The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States— California, Oregon, and Washington

By RICHARD B. SAUL, OLIVER E. BOWEN, CALVIN H. STEVENS, GEORGE C. DUNNE, RICHARD G. RANDALL, RONALD W. KISTLER, WARREN J. NOKLEBERG, JAD A. D'ALLURA, ELDRIDGE M. MOORES, RODNEY WATKINS, EWART M. BALDWIN, ERNEST H. GILMOUR, *and* WILBERT R. DANNER

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Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in California, Oregon, and Washington

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CONTENTS

ILLUSTRATIONS

THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—CALIFORNIA, OREGON, AND WASHINGTON

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ABSTRACT

Rocks of Carboniferous age in California, Oregon, and Washington are described in seven separate reports. These rocks are a part of the sedimentary record in the Cordilleran geosyncline and in what appears to have been an adjacent, tectonically active ocean basin to the west and northwest.

Rocks deposited near the axis of the geosyncline are described in two reports on exposures in southeastern California. One report covers a group of economically important, metamorphosed, sparsely fossiliferous carbonate-rich sequences in the southwestern Mojave Desert. The other contains data on a well-preserved record of largely carbonate deposition on an eastern cratonic shelf and in a more western foreland basin, in the area east and southeast of the Sierra Nevada. Here, facies changes and unconformities appear to reflect tectonic events in an orogenic highland to the north and perhaps west of that region.

In the eastern Sierra Nevada, metamorphosed Carboniferous sedimentary rocks are exposed discontinuously in roof pendants. Fossils are rare. Correlation is mainly based on similarity of lithology to the nearest fossiliferous rocks. Regional differences in strike between these rocks and rocks of similar character and age to the east suggest a large-scale tectonic dislocation or regional angular unconformity. In the north-central Sierra Nevada, the Carboniferous section is predominantly a chert-epiclastic sequence and is sparsely fossiliferous.

In the eastern Klamath Mountains of California, the Carboniferous is mainly argillite and volcaniclastic rocks containing minor amounts of chert, greenstone, limestone, and siltstone. The sparse faunas, which range in age from late Mississippian through Pennsylvanian to early Permian, are part of an Asiatic province and have few species in common with typical North American faunas.

In Oregon, sedimentary rocks of Carboniferous age are known near the head of Crooked River in the southern Blue Mountains. Two formations are named. The older, composed mainly of limestone, is middle and upper Meramecian and Chesterian. The younger, of Morrowan age, is composed of conglomerate, sandstone, and plant-bearing mudstone. In northeastern Oregon, in an argillite, a fusulinid fauna is assigned to the Desmoinesian. In Oregon, all Carboniferous strata are probably allochthonous, having been emplaced during plate movements.

Scattered Carboniferous rocks in western and eastern Washington range in age from Chesterian to Desmoinesian and possibly Missourian. Some of the Carboniferous rocks in western Washington contain Tethyan faunas and may have been tectonically transported north and east from the Permian equatorial area. Fossils in the Carboniferous rocks of northeastern Washington appear to have eastern North American or Rocky Mountain affinities.

INTRODUCTION

By RICHARD B. SAUL

THE CORDILLERAN GEOSYNCLINE

The Grand Canyon of the Colorado River is one of the most impressive natural features on the North American Continent. It is 1,500 to 1,800 m deep. In its walls the Paleozoic Era is represented by about 1,300 m of sedimentary rocks (fig. 1). About 400 km west of the Grand Canyon, in the Panamint Range of California, is a thicker, more

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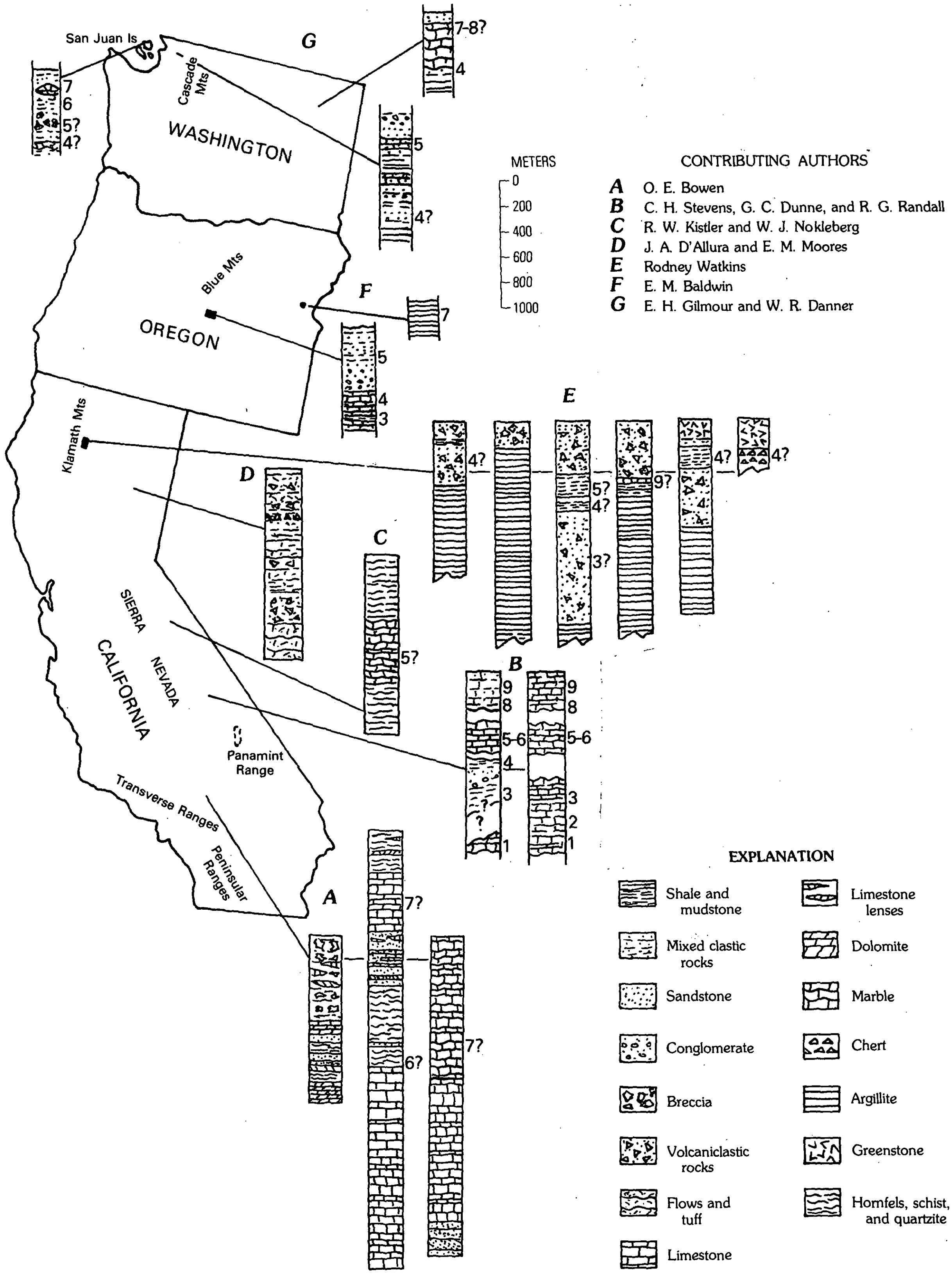
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Blue Mts
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OREGON
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Panamint Range
Transverse Ranges
Peninsular Ranges
A
7?
6?
7?
EXPLANATION
Shale and mudstone
Mixed clastic rocks
Sandstone
Conglomerate
Breccia
Volcaniclastic rocks
Flows and tuff
Limestone
Limestone lenses
Dolomite
Marble
Chert
Argillite
Greenstone
Hornfels, schist, and quartzite

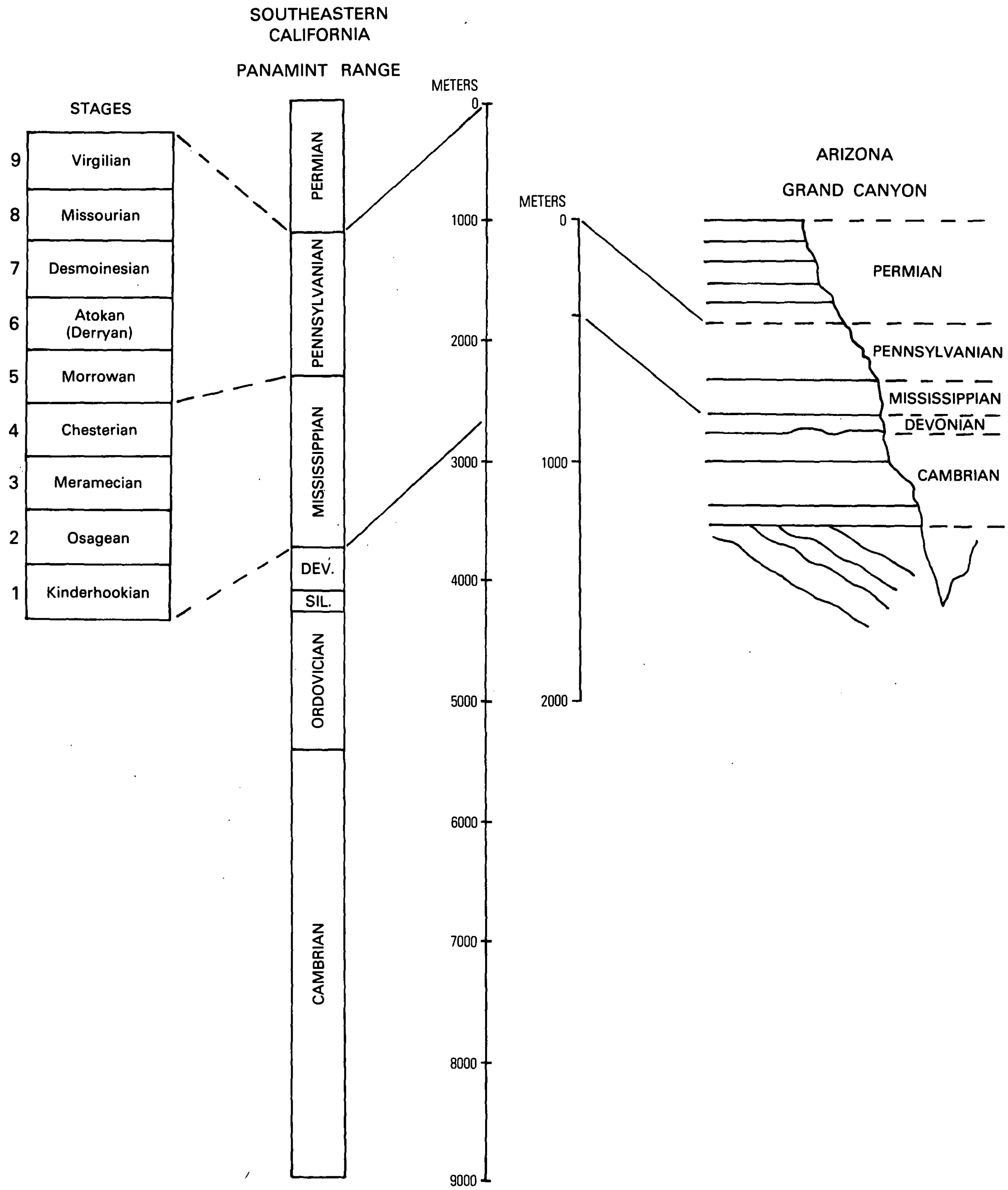

FIGURE 1.—Regional aspects of the Carboniferous rocks in and west of the axis of the Cordilleran geosyncline in California, Oregon, and Washington. Because of the uncertainties of many age assignments, the commonly altered or unfossiliferous character of the rocks, and the scale of this figure, the thicknesses are approximate and the lithology is generalized. The upper right-hand columns at F and G are localities, not described sections.

complete Paleozoic section but one that is faulted and folded. If undisturbed, the section in the Panamint Range would require a canyon about 9,000 m deep for full exposure. Indeed, in California, if the entire conformable sedimentary sequence, including the late Precambrian, were to be considered, the section would be more than 15,000 m thick. Unfortunately such an unbroken sequence of Paleozoic rocks is not exposed in California, Oregon, or Washington, although the section in southeastern California can easily be pieced together. There are, instead, widely scattered exposures of faulted, deformed, and in places, intruded and metamorphosed parts of the sequence. Therein has lain some of the difficulty facing Paleozoic stratigraphers in general and students of the Carboniferous in particular in the Cordilleran geosyncline.

EARLY WORK

Careful examination of the rocks of the region began in the late 1800's. By the turn of the century, a base of useful literature had begun to accumulate. Because of the wide variety in the age and type of rocks exposed in California, Oregon, and Washington, these areas have attracted a large and diverse cadre of earth scientists. The literature has accrued exponentially. Most of the early work was done through the aegis of the U.S. Geological Survey. Descriptions of the rocks of Carboniferous age are minor parts of the older publications. The early work usually centered on problems of ground-water supplies and the geology of mining districts. The abundant carbonate rocks were good hosts to ores of both base and noble metals. In 1912, James M. Hill published index maps of topographic and geologic surveys of the Western States that illustrate the influence of the mining districts on those endeavors. Not until recent years have workers chosen to study the rocks and rock-forming events of specific Periods in the Paleozoic.

As topographic maps became available for certain districts, detailed geologic studies of specific quadrangles were published. One such work, involving well-exposed rocks of Carboniferous age, is "Geology and ore deposits of the Goodsprings quadrangle, Nevada" by D. F. Hewett (1931). This effort to assist the development of a mining district is a classic of structural and stratigraphic exposition. Through such investigations, great progress was made in understanding the geologic history of the Cordilleran geosyncline.

In the eastern Transverse Ranges of California and in the regions to the east and south, early descriptions of Paleozoic rocks were generally part of academically oriented geologic mapping. However, such reports contributed to the search for industrial minerals. The work by Vaughan (1922) in which he described the Furnace Limestone is an example.

Knopf and Kirk (1918) were among the earliest to describe the rocks and mineral resources of the thick Paleozoic section along the east flank of the Sierra Nevada. Some of the best early work in the Sierra Nevada and Klamath Mountains of California was conducted by Diller and is presented in U.S. Geological Survey Bulletins and Folios, and in professional journals.

In 1902, Condon wrote a geologic history of Oregon in which Paleozoic rocks were described, but most of the Carboniferous rocks were located by E. L. Packard (1928, 1932) and his students.

The Paleozoic section in western British Columbia extends southward, to a limited extent, into the State of Washington. Most of the earliest work was done by Canadians such as Clapp (1909). In 1927, McLellan published a report on the San Juan Islands, in northwestern Washington, which describes structural, stratigraphic, and economic aspects of the geology. Here, as elsewhere in the Western States, significant geologic research emerged around the turn of the century.

DISTRIBUTION OF THE ROCKS

In the three States covered by this report, the least altered, most fossiliferous, and most complete sections of Carboniferous rocks are exposed in the Basin Ranges east of the Sierra Nevada in California. Near and south of the latitude of the Transverse Ranges of California (fig. 1), rocks of probable or possible Carboniferous age are generally altered and difficult to date, at least in part because of the emplacement of Mesozoic plutonic rocks. Similarly, rocks of Carboniferous age are sparsely distributed in roof pendants in the batholithic rocks of the Sierra Nevada. A section of metamorphosed sedimentary rocks of late Paleozoic age, some of which may prove to be Carboniferous, forms a belt in the western foothills of the Sierra Nevada. A mixed sequence of sparsely fossiliferous clastic, volcaniclastic, and carbonate rocks of Carboniferous age is exposed in the eastern Klamath Mountains in northwestern California.

Rocks ranging in age from Devonian through Permian have been mapped in a faulted and folded section in the Blue Mountains of central Oregon. There the Carboniferous comprises fossiliferous, mixed calcareous, clastic, and argillaceous rocks and minor amounts of limestone overlain by conglomerate, wacke, and plant-bearing mudstone. An argillite of possible Pennsylvanian age is to the northeast, near Baker.

In the State of Washington, Carboniferous rocks are found in two different sections, both of which are more extensively exposed to the north in British Columbia. One belt is in the Northern Cascade Range; the other is exposed in the San Juan Islands and in the foothills of the Northern Cascades and Middle Cascades on the mainland (Danner, 1977). The rocks in the Cascade Range consist of argillite and siltstone of Mississippian?-Pennsylvanian age overlain by fossiliferous Pennsylvanian limestone. The section in the San Juan Islands comprises volcanic flows and breccia, shale, siltstone, tuff, graywacke, lenses of fossiliferous limestone, and a few thin seams of low-grade coal.

ECONOMIC IMPORTANCE

The presence of coal strata in the Eastern States may have caused early expectations of coal in the Carboniferous of the West. Although thin local seams are present in the Pennsylvanian of the San Juan Islands, in the State of Washington (McLellan, 1927), no commercially exploitable deposits have been found. The role of Carboniferous carbonate rocks as host for metallic ores has been noted. The growth of population on the Pacific Coast has increased demand for carbonate rocks for industrial purposes. Much of the information on deposits of known or potential value in Carboniferous rocks is produced or collated by State agencies: in California, the California Division of Mines and Geology, Department of Conservation, Resources Agency; in Oregon, the State of Oregon, Department of Geology and Mineral Industries; and in Washington, Washington State, Department of Natural Resources, Division of Geology and Earth Resources.

PRESENT RESEARCH

An excellent summary of current research exists in a symposium volume titled "Paleozoic paleogeography of the western United States" (Pacific Coast Paleogeography Symposium, 1977). Because that symposium involved or influenced most of the contributors to this work, a rough summary is presented as follows: The axis of the Cordilleran geosyncline had a north-northeasterly trend. The axis lay athwart what is now southeastern California, resulting in the thick accumulation of Paleozoic marine rocks in that region. The thinner, Grand Canyon section accumulated on the cratonic shelf along the southeast margin of the geosyncline. To the northwest, in the region of central California, an orogenic highland belt from which sediments were derived trended northeastward. A trench lay along the southeast margin of the highland. The boundary between the trench and the highland is described as a system of northwest-dipping thrust faults. To the northwest, through northern California, Oregon, and Washington, carbonate rocks become subordinate to clastic, volcaniclastic, and volcanic rocks. This may have been a region of island arcs in or west of an ocean basin adjacent to and west of the Cordilleran geosyncline. Across the western basin, rocks and fossil faunas from a different province appear to have been rafted against the continental plate above an east-dipping subduction zone.

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 California Division of Mines and Geology, Department of Conservation, Resources Agency; the State of Oregon, Department of Geology and Mineral Industries; and Washington State, Department of Natural Resources, Division of Geology and Earth Resources.

CARBONIFEROUS AND PROBABLE CARBONIFEROUS METASEDIMENTARY ROCKS IN THE SOUTHWESTERN MOJAVE DESERT, CALIFORNIA

By Oliver E. Bowen

ABSTRACT

This paper deals with partly metamorphosed late Paleozoic rocks in the southwestern Mojave Desert. In the light of the relatively abundant faunas in the Carboniferous rocks of eastern California, a review of the lithology and gross stratigraphy of these sparsely fossiliferous rocks seems in order.

The probable Carboniferous rocks in the southwestern Mojave Desert have the following things in common:

1. The lithofacies consist predominantly of quartz-mica schist, limestone and quartzite.
2. Fossils are widely scattered and the preservation is seldom better than fair.

3. The Carboniferous rocks occur as small or large pendants suspended in granitic rocks.
4. In most pendants the stratigraphic section is incomplete.
5. In general the rocks are well exposed.

The most detailed studies have been done on the Oro Grande series which crops out in many pendants found within or close to the quadrilateral determined by the cities of Victorville, Kramer Junction, Barstow, and Lucerne Valley. The maximum thickness of the Oro Grande series is 2,952 m, whereas the type section of Quartzite Mountain is only 723 m thick.

The Oro Grande series is believed to correlate with the Furnace Limestone and the Chicopee and Sarrogossa Quartzite formations of the San Bernardino Mountains. These formations aggregate 3,409 m; the Furnace Limestone makes up 2,447 m of the total.

Limestone is by far the most important industrial raw material quarried in the southwestern Mojave Desert, and the portland cement industry is the largest consumer. Quartzite is quarried extensively for use in portland cement, railroad ballast, road base, and allied construction materials. Other products such as magnesite, gold, silver, copper, and tungsten have been produced intermittently.

HISTORY

Before publication by the author of "Geology and mineral deposits of Barstow quadrangle" (Bowen, 1954) and "Mineral deposits in the Oro Grande series" (Bowen and Ver Plank, 1965), the only reasonably detailed description of the probable Carboniferous rocks in the southwestern Mojave Desert was by W. J. Miller in 1944. Miller briefly described lithologic units at the type section of the Oro Grande series but found no diagnostic fossils. Brief references to the lithology of the late Paleozoic rocks are to be found in Hershey (1902), Darton (1915), and Pack (1914). A good description of the Furnace Limestone and associated quartzite formations was published by F. E. Vaughan in 1922. Woodford and Harris supplemented Vaughan's work in 1928. Both of these papers discuss the probable Carboniferous sequence in the San Bernardino Mountains immediately adjoining the Barstow 30-minute quadrangle to the south. The same area was discussed in a short paper by Guillou in 1953 and in a more extensive one by Richmond in 1960. Richmond's paper contains the best description of the stratigraphy and fossil record of the late Paleozoic rocks of any dealing with the San Bernardino Mountains. Weise (1950) discussed probable Paleozoic rocks in the Neenach quadrangle.

Between 1960 and 1965, geologic maps of four 15-minute quadrangles were released by the U.S. Geological Survey covering the entire older Barstow 30-minute quadrangle (Dibblee 1960a, b, c, d). As these map sheets were preliminary, very little discussion of the map units was possible (fig. 2).

GEOLOGIC SETTING

All the areas being discussed are underlain by granitic rocks; the metasedimentary rocks in general are found in pendants surrounded by granitic rocks. At no place is the base of the probable Carboniferous section exposed, and the basal contact for any one sequence is along an instrusive rock, or in a few places, a fault.

In two places, at least, the probable Carboniferous rocks are overlain by metasedimentary rocks containing diagnostic Permian fossils. Near Sidewinder Mountain, west of the Reserve quarry of Southwestern Portland Cement Company, the Permian Fairview Valley Formation rests nonconformably on the Oro Grande series. In the Goler Wash vicinity of the El Paso Mountains, fusulinid-bearing Permian rocks are conformable on a sequence of rocks that may be partly Carboniferous and partly Permian.

The lithology of the probable Carboniferous rocks (fig. 3) reflects few diastrophic events. Limestone tends to be pure, clay shale has little or no coarse sand or pebbles, and the quartzite, except in the El Paso Range, is made up of clean sand. These rocks most probably result from intense chemical weathering in a warm, humid climate.

Sea-floor dolomitization was predominant, although some dolomite may have formed by introduction of magnesium mobilized at the time of influx of the granitic rocks.

Coarse conglomerate and sedimentary breccia, probably reflecting mountain-building activity, appear in the Permian and probably in the Pennsylvanian as well, as would be expected in concluding epochs of the Paleozoic. This characteristic is in keeping with events reflected in the Permian-Carboniferous sequence in eastern California.

LITHOLOGY AND LITHOLOGIC SEQUENCE

The only detailed, measured sections of probable Carboniferous age are in either the Barstow 30-minute quadrangle or the adjacent Shadow Mountains 15-minute quadrangle (Bowen, 1954). In the Shadow Mountains, the Oro Grande series reaches a thickness of 3,414 m and is primarily a crystalline limestone-quartz-mica schist sequence. Thin quartzite and hornfels layers are present within the schist, but they do not form mappable units except at a large scale. The much thinner (1,285 m) type sec-

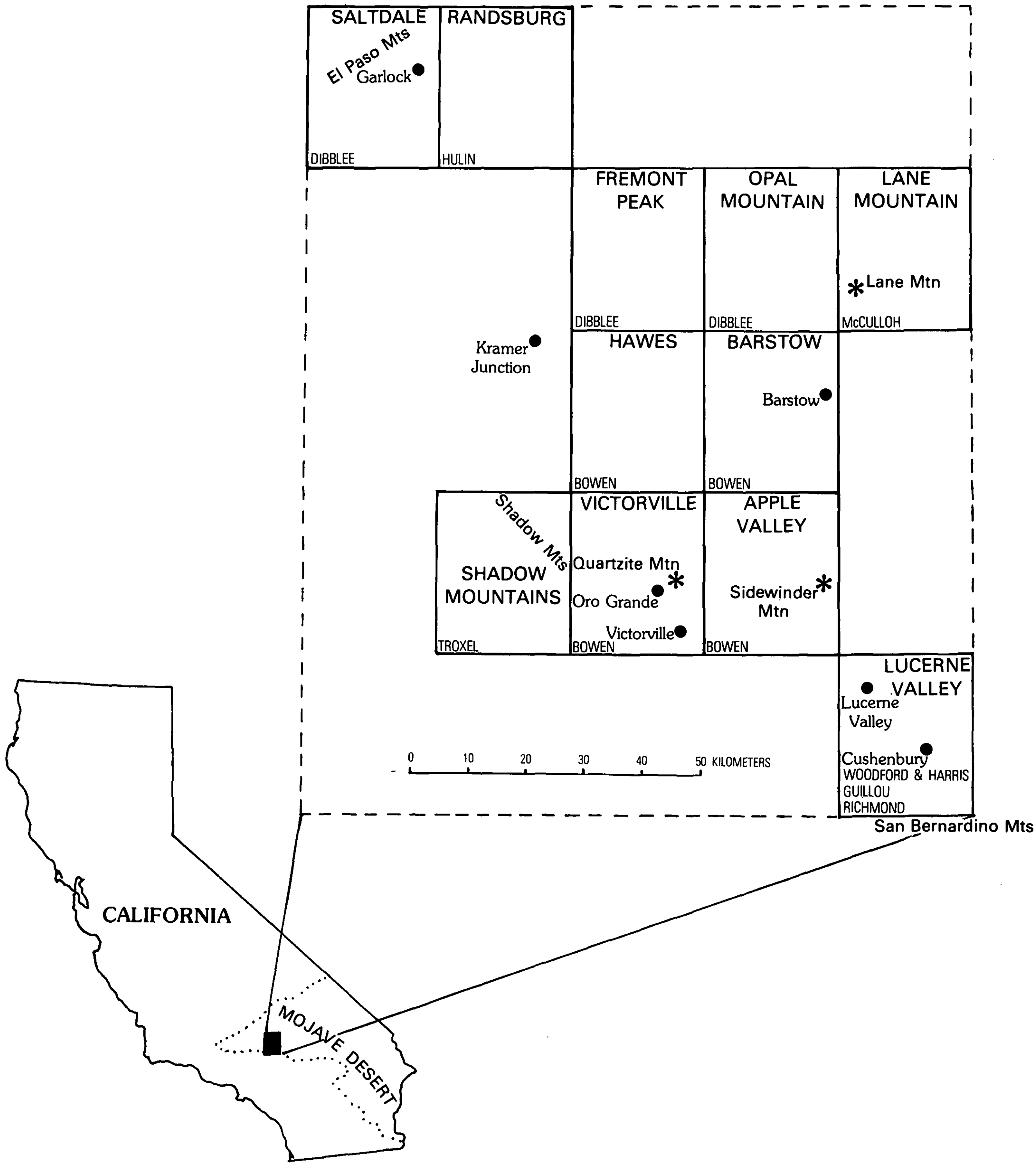

FIGURE 2.—Location of quadrangles in which Carboniferous rocks are exposed. Names of authors responsible for mapping appear in southwest corner of quadrangle.

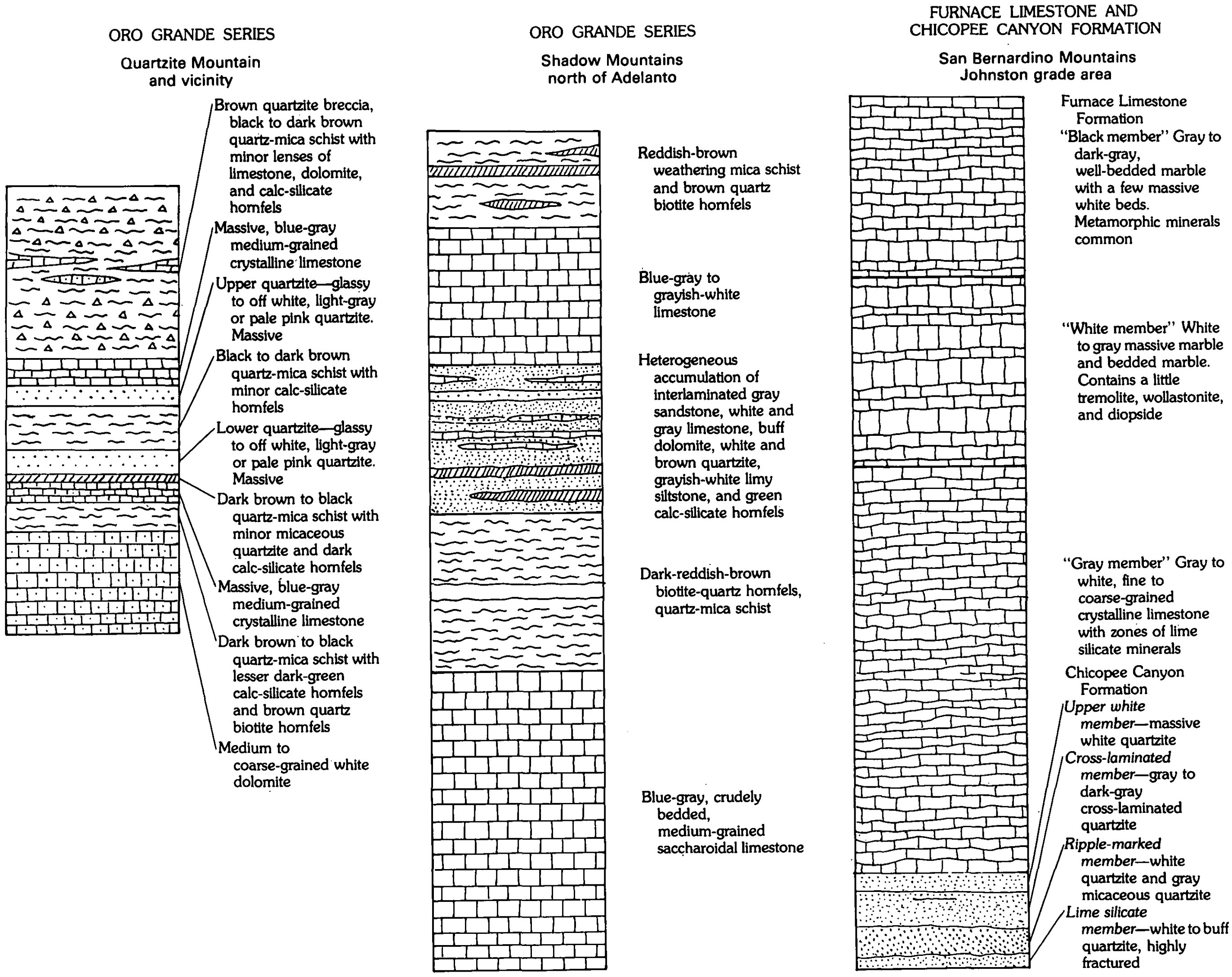

FIGURE 3.—Columnar sections of Carboniferous(?) rocks in the southwestern Mojave Desert.

tion on Quartzite Mountain contains two quartzite units 65 and 90 m thick, respectively.

Typical of the Shadow Mountains section of the Oro Grande series is a heterogeneous sandstone (unit 3) containing both quartz and calcite grains (intermingled and in discrete beds), white and gray crystalline limestone, buff dolomite, white and brown quartzite, grayish-white siltstone, and greenish calc-silicate hornfels. This sandstone is distinguishable, as it is interbedded with crystalline limestone and quartzite—both much more intensely metamorphosed.

The five-unit Shadow Mountains section of the Oro Grande series is, top to bottom, as follows:

	Meters
5. Reddish-brown-weathering mica-quartz schist and brown quartz-biotite hornfels	400
4. Blue-gray to grayish-white crystalline limestone	581
3. Light-colored mixed unit of sandstone, limestone, dolomite, quartzite, and schist	600
2. Reddish-brown to black mica schist and dark-brown biotite-quartz hornfels	672
1. Blue-gray, massive, medium-grained, crudely bedded crystalline limestone	1161
Total	3414

In and adjacent to the type section of the Oro Grande series on Quartzite Mountain in the Apple Valley 15-minute quadrangle, or in the Barstow

30-minute quadrangle, 9 units of the Oro Grande series are mappable at scales of 2,000 feet (610.5 m) per inch or larger. Some of these have subunits. From top to bottom, the sequence is as follows:

	Meters
9. Interbedded dark quartz-mica schist; coarse-grained, blue-gray crystalline limestone; quartzite breccia; and blue-gray and white crystalline limestone	400
8. Blue-gray, medium-grained crystalline limestone	138
7. Massive pinkish-white quartzite with rare traces of bedding	65
6. Black to dark-brown mica-quartz schist	82
5. Glassy to off-white or light-gray to pale-pink quartzite	90
4. Dark-brown to black quartz-mica schist with thin beds of quartzite	28
3. Blue-gray, massive, medium-grained crystalline limestone	90
2. Dark-brown to black quartz-mica schist with lesser dark-green calc-silicate hornfels	116
1. Coarse-grained, massive, white crystalline dolomite with thin lenses and patches of limestone	436
Total	1445

Numerous other pendants of the Oro Grande series rocks are scattered through the southwestern Mojave Desert, but the sections are less complete. The Oro Grande series correlates most closely with the Furnace Limestone and the Chicopee Formation of the San Bernardino Mountains. Its base is not exposed, but it is overlain unconformably by the Permian Fairview Valley Formation.

The complete section of the Oro Grande series undoubtedly is materially thicker than the 3,414-m Shadow Mountains section. McCulloh (oral commun., 1953) has described a nonfossiliferous sequence in the Lane Mountain area north of Barstow that is lithologically similar to the Oro Grande series but that contains more quartz-mica schist; it is 8,720 m thick. Vaughan (1922), Woodford and Harris (1928), Guillou (1953), and Richmond (1960) have estimated the Furnace Limestone to be 1,333 to 3,633 m thick at various places in the San Bernardino Mountains; all these sections are incomplete. If we take the quartzite of the Chicopee Formation and the Furnace Limestone to be more or less equivalent to the Oro Grande series, the total Carboniferous section in the Victorville-Cushenberry Canyon area may well be 4,100 m thick. McCulloh's section in the Lane Mountain area may indicate that the thickness of the Carboniferous strata in the southwestern Mojave Desert may be more than 8,700 m.

The Garlock series, an apparently continuous section of Paleozoic rocks, has been described by Hulin (1925) and Dibblee (1952) in the El Paso Mountains north of Garlock in the Randsburg and Saltdale 15-minute quadrangles. Although this sequence is probably isoclinally folded, it totals 12,716 m. Presence of one horizon of Permian fusulinids close to the apparent stratigraphic midpoint in the Garlock series suggests that it is at least half Permian or younger. Older rocks are apparently conformable with the Permian sequence. The Garlock assemblage is unlike the probable Carboniferous and Permian rocks south of the Garlock fault in the southwestern Mojave Desert, and it differs materially from the Permo-Carboniferous rocks to the north.

AGE OF THE ROCKS

The presence of two poorly preserved brachiopods (probably *Chonetes* sp., C. W. Merriam, oral commun., 1956) about 868 m above the lowermost exposed beds in the Oro Grande series section in the Shadow Mountains suggests a probable Pennsylvanian age for much of the sequence there. Presence of round crinoid columnals and debris in patches of obvious calcarenite at several localities in the Oro Grande series in the Quartzite Mountain area suggests a Paleozoic rather than a Mesozoic age. Strata from the type locality on Quartzite Mountain I consider to be approximately equivalent to the two lower members of the Shadow Mountains section. These are also equivalent to the Furnace Limestone and the Chicopee Formation (quartzite) in the San Bernardino Mountains. The lithology and sparse fossils indicate correlation among these formations.

The Oro Grande series is unconformably overlain by the Permian Fairview Valley Formation west of the Reserve quarry of Southwestern Portland Cement Company so that it is unlikely that any of the beds of the Oro Grande series in either the Quartzite Mountain or Shadow Mountains areas contain rocks of Permian age.

The fossil evidence thus far recovered from the Furnace Limestone of the San Bernardino Mountains indicates strata of both Mississippian and Pennsylvanian age. The Oro Grande series is also probably in part Pennsylvanian and in part Mississippian.

ROCKS AND MINERALS OF ECONOMIC IMPORTANCE

Limestone.—By far the most important industrial raw material taken from Carboniferous sequences in the southwestern Mojave Desert is limestone, and by far the largest consumer is the portland cement industry. The limestone deposits are medium to coarsely crystalline and are blue-gray to white. Purities as much as 98 percent $CaCO_3$ are common. Portland cement plants consume at least 4 million tons of limestone annually from probable Carboniferous deposits in the southwestern Mojave Desert. Amcord Inc., Riverside Division, with a plant at Oro Grande; the Kaiser Cement and Gypsum Corporation, with a plant at Cushenbury; and the Southwestern Portland Cement Company at Victorville are the principal consumers of limestone from the Oro Grande series and the Furnace Limestone.

Limestone from these rocks also plays an important role in the manufacture of beet sugar, glass, lime, and steel. It is used as white filler, roofing granules, road base, railroad ballast, and for aggregate in asphalt concrete and portland cement concrete. Pfizer, Inc., at Cushenbury, is the principal producer of these products, although several others are intermittently active in marketing competitive products.

Marble.—Marble dimension stone and ornamental stone have been quarried intermittently from the Oro Grande series and Furnace Limestone. The sawed polished dimension stone was used principally for floor and wall facings in large buildings. The old California State Mining Bureau headquarters at the Ferry Building, San Francisco, Calif., had a large slab of white, green, and black dolomite from the Three Color Marble quarry on the northeast side of Sidewinder Mountain. Building facings were also cut in the Gem quarry, about 1 mile north of Sidewinder Mountain and from the vicinity of Quartzite Mountain near Victorville. The ease of getting low-cost marble from Italy has largely eliminated quarrying of California's very beautiful marble.

Quartzite.—The very pure quartzite from the Oro Grande series, which has a silica content generally more than 98 percent has been used extensively for manufacture of silica refractories and portland cement. Because of its hardness and durability, this quartzite also has been used extensively for railroad ballast, road base, and aggregate for asphalt concrete and portland cement concrete. Amcord, Inc. and California Portland Cement Company have been the largest consumers.

Metallic minerals.—Gold, silver, copper, and tungsten have been produced in a small way from vein and replacement deposits in the Oro Grande series. The Carbonate gold mine near Oro Grande is noteworthy because of pockets of coarse gold found in the vicinity of the main shaft at a depth of 55.4 m. This mine was discovered about 1880, but most of the gold was produced between 1900 and 1942. Many other gold prospects are found in the Oro Grande series in the Victorville-Oro Grande and Cushenbury Canyon vicinities. All the gold deposits contain silver.

The only copper mine of much consequence has been the Amazon just east of Quartzite Mountain. Discovered about 1880 and first worked by Mormons, the early production was probably small. Between 1900 and 1942, a few hundreds of tons of chalcopyrite ore was shipped to smelters. The principal ore mineral was chalcopyrite, and it was commonly associated with magnetite. The wall rocks are limestone and quartzite cut by shear zones trending N. 10° W. to N. 10° E. Ore is found in the shear zones and in adjacent wall rocks as replacements.

Magnesite.—A small tonnage of high-purity magnesite was mined during 1940 on the Red Ball claims half a mile northeast of Sidewinder Mountain, for use in oxychloride cement. This cement was in demand for airfields in the Pacific theater during World War II. The magnesite occurs as hydrothermal veins, associated with black hornblende lamprophyre, cutting dolomite of the Oro Grande series. Most of the dikes and veins strike N. 35° E. and dip southeast at angles of 10° to 30°. The thickest veins are not much more than 1 m wide and can be as thin as about 25 cm.

CARBONIFEROUS STRATIGRAPHY OF PART OF EASTERN CALIFORNIA

By CALVIN H. STEVENS, GEORGE C. DUNNE, and RICHARD G. RANDALL

ABSTRACT

Carboniferous rocks in eastern California were deposited along the western margin of the North American craton. During Mississippian time, carbonate sediment was deposited on a westward-sloping shelf in the southeastern part of the area; mostly fine siliceous clastic sediment accumulated in a moderately deep water foreland basin to the northwest. During Pennsylvanian time, limestone was deposited throughout the region; that to the southeast was deposited on a relatively shallow water, carbonate shelf, whereas that to the northwest was deposited as a turbidite sequence that accumulated in relatively deep water. Widespread unconformities apparently formed during the late Mississippian (late Meramecian), and during the late Middle Pennsylvanian (Desmoinesian). The unconformities and changes in lithologic and thickness patterns probably reflect tectonic events associated with the Antler orogenic belt, postulated to have extended north and perhaps west of the area of this study.

INTRODUCTION

This paper summarizes the Carboniferous stratigraphy in an area of about 20,000 km^2 in eastern California bounded by three major geologic features: the Garlock fault on the south, the Death Valley-Furnace Creek fault zone on the east, and the Sierra Nevada batholith on the west (fig. 4). South of the Garlock fault, along which as much as 60 km of left-lateral displacement may have taken place (Davis and Burchfiel, 1973), exposures of Carboniferous rocks are sparse and poorly dated. East of the Death Valley-Furnace Creek fault zone, Carboniferous rocks may have been displaced 100 km in a right-lateral sense (Poole and Sandberg, 1977). In the Sierra Nevada to the west, few rocks of Carboniferous age have been identified. Thus, the present study area is a natural geologic unit for analysis of the Carboniferous rocks exposed here.

We thank Forrest Poole for many helpful suggestions concerning both the study and the manuscript, and David Andersen and Rachel Gulliver who helped greatly in improving the manuscript.

GENERAL GEOLOGIC RELATIONSHIPS

Geomorphically, the area of study forms part of the westernmost Basin and Range province. Carboniferous rocks crop out widely in many of the ranges where exposures generally are excellent; intervening alluviated valleys, however, preclude long distance continuous tracing of units. Because numerous thrust faults of Mesozoic age are exposed or are inferred to underlie much of the study area (Stewart and others, 1966; Burchfiel and others, 1970; Johnson, 1971; Stevens and Olson, 1972), uncertainty exists as to the original locations of various terranes. Because the amount of slip on these faults is not known, no palinspastic restorations have been made in the compilation of our facies and isopachous maps; however, restorations are desirable, and they may become feasible in the future when the major structural features of the region are better understood.

Three localities of known or inferred Carboniferous rocks near the margins of the study area deserve mention; they are not otherwise included in the compilation because they cannot be correlated readily with other units in the area. These are: the Garlock Formation of Dibblee (1967) exposed just north of the Garlock fault in the El Paso Mountains; a slightly metamorphosed section in the Benton Range (fig. 4, loc. 26) near the northern boundary of the area; and metasedimentary rocks in the Mount Morrison pendant (loc. 25) in the eastern Sierra Nevada.

The Garlock Formation evidently includes rocks of several ages, some older and some younger than Carboniferous (F. G. Poole, oral commun., 1977). A flysch sequence there is considered by Poole (1974) to be Mississippian and possibly Pennsylvanian in age. No fossils have been obtained from the rocks in the Benton Range (fig. 4, loc. 26), but an argillite and carbonate sequence in the east-central part of the range appears very similar to the Rest Spring Shale and Keeler Canyon Formation in the Inyo Mountains to the south. The Mount Baldwin Marble in the Mount Morrison pendant in the Sierra Nevada (loc. 25) has yielded probable Early Pennsylvanian fossils (Rinehart and Ross, 1964), so it evidently is coeval with the lower part of the Keeler Canyon Formation. The underlying clastic unit may correlate with some of the siliceous clastic rocks in the Perdido Formation-Rest Spring Shale sequence in the Inyo Mountains.

PREVIOUS WORK

The first significant work on Carboniferous stratigraphy in eastern California was that of McAllister (1952), who named and described four Carboniferous units (Tin Mountain Limestone, Perdido Formation, Rest Spring Shale, and Tihvipah Limestone) exposed near Quartz Spring (loc. 20) in the northern Panamint Range. The stratigraphic scheme devised by him has been followed by most subsequent workers in the area, although the Mississippian nomenclature has since been slightly augmented (Hall and MacKevett, 1958); in addition, the Keeler Canyon Formation, named by Merriam and Hall (1957) for a largely Pennsylvanian limestone unit, evidently includes McAllister's Tihvipah Limestone —a name now largely abandoned—as well as younger limestone. Johnson (1957) proposed the name Anvil Spring Formation for a sequence of Carboniferous and Permian rocks in the southern Panamint Range (loc. 1), but inasmuch as that section is composed of several readily recognized, pre-

Area and number	Reference	Tin Mt. Limestone	Perdido Formation	Argus Limestone	Rest Spring Shale	Lower Keeler Canyon Fm.
Butte Valley (1)	(unpub. data)	?	present	235	0	present
Tucki Mountain (2)	Hunt and Mabey (1966)	300	145	75	230	760?
Tucki Mountain (3)	Randall (1975)	460	300	140+	225	650+
Bendire Canyon (4)	Moore (oral commun.)	?	?	?	?	120–210
Argus Range (5)	Holden (1976)	120	120	200	0	present
Argus Range (6)	Hall (1971)	115	115	200	0	30+
SE Darwin Hills (7)	Moffitt (oral commun.)	?	405+	95	13	0–10
SE Darwin Hills (8)	(unpub. data)	?	present	123	present	present
Panamint Butte (9)	Hall (1971)	135	120	200	0	445+
Santa Rosa Hills (10)	(unpub. data)	130	455	25	30	present
Santa Rosa Hills (11)	Hall and MacKevitt (1962)	135	(data not applicable)		0–15	<120
Marble Canyon (12)	Pelton (1966)	135	352?	113?	0	present
Goldbelt Springs (13)	Stadler (1968)	175	95	75	0	present
SE Inyo Mountains (14)	Elayer (1974)	105	120	0	215+	present
SE Inyo Mountains (15)	Merriam (1963)	25–105	0–25	0	>305	45–60
SE Inyo Mountains (16)	Stuart (1976)	25–105	15	0	present	60
SE Inyo Mountains (17)	Kelley (1973)	?	60	0	335	present
Ubehebe Mine (18)	McAllister (1956)	145	185	0	60–305	<45
Quartz Spring (19)	Langenheim and Tischler (1960)	110	210	0	present	present
Quartz Spring (20)	McAllister (1952)	145	185	0	>120	>60
Dry Mountain Quad. (21)	Burchfiel (1969)	0–130	185–215	0	230–275	present
Mazourka Canyon (22)	Stevens and Ridley (1974)	0	45–185	0	535	present
Mazourka Canyon (23)	Ross (1965)	0	90–185	0	<760	present
Tinemaha Reservoir (24)	(unpub. data)	?	present	0	present	595+
Mount Morrison (25)	Rinehart and Ross (1964)	?	?	?	present?	150?
Benton Range (26)	(unpub. data)	?	?	?	present?	present?
Talc City Hills (27)	Gulliver (1976)	present	present	present	present	present

FIGURE 4.—Location and number of measured sections and thickness of rock units in meters.

viously named Carboniferous and Permian units, this formational name herein is abandoned. The nomenclatural scheme used here is shown on a diagrammatic cross section (fig. 5).

Gross lateral changes in Mississippian rocks have been investigated by Pelton (1966) and Randall (1975), but detailed regional studies of these units have yet to be made. Pennsylvanian rocks are much more poorly known. Scattered Pennsylvanian sections have been studied, but this system has not been subjected to regional analyses. Therefore, many details of the stratigraphic relationships still are in doubt, and the nature of lithologic and thickness differences from place to place is poorly known.

CARBONIFEROUS PALEOTECTONIC SETTING

The paleotectonic setting of most of eastern California during the Carboniferous seems reasonably clear, although the significance of some sections is not well understood and not all the late Paleozoic tectonic belts recognized farther northeast in Nevada can be traced readily into California (fig. 6). Mississippian paleogeographic belts in northeastern Nevada were, from east to west, a carbonate shelf, a foreland basin, and the Antler orogenic highland (Poole, 1974; Rose, 1976; Poole and Sandberg, 1977). In eastern California, the carbonate shelf and foreland basin have been recognized. Part of the Antler orogenic highland has been identified tentatively in the Sierra Nevada (Speed and Kistler, 1977) northwest of the study area. Unlike Mississippian strata, the Pennsylvanian section in eastern California differs considerably from that in northeastern Nevada. A carbonate shelf, however, is recognized on the east in both areas.

STRATIGRAPHIC SETTING

Carboniferous rocks are underlain throughout most of the region by Devonian rocks assigned to the Lost Burro Formation. The contact seems conformable but abrupt, and was interpreted by Langenheim and Tischler (1960) and Poole (1974) to represent an interruption in sedimentation. The only known exception to this stratigraphic interpretation is in the Independence quadrangle in the extreme western Inyo Mountains (loc. 23). There, the Lost

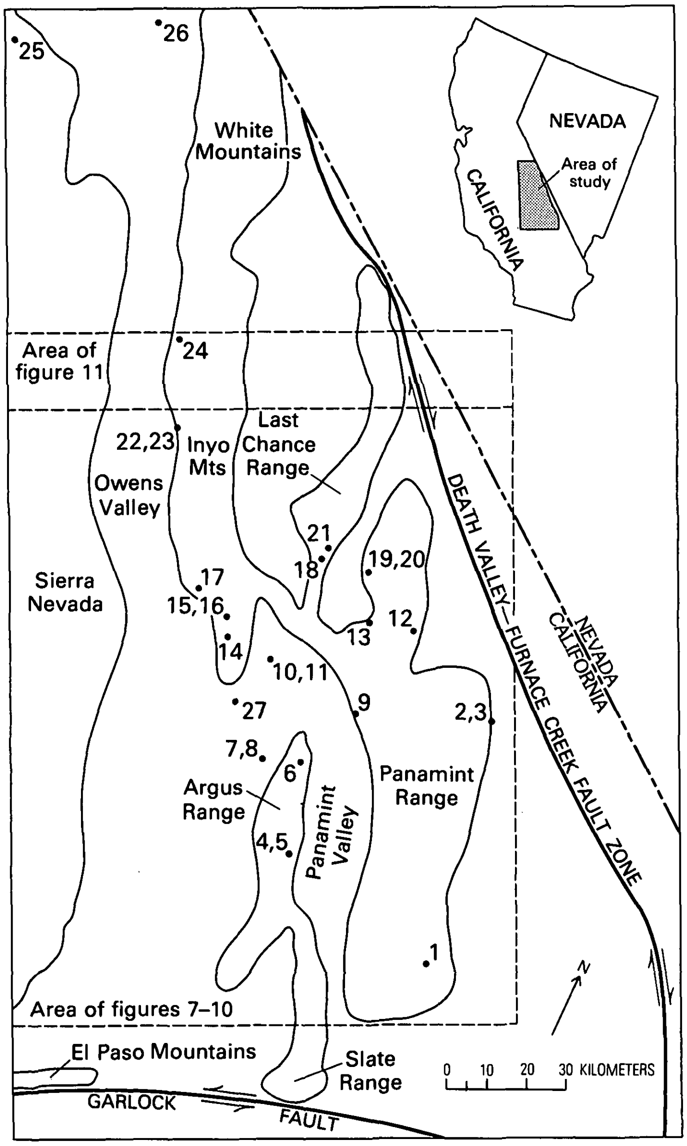

FIGURE 4.—Continued.

Burro Formation is not present, and the position of the Devonian-Mississippian contact still has not been established. The systemic boundary may be at the base of the Perdido Formation, as restricted by Stevens and Ridley (1974), or it may be at the base of the Squares Tunnel beds of Stevens and Ridley. The contact below the Squares Tunnel beds clearly is disconformable; the contact at the base of the Perdido Formation also may be disconformable.

Carboniferous rocks of the region apparently are overlain by rocks of Permian age everywhere except in part of the southern Inyo Mountains (loc. 15), where locally the Pennsylvanian part of the Keeler Canyon Formation is overlain unconformably by Triassic marine strata. The boundary between Permian and Carboniferous rocks is generally within the Keeler Canyon Formation, and in most areas it is not marked by a lithologic change.

As far as is known, no major tectonic event affected this area during the Carboniferous, but minor events are indicated by changing lithofacies and isopachous map patterns.

GENERAL STRATIGRAPHIC RELATIONSHIPS

Within the area of study, the Carboniferous section can be divided as shown in figure 5. Two widespread disconformities, one formed during the Late Mississippian (late Meramecian) and the other formed during the Middle Pennsylvanian (Desmoinesian), are recognized. The older disconformity generally is marked by a sharp lithologic change from limestone, locally dated as middle Meramecian, to fine siliceous clastic rocks locally considered late Chesterian in age (Poole and Sandberg, 1977). Poole and Sandberg suggested that a middle Meramecian uplift affected much of western United States.

The second widespread disconformity, separating lower Middle from Upper Pennsylvanian rocks, is recognized over much of the area. Most lower Middle Pennsylvanian (Derryan) rocks are fine grained and characterized by the presence of round chert nodules commonly the size of golfballs. In the central and western parts of the area, the Upper Pennsylvanian sequence above the unconformity is represented by interbedded fine- and coarse-grained carbonate units, which represent a turbidite sequence. Beds immediately above the unconformity apparently range in age from Missourian in the southern Inyo Mountains (loc. 15) to Wolfcampian (Early Permian) in the Santa Rosa Hills (loc. 10). The break between the two Pennsylvanian sequences often appears abrupt.

CARBONIFEROUS UNITS

TIN MOUNTAIN LIMESTONE

Wherever the Tin Mountain Limestone has been recognized, it overlies the Devonian Lost Burro Formation with apparent conformity, although Poole (1974) and Poole and Sandberg (1977) considered the contact disconformable. At the type area near Quartz Spring (loc. 20), the contact is marked by a change from very light-gray quartzite of the Quartz Spring Sandstone Member of the Lost Burro Formation to the clayey lower Tin Mountain Limestone (Langenheim and Tischler, 1960). There, the lower part of the Tin Mountain Limestone con-

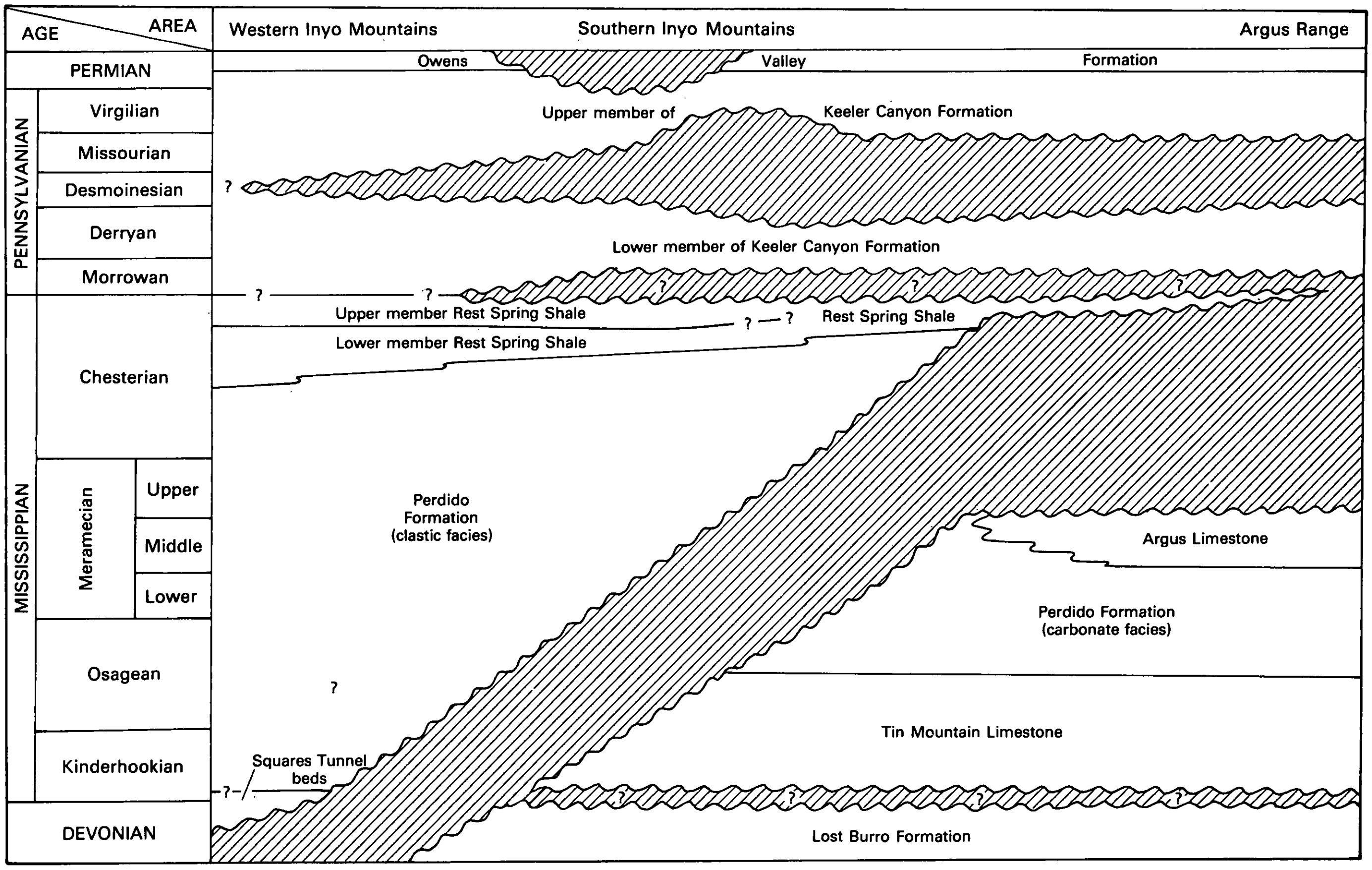

FIGURE 5.—Diagrammatic cross section of eastern California showing stratigraphic nomenclature and correlations.

sists of dark-gray limestone beds 5 to 15 cm thick separated by much thinner beds of light-bluish-gray to pale-red shale (McAllister, 1952). The upper part consists of medium-gray limestone in beds a few centimeters to 50 cm thick. Some beds are composed largely of crinoid stems. The persistence of dark limestone, pale-red shale partings, very dark-gray chert only in nodules, and an abundance of *Syringopora* is considered diagnostic of the Tin Mountain Limestone (McAllister, 1952).

Throughout most of the region considered, the Tin Mountain Limestone is 105 to 145 m thick (fig. 7). Thinning, however, takes place northwestward in both the Inyo and Last Chance Ranges. This thinning has been attributed to post-Tin Mountain and pre-Perdido erosion because locally uppermost Tin Mountain Limestone beds are missing (Burchfiel, 1969). At Tucki Mountain (loc. 3), where all Carboniferous units apparently are anomalous with regard to thickness and/or lithology, the Tin Mountain Limestone is much thicker than elsewhere (300 m estimated by Hunt and Mabey, 1966; 460 m computed by Randall, 1975). Stevens and others (1974) have suggested that the rocks composing Tucki Mountain and adjacent parts of the southern Panamint Range have been displaced several tens of kilometers, but resolution of this question requires further work.

The Tin Mountain Limestone is the most fossiliferous Carboniferous formation in the region. Langenheim and Tischler (1960) listed 18 species of brachiopods, 13 species of corals, 6 species of gastropods, and smaller numbers of several other groups of fossils. In the Panamint Butte quadrangle (locs. 6, 9), Hall (1971) listed 18 species of brachiopods, 15 species of gastropods, 14 species of corals, and smaller numbers of 5 other groups. These diverse fossils demonstrate that the Tin Mountain Limestone is Early Mississippian in age (Langenheim and Tischler, 1960; Hall, 1971).

Limited evidence suggests that the Tin Mountain Limestone was deposited in fairly shallow water. Cerioid corals, which are especially abundant on the east side of the central Argus Range (loc. 5),

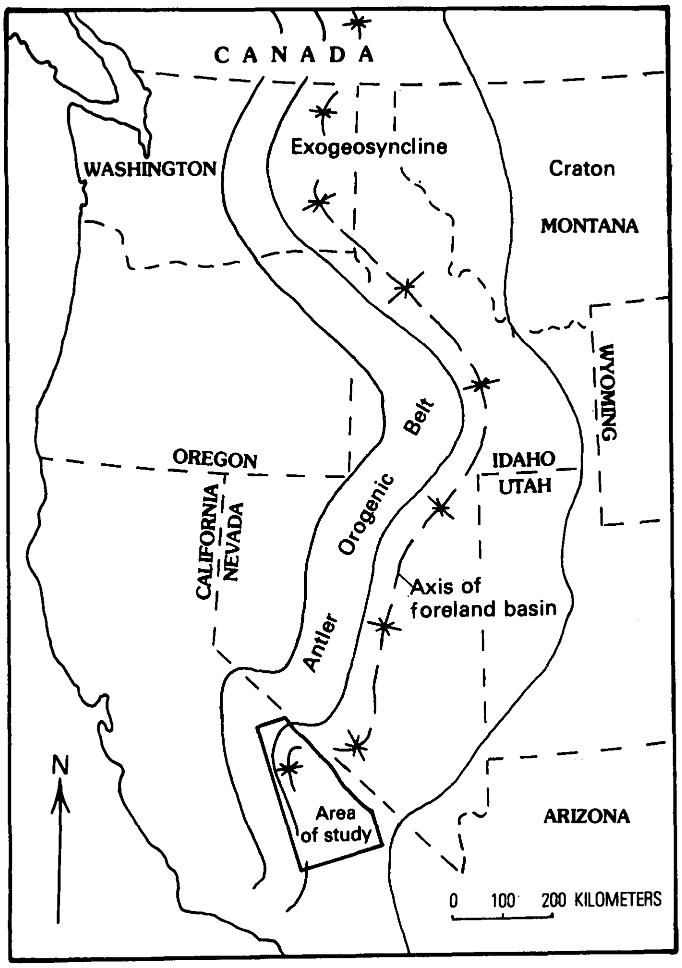

FIGURE 6.—Paleotectonic map of eastern California during the Carboniferous Period.

may be the best indicators of environment. In Upper Mississippian rocks in the Santa Rosa Hills and Lower Permian rocks in northeastern Nevada, corals with this morphology evidently lived in relatively shallow water near the shelf margin (Stevens, 1977). Evidence for strong currents or extremely shallow water is meager except in the Quartz Spring area, where Tischler and Langenheim (1960) noted bioclastic limestone beds more than 1 m thick that have well-developed crossbedding and lenses of coarse fragmental rock. Deposition of the Tin Mountain Limestone is interpreted here to have been on a broad shelf that had good circulation at water depths perhaps less than 20 to 30 m.

PERDIDO FORMATION

The Perdido Formation overlies the Tin Mountain Limestone with apparent conformity except in the south-central to western Inyo Mountains (locs. 15, 22) and in the Last Chance Range (loc. 21), where the Tin Mountain Limestone is thin or absent.

Two distinct facies of the Perdido Formation are recognized—a southeastern carbonate and a northwestern clastic facies (fig. 8). At the type locality in the Quartz Spring area, the clastic facies overlies the carbonate facies. Elsewhere, apparently only one facies is present in any given area, except locally, where the two facies may have been juxtaposed by thrust faulting, as in the Talc City Hills (Gulliver, 1976).

Carbonate facies.—At the type locality (loc. 20), the lower cherty limestone facies of the Perdido Formation rests on the Tin Mountain Limestone. The contact is a well-defined bedding plane which separates thick-bedded, coarse-grained pelmatozoan limestone below from relatively thin-bedded, fine, cherty, argillaceous limestone above (Langenheim and Tischler, 1960). The lower part of the Perdido Formation consists primarily of nodular layers of limestone 10 to 15 cm thick, which are mostly fine grained and black. Minor coarse-grained and pelmatozoan limestone is present. Interbedded black chert weathers reddish orange or very dark gray and is found in almost all limestone units. Most chert beds are less than 15 cm thick, and many are nodular and discontinuous layers. Bedding-plane partings of yellowish-gray to red shale are widespread and make up slightly more than 25 percent of the basal cherty sequence (Langenheim and Tischler, 1960). A middle, chert-free unit in the lower Perdido Formation is characterized by beds 5 to 60 cm thick and by the presence of more shale beds than below. Limestone beds in the upper unit of the lower Perdido Formation are thicker than those at the base, ranging from 15 cm to more than 1 m in thickness, but the black limestone and cherty shale is much like that of the lower unit.

Clastic Facies.—The upper part of the Perdido Formation at the type locality (loc. 20) is mainly red weathered and calcareous siltstone (Langenheim and Tischler, 1960). A few layers of cherty and shaly limestone as much as 50 cm thick are present, and the uppermost 12 m consists of limestone conglomerate, limestone, and calcareous siltstone or shale. A limestone conglomerate at the base of the 12-m-thick upper sequence contains boulders of Perdido limestone, chert, and siltstone as much as 10 cm in diameter in a richly fossiliferous limestone matrix (Langenheim and Tischler, 1960). A somewhat similar limestone conglomerate, interpreted by us as a submarine debris flow, is found in the southeasternmost Inyo Mountains.

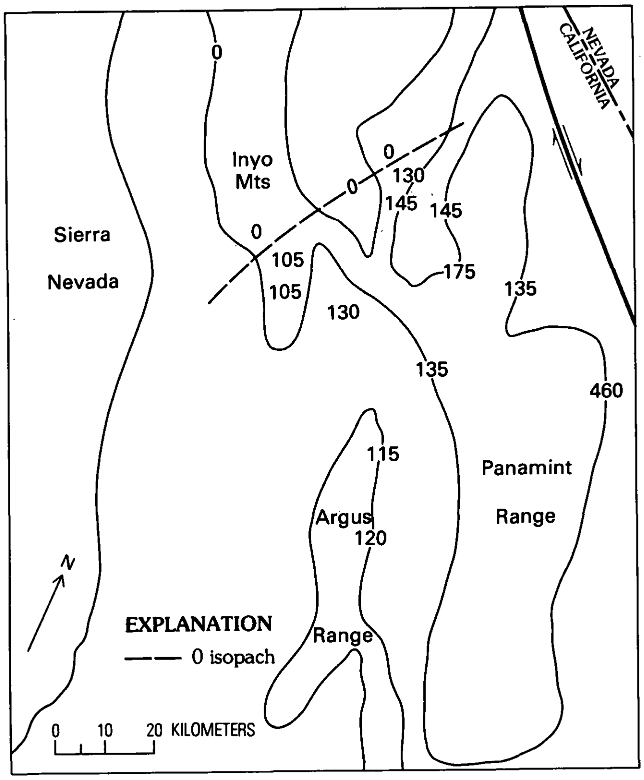

FIGURE 7.—Thickness, in meters, of the Tin Mountain Limestone.

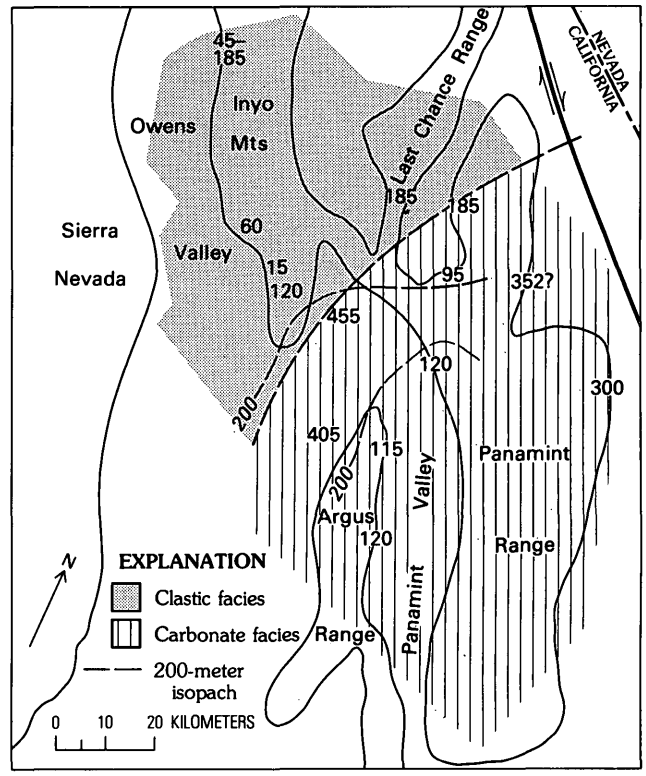

FIGURE 8.—Thickness, in meters, and distribution of facies of the Perdido Formation.

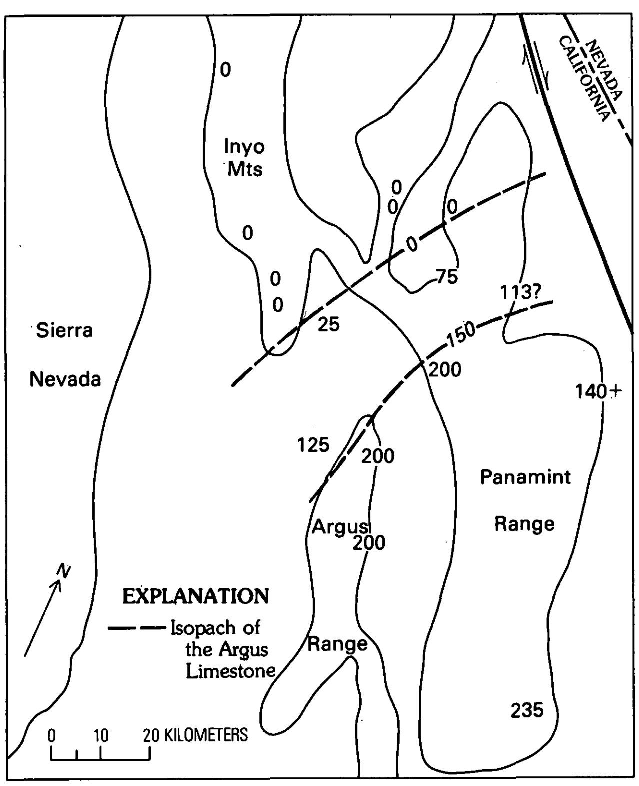

FIGURE 9.—Thickness, in meters, of the Argus Limestone.

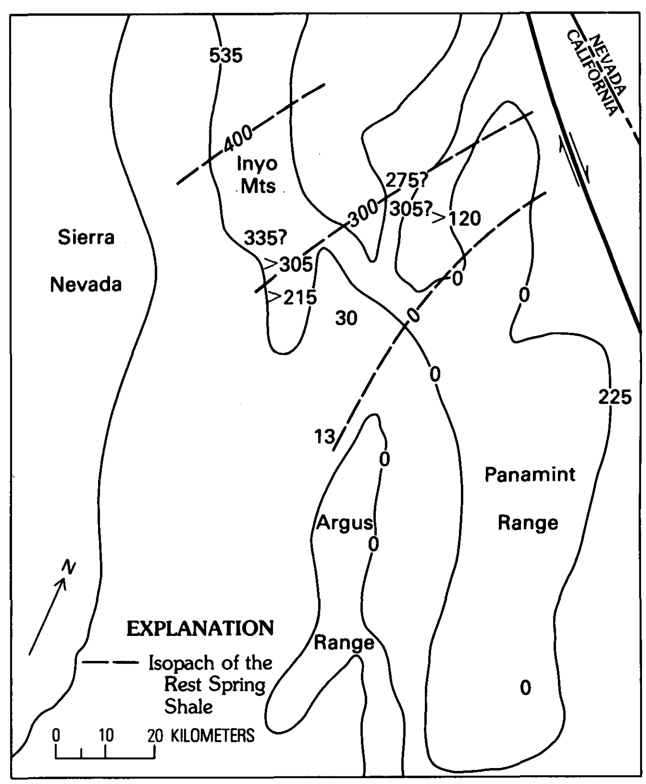

FIGURE 10.—Thickness, in meters, of the Rest Spring Shale.

Perdido Formation facies interpretation.—Thickness of the Perdido Formation is quite variable (fig. 8). The maximum thickness of 455 m is near the transition between the southeastern carbonate and northwestern clastic facies. Northwestward, into the clastic facies, thicknesses decrease and then generally increase. Southeastward into the carbonate facies, thicknesses decrease abruptly except for the anomalously thick section at Tucki Mountain (loc. 2).

Stratigraphic relations between the carbonate and clastic facies of the Perdido Formation are perplexing. As yet, we have no faunal evidence that the carbonate rocks are replaced laterally (to the northwest) by clastic rocks of the same age, although this seems to be the most likely explanation. In both the Quartz Spring area (loc. 20) and southeasternmost Inyo Mountains (east of loc. 14), carbonate debris flows derived from a carbonate shelf are found in the clastic facies, indicating that during deposition of the clastic facies a carbonate shelf existed within or adjacent to the study area.

Except for locally abundant pelmatozoan columnals, fossils generally are uncommon in the Perdido Formation. Langenheim and Tischler (1960) reported a plant, corals, brachiopods, pelecypods, gastropods, and cephalopods, which they interpreted as Late Mississippian in age. Conodonts have been recovered from several parts of the carbonate facies of the Perdido Formation (strata formerly mapped as Lee Flat Limestone) in the Santa Rosa and Darwin Hills (G. C. Dunne, California State University and R. H. Miller, San Diego State University, unpub. data, 1977), which indicate that it is Meramecian in age. Ammonoids from the clastic facies of the Perdido Formation in the Quartz Spring area (loc. 20) have been dated as Chesterian. This unit was placed with the Rest Spring Shale by Poole and Sandberg (1977), who interpreted this entire clastic sequence to be considerably younger than the Perdido carbonate facies.

The environment of deposition of the clastic facies of the Perdido Formation is perhaps better understood than that of the carbonate facies. In the west-central Inyo Mountains (loc. 22), the base of the Perdido Formation is marked by a debris flow containing slide blocks as much as 30 cm in diameter. These deposits are concentrated in submarine channels that previously had been partially filled with bedded radiolarian chert (Stevens and Ridley, 1974). These rocks are overlain by fine-grained clastic rocks and carbonate grain flows and turbidites. To the southeast, the clastic facies of the Perdido Formation is represented by a thin sequence of fine-grained, light-gray quartzite and dark siltstone. In the Inyo Mountains, shale and siltstone beds contain numerous trace fossils similar to those of the *Nereites* community illustrated by Poole (1974), which suggest deep-water deposition. Carbonate debris flows, interbedded with fine-grained clastic rocks, also suggest that the clastic facies was deposited in water considerably deeper than that inferred for the carbonate shelf.

The depositional environment of the carbonate facies is more difficult to interpret. The very fine grained limestone contains few shallow-water indicators except in the Quartz Spring area, where crossbedded, coarse-grained pelmatozoan limestone was reported by Langenheim and Tischler (1960). We believe that rocks of this facies were deposited on a moderately deep water shelf. As this interpretation is based partly on the relationship of the carbonate facies with the overlying Argus limestone, a more complete discussion is deferred.

ARGUS LIMESTONE

Argus limestone is an informal formational name used here for strata in the Argus and Panamint Ranges previously referred to as the Lee Flat Limestone. This unit rests conformably on, and is approximately coextensive with, the carbonate facies of the Perdido Formation. The contact between the two units is placed at a point where upward in the section, the limestone becomes distinctly coarser grained, more pelmatozoan-rich, lighter in color and more massive, and where chert becomes much less abundant. In contrast to the carbonate facies of the Perdido Formation, which thins southeastward, the Argus limestone (fig. 9) thickens southeastward, except at Tucki Mountain (loc. 3).

In most exposures, the Argus limestone contains no fossils other than pelmatozoan columnals, which commonly are so abundant that they form a major part of the formation. In the Santa Rosa Hills (loc. 10), however, a variety of fossils has been recovered, including 3 species of colonial rugose corals, 4 species of conodonts, and 12 species of Foraminifera. Several species of conodonts have also been recovered from the Argus limestone in the southeast Darwin Hills (loc. 8). These fossils indicate that the unit in these areas is mostly, if not entirely, middle Meramecian in age (Dunne and others, 1977). Corals from the Argus limestone in the Panamint Range (Hunt and Mabey, 1966) suggest a similar age for the unit in that region also.

The Argus limestone is believed to have been deposited in shallow water. The unit is characterized by abundant pelmatozoans in well-sorted and well-washed limestone that suggest reworking by moderately strong marine currents or waves. In addition, the abundance of cerioid corals at several horizons in the Santa Rosa Hills (loc. 10) suggests relatively shallow water, perhaps a shelf edge above deeper water to the west, as has been proposed for similar occurrences of Permian cerioid corals (Stevens, 1977).

Fossils show that the Argus limestone and the carbonate facies of the Perdido Formation are partly coeval; lithologic characteristics and geographic position suggest that the calcareous facies of the Perdido Formation is an offshore, deeper water facies of the Argus limestone. Farther northwest, the clastic facies of the Perdido Formation may have been accumulating simultaneously in deeper water. We speculate that the shallow-water Argus limestone prograded westward across the calcareous facies of the Perdido Formation, ultimately reaching the Santa Rosa Hills (loc. 10), but not the Quartz Spring area (loc. 20) or southern Inyo Mountains (loc. 14).

REST SPRING SHALE

According to our studies, the Rest Spring Shale is conformable on the clastic facies of the Perdido Formation in the northwestern part of the area. Thin clastic beds correlated with the Rest Spring Shale rest, perhaps disconformably, on the Argus limestone in the Darwin quadrangle (locs. 7, 10). At the type locality near Quartz Spring (loc. 20), the Rest Spring Shale consists of a lower argillaceous shale, which is olive gray to dark gray when fresh (McAllister, 1952); it grades upward into an upper unit of siltstone to fine-grained sandstone. Possible intraformational conglomerate containing sandstone clasts as much as 5 cm across was reported by McAllister (1952); he also described some beds showing channeling, crossbedding, and ripple marks.

Accurate thicknesses of the incompetent Rest Spring Shale are difficult to measure because this formation commonly is the locus of folding and faulting. At the mouth of Mazourka Canyon (loc. 23), however, a complete section is 535 m thick (Stevens and Ridley, 1974). The formation thins southeastward (fig. 10), while showing an increase in quartz-sand content. In the Argus Range near the apparent limit of deposition, a clastic unit only about 2 m thick may represent the Rest Spring Shale.

Fossils are uncommon in the Rest Spring Shale. Ammonoids occur at several localities, and there are a few occurrences of brachiopods, plants, bryozoans, and microfossils (McAllister, 1952). Merriam (1963) reported similar fossils in the southern Inyo Mountains. Ammonoids in the Inyo Mountains (Merriam, 1963; Ross, 1965) and the Quartz Spring area (McAllister, 1952) are considered Late Mississippian (Chesterian) in age. Chesterian fossils also occur in the underlying clastic facies of the Perdido Formation in the Quartz Spring area (McAllister, 1952), and Derryan (Middle Pennsylvanian) fossils are found near the base of the overlying Keeler Canyon Formation (Meriam, 1963); hence, the formation is Chesterian to perhaps as young as Derryan in age.

Environmental indicators in the Rest Spring Shale are sparse. Trace fossils in many of the western outcrops are similar to those reported by Poole (1974) as representing the *Nereites* community and interpreted to represent relatively deep water. The uniformly fine-grained nature, dark color, and paucity of fossils in most of the area also suggest a basinal environment far from shore. Channeling and crossbedding in the upper part of the sequence in the Quartz Spring area could be features associated with a submarine channel system in deep water, although alternatively they may reflect the onset of shallow-water conditions.

We propose that the basin in which the Rest Spring Shale accumulated was northwest of the edge of the carbonate shelf in the Santa Rosa Hills (loc. 10) and that it deepened northwestward beyond the Inyo Mountains. Thus, this area is inferred to be on the southeastern side of the foreland basin (fig. 6) that lay east of the Antler orogenic highlands (Poole, 1974; Poole and Sandberg, 1977; Speed and Kistler, 1977).

In much of the region, the Rest Spring Shale is divisible into two units here called the lower and upper members of the Rest Spring Shale. The two members generally are found together, and the overall distribution suggests that they are essentially coextensive.

Lower member.—The term Chainman Shale was used in the Inyo Mountains by several workers (Langenheim, 1963; Merriam, 1963; Stevens and Ridley, 1974) for this relatively homogeneous, very dark-gray shale unit. Trace fossils locally are abundant on bedding planes, but other fossils are rare. The section at the mouth of Mazourka Canyon (loc. 22) is the only locality known to us where this unit apparently is structurally undisturbed; here, this member is about 100 m thick (Stevens and Ridley, 1974). This unit, which may constitute the entire Rest Spring Shale at the type section near Quartz Spring, crops out widely in the Inyo and Last Chance Ranges.

Upper Member.—The upper member of the Rest Spring Shale, referred to as the Hamilton Canyon Formation by Langenheim (1962) and Stevens and Ridley (1974), overlies the lower member with apparent conformity. It is composed of dark-brown, blocky-weathering andalusite hornfels, generally containing obscure bedding. The outcrop character, bedding, composition, and color are different from that of the lower member, so the two units normally can be distinguished easily. This unit has been recognized from Tinemaha Reservoir (loc. 24) on the northwest to the Darwin Hills (northwest of loc. 8) on the southeast. It is present throughout the Inyo Mountains and probably is represented in the Last Chance Range in an allochthonous block described by Burchfiel (1969) as andalusite hornfels. Near the mouth of Mazourka Canyon (loc. 22), in an apparently undisturbed section, this unit is about 430 m thick (Stevens and Ridley, 1974).

KEELER CANYON FORMATION

The Keeler Canyon Formation overlies the Argus limestone or Rest Spring Shale everywhere in the area of study. Rich (1977) indicated an absence of earliest Pennsylvanian rocks in this area and Gordon and Poole (1968) reported their absence to the east. If an unconformity is present at the base of the Keeler Canyon Formation, however, it is not conspicuous. Two distinct, predominantly limestone units that differ in lithology and age were combined by Merriam and Hall (1957) to form the Keeler Canyon Formation. Here, the two units are referred to as the lower and upper members of the Keeler Canyon Formation and are described separately.

Lower member.—The lower member of the Keeler Canyon Formation at most locations consists of fine-grained, silty, dark-gray limestone with rounded, very dark-gray chert nodules and some calcareous shale. In the Santa Rosa Hills, Hall and MacKevett (1962) also reported thin limestone conglomerate beds. Fossils are not diverse, but fusulinids and pelmatozoan stems often are abundant, and horn corals and brachiopods occur sporadically. *Fusulinella,* which indicate a Derryan (early Middle Pennsylvanian) age, are reported from the southern Inyo Mountains and Santa Rosa Hills (Merriam, 1963), the Argus Range (Hall, 1971), Tucki Mountain (R. G. Randall, San Jose State University, unpub. data, 1975), and Tinemaha Reservoir (C. H. Stevens, San Jose State University, unpub. data, 1976).

The lower member of the Keeler Canyon Formation crops out throughout the region. Where the Keeler Canyon Formation overlies the Rest Spring Shale, the base is placed at the bottom of the lowest limestone in the predominantly limestone sequence, even though some shale similar to the Rest Spring is found higher in the section along Owens Valley. Where the Rest Spring Shale has not been mapped separately, the dark-gray silty limestone of the Keeler Canyon Formation is easily distinguished from the light-gray Argus limestone below.

The lower member ranges in thickness from a few meters, in parts of the Darwin Hills (loc. 8) and Santa Rosa Hills (loc. 10), to 100 to 120 m in most other areas (fig. 11). Much greater thicknesses are present at Tucki Mountain (loc. 3), where Derryan fusulinids have been collected near the top of a 650-m-thick section, and near Tinemaha Reservoir (loc. 24), where similar fusulinids are found near the top of a 600-m-thick section. In the Santa Rosa Hills, this member is overlain by conglomerate of probable earliest Permian age. Elsewhere, an unconformity above the lower member of the Keeler Canyon Formation apparently separates lower Middle from Upper Pennsylvanian strata; Desmoinesian strata may be missing in most of the area. The overall distribution of thicknesses of the lower Keeler Canyon Formation suggests that uplift and erosion, especially in the Santa Rosa and Darwin Hills area (locs. 10, 7) gave rise to some of these differences. The significance of the very thick sequences on the east at Tucki Mountain (loc. 3) and on the northwest at Tinemaha Reservoir (loc. 24), however, is not understood.

The environment of deposition also is difficult to evaluate. The fine-grained nature of the sedimentary rock, the paucity of fossils, and the stratigraphic position above the Rest Spring Shale or its thin equivalent, however, suggest a relatively deep-water shelf or basinal environment.

Upper member.—The upper member generally is represented in the northwestern part of the area by a calcareous turbidite sequence that presumably was deposited in deep water. Measurements of many flute casts and other directional features in the southern Inyo Mountains (loc. 15) show transport in a S. 55° W. direction, whereas approximately equivalent strata in the Ubehebe mine area (loc. 18) indicate transport southward (Tim Parker, oral

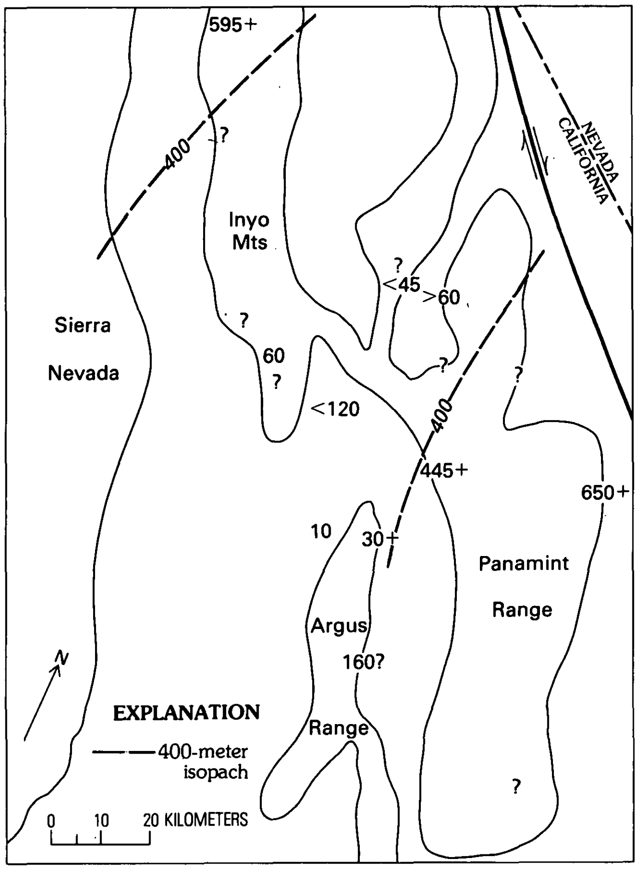

FIGURE 11.—Thickness, in meters, of the lower member of the Keeler Canyon Formation.

commun., 1976). Farther southeast in the Santa Rosa and Darwin Hills (locs. 10, 7), equivalent strata are very thin and conglomeratic. These areas may have furnished much of the debris for the turbidite sequence farther northwest. Still farther southeast, in the southern Panamint Range (loc. 1), coeval rocks are fine grained and contain brachiopods and bryozoans. These beds are interpreted as representing shallow-shelf deposition.

Thickness of the upper member ranges from a few meters to perhaps 1,000 m. Fusulinids are very abundant in the region between Panamint Valley and central Inyo Mountains (loc. 17), and these fossils show that the upper member of the Keeler Canyon Formation is Late Pennsylvanian and earliest Permian in age.

Generally, the upper Keeler Canyon Formation rests unconformably on the lower member, and in one locality in the southeastern Darwin Hills (loc. 8), it rests directly on the Rest Spring Shale.

INTERPRETATIONS AND SUMMARY

Carboniferous rocks in the region between the Sierra Nevada batholith and the Death Valley-Furnace Creek fault zone were deposited west of the western margin of the North American craton (Poole, 1974; Poole and Sandberg, 1977; Rich, 1977). All Carboniferous units of the southeastern part of the area of study were deposited in shallow-marine water, whereas all units in the northwestern part may have been deposited in deep water. In the intervening area (between the south-central Inyo Mountains and the Santa Rosa Hills), depositional environments may have fluctuated from relatively shallow to deep water as influenced by varying combinations of transgression, regression, deformation, and shelf progradation.

Carboniferous deposition began with formation of the dominantly shallow-water Tin Mountain Limestone on a shelf that extended as far northwest as the south-central Inyo Mountains. Tin Mountain deposition may have been terminated by rapid subsidence of the shelf because of eastward growth of the Antler foreland basin. Concurrently, submarine erosion of the Tin Mountain Limestone, localized near the original depositional margin of this unit in the southern Inyo Mountains and Last Chance Range, may have taken place at a relatively deep, hingeline position.

Deposition of the carbonate facies of the Perdido Formation began in moderately deep water on a depressed shelf in the southeastern part of the area; the clastic facies accumulated in deeper water to the west. The carbonate facies of the Perdido Formation may have accumulated relatively slowly, but the rate of deposition was greater than that of subsidence, so that later the shallow-water clastic Argus limestone began to prograde westward across the Perdido carbonate shelf. Progradation of the Argus limestone, however, was terminated before these clastic limestones reached the edge of the shelf.

To the northwest, over all of the area where the clastic facies of the Perdido Formation had been deposited previously, fine siliceous sediment of the Rest Spring Shale accumulated in relatively deep water. Subsidence of the shelf resulted in deposition of a thinner and possibly younger wedge of Rest Spring Shale on the margin of the carbonate shelf in the Santa Rosa Hills and Darwin Hills, a pattern similar to the eastward-spreading flysch sediment reported elsewhere along the eastern margin of the Antler flysch trough (Poole, 1974; Poole and Sandberg, 1977).

Events causing an increase in carbonate production and a decrease in the availability of fine, siliceous, clastic sediment during Early Pennsylvanian time resulted in the change in deposition to limestone in the lower Keeler Canyon Formation in a rather deep-water, carbonate-shelf or basinal environment. During Desmoinesian (Middle Pennsylvanian) time, nondeposition and/or erosion was widespread, but in the Late Pennsylvanian, deposition began again. In the eastern Darwin Hills and Santa Rosa Hills, little, if any, sediment accumulated initially, but to the west, thick sequences of limestone turbidites formed. Deposition in this turbidite basin continued into the Permian without a break. To the southeast, in the southern Panamint Range, deposition of relatively shallow-water shelf carbonates continued.

CARBONIFEROUS ROCKS OF THE EASTERN SIERRA NEVADA

By RONALD W. KISTLER and WARREN J. NOKLEBERG

ABSTRACT

Metamorphosed Carboniferous sedimentary rocks are exposed discontinuously in roof pendants in the eastern Sierra Nevada for about 110 km in a northwest-trending belt that averages about 3 km in width. The original Carboniferous strata were predominantly siliceous and calcareous mudstone and minor limestone, quartz-sandstone, and chert. Identifiable fossils are rare in these rocks, and age assignments in most roof pendants are made on the basis of lithologic correlations with the nearest fossiliferous rocks. The Carboniferous rocks are strongly deformed, and N. 20°–30° W. -trending folds are the dominant structures in all pendants along the belt. The Carboniferous rocks are west of and apparently unconformably overlay adjacent metamorphosed sedimentary rocks of Ordovician and Silurian(?) age. Farther west, the Carboniferous rocks are unconformably overlain by metamorphosed Mesozoic volcanic flows and sedimentary rocks. The regional strike of Carboniferous rocks in the eastern Sierra Nevada transects, at a large angle, regional trends of similar lithologies of the same age that crop out to the east. The transection of these regional trends is probably due either to severe, large-scale tectonic dislocations, or a regional angular unconformity.

INTRODUCTION

Metamorphosed Carboniferous sedimentary rocks are exposed discontinuously for about 110 km in a northwest-trending belt of roof pendants in the east-central part of the Sierra Nevada batholith (fig. 12). This paper summarizes lithologies, fossils, and structures in this belt, and discusses relations of Carboniferous rocks in this and adjacent belts.

PINE CREEK PENDANT

The Pine Creek pendant (fig. 12, loc. 1), mapped and described by Bateman (1965), contains three seemingly conformable units that were correlated with fossiliferous Pennsylvanian and Permian(?) strata in the Mount Morrison pendant exposed about 15 km to the northwest. The basal unit, which consists of about 350 m of pelitic hornfels, micaceous quartzite, and vitreous quartzite, is overlain by about 250 m of marble. The marble unit is overlain by an upper unit consisting of about 1,000 m of micaceous quartzite. The basal unit is intruded by granitic rock, and the upper unit is faulted against metavolcanic rock of Triassic or Jurassic age. The Carboniferous strata are tightly folded, fold axes plunging subhorizontally in vertical axial surfaces that strike about N. 20° W.

MOUNT MORRISON PENDANT

The Mount Morrison pendant (fig. 12, loc. 2), mapped and described by Rinehart and Ross (1964), contains more abundant and better preserved fossils than any other pendant in the eastern Sierra Nevada (Rinehart and others, 1959). The basal Carboniferous unit, the Bright Dot Formation (about 700 m thick) of Pennsylvanian(?) age, is composed of a lower unit of pyritic muscovite, siliceous hornfels, and metachert and an upper unit of calc-silicate hornfels alternating with siliceous hornfels. The Bright Dot Formation shows a gradational to sharp contact with the overlying Mount Baldwin Marble of Pennsylvanian age. This unit is composed of a 165-m-thick, medium-gray or bluish-gray fine-grained marble. Nodular chert is locally abundant and commonly contains impressions of brachiopod and crinoid molds. The Mount Baldwin Marble is conformably overlain by the 165- to 300-m-thick Mildred Lake Hornfels of Pennsylvanian and (or) Permian age. The Mildred Lake Hornfels is predominantly light- to dark-gray, massive siliceous hornfels that weathers red-brown but locally includes abundant greenish-gray calc-silicate hornfels layers. The Mildred Lake Hornfels is conformably overlain by the 300-m-thick Lake Dorothy Hornfels also of Pennsylvanian and (or) Permian(?) age. The Lake Dorothy Hornfels is composed of thin-bedded, microgranular plagioclase-pyroxene-quartz

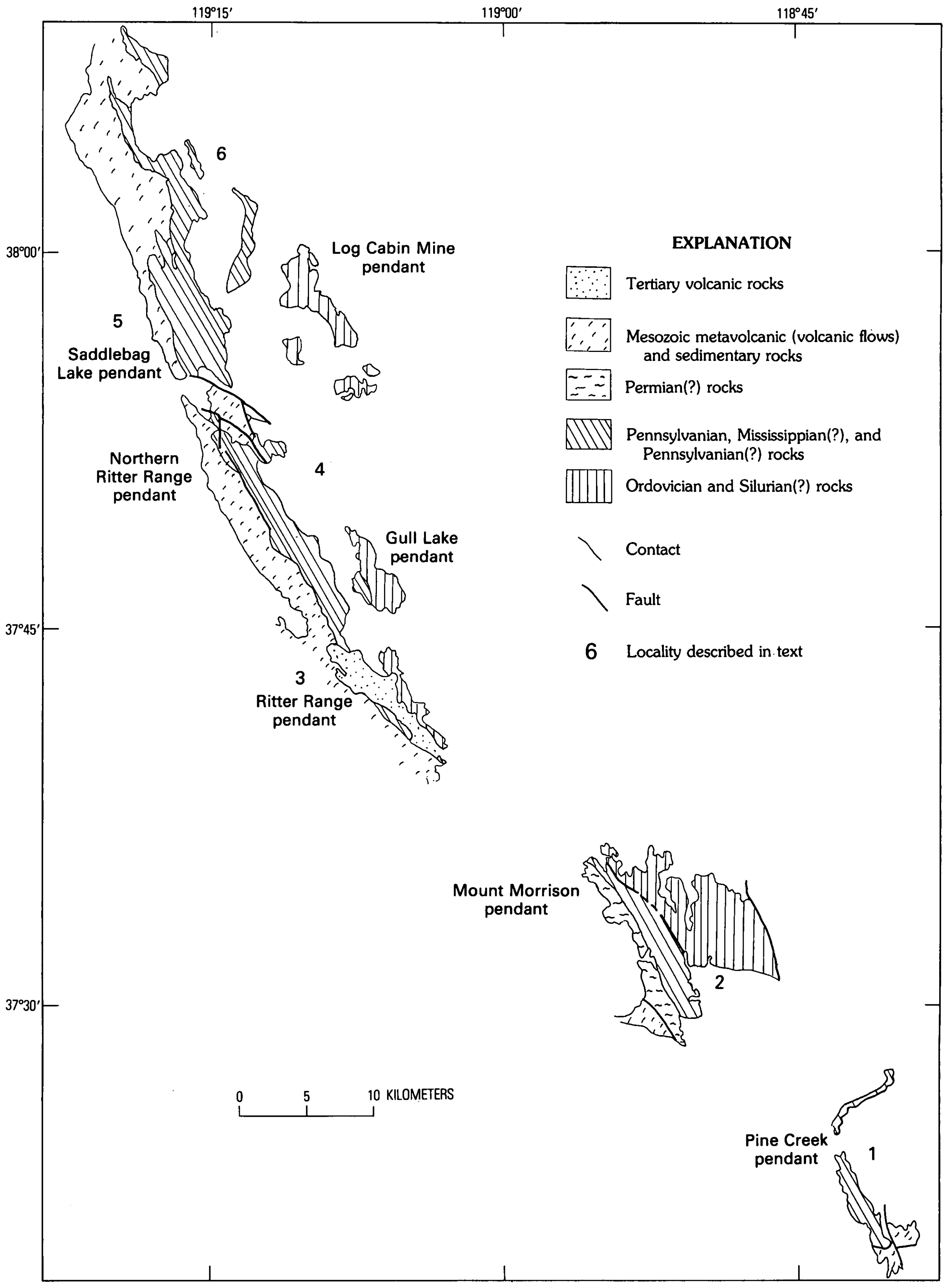

FIGURE 12.—Generalized geologic map showing distribution of Carboniferous rocks and adjacent stratified rocks in roof pendants in the eastern Sierra Nevada, California.

hornfels and alternating grayish-black and yellowish-gray layers that give the rock a striped appearance. The Lake Dorothy Hornfels is conformably overlain by the 1,000-m-thick Bloody Mountain Formation of Permian(?) age. The Bloody Mountain Formation is composed of medium- to dark-gray massive calc-silicate hornfels and siliceous hornfels that weather dark red-brown. Layers of marble are common in some intervals of this formation, and conglomerate lenses are sparse.

The basal Carboniferous unit, the Bright Dot Formation, is faulted against Ordovician and Silurian(?) metasedimentary rock on the east side. The upper unit, the Permian(?) Bloody Mountain Formation, is faulted against Triassic or Jurassic metavolcanic rock on the west side. Rinehart and Ross (1964) mapped tight northwest-trending folds in the Carboniferous rocks, and Russell and Nokleberg (1977), in their structural analysis, described two deformations in the Carboniferous rocks. The first and dominant deformation resulted in upright folds whose axes plunge subhorizontally in vertical axial surfaces striking about N. 20° W. The second deformation resulted in minor upright folds whose axes plunge moderately northwest or southeast in axial surfaces striking about N. 60° W. Rinehart and Ross (1964) and Russell and Nokleberg (1977) noted that the northwest-striking structures in the Carboniferous rocks diverge from the predominantly north-striking structures in the Ordovician and Silurian(?) rocks to the east. Both pairs of authors proposed that the Laurel-Convict fault, which separates the lower and upper Paleozoic rocks, occurred along an angular unconformity.

SOUTHERN RITTER RANGE PENDANT

The south end of the Ritter Range roof pendant (fig. 12, loc. 3), mapped and described by Huber and Rinehart (1965), contains Carboniferous rocks along its east margin. Hornfels and marble in this area were correlated with Pennsylvanian and Permian(?) rocks in the Mount Morrison pendant about 20 km to the southeast. Lithologies in the southern Ritter Range pendant are predominantly moderately well-bedded, dark-gray siliceous hornfels and lesser amounts of interbedded pelitic hornfels, slate, quartzite, chert, and small outcrops of crinoidal marble, similar to the Mount Baldwin Marble. Because of extreme deformation and poor exposure, the stratigraphic sequence is poorly understood. Beds strike about N. 30° W. in the Pennsylvanian and Permian(?) rocks, but strike north in isolated outcrops of Ordovician(?) and Silurian(?) metasedimentary rocks east of the roof pendant. Tertiary volcanic rocks and alluvium conceal the contact between lower and upper Paleozoic rocks. The Carboniferous rocks may be unconformably overlain by Triassic(?) metavolcanic rocks to the west. Fragments and cobbles of the underlying metasedimentary rocks are found in the basal conglomerate of the metavolcanic section (Huber and Rinehart, 1965).

NORTHERN RITTER RANGE AND GULL LAKE PENDANTS

The northern extension of the Ritter Range pendant (fig. 12, loc. 4), mapped and described by Kistler (1966a, b), contains a sequence of bedded quartzofeldspathic hornfels, calc-silicate hornfels, carbonaceous-cherty marble, and chert. These rocks are correlated with the Pennsylvanian and Permian(?) strata of the Mount Morrison pendant. In the central part of the northern Ritter Range pendant, four varieties of crinoids, two brachiopod genera, and one pelecypod genus that were recently found in an encrinal chert, establish a late Paleozoic, possibly Mississippian age (Mackenzie Gordon, Jr., written commun., 1977). In the Gull Lake pendant, Kistler (1966a, b) correlated a carbonaceous marble, a calc-silicate hornfels, quartzite, and quartzofeldspathic hornfels unit, and a marble and calc-silicate hornfels unit with the Pennsylvanian and Permian(?) strata exposed in the Mount Morrison pendant. In contrast, Rinehart and Ross (1964) had correlated these strata with Ordovician and Silurian(?) strata in the Mount Morrison pendant. The original correlation of Rinehart and Ross (1964) is followed here. The contact between the lower and upper Paleozoic rocks is exposed only in the Gull Lake pendant, where the upper Paleozoic (Carboniferous) rocks are now interpreted as resting depositionally on Ordovician and Silurian(?) strata. The Carboniferous rocks are in turn unconformably overlain by Triassic metavolcanic rocks. The basal unit of the metavolcanic rocks is, in some places, a conglomerate containing cobbles similar to lithologies in the underlying Carboniferous sequence. In the eastern Sierra Nevada, the contact between the Mesozoic metavolcanic rocks and the Paleozoic metasedimentary rocks is an angular unconformity that is sheared and locally faulted. Morgan and Rankin (1972) suggested that the contact between these two groups of rocks is everywhere a fault, whereas Brook, Nokleberg, and Kistler (1974) interpreted the contact as an unconformity that is locally faulted.

Carboniferous rocks within the northern extension of the Ritter Range pendant are tightly folded, and the geometry of bedding is dominated by a statistical fold axis plunging gently northwest in a vertical axial surface that strikes N. 30° W. These folds diverge from the folded north-striking strata in the Ordovician and Silurian(?) rocks below.

SADDLEBAG LAKE PENDANT

The Saddlebag Lake pendant (fig. 12, loc. 5), mapped and described by Brook (1977), contains Carboniferous strata consisting of pelitic, quartzofeldspathic, siliceous, and minor calc-silicate hornfels. At the north end of Saddlebag Lake, crinoid fragments and corals recently found in an encrinal limestone were identified by J. W. Durham as possibly Mississippian in age (C. A. Brook, oral commun., 1977). The Carboniferous rocks are tightly folded, the dominant, older folds plunging gently northwest in a vertical axial surface that strikes N. 20° W. The Carboniferous rocks are intruded by Upper Triassic granitic rocks to the east and are unconformably overlain by Permian and Triassic metavolcanic rocks to the west. Fragments and cobbles of the underlying metasedimentary rocks are found in the basal conglomerate of the metavolcanic rock section.

The north end of the Saddlebag Lake pendant (fig. 12, loc. 6), mapped and described by Chesterman (1975) and Chesterman and Gray (1975), was separated into three units: (1) quartzofeldspathic hornfels, calc-silicate hornfels, biotite schist, and minor marble; (2) quartzite, quartzofeldspathic hornfels, metaconglomerate, and minor calc-silicate hornfels; and (3) mineralized encrinal limestone containing crinoid stems of probable Carboniferous age. These three lithologic units unconformably overlie Ordovician and Silurian(?) metasedimentary rocks and are unconformably overlain by Triassic metavolcanic rocks. The contacts with older and younger wallrock units, however, are obliterated by granitic intrusions.

SUMMARY

In the eastern Sierra Nevada, Carboniferous rocks of Mississippian(?) and Pennsylvanian age crop out in a northwest-trending belt approximately 110 km long, but averaging only 2 to 3 km in width. Everywhere to the east, the adjacent stratified rocks are older and include either Ordovician, or Ordovician(?) and Silurian(?) metasedimentary rocks. Everywhere to the west, the adjacent stratified rocks are Triassic and (or) Jurassic metavolcanic rocks. In the Mount Morrison pendant, the Permian(?) metasedimentary rocks are found between Carboniferous rocks and Mesozoic metavolcanic rocks to the west. Permian metasedimentary rocks may be found in all the pendants. Fossils useful in dating the rocks are absent.

Lithologies in the Carboniferous belt are predominantly quartzofeldspathic, siliceous, and calc-silicate hornfels. Marble, quartzite, conglomerate and chert are sparse. Weathering of disseminated pyrite, common in quartzofeldspathic hornfels, imparts a red-brown color to these otherwise dark-gray rocks. Volcanic rocks are not recognized in this Carboniferous sequence. A minor facies change may be manifested by more abundant quartz sandstone in the southern part of the belt. Sparse diagnostic fossils indicate that the northern part of the belt may include Mississippian rocks not recognized to the south.

Carboniferous strata in the eastern Sierra Nevada are tightly folded, and detailed structural studies in several of the pendants indicate at least two episodes of deformation (Brook, 1977; Kistler, 1966a; Russell and Nokleberg, 1977). The more prominent and older deformation is defined by trends of lithologic units, structural geometry of bedding, major folds, faults, and related minor structures. The most pronounced structures of the older deformation are tightly appressed folds having subvertical axial surfaces that strike N. 20°–30° W. and fold axes that plunge subhorizontally or gently northwest. This deformation, which also folded the unconformably overlying Triassic metavolcanic rocks, took place during the Middle Triassic. This timing is defined in the Pine Creek pendant where N. 20°–30° W.-trending major folds were intruded and warped by forceful emplacement of Upper Triassic plutons (Bateman, 1965; Evernden and Kistler, 1970). Folds of similar style and orientation in the Saddlebag Lake and northern Ritter Range pendants are intruded by Upper Triassic plutons in the Mono Craters quadrangle (Kistler, 1966a; Evernden and Kistler, 1970).

The abrupt eastern boundary of outcrops of Carboniferous rocks in some places is parallel to the dominant N. 20° W. trend of folds and faults in the belt. In the Mount Morrison pendant, the eastern limit of Carboniferous rocks is a major fault. Rinehart and Ross (1964) suggested that this contact of Carboniferous rocks with adjacent Ordovician and Silurian(?) rocks is a faulted unconformity because north-striking bedding and folds in the lower Paleozoic rocks sharply diverge from northwest-striking bedding and folds in the upper Paleozoic rocks. This structural divergence between lower and upper Paleozoic rocks is found along the entire belt.

REGIONAL CONSIDERATIONS

The regional strike of Carboniferous rocks in the eastern Sierra Nevada transects, at a large angle, regional trends of similar rocks of the same age (Poole, 1974; Stevens, 1977; Speed, 1977), the western limit of ensialic continental crust (Kistler and Peterman, 1978), the trace of the Golconda allochthon (Speed, 1977), and the Permian volcanic-arc terrane of Speed (1977) (fig. 13). The transection of these regional trends is probably due to severe, large-scale tectonic dislocations. Considerable tectonic transport is indicated by observations made in the southeast in the Inyo Mountains, where the pre-Middle Jurassic allochthon of the Inyo thrust includes Pennsylvanian and Permian strata (Stevens and Olson, 1972). Triassic emplacement of the Inyo allochthon and deformation of the Carboniferous rocks in the eastern Sierra Nevada are possibly contemporaneous. If the folding and thrusting were contemporaneous, the northwest-trending contact of the Carboniferous rocks with the lower Paleozoic rocks in the eastern Sierra Nevada may be tectonic. If so, the Carboniferous strata were transported from the west to their present position. Similarities of Carboniferous fossils in the eastern Sierra Nevada with Carboniferous fossils of the platform facies in the Great Basin to the east, however, suggest that any thrust displacement need not have been great.

An alternative explanation for the northwest-trending contact between the Carboniferous and Ordovician and Silurian(?) metasedimentary rocks in the eastern Sierra Nevada is a locally faulted regional angular unconformity. A similar regional angular unconformity was described by Speed (1977) for a continental borderland terrane (fig. 13) in northwestern Nevada, west of the Mississippian Antler foreland basin of Poole (1974) and Poole and Sandberg (1977). In this terrane, Pennsylvanian and Permian terrigenous clastic and carbonate rocks were deposited unconformably on deformed lower Paleozoic rocks of the ancestral Antler orogenic belt. The Carboniferous belt in the eastern Sierra Nevada has a similar unconformable relation to the underlying lower Paleozoic rocks. If the Carboniferous strata in the eastern Sierra Nevada are correlative with the continental borderland terrane

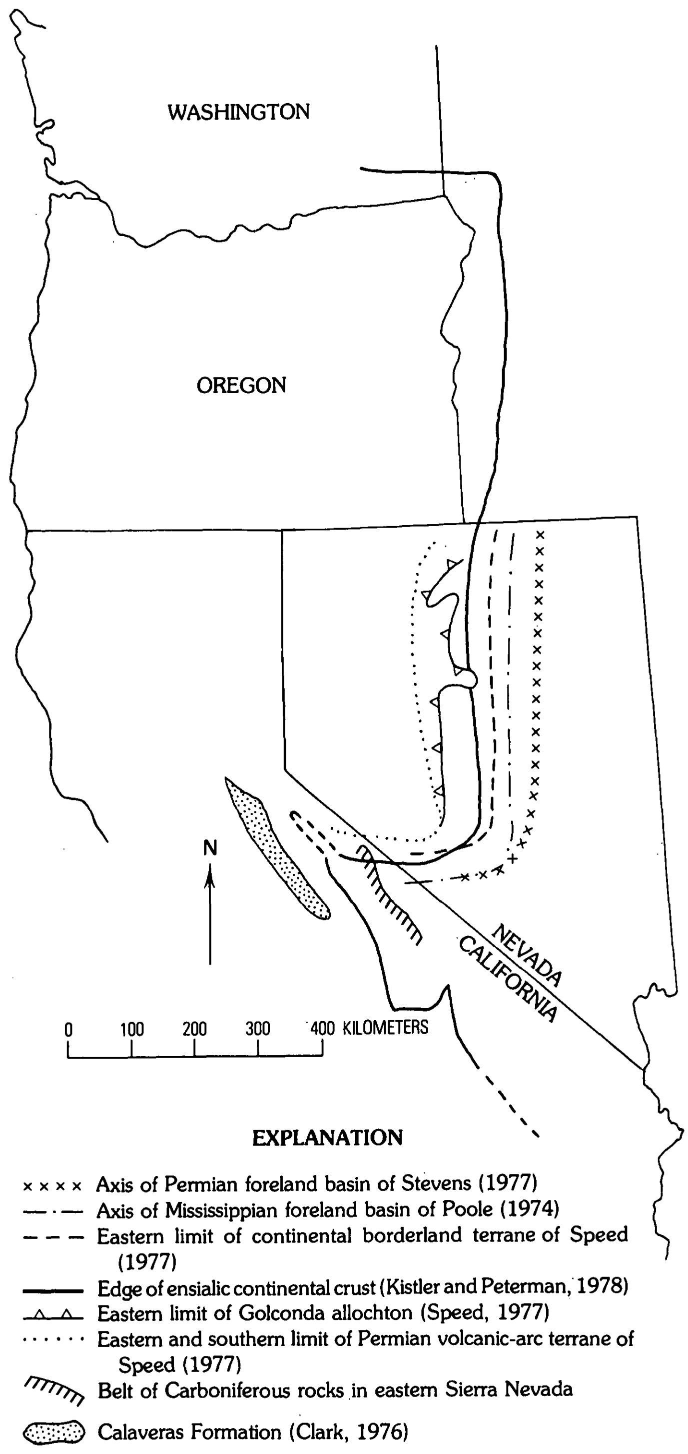

FIGURE 13.—Diagram showing relation of belt of Carboniferous rocks in the eastern Sierra Nevada to adjacent belts of similar age.

of Speed (1977), they need not have been thrust from the west to their present position.

The Calaveras Formation of Carboniferous age is found to the west in a northwest-trending belt in the foothills of the central and northern Sierra Nevada (Clark, 1976) (fig. 13). The main mass of the Sierra Nevada batholith separates the two belts. The lithologies and deformational histories of the two belts differ greatly. Further studies are required to explain these strong differences in parallel-trending belts of Carboniferous rocks.

CARBONIFEROUS ROCKS OF THE NORTHERN SIERRA NEVADA, CALIFORNIA

By JAD A. D'ALLURA and ELDRIDGE M. MOORES

ABSTRACT

Paleozoic rocks of the northern Sierra Nevada are present in two belts, an eastern and a western, separated by a peridotite belt, the last possibly partly of late Paleozoic age. In the eastern belt, Carboniferous rocks are represented mainly by a chert-epiclastic sequence intercalated between thick upper Devonian(?)-Mississippian and Permo-Triassic andesitic volcanic sequences. This stratigraphic sequence may reflect island-arc volcanism in Devonian time, formation and subsidence of a remnant arc in Carboniferous time, and renewal of arc volcanism in Permian time.

Known Carboniferous rocks in the western belt are limited to isolated exposures of carbonate rocks, which generally represent exotic blocks in a chaotic deposit.

INTRODUCTION

In the northern Sierra Nevada, Paleozoic rocks are present in two main terranes, the eastern and the western belts (see fig. 14). The eastern belt (figs. 15 and 16) is best known north of lat 38° 30′ N., where it consists generally of a stratigraphic sequence, from bottom to top as follows (fig. 15): a pre-Devonian sequence consisting of quartzose sandstone, lithic sandstone, phyllite, chert, limestone, and minor volcanic mafic and ultramafic rocks generally assigned to the Shoo Fly Formation and its equivalents, overlain by Devonian-Carboniferous, Permo-Triassic, and Jurassic volcanic-sedimentary sequences. The eastern belt is bordered on the west by the Feather River peridotite belt, a 15 × 150-km belt of metamorphosed ultramafic and associated mafic rock. The only published radiometric age date on igneous rocks in this belt is a single Pb-U date of 300 m.y. on an albitite (Weisenburg and Ave Lallemant, 1977). West of this peridotite belt and its possible southeast extension (see fig. 14), rocks of Carboniferous age are present in a generally chaotic unit, referred to as the Calaveras complex (Schweickert and others, 1977). These terranes as herein defined differ significantly from the original usage of Diller (1908) and Turner (1897) and follow more closely that of Heitanen (1974, 1976) and Moores (in press).

EASTERN BELT

In the northeastern Sierra Nevada, pre-Late Jurassic rocks consist of a 120-km-long exposure of thick volcanic-sedimentary sequence (figs. 14, 15, and 16), which was isoclinally folded and thrust eastward during the Late Jurassic "Nevadan" deformation. All rocks generally show greenschist-facies metamorphic assemblages, as well as relict mineralogy of the original rocks. Primary textures are largely preserved and facilitate paleoenvironmental reconstruction. North of the Lakes Basin area (fig. 14), the rocks crop out in two structural blocks separated by the Grizzly Mountain fault. Near and south of the Lakes Basin, the rocks form a single belt that dips steeply to the east.

Carboniferous rocks in this part of the Sierra Nevada belong primarily to the Peale Formation (Diller, 1908; McMath, 1966), though part of the over- and underlying rocks may also be of Carboniferous age (see fig. 15). Peale rocks grade into the over- and underlying volcanic sequences (see fig. 15). They include deposits of both submarine and possibly subaerial volcanic rocks and nonvolcanic chert, slate, lithic wacke, breccia, and conglomerate. The thickness of the unit is variable but ranges from a minimum of less than 480 m to a maximum of more than 1,100 m (Diller, 1908; Turner, 1894, 1896, 1897; Lingren, 1900; Durrell and Proctor, 1948; McMath, 1966; Durrell and D'Allura, 1977; and D'Allura, Moores, and Robinson, 1977).

PEALE FORMATION

The Peale Formation has been divided into two members: the lower one is composed primarily of feldspar-phyric trachyte or (quartz) latite flows, tuff, and breccia; the upper unit is composed of manganiferous chert and epiclastic sedimentary rocks as well as local pyroclastic rocks (McMath, 1966; D'Allura, 1977). Neither member is equally thick or represented in all areas.

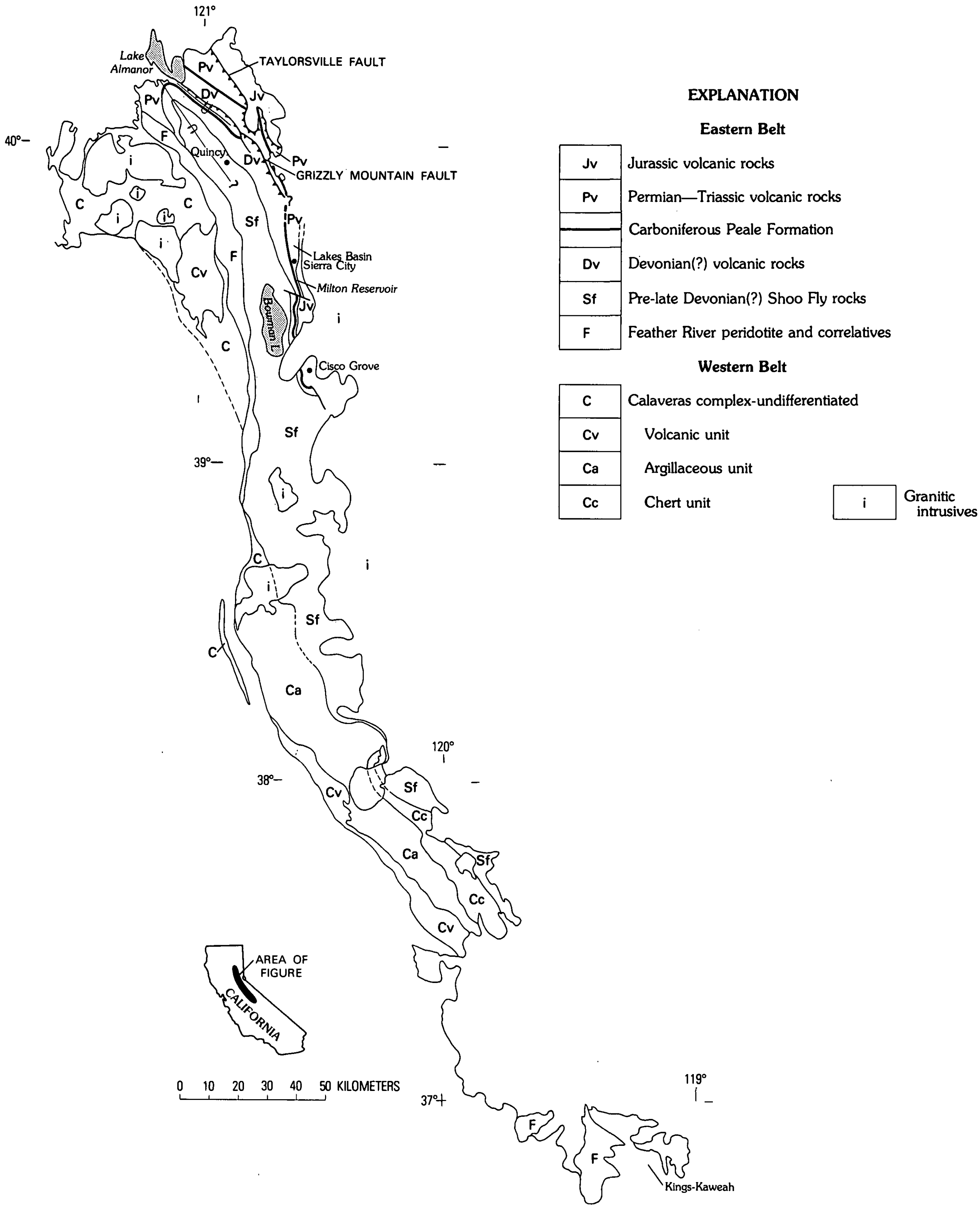

FIGURE 14.—Generalized map of prebatholithic units, northern Sierra Nevada, California.

FIGURE 15.—Simplified description of Paleozoic rocks of the northeastern Sierra Nevada, California.

Formation	Description	
Robinson	Gray or black, green andesitic wacke, conglomerate, or breccia; some calcareous horizons. Permian fossils found in Taylorsville area.	Arlington-green volcaniclastic sandstone, shale, mafic volcanics, silicic tuffs.
Reeve	Gray to dark green andesitic flows, pillows, and volcaniclastic rocks; characterized by large platey plagioclase phenocrysts. Middle Permian fossils found in Taylorsville and Quincy areas as well as northeast of the Lakes Basin area.	
Goodhue	Dark green to nearly black andesitic basalt pillows, breccia and tuff; augite, plagioclase, and pseudomorphed olivine phenocrysts. Late Pennsylvanian to Early Permian fossil found in boulder, Lakes Basin area.	
Peale		
upper member	Upper calcareous horizon, conglomerate or breccia, lithic wacke and purple siltstone overlying red, gray, white, or black chert; some volcanic admixture; composition variable. Early Mississippian fossil found at base of unit in Taylorsville area; Early Permian fauna in probable upper member rocks, Bowman Lake area.	
lower member	Dark gray to black or green trachyte to (quartz) latite flows, pillows, and volcaniclastic rocks; locally contains pink alkali feldspar phenocrysts.	
Taylor	Green andesite pillows, flows and volcaniclastic rocks; augite, diopsidic augite and plagioclase phenocrysts.	
Elwell	Black chert containing phosphate nodules; silicic and andesitic volcaniclastic rocks. Late Devonian fossils, Lakes Basin area.	
Sierra Buttes	Light green dacite and rhyolite volcanic rocks.	
Shoo Fly	Quartz wacke, pelitic rocks, and chert. Locally contains ultramafic rocks and serpentinite.	

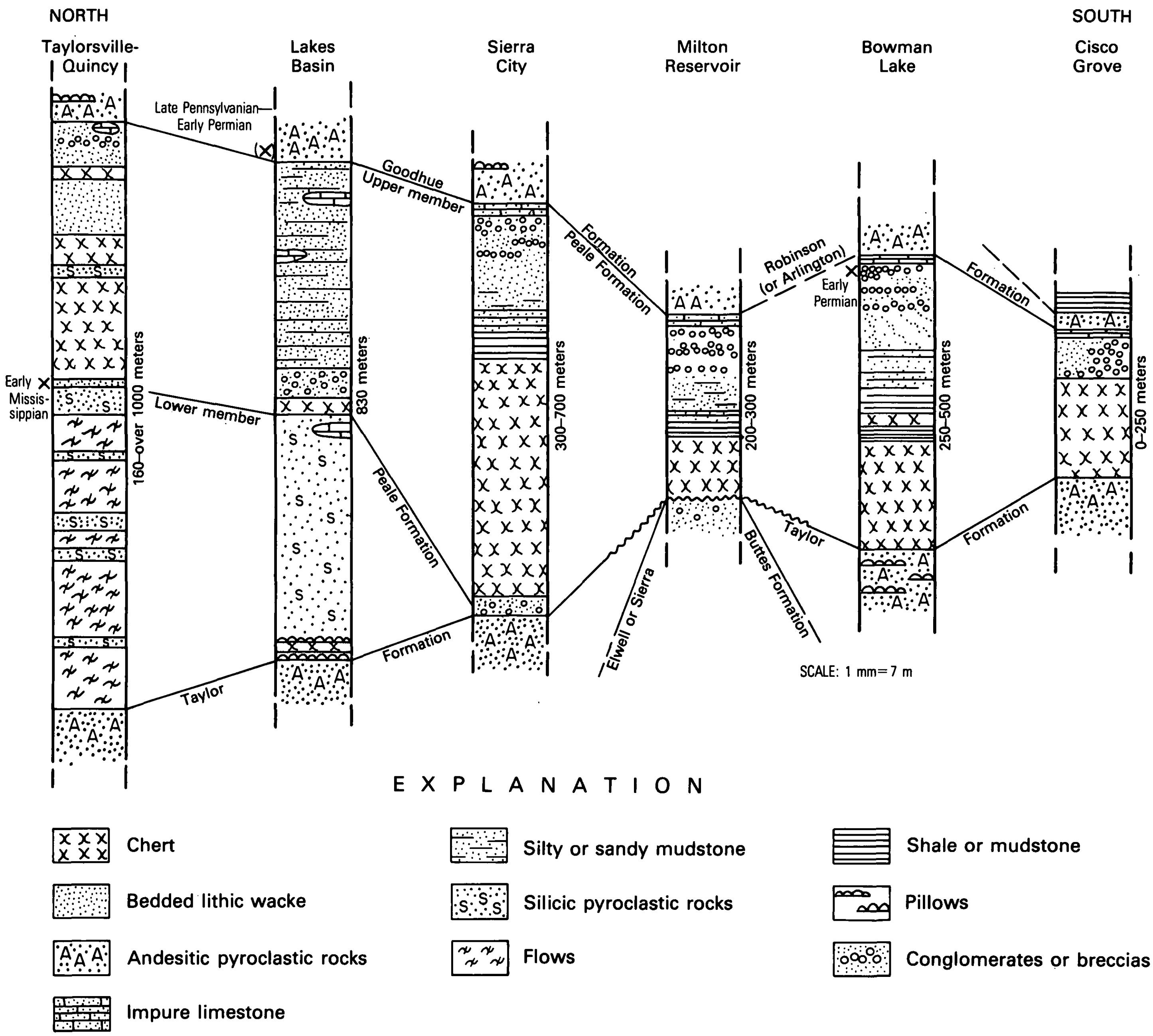

FIGURE 16.—Generalized correlation section of Carboniferous rocks from Taylorsville to Cisco Grove area, northeastern Sierra Nevada, California. Rock types are highly variable in most areas and are only schematically shown. Thickness of the calcareous unit is highly exaggerated.

LOWER MEMBER

Silicic volcanic rocks of the lower member of the Peale Formation intrude and overlie Taylor andesite. The thickness of this unit ranges from zero to more than 1,000 m. Purple-black and dull-gray to pale-green trachyte or (quartz) latite dikes, flows, and pyroclastic rocks are most common, though the character of the rocks changes from area to area. Most rocks are characterized by small phenocrysts of equant to lath-shaped white to pink alkali feldspars in an aphanitic groundmass.

Exposures of the lower member are restricted from the Lakes Basin north; the unit is best exposed in three areas: in the Lakes Basin, east and northeast of Quincy, and south of Lake Almanor. On both sides of the Grizzly Mountain fault, north of lat. 40° N., the lower member consists of flows and comagmatic breccias. East of the fault, pink feldspar-bearing, light- to moderately green tuff and breccia dominate to the north, whereas purple-black, fine-grained shallow intrusive and extrusive rocks containing minor amounts of pyroclastic rock are most common to the south. In the Lakes Basin, lower Peale rocks are composed of reddish-purple to black pillow lava overlain by graded silicic tuff and volcanic breccia (Durrell and D'Allura, 1977). Except for some thin beds of ash and volcanic breccia east of Sierra City, lower member rocks do not crop out south of the Lakes Basin.

Three probable vent or near-vent facies have been recognized—one 11 km north-northeast of Quincy, another 16 km east of Quincy, and a pillowed locality in the Lakes Basin area. The former two areas are characterized by fine-grained shallow sills and dikes, flows, and comagmatic pyroclastic rocks.

In thin section, most feldspar is pink, perthitic, or anti-perthitic, although small white albitized plagioclase laths also are common in some areas. The pink or red color results from minute hematite inclusions. The groundmass may show aphanitic or trachytic textures but is invariably largely recrystallized to mosaics of quartz and albite with muscovite, magnetite, and hematite. Calcite and ferrostilpnomelane are common accessory minerals. Micropoikilitic quartz and albite which has probable perlitic or orb texture is preserved by dusty halos of ferrostilpnomelane; these features suggest that at least a few of the rocks were originally glassy. The dark-gray to black or green color in the rocks results from abundant magnetite or ferrostilpnomelane or green biotite, respectively. Chemically the rocks are quartz normative, although modal quartz is rare. Quartz veins or accumulations are common locally and suggest silicification, the finer grained pyroclastic rocks having been most affected.

UPPER MEMBER

The upper member of the Peale Formation consists of a distinctive assemblage from bottom to top of chert, clastic rocks, and calcareous deposits. Each of these rock types provides the basis for a separate unit, as described below. The proportion of rock types, as well as the clast type in the clastic unit, varies from place to place.

Chert unit.—In the lowest of the three units of the Peale upper member, chert is the most common and laterally continuous rock type, ranging in thickness from 20 to 350 m. The chert may be red, purple, green, gray, black, or white. In places, for example, east of the Grizzly Mountain fault east of Quincy, this unit constitutes a minor part ($1/16$ to $1/8$) of the member, whereas elsewhere, for example, south of Bowman Lake, it dominates the section.

The chert beds generally range in thickness from 10 to 30 cm and are commonly interbedded with thin shale or silty shale. In places, the chert is associated with syngenetic manganese deposits. In some areas, for example, south of Bowman Lake, silty mudstone beds are abundant towards the top of the member. Penecontemporaneous deformation structures are relatively common in both the chert and interbedded fine-grained clastic rocks.

Poorly preserved relict Radiolaria exist in thin section as clear mosaics of quartz. The rocks carry variable amounts of biotite or ferrostilpnomelane.

Clastic unit.—Clastic rocks as much as 350 m thick overlie the chert unit in all areas. They consist of slate, phyllite, lithic and volcanic wacke, and conglomerate and breccia.

Though variable in extent and thickness, the clastic rocks increase in importance toward the south and are especially important near Bowman Lake (where fossils have been discovered in rocks tentatively assigned to this unit). North of the Lakes Basin, olive-drab to black or maroon slate and subordinate volcanic or lithic wacke and tuff make up this unit, which is slightly thinner than the underlying chert unit. In the Lakes Basin area, the unit is represented by 350 m of dark, partly calcareous chloritic slate overlying a thin chert unit. South of the Lakes Basin, silty mudstone, purple muddy siltstone, and lithic wacke with lenses of pebble conglomerate or breccia dominate the Peale exposures.

Most clasts are intraformational, composed of white or gray chert and purple to dark-green siltstone or mudstone. However a small percentage (generally 5 percent or less) of coarser grained nonintraformational clasts are present in all areas.

Though seldom abundant, clasts derived from underlying volcanic units are locally present. Purple volcanic clasts typical of the lower member of the Peale are found in and north of the Lakes Basin area. Clasts of typical bipyramidal quartz-bearing Sierra Buttes dacite and augite-rich green Taylor andesite are sparsely present everywhere and are abundant south of Taylorsville and southeast of Bowman Lake. Clasts of quartz wacke and veined gray to black chert, probably derived from the Shoo Fly Formation, are ubiquitous but are most common near and south of Bowman Lake.

Other clasts not derived from any exposed or recognized units are scattered through the section. These clasts include, in order of decreasing abundance, volcanic rock fragments, fine- to medium-grained diorite, gabbro, and pink granite. Volcanic rock fragments in this group are dominantly silicic in composition, although andesitic or basaltic clasts are common. Amygdaloidal structure in andesites and rare perlitic structure in silicic rocks are preserved.

The volcanic and plutonic clasts dominate at the fossil locality northeast of Bowman Lake. There, amygdaloidal andesitic volcanic rocks, porphyritic green and purple silicic volcanic rocks, purple siltstone, abundant green or red chert typical of the underlying Peale chert, medium-grained plutonic rocks, and minor but significant carbonate organic debris constitute the bulk of the clasts. Although, except in the uppermost beds, clastic hornblende is a rare or subordinate phase in the matrix of most of the conglomerate or breccia beds, it is common in the area south of Milton Reservoir. This hornblende-bearing breccia or conglomerate probably interdigitates with hornblende tuff of the overlying Goodhue Formation. These rocks are probably part of the Peale, not the Goodhue, though their stratigraphic position is by no means certain.

Calcareous unit.—In most areas south of the 40th parallel, a calcareous unit forms the top of the upper member of the Peale Formation. Nowhere more than 35 m thick, this unit consists of gray silty limestone (marble and calc-silicate rock near plutons) containing scattered clasts of angular to subrounded rock fragments, the latter including chert. East of Quincy, the unit is represented by a discontinuously exposed skarn in a roof pendant of a quartz diorite pluton, or by a sparsely calcareous zone east of the Grizzly Mountain fault. East-southeast of Sierra City, the unit is 4–10 m wide and consists of calcareous rocks interbedded with basaltic wacke and chert. At the fossil locality near Bowman Lake, the unit is represented by fossiliferous limestone lenses intercalated with the upper conglomeratic beds of the clastic unit. The unit is not present 2.5 km southeast of Bowman Lake, but it reappears near Cisco Grove.

TAYLOR AND GOODHUE-ARLINGTON FORMATIONS

As parts of the underlying Taylor Formation or the overlying Goodhue-Arlington Formations may have been deposited in Carboniferous time, a brief discussion of them is in order.

The Taylor is composed of pyroxene-bearing basaltic andesite and andesite tuff, volcanic wacke, and breccia. Its composition varies from base to top and from place to place. However, it is generally more mafic in its lower part and more silicic toward the top. A greater volume of silicic andesite in the Lakes Basin area and a more mafic composition than usual in the Bowman Lake area are exceptions to the above trend. Local vents marked by accumulations of pillows and coarse breccia are present southwest of Taylorsville, in the Lakes Basin area, and east and south-southeast of Bowman Lake. The volcanic deposits decrease in grain size west of the Grizzly Mountain fault from Taylorsville north, and south of Cisco Grove.

The basal part of the Goodhue Formation in the Lakes Basin area is composed of green hornblende andesite tuff and fine volcanic breccia. The thickness of this basal unit varies. The unit is present in significant amounts mainly east of Quincy, in the Lakes Basin area, and locally as fine- to medium-grained tuff near Milton Reservoir.

The rocks above the basal hornblende-bearing unit are dark-green olivine pyroxene basalt and andesitic basalt tuff, volcanic wacke, breccia, and flows. The olivine, which commonly shows a good crystal habit, has been totally altered to various metamorphic mineral assemblages including serpentine, epidote, hornblende, ferrostilpnomelane, biotite, and chlorite.

The Goodhue formation generally is present east of the Grizzly Mountain fault from Taylorsville south, and from Quincy south to Milton Reservoir. West of the fault and north of Quincy, the Peale is overlain by rocks assigned to the Arlington Formation.

Arlington rocks consist chiefly of graded volcanic wacke deposits, which in some places show abundant bottom markings. They generally become finer grained and bedded from around Mt. Hough northwestward towards Lake Almanor.

In the exposures south of Milton Reservoir, no rocks are assigned to the Goodhue Formation. However, in this area, thin beds of green fine-grained tuff crop out below easily recognized younger Reeve rocks (see fig. 15) and correlate with andesitic tuff and volcanic wacke that overlie gradationally the upper calcareous unit of the Peale in the Bowman Lake and Cisco Grove areas. Possibly much of this andesitic material may be upper Paleozoic and may be correlative with the Robinson (or Arlington) Formation.

CONTACTS

The contacts between the Peale and the overlying and underlying units appear generally conformable and gradational. The basal contact with the Taylor is intrusive in places but is mostly depositional, marked by a change in volcanic-rock composition.

From the relations described above, clearly the upper contact of the Peale with the overlying volcanic deposits is gradational and complex. Where the contact with the Goodhue is exposed, chert or clastic (or calcareous) rocks are interbedded with crystal-vitric or hornblende basaltic or andesitic tuff, the latter of which grades in turn into dark-green olivine basalt typical of the Goodhue Formation. Where overlain by Arlington rocks, the contact is again gradational, and placing the contact between clastic rocks of the Peale and those of the overlying Arlington is difficult.

Southeast of Bowman Lake, the upper calcareous conglomerate-breccias or breccia-conglomerates are interbedded with green silicified tuff and crystal-lithic tuff of probable Arlington (or Robinson) equivalent volcaniclastic rocks. However, to the south, the Peale rocks are eroded. Here the Arlington(?) volcaniclastic rocks lie directly over the fine-grained purple lithic wacke and silty mudstone with a moderate angular unconformity. The basal volcaniclastic rocks contain rounded pebbles of chert, quartzite, and some aphanitic volcanic rock fragments derived from preexisting rocks.

BIOSTRATIGRAPHY

Fossils in the volcanic-sedimentary complex of the northeastern Sierra Nevada are scarce, and precise age assignments are not possible. However, rock units apparently transgress the boundaries of the Carboniferous System. The volcanic rocks of the Peale lower member and of the Taylor Formation are undated and may be partly or wholly Late Devonian or Early Mississippian in age. The rocks of the Peale upper member contain undated radiolaria; however, these rocks may range in age from Early Mississippian to possibly Early Permian, on the basis of two fossil localities, separated by 70 km.

Near Taylorsville, McMath (1966) discovered an Early Mississippian brachiopod fauna close to the base of the upper member of the Peale Formation. An undescribed trilobite from the same locality also suggests a similar age (McMath, written commun., 1973). East of Bowman Lake, fusulinids, including a single specimen of *Triticites*, several specimens of *Schwagerina* generally similar to *S. diversiformis*, and a specimen that is probably *Thompsonella*(?) (C. A. Ross, written commun., 1975) were found in the matrix of a chert and volcanic breccia-conglomerate near the top of the upper member (D'Allura and others, 1977). The fauna, which suggests an Early Permian age, may have been reworked from older sediments, but the possibility seems remote as the fossils are discrete entities, have not been silicified, and are associated with individual bryozoan, crinoid, and coral(?) fragments.

The rocks of the basal Goodhue Formation have been dated tentatively as Late Pennsylvanian to Early Permian on the basis of the transported fossil *Helicoprion sierrensis* (Durrell and D'Allura, 1977). Hence Goodhue and Peale rocks may be partly time equivalent.

ENVIRONMENTAL INTERPRETATION

The volcanic-sedimentary rock sequence of which the Taylor, Peale and overlying rocks are part, probably reflects the existence of two volcanic island-arc sequences, one of probable Devonian-Mississippian age (Taylor, lower Peale) and one of probable Permo-Triassic age (Goodhue, Reeve, Arlington) (D'Allura and others, 1977). Hence, earliest Carboniferous time probably was marked in this region by arc-type volcanism.

The gradation from the volcanic lower Peale to the upper Peale, which contains radiolarian chert and some manganese deposits, suggests that in Carboniferous time, arc-type volcanism gradually yielded to a period of pelagic sedimentation marked by only sporadic volcanism (represented by scattered volcanic beds in the chert unit).

The succeeding gradation in the upper Peale from chert to clastic rocks with intercalations of coarse, mostly locally derived, debris suggests increasing crustal instability or a shifting locus of crustal instability. The lenticular nature of individual units, the changes over short distances of thickness and lithology of the clastic unit, and the presence of turbidite or grain flow deposits, suggest local relief possibly within an area of fault-bounded highs and basins. That this relief was not constructional in origin is suggested by the relatively minor volcanic activity. The source of plutonic and some volcanic-rock clasts remains unknown, although it conceivably may have been partly the Feather River peridotite belt to the west.

The gradation in turn from epiclastic deposits to tuffaceous rocks of the overlying Goodhue-Arlington Formations, suggests the gradual onset of volcanism of the Permo-Triassic arc complex after these structural disturbances.

In an earlier article (D'Allura and others, 1977), we proposed a plate-tectonic model whereby the cessation of arc volcanism, followed by pelagic sedimentation, then renewed arc volcanism, represented the formation and subsidence of a remnant arc (Karig, 1974). The range in fossil dates for this cessation in volcanism includes the time of the Antler orogenic episode in central Nevada (Silberling and Roberts, 1962).

WESTERN BELT

Recent work on the western or Calaveras terrane indicates that much of it is made up of a partly chaotic sequence of rocks. Schweickert and others (1977) have separated the Calaveras into a series of units, from west to east, as follows: a volcanic unit composed of mafic pillow lava, pillow breccia, tuff breccia, and bedded tuff, which interfingers locally with so-called "slaty mudstone and diamictite"; an argillite unit, dominantly clastic, composed of meter- to kilometer-sized fragments of quartzite, chert, calcareous rocks, and argillaceous sedimentary rocks; a chert unit, characterized by thick sequences of well-bedded, rhythmic chert containing black argillaceous partings which interfingers with "diamictite"; a quartzite unit, composed of well-bedded quartzite and quartz-rich sandstone, interfingering with chaotic units.

Regional correlations and reconnaissance suggest, however, that the eastern quartzite unit in the southern and central Sierra Nevada may be a southern extension of the Shoo Fly rocks of the eastern belt (Moores, in press); the contact between the western and eastern belts possibly is a suture represented in part by a mylonite zone (Schweickert, 1977) and in part by the Feather River ultramafic belt. This suggested correlation is illustrated on figure 14. One complication with this suggested picture is the possible correlation of the Feather River peridotite with the Carboniferous Kings-Kaweah ultramafic complex to the south (Saleeby, 1977) which is *west* of the main Calaveras terrane, rather than *east* of it, as is the Feather River peridotite.

Most fossiliferous limestone inclusions and masses reflect shallow-water deposition. They yield Carboniferous or Permian fossils, but no systematic distribution of ages within these blocks has been recognized. These limestone blocks and the chaotic units that include them represent either submarine landslide deposits derived from carbonate-bearing volcanic islands or (Schweickert and others, 1977) the juxtaposition of diverse rocks in an accretionary prism.

ACKNOWLEDGMENTS

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CARBONIFEROUS ROCKS OF THE EASTERN KLAMATH MOUNTAINS, CALIFORNIA

By RODNEY WATKINS

ABSTRACT

The Carboniferous System is represented in the eastern Klamath Mountains of California by the Bragdon Formation and the conformably superjacent Baird Formation. Both formations are sparsely fossiliferous. The Bragdon Formation conformably overlies the Middle Devonian Kennett Formation and, where the Kennett is missing, the pre-Kennett Balaklala Rhyolite. The Bragdon Formation consists primarily of argillite, locally prominent volcaniclastic facies, and minor shelly siltstone. The fossil faunas are Late Mississippian in age. The Baird Formation is conformably overlain by the Lower Permian McCloud Limestone. The Baird Formation consists mainly of volcaniclastic rocks and minor amounts of argillite, shelly siltstone, chert, greenstone, and limestone facies. The fossil faunas range in age from Late Mississippian through Pennsylvanian to Early Permian.

The Bragdon and Baird Formations record a shoaling throughout Carboniferous time. Upward increase in wacke beds in the argillite indicates change from distal to proximal turbidite deposition. The distribution of volcaniclastic facies suggests episodic deposition from local shifting source areas, such as volcanic islands, during a transition from basin and slope to shelf conditions.

The fauna of the two formations—mainly brachiopods, crinoids, bryozoans, mollusks, and corals—is part of an Asiatic province and has few species in common with typical Carboniferous faunas of North America.

INTRODUCTION

The Carboniferous System is represented in the eastern Klamath Mountains of California by the Bragdon Formation and the overlying Baird Formation. These units were named and mapped by Fairbanks (1894), Hershey (1902), and Diller (1905, 1906). Subsequent stratigraphic studies have been made by Kinkel, and others, (1956), Albers and Robertson (1961), Lydon and Klein (1969), and Watkins (1973).

BRAGDON FORMATION

The Bragdon Formation covers extensive parts of Shasta and Trinity Counties, but its base is ex-

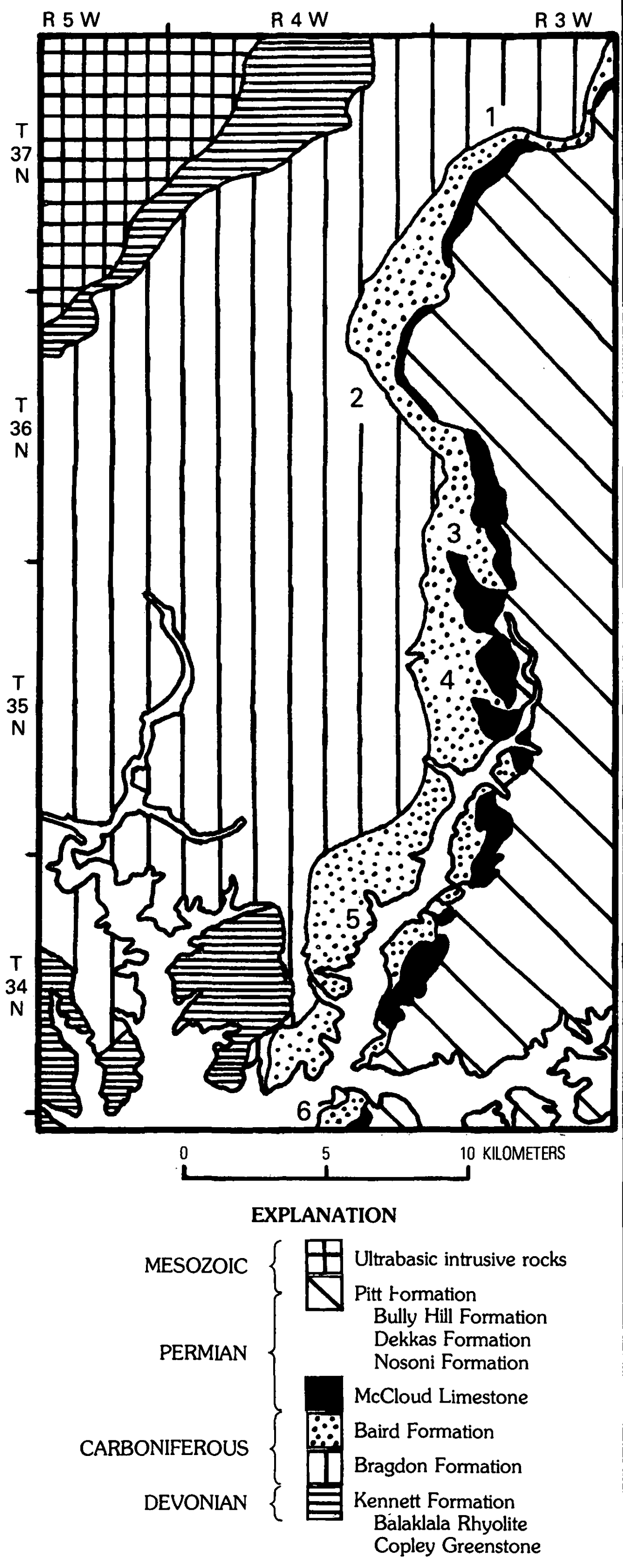

FIGURE 17.—Geologic map around the northern part of Shasta Lake, eastern Klamath Mountains, California.

posed in only a few areas near the Sacramento Canyon (fig. 17). Here it conformably overlies the Kennett Formation, which contains conodonts of Middle Devonian age (Savage, 1976). In places, the Kennett is missing, and the Bragdon conformably overlies the Balaklala Rhyolite of pre-Kennett age. The Bragdon Formation is barren of fossils for most of its geographic and stratigraphic extent. Locally, however, brachiopods of Late Mississippian age occur in the uppermost part of the Bragdon on the east slopes of Hanland Peak (Watkins, 1973, 1974). The upper contact of the Bragdon is mapped at the highest stratigraphic appearance of distinctive, pebble-bearing wacke beds which conformably underlie the Baird Formation. This contact probably is not everywhere the same age.

The Bragdon Formation consists mainly of rocks designated as the argillite facies in figure 18. Several small sections totaling 87 m in thickness were measured in the upper drainage of Middle Salt Creek. Sediment types in these sections are: 33.1 percent argillite that has flat parallel lamination; 8.4 percent silty and tuffaceous argillite that has flat parallel lamination; 0.8 percent silty and tuffaceous argillite containing plant debris; 3.1 percent lithic wacke that has flat parallel lamination and/or low-angle planar cross lamination; 18.2 percent lithic wacke, massive, or in beds graded from coarse sand at base to fine sand at top; 36.4 percent lithic wacke including clasts from pebble to boulder size and a variety of sedimentary structures. Wackes form tabular beds that have sharp flat contacts and basal, flute, and load casts. The thickness and stratigraphic frequency of wacke beds increase up section in the Bragdon Formation, culminating in conglomeratic units 16 to 20 m thick. Bioturbation is notably absent in the argillite facies, except for minor intervals in the upper few hundred meters of the Bragdon. Bioturbated fossiliferous siltstones associated with this facies near Kabyai Creek were described by Watkins (1973). The Bragdon Formation also contains volcaniclastic facies around the summit of Hanland Peak. These sedimentary rocks are identical in character with the volcaniclastic facies of the Baird Formation, which is described below.

BAIRD FORMATION

The Baird Formation (fig. 17) consists of a variety of sedimentary and volcanic rock types. Several hundred meters of the argillite facies is present on Hirz Mountain, distinguished from the argillite fa-

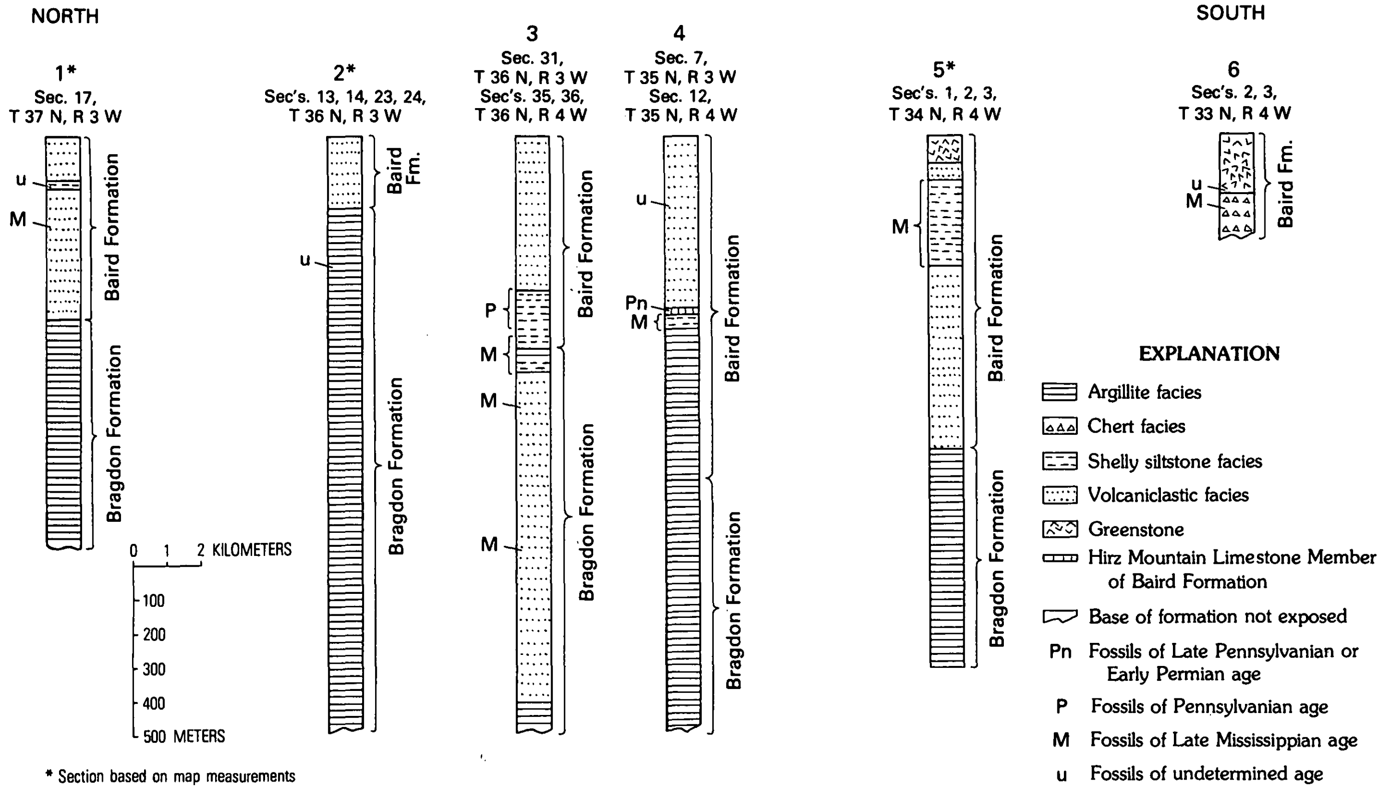

FIGURE 18.—Columnar sections of Carboniferous rocks in the eastern Klamath Mountains, California (see text for description of facies). 1, Tow Dow Creek; 2, High Mountains and headwaters of Middle Salt Creek; 3, east slopes of Hanland Peak and Kabyai Creek; 4, Hirz Mountains; 5, Ycotti Creek and Greens Creek; 6, south of Pitt River Bridge. Age assignments also represent all observed occurrences of shelly fossils. Thickness of section 5 is based on estimates by Albers and Robertson (1961).

cies of the Bragdon by the lack of conglomeratic wacke beds. The Baird Formation also contains a chert facies in the Greyrock section south of Pitt River Bridge. This facies consists of thin tabular beds of chert and cherty argillite, minor bioclastic limestone, and no apparent bioturbation. The shelly siltstone facies has several disjunct occurrences within the Baird, as shown in figure 18, and is the only part of the formation that has bioturbation and common shelly fossils. Fifteen meters of the facies was examined in detail near Greens Creek. It consists of: 50.0 percent very tuffaceous siltstone and fine sandstone that has flat parallel lamination, rare low-angle cross lamination, and rare mollusk shells; 49.9 percent siltstone and silty mudstone that has intense bioturbation and scattered mud-supported shells of many phyla; 0.1 percent closely packed shell debris in thin tabular beds. The shelly siltstone facies also contains limestone units near Kabyai Creek, which have been described by Watkins (1973). The major exposure of the shelly siltstone facies is along the McCloud River between Campbell Creek and Potter Creek. In most years, this area is covered by Shasta Lake.

The volcaniclastic facies is the only unit in the Baird Formation that is continuous along strike (fig. 18). Twenty-five meters of strata was measured in this facies on the southwest side of High Mountain; it consists of: 85.4 percent purple mudstone and silty mudstone, massive, containing floating volcanic lithoclasts; 9.7 percent arenite, in beds graded from coarse sand at base to fine sand at top, sometimes having low-angle cross lamination in upper part; 4.8 percent arenite containing pebbles at base of beds. The arenite beds are tabular, laterally continuous, and have sharp flat contacts. They are composed mainly of volcanic-rock fragments. The fine-grained purple sedimentary rocks are probably a volcanic mudflow, as some of their lithoclasts are intruded by the muddy groundmass of the rock. Tuff and minor fossiliferous limestone are also present in this facies, as described by Watkins (1973). A unit of greenstone forms the upper part of the Baird Formation in the southern part of its outcrop area

(Albers and Robertson, 1961) and is laterally equivalent to the volcaniclastic facies (fig. 18).

Age relations of the Baird Formation are shown in figure 18. The lower part of the Baird includes the brachiopods *Dorsoscyphus, Semicostella,* and *Striatifera,* which indicate a Late Mississippian age (Watkins, 1973, 1974). The higher part of the Baird Formation is usually barren of fossils, but on the east slopes of Hanland Peak it contains fusulinids and brachiopods of Pennsylvanian age (Skinner and Wilde, 1965; Watkins, 1973). Stratigraphic sections are not fossiliferous enough to locate a Mississippian-Pennsylvanian boundary precisely, and sedimentation appears to have been continuous across this interval. The youngest fauna in the Baird Formation is in the Hirz Mountain Limestone Member of Watkins (1973). This limestone crops out for less than 2 km along strike. It contains *Diplanus* and other brachiopods, which suggest a latest Pennsylvanian or Early Permian age. Where contacts have not been faulted or intruded by diorite, the Baird is conformably overlain by the Lower Permian McCloud Limestone. Watkins (1973) summarized evidence for the partial lateral equivalency of the upper part of the Baird and the lower part of the McCloud.

SEDIMENTARY ENVIRONMENTS

The Bragdon and Baird Formation record a general shoaling in the eastern Klamath area throughout Carboniferous time. The argillite facies of the Bragdon is a basin-and-slope deposit. Laminated argillite facies represent slow clay deposition under abiotic conditions, and wacke beds represent turbidite deposition. Upward increase in thickness and complexity of wacke beds in this facies indicates a change from distal to proximal turbidite deposition, and many of the thick conglomeratic wackes in the upper part of the Bragdon probably represent deposits of submarine channels near the top of a slope system. The beginnings of bioturbation and rare transported shelly fossils at the top of the argillite facies also suggest shoaling from basin towards shelf conditions.

The volcaniclastic facies and shelly siltstone facies are shelf deposits, which are found at the top of the Bragdon and throughout the Baird Formation. The volcaniclastic facies represents submarine tuff deposits, volcanic mudflows, and shelf-type turbidite deposits derived from volcanic source areas. Its variations in age, thickness, and stratigraphic relations (fig. 18) suggest episodic deposition from local changing source areas such as volcanic islands. The shelly siltstone facies is a typical bioturbated offshore shelf deposit containing a rich fauna of invertebrates. Environmental variation within the facies is indicated by the presence of several types of benthic invertebrate communities (Watkins, 1973, 1974).

Shoaling in the eastern Klamaths culminated in Early Permian times with the spread of shallow shelf carbonate deposits across the area. This environmental transition is best preserved in sections along the middle part of Nawtawaket Creek. Here, the upper part of the volcaniclastic facies of the Baird Formation is interbedded with graded beds of redeposited limestone, and the entire sequence is overlain by thick massive carbonate rocks of the McCloud Limestone. These relations suggest that the McCloud was deposited at shallower depths than the volcaniclastic facies of the Baird and that downslope transport of carbonate sediment into terrigenous and volcanic deposits took place. The petrography of the McCloud also indicates very shallow shelf conditions (Demirmen and Harbaugh, 1965).

FAUNAL AFFINITIES

The occurrence of invertebrate faunas in the Bragdon and Baird Formations is shown in figure 18. Horizons containing fossils are relatively few and are separated by hundreds of meters of barren sedimentary rocks. The faunas are dominated by brachiopods, crinoids, bryozoans, mollusks, and corals; extensive species lists are contained in Smith (1894) and Watkins (1973). Taxonomic treatment of this fauna is limited, however, to descriptions of a few brachiopod, bivalve, and trilobite species by Muir-Wood and Cooper (1960), Dutro (1955), Wheeler (1935), and Watkins (1974, 1975).

Biogeographically, the fauna of the Bragdon and Baird Formations is part of an Asiatic province and has few species in common with typical Carboniferous faunas of North America (Smith, 1894; Watkins, 1974). Watkins (1973, 1974) described eight invertebrate communities from the Bragdon and Baird that are characterized by differences in species composition, species diversity, trophic relations, and sedimentary occurrence. Additional undescribed communities in the Baird Formation are found southwest of Tater Hill and along Tom Dow Creek.

CARBONIFEROUS FORMATIONS IN OREGON

By EWART M. BALDWIN

ABSTRACT

Carboniferous strata are known in Oregon only in the Suplee area near the head of Crooked River, about 25 km southeast of Paulina. Two formations have been named. The older is the middle and upper Meramecian and Chesterian Coffee Creek Formation, composed mainly of limestone, and the younger is the Morrowan Spotted Ridge Formation, composed of conglomerate, sandstone, and plant-bearing mudstone.

Beds within the Elkhorn Ridge Argillite in the Durkee quadrangle contain a fusulinid fauna assigned to the Desmoinesian stage of the Pennsylvanian. All Carboniferous strata are probably allochthonous and were emplaced during plate movements.

INTRODUCTION

Carboniferous strata are known only from central Oregon, with a possible occurrence in northeastern Oregon. Early discoveries of Carboniferous strata are usually credited to Thomas Condon (1902). E. L. Packard (1928, 1932) and his students found and described many other localities. The beds crop out at the head of Crooked River near Suplee (fig. 19). The type sections of the Carboniferous formations are approximately 25 km southeast of Paulina in areas only partly covered by detailed topographic maps.

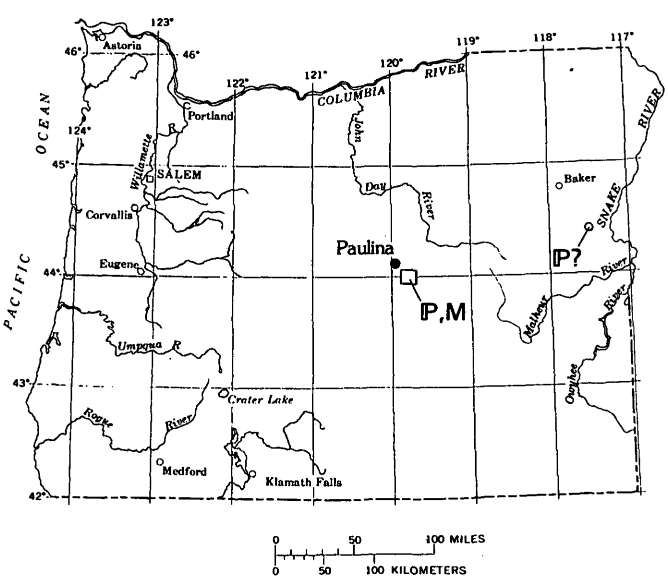

FIGURE 19.—Index map of Oregon showing locality of the Elkhorn Ridge Argillite, Pennsylvanian? (ℙ?); Spotted Ridge Formation, Pennsylvanian (ℙ); and Coffee Creek Formation, Mississippian (M).

Merriam and Berthiaume (1943) mapped and described the Mississippian, Pennsylvanian, and Permian rocks along upper Grindstone Creek, a tributary of Crooked River. They gave the name Coffee Creek Formation to the Mississippian limestone beds containing the large brachiopods noted by Packard. The Pennsylvanian plant-bearing beds associated with the conglomerate and sandstone were named the Spotted Ridge Formation, and the overlying Permian limestone was called the Coyote Butte Formation. Middle Devonian beds nearby were reported later by Kleweno and Jeffords (1962), but they have not been formally named.

The most detailed mapping of the Paleozoic units has been by H. J. Buddenhagen, whose map is on open file at the State of Oregon Department of Geology and Mineral Industries in Portland. Figure 20 is a part of that map. Buddenhagen (1967) published a summary of his work. The Suplee area was mapped by Dickinson and Vigrass (1965) who dealt mainly with the Mesozoic strata. Paleozoic formations are shown on the geologic map of eastern Oregon east of the 121st meridian (Walker, 1977).

Structural relationships are difficult to determine because of intense deformation and because the rolling grass-covered terrain presents an outcrop area of only about 10–15 percent. Thus, relationships between units must be inferred. A recent summary of the Paleozoic units of central and northeastern Oregon by Vallier, Brooks, and Thayer (1977) discusses lithology, stratigraphic units, and their ages. They conclude that contacts are commonly thrust planes and that faunas of Tethyan and North American affinities are intermixed because of plate movements.

COFFEE CREEK FORMATION

The Coffee Creek Formation was named by Merriam and Berthiaume (1943) for a small tributary of Grindstone Creek, southeast of Wade Butte (fig. 20). The type section is in sec. 30, T.18 S., R. 25 E. The area had been covered in reconnaissance by Packard (1928, 1932), but the most detailed mapping is by Buddenhagen (fig. 20).

The Coffee Creek Formation is in fault contact with the Spotted Ridge, Coyote Butte, and Triassic formations. No depositional contacts are known, but

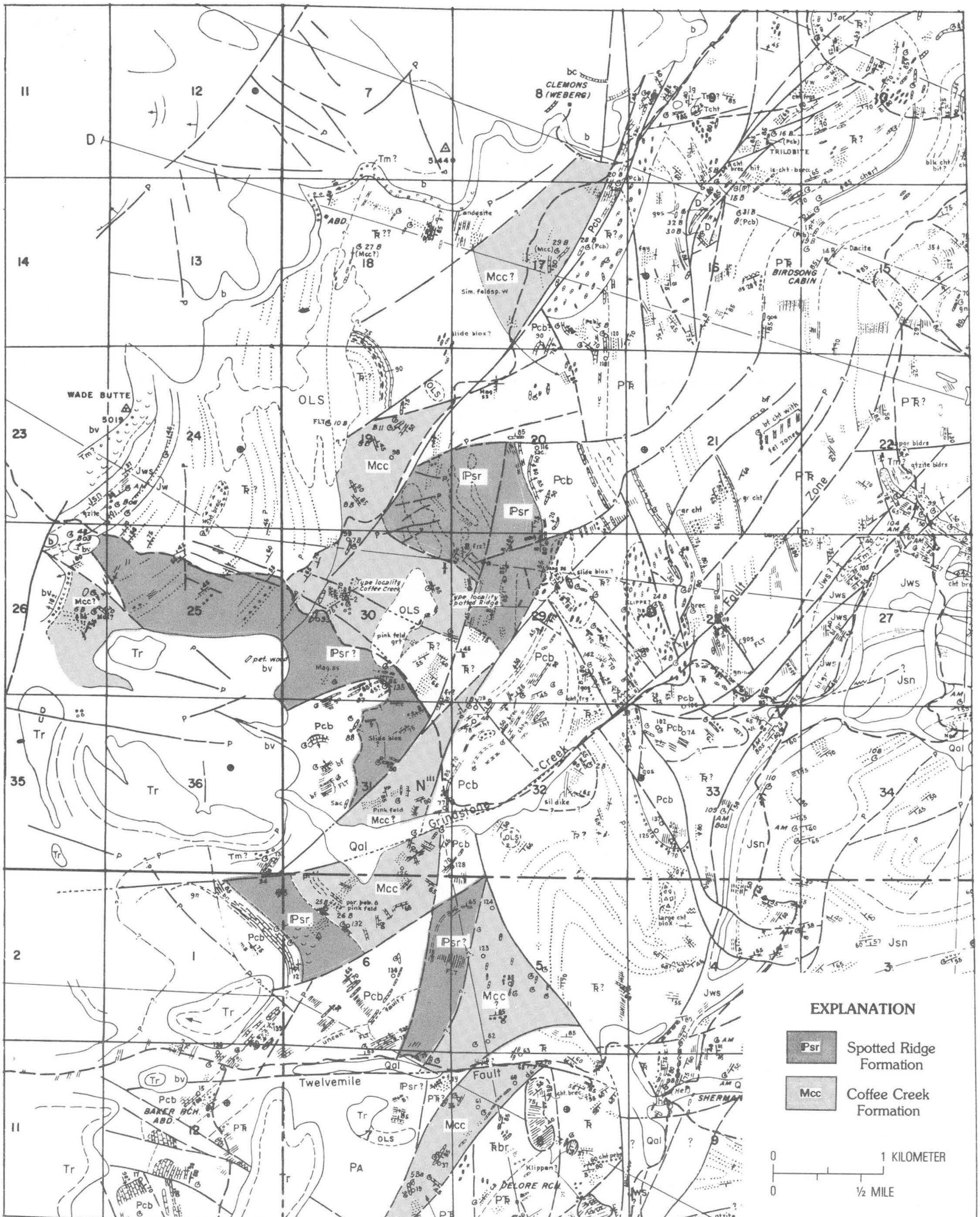

FIGURE 20.—Carboniferous formations in central Oregon. Areas of Carboniferous rocks are shaded. Geology by H. J. Buddenhagen.

the Triassic beds in Wade Butte appear to rest on the Mississippian limestone on the west. No underlying strata are known in juxtaposition.

Merriam and Berthiaume described the type section as follows:

A conspicuous linear outcrop at the type section shows about 75 feet of strata dipping about 53° NW. Within the upper 40 feet very dark gray to black argillaceous and carbonaceous limestones are in places rather thin-bedded. These deposits are locally packed with the brachiopod *Striatifera.* Forty-five feet from the top of the limestone section is a bed of very sandy limestone with *Striatifera* immediately below which lies the main *Gigantella* horizon. The usually large productid *Gigantella* is very profuse here in a fine-grained and rather pure limestone of deep neutral gray; the large brachiopod is apparently restricted at this point to a bed varying in thickness from one to two feet. Within and below the *Gigantella* bed solitary and compound rugose corals are abundant; these are embedded in gray limestone or immediately below in argillaceous limestones weathering to a light grayish brown. In the lower 30 feet of this section these argillaceous layers are interbedded with purer gray limestones, while toward the base sandy limestones and calcareous sandstone predominate.

The Formation is traceable along the strike for approximately 2 km, and Merriam and Berthiaume (1943, p. 151) estimated a thickness of 275–300 m.

The Coffee Creek Formation was assigned a middle and upper Meramecian and Chesterian age by Poole and Sandberg (1977) who suggested that it was deposited in an inner-arc basin between the Antlers orogenic highland to the east and the Klamath-North Sierran island arc to the west. Poole and Sandberg (1977, p. 82) stated:

Our Mississippian model involves continued Benioff-type subduction of Pacific oceanic crust beneath an island-arc complex above an east-dipping subduction zone separated from the continental slope and shelf by an inner-arc basin.

SPOTTED RIDGE FORMATION

The Spotted Ridge Formation is in juxtaposition with the Coffee Creek Formation and is separated from it and from nearby Permian and Triassic formations by faults. Cenozoic erosion has produced a rolling grass- and sagebrush-covered terrain containing shallow ravines. Outcrops vary according to the type of sedimentary rocks; the conglomerate and sandstone are more in evidence than the mudstone.

The Spotted Ridge Formation was named by Merriam and Berthiaume (1943). They included in it approximately 300–500 m of beds ranging from coarse conglomerate and crossbedded sandstone to compact mudstone and noted that the formation was variable both vertically and laterally. Minor amounts of chert and magnetite sandstone are present.

The conglomerate has been examined by Taubeneck (1969), who found that most granitic clasts are quartz diorite. Some clasts are granodiorite; one is quartz monzonite. The only clast having a gneissoid texture is quartz monzonite. The source of the conglomerate is unknown.

A medium-grained sandstone was examined by Sam Boggs, Jr., of the University of Oregon. This rock contained 48 percent volcanic rock fragments, 8 percent quartz, 4 percent polycrystalline quartz, 1 percent chert, 15 percent plagioclase feldspar and no evidence of potassium feldspar, 8 percent authigenic chlorite, (?)3 percent authigenic hematite and more than 10 percent matrix consisting mainly of chlorite. He stated:

Some of the softer rock fragments have been squeezed and flattened by compaction and many of the fragments are partially to completely altered to chlorite. Most of the plagioclase grains show some degree of alteration to sericite. Using Gilbert's classification, this sandstone is a lithic (volcanic) wacke.

The inconsistent character of clastic sedimentary deposits and the intermixture of continental and marine beds indicate that the formation was deposited near the shoreline in a rapidly filling basin during a time of active tectonism.

Carbonaceous sandstone and siltstone are present throughout the formation, but the upper part of the formation includes mudstone containing an abundant flora. Merriam and Berthiaume (1943, p. 152) described the location (locality 115) as follows:

The lenticular mudstones and siltstones are of an unusual shade of medium-grayish olive green. Lamination is usually not well defined, and fissility is undeveloped. The sediment is very compact and brittle. In general, the plants lie more or less parallel to bedding though occasional leaves and stems are decidedly oblique in position. The plants occur as coaly films; stems are much flattened but retain evidence of vascular structure. * * * While certain tongues or lenses within the plant-bearing beds are marine or brackish it is believed that most of the sediments in this facies are land-laid, though an estuarine origin is not unlikely. The plants do not appear to have suffered transportation; in fact some calamite stalks with whorls of twigs appear to be essentially in position of growth.

Read and Merriam (1940) examined the flora, but a more detailed study was made by Mamay and Read (1956), who found additional material. They considered the flora to be Early Pennsylvanian, somewhat equivalent to the Pottsville of Pennsylvania.

A marine fauna is found in a ravine just north of the road that leads eastward from Coffee Creek over a low ridge and descends into Grindstone Creek. The fauna, exposed just north of the south line of sec. 30, T. 18 S., R. 25 E., is in gritty sandstone and fine conglomerate, that has clasts commonly as much as a centimeter in diameter. The writer visited the locality twice, accompanied by Gregory Miles, Jack Messe, Thomas Sharp, and William Gandera. Daniel E. Penttila contributed fossils from the same outcrops.

The fauna was identified by MacKenzie Gordon, Jr., of the U.S. Geological Survey in consultation with G. A. Cooper, National Museum of Natural History; and John Pojeta, Jr., and E. L. Yochelson, U.S. Geological Survey. The fauna is assigned by them to the Morrowan stage of the Pennsylvanian, with suggested correlations with other units. The following genera were identified:

Corals:	
Lophophyllidium sp.	1
Bryozoans:	
Fenestella sp.	1
Brachiopods:	
Schizophoria? sp. indet.	fragment
Derbyia? sp. indet.	fragment
Rugoclostus? sp. indet.	fragment
Rhynchonelloid, gen. and sp. indet.	fragment
Neospirifer sp.	3
Pelecypods:	
Nuculopsis sp.	1
Phestia sp.	14
Permophorus sp.	3
Edmondia sp.	1
Solemya sp.	1
Rostroconchs:	
Bransonia sp.	1
Gastropods:	
Sinuatina sp.	3
Euphemites sp.	2
Bellerophon (*Bellerophon*) sp.	9
Retispira sp. indet.	9
Glabrocingulum (*Ananias*) sp.	8
Pleurotomariacean?, gen. and sp. indet.	2
Shansiella? sp.	2
Girtyspira sp.	1
Meekospira? sp. indet.	2
Ammonoids:	
Syngastrioceras? sp. indet.	fragment
Cancelloceras cf. *C. cancellatum* (Bisat)	20 (mostly fragments)
Vermes?:	
Worm tube or scaphopod	1
Echinoderms:	
Crinoid columnals	

MacKenzie Gordon, Jr. (written commun., 1977), notes:

The preservation of the ammonoids permits identification of the genus *Cancelloceras*, a reticulate form of *Gastrioceras*, known in northwest Europe at the base of the Lower *Gastrioceras* (*G.*) Zone and recently recognized in the Hale Formation of Arkansas. This permits an Early Pennsylvanian age to be assigned to the Spotted Ridge Formation, from which these fossils were collected.

Whether or not beds of later than Morrowan Pennsylvanian age are present in the Spotted Ridge Formation is not presently clear. A single well-preserved specimen from float in Crook County, Oregon, was described in 1940 as *Eoasianites merriami* Miller and Furnish. Now known as *Somoholites merriami* (Miller and Furnish), it has been recognized in the Barnett Hill Member of the Atoka Formation in Oklahoma and the Hare Fiord reef deposits of Ellesmere Island, Arctic Canada, by Saunders (1971, p. 109). To this I can add the well known Smithwick Shale locality, of Atokan age, in McCulloch County, Texas. Whether this Atokan *Somoholites* from central Oregon came from some part of the Spotted Ridge Formation or whether it is from an as yet unrecognized stratigraphic unit in that vicinity is a matter yet to be determined.

ELKHORN RIDGE ARGILLITE

The Elkhorn Ridge Argillite was named by Gilluly (1937) for exposures in Elkhorn Ridge a short distance west of Baker. The formation consists of approximately 1,750 m of silicified highly contorted argillite, tuff, chert, and some limestone and greenstone. The argillite, which makes up the greater part of the formation, is fine grained, thinly laminated, and consists of quartz, andesine, muscovite, chlorite, and black carbonaceous material.

The age and position of the Elkhorn Ridge Argillite has been discussed by Vallier, Brooks, and Thayer (1977). Fusulinids within the unit have been assigned to the Leonardian and the unit considered essentially equivalent to the Coyote Butte Formation of central Oregon, which overlies the Spotted Ridge Formation. Fusulinids from the Virtue Hills east of Baker were found by Bostwick and Koch (1962) and identified as *Yabeina* and *Schwagerina*. They were large, well advanced, and probably Ochoan. Thus, the preponderant evidence points to Middle and Late Permian age, with a possibility of some Triassic beds.

However, D. A. Bostwick (written commun., 1977) reported fusulinids of Middle Pennsylvanian (Desmoinesian) age in beds assigned to the Elkhorn Ridge Argillite in the lower half of sec. 2, T. 10S., R. 43 E., in the Durkee quadrangle. Apparently the Elkhorn Ridge Argillite ranges into the Middle Pennsylvanian as well unless rafted blocks of this age resembling the Elkhorn Ridge have been brought into juxtaposition during plate movements.

Vallier, Brooks, and Thayer (1977, p. 461) discussed the age and setting for the emplacement of the Paleozoic units of northeastern Oregon. They stated:

The rocks have undergone severe deformation, which placed supracrustal and basement rocks in structural contact to form a melange-like chaotic assemblage. Tectonic shuffling may have taken place on a major scale. For example, limestone bodies containing Tethyan fusulinid faunas are relatively close to those with non-Tethyan affinities (Bostwick, personal commun., 1977) * * * Known ages of the rocks in this terrane range from Pennsylvanian to Mesozoic, indicating that the chaotic mixture formed throughout a long time period, perhaps with last major movement in the Late Triassic or Early Jurassic.

CARBONIFEROUS ROCKS IN WASHINGTON

By ERNEST H. GILMOUR and WILBERT R. DANNER

ABSTRACT

Scattered Carboniferous rocks in both western and eastern Washington range in age from Chesterian to Desmoinesian and possibly Missourian. Some of the Carboniferous rocks in western Washington contain Tethyan faunas and are believed to have been tectonically transported north and east from the Permian equatorial area. Fossils in the Carboniferous rocks of northeastern Washington are thought to have eastern North American or Rocky Mountain affinities.

INTRODUCTION

Carboniferous rocks are found in three areas of Washington: the San Juan Islands in northwest coastal Washington; the Northern Cascade Mountains; and scattered localities in northeast Washington (fig. 21). In western Washington, most fossils are found in limestone lenses that are interbedded

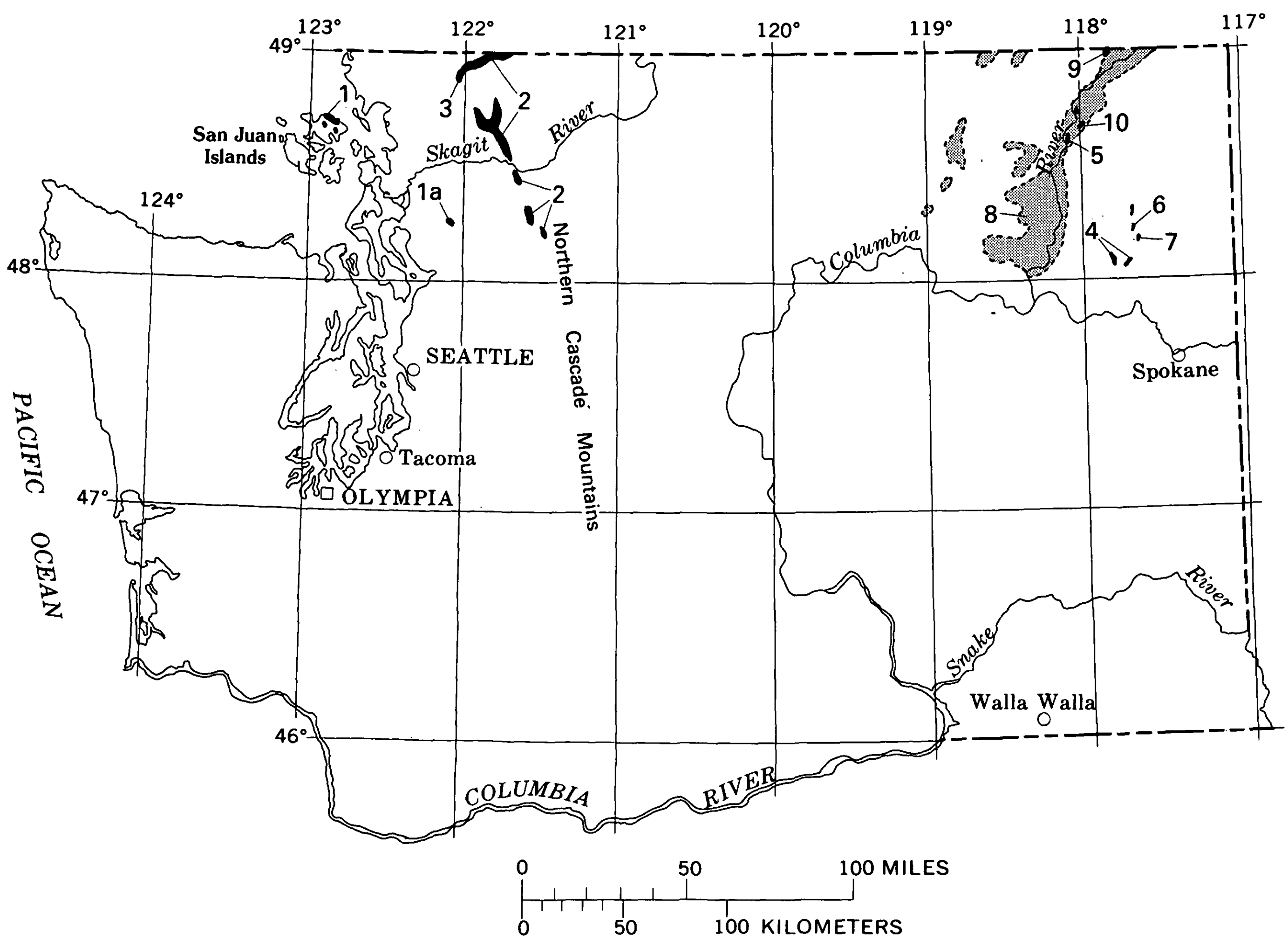

FIGURE 21.—Carboniferous rocks and rocks of questionable Carboniferous age exposed in Washington. Locality numbers are referred to in text. Solid areas are known Carboniferous rocks and shaded areas are upper Paleozoic undifferentiated.

with thick detrital sedimentary sequences and associated volcanic rocks. In eastern Washington, both Mississippian and Pennsylvanian fossiliferous limestone bodies have been described as biohermal buildups deposited in relatively shallow water in the eastern part of the "Cordilleran eugeosyncline." The western Washington occurrences are well exposed in beach cliffs on the San Juan Islands and in the alpine regions (fig. 22) of the Northern Cascade Mountains but are otherwise mantled by a thick sequence of Pleistocene and recent sediments and by dense vegetation. They have been folded and faulted and subjected to low-temperature—high-pressure metamorphism of the prehnite-pumpelleyite facies. Volcanism, plutonism, folding, and block faulting (Yates, 1970) have disturbed and metamorphosed much of the Carboniferous strata in eastern Washington. Also in eastern Washington, glaciofluvial, lacustrine, and alluvial deposits cover much of the bedrock.

SAN JUAN ISLANDS

Rocks of Early and Middle Pennsylvanian age in the San Juan Islands make up the middle part of the Trafton Group. On Orcas Island (fig. 21, loc. 1), they are estimated to be 150 to 300 m thick (Danner, 1966). Small limestone pods and lenses containing Pennsylvanian fossils are interbedded with thin-bedded shale, siltstone, graywacke, and volcanic flows and breccia. At least one thin seam of poor quality coal is found on the northeast coast of Orcas Island.

The age of the Trafton Group ranges from Devonian to at least Late Permian, but until recently, no Mississippian strata have been conclusively identified, although brachiopods assigned to that age are found on Orcas Knob on Orcas Island associated with other faunas thought to be of Early Pennsylvanian age. *Eostaffella, Nankinella, Millerella?, Tetrataxis,* endothyrid Foraminifera, *Komia,* corals,

FIGURE 22.—Lower Pennsylvanian Limestone of Red Mountain Subgroup exposed at the base of Washington Monument Peak, Skagit County, Washington, Northern Cascade Mountains. View looking northwest. Limestone is underlain by argillaceous rocks and overlain by coarse clastic rocks of Pennsylvanian or Early Permian age.

bryozoans, brachiopods, and one species of trilobite have been collected from the Carboniferous strata (Danner, 1966; Sada and Danner, 1973).

The Trafton Group rocks are considered to be an exotic belt of Paleozoic rocks differing lithologically from other Paleozoic rocks in western Washington and containing a Tethyan fauna (Danner, 1977). This western Cordilleran Tethyan belt must have been tectonically transported north and east from the Permian equatorial area to its present location.

The Trafton Group extends southeastward into the foothills and mountains of the southern part of the Northern Cascades, but until recently, only Permian faunas had been found in this area. One outcrop of radiolarian chert of this group (fig. 21, loc. 1a), previously assigned a Permian age, is now reported to contain conodonts and radiolarians of Mississippian age (J. Whetten and D. Jones, oral commun., 1977).

NORTHERN CASCADE MOUNTAINS

The Chilliwack Group (Daly, 1912; Moen, 1962; Smith, 1962; Monger, 1966; Danner, 1957, 1966, 1970, 1977) contains rocks of Pennsylvanian age exposed in a northwest-southeast band (fig. 21, loc. 2) extending from near Harrison Lake in southwestern British Columbia south across the border into Washington State through Whatcom, Skagit, and Snohomish Counties in the Northern Cascade Mountains. The Chilliwack Group is composed of thin-bedded argillite, siltstone, and graywacke together with interbedded massive to well-bedded argillaceous limestone, conglomerate, minor radiolarian chert, and andesitic and dacitic volcanic rocks. The Pennsylvanian part of the group (Red Mountain Subgroup) is composed largely of thin-bedded argillite and cherty argillite, siltstone, graywacke, and argillaceous limestone. The limestone is near the top of the subgroup and is overlain by sandstone and conglomerate of either Pennsylvanian or Permian age which contain plant debris. *Lepidodendron* and *Calamites* (identified by G. E. Rouse) occur in this sandstone on Red Mountain.

Thickness of the Pennsylvanian rocks is estimated to be 300 to 600 m. Lenticular beds of limestone at least 120 m thick crop out on Red Mountain at the type area of the subgroup (fig. 21, loc. 3). Much of the limestone is organoclastic and oolitic.

The age of the Chilliwack Group ranges from at least Devonian to middle Permian. Some of the limestone contains brachiopods similar to *Gigantoproductus* and may be of Mississippian age, but the same limestones contain a microfauna identified as being of Early Pennsylvanian age and corals thought to be of Permian age. Other limestones containing abundant *Endothyra* may be of Mississippian age. Large crinoid columnals (fig. 23) 40 mm or more in diameter are characteristic of many of the Pennsylvanian limestones and are considered to be good index fossils for field identification of these Lower Pennsylvanian rocks.

The faunas of the Chilliwack Group are non-Tethyan but of a distinctive non-American aspect; the Chilliwack Group is believed to have formed as an island arc in a subtropical climate in the Paleozoic Pacific Ocean and to have been rafted in against North America during mid-Mesozoic time. The Red Mountain Subgroup correlates with the Harper Ranch Group near Kamloops to the north in British Columbia and with the upper part of the Baird Formation in northern California.

NORTHEASTERN WASHINGTON

Rocks of known Carboniferous age and rocks of questionable Carboniferous age are found in northeastern Washington. Some rocks mapped as Permian may include Carboniferous strata. Outcrops are usually limited in extent, tectonically disturbed and metamorphosed (Yates, 1970; Mills, 1977); consequently, it is difficult to correlate stratigraphic units any distance with much confidence.

Documented Carboniferous rocks have been reported by various workers in several places. Enbysk (1956) reported both Mississippian and Pennsylvanian fossils near Kulzer (fig. 21, loc. 4) in southeastern Stevens County. The Upper Mississippian (Chester) rocks include the ostracodes *Graphiodactylus tenuis, Jonesina carterigera,* and *Cavellina* aff. *C. coryelli;* coral *Triplophyllum* sp.; brachiopods *Spirifer* cf. *S. pellaensis* and *Chonetes* sp. Pennsylvanian fossils were identified (Enbysk, 1956) from a limestone near Springdale in southeastern Stevens County. These fossils include *Spirifer* aff. *S. rockymontanus, Rhombopora nitidula,* and *Lophophyllidium* cf. *L. proliferum.* Six genera of Foraminifera were also identified, including *Rhabdammina, Ammobaculites, Endothyra, Millerella, Globivalvulina,* and *Trochammina.* Enbysk reports these species as having eastern North American or Rocky Mountain affinities. Recently, Bruce Wardlaw (oral commun., 1977) has reported Pennsylvanian (Desmoinesian or younger) fossils from the Kettle Falls quadrangle (fig. 21, loc. 1) in Stevens County. The fauna consists of brachiopods, pelecypods, trilobites, and dendroid and fenestrate bryozoans. Some of the fossils described are *Cyrtorostra* sp., *Costachonetes* sp.,

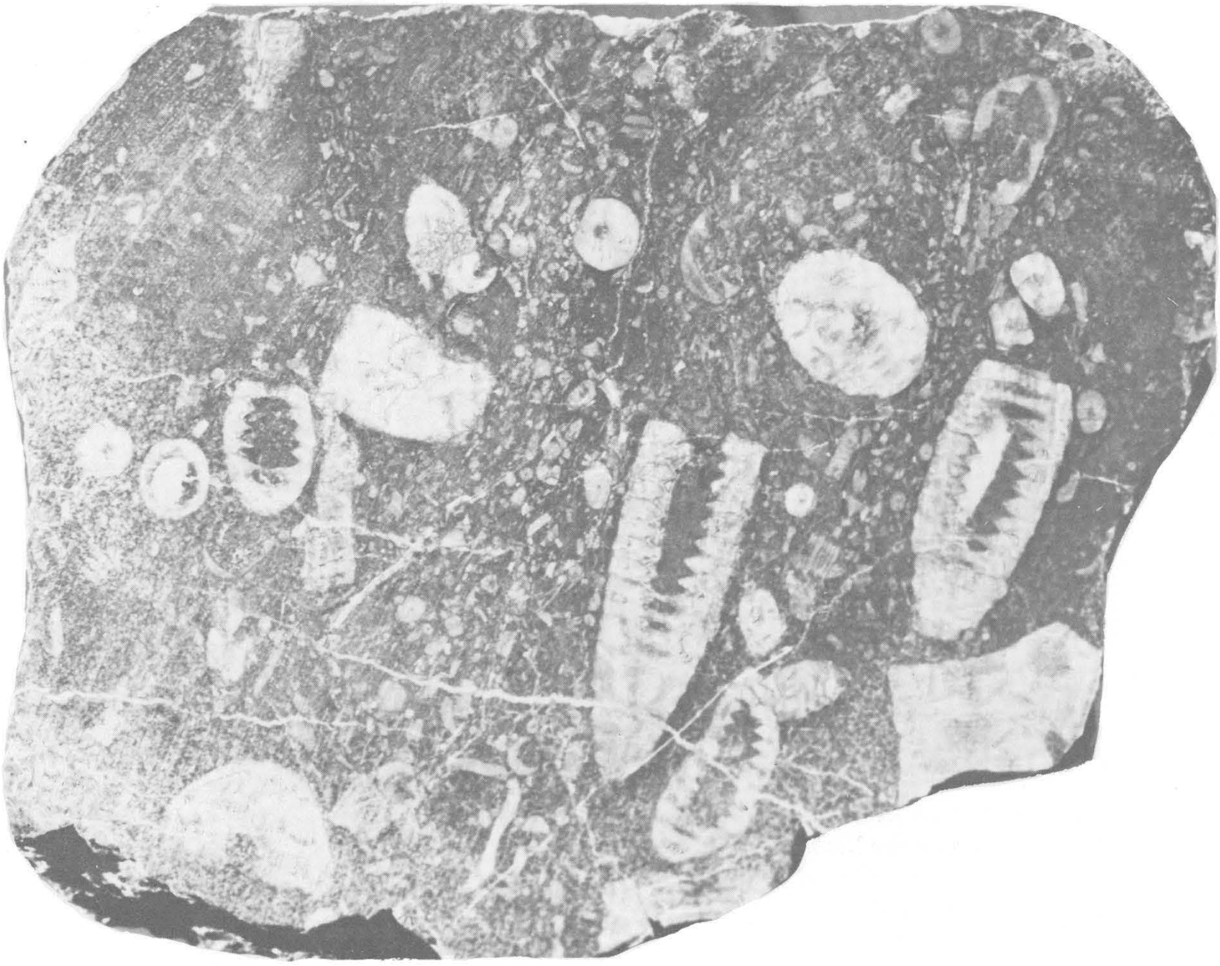

FIGURE 23.—Cut slab of crinoidal limestone of Early Pennsylvanian age, Red Mountain, Whatcom County, Washington.

Neospirifer cf. *N. triplactus?* (Hall), *Rhynchopora* sp., *Waagenoconcha* sp., and *Kutorginella* sp. Miller (1969) reported at least 180–210 m of limestone containing abundant chert north of Valley (fig. 21, loc. 6) that contains Mississippian fossils. McLaughlin and Simons (1951) described Late Mississippian (Chester) ostracodes from a limestone 2.4 km east of Valley (fig. 21, loc. 7), and other workers have identified Mississippian brachiopods, corals, and conodonts.

An extensive area of sedimentary rocks including strata of Carboniferous (?) age has been referred to as upper Paleozoic undifferentiated or upper Paleozoic and Triassic (Mills, 1962) in northeastern Washington (fig. 21, loc. 8). This area extends southward from the Canadian border and parallels the Columbia River to the confluence of the Columbia and Spokane Rivers. Some of these rocks are probably Pennsylvanian in age.

Yates (oral commun., cited by Irwin, 1975) believes that the limestone lenses and associated graywacke and argillite in northern Stevens County (fig. 21, loc. 9) are a southward continuation of fossiliferous rocks of the Mt. Roberts Formation of southern British Columbia. Little (1960) listed several fossils of "probable Pennsylvanian age" in the Mt. Roberts Formation of southern British Columbia. The Mt. Roberts Formation consists of fine clastic rocks intercalated with pyroclastic debris and mafic flow rocks and fossiliferous limestone lenses. Yates (1970) considered these rocks to have been deposited in the Cordilleran eugeosyncline.

Some of the rocks previously mapped as Permian in northeastern Washington have recently been identified as Pennsylvanian (?). West (1976) reported *Pseudoendothyra* sp. from a biohermal bank 5 km northeast of Kettle Falls (fig. 21, loc. 10). This limestone is in close proximity to similar limestones containing Permian fusulinids. As additional detailed studies are conducted, more of the area identified as upper Paleozoic undifferentiated will probably be found to be of Carboniferous age.

ECONOMIC PRODUCTS

Limestone has been the principal economic product from Carboniferous rocks in Washington. Before 1900, Carboniferous limestone was quarried and used for building stone and the production of burned lime. Since 1900, large quantities of limestone have been used for portland cement, in the paper pulp industry, and for agricultural purposes. Two excellent reports on the limestone resources of Washington have been published by Mills (1962) and Danner (1966).

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

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.)

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

M. Iowa, by Matthew J. Avcin and Donald L. Koch
N. Missouri, by Thomas L. Thompson
O. Arkansas, by Boyd R. Haley, Ernest E. Glick, William M. Caplan, Drew F. Holbrook, and Charles G. Stone
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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-M-DD

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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

CONTENTS