. 10 W.
19. Scipio Lake, sec. 14, T. 20 S., R. 2 W.
20. Emery, sec. 34, T. 22 S., R. 5 W.
21. South Last Chance, sec. 18, T. 26 S., R. 7 E.
22. Cainville, sec. 29, T. 28 S., R. 8 E.
23. San Rafael, sec. 28, T. 24 S., R. 10 E.
24. Sinbad, sec. 5, T. 22 S., R. 12 E.
25. Hiawatha, sec. 13, T. 15 S., R. 7 E.
26. Grassy Trail, sec. 1, T. 16 S., R. 12 E.
27. The Knoll, sec. 11, T. 26 S., R. 19 E.
28. Beaver Dam Mountains, T. 42 S., R. 18 W.
29. LaVerkin, sec. 30, T. 40 S., R. 12 W.
30. Kanab, sec. 2, T. 43 S., R. 8 W.
31. Kaibab Gulch, sec. 34, T. 42 S., R. 2 W.
32. Judd Hollow, sec. 19, T. 43 S., R. 2 E.
33. Upper Valley, sec. 12, T. 36 S., R. 1 E.
34. Antimony Canyon, sec. 30, T. 30 S., R. 2 W.
35. Nokai, sec. 27, T. 40 S., R. 12 E.
36. Lime Ridge, sec. 28, T. 40 S., R. 20 E.

regional unconformity at the top of the Joana Limestone in western Utah and eastern Nevada. Sadlick (1965) followed this interpretation but was first to recognize a fondothem facies in the overlying Chainman Formation. Current interpretation (Gutschick, 1976) is that the lowermost part of the Chainman Formation represents the starved-basin facies and that its phosphatic shales are equivalent to the lower part of the Deseret Limestone (fig. 3). Most of the terrigenous clastic deposits of the Chainman Formation are turbidite shales and silts derived from the Antler Highland about 161 km farther west. Sadlick (1965) divided the Chainman Formation into six lithostratigraphic members. In ascending order, they are: the Needles Siltstone, Skunk Springs Limestone, Camp Canyon, Donner, Willow Gap Limestone, and Jensen. The Donner has not yet been recognized in Utah. The Needles Siltstone and Skunk Springs Limestone Members and the shale and siltstone in the lower part of the Camp Canyon Member represent the basinal infillings. The phosphatic shale in the Needles Siltstone Member above the Joana Limestone represents the time equivalent of the Osagean-lower Meramecian carbonate bank farther east (Rose, 1976b). The shale in the lower part of the Camp Canyon Member in the Confusion Range is a restricted basinal facies, which is equivalent to, and is covered by, the upper Meramecian-Chesterian carbonate bank of the Great Blue and Ochre Mountain Limestones (fig. 6). The Woodman Formation (fig. 3) of the Gold Hill district (fig. 1, loc. 19) is approximately equivalent to the Needles Siltstone Member and the lower part of the Camp Canyon Member of the Chainman Formation.

The upper part of the Camp Canyon Member and the Willow Gap Limestone Member of the Chainman Formation are approximately equivalent to the Ochre Mountain or Great Blue Limestones (fig. 3). In the Confusion Range synclinorium, the facies on the east limb are markedly different from those on the west limb. At Skunk Springs (fig. 4, sec. 17) and in the Burbank Hills (fig. 1, loc. 36), coarse clastic limestones of the Camp Canyon and Willow Gap Limestone Members represent the westernmost exposures of the Chesterian carbonate bank. In the Needles Range (fig. 4, sec. 16) and on the west side of the Confusion Range, the Chainman Formation is entirely within the basinal facies. The limestones of the Chainman Formation are black calcilutites, whereas the Great Blue carbonate bank consists of light-gray calcarenites.

In northwestern Utah, a decollement in the Chainman Formation has complicated the stratigraphic sequence of the Mississippian rocks. Thicknesses of lithostratigraphic units are variable because younger units have been thrust over older units. Sadlick (1965) reported that the lower part of the Camp Canyon Member of the Chainman rests unconformably upon either the Joana Limestone or the Pilot Formation in the Silver Island Mountains (fig. 4, sec. 1). Earlier, Sadlick and Schaeffer (1959) had interpreted this observation as evidence for their Wendover phase of the Antler orogeny. The present writers, recognizing the structural complications in northwestern Utah, suggest that the Mississippian stratigraphy needs to be reexamined. At this time, no reliable sections have been published for Mississippian deposits in northwestern Utah or northeastern Nevada.

In northern Utah, the Tintic nomenclature of Morris and Lovering (1961) is applicable to all the outcrops west of Logan (fig. 1). The Lodgepole Limestone of the Logan area is equivalent to the Fitchville and Gardison Limestones of the East Tintic Mountains (fig. 1, loc. 33). The Deseret Limestone and Humbug Sandstone are present in both the allochthonous and autochthonous sequences of the Wasatch, Uinta, and Basin and Range Mountains (fig. 1). The Great Blue Limestone and Manning Canyon Formation terminology has been extended into the Wellsville Mountains (fig. 1, loc. 16) west of Logan and into the Deep Creek Mountains of southeastern Idaho. To the east in the Uinta and Wasatch Mountains, the Upper Mississippian rocks of late Meramecian and Chesterian age are better termed the Doughnut Formation rather than the Great Blue or Manning Canyon. The Doughnut Formation includes the rocks of late Meramecian through Chesterian age that are reduced in stratigraphic thickness and occupy the stratigraphic position between the Humbug Sandstone and the Pennsylvanian Round Valley Limestone (fig. 3). This abbreviated Upper Mississippian section extends eastward in the outcrop to Whiterocks Canyon (fig. 4, sec. 11) along the south flank of the Uinta Mountains and into the subsurface at Mounds (fig. 4, sec. 15) in the northern San Rafael area near Price. A similar section of Upper Mississippian rocks is present in southwestern Utah in the southern Wah Wah Mountains (fig. 1, loc. 38) and northern Beaver Dam Mountains (fig. 1, loc. 44). Both these sections are allochthonous and are equivalent to the Battleship Wash Limestone and Indian Springs Formation in southern Nevada (fig. 3).

In Old Laketown Canyon (fig. 4, sec. 7) at the southeast corner of Bear Lake in northern Utah, Sando and others (1976) have described an Upper Mississippian section that is similar to the Skunk Springs (fig. 4, sec. 17) section in the Confusion Range in western Utah. The section above the Lodgepole Limestone includes the Little Flat Formation and the Monroe Canyon (Great Blue) Limestone. The lower phosphatic shales of the Little Flat Formation are equivalent to the starved basin facies of the lower part of the Deseret Limestone, and the upper siltstones of the Little Flat are equivalent to the Humbug Sandstone. The Monroe Canyon Limestone has prograded over the siltstone of the Little Flat Formation as the Great Blue-Ochre Mountain Limestones have prograded over the Chainman or Woodman Formations in western Utah.

Shale of the Manning Canyon Formation was deposited in deltaic, estuarine, and near-shore marine environments. The formation extends from the East Tintic Mountains (fig. 1, loc. 33) northward into southern Idaho. In contrast to the Diamond Peak and Chainman Formations that are flysch that filled the Antler Foreland basin west of the Great Blue carbonate bank, the Manning Canyon Formation consists of clastic deposits that prograded westward through the Doughnut trough across the interior of the Chesterian carbonate bank (fig. 6). The deposition of these clastic sediments on the Upper Mississippian carbonate bank in Utah caused a swamp to form near sea level. Shale deposited in temporary swamp environments had earlier encroached upon the Great Blue carbonate bank during deposition of the Long Trail, Chiulos, and Herat Shales (fig. 3). The Manning Canyon Formation and the upper part of the Chainman Formation eventually buried the carbonate bank in shale and sandstone. Contemporaneously during the Late Mississippian, a lateritic regolith formed on the exposed Redwall subaerial platform to the southeast. The present edge of the erosional wedge of the Upper Mississippian rocks is shown in figure 6.

PENNSYLVANIAN LITHOSTRATIGRAPHY

Key stratigraphic columns of surface and subsurface sections of the Pennsylvanian are illustrated on figure 10 and the approximate series time units are designated. Formational names of rock units are shown in the correlation chart (fig. 3). Figures 7–9 are paleogeographic maps of Utah in Early, Middle, and Late Pennsylvanian time.

Morrowan and Atokan (fig. 7) deposits are well represented throughout Utah; the thickest deposit is 1,000 m of calcilutite in the Oquirrh basin. On the unstable Ely shelf, 350 to 425 m of cyclical calcarenite, calcisiltite, and calcilutite was deposited. Less than 150 m of pelletal and birdseye calcilutite, oolitic calcarenites, and biostromal calcirudite was deposited on the Bahamian-type Callville platform. Coral biostromes are common rocks deposited in all three environments.

The West Canyon Limestone in the Oquirrh basin was deposited in deeper water than deposits on the Ely shelf or Callville platform, but the environment was still in the photic zone. This lower limestone of the Oquirrh Group has been recognized north to the Utah-Idaho border in Cache and Box Elder Counties, where the Oquirrh and Sublette basins merge. No evidence is preserved to indicate that the Oquirrh basin of Utah and the Bird Spring basin of southern Nevada were connected along the Wasatch Hinge Line; instead, the connection between these basins was farther west. In both basins, marine carbonate deposition was continuous from Morrowan through Atokan to Des Moinesian time.

Southeastern Utah was invaded by Early Pennsylvanian seas which reworked the lateritic regolith on the Redwall carbonate platform into the Molas Formation. Chert-pebble conglomerates, derived from Paleozoic rocks stripped during the initial uplift of the Uncompahgre, are common in the lower part of the Molas in southwestern Colorado, but red siltstones are more characteristic in southeastern Utah. Reduction in the marine environments produced green shales and siltstones. Overlying the time-transgressive clastic units of the Molas Formation is a predominantly carbonate section of Atokan and earliest Des Moinesian age; this section is generally placed in the Pinkerton Trail Formation, although a disconformity probably exists between the Atokan and Des Moinesian in southeastern Utah.

In northern Utah on the Round Valley shelf (fig. 7), which overlies the Mississippian Doughnut trough (fig. 6), sedimentation was continuous or only slightly interrupted from Chesterian to Morrowan time. The Round Valley Limestone of Morrowan age represents a marine invasion over the deltaic and estuarine environments of the Doughnut Formation. Because the Upper Mississippian rocks in northern Utah contained only a few lateritic beds, the Round Valley does not contain a basal red-bed unit comparable to that in the Molas Formation. The Round Valley Limestone is the shelf equivalent of the West Canyon Limestone of the Oquirrh basin.

By Atokan time, the seas had submerged the entire State of Utah, and carbonate deposition was dominant. The only clastic material being deposited was interbedded with limestone in southeastern

Utah near the Uncompahgre (fig. 8). Atokan rocks are not reported to be in the Round Valley Limestone or Hells Canyon Formation in the Uinta Mountains; however, Bissell and Childs (1958) reported that *Fusulinella* is present 250 m above the base of the type section of the Weber Sandstone northeast of Morgan (fig. 10, sec. 7). The absence of reports of Atokan rocks in the Uinta Mountains may be the result of nondeposition, pre-Des Moinesian erosion, or a lack of fusulinids in the rocks. Probably some rocks in the Hells Canyon and Morgan Formations are Atokan in age (fig. 3).

The Des Moinesian depositional patterns were strongly affected by the eroding of the Uncompahgre Mountains and the sinking of the adjacent Oquirrh, Paradox, and Eagle basins (fig. 8). Erosion of the Precambrian crystalline rocks resulted in thick arkosic alluvial fans that intertongued with sabka evaporites and euxinic shales. Northwest of the Uncompahgre, the Oquirrh basin was a major depocenter for fine arkosic sandstones. Submarine sandstones episodically prograded over the carbonates of the basin. North of the Uncompahgre, the sands were distributed as a thick uniform blanket on the Hells Canyon-Morgan shelf and then passed down the Morgan slope into the Oquirrh basin. The Oquirrh basin received 1,900 m of Des Moinesian strata in a sandstone-to-limestone ratio of 1:1. Actually, detrital quartz is present in the limestone as well as in the sandstone because many of the limestones are calcisiltites. This influx of sand definitely had its source in the Uncompahgre uplift.

The Callville platform remained a broad, stable, Bahamian-type environment. Biostromes flourished along its western and southeastern edges. Algal stratigraphic reefs were a barrier across the only access into the Paradox basin during salt deposition at Aneth in southeastern Utah (fig. 8). Smaller algal patch reefs are in limestones equivalent to the evaporites in the outcrops of the Hermosa Group in the San Juan River Canyon (fig. 1, loc. 45). The western margin of the Paradox basin was intermittently a subaerial tidal flat, and the Paradox salt units are represented by diastems in the limestone sequence. Figure 8 shows the inner depositional edge of halite and the outer depositional edge of anhydrite. Primary dolomite was precipitated contemporaneously with gypsum; however, extensive secondary dolomitization of the Callville Limestone around the Emery high is related to reflux replacement below the Wolfcampian unconformity. Black organic dolomitic shales interbedded with the halite beds of the Paradox Formation are the principal hydrocarbon source rocks. Anhydrite beds of the Eagle basin had a similar depositional history north of the Uncompahgre. Most of the sabka evaporites are in Colorado. The Paradox Formation, containing a maximum of 1,200 m of evaporites, represented a very short period of the early Des Moinesian. Deposition of these evaporites was followed by a sudden extensive marine invasion which produced the widespread Desert Creek and Ismay Limestones which have equivalents in all areas of Utah, except where removed by pre-Wolfcampian erosion.

The Morgan shelf of the Uinta Mountains and northern Utah (fig. 8) received clastic material throughout the Des Moinesian. The Hells Canyon Formation on the south flank of the Uintas is thin-bedded red-gray-purple shale, siltstone, sandstone, and fossiliferous limestone containing early Des Moinesian fusulinids. The overlying Morgan Formation is predominantly reddish-brown siltstones and sandstones and thin limestone. Estuarine environments are common in both formations. The red beds and clastic deposits of the Morgan are approximately equivalent to the evaporites of the Paradox Formation. The reddish Morgan is overlain by and is laterally equivalent to the yellowish-gray rocks in the lower part of the Weber Sandstone. These yellowish-gray rocks are overlain by gray fossiliferous limestone which is also in the lower part of the Weber Sandstone and is equivalent to the post-Paradox Desert Creek and Ismay Limesones and unnamed limestones (fig. 3).

The Ely shelf in western Utah received increasing quantities of very fine quartz and chert silt from the Antler belt. Calcisiltites of the Hogan Member of the Ely Limestone (Robinson, 1961) are as much as 70 percent silica, as fine clastic quartz and chert and spicules. Chert-pebble conglomerates are present locally in the Des Moinesian sections 161 km farther west in central Nevada. The Des Moinesian lithologies are cyclical, like those of the Morrowan and Atokan, but calcarenites make up a much smaller percentage of the rock column. Calcisiltites also characterize the Des Moinesian rocks of the Bird Spring basin in southeastern Nevada.

A disconformity exists between the Middle and Upper Pennsylvanian deposits in all the marine sequences in Utah, but the boundary is undefined in the Weber Sandstone and in the arkoses adjacent to the Uncompahgre uplift.

Missourian and Virgilian time was a period of accelerated uplift of the Uncompahgre (fig. 9). Continental sedimentation on alluvial fans was continuous in the Late Pennsylvanian, and more than 1,500 m of arkose was deposited adjacent to the south flank of the Uncompahgre Mountains. Much of this arkose was reworked by marine currents and bypassed the Weber shelf to be deposited in the Oquirrh basin. The Jordan and Commercial Limestones at the base of the Bingham Mine Formation are the oldest Missourian rocks in the Oquirrh basin. The Jordan Limestone rests unconformably upon the Des Moinesian Butterfield Peaks Formation (fig. 3). Above the Commercial Limestone, more than 1,200 m of arkosic sandstone is in the 2,000-m-thick Bingham Mine Formation (fig. 10, sec. 4). Even though the ratio of clastic material to limestone is 4:1, subsidence exceeded the rapid deposition in the Oquirrh basin. Fine-grained laminated sandstone containing trace fossils on bedding planes suggests low-energy below-wave-base deposition. In contrast, sandstones in the Weber are tabular and crossbedded, indicating a high-energy shelf environment. At the base of the Wolfcampian Curry Peak Formation, a polymictic carbonate, chert-pebble conglomerate containing reworked Pennsylvanian silicified fossils marks the Lower Permian boundary in the Oquirrh Mountains (fig. 3). This boundary is not defined in the Weber Sandstone.

Upper Pennsylvanian limestones and clastic sedimentary rocks in southeastern Utah are named the Honaker Trail Formation (fig. 3). In the type section at Honaker Trail, no Virgilian rocks are present, and red beds of the Permian Halgaito Formation unconformably overlie Missourian limestones. In the Paradox basin, Missourian rocks rest unconformably upon Des Moinesian limestones that have been more deeply eroded toward the west margin of the Paradox basin where the Honaker Trail Formation rests unconformably upon the Desert Creek Limestone. Virgilian rocks are restricted to the Moab trough (fig. 9). Erosion on the pre-Wolfcampian unconformity has removed much of the Upper Pennsylvanian sequence in southwestern and south-central Utah. Now in the Paradox basin, the Wolfcampian Elephant Canyon Limestone to the east and the Pakoon Dolomite to the west unconformably overlie, respectively, the beveled Pennsylvanian rocks of the Hermosa Group and Callville Limestone. Near St. George (fig. 10, sec. 28), a small area contains Virgilian limestones in the upper part of the Callville; no Missourian rocks have been reported. Similar calcarenites and calcilutites of the Virgilian series are present on the Callville platform in southern Nevada and on the Ely shelf in northeastern Nevada and northwestern Utah. At Frenchman Mountain near Las Vegas, clinoform Virgilian limestones are transitional between the Callville platform and the Bird Spring basin. The Pakoon Dolomite overlies unconformably the Pennsylvanian Callville Limestone everywhere in southwestern Utah, except at Scipio Lake where the Kaibab Formation rests unconformably upon the Mississippian in a subsurface section (fig. 10, sec. 19).

The Weber Sandstone, which is 700 m thick at its type locality in Weber Canyon (fig. 10, sec. 7) northeast of Morgan (Bissell and Childs, 1958), includes both Upper Pennsylvanian and Lower Permian sandstone (fig. 3). The highest Des Moinesian fusulinids are present approximately 300 m above the base, so the upper 400 m may be either Late Pennsylvanian or Permian. Bissell and Childs (1958) also indicated that the Weber Sandstone is 310 m thick along the Duchesne River (fig. 10, sec. 10) on the south flank of the Uinta Mountains. Poorly preserved *Triticites* are reported to be 90 m above the base of the Weber Sandstone in the Duchesne River section (Bissell and Childs, 1958). An accurate age assignment was impossible because of the poor preservation. *Schwagerina* was also collected in the same study in the upper 30 m of the Weber Sandstone at the Morris Ranch section northeast of Vernal (fig. 1). Bissell estimates that 100 to 200 m of the lower Weber Sandstone in northeastern Utah is Pennsylvanian and that the remaining part is Permian.

In west-central Utah, Wolfcampian Riepe Springs Limestone containing a thin basal chert-pebble conglomerate overlies unconformably the Atokan or Des Moinesian Ely Limestone. In northwestern Utah, Virgilian limestones rest unconformably upon the Des Moinesian. Chert-pebble conglomerates of the Virgilian (?)-Wolfcampian Strathern Formation overlie fusulinid-bearing Virgilian limestones. Most of these conglomerates are Wolfcampian; however, Schaeffer (1960) included those in the Silver Island Range in the Virgilian. These conglomerates are well exposed at Rishel Peak (fig. 10, sec. 1) north of Wendover and in the Spruce Mountain area of northeastern Nevada. Detailed descriptions of the Pennsylvanian rocks of the Gold Hill district have not been published, but the district does contain Morrowan, Atokan, Des Moinesian, and Virgilian limestones that are not of the Oquirrh facies. The Wolfcampian Ferguson Mountain Formation, not the Strathern Formation, overlies the Virgilian limestones at Gold Hill.

Late Pennsylvanian fusulinids have been reported in isolated ranges in northern Utah. Maurer (1970) reported a thin, 30- to 120-m Missourian section in the Cedar Mountains (fig. 10, sec. 3); Rigby (1958) reported 2,000 m of Missourian in the Stansbury Mountains (fig. 1, loc. 22); and Williams (1948) reported 900 m of Missourian and Virgilian in the Wellsville Mountains (fig. 1, loc. 16). Reported fusulinid-bearing strata of Virgilian age are more widespread than those of Missourian age in the Basin and Range province.

The lithostratigraphy of Upper Pennsylvanian rocks in northern Utah has not been sufficiently investigated to synthesize a meaningful paleogeography for the Oquirrh basin, the Wells slope, or the Weber shelf. Stratigraphy of the Pennsylvanian rocks in the northwest quarter of Utah is described sufficiently for general characterization in only two ranges: the Silver Island Range (fig. 10, sec. 1) and the Cedar Mountains (fig. 10, sec. 3). Stratigraphic knowledge is lacking because (1) all the rocks between the Upper Mississippian strata and the Upper Permian Phosphoria Formation have been lumped into the Oquirrh Formation, and (2) denudation faulting has caused the rocks of the Oquirrh Formation to have a chaotic present distribution. Graduate students have not adequately lithologically divided the Oquirrh Formation in order to resolve the structural complexities in northwestern Utah. Rock sequences have only been grossly assigned to time series on the basis of scattered fusulinid collections. Even series designations are few and scattered in the Grouse Creek and Goose Creek Mountains and Raft River Range (fig. 1) of northwesternmost Utah.

The Silver Island Range north of Wendover (fig. 1, loc. 4) has excellently exposed sections of the Pennsylvanian at A-1 Canyon and Rishel Peak (fig. 10, sec. 1). Schaeffer (1960) did not divide the cyclical limestone, but Morrowan, Atokan, and Des Moinesian calcarenites, calcisiltites, and calcilutites are disconformably overlain by Virgilian-Wolfcampian dolomites and chert-pebble conglomerates of the Strathern Formation. Des Moinesian calcisiltites of the Hogan Member of the Ely Limestone are distinctive. Anderson (1957) reported that limestones at Crater Island (fig. 1, loc. 5) may be Virgilian and mentioned that two lithologies of Permian age there rest unconformably upon the conglomerate of the Mississippian Diamond Peak Formation. He described thinning of the Chainman Formation from 365 to 0 m and of the Joana Limestone from 10 to 0 m along strike. Neither Schaeffer (1960) nor Anderson (1957) recognized the decollement thrusting in the Silver Island Range that has caused structural thinning of the shale in the Chainman Formation and of the Joana Limestone. This thrusting juxtaposed different Pennsylvanian and Permian rocks upon the decollement surface.

Paddock (1956) reported that the Leonardian Pequop Formation unconformably overlies the Devonian Stansbury carbonate conglomerate in the Newfoundland Mountains (fig. 1, loc. 6). In the southern Grouse Creek Mountains (fig. 1, loc. 46), the Wolfcampian Ferguson Mountain and Strathern Formations are unconformable upon the Chainman Formation. These omissions of Pennsylvanian sequences have been interpreted previously by several investigators as evidence for a northwest Utah highland during the late Paleozoic. However, firm paleogeographic conclusions should not be drawn from the incomplete stratigraphic data in northwestern Utah until structural studies are completed because denudation faulting above the Chainman decollement has placed structurally different sequences of Pennsylvanian through Triassic rocks as discrete nappes upon both the Mississippian Chainman Formation and Devonian carbonates. Adjacent to the Raft River gneiss dome in the Goose Creek Mountains and Raft River Range, Compton (1972, 1975) has mapped Pennsylvanian rocks in thrust contact with regionally metamorphosed Precambrian, Cambrian, and Ordovician rocks.

Stifel (1964) mapped much of the Terrace and Hogup Mountains (fig. 1, locs. 9, 10) as Oquirrh, but the sequence is better interpreted as Leonardian Pequop Formation, Wolfcampian Ferguson Mountain Formation, and unnamed Virgilian rocks. R. C. Douglass (unpub. data, 1972) reported *Pseudofusulinella* and *Triticites* from collections of R. R. Compton (1975) in the Raft River Mountains (fig. 1, loc. 2). Compton has used the term "Oquirrh" in the Raft River Mountains on the basis of paleontological rather than lithological correlation. Doelling's (1964) section (fig. 10, sec. 2) in the Lakeside and Grassy Mountains (fig. 1, loc. 7) and Maurer's (1970) section (fig. 10, sec. 3) in the Cedar Mountains document that at least this far west, the lithofacies of the Pennsylvanian type Oquirrh are still present. The proportion of clastic material to limestone has, however, dropped drastically, further supporting the thesis that the fine arkosic sandstone of the type Oquirrh was derived from the Uncompahgre uplift. Outcrops in the Cedar (fig. 10, sec. 3) and Lakeside (fig. 10, sec. 2) Mountains are definitely the farthest west for which the term

"Oquirrh" should be used for Pennsylvanian rocks. Maurer (1970) and Doelling (1964) reported fusulinids representing all the Pennsylvanian series, but they were unsuccessful in attempting to correlate the sections in the Cedar and Lakeside Mountains lithologically with the type Oquirrh Formation in the Oquirrh Mountains (fig. 10, sec. 4) or even between their two adjacent ranges.

Olson's dissertation (1960) on the Promontory Mountains (fig. 1, loc. 12) reported Morrowan, Atokan, and Des Moinesian fusulinids, but his lithostratigraphic data are grossly generalized as 2,150 m of sandstone and limestone bearing Morrowan fossils near the base and Wolfcampian fossils above. About 50 km north in the Tremonton-Portage-Clarkston Mountains area, Bissell reports that the Morrowan West Canyon Limestone is 400 m thick and that the remaining Pennsylvanian and Permian sequence below the Phosphoria Formation is approximately 1,400 m thick. Bissell (*in* Peace, 1956) reported Atokan and Morrowan fusulinids from the subsurface at Rozel Point and Curlew Valley (fig. 1, locs. 11, 3). The documented widespread distribution of Lower and Middle Pennsylvanian rocks in northwestern Utah further indicates that the hypothetical northwest Utah paleohigh interpreted from Paddock's (1956) observation of Leonardian rocks resting upon Devonian rocks in the Newfoundland Mountains (fig. 1, loc. 6) probably did not exist.

The use of the name Wells Formation for Pennsylvanian rocks in the Logan area of northern Utah is another problem of terminology that has yet to be resolved. Richards and Mansfield (1912) named the formation in Wells Canyon in Bannock, Idaho, for 740 m of limestone and sandstone below the Phosphoria Formation. Williams (1948) reported Morrowan, Des Moinesian, Missourian, and Virgilian fusulinids in 1,800 m of "Wells" (Oquirrh) Formation at Wellsville Mountain. Nygreen (1958) was the first to show that the West Canyon Limestone was present at the Dry Lake section at Wellsville Mountain. Bissell states that recent fusulinid studies at Wellsville Mountain (fig. 10, sec. 5) indicate that the Oquirrh Formation has approximately 270 m of Morrowan and Atokan, 340 m of Des Moinesian, 135 m of Missourian, and 290 m of Virgilian. The Wells Formation is now best restricted to the Bear River Range (fig. 1, loc. 17) and Crawford Mountains (fig. 10, sec. 8), where 150–300 m of sandstone, limestone, and dolomite crop out. The correlation with the type area in Wells Canyon, Idaho, is not documented.

CARBONIFEROUS BIOSTRATIGRAPHY

The Carboniferous formations of Utah contain faunas from the earliest Kinderhookian to the youngest Virgilian and essentially all the paleontological zones are represented in carbonate bank, euxinic, deltaic, estuarine, or basin facies. All invertebrate groups and a variety of floras are well represented within the various environments. Taxonomy of the invertebrates is incomplete, but index fossils identified to genera and some species are listed on the biostratigraphic chart (fig. 2).

The earliest Kinderhookian age assignments are based on conodonts in the Fitchville Limestone and the Pilot and Leatham Formations. In the siltstone facies of the Pilot and Leatham, Kinderhookian conodonts overlie the *Syringothyris* zone of Late Famennian age. Late Kinderhookian and early Osagean brachiopod and coral faunas are abundant in limestones of the Whitmore Wash and Thunder Springs Members of the Redwall Limestone and in the Fitchville, Gardison, Joana, and Lodgepole Limestones. Conodonts and endothyrids have also proven useful for zonation in these limestones. The "Curley" bed at the top of the Fitchville Limestone is a widespread stromatolite horizon (Proctor and Clark, 1956). Algal limestones having birdseye textures are also common in the Redwall carbonate bank. Waulsortian crinoidal banks are present in the Thunder Springs Member of the Redwall Limestone in the Paradox basin, and some are also present in the Joana Limestone in eastern Nevada. The bedded cherts of the Thunder Springs and Gardison were derived from abundant siliceous sponges that flourished during times of slightly deeper water than was present during most other times of carbonate deposition.

Beginning in late Osagean time, subsidence produced a starved basin across northwestern Utah. The southern margin of this basin trended northeast from lat 37°45′N. to 40°15′N. (fig. 5), and the Redwall carbonate bank was to the southeast. This separation into two distinct environments produced a marked change in the faunal realms. Sandberg and Gutschick (1977) have shown by conodont zonation that the environmental differentiation began in central Utah at the top of coral zone C_1 in the carbonate bank, and Sadlick (1965) showed that it continued to the top of cephalopod zone P_1, or the top of coral zone F in western Utah. The pre-E zone brachiopods of the starved basin are *Quadratia hirustiformis*, Leiorhyncoidea, and Orbiculoidea. Trace fossils are common. *Goniatites crenistriae* and

G. multiliratus are the indices of the waning stage of the starved basin in western Utah during the late Meramecian.

Dorlodotia inconstans formed widespread coral biostromes during the early Meramecian on the Redwall carbonate bank. These zone D corals are the youngest found in the Redwall bank in southern Utah because the bank was subsequently subaerially exposed until the Morrowan time. The *Ekvasophyllum* corals of zone E are the youngest fauna in the prograded Deseret carbonate bank in central Utah.

In western Utah, a flysch facies of submarine fans gradually filled the starved basin and by Chesterian time, the basin contained a prolific molluscan fauna of goniatites, belemnites, pelecypods, and gastropods. *Goniatites granosus* is the index fossil for the earliest Chesterian; *Cravenoceras* and *Eumorphoceras* are present higher in the sequence.

Corals and brachiopods dominated the megafauna of the Great Blue carbonate bank (fig. 6) which extended almost to the western boundary of Utah. *Cravenoceras* cephalopods are mixed with the coral and brachiopod faunas in calcarenite outcrops at Burbank Hills and the Confusion Range in western Utah (fig. 1, locs. 36, 30). *Faberophyllum* and *Straitifera brazeriana* are common in the lower part of the Great Blue Limestone overlying the nearly barren Humbug Sandstone of the Doughnut trough. The upper Great Blue Limestones have *Caninia excentrica* and *Spirifer brazerianus* as index fossils. Periodically, the interior carbonate bank became emergent, and prodeltaic shales such as the Long Trail Shale of the Oquirrh Mountains and the Herat Shale at Gold Hill were deposited. These shales have *Lepidodendron* plant imprints associated with hematitic regoliths (Chamberlain, 1978). The reestablishment of the carbonate bank in the Late Mississippian continued intermittently until finally the bank was buried by deltaic clastic deposits of the Manning Canyon Formation.

The Manning Canyon Formation and the Jensen Member of the Chainman Formation completely buried the Great Blue carbonate bank with late Chesterian deltaic and estuarine deposits containing a mixed molluscan, bryozoan, and brachiopod fauna in limestone interbedded with carbonaceous shale and siltstone. *Diaphragmus, Archimedes,* and spiriferoids are common. *Eumorphoceras* and *Rayenoceras* are present. *Sigillaria* roots and *Lepidodendron* and *Stigmaria* imprints as well as a diversified Lycopodophyta flora are present in many localities. Tidwell and others (1974) stated that floras in sandstone of the upper part of the Manning Canyon Formation and in sandstone of the upper part of the Diamond Peak Formation are generally Pennsylvanian (Namurian B) in age. Stratigraphically lower floras in the Doughnut and Indian Springs Formations are Chesterian in age.

A return to open-marine circulation at the end of Mississippian time produced a widespread coarse detrital limestone containing the *Rhipidomella nevadenis* zone throughout the miogeosyncline area and into the Doughnut trough. Rocks of this zone overlie the highest rocks from which *Eumorphoceras bisulcatum* and the Pennsylvanian (Namurian B) floras were collected. Because the *R. nevadensis* zone is generally referred to as Chesterian, a discrepancy exists between the age indicated by the flora and that indicated by the invertebrates at the Mississippian-Pennsylvanian boundary.

The Morrowan seas reworked the regolith on the Redwall bank and expanded southeastward. The Doughnut trough was no longer recognizable. Algal limestones accumulated on the very shallow Callville platform (fig. 7). On the Morgan Shelf (fig. 9) in northern Utah and on the Hermosa Shelf in southeasternmost Utah, thin clastic limestones containing a brachiopod-bryozoan-crinoid biofacies were deposited. The Ely shelf was a slightly deeper environment in western Utah where several hundred meters of fossiliferous cyclical limestone accumulated. More rapid subsidence in the Oquirrh basin caused a prolific brachiopod-bryozoan-sponge biocoenose to accumulate below wave base. The Hermosa biofacies, a more diversified invertebrate fauna reflecting shallow nearshore environments, contrasts with the Callville biofacies, which is a sparse population reflecting a Bahamian-type platform.

By Atokan time, Utah was essentially submerged, except perhaps local areas near the Colorado border adjacent to the Uncompahgre uplift. *Chaetetes, Caninia, Multithecopora,* and *Barbouria* corals constructed extensive biostromes across the shelf environments. Fusulinid coquinas of *Profusulinella* and *Fusulinella* are common in beds within the carbonate cycles. Only in the Oquirrh basin where the water was deeper are the *Chaetetes* biostromes small and discontinuous. In the early Des Moinesian (Cherokee), the Paradox sabka formed adjacent to the Uncompahgre uplift (fig. 8). Salt layers in the Paradox alternate with euxinic black dolomitic shales that contain carbonized wood fragments, conodonts, phosphatic brachiopods, agglutinated Foraminifera, and fish remains (Stone, 1968). Algal limestones formed the stratigraphic reef barrier to the salt basin in the Four Corners region. The Callville platform west of the sabka was a supratidal flat. A few small algal patch reefs of Cherokee age are found in the Hermosa Group; the best exposures are in the gorge near the Goosenecks of the San Juan River (fig. 1, loc. 45).

The most widespread of all the Pennsylvanian open-marine environments existed in the middle Des Moinesian. The Desert Creek and Ismay Limestones of the Hermosa Group (fig. 3) were deposited in an open-marine environment that followed the restricted sabka environment. Equivalent limestones containing abundant *Fusulina* and *Wedekindellina* were deposited over the entire State and even covered the arkosic alluvial fans adjacent to the Uncompahgre. *Chaetetes* biostromes containing abundant brachiopod-coral-bryozoan assemblages flourished and extended from shelves into the deeper waters of the Oquirrh basin. Small syringoporid patch reefs tens of meters long have been observed in the Des Moinesian limestones of the Oquirrh Mountains. After this maximum Des Moinesian transgression, the seas gradually became restricted, and a regional hiatus marks the end of the series.

The earliest Missourian fauna containing *Wedekindellina ultimata* was found by Welsh (Welsh and James, 1961) in the Jordan Limestone of the Oquirrh Mountains associated with a biocoenose of productids, bryozoans, gastropods, and sponges. Missourian fusulinid-bryozoan faunas are found in both the Honaker Trail Formation of the Paradox basin and the Bingham Mine Formation of the Oquirrh basin. Virgilian fusulinids are found in the limestones of the northern Ely shelf, the Oquirrh basin, the southwestern Callville platform, and the Moab trough (fig. 9). Upper Pennsylvanian sandstones of the Oquirrh basin have abundant trace fossils on bedding planes indicative of water depths below wave base. Syringoporid biostromes are common in the Virgilian limestones in all basins. Large *Pseudozaphrentoides* corals and siliceous sponges are indigenous in Missourian limestones of the Oquirrh facies. Productids, bryozoans, corals, fusulinids, and sponges are abundant in most limestones of the Bingham Mine Formation. The Virgilian limestones of the Callville platform and Ely shelf are oolitic, pelletal, free of silt-size quartz, and have birdseye texture that suggests an important algal contribution. The Ely shelf was not receiving detritus from the Antler Highlands nor was the Oquirrh basin. The Honaker Trail Formation of the Hermosa Group has a mixed invertebrate fauna of brachiopods, bryozoans, corals, and mollusks reflecting the shallow estuarine facies southwest of the Uncompahgre uplift.

The youngest Virgilian fauna containing *Dunbarinella* has not been collected by the writers in Utah, although this zone is present in southeastern Nevada in the Bird Spring basin. In the Oquirrh basin, where a thick Virgilian sequence is present, the rocks are mostly submarine deltaic sandstone and thin silty limestone. Pre-Wolfcampian erosion has removed most of the Upper Pennsylvanian rocks on the Emery high (fig. 9) and in southwestern Utah so that the Late Pennsylvanian paleogeographic record is incomplete.

Except for the euxinic facies of the Paradox basin, the Pennsylvanian faunas are generally open marine in carbonate banks, shelves, or basins. Preservation of trace fossils and articulate invertebrates in the Oquirrh sedimentary rocks is a reflection of low-energy deeper water. Crinoid columnals are present in most Pennsylvanian limestones, but branches are common in the sedimentary rocks of the Oquirrh that were deposited in quiet water. Mollusks are present as part of the basin and carbonate bank fauna but are nowhere common. Partly restricted environments like those in the Mississippian containing exclusive molluscan assemblages did not form in the Pennsylvanian.

COLLECTING LOCALITIES

Fifteen localities have been selected as representative of the lithostratigraphy of the Carboniferous deposits in Utah (fig. 11). These localities have fossils that are characteristic of the lithofacies and time-stratigraphic units. The following list gives the locality number used in figure 11, the township and range, and the local name. A section designation is not given because several areas along strike are suitable for collecting.

(1) T. 11 N., R. 2 E.	Left Fork, a tributary of Blacksmith Fork south of Logan, has excellent exposures of the Lodgepole Limestone. Kinderhookian and Osagean invertebrates are easily collected in the talus.
(2) T. 10 N., R. 1 W.	The Dry Lake section along the abandoned road in the Great Blue Limestone has brachiopod and coral faunas of Meramecian and Chesterian age.
(3) T. 1 S., R. 3 W.	Rogers Canyon at the northwest corner of the Oquirrh Mountains has one of the best exposed sections for studying the biostratigraphy of the Morrowan, Atokan, and Des Moinesian series. Silica

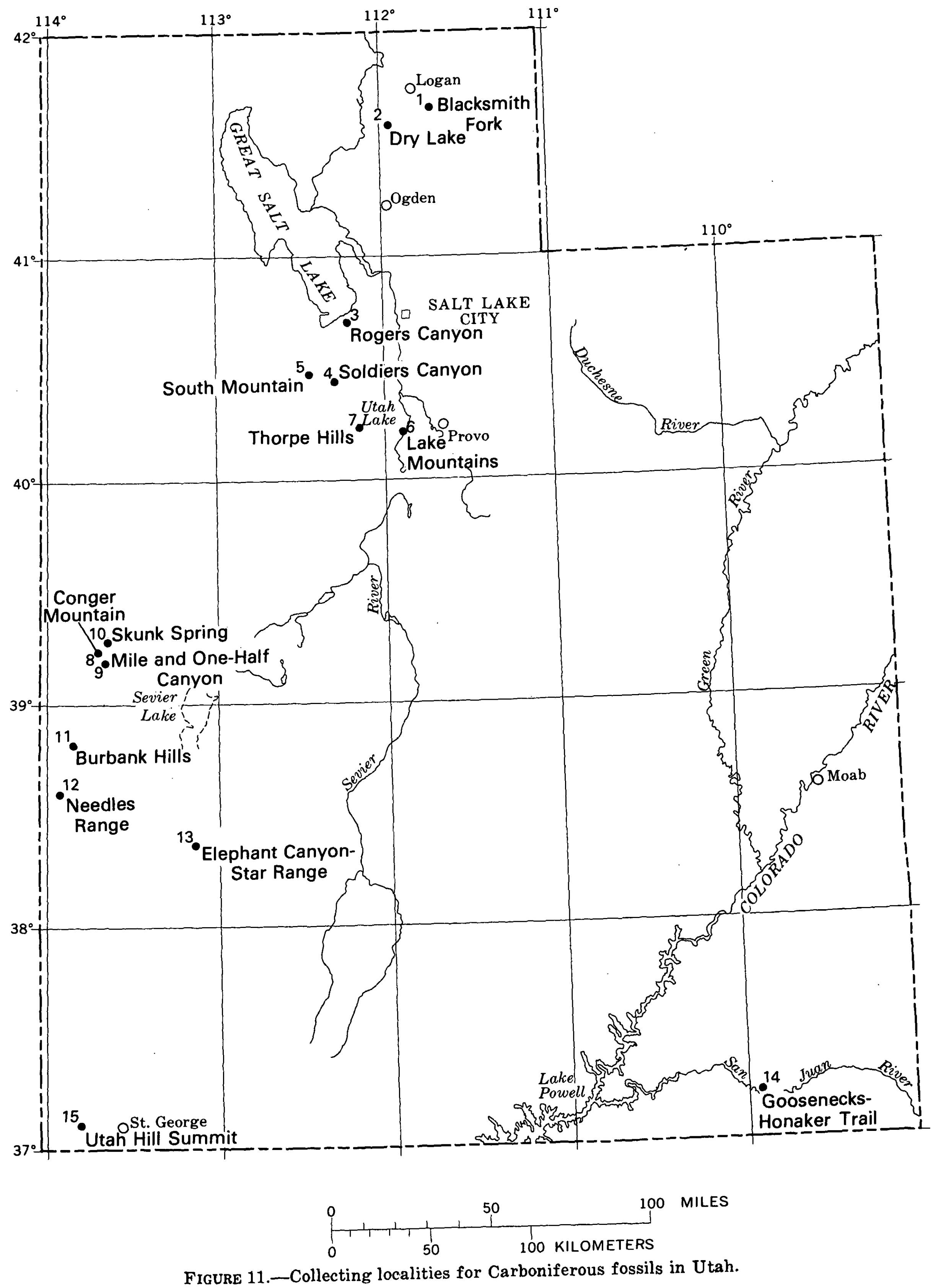


FIGURE 11.—Collecting localities for Carboniferous fossils in Utah.

sponges, crinoids, brachiopods, and corals are part of the biocoenosis.

(4) T. 4 S., R. 4 W. Soldiers Canyon east of Stockton, Utah, has a diversified section of nonmarine and marine deposits containing Chesterian and Morrowan fauna.

(5) T. 4 S., R. 5 W. South Mountain in Tooele valley is the type area of the Missourian and Virgilian Bingham Mine Formation of the Oquirrh Group. This is the most accessible locality for collecting trace fossils, corals, and brachiopods of the Late Pennsylvanian.

(6) T. 7 S., R. 1 W. Clay quarries in the Manning Canyon Formation yield a well-preserved flora of Pennsylvanian (Namurian B) age in the Lake Mountains.

(7) T. 7 S., R. 3 W. The Thorpe Hills, 8 km west of Fairfield, display a diversified brachiopod, coral, and bryozoan fauna of Morrowan age in the West Canyon Limestone of the Oquirrh Group.

(8) T. 18 S., Rs. 16–17 W. Conger Mountain in the Confusion Range has horizontal ledges of Ely Limestone that have an abundant brachiopod, bryozoan, coral, and fusulinid fauna of Morrowan, Atokan, and Des Moinesian age. *Chaetetes* biostromes are thick and continuous.

(9) T. 19 S., R. 16 W. The early Kinderhookian brachiopods and conodonts are most easily collected from the upper part of the Pilot Formation just below the Joana Limestone hogback at Mile and One-Half Canyon in the Confusion Range. Late Kinderhookian and Osagean corals and brachiopods may be collected from the Joana Limestone hogback.

(10) T. 18 S., R. 16 W.
(11) T. 23 S., R. 19 W.
(12) T. 25 S., R. 19 W. The Confusion Range, Burbank Hills, and Needles Range have long strike valleys of the Chainman Formation. These are the best collecting localities for goniatites and other mollusks. The Skunk Springs section (fig. 11, loc. 10) south of Cowboy Pass has abundant Chesterian brachiopods and corals of the Great Blue carbonate bank. These sections represent the transition from the carbonate bank to the flysch basin and provide fossils of different environments.

(13) T. 28 S., R. 12 W. The Redwall (Monte Cristo) Limestone of Kinderhookian and Osagean age is exposed in canyons in the Star Range, 16 km southwest of Milford, Utah. Elephant Canyon has well-exposed ledges for collecting corals, brachiopods, and bryozoans.

(14) T. 41–42 S., R. 18 E. The ledges of the Hermosa Group at the Goosenecks of the San Juan River have excellent collecting for Des Moinesian and Missourian brachiopods and corals. Algal patch reefs in the Paradox Formation are well exposed, and the black shales contain conodonts and fish teeth and bones, as well as phosphatic brachiopods. Honaker Trail is one of the easier accesses to the canyon walls.

(15) T. 42 S., R. 18 W. The Morrowan-Atokan, Des Moinesian, and Virgilian limestones of the Callville Limestone are accessible for collecting just east of the Utah Hill summit on U.S. Highway 91 in the Beaver Dam Mountains. Brachiopods, bryozoans, corals, and fusulinids are common. The Virgin Canyon tributaries off Interstate Highway 15 in Arizona are also favorable localities for collecting these faunas.

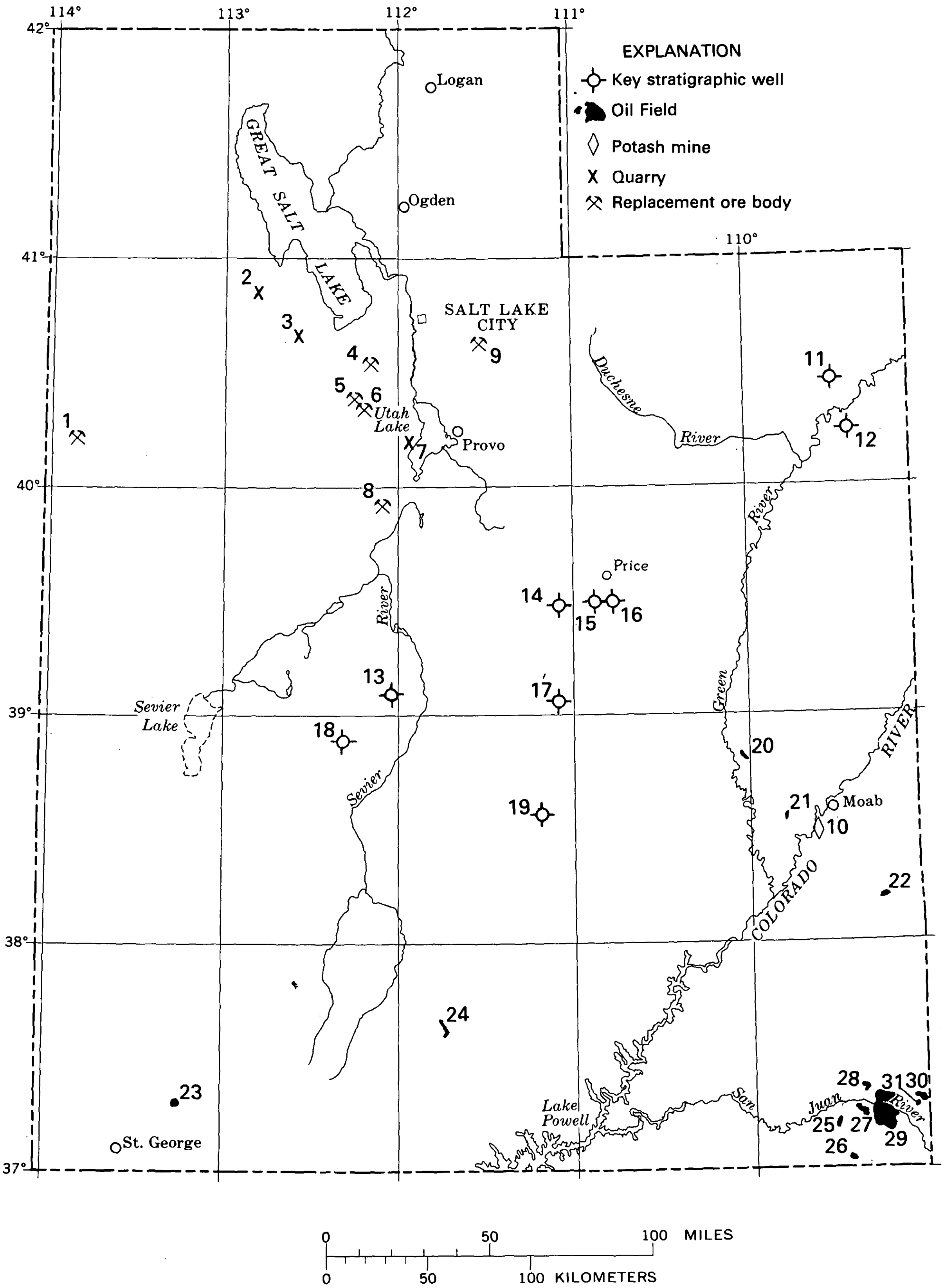
IGNEOUS AND METAMORPHIC ROCKS

Utah does not contain any igneous rocks known to be of Carboniferous age. Carboniferous rocks are regionally metamorphosed near Jurassic gneiss domes in western Utah, and contact metamorphism is common adjacent to Cretaceous and Tertiary stocks.

ECONOMIC PRODUCTS

Coal.—The Carboniferous rocks of Utah do not contain any economic coal deposits. Thin coal beds are present in the deltaic facies of the Manning Canyon and Doughnut Formations in central Utah. Plant fossils and carbonaceous fragments are locally present in the Great Blue Limestone and Chainman, Paradox, and Indian Springs Formations.

Petroleum.—Most of the oil production from the Carboniferous units has been from east of the Wasatch Hinge Line in the Paradox basin. The Anderson Junction field (fig. 12, loc. 23) near St. George produced from the Pennsylvanian Callville Limestone and is the only field near the hinge line.


EXPLANATION
Key stratigraphic well
Oil Field
Potash mine
X Quarry
Replacement ore body
114°
113°
112°
111°
110°
42°
41°
40°
39°
38°
37°
Logan
Ogden
GREAT SALT LAKE
SALT LAKE CITY
Utah Lake
Provo
Duchesne River
Green River
Price
Sevier Lake
Sevier River
COLORADO RIVER
Moab
Lake Powell
San Juan River
St. George
0 50 100 MILES
0 50 100 KILOMETERS

Thirty-one Pennsylvanian fields have produced 320 million barrels of oil; Greater Aneth (fig. 12, loc. 29), which has produced 280 million barrels, is the only giant field. Other fields in southeastern Utah that have produced more than 1 million barrels are: Ismay-Flodine Park, 9.5 million; Boundary Butte, 4 million; McElmo Mesa, 2.1 million; Tohonadla, 1.7 million; Bluff, 1.3 million; and Gothic Mesa, 1 million. All these fields are in stratigraphic reefs near the entrance into the Paradox basin. The Ashley Valley field (fig. 12, loc. 11) in the Uinta Basin has minor Pennsylvanian production from the upper part of the Weber Sandstone which is probably Permian; a deep test in the Red Wash field yielded a legitimate show from the middle of the Weber Sandstone.

Mississippian production has been 41 million barrels; Lisbon (fig. 12, loc. 22) has produced 40 million barrels, and Salt Wash (fig. 12, loc. 20) 1.2 million barrels. Upper Valley (fig. 12, loc. 24) and Big Flat (fig. 12, loc. 21) have minor production. Dolomitized crinoidal banks are the main reservoirs, and the oil is probably derived from the Paradox source rocks. The dolomitic shales of the Paradox Formation are the primary source rocks for most of the Carboniferous production.

Potential source rocks for oil in undiscovered Carboniferous reservoirs are shales of the Devonian Pinyon Peak and Pilot Formations, the phosphatic shales of the Mississippian Little Flat Formation, Chainman Group, and Deseret Limestone, and the organic-rich shales of the Great Blue Limestone and Doughnut and Manning Canyon Formations.

Metals.—Mississippian and Pennsylvanian limestones are the host rocks for vein, manto, and skarn deposits in the mining districts of Utah (fig. 12).

Pennsylvanian limestones of the Oquirrh Group are hosts for extensive skarn mineralization. For 50 years, the U.S. and Lark mines in the Bingham district (fig. 12, loc. 4) produced copper, lead, zinc, and silver from replacement deposits in Des Moinesian and lower Missourian limestones. The Anaconda Company is presently developing a large copper skarn ore body in the Missourian Jordan and Commercial Limestones at its Carr Fork underground mine northwest of the Bingham pit.

Some horizons in the Mississippian Humbug Sandstone are hosts for silver, lead, and zinc bedded-ore replacement deposits in the Ontario mine, Park City district (fig. 12, loc. 9). The Chief, Godiva, Iron Blossom, and Plutus veins, the main ore zones in the Tintic district (fig. 12, loc. 8), have bedded replacement deposits in the Fitchville, Gardison, and Deseret Limestones. These manto ores are primarily copper, silver, and gold.

Ochre Mountain Limestone is host of arsenic-gold replacement bodies in the Gold Hill district (fig. 12, loc. 1). Copper-lead-silver replacements are also reported in the Ely Limestone at Gold Hill. Many other districts in Utah have smaller replacement deposits in Carboniferous beds.

Beds of the Mississippian Great Blue Limestone that are rich in organic matter are hosts for disseminated gold deposits of the Carlin type in the Mercur district (fig. 12, loc. 6).

FIGURE 12.—Localities at which economic products have been obtained from Carboniferous rocks in Utah. Also shown are locations of key wildcat wells and oil fields where subsurface stratigraphic data on the Carboniferous are available.

Ore Deposits:
- 1. Gold Hill (Au, As)
- 4. Bingham (Cu, Pb, Zn, Ag, Au)
- 5. Ophir (Pb, Zn Ag)
- 6. Mercur (Au)
- 8. Tintic (Ag, Zn)
- 9. Park City (Pb, Zn, Ag)

Quarries:
- 2. Lakeside Lime
- 3. Flux Lime
- 7. Lake Mountains Clay

Potash mine:
- 10. Cane Creek

Stratigraphic wells:
- 11. Ashley Valley
- 12. Red Wash
- 13. Scipio Lake
- 14. Hiawatha
- 15. North Spring
- 16. Miller Creek
- 17. Ferron
- 18. Meadow
- 19. Last Chance

Oil fields:
- 20. Salt Wash
- 21. Big Flat
- 22. Lisbon
- 23. Anderson Junction
- 24. Upper Valley
- 25. Tohonadla
- 26. Boundary Butte
- 27. Gothic Mesa
- 28. Bluff
- 29. Greater Aneth
- 30. Ismay-Flodine Park
- 31. McElmo Mesa

Nonmetallic products.—Solution mining at Texas Gulf's Cane Creek mine (fig. 12, loc. 10) yields 200,000 to 300,000 tons of potash yearly from the Paradox Formation near Moab, Utah; the mine has a minimum estimated life of 20 years. The Manning Canyon Formation (fig. 12, loc. 7) is a source of clay for the brick industry. Limestone quarried by Flintkote Corporation from the Great Blue Limestone in the Stansbury Range (fig. 12, loc. 3) is a major source of high-calcium lime which is used for smelter flux and other industrial purposes. Southern Pacific quarries large quantities of the Great Blue Limestone in the Lakeside Mountains (fig. 12, loc. 2) for riprap. Increasing quantities of these limestones are being used as a dust retardant in the coal mines near Price.

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

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110–M–DD

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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N. Missouri, by Thomas L. Thompson
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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

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.

FOREWORD

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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