Studies of the Permian Phosphoria Formation and Related Rocks, Great Basin–Rocky Mountain Region

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1163-A, B, C, D

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Bruce R. Wardlaw, Editor

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By BRUCE R. WARDLAW

ABSTRACT

The transgression of the Permian Retort Phosphatic Shale Member of the Phosphoria Formation is dated by the occurrence of diagnostic brachiopods. The complex pattern of this transgression reflects the paleogeography and indicates two initial basins of deposition: one in southwestern Montana and one in southeastern Idaho.

INTRODUCTION

Relative ages for the Phosphoria, Park City, and Shedhorn Formations of Idaho, Montana, and Wyoming can be determined by an application of the regional biostratigraphic zonation proposed by Wardlaw and Collinson (1977; 1978a; this volume, Chapter D) for the Park City Group in Nevada and Utah. Many of the key brachiopods are the same in both areas; conodonts also support this determination (Wardlaw and Collinson, 1978b, 1979). Most of the brachiopod collections referred to in this report are listed by Wardlaw (1978). The brachiopods are not always present but are prevalent enough for dating the time of initial transgression of the Retort Phosphatic Shale Member of the Phosphoria Formation. Brachiopods are rare and seem to have found it unfavorable to live in the environments of deposition of the Phosphoria and Park City Formations in or below the Retort Phosphatic Shale Member in much of western Wyoming. Elsewhere, in the Retort depositional area, brachiopods seem to be fairly common.

Wardlaw and Collinson (1977, 1978a) proposed three Wordian (lower Guadalupian[1]) zones. They are, in ascending order: the *Thamnosia depressa* Zone, the *Kuvelousia leptosa* Zone, and the *Yakovlevia multistriata-Neogondolella bitteri* Zone. The zones have since been more simply referred to (Wardlaw, Collinson, and Maughan, this volume, Chapter C) as the *Thamnosia*, *Kuvelousia*, and *Yakovlevia* Zones. All three of the diagnostic brachiopods (*Thamnosia*, *Kuvelousia*, and *Yakovlevia*) are found in much of the area discussed. Other diagnostic brachiopods of the *Yakovlevia* Zone are *Timaniella* n. sp. and *Bathymyonia* n. sp. B (Wardlaw and Collinson, 1978a, 1979).

Because the brachiopods maintain a consistent biostratigraphic position over the Great Basin-Rocky Mountain area in many different facies, it seems reasonable to use the zones as relative time indicators. The zones show a complex transgression of the Retort Phosphatic Shale Member of the Phosphoria Formation over Wyoming and Utah. Geologic sections used to illustrate the transgression are shown in figure 1. Figure 2 shows the distribution of the Retort Phosphatic Shale Member and the brachiopods that occur just below it. Though much of the data is taken from the thrust belt in Idaho and Wyoming, and interpretations are made across it, the thrusts do not appear to alter the relative position of each section for the scale of this analysis. Sections on different thrust plates show similar east-west trends and these trends vary north and south.

BRACHIOPOD EVIDENCE

MONTANA LOCALITIES

Dalys Spur.—Thamnosia depressa (Cooper) occurs just below the Retort Phosphatic Shale Member in the Shedhorn Sandstone, indicating correlation of initial deposition of the conformable Retort during the *Thamnosia* Zone.

Big Sheep Creek.—Thamnosia depressa (Cooper) occurs just below the Retort in the Shedhorn Sandstone, indicating initial deposition of the Retort during the *Thamnosia* Zone.

[1]Assigned to the Early Permian by the U.S. Geological Survey.

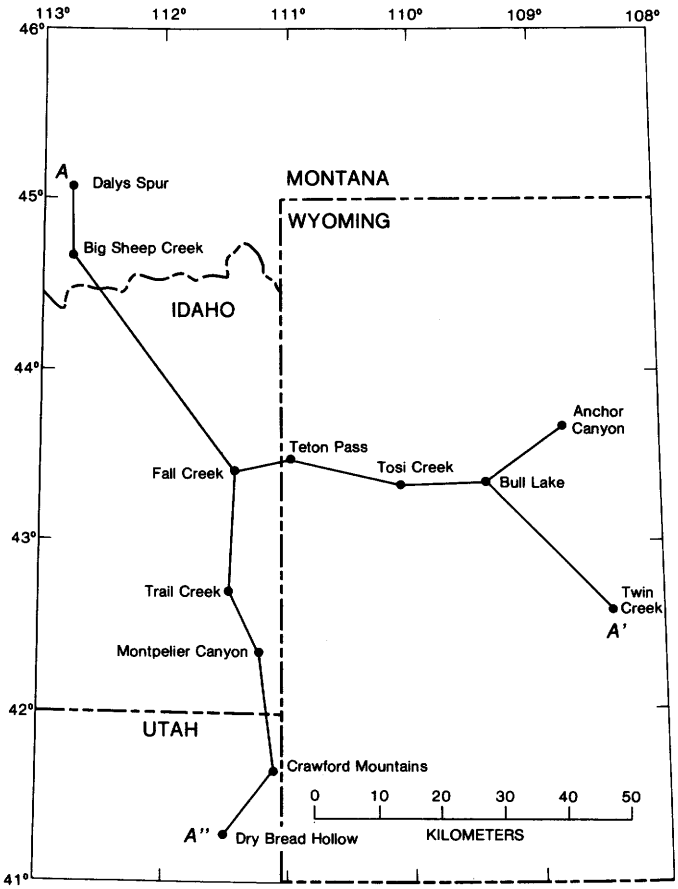

FIGURE 1.—Location of geologic sections.

IDAHO LOCALITIES

Fall Creek.—Neospirifer striatoparadoxus (Toula) occurs below the Retort in the Franson Member of the Park City Formation, along with several other brachiopods (Wardlaw, 1978). This probably represents a fauna at or near the *Thamnosia-Kuvelousia* zonal boundary. Only a few feet of Retort exist here, the majority having been eroded away before Triassic deposition.

Trail Creek.—In the divide between Trail Creek and Wood Canyon, *Kuvelousia leptosa* Waterhouse occurs just below the Retort in a cherty carbonate of the Rex Chert Member of the Phosphoria Formation, indicating initial deposition of the Retort during the *Kuvelousia* Zone.

Montpelier Canyon.—Thamnosia depressa (Cooper) occurs just below the Retort in the Franson Member of the Park City Formation, indicating initial deposition of the Retort during the *Thamnosia* Zone.

UTAH LOCALITIES

Crawford Mountains.—No diagnostic fossils exist below the Retort, but at the Frank mine prospect, in a very thin Retort, occurs an abundant brachiopod fauna including *Timaniella* n. sp. This probably represents sedimentation beginning at or near the *Kuvelousia-Yakovlevia* zonal boundary. The Retort has been greatly reduced by erosion prior to Triassic sedimentation.

Dry Bread Hollow.—Kuvelousia leptosa Waterhouse occurs below the Retort in the Franson Member of the Park City Formation, indicating initial deposition of the Retort during the *Kuvelousia* Zone.

WYOMING LOCALITIES

Teton Pass.—No diagnostic fossils occur below the Retort in the Franson Member of the Park City Formation.

Tosi Creek.—No diagnostic fossils occur below the Retort in the Franson Member of the Park City Formation.

Bull Lake.—Yakovlevia multistriata (Meek) and *Timaniella* n. sp. occur just below the Retort in the Franson Member of the Park City Formation. In the Ervay Carbonate Member of the Park City Formation (just above the Retort), *Yakovlevia multistriata* (Meek), *Timaniella* n. sp., and *Bathymyonia* n. sp. B occur at its base. Therefore, diagnostic fossils of the *Yakovlevia* Zone bracket the Retort.

Anchor Canyon.—Timaniella n. sp. and *Bathymyonia* n. sp. B occur just below and in the very thin Retort, indicating initial deposition of the Retort during the *Yakovlevia* Zone.

Twin Creek.—Timaniella n. sp. and *Bathymyonia* n. sp. B occur in the Retort, indicating initial deposition of the Retort during the *Yakovlevia* Zone.

The inferred age for the base of the Retort (fig. 3), along the traverses shown in figure 1, indicates a rather straightforward transgression from southwestern Montana into Wyoming through most of Wordian time. The pattern is more complex in Idaho and Utah, where the complexity of the transgression reflects a paleogeography of minor basins and rises that were differentially transgressed. It appears that the beginning of Retort deposition was nearly simultaneous in southwestern Montana and southeastern Idaho, whereas deposition in central-eastern Idaho began later. This implies two separate initial basins of deposition. A depositional basin developed in Utah in middle Wordian time. This basin was separated from the southeastern Idaho basin until late Wordian time.

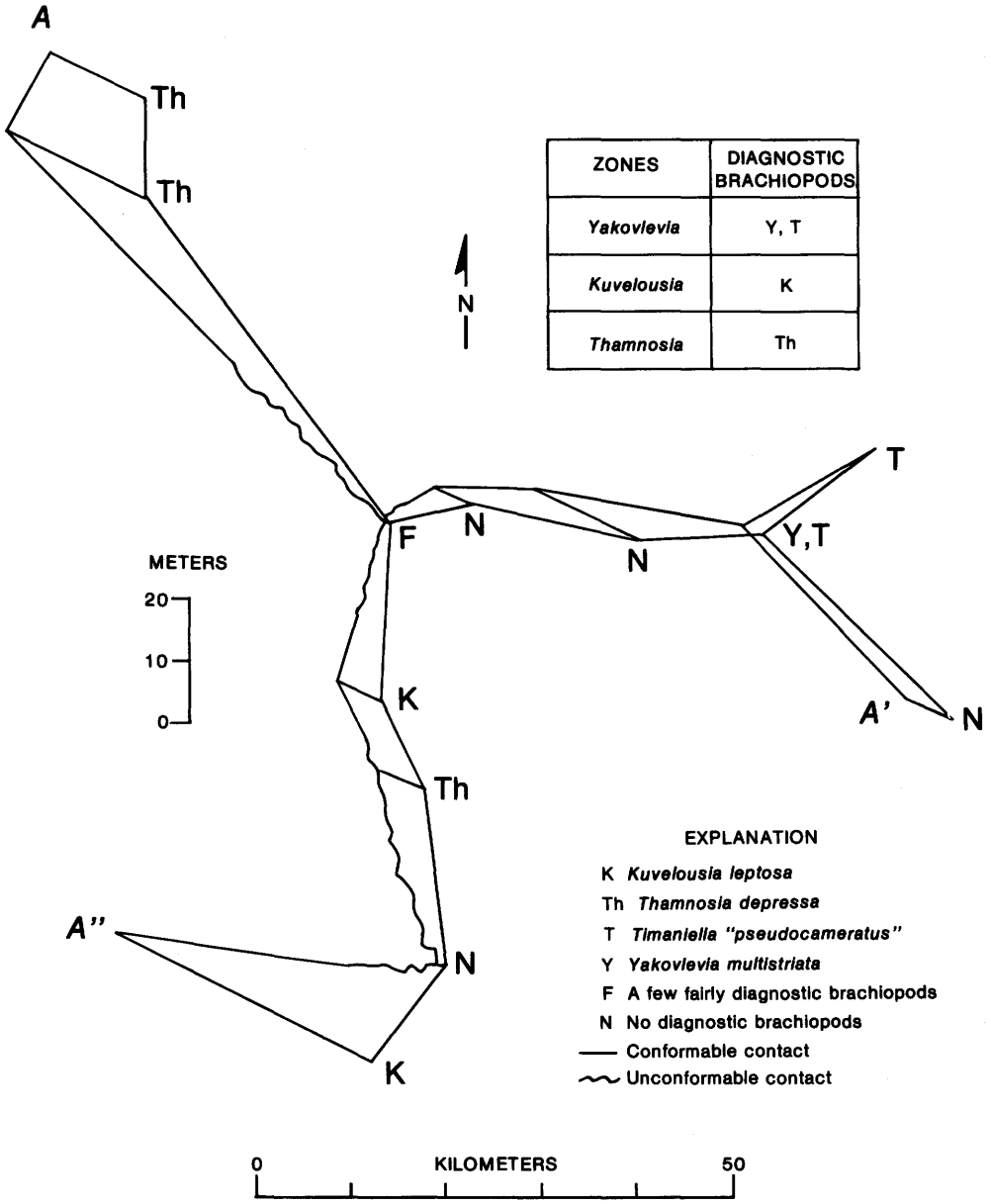

FIGURE 2.—Fence diagram of Retort Phosphatic Shale Member of the Phosphoria Formation, showing occurrences of brachiopods immediately below the Retort. Localities as in figure 1.

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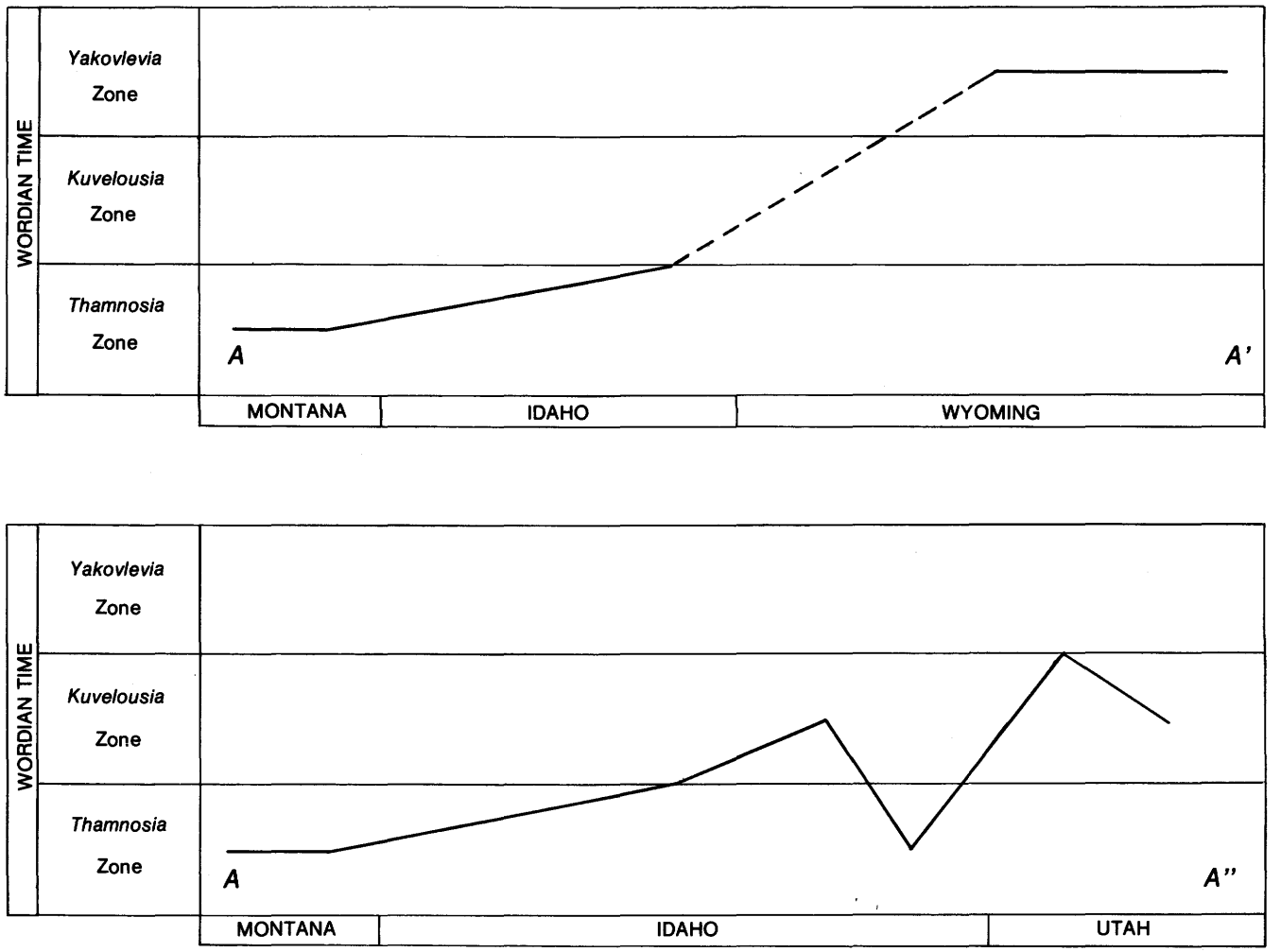

FIGURE 3.—Relative age of the base of the Retort Phosphatic Shale Member of the Phosphoria Formation in Idaho, Montana, Utah, and Wyoming, following traverses A–A′ and A–A″, shown in figure 1. Dashed where inferred.

The Murdock Mountain Formation: A New Unit of the Permian Park City Group

By BRUCE R. WARDLAW, JAMES W. COLLINSON, *and* EDWIN K. MAUGHAN

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THE MURDOCK MOUNTAIN FORMATION: A NEW UNIT OF THE PERMIAN PARK CITY GROUP

By BRUCE R. WARDLAW, JAMES W. COLLINSON,[1] and EDWIN K. MAUGHAN

ABSTRACT

A new formation is proposed for middle Permian rocks of a transitional facies positioned laterally between the Rex Chert Member of the Phosphoria Formation in northeastern Utah and southeastern Idaho and the Plympton Formation in northeastern Nevada and northwestern Utah.

INTRODUCTION

The Murdock Mountain Formation is proposed here for a sequence of dolomitic chert, dolomite, fine-grained sandstone, and siltstone that occurs as a middle formation within the Park City Group of northeastern Nevada and northwestern Utah. The type section is located on the east flank of Murdock Mountain, north-center sec. 36, T. 39 N., R. 67 E., Loray 7½-minute quadrangle, Leach Mountains, Elko County, Nev. (fig. 4). The beds form a homoclinal section striking N. 39° E. and dipping at about 27° W. The formation conformably overlies the Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation and is conformably overlain by the Gerster Limestone. The Murdock Mountain Formation is laterally equivalent to the Plympton Formation, also of the Park City Group, in west-central Utah and east-central Nevada, and to the Rex Chert Member of the Phosphoria Formation in southwestern Idaho. (See also Chapter C, this volume.)

DISCUSSION

A diagrammatic section of the Murdock Mountain Formation at the type section is shown in figure 5. The formation is 385.5 m thick at the type section. The lower contact is gradational; phosphatic mudstone and phosphorite in the underlying Meade Peak Tongue grade upward into less phosphatic beds of cherty siltstone, chert, dolomite, and limestone in the basal Murdock Mountain Formation. Most of the Murdock Mountain Formation is composed of slope-forming cherty siltstone, silty chert, fine-grained sandstone, and thin beds of dolomite. Thick units of dark-gray bedded chert form prominent ledges throughout the sequence. Lateral gradation of chert to cherty limestone within beds and relict limestone textures and fabrics in the chert indicate that much of the bedded chert formed by secondary replacement of limestone. The chert interval near the base of the formation contains less secondary chert and is, therefore, much like the chert of the Rex Chert Member of the Phosphoria Formation. Two chert units in the lower part of the Gerster Limestone in the Leach Mountains (Nevada) and the Terrace Mountains (northwestern Utah) probably represent tongues of the Murdock Mountain Formation. (See Chapter C.)

A well-preserved fauna from near the base of the Murdock Mountain Formation contains *Cancrinella phosphatica* Girty, *Crurithyris arcuata* Girty, *Echinalosia* n. sp., *Leiorhynchoidea weeksi* Girty, *Hindeodus* sp., *Neogondolella idahoensis* (Youngquist, Hawley, and Miller), and *Xaniognathus abstractus* (Clark and Ethington). This fauna indicates a Roadian Age (stage name of Furnish, 1973). Diagnostic fossils were not found in the middle and upper parts of the formation. However, the overlying Gerster Limestone, the upper formation of the Park City Group, has been dated as Wordian by its abundant brachiopod and conodont faunas (Wardlaw, 1977; Wardlaw and Collinson, 1977; this volume, Chapter D). The Murdock Mountain Formation is therefore Roadian to earliest Wordian in age (Early-Late Permian according to Furnish (1973) or Early Permian according to the U.S. Geological Survey) (fig. 6).

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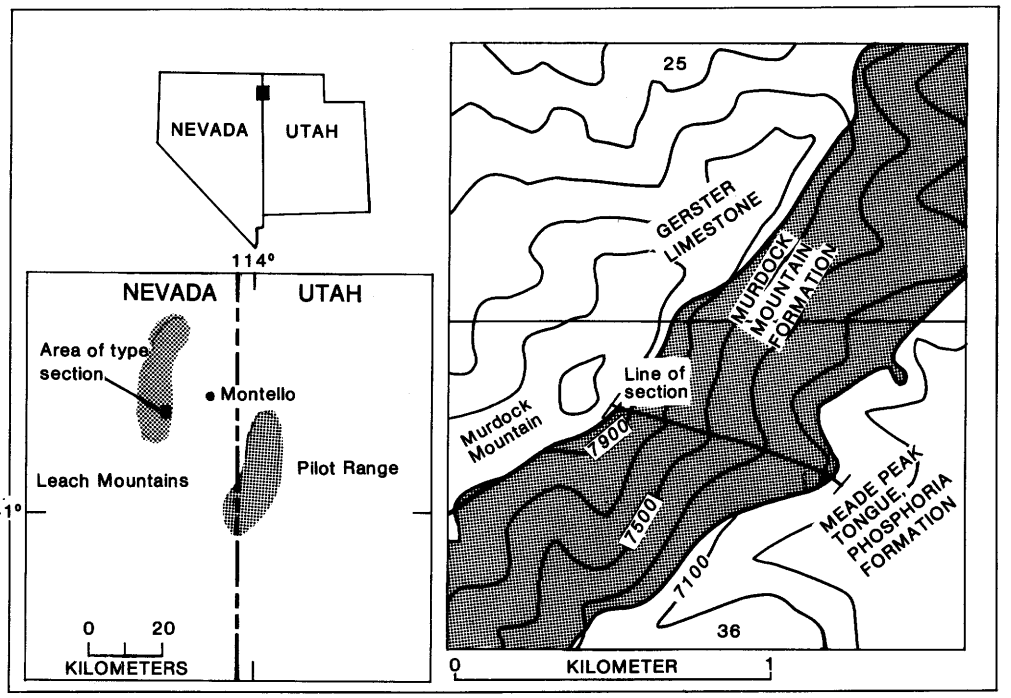

FIGURE 4.—Location of the type section of the Murdock Mountain Formation in the Leach Mountains, Elko County, Nev. Contour interval 200 ft (61 m). Base from U.S. Geological Survey 1:24,000 Loray (1967).

The Murdock Mountain Formation is transitional in character between the equivalent Plympton Formation of west-central Utah and east-central Nevada and the Rex Chert Member of the Phosphoria Formation in northeastern Utah and southeastern Idaho. The Murdock Mountain Formation contains a lesser proportion of bedded chert than the Rex Chert Member to the north and a greater proportion of fine-grained sandstone and chert than the predominantly dolomitic Plympton Formation to the south. Much of the chert within the unit is secondary.

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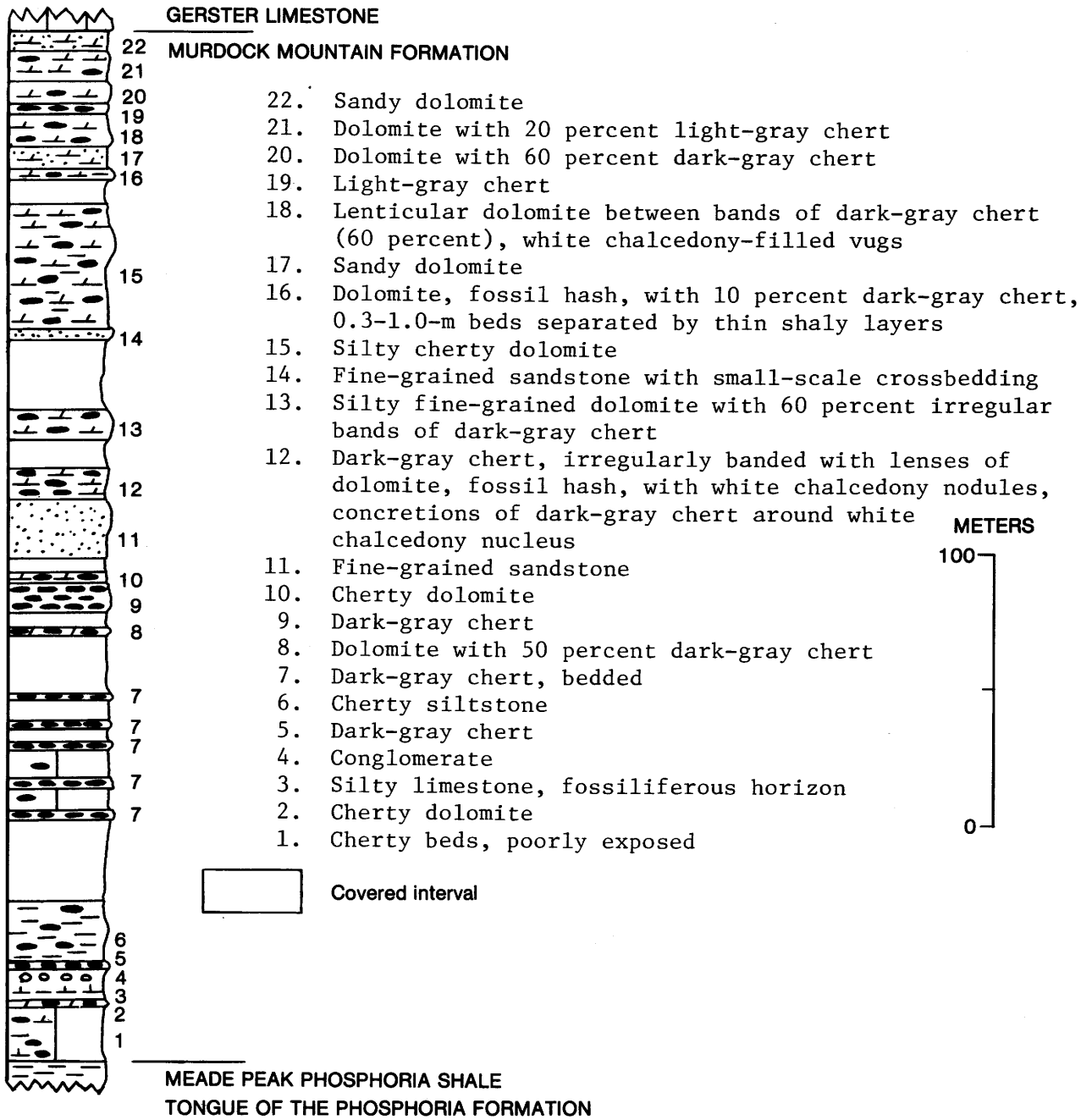

FIGURE 5.—Columnar section of the Murdock Mountain Formation.

Furnish (1973, fig. 1)			Subdivisions in use by U.S. Geological Survey
SERIES		STAGE	SERIES
UPPER PERMIAN	DZHULFIAN	CHANGHSINGIAN	UPPER PERMIAN
		CHHIDRUAN	
		ARAKSIAN	
	GUADALUPIAN	AMARASSIAN	
		CAPITANIAN	
		WORDIAN	LOWER PERMIAN
LOWER PERMIAN	ARTINSKIAN	ROADIAN	
		LEONARDIAN	
		AKTASTINIAN	
	SAKMARIAN	STERLITAMAKIAN	
		TASTUBIAN	
		ASSELIAN	

FIGURE 6.—Subdivisions of the Permian.

Stratigraphy of Park City Group Equivalents (Permian) in Southern Idaho, Northeastern Nevada, and Northwestern Utah

By BRUCE R. WARDLAW, JAMES W. COLLINSON, *and* EDWIN K. MAUGHAN

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STRATIGRAPHY OF PARK CITY GROUP EQUIVALENTS (PERMIAN) IN SOUTHERN IDAHO, NORTHEASTERN NEVADA, AND NORTHWESTERN UTAH

By BRUCE R. WARDLAW, JAMES W. COLLINSON, and EDWIN K. MAUGHAN

ABSTRACT

The relationships of the Permian Park City Group to the Phosphoria and Park City Formations are clarified by the stratigraphy of four sections in northwestern Utah, northeastern Nevada, and southern Idaho.

INTRODUCTION

Biostratigraphic data confirm that the Park City Group and the Park City and Phosphoria Formations compose a heterogeneous body of closely related rocks of Roadian and Wordian Age (stages of Furnish, 1973) that once extended across the cratonic and miogeosynclinal areas of Utah and eastern Nevada. The Park City Group (Kaibab Limestone, Plympton Formation, and Gerster Limestone) of east-central Nevada and west-central Utah is correlated with the Phosphoria and Park City Formations of northeastern Utah, southwestern Wyoming, and southeastern Idaho, through the use of four key sections in the intervening area of northwestern Utah, northeastern Nevada, and southern Idaho (fig. 7). The three sections in the Terrace and Cedar Mountains (Utah) and the Leach Mountains (Nevada) are assigned to the Park City Group; the section in the Cassia Mountains (Idaho) belongs to the Phosphoria Formation. The Grandeur Tongue of the Park City Formation, which is equivalent to the Kaibab Limestone, is elevated to formation rank in the Cedar and Terrace Mountains. The Meade Peak Phosphatic Shale Member (locally a tongue in northeastern Nevada and northwestern Utah) of the Phosphoria Formation is a useful marker horizon over the entire region. Rocks transitional from the Plympton Formation to the Rex Chert Member of the Phosphoria Formation occur in the Leach and Terrace Mountains. The Gerster Limestone is most complete in the Leach Mountains; elsewhere biostratigraphic zones are beveled by Late Permian-Early Triassic erosion.

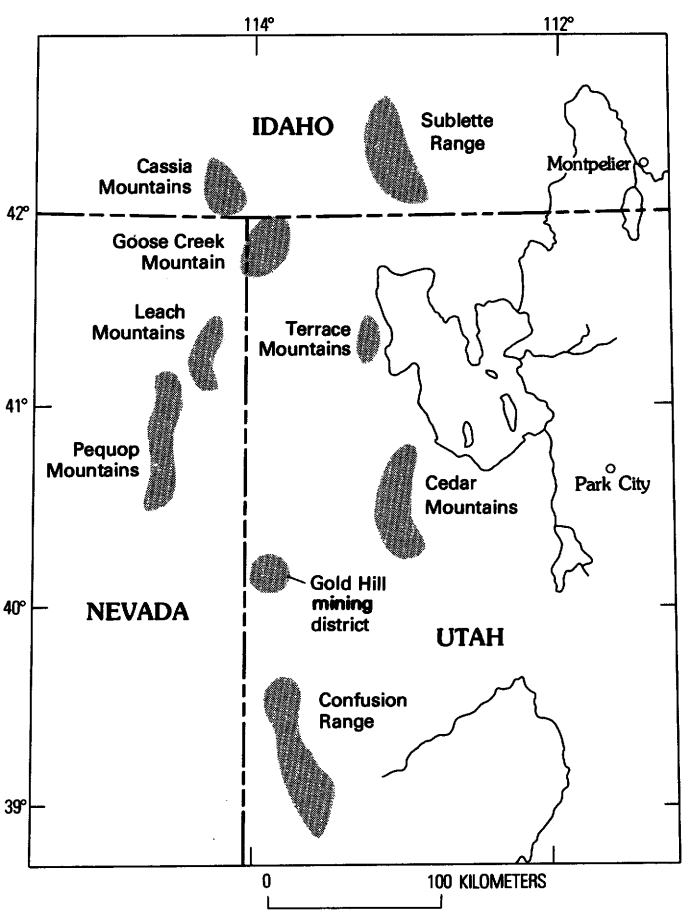


FIGURE 7.—Index map of area of investigation.

Isopachs of the Park City Group and its equivalents indicate that an east-trending axis of thinning in east-central Nevada and west-central Utah separates the depositional basin into two distinct structural lobes, one centered in west-central Utah and the other in northeast Nevada. Facies relationships suggest that these were not bathymetric basins; deeper water existed to the north in Idaho. A carbonate shelf deepening toward the chert and phosphatic-mudstone depositional areas in Idaho, extended across Utah to central Nevada during Roadian and Wordian time. A series of highlands or islands bordered the carbonate shelf along the Antler orogenic belt in central Nevada and served as source areas for sandstone and conglomerate.

STRATIGRAPHY OF THE WESTERN PHOSPHATE FIELD

The stratigraphy of the western phosphate field was revised by McKelvey and others (1956, 1959) to reflect the complex relationships between Permian chert-mudstone-phosphorite facies, carbonate facies, and sandstone facies. The name Phosphoria Formation was retained for phosphorite, phosphatic mudstone, carbonaceous mudstone, and chert in southeastern Idaho and adjacent areas. The Park City Formation was retained for predominantly carbonate rock sequences such as in the type area near Park City, Utah. The name Shedhorn Sandstone was introduced for equivalent rocks in northwestern Wyoming and adjacent parts of Montana. The Phosphoria and Park City Formations were subdivided into members. When a member of one formation was identified within the sequence of the other formation, it was called a tongue of the former.

The Phosphoria Formation was originally named by Richards and Mansfield (1912, p. 684–689) for the sequence at Phosphoria Gulch, near Montpelier, Bear Lake County, Idaho. McKelvey and others (1959) recognized the following members (in approximate ascending order): lower chert member, Meade Peak Phosphatic Shale Member, Rex Chert Member, cherty shale member, Retort Phosphatic Shale Member, and Tosi Chert Member. Not all of these members occur at the type section, and some are lateral equivalents of one another. These relationships are shown diagrammatically in figure 8.

The Park City Formation, named by Boutwell (1907, p. 443–446), was subdivided by McKelvey and others (1959) into three members (in ascending order): Grandeur Member, Franson Member, and Ervay Carbonate Rock Member. All of these members are predominantly carbonate, and they are separated by tongues of the Phosphoria Formation.

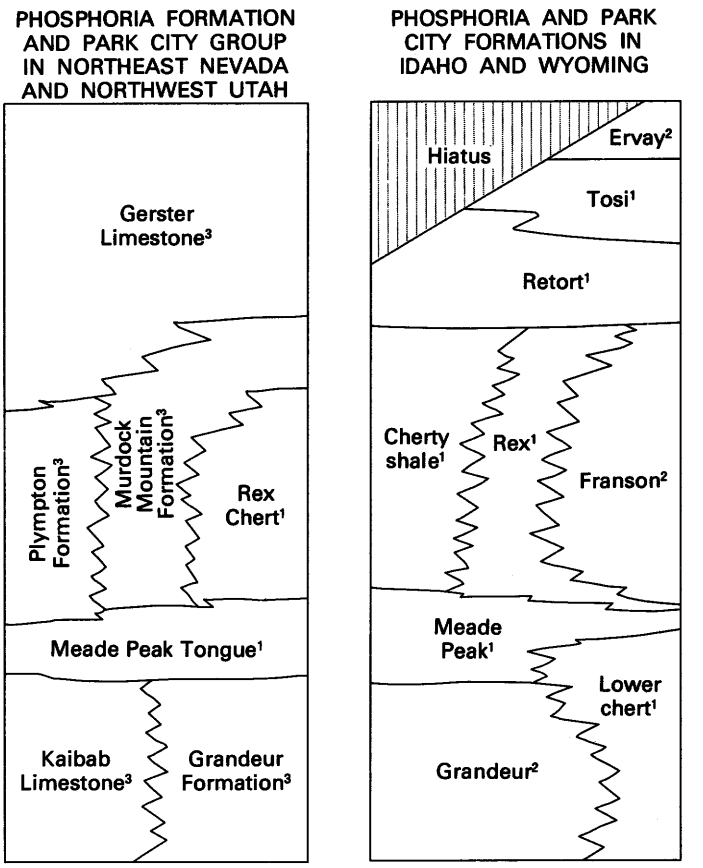


FIGURE 8.—Diagram of formation and member relationships of the Park City Group and the Phosphoria and Park City Formations of Permian age.

The Shedhorn Sandstone (McKelvey and others, 1959) is mainly to the north of the region considered here.

STRATIGRAPHY OF EAST-CENTRAL NEVADA AND ADJACENT UTAH

Hose and Repenning (1959, p. 2178) raised the name Park City in rank to Park City Group for rocks that comprised (in ascending order) the Kaibab Limestone, Plympton Formation, and Gerster Limestone in the Confusion Range, Utah. The formations were also recognized in east-central Nevada (Steele, 1960).

The Kaibab Limestone in east-central Nevada and adjacent Utah is a 75-m- to 150-m-thick unit of massive cliff-forming limestone and cherty dolomite. The formation in this region is equivalent to the lower part of the Kaibab Limestone and possibly to the Lower Permian Toroweap Formation at the type locality of these formations in the Grand Canyon area as described by Noble (1928) (Baird and Collinson, 1975).

The Plympton Formation was named by Hose and Repenning (1959, p. 2181–2184) in the Confusion Range for a 212-m-thick sequence of dolomite and chert, containing minor amounts of pelletal phosphate, chert-pebble conglomerate, carbonate "breccia," sandstone, siltstone, and gypsum. Several authors have speculated that phosphatic beds near the base of the Plympton represent a tongue of the Meade Peak Phosphatic Shale Member (Cheney and others, 1956, p. 1716–1719; Hodgkinson, 1961, p. 180; Bissell, 1962, p. 241; Roberts and others, 1965, p. 1942–1943).

The Gerster Limestone was named by Nolan (1935, p. 39) for a thin-bedded sandy and shaly limestone sequence exposed at Gerster Gulch in the Gold Hill mining district, Utah. A richly fossiliferous limestone over its regional extent, the Gerster Limestone varies from 43 m to 341 m in thickness in east-central Nevada and adjacent Utah (Wardlaw and Collinson, 1978).

STRATIGRAPHY OF NORTHEASTERN NEVADA, NORTHWESTERN UTAH, AND SOUTHERN IDAHO

The detailed stratigraphy of four measured sections is shown in figure 9. The sequences in the Leach Mountains, Terrace Mountains, and Cedar Mountains are predominantly carbonate and are referable to the Park City Group. The Grandeur is recognized in the Terrace and Cedar Mountains as part of the Park City Group and is elevated to formational status. Its correlative in the Leach Mountains is the Kaibab Limestone. The sequence in the Cassia Mountains belongs to the Phosphoria Formation. The thicknesses of these measured sections are reliable, except perhaps for the lower part of the section in the Terrace Mountains where the Grandeur Formation and the Murdock Mountain Formation, a new name (this volume, Chapter B), are poorly exposed and complexly faulted.

The Grandeur Formation forms the base of the Park City Group in northwestern Utah and is composed of carbonate, which is mostly cherty dolomite and has lesser amounts of bioclastic limestone, chert, mudstone, and sandstone. Although the Grandeur is lithologically similar to the Kaibab Limestone which occurs in the Leach Mountains, it is more heterogeneous, containing sandstone, siltstone, phosphorite, and chert. In the Leach Mountains the base of the Park City Group consists of a thin sequence of Kaibab Limestone overlying the Lower Permian Arcturus Formation or Loray Formation of Steele (1960). Most subsequent workers have included the Loray in the Grandeur. The most common fossils are crinoid and bryozoan fragments and whole brachiopods.

The Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation overlies the Grandeur Formation. It is characterized by dark carbonaceous mudstone and thin beds of phosphorite and dark bioclastic limestone. Snails are the most abundant fossils; brachiopods, conodonts, and impressions of ammonoids also occur.

The greatest facies changes in this region occur in the interval above the Meade Peak Phosphatic Shale Tongue and below the Gerster Limestone. In the Cedar Mountains a sequence of dolomite, chert, mudstone, and sparse limestone is assigned to the Plympton Formation. To the north in the Cassia Mountains, this interval is occupied by massive chert of the Rex Chert Member of the Phosphoria Formation. In the Leach and Terrace Mountains, a unit that seems to be transitional between the Plympton Formation and the Rex Chert Member consists of chert, cherty dolomite, limestone, and sandstone; it is called the Murdock Mountain Formation. The sandstone in the Cassia and Leach Mountains is unlike the Shedhorn Sandstone and was probably derived from the same westerly source as the Permian Edna Mountain Formation of northeastern Nevada (Roberts and others, 1965, p. 1941).

The Gerster Limestone forms the upper unit of the Park City Group throughout its regional extent. It does not occur with the Phosphoria Formation in the Cassia Mountains, because the upper part of the sequence has been removed by erosion. The Gerster Limestone is a cherty bioclastic limestone containing minor beds of chert, dolomite, and siltstone. Crinoid and bryozoan fragments and, commonly, silicified whole brachiopods make up much of the rock. The lithology and fauna of the Gerster Limestone are similar to those of the Franson Member of the Park City Formation.

Two intervals of secondary chert replacing carbonate within the Gerster Limestone in both the Leach and Terrace Mountains sections represent tongues of the Murdock Mountain lithology. In the upper part of the Gerster in the Leach Mountains is a thick interval of alternating limestone and secondary chert replacing limestone, which could be interpreted as another tongue of the Murdock Mountain Formation but is here kept in the Gerster. In the middle of this interval is a platy limestone that may be equivalent to the Retort Phosphatic Shale of the Phosphoria Formation.

STRATIGRAPHIC CORRELATIONS

Figure 10 shows the application of the biostratigraphic zones of Wardlaw and Collinson (1977; this volume, Chapter D). The four columnar sections of the present study are correlated with the Fort Douglas (Cheney and others, 1953) and Sublette Range (Smart and others, 1954) sections summarized by McKelvey and others (1959) and with the Gerster Gulch (Gold

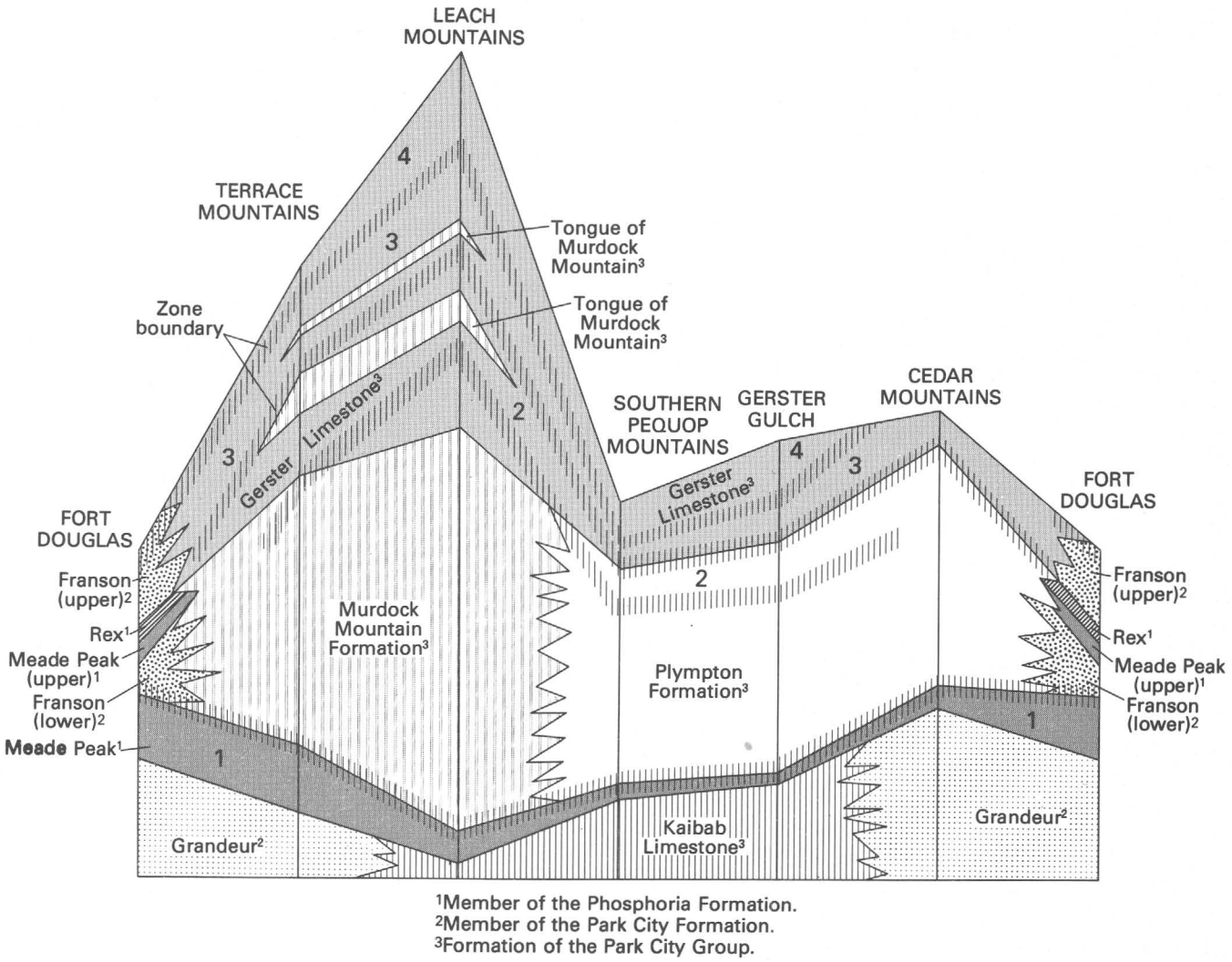
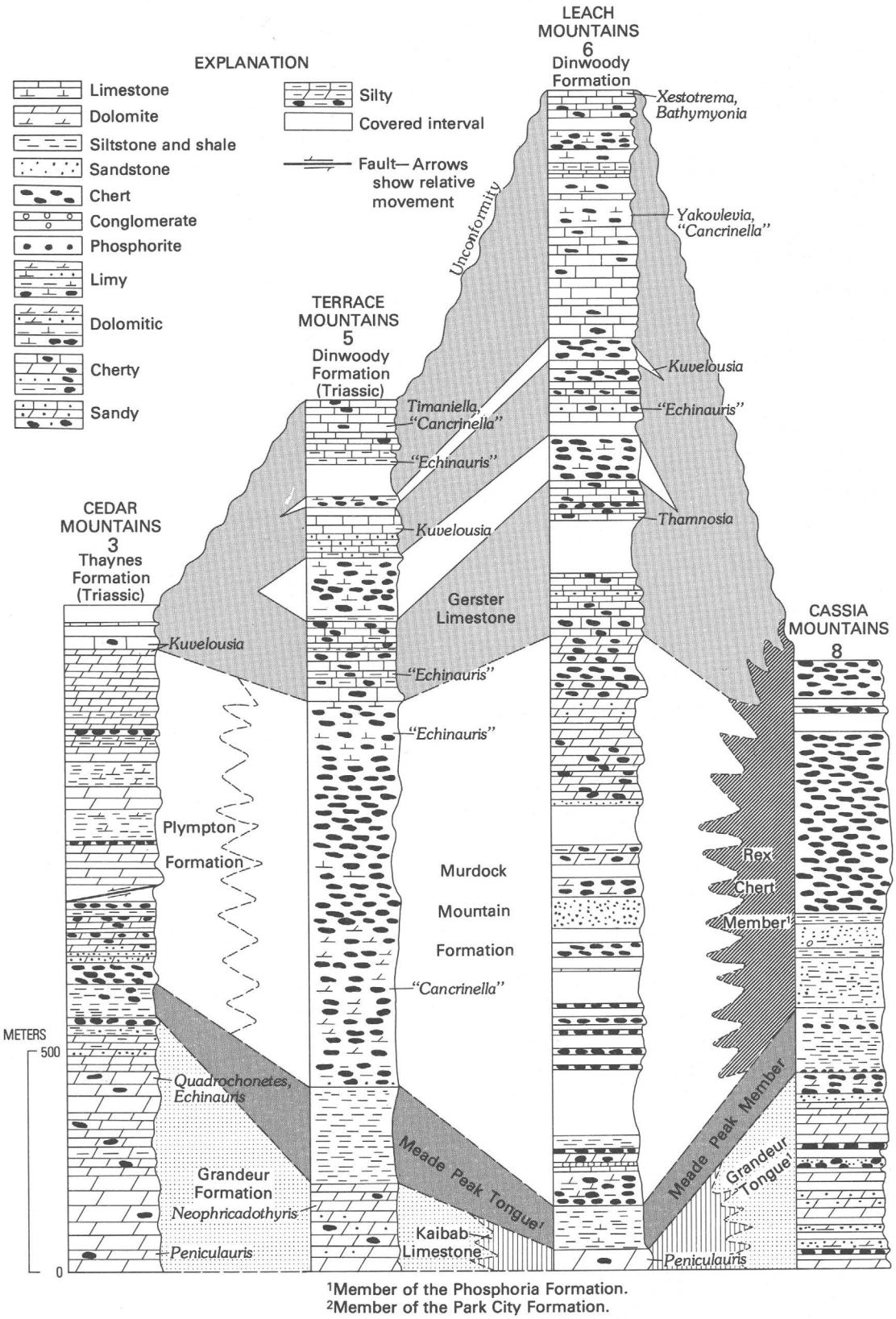


FIGURE 9.—Biostratigraphic zonation of Park City-Phosphoria equivalents. The zones are: 1, *Peniculauris*; 2, *Thamnosia*; 3, *Kuvelousia*; and 4, *Yakovlevia*.

Hill District) and southern Pequop Mountains sections of Wardlaw and Collinson (1977). The *Penicularis* Zone is modified from Zone 2 of Wardlaw and Collinson (1977), which is based on brachiopods and conodonts. The *Thamnosia, Kuvelousia,* and *Yakovlevia* Zones are equivalent to the *Thamnosia depressa* (Zone 4), *Kuvelousia leptosa* (Zone 5), and *Yakovlevia multistriata-Neogondolella bitteri* (Zone 6) Zones. The *Penicularis* Zone is interpreted by Wardlaw and Collinson (1977) to be Roadian. The Meade Peak is also Roadian (Furnish, 1973, p. 534) on the basis of ammonoid faunas. The *Thamnosia, Kuvelousia,* and *Yakovlevia* Zones are Wordian. These stage names follow the usage of Furnish (1973). His Roadian and Wordian are assigned to the Early Permian Epoch by the U.S. Geological Survey.

Interpretation of the biostratigraphic zones as relative time lines clarifies formational interrelationships (fig. 11). This is a reasonable interpretation because the zones are widely distributed and are not limited to a single facies. These correlations are further supported by lithostratigraphic continuity of such widespread units as the Meade Peak Phosphatic Shale Member.

Biostratigraphic data confirm the following temporal relationships: (1) The Kaibab Limestone of northeastern and east-central Nevada and adjacent Utah, the Grandeur Formation of northwestern Utah, and the Grandeur Member of the Park City Formation in northeastern Utah are equivalent. (2) A tongue of the Meade Peak Phosphatic Shale Member is widespread and occurs between the base of the Plympton Forma-



[1]Member of the Phosphoria Formation.
[2]Member of the Park City Formation.

FIGURE 10.—Columnar sections of Park City-Phosphoria equivalents in Idaho, Nevada, and Utah. Quotation marks indicate undescribed genera.

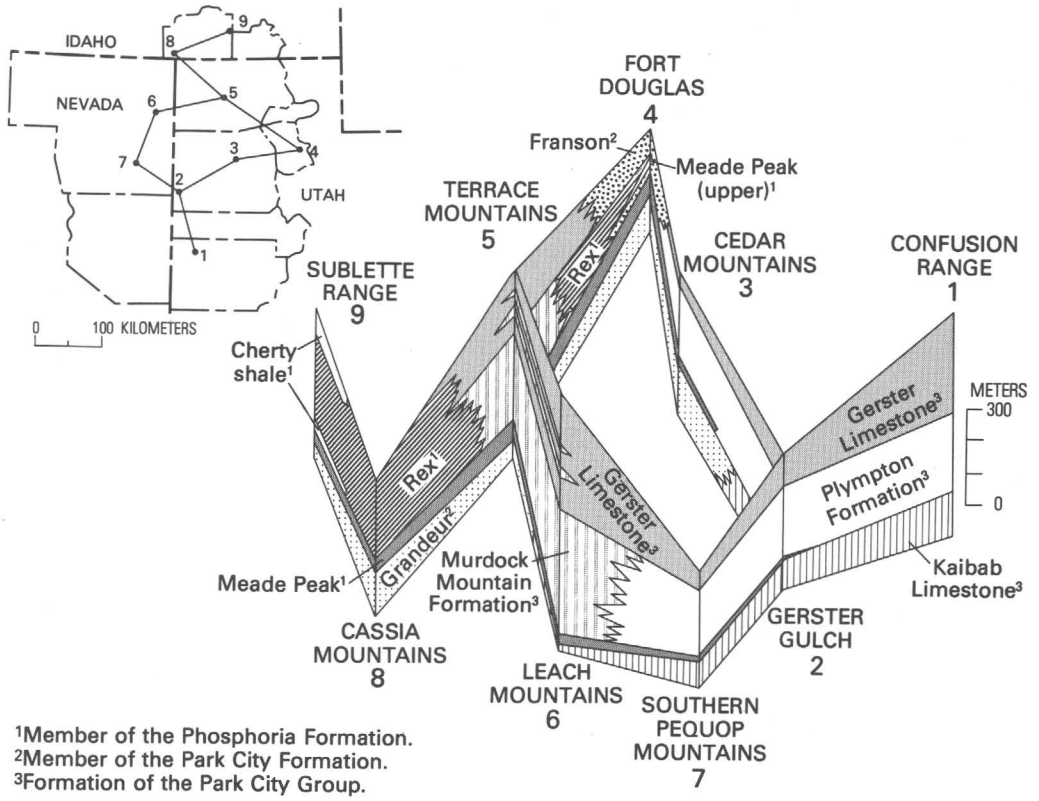


FIGURE 11.—Fence diagram showing formational interrelationships of the Phosphoria and Park City Formations and the Park City Group in Idaho, Nevada, and Utah.

tion and the top of the Grandeur. The lower part of the Plympton Formation in the Confusion Range and the Meade Peak Phosphatic Shale Tongue are equivalent; therefore, the lower Plympton and the Meade Peak Member of the Phosphoria Formation are equivalent. (3) The Rex Chert Member of the Phosphoria Formation, the major part of the Plympton Formation, and the major part of the Murdock Mountain Formation in the Leach and Terrace Mountains are equivalent. (4) The uppermost part of the Plympton Formation, which contains sparse beds of fossiliferous limestone in east-central Nevada, is equivalent to the lowermost part of the Gerster Limestone in the Leach and Terrace Mountains. These limestone beds in the upper Plympton contain specimens of *Thamnosia* (Wardlaw and Collinson, 1977) and probably represent tongues of the Gerster Limestone from the north. (5) The uppermost Plympton Formation and much of the Gerster Limestone are equivalent to the Franson Member of the Park City Formation. (6) Late Permian-Early Triassic erosion beveled the Gerster Limestone into the *Yakovlevia* Zone in the Cedar Mountains and greatly limited the upper part of the Franson in the Fort Douglas section. (7) Where the Gerster Limestone is most complete, such as in the Leach and Terrace Mountains and in the Confusion Range, the upper part may be equivalent to or younger than the Ervay Carbonate Rock Member of the Park City Formation.

INTERPRETATION

The isopach map (fig. 12) indicates thinning along an east-west axis passing near the southern Pequop Mountains and Gerster Gulch (the Gold Hill mining district). This axis is projected eastward into an area where data are sparse, because trends of similar highs are recorded for Pennsylvanian and older Permian rocks in this region, such as the Cortez-Uinta axis (Roberts and others, 1965, p. 1937; Marcantel, 1975, p. 2082). Although this thinning is partly due to post-depositional erosion, the thinning of biostratigraphic zones in the Gerster Limestone in the southern Pequop Mountains and Gold Hill mining district indicates that this axis was active by Wordian time (Wardlaw and Collinson, 1978).

The axis of thinning appears to separate the depositional basin into two distinct structural lobes, one centered in west-central Utah and the other in north-

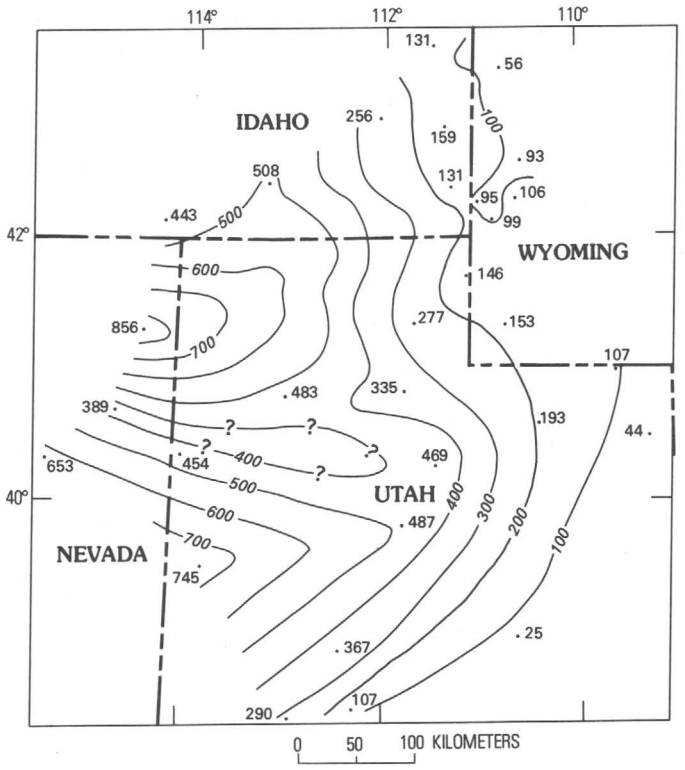


FIGURE 12.—Isopach map of Park City-Phosphoria equivalents. Thicknesses (in meters) based on data from Cheney and others (1953); Smart and others (1954); Sheldon (1963); Baker and others (1949); Welsh (1972); Crosby (1959); Wardlaw and Collinson (1978); Sheldon and others (1953); Sheldon and others (1954); McKelvey and others (1953); Schell and Gere (1964); and this study. Isopach queried where data sparse.

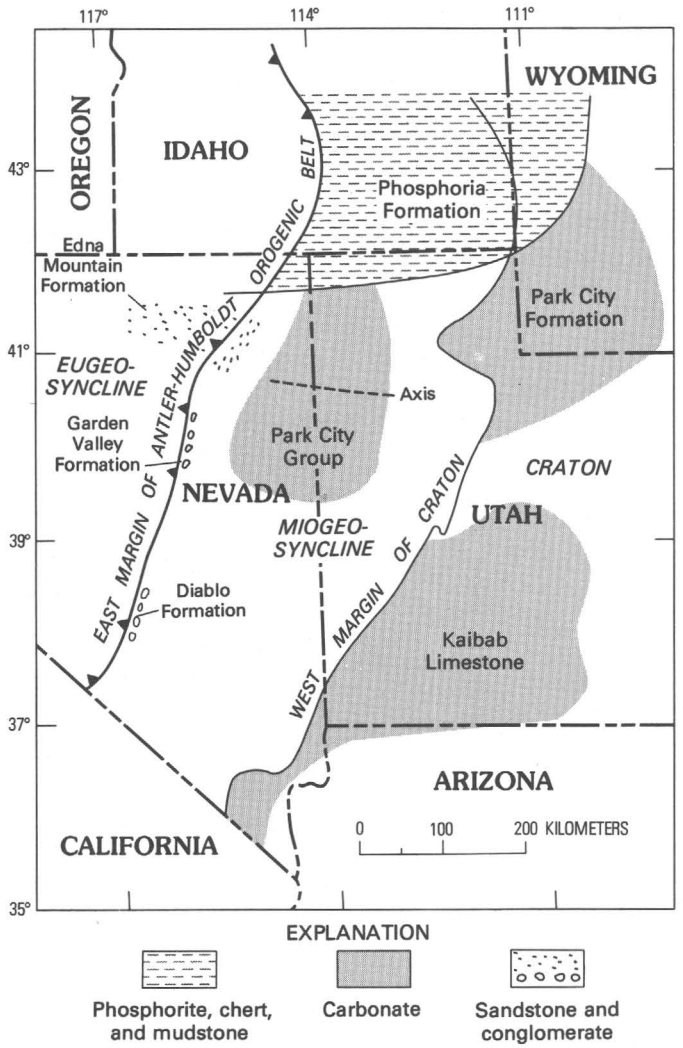


FIGURE 13.—Tectonic and rock-unit distribution of Permian Park City equivalents (modified from Roberts and others, 1965, p. 1941).

eastern Nevada (fig. 12). Areas of greatest thickness probably do not coincide with bathymetric centers of the basin. McKelvey and others (1959, p. 5–6) interpreted the chert, phosphorite, and mudstone of the Phosphoria Formation as representing the deeper water facies, and they placed the deepest part of the basin in east-central Idaho. The thinning of the sequence to the north into Idaho, as indicated by the isopachs (fig. 12), probably reflects slower depositional rates in deeper water.

The deeper water area of central Idaho was bordered by a carbonate shelf that extended from the cratonic area of eastern Utah to the west margin of the miogeosyncline in central Nevada (fig. 13). The Park City Formation and the partly equivalent Kaibab Limestone were deposited on the craton. The much thicker Park City Group is found in the miogeosycline. An increasingly greater proportion of chert and phosphatic mudstone in the Park City Group as it is traced northward from east-central Nevada and adjacent Utah to Idaho suggests gradual deepening of this shelf.

The miogeosyncline was apparently separated from the eugeosyncline by a series of highlands or islands along the Antler orogenic belt. In north-central Nevada the Park City Group grades into sandstone and calcareous sandstone of the Edna Mountain Formation of Wordian Age (Silberling and Roberts, 1962, p. 16). Conodonts of Roadian Age (Zone 3 of Wardlaw and Collinson, 1977) were found in a limestone sample from high in the conglomeratic Permian Garden Valley Formation at Twin Springs Hills, 40 km west of Eureka, Nev. (collected by Kent Chamberlain, Univ. Nevada, Las Vegas). Farther south in the Candelaria Hills, Esmeralda County, and Toiyabe Range, northern Nye County, the sandy and conglomeratic Permian

Diablo Formation contains a Wordian brachiopod fauna (Silberling and Roberts, 1962, p. 28).

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Biostratigraphic Zonation of the Park City Group

By BRUCE R. WARDLAW *and* JAMES W. COLLINSON

STUDIES OF THE PERMIAN PHOSPHORIA FORMATION AND RELATED ROCKS, GREAT BASIN-ROCKY MOUNTAIN REGION

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ABSTRACT

Five biostratigraphic zones based on the distribution of brachiopods and conodonts are proposed for the Park City Group. They are: the *Peniculauris ivesi-Neostreptognathodus prayi* Zone, the *Peniculauris bassi-Neostreptognathodus sulcoplicatus* Zone, the *Peniculauris bassi-Neostreptognathodus* sp. C Zone, the *Thamnosia depressa* Zone, and the *Yakovlevia multistriata-Neogondolella bitteri* Zone. They range in age from Leonardian to Wordian.

INTRODUCTION

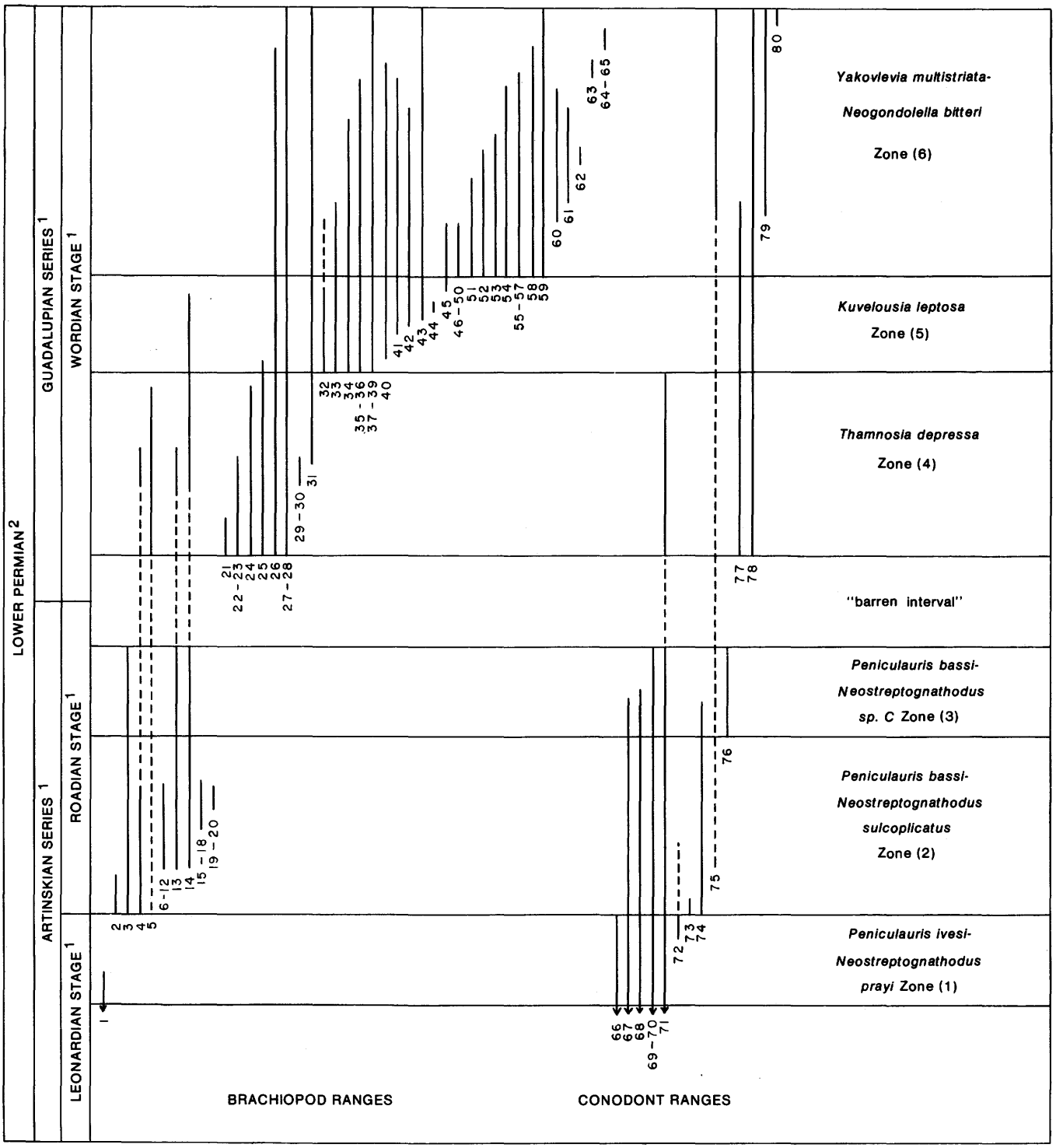
The biostratigraphic zonation proposed here is based on the ranges of brachiopod and conodont species (fig. 14). The distribution of the biostratigraphic zones in the Park City Group is shown in figure 15. Samples for conodonts were collected at intervals of 3–5 m where practical. Large samples for brachiopods were collected at intervals usually averaging 7–10 m, for the purpose of etching to obtain the silicified material. Crackouts were collected throughout the section and the data were augmented by field identifications. The lower part of the sequence is best represented by conodonts and the upper part by brachiopods; the zonation is slanted accordingly. Because our data are from a relatively small region, fossil ranges partly reflect basin-wide facies changes. These ranges will probably expand as data from other regions are added. The zones are Oppel-zones (Hedberg, 1976), with the exception of Zones 1 and 3, which are based on ranges of conodonts.

The time-stratigraphic subdivision of the Permian System proposed by Furnish (1973) is followed. Taxa without specific names are designated by letters of the alphabet and conform to the usage of these names in the theses of Wardlaw (1974), Baird (1975), and Marcantel (1975).

PENICULAURIS IVESI-NEOSTREPTOGNATHODUS PRAYI ZONE (1)

Based on the range on the conodont *N. prayi,* this zone is similar to the *Neostreptognathodus sulcoplicatus-N. prayi* Assemblage Zone of Behnken (1975, p. 292–293). In emending *N. sulcoplicatus* (Youngquist, Hawley, and Miller) Behnken (1975, p. 211–212; pl. 1, figs. 2, 4) included what we regard as *Neostreptognathodus* sp. D from the Pequop Formation of Steele (1960) and the Arcturus Formation, thereby erroneously extending the range of *N. sulcoplicatus* to the Leonardian Stage of Furnish (1973).

Examples of *N. prayi* Behnken occur in the lower two-thirds of the Kaibab sections in eastern Nevada and western Utah, except in the Confusion Range section, where they occur in the lower half of the formation. In addition to finding *N. prayi* in the Kaibab Limestone, Behnken (1975, p. 287) reported it from the upper part of the Arcturus and Pequop Formations, which are older than the Kaibab. Baird (1975) found *N. prayi* in the Toroweap Formation of southern Utah. In West Texas, Behnken (1975, p. 293) described *N. prayi* from the Bone Spring Limestone, Victorio Peak Limestone, and from the basal part of the overlying Cutoff Shale. He implied that *N. prayi* ranges from the upper Leonardian into the lower Wordian in age. This Wordian age assignment is apparently based on a report by Bissell (1964, p. 616–617, 620, 624) of Guadalupian ammonoids in the underlying Loray Formation, which has since proved to be erroneous (W. M. Furnish, oral commun., 1976). The occurrence of *N. prayi* in the Bone Spring and Victorio Peak Limestones strongly suggests a late Leonardian age for this zone.



[1] Of Furnish (1973).

[2] The U.S. Geological Survey does not recognize the Roadian-Wordian boundary as the Lower Permian-Upper Permian boundary as some American workers do. The Wordian-Capitanian boundary is recognized as the division.

Behnken (1975, p. 290) indicated that *Neogondolella idahoensis* occurs with *N. prayi* in the West Texas sequence. A broken fragment identified by Baird (1975) as *N.* cf. *N. idahoensis* was found in the upper part of the *N. prayi* Zone in eastern Nevada. The brachiopod *Peniculauris ivesi* (Newberry) is common in the Toroweap Formation in southern Utah and northern Arizona. It sporadically occurs elsewhere from the upper part of the Pequop and Loray Formations in Nevada and one occurrence in the lowermost part of the Kaibab at Spruce Mountain in Nevada. All occurrences fall within the range of *N. prayi.*

PENICULAURIS BASSI-NEOSTREPTOGNATHODUS SULCOPLICATUS ZONE (2)

The base of this zone is marked by the lowest occurrence of *N. sulcoplicatus* (Youngquist, Hawley, and Miller), and *Neostreptognathodus* sp. B (Baird, 1975). The top of this zone is defined by the lowest occurrence of *Neostreptognathodus* sp. C (Baird, 1975). The *N. sulcoplicatus* Zone occurs in the upper Kaibab Limestone and presumably the lower part of the Plympton Formation of eastern Nevada and western Utah and in the lower two-thirds of the Kaibab at its type section in southern Utah. Youngquist, Hawley, and Miller (1951) first described this species from the lower Phosphoria Formation in southeastern Idaho. Clark and Ethington (1962) described *N. sulcoplicatus* along with *Xaniognathus abstractus* (Clark and Ethington) from the Meade Peak Member of the Phosphoria Formation in southeastern Idaho and Wyoming. *Neogondolella idahoensis* was also described from these rocks by Youngquist, Hawley, and Miller (1951) and Clark and Ethington (1962).

An important component of the Meade Peak conodont fauna, *Neogondolella serrata* (Youngquist, Hawley, and Miller), has not been reported from eastern Nevada or western Utah, probably because the phosphatic shale facies has not been adequately sampled. We, nevertheless, believe that the *N. sulcoplicatus* Zone in eastern Nevada and western Utah is equivalent to the Meade Peak fauna, which Furnish (1973) assigned to the Roadian Stage. This age assignment eliminates the problem posed by Behnken (1975, p. 290) that conodont species of "Roadian age" in Texas range into strata of "Wordian age" in Nevada.

The brachiopods *Peniculauris bassi* (McKee), *Rugatia occidentalis* (Newberry), *Kozlowskia* sp., *Meekella* sp., *Megousia eucharis* (Girty), and *Neophricadothyris* sp. A are abundant in this zone. From the many sections of the Permian of the western United States examined by the authors, this seems to be the highest occurrence of *Meekella* and *Kozlowskia* in the West. They are widespread, occurring throughout the Grandeur Member of the Park City Formation in Montana and Wyoming and in the Kaibab Limestone in Arizona and Utah, as well as in the Concha Limestone in Arizona. *Kozlowskia* is strictly a Pennsylvanian to Lower Permian form. *P. bassi, R. occidentalis,* and *Neophricadothyris* are the dominant

FIGURE 14 (left).—Generalized range chart of brachiopod and conodont species from the Park City Group.

1. *Peniculauris ivesi* (Newberry)
2. *Lissochonetes* sp. A
3. *Peniculauris bassi* (McKee)
4. *Derbyia* sp. A
5. *Rhynchopora taylori* Girty
6. *Neophricadothyris* sp. A
7. *Megousia eucharis* (Girty)
8. *Meekella* sp.
9. *Echinauris* sp. A
10. *Quadrochonetes* sp. A
11. *Kozlowskia* sp.
12. *"Cancrinella"* sp.
13. *Rugatia occidentalis* (Newberry)
14. *Composita* cf. *C. parva* Branson
15. *Waagenoconcha* sp.
16. *Neospirifer* sp.
17. *Spiriferellina?*
18. *Cenorhynchia* sp.
19. *Phrenophoria* sp. A
20. *Liosotella?*
21. *"Echinosteges"*
22. *Sphenalosia* sp. A
23. *Dielasma* sp. A
24. *Thamnosia depressa* (Cooper)
25. *Bathymyonia* sp. A
26. *Derbyia sulca* (Branson)
27. *Xestotrema pulchrum* (Meek)
28. *Hustedia* sp. A
29. *Spiriferellina* sp. A
30. *Thamnosia* sp. A
31. *"Echinauris" subhorrida* (Meek)
32. *Kuvelousia leptosa* Waterhouse
33. *Waagenites* sp. A
34. *Dyoros* sp. A
35. *Dielasma* cf. *D. phosphoriensis* Branson
36. *Cleiothyridina* sp. A
37. *Bathymyonia nevadensis* (Meek)
38. *Composita mira* Girty
39. *Ctenalosia fixata* Cooper and Stehli
40. *Cleiothyridina* sp. B
41. *"Grandaurispina"* sp. A
42. *Sphenosteges hispidus* (Girty)
43. *Phrenophoria* sp. B
44. *Cenorhynchia* sp. A
45. *Spiriferella scobina* (Meek)
46. *Phrenophoria* sp. C
47. *Petasmatherus* sp. A
48. *Rostranteris* sp.
49. *Girtyella?*
50. *Heterelasma* sp. A
51. *Plectelasma* sp. A
52. *Echinalosia* sp. A
53. *Waagenites* sp. B
54. *Odontospirifer* sp. A
55. *Cenorhynchia* sp. B
56. *Plectelasma* sp. B
57. *Hemiptychina* sp. A
58. *Quadrochonetes* sp. B
59. *Timaniella "pseudocameratus"*
60. *Yakovlevia multistriata* (Meek)
61. *Liosotella delicatula* Dunbar
62. *Heteralosia* sp.
63. *Kochiproductus* sp.
64. *"Grandaurispina"* cf. *"G." arctica* (Waterhouse)
65. *Dielasma spatulatum* Girty
66. *Neostreptognathodus prayi* Behnken
67. *Neostreptognathodus* sp. D
68. *Neostreptognathodus clinei* Behnken
69. *Xaniognathus abstractus* (Clark and Ethington)
70. *Ellisonia festiva* (Bender and Stoppel)
71. *Anchignathodus* sp. A
72. *Neogondolella idahoensis* (Youngquist, Hawley, and Miller)
73. *Neostreptognathodus* sp. B
74. *Neostreptognathodus sulcoplicatus* (Youngquist, Hawley, and Miller)
75. *Xaniognathus tribulosus* (Clark and Ethington)
76. *Neostreptognathodus* sp. C
77. *Neospathodus arcucristatus* Clark and Behnken
78. *Ellisonia* sp. A
79. *Neogondolella bitteri* (Kozur)
80. *Neospathodus divergens* (Bender and Stoppel)

elements of the fauna of the Grandeur but also carry through to the Meade Peak. *Megousia eucharis* is common in the Grandeur and Meade Peak. The highest occurrence of *Peniculauris* and *Rugatia* in the West Texas Permian is Roadian.

PENICULAURIS BASSI-NEOSTREPTOGNATHODUS SP. C ZONE (3)

The base of this zone is determined by the first occurrence of *Neostreptognathodus* sp. C (Baird, 1975). Examples of this form dominate the conodont fauna of the upper 45 m of the type section of the Kaibab Limestone in southern Utah (Noble, 1928) and also occur in the lower part of the Plympton Formation in the Confusion Range in western Utah. The upper limit of this zone is not well defined, because the top of the Kaibab in southern Utah is truncated by an unconformity; and in western Utah the lower part of the Plympton is sparsely fossiliferous. For example, Behnken (1975, p. 293) reported a "very meager" conodont assemblage from the lower part of the Plympton Formation including *Neostreptognathodus clinei* (Behnken). Further sampling, particularly in the Phosphoria and related rocks, is likely to narrow this gap. Brachiopods are poorly preserved in this zone. *Peniculauris* is the only identifiable brachiopod found so far from the lower Plympton. The Kaibab brachiopod assemblage and the conodont faunas typified by species of *Neostreptognathodus* became extinct at this time. The presence of *Peniculauris* and the age of the overlying brachiopod faunas indicate a Roadian Age for this zone. The upper boundary probably marks the Artinskian-Guadalupian boundary.

THAMNOSIA DEPRESSA ZONE (4)

This zone is based on the nearly coincident ranges of *Thamnosia depressa* (Cooper) and *Bathymyonia* sp. A. *T. depressa* occurs in the limestone tongues of the upper part of the Plympton Formation, the limestone tongues in the Rex Chert Member of the Phosphoria Formation, and at El Antimonio, Mexico. *Sphenalosia* and *"Echinauris" subhorrida* (Meek), *Derbyia sulca* (Branson), *Xestotrema pulchrum* (Meek), and *Hustedia* sp. A start in this zone. The highest occurrence of *Rugatia occidentalis* is in the upper Plympton Formation. *Rugatia*, which is more common in the Great Basin than in West Texas, appears to have a longer range here than in West Texas, ranging into the lower Wordian equivalents.

This zone is more or less equivalent to the *Neospathodus arcucristatus* "Fauna" of Clark and Behnken (1971) from the upper Plympton Formation and basal Gerster Limestone at Palomino Ridge (Phalen Butte). The upper Plympton Formation contains a sparse conodont assemblage including *N. arcucristatus, Ellisonia* sp. A (E. Marcantel, 1975), and *Anchignathodus* sp. A (E. Marcantel, 1975=*A. minutus* of Behnken, 1975).

Yochelson and Fraser (1973) reported an unusually well preserved molluscan faunule from unit 5 of the Plympton Formation in the southern Pequop Mountains. Silicified pelecypods from approximately the same horizon in the Spruce Mountain section are probably examples of the genus *Schizodus* (D. W. Boyd, written commun., 1975).

KUVELOUSIA LEPTOSA ZONE (5)

The base of this zone is determined by the first occurrence of *Kuvelousia leptosa* Waterhouse, *Ctenalosia fixata* Cooper and Stehli, *Waagenites* sp. A, and several other Gerster brachiopods. The range of *K. leptosa* is commonly equivalent to this zone. The zone ends with the first occurrence of several upper Gerster brachiopods such as *Timaniella "pseudocameratus."* *K. leptosa* is widespread, occurring in all Gerster sections, the upper limestones of the Rex Chert Member of the Phosphoria Formation, the Franson Member of the Park City Formation, the Diablo Formation at Candelaria, Nev., and the lower part of the Seven Devils Group and related rocks, Oregon and Idaho. *Kuvelousia* is strictly an Upper Permian genus. Conodonts are rare in this zone. Only *Neospathodus arcucristatus* and *Ellisonia* sp. A occur. The range of *Anchignathodus* sp. A ends below this zone in unit 5 of the Plympton and the range of *Neogondolella bitteri* starts in the upper Gerster in the zone above.

YAKOVLEVIA MULTISTRIATA-NEOGONDOLELLA BITTERI ZONE (6)

The base of this zone is determined by the first occurrence of the brachiopods *Timaniella "pseudocameratus," Petasmatherus* sp. *A, Heterelasma* sp. A, *Echinalosia* sp. A, *Odontospirifer* sp. A, *Plectelasma* sp. A and B, *Hemiptychina* sp. A, and others. The range of the widespread and abundant *Yakovlevia multistriata* (Meek) is totally inclusive within this zone. *Y. multistriata* occurs elsewhere in the Edna Mountain Formation, Nevada, and the upper part of the Franson and the lower part of the Ervay Members of the Park City Formation in Wyoming. *T. "pseudocameratus"* is also widespread, occurring in the Edna Mountain Formation, in the Diablo Forma-

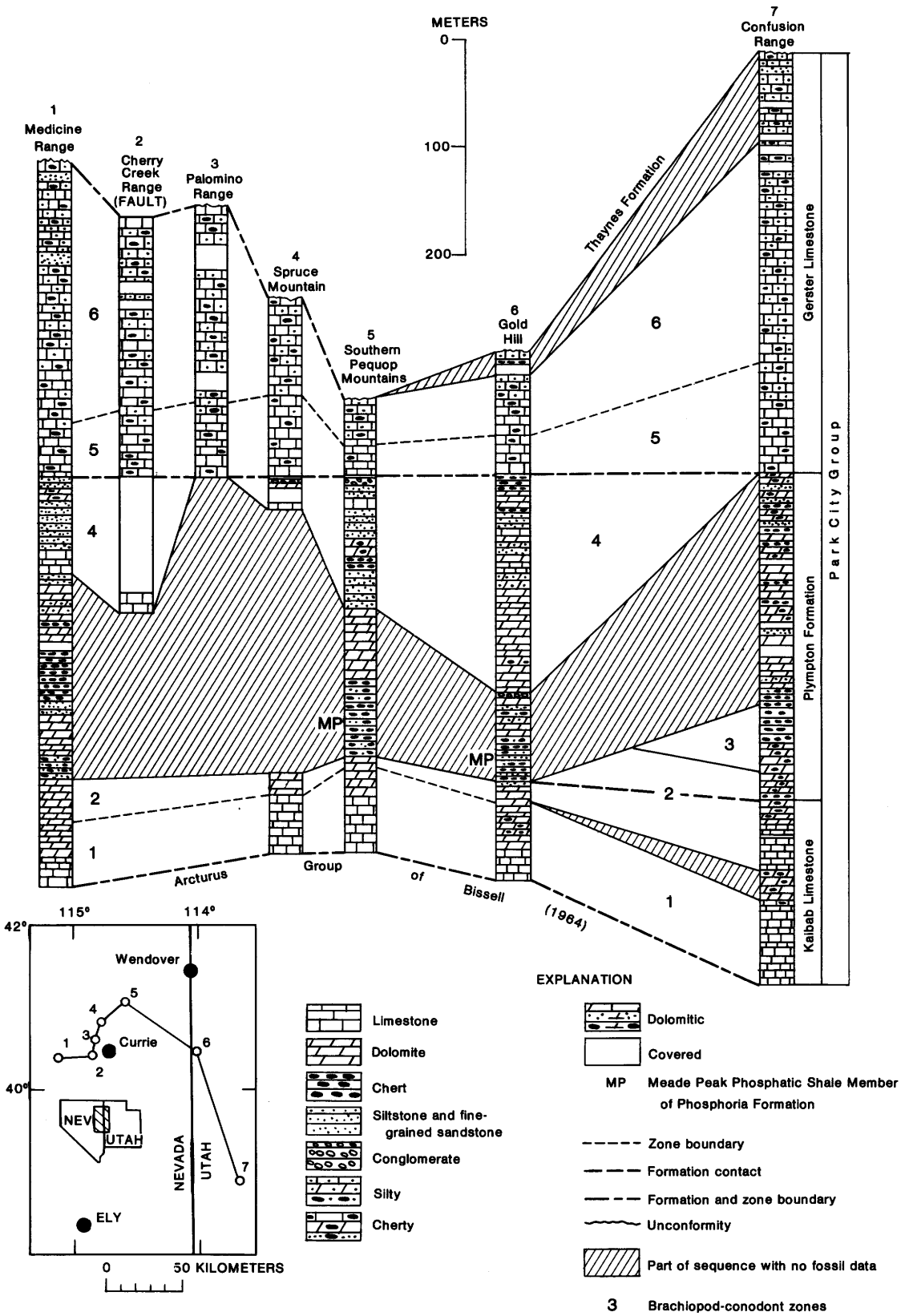


FIGURE 15.—Distribution of biostratigraphic zones in the Park City Group.

tion at Candelaria, Nev., at Taylorsville, Calif., and in the Retort Phosphatic Shale Member of the Phosphoria Formation in Wyoming. In West Texas, *Yakovlevia* occurs in Roadian and Wordian beds; *Petasmatherus* occurs in Lower Permian and Wordian beds of Furnish (1973); *Echinalosia* occurs only in Wordian beds.

The name *N. bitteri* was propsed by Kozur (1975, p. 19–20) for the form assigned by Clark and Behnken (1971, p. 424, 434–435) to *Gondolella rosenkrantzi* Bender and Stoppel.

This zone is similar to the "*Gondolella rosenkrantzi*" Zone plus the *Neospathodus divergens* "Fauna" of Clark and Behnken (1971, p. 428). Behnken (1975, p. 293) later combined the *Neospathodus arcucristatus* "Fauna" with the "*Gondolella rosenkrantzi*" Zone, because he found these two forms occurring together throughout the central Butte Mountains (30-mile Ranch) sequence. He suggested that the stratigraphic separation of these two forms at the Phalen Butte (Polomino Ridge) section was "ecologic" rather than biostratigraphic. We agree that the distribution of these forms is in part facies controlled, but the biostratigraphic overlap is slight in all of our sections, including the one from the central Butte Mountains.

A few examples of *N. divergens* (Bender and Stoppel) were found near the top of our sections in the central Butte Mountains, Cherry Creek Range, Palomino Ridge and, possibly, the Medicine Range (Marcantel, 1975). (See fig. 15.) This is the same interval that Behnken (1975, p. 293) included in the *Neogondolella "rosenkrantzi"-Neospathodus divergens* Assemblage Zone. He also reported the brachiopod *Xestotrema pulchrum* (Meek) and elements of the conodont *Xaniognathus tribulosus* (Clark and Ethington). These conodonts in addition to the many species of brachiopod are also common in our section of the upper part of the Gerster Limestone, but *N. divergens* was not abundant enough in our collections to recognize this as a separate zone.

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