The Phosphoria, Park City and Shedhorn Formations in the Western Phosphate Field

GEOLOGICAL SURVEY PROFESSIONAL PAPER 313-A

This report concerns work done as part of the program of the Department of the Interior for development of the Missouri River basin and work done partly on behalf of the U. S. Atomic Energy Commission. It is published with the permission of the Commission

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By V. E. McKELVEY *and others*

GEOLOGY OF PERMIAN ROCKS IN THE WESTERN PHOSPHATE FIELD

GEOLOGICAL SURVEY PROFESSIONAL PAPER 313-A

With sections by JAMES STEELE WILLIAMS, R. P. SHELDON, E. R. CRESSMAN, T. M. CHENEY, *and* R. W. SWANSON

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PREFACE

Phosphorus is vital to the national economy because it is required to sustain the agricultural productivity of our soils. It is also used extensively in the chemical industry, particularly in the manufacture of detergents. Nearly all the phosphorus and phosphate compounds produced in this country are derived from sedimentary phosphorites, such as those in the western field. In addition to phosphate, some phosphorites contain minor amounts of certain elements that are now or may eventually be recovered during the production of phosphate. Chief among these are fluorine, uranium, vanadium, and rare earths. Some of the black shales associated with the phosphorites also contain vanadium, zinc, nickel, molybdenum, selenium, and distillable hydrocarbons. Moreover, the oil in some important fields may have been derived from source beds associated with phosphorites. For these several reasons, then, phosphorite formations are among our most valuable natural resources.

The most extensive phosphorite beds in the United States are in the Phosphoria formation of Permian age, which crops out in many areas in Idaho, Montana, Wyoming, and Utah. The importance of the phosphate deposits in this formation was recognized early in the present century, and in 1908 the Secretary of the Interior withdrew from public entry large areas in the region in which the phosphate deposits are found. Ownership rights to phosphate and certain other minerals were separated from the surface rights in 1914 and leasing laws were passed later to permit mining of the phosphate deposits. As a result of the 1908 land withdrawal, it was necessary to classify the phosphate lands and separate them from nonphosphate lands as expeditiously as possible. With this as the main objective the Geological Survey undertook much geologic mapping in the western field between 1908 and 1916. Much of this work was summarized by G. R. Mansfield in Professional Paper 152 and most of the remainder has been published in several Geological Survey Bulletins.[1] The chief aim of these early surveys was the delineation of the structure and position of the phosphatic rocks rather than the determination of their quality, thickness, and detailed stratigraphy. The phosphatic rocks were measured and sampled, however, where natural exposures and prospect pits permitted.

Similar work continued intermittently and on a reduced scale until World War II. During W. W. Rubey's work in the Afton quadrangle of western Wyoming the Public Works Administration provided funds to sample the phosphatic beds and associated rocks. Several trenches were dug in 1938. Analyses of some of the samples collected from these trenches showed the presence of as much as 1 percent V_2O_5, 0.3 percent NiO_2, and 0.1 percent Mo_2O_3 in a nonphosphatic black shale zone. Because of the strategic importance of vanadium at that time, an extensive sampling program was begun in 1942 under Mr. Rubey's direction to explore the vanadium content of the Phosphoria formation. A well-defined vanadiferous zone was found in several areas in western Wyoming and southeastern Idaho; this zone was explored in more detail in some areas by the Bureau of Mines and the Wyodak Coal and Manufacturing Co., agent for the Metals Reserve Corporation. Analyses of samples collected showed the vanadiferous zone to contain as much as 1.3 percent ZnO and some of the phosphate beds to contain 0.01 to 0.02 percent U.

As a result of the great wartime expansion in agriculture, domestic consumption of phosphate fertilizer increased sharply in the early 1940's. Most of this increase was supported by production from the Florida field, but by 1946 it was clear that production in the western field also would undergo considerable expansion. Because better information on the distribution, quality, and thickness of phosphorite beds in different parts of the field would facilitate this expansion, and because the phosphorite and associated rocks evidently contained other minerals of great potential importance to the Nation, the Geological Survey decided in 1947 to resume investigations of the western phosphate field.

The aims of the new work were to determine the distribution of the phosphatic rocks, the reserves, the regional trends of phosphate and other important minerals, the structures in which the containing beds lie, and the origin of the minerals and the rocks in which they are found. These objectives have been approached by several types of work, chiefly: (1) measurement, description, sampling, and analysis of the phosphorites and associated rocks in trenches or

[1] See Harris, R. A., Davidson, D. F., and Arnold, B. P., 1954, Bibliography of the geology of the western phosphate field: U. S. Geol. Survey Bull. 1018, 89 p.

other exposures at intervals of 3 to 25 miles over most of the field; (2) geologic mapping, at scales of 1:12,000 to 1:62,500 of several previously unmapped areas, mostly in Montana and southeastern Idaho, and remapping at a scale of 1:24,000, of the area in southeastern Idaho that contains most of the thickest and richest deposits in the field; (3) laboratory studies of the mineralogy, petrography, and chemical composition of the rocks; and (4) reconnaissance examination of previously unmapped areas in which phosphatic rocks might occur but had not been reported. The work was designed to acquire geologic information that would aid industry in making preliminary selections of deposits and of combinations of beds suitable for mining and that would aid the Federal Government in national planning and in the leasing of phosphate deposits on the public domain.

Most of the field investigations planned have been completed and the results summarized in preliminary form in U. S. Geological Survey bulletins, circulars, and open-file releases.[2] The reports that make up Professional Paper 313 present the data on the chemical composition, thickness, and stratigraphy of the phosphorites and associated rocks in the western phosphate field, together with estimates of resources of the valuable minerals and interpretative discussions of regional geologic relationships.

The investigations described herein have been supported in part by the Raw Materials Division of the U. S. Atomic Energy Commission and the Missouri River Basin Committee of the Department of the Interior. The contributions of the many individuals who have participated in the work are described in the individual chapters that follow.

[2] For a summary of the status of component investigations see Swanson, R. W., McKelvey, V. E., and Sheldon, R. P., 1953, Progress report on investigations of western phosphate deposits: U. S. Geol. Survey Circ. 297.

CONTENTS

	Page
Abstract	1
Introduction	1
Fieldwork and acknowledgments	1
Regional stratigraphy and facies	2
Nomenclature, by V. E. McKelvey, E. R. Cressman, R. P. Sheldon, and T. M. Cheney	5
History	5
Problems	8
Plan and justification	9
Park City formation	11
General description, by R. P. Sheldon and T. M. Cheney	11
Grandeur member, by T. M. Cheney, R. W. Swanson, R. P. Sheldon, and V. E. McKelvey	12
Franson member, by T. M. Cheney	15
Ervay carbonate rock member, by R. P. Sheldon	19
Phosphoria formation	20
General description, by V. E. McKelvey	20
Lower chert member, by R. P. Sheldon	22
Meade Peak phosphatic shale member, by V. E. McKelvey	22
Rex chert member, by V. E. McKelvey	25
Cherty shale member, by V. E. McKelvey	28
Retort phosphatic shale member, by R. W. Swanson	29
Phosphoria formation—Continued	
Tosi chert member by R. P. Sheldon	30
Shedhorn sandstone, by E. R. Cressman and R. W. Swanson	31
Lower member	32
Upper member	33
Nomenclature of other units of Park City age, by T. M. Cheney and R. P. Sheldon	33
Fauna, age, and correlation of rocks of Park City age, by James Steele Williams	36
Park City formation	36
Grandeur member	36
Franson member	37
Ervay carbonate rock member	37
Phosphoria formation	38
Meade Peak phosphatic shale and lower chert members	38
Rex chert and cherty shale members	38
Retort phosphatic shale and Tosi chert members	39
Underlying and overlying rocks	39
Regional and intercontinental correlation of rocks of Park City age	40
Literature cited	41
Index	45

ILLUSTRATIONS

[Plates in pocket]

PLATE 1. Index map showing localities mentioned in report.
2. Nomenclature of Phosphoria, Park City, and Shedhorn formations in the western phosphate field.
3. Composite correlation diagram of the Phosphoria, Park City, and Shedhorn formations.

	Page
FIGURE 1. Stratigraphic relations of Phosphoria, Park City, and Chugwater formations	3
2. Lithology and thickness of Phosphoria formation and its stratigraphic equivalents	4
3. Interpretation of vertical sequence of rocks of upper part of Wells formation and Phosphoria formation	6
4. Stratigraphic sections of Park City and Phosphoria formations in Utah	14
5. Stratigraphic sections of Phosphoria and Park City formations in southern Idaho and western Wyoming	16
6. Stratigraphic sections of Phosphoria, Park City, and Shedhorn formations in Montana	17

TABLES

	Page
TABLE 1. Stratigraphic section of Grandeur member	12
2. Stratigraphic section of Franson member	18
3. Stratigraphic section of Phosphoria formation on Snowdrift Mountain	20
4. Generalized section of Retort phosphatic shale member	29
5. Stratigraphic section of Tosi chert member	30
6. Stratigraphic section of Shedhorn, Phosphoria, and Park City formations	31
7. Stratigraphic section of Mackentire tongue	35

GEOLOGY OF PERMIAN ROCKS IN THE WESTERN PHOSPHATE FIELD

THE PHOSPHORIA, PARK CITY, AND SHEDHORN FORMATIONS IN THE WESTERN PHOSPHATE FIELD

By V. E. McKELVEY and OTHERS

ABSTRACT

The Phosphoria formation of Permian age consists mainly of chert, carbonaceous mudstone, and phosphorite at the type locality in southeastern Idaho. These rocks intertongue with and pass laterally into a dominantly sandy sequence in south-central Montana and northwestern Wyoming and into a dominantly carbonatic sequence in west-central Wyoming and northeastern Utah, although thin tongues of phosphatic and cherty rocks persist over all these areas. The carbonatic sequence in turn intertongues with and passes laterally into greenish-gray and red beds in eastern Wyoming and southeastern Montana, eastern Utah, and northwestern Colorado. The plan of nomenclature developed to describe these rocks and their relationships has the following as its chief elements: (1) it retains the name "Phosphoria formation" for the chert-mudstone-phosphorite facies and identifies as tongues of the Phosphoria formation rocks of these lithologies that interfinger with sandstone and carbonate rock along the fringe of the phosphate field; (2) it retains the name "Park City formation" (Permian) for the sequence of carbonate rock in Utah, restores this name for similar carbonate rock in west-central Wyoming, and identifies as tongues of the Park City formation beds of carbonate rock that interfinger with other formations in Idaho, western Wyoming, and Montana; and (3) it introduces the new name "Shedhorn sandstone" for sandstone of Phosphoria age in northwestern Wyoming and adjacent parts of Montana, and identifies as tongues of the Shedhorn the beds of sandstone that interfinger with the Phosphoria and Park City formations in northwestern Wyoming and southwestern Montana.

INTRODUCTION

The Geological Survey's recent investigations of the geology of the western phosphate field have disclosed much new information on the stratigraphy of the Phosphoria and Park City formations and their partial correlatives (pl. 1). This information showed the need for a critical review and revision of the stratigraphic nomenclature of the rocks of Park City age, and a summary description of the nomenclature adopted was published in 1956 (McKelvey and others). The present report gives a more complete description of the regional stratigraphy, history and problems of nomenclature, and lithology of the stratigraphic units recognized by formal and informal names.

The plan of nomenclature adopted may be summarized as follows (pls. 2 and 3):

(1) The name "Phosphoria formation" is retained, as it was originally used, for phosphorite, phosphatic mudstone, carbonaceous mudstone, and chert in southeastern Idaho and adjacent areas; rocks of these lithologies that interfinger with sandstone and carbonate rock along the northern, eastern, and southern edges of the field are identified as tongues of the Phosphoria.

(2) The name "Park City formation" is retained for the sequence of carbonate rocks in the type area of the Park City in Utah; beds of carbonate rock that interfinger with the Phosphoria and with sandstone in Idaho, Wyoming, and Montana are identified as tongues of the Park City.

(3) A new name, the "Shedhorn sandstone," is introduced for rocks of Phosphoria age in northwestern Wyoming and adjacent parts of Montana that are composed mainly of sandstone; beds of sandstone that interfinger with the Park City and Phosphoria formations in Montana and Wyoming are identified as tongues of the Shedhorn.

(4) Members and tongues of the Phosphoria, Park City, and Shedhorn formations are designated by formal and informal names.

(5) The name "Wells formation" is retained for rocks in western Wyoming, eastern Idaho, and northern Utah, but is restricted to the carbonate rock, sandstone, and red beds that lie below the upper carbonate rock beds that are reassigned to the newly named Grandeur member of the Park City.

(6) The names "Embar" and "Teton" are abandoned.

FIELDWORK AND ACKNOWLEDGMENTS

The investigations on which this report is based are a part of a broad study of the geology and mineral resources of the Phosphoria formation and its partial correlatives in the western phosphate field, undertaken partly on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission and the Missouri Basin Committee of the U. S. Department of the Interior.

The fieldwork, begun in 1947, consisted partly of geologic mapping in southeastern Idaho and southwestern Montana but mainly of describing and sampling sections of the rocks of Park City age at numerous localities in Montana, Idaho, Wyoming, Nevada, and Utah. Rocks of the interval were described and sampled at about 250 localities during the course of this work. Abstracts of the lithologic data and analyses from most of these stratigraphic sections have been published in U. S. Geological Survey Circulars 208–211, 260, 262, 301–307, 324–327, and 375. We also had access to descriptions of sections measured by other workers at about 125 additional localities, mostly in Wyoming. Many of these are unpublished descriptions of subsurface sections furnished by oil companies; some are unpublished sections measured by Eliot Blackwelder; most of the remainder are given in several Geological Survey publications or in theses on file at the University of Wyoming at Laramie.

The specific contributions of the many who aided in the collection of data on which this report is largely based are indicated in the circulars listed above and are gratefully acknowledged here even though they cannot be listed in detail. With reference to the specific problem that forms the subject of this report, we wish to acknowledge with thanks the advice received from W. W. Rubey, J. D. Love, George Horn, L. S. Gardner, Norman Silberling, C. W. Merriam, J. D. Sears, W. G. Pierce, M. R. Klepper, W. B. Myers, F. C. Armstrong, L. D. Carswell, R. A. Gulbrandsen, David Dunkle, Helen Duncan, MacKenzie Gordon, Jr., L. G. Henbest, J. T. Dutro, Jr., J. E. Smedley, E. L. Yochelson, and the members of the Geological Survey's Committee on Geologic Names. (We do not wish to imply, however, that all the geologists named favor all the provisions of the plan of nomenclature adopted.) Mr. Rubey's contributions are especially noteworthy, for he has not only materially helped develop the plan of nomenclature but has been a continuing source of guidance and inspiration since the investigation began in 1947.

REGIONAL STATIGRAPHY AND FACIES

The type locality of the Phosphoria formation in southeastern Idaho lies near the eastern margin of the Cordilleran miogeosyncline (Kay, 1947). At its type locality the Phosphoria consists, from base to top, of 200 feet of interbedded nonresistant dark-brown phosphorite, phosphatic or carbonaceous mudstone, and minor, dark fine-grained carbonate rock; 155 feet of resistant dark-gray chert and minor amounts of carbonate rock and cherty mudstone; and 97 feet of nonresistant dark-brown cherty mudstone, mudstone, and minor amounts of chert, carbonate rock, and phosphorite (table 3). Nearby sections are similar in both vertical sequence of units and total lithologic aspect, but equivalent strata differ markedly in both respects over the field as a whole (pl. 3, figs. 1, 2).

The differences are illustrated along an east-west section from southern Idaho to central Wyoming (fig. 1). In the Fort Hall-Blackfoot Dam area, 35 to 55 miles northwest of the type locality, the Phosphoria formation consists of a lower phosphatic shale, about 135 feet thick, and an upper unit, about 500 feet thick, of nonresistant cherty mudstone, mudstone, and minor amounts of chert. Farther westward, in the Sublett Range east of Malta in Cassia County, Idaho, the lower unit is less phosphatic and is only about 85 feet thick. The upper part of the formation is about 1,200 feet thick and consists of interbedded resistant dark chert and nonresistant dark cherty mudstone and mudstone. About 40 miles east of the type locality, in the Wyoming Range, the rocks of Phosphoria age consist of about 40 feet of moderately resistant dark chert at the base, overlain successively by 75 feet of nonresistant dark phosphatic mudstone, phosphorite, and dark carbonate rock; 150 feet of resistant light-colored carbonate rock, locally cherty, and minor amounts of sandstone; 35 feet of nonresistant black mudstone; and 30 feet of resistant dark chert. Still farther east, in the Wind River Mountains near Lander, the section consists of about 45 feet of light-gray carbonate rock and sandstone, overlain successively by 2 feet of phosphorite; 130 feet of interbedded light-gray carbonate rock and greenish-gray carbonatic shale; 50 feet of dark mudstone and phosphorite; 15 feet of chert; and 40 feet of sandy and argillaceous carbonate rock. In the Freezeout Hills, about 350 miles east of the type locality of the Phosphoria, rocks of Phosphoria age are about 300 feet thick and consist of red beds and gypsum and two interbeds, each about 15 feet thick, of carbonate rock (Thomas, 1934, p. 1680).

Somewhat similar facies changes take place to the north and south of the type area. In northwestern Wyoming and adjacent Montana, however, correlative strata are composed mainly of sandstone. Sand is also a more important constituent in northeastern Utah, though it is subordinate to carbonate rock there. Observations in northwestern Utah and northeastern Nevada indicate that the sequence of facies of roughly correlative strata between the Sublett Range and the Confusion Range, Utah, is similar to that observed east of the Sublett Range. The thickness of the rocks, however, continues to increase as far as northeastern Nevada; in the vicinity of Montello, Nev., it is about 3,200 feet.

The regional picture of the lithology of rocks roughly correlative with the Phosphoria, then, is one of a facies composed mainly of cherty, carbonaceous, or phosphatic mudstone, chert, and phosphorite in eastern Idaho, southwestern Montana, and western Wyoming, bor-

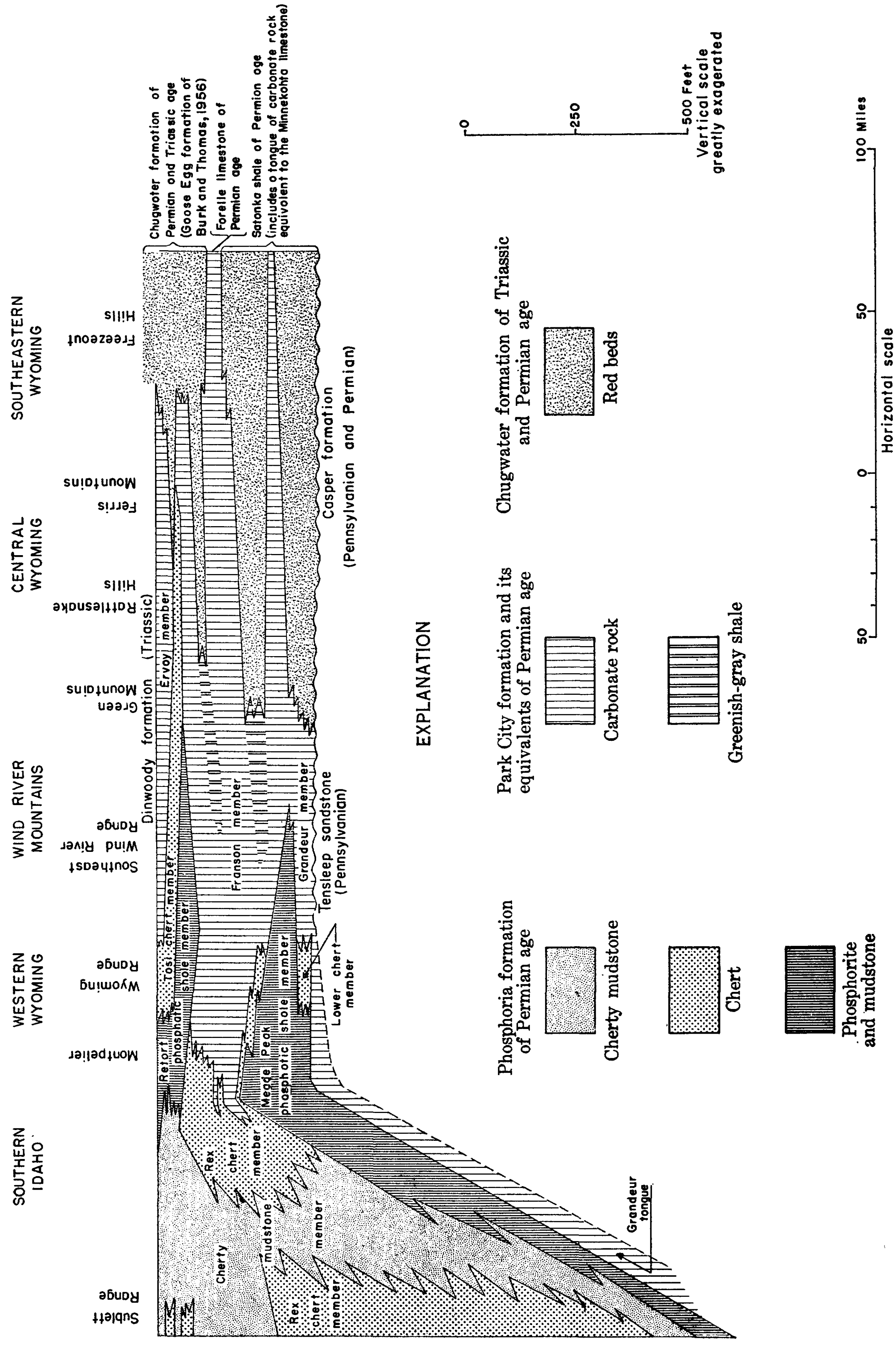


FIGURE 1.—Stratigraphic relations of the Phosphoria, Park City, and Chugwater formations in Idaho and Wyoming.

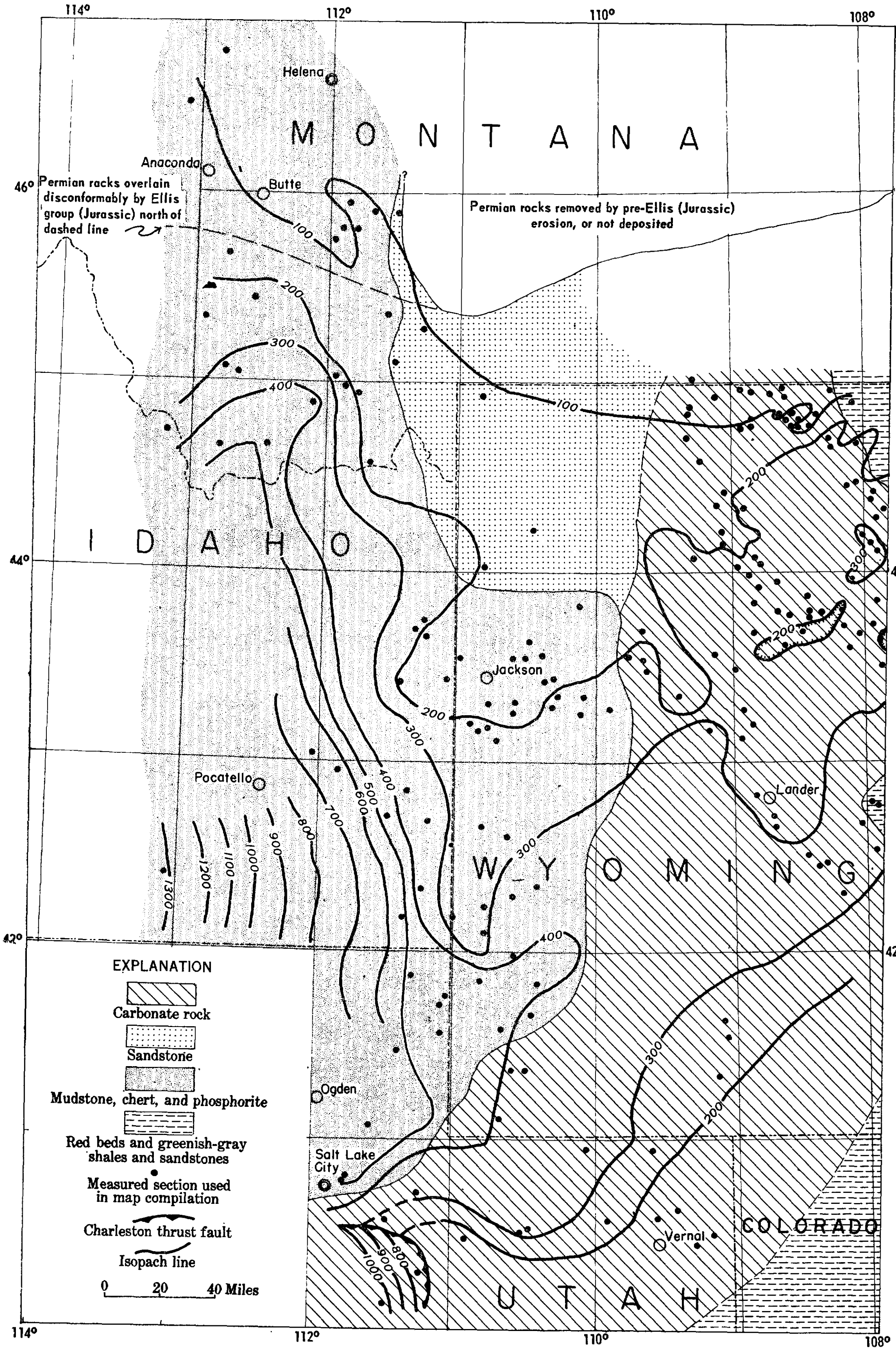


FIGURE 2.—Dominant lithology and thickness of Phosphoria formation and its stratigraphic equivalents.

dered on the east, south, and southwest by a carbonate-rock facies and on the northeast by sandstone (fig. 2). Greenish-gray calcareous shales, red beds, and saline rocks border the carbonate-rock facies farther to the east in Wyoming and eastern Utah. These facies interfinger, and tongues of each rock type extend long distances into areas dominated by one of the others.

The facies relationships observable from place to place between thick, roughly equivalent time zones, as well as local differences in the lithology of individual layers or thin zones bounded by key beds, indicate that the horizontal sequence of facies toward the eastern and southern shores of the ancient Phosphoria sea is approximately as follows: (1) carbonaceous mudstone, (2) phosphorite, (3) chert, (4) light-colored carbonate rock and sandstone, (5) saline rocks, (6) greenish-gray mudstone, and (7) red beds (pl. 3 and fig. 1). This sequence is reproduced, in whole or part, in the same and in reverse order in vertical section where the facies intertongue. A complete cyclic sequence 7–6–5–4–3–2–1–2–3–4–5–6–7 has not been found, but parts of it are found throughout the field. Thus, in the vicinity of the type locality of the Phosphoria formation in southeastern Idaho, as shown in figure 3, red beds in the upper part of the Wells formation[1] are overlain successively by sandstone, light-gray limestone, and cherty limestone of the Wells formation of Richards and Mansfield (1912); phosphorite, phosphatic mudstone, mudstone, phosphatic mudstone, and phosphorite of the phosphatic shale member of the Phosphoria formation; cherty carbonate rock, dark chert, carbonate rock, dark chert, cherty mudstone and mudstone, and cherty phosphorite of the Rex chert member of the Phosphoria formation (as defined by Richards and Mansfield, 1912, p. 684). The vertical sequence is interrupted locally by interbedding of other lithologies, generally ones adjacent in the above list. The horizontal sequence too is seldom as complete or regular as listed above.

Several factors probably contributed to the formation of the different rock types, but it seems probable that the depth of water was one of the chief controls. Thus, we interpret the horizontal sequence of facies from carbonaceous mudstone to red beds as the product of deposition on a shoaling sea floor. We interpret the vertical sequence from red beds to carbonaceous mudstone and the sequence from carbonaceous mudstone to carbonate rock as the products of deposition on a sinking and on a rising bottom respectively. Thus, the rocks from the upper part of the Wells to the middle of the Rex represent a nearly complete cycle of marine transgression and regression, and those from the middle of the Rex to the top represent a partial cycle. The section in western Wyoming (fig. 1) shows two complete cycles. The position of the deepest part of the basin and the shoreline shifted considerably during the deposition of the rocks of Phosphoria age. Mostly, however, the deepest part seems to have been in east-central Idaho and perhaps adjacent parts of Montana and Utah. The area of greatest accumulation and of geosynclinal subsidence, however, was farther west.

Although some of the differences in the total aspect of the rocks of Phosphoria age over the field are explained by thickening or thinning of the individual units and by overlap, most of the differences are due to the facies changes described above. Generally, rocks at the base and top of a given unit grade horizontally into rocks of other lithology, so that on a regional scale many lithologic contacts must transgress time planes.

Time planes may be established locally by key beds or over larger areas by the horizons of maximum transgression and regression following the concept of Sears and others (1941, p. 105) and Israelsky (1949, p. 97), and in a general way, the age of gross divisions of a formation can be established by fossils; the relative age of many units, even some that are horizontally continuous, cannot be established precisely now, however, so that it is often necessary to speak of them as "partly correlative" or "partly equivalent."

NOMENCLATURE

By V. E. McKelvey, E. R. Cressman, R. P. Sheldon, and T. M. Cheney

HISTORY

The first formation name applied to rocks of Park City age in the western phosphate field was "Quadrant formation," used by Peale in 1893 (p. 39–43) for Carboniferous rocks lying between the Madison and the Ellis formations in the Three Forks, Mont., region. Weed (*in* Hague and others, 1896, p. 5) redefined the Quadrant formation as the Quadrant quartzite and placed the upper beds of Peale's Quadrant in a new formation, the Teton, named from the Teton Range, Wyo. The Teton included what were then called Juratrias rocks between the Quadrant quartzite and the Ellis of Jurassic age. It was composed of a "basal sandstone, usually dull-brown in color and more or less calcareous, characterized by rods and rolls of white chert, and carrying interbedded gray limestones containing linguloid shells," which is at least in part clearly the Phosphoria equivalent. "Above this basal bed are gray and greenish calcareous shales, often micaceous

[1] The red beds in the upper part of the Wells formation, which have received little mention in the literature, crop out at several places in southeastern Idaho, including Wolverine, Mabie, and Montpelier Canyons, south Schmid Ridge, and the ridge north of Hot Springs. They may be found in float at many other localities.

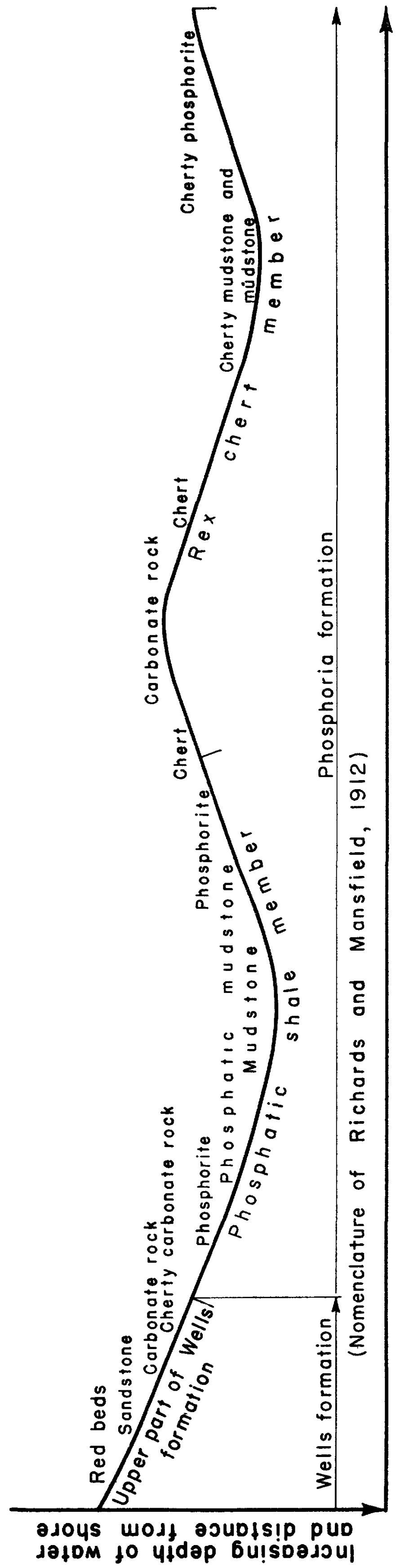


FIGURE 3.—Diagrammatic representation and interpretation of vertical sequence of rocks of upper part of Wells formation and Phosphoria formation in southeastern Idaho, showing cyclical deposition of beds.

and capped by a red arenaceous shale that forms a conspicuous part of the formation" (Weed, op. cit.). Blackwelder (1911, p. 455) referred to the Yellowstone Park section and used the name "Teton" in that connection, but neither he nor subsequent writers have used the name in describing original work. Other early workers in southwestern Montana, including Calkins as late as 1915 (Calkins and Emmons, 1915, p. 8), included the beds of Phosphoria age in the Quadrant.

In 1906, Darton (p. 17) named "a prominent series of limestone and chert beds lying between the Tensleep sandstone and the Chugwater red beds" (a sequence roughly equivalent to the lower two members of the Teton) the "Embar formation," from Embar post office and ranch on Owl Creek near the east end of the Owl Creek Mountains, Wyo. He assigned these rocks to the Carboniferous. A year later, Boutwell (1907, p. 443) gave the name "Park City formation" to the limestone and intercalated quartzite and sandstone lying between the Weber quartzite and the Woodside shale in the Park City district, Utah. Although Boutwell first classed the Park City as Pennsylvanian, he provisionally assigned the upper part to the Permian in his final report (1912, p. 51). Use of the name "Park City" was extended to beds in southeastern Idaho by Gale and Richards (1910, p. 475), and to beds in western Wyoming by Veatch (1907, p. 50) and Blackwelder (1911, p. 460–467). During the same period, the name "Embar" was used for rocks of the Wind River Mountains and adjacent areas which are southwest of the Embar type area (Blackwelder, 1911, p. 471–479).

In 1912, Richards and Mansfield gave the name "Phosphoria" to the upper two members of the Park City as previously mapped in the phosphate district of Idaho and Utah, and designated Phosphoria Gulch, Bear Lake County, Idaho, the type locality. They referred to the lower part as the "phosphatic shale member" and named the upper the "Rex chert member" for the Rex Peak area in the Crawford Mountains of northeastern Utah. The same authors gave the name "Wells formation" to rocks previously mapped in the phosphate district as the lower member of the Park City and the Morgan and Weber formations. According to Girty (1927, p. 79), the decision to abandon the use of the name "Park City formation" for the rocks in Idaho stemmed from the belief that the lower member of the Park City was Pennsylvanian in age, whereas the upper members were Permian. Inasmuch as Richards and Mansfield (1912, p. 687) correlated the Phosphoria with parts of the Park City in its type area, with part of the Embar formation in Wyoming, and with the phosphatic beds above the Quadrant in certain areas in Montana, but stated that "the distribution of the Phosphoria formation, so far as at present known, is limited to portions of southeastern Idaho, northeastern Utah, and western Wyoming," they apparently intended to apply the name "Phosphoria" to a distinct lithofacies, and not to rocks whose lithologic aspects differ from those in the type region of the Phosphoria. This interpretation is supported by Blackwelder's later use of the name "Park City" to include rocks (mainly dolomite and limestone) which he had previously called Embar; these rocks, in west-central Wyoming, include "the equivalent of the Phosphoria formation in eastern Idaho, as defined by Richards and Mansfield, but in addition also the upper part of their Wells formation" (Blackwelder, 1918, p. 423). Blackwelder called the upper part of Darton's "Embar" the Dinwoody formation, of either Permian or Early Triassic age or both. Condit (1916) listed the Park City and Dinwoody formations in the Wind River and Owl Creek Mountains as subordinate parts of the Embar, and Collier (1920a, p. 65, 1920b, p. 153) considered them to be formational subdivisions of the Embar group.

The concept that use of the name "Park City" or "Phosphoria" should depend upon the continuity of a given lithology rather than on age relations was short lived, however. Condit (1924, p. 10–11) reported that, although Blackwelder had applied the name "Park City" to the lower beds because of their equivalence to beds of that name in northeastern Utah, "Later studies, by several workers, have proved that the part of the Embar beneath the Dinwoody corresponds to only the upper or Phosphoria part of the Park City formation of Utah, and the U. S. Geological Survey now designates this lower part of the Embar of western Wyoming as Phosphoria formation, instead of Park City formation." Lee (1927, p. 9) also justified the use of the name "Phosphoria" for beds in central and even eastern Wyoming on the basis that the unit "contains marine fossils that establish its Permian age and correlate it with the Phosphoria of southeastern Idaho." Thomas (1934, p. 1664) later recognized the Sybille,[2] Forelle, and Ervay tongues of the Phosphoria in the Chugwater formation in central and southeastern Wyoming, a usage since followed by Tourtelot (1952) and others. The Wyoming geologic map (Love and others, 1955) classes both the lower part of the red beds of the Chugwater and Thomas' tongues of the Phosphoria in the Rattlesnake Hills and other localities in east-central Wyoming as the Phosphoria formation. In 1956, however, Burk and Thomas introduced the name Goose Egg formation for "the sequence of interbedded red to ocher shales and siltstones, thin limestones, gypsums, and limestone breccias," that crop out near Goose Egg post

[2] In 1948 Thomas discarded the name "Sybille" for "Minnekahta."

office, Wyoming. These strata overlie the Tensleep, Casper, Hartville, or Minnelusa formations and are overlain by the Chugwater formation throughout eastern Wyoming.

Although the use of the name "Embar" was abandoned by the U. S. Geological Survey in 1934, Pierce and Andrews used it in 1941 (p. 110). They used the name "Phosphoria" for "a series of limestones and sandstones, with chert and phosphate near the base" in the Bighorn Basin but stated that "Additional work, subsequent to the writing of this report, has led to doubt concerning the advisability of using Phosphoria here, because the rocks differ decidedly in lithology from the Phosphoria of the typical area and because the term Embar is so well established in local usage." Stipp (1947) described Phosphoria correlatives in the Shoshone River canyon, Wyoming, as "the lower four-fifths of the Embar formation"; Andrews and others (1945) used the name "Embar" on the preliminary geologic map of Montana for strata of Permian age only, and Richards (1955) followed their usage. Rioux (1958) used the Goose Egg formation of Burk and Thomas for red beds stratigraphically equivalent to the Dinwoody and Phosphoria on the eastern side of the Bighorn Basin, and it seems likely that this name will be used elsewhere in central and eastern Wyoming for red beds formerly listed as Phosphoria or Embar.

The use of the name Phosphoria was also extended to rocks in Montana, where it was first applied to beds in the Elliston phosphate field by Stone and Bonine (1914, p. 375) and later to all beds in western Montana of Permian age (Pardee, 1917, p. 203, 1936, p. 179; Condit, 1918, p. 113; Richards and Pardee, 1925, p. 8; Condit, and others, 1928, p. 147). The definition of the limits of the formation has varied, however. Condit and others (1928, p. 183, 199), for example, rather consistently put the base of the formation at the base of the lowest phosphatic beds, but Richards and Pardee (1925, p. 8, 28) included carbonate rock between the sandstone of the Quadrant formation and the lowest phosphatic rock, because fossils collected from these beds suggested they were "more closely related to the phosphate beds than to the underlying Quadrant formation" (idem, p. 8). In recent years, the rocks above the sandstone of the Quadrant and below the Dinwoody have been divided into five units provisionally named, from oldest to youngest, the A, B, C, D, and E members of the Phosphoria formation (Butler and Chesterman, written communication, 1945; Klepper, 1951, p. 61; Swanson and others, 1953b, p. 1; Cressman, 1955, p. 4). A similar provisional terminology has been used for subdivisions of the Phosphoria in northwestern Wyoming (Sheldon and others, 1953, p. 4; Sheldon, 1957).

Matthews (1931) and J. Stewart Williams (1939, p. 85) applied the name "Phosphoria formation" to the upper two members of the Park City formation in its type region in Utah and restricted the name "Park City" to the lower member, but more recent authors (Baker and J. Steele Williams, 1940, p. 625; Thomas and Krueger, 1946, p. 1264; Baker and others, 1947; Huddle and McCann, 1947; Kinney, 1951) have used the name "Park City" in its original sense for formations in the Wasatch and Uinta Mountains. Nolan (1930; 1935, p. 39) gave a new name, the Gerster formation, to a sequence of rock in the Gold Hill area of western Utah. The formation consists dominantly of bioclastic limestone which he recognized as a partial correlative of the Phosphoria and Park City formations. Newell (1948) described beds of the same age farther south in the Confusion Range as the Phosphoria formation. Hose and Repenning (in press) have designated the strata in the Confusion Range equivalent to the Park City formation, from oldest to youngest, the Kaibab, Plympton and Gerster formations and classed these formations as the Park City group.

In summary, the rocks of Park City age in and near the western phosphate field have been described under several stratigraphic names. Although the Phosphoria was defined partly on lithologic grounds, it is evident also that the decision to abandon use of the name "Park City" in southeastern Idaho was influenced by a desire to avoid including rocks of different systems in the same formation. The weakness of this concept as a guiding principle in stratigraphic nomenclature is well illustrated by the fact that later work has shown the Grandeur member of the Park City to be of Permian age. Once the name "Phosphoria" was chosen, its use was gradually extended, largely because of faunal evidence, to cover rocks in most parts of the western phosphate field, and also to include rocks of much different lithology from those in the type area of the Phosphoria.

PROBLEMS

The vacillations in the previous usage of such names as "Embar," "Phosphoria," and "Park City" clearly show the existence of knotty problems in the nomenclature of the Phosphoria and its partial correlatives. The most formidable of these problems now is the precedent set by previous usage, particularly the extension of the use of the name Phosphoria on faunal rather than lithologic evidence, but other problems are presented by the stratigraphic relationships, chief among which are:

(1) The assemblage of rocks found in any vertical section of the whole sequence, or any major part of it, is diverse in lithology. Component lithic units change in thickness laterally; some of them feather out by overlap, others pass laterally into rocks of other composition, but parts of some lithic units are represented, at least in small amount, in virtually all parts of the field.

(2) Because the Phosphoria formation contains no fossils as yet known to be suitable for establishing time planes, correlation must be based on lithologic relationships. Such correlation, even of major units, is subject to serious errors. For example, several authors mistakenly correlated the upper phosphatic shale in Montana with the lower phosphatic shale of Idaho (Condit and others, 1928, p. 166) and the upper chert in Montana with the Rex chert member of Idaho (Richards and Pardee, 1925, p. 8).

(3) The assemblage of rocks that may be separated for mapping purposes from older and younger rocks in a given area is not necessarily of the same age in different parts of the field.

PLAN AND JUSTIFICATION

It is not possible to solve all the nomenclatural problems in logical fashion without altering previous usage of some stratigraphic names. We believe that the plan of nomenclature proposed here is not only workable but describes and clarifies the stratigraphic relationships. The fundamental plan itself is not new. It is based on the venerable principle of recognition of lithic units by formal and informal names and the application of these names as far as the characterizing lithologic types remain dominant (Powell, 1882, p. XLV–XLVI; Walcott, 1903, p. 23). Three intertonguing lithic units are recognized as formations (pls. 2 and 3) and defined as follows: (1) the Park City formation, consisting of carbonate rock and subordinate sandstone; (2) the Phosphoria formation, consisting of phosphatic, carbonaceous, and cherty rocks; and (3) the Shedhorn sandstone. The Park City formation is best developed in central and eastern Utah and in southwestern and west-central Wyoming, but tongues extend to eastern Idaho and to Montana as well. The Phosphoria formation is best developed in eastern Idaho, northern Utah, western Wyoming, and southwestern Montana, but tongues extend over a much wider area. The Shedhorn sandstone is best developed in the general vicinity of Yellowstone Park, but tongues extend over much of southwestern Montana and northwestern Wyoming. These three formations can be regarded as end-member types that interfinger over much of the area of the western phosphate field. In the areas where they are best developed, however, the Park City and Shedhorn formations contain a thin tongue of the Phosphoria, so that even in their type areas continuous sections of the Park City and Shedhorn end-member lithologies do not exist.

Eleven subdivisions of these formations are recognized as members. Members of the Park City formation are designated the Grandeur member, the Franson member, and the Ervay carbonate rock member. Those belonging to the Phosphoria formation are the Meade Peak phosphatic shale member (the phosphatic shale member of Richards and Mansfield), the lower chert member, the Rex chert member, the cherty shale member, the Retort phosphatic shale member, and the Tosi chert member. Subdivisions of the Shedhorn are the lower and upper members. The subdivisions of a given formation are called tongues in areas where only one is present or where most of the rocks of Park City age belong to one of the other formations; they are called members elsewhere. The same formal or informal name is used for each of the subdivisions, whether it is a tongue or a member.

Most of the members are mappable at scales of 1:24,000 or 1:62,500 in their type areas, but in some areas where the formations intertongue both members and tongues are too thin to be mapped separately, and, for cartographic purposes, they must be grouped with the next larger unit. For example, over much of its area of occurrence, the lower chert member of the Phosphoria formation is too thin to be mapped separately at ordinary field scales; in mapping, therefore, it is best left undifferentiated from the adjacent Meade Peak member, but it can be identified separately in detailed stratigraphic sections. Similarly, the Meade Peak member of the Phosphoria must be mapped with the Rex member in much of southwestern Montana, and the Retort member with the Tosi member in northwestern Wyoming. The same procedure should be followed with respect to featheredges of the formation as a whole. Thus, in much of west-central Wyoming and south-central Montana, the tongues of the Phosphoria are too thin to be differentiated from the Park City formation or Shedhorn sandstone in mapping. In those areas the cartographic unit necessarily becomes the Park City or the Shedhorn; the tongues of the Phosphoria can be identified on stratigraphic sections and charts and they can be described in the map explanation as "Park City formation (contains undifferentiated tongues of the Meade Peak phosphatic shale, Retort phosphatic shale, and Tosi chert members of the Phosphoria formation)".

The nomenclature in northeast Nevada and western Utah will be reviewed in a later paper. Hose and Repenning (in press) have classed the rocks of Park City age in the Confusion Range as the Park City group. The stratigraphic relations between the rocks of Park City age in southern Idaho and the Confusion Range, are much the same as the relations between the type Phosphoria and the type Park City formations. We therefore believe the same general system of nomenclature may be applied in the future to this western area. We do not propose any modification in the nomenclature of the greenish-gray sandstone and shale that fringe the eastern and southern parts of the phosphate field because we have not studied them sufficiently. The greenish-gray rock is a distinctive rock type, and if later work shows greenish-gray beds to be extensive, they can then be recognized by a separate name.

Weed's "Teton formation" and Darton's "Embar formation" are considered obsolete, and the Geological Survey has now abandoned use of both.

Preliminary discussions with other geologists familiar with the problem indicate that several of the actions taken here may not seem logical or necessary to all workers without a full statement of justification. The following actions especially have been suggested as susceptible to alternative treatment: (1) restricting the name "Phosphoria" to rocks like those in the type area instead of continuing the practice of applying the name to all rocks of that age in the western field; (2) recognizing by formal and informal names lithic subdivisions that in some places are not mappable separately; (3) differentiating the Shedhorn sandstone from the Park City formation instead of applying one name to the combined sandstone and carbonate facies; (4) recognizing the Park City and Shedhorn as formations even though they contain a tongue of the Phosphoria in their type areas; and (5) using the name "Park City" for beds in west-central Wyoming, for which this name had only a brief use many years ago, instead of the name "Embar" which has been long though sporadically used.

Use of the name "Phosphoria" is restricted because such action conforms with the definition of formations on lithologic rather than faunal criteria—a cardinal principle of the American system of stratigraphic nomenclature; thus, the nomenclature adopted here is designed to emphasize the differences in lithology of the rocks of Phosphoria age in the western field. No better justification for this could be given than Powell's (1888):

> * * * the classification involved in a cartographic system designed for general use should be objective, rather than theoretic; it should be based upon rock masses in their observed and readily observable relation rather than upon time intervals contemplated in historic geology, or even upon the organic remains contemplated in biotic geology; it should be petrographic rather than chronologic or paleontologic * * * The structural geologic unit is the "formation." It is defined primarily by petrography and secondarily by paleontology; and, in thoroughly studied regions, is generally found to constitute a genetic unit.

As Powell pointed out also, units so defined and mapped are significant "alike to the theoretic physicist or astronomer, the practical engineer or miner, and the skilled agriculturist or artisan" as well as to the stratigraphic paleontologist. It is particularly important that lithic units be recognized in the rocks of Phosphoria age because some of them are of considerable economic importance. For example, valuable phosphate deposits are generally associated with chert and mudstone. Designation of these rocks as Phosphoria aids in the search for minable phosphate deposits. Similarly, recognition of the fact that oil in the rocks of Phosphoria age in Wyoming occurs not in rocks whose lithology is typical of the Phosphoria formation but in carbonate rocks here designated the Park City immediately suggests other areas, such as southwestern Wyoming and northern Utah, where the Park City may be favorable for the occurrence of oil (Cheney, 1955).

It may be argued that the rocks of Phosphoria age can be identified as Phosphoria on the basis of lithology, without use of the evidence of fossils, because rocks of Phosphoria age contain at least minor amounts of chert, phosphorite, or carbonaceous mudstone over a wide area, and hence that the names Shedhorn and Park City are unnecessary. Even though the characterizing constituents are found within the interval over a wide area, we reject this as a basis for classing all the rocks as one formation on the fundamental ground that a formation must be defined on the dominance of some lithologic characteristic or combination of characteristics, such as color, hardness, composition, bedding, or other physical property. A "characterizing" feature found in minor amounts might well be used to differentiate formations, but only, it seems to us, where some quantitative concept—something more than mere presence or absence—is attached to its abundance and distribution. Moreover, it seems best that subtle "characterizing" features be used only to divide thick sections of rocks that are otherwise homogeneous. If subordinate features are used, as fossils sometimes have been, to define formations regardless of major changes in lithology, they serve only to extend use of formational names so widely that they become synonymous with time terms. This accomplishes nothing not easily gained by the use of terms such as "Permian rocks" or "rocks of Phosphoria age", and it conceals much significant information.

It is true that the recognition of three intertonguing formations and of their lithic subdivisions leads to the introduction of several new names and to the definition of units that are not everywhere mappable. We have avoided introducing new names as much as possible by using informal names for some of the members, but because names such as the "upper phosphatic shale" became inappropriate where no lower shale is present, it has been necessary to introduce five new formal names for members in order to identify positively the subdivisions wherever they occur. The latter objective needs no special justification, for, because it aims at the understanding of the lateral relationships and extent of rock units—information that has great economic and scientific value—it is one of the prime objectives of most stratigraphic work. Similarly, no special defense is required for the formal recognition of unmappable members and tongues because this is common, approved practice (Ashley and others, 1933). In some fringe areas, such as northwestern Wyoming, where the three Permian formations intertongue but are not mappable separately, we do not propose that all the formations be mapped separately. We believe, however, that recognition, wherever practicable, of the formations and their subdivisions will further the understanding of the origin of the rocks and will aid in the search for any oil and mineral deposits they may contain.

Because the Shedhorn sandstone extends over a smaller area than the other formations and because the Park City formation in Utah contains some sandstone not differentiable stratigraphically, it has been suggested that the name Park City be applied to the combined carbonate and sandstone facies. However, the sandstone facies in Montana and northwestern Wyoming constitutes a lithic unit readily distinguishable from the rocks in adjacent areas; it forms the major part of the rocks of Phosphoria age over an area of about 6,500 square miles and tongues of it are recognizable over a much larger area; therefore, we believe it desirable to separate the Shedhorn as well as the Phosphoria and the Park City. Recognition of the unit in formal nomenclature serves to emphasize the location and extent of this sandstone facies, and this in turn contributes to the understanding of economic and genetic problems. At some later date it may be possible to differentiate as a separate unit the sandstone beds that form subordinate and probably stratigraphically discontinuous parts of the Park City in Utah, but inability to do this now should not delay the designation of formations differentiable elsewhere on the basis of available information.

The point that may be raised with reference to the designation of the Park City and Shedhorn as formations though they contain a tongue of the Phosphoria in their type areas has been discussed by Thomas (1934, p. 1660):

The interfingering of the Phosphoria [the Park City of this report] and the Dinwoody with the Chugwater brings about troublesome problems in nomenclature. Limestones and sandstones extending eastward from the Wind River Mountains between red shales are treated as *tongues* of the Phosphoria and the Dinwoody formations. If there should be a locality at which all Phosphoria and Dinwoody tongues have thinned out, although such a section is unknown, it would there be impossible to differentiate the Phosphoria, the Dinwoody, and the Chugwater portions of the red shale series, and the entire sequence would be designated as Chugwater. Hence, all the red shales extending westward from central Wyoming into the Phosphoria and the Dinwoody formations are treated as tongues of the Chugwater formation.

J. B. Reeside, Jr. (written communication, 1955), expressed the opinion that "it does not seem * * * necessary that the perfect 'end member' exist—it seldom does, in practice."

With respect to the Embar problem, we consider it unwise to use both the names "Embar" and "Park City" for rocks that have almost the same lithology and that are physically continuous. The name "Park City" has always been in good standing for the mainly carbonate rock section in central and eastern Utah; it was once used for the dominantly carbonate-rock section of central Wyoming by Blackwelder (1918, p. 423) and others; and it has seldom been used for older or younger rocks in either Utah or Wyoming than those to which we propose to apply it now. Thus, it seems desirable to use that term in preference to "Embar", which has been officially abandoned once (Thomas, 1934, p. 1670; Wilmarth, 1938, p. 683) and has been used in several different senses by different workers.

PARK CITY FORMATION

GENERAL DESCRIPTION

By R. P. SHELDON and T. M. CHENEY

The Park City formation of Permian age was named by Boutwell (1907, p. 443–446) who defined it as the beds underlying the red shales of the Woodside formation of Triassic age and overlying the Weber quartzite of Pennsylvanian age in Big Cottonwood Canyon near Salt Lake City, Utah. There the Park City formation consists mostly of carbonate rock, some of which is cherty, and calcareous sandstone.[3] In 1909 Gale (Gale and Richards, 1910, p. 460) recognized the presence of a phosphatic shale member within the Park City formation at the type locality, and shortly thereafter the member was shown to be continuous with the phosphatic shale member of the Phosphoria formation (Richards and Mansfield, 1912, p. 684–689). Nevertheless, the phosphatic shale unit in Utah, south of the Crawford Mountains continued to be known as the middle member or middle shale member of the Park City formation. In this report, however, it is called the Meade Peak phosphatic shale tongue of the Phosphoria formation. Thus, at its type locality the Park

[3] In 1954 Mr. Boutwell told M. D. Crittenden, Jr., that he had described the Park City formation from outcrops on the ridge between Mill D North Fork Creek and Beartrap Hollow on the north side of Big Cottonwood Creek in the S½SW¼ sec. 9 and N½NW¼ sec. 16, T. 2 S., R. 3 E., Salt Lake County, Utah.

City formation consists of a lower (Grandeur) member and an upper (Franson) member, both composed mainly of carbonate rock, separated by the Meade Peak phosphatic shale tongue of the Phosphoria formation. Tongues of the Park City formation extend into eastern Idaho, southwestern Montana, central and eastern Wyoming (pl. 3), and northwestern Colorado.

The carbonate rock of the Park City probably originated in several ways and was deposited in several different physical-chemical, shallow-water environments. Much of the limestone is bioclastic and brachiopod and bryozoan coquinas are common, indicating that calcite was stable and oxygen was available in the sea water—that is, the pH was greater than 7.8 and the Eh greater than zero (Krumbein and Garrels, 1952, p. 26). The bioclastic limestone is commonly sandy or is gradationally interbedded with sandstone, showing that the action of currents was sufficiently strong to move sand and to winnow out argillaceous sediment. The coquinas, on the other hand, are commonly argillaceous. The minor, and in some rocks important, amounts of phosphatic brachiopods and bryozoans, replaced by collophane found in some of the limestone beds, indicate that at times the sea water or connate water was richer than usual in phosphorus.

Dolomite is as common in the Park City as limestone and much of it is texturally similar to limestone. The dolomite is generally poor in fossils or fossil fragments, but palimpsest fossils have been observed in several thin sections. Sand-size quartz grains in many of the dolomite beds indicate that the original carbonate particles were also sand size. Bryozoans replaced by collophane and glauconite are common, and X-ray studies have shown mixtures of calcite and dolomite. These features suggest that many of the dolomite beds were originally biogenic calcareous sands.

Some of the dolomite in the Park City is cryptocrystalline to microcrystalline or oolitic; it is possibly a chemical precipitate of dolomite or a precipitate of calcite that was later dolomitized. These sediments also probably were deposited at a pH greater than 7.8 and an Eh greater than zero; they are commonly interbedded with and grade laterally into anhydrite or gypsum. Thus, the salinity of the sea water in which some of these carbonates were deposited may have been greater than normal.

GRANDEUR MEMBER

By T. M. Cheney, R. W. Swanson, R. P. Sheldon, and V. E. McKelvey

The Grandeur member of the Park City formation is here defined as the interbedded carbonate rock, cherty carbonate rock, carbonatic sandstone, and carbonatic siltstone that overlie the Weber quartzite of Pennsylvanian age in Utah, the Wells formation of Pennsylvanian and Permian age in Idaho (as restricted in this report), the Tensleep sandstone of Pennsylvanian and Permian age in Wyoming, and the Quadrant formation of Pennsylvanian age in Montana; it underlies the Meade Peak phosphatic shale member of the Phosphoria formation. The member is not well exposed in the type area of the Park City formation in Big Cottonwood Canyon, but a section, here designated as the type section, exposed about 1 mile southwest of Grandeur Peak, after which the member is named, in the central Wasatch Mountains, is given in table 1 and in section 2, figure 4. At the type locality the Grandeur member is about 280 feet thick and consists mainly of limestone and dolomite, some of which contains chert nodules; calcareous sandstone is a subordinate constituent. The base of the member is marked by a thick dark-gray bioclastic limestone which is easily distinguishable from the underlying lighter colored sandy limestone and sandstone of the Weber quartzite. The upper contact is the horizon above which the nonresistant black phosphatic shales of the Meade Peak are dominant.

The Grandeur has been identified at numerous other localities in the Wasatch Mountains from a few miles north of the Weber River south to the vicinity of Nephi. It reaches its maximum known thickness of about 880 feet in the overthrust block of the southern Wasatch Mountains (Baker and others, 1949, p. 1188), and it is at least 250 feet thick throughout the range. Although the Grandeur member is dominantly carbonate or cherty carbonate rock in the Wasatch Mountains, calcareous sandstone is an important constituent; thin phosphatic beds are commonly present near the top and base of the member.

TABLE 1. *Type stratigraphic section of the Grandeur member of the Park City formation in sec. 36, T. 1 S., R. 1 E., on the north side and near the mouth of Mill Creek Canyon, Salt Lake County, Utah*

[Section measured and described by T. M. Cheney, 1954]

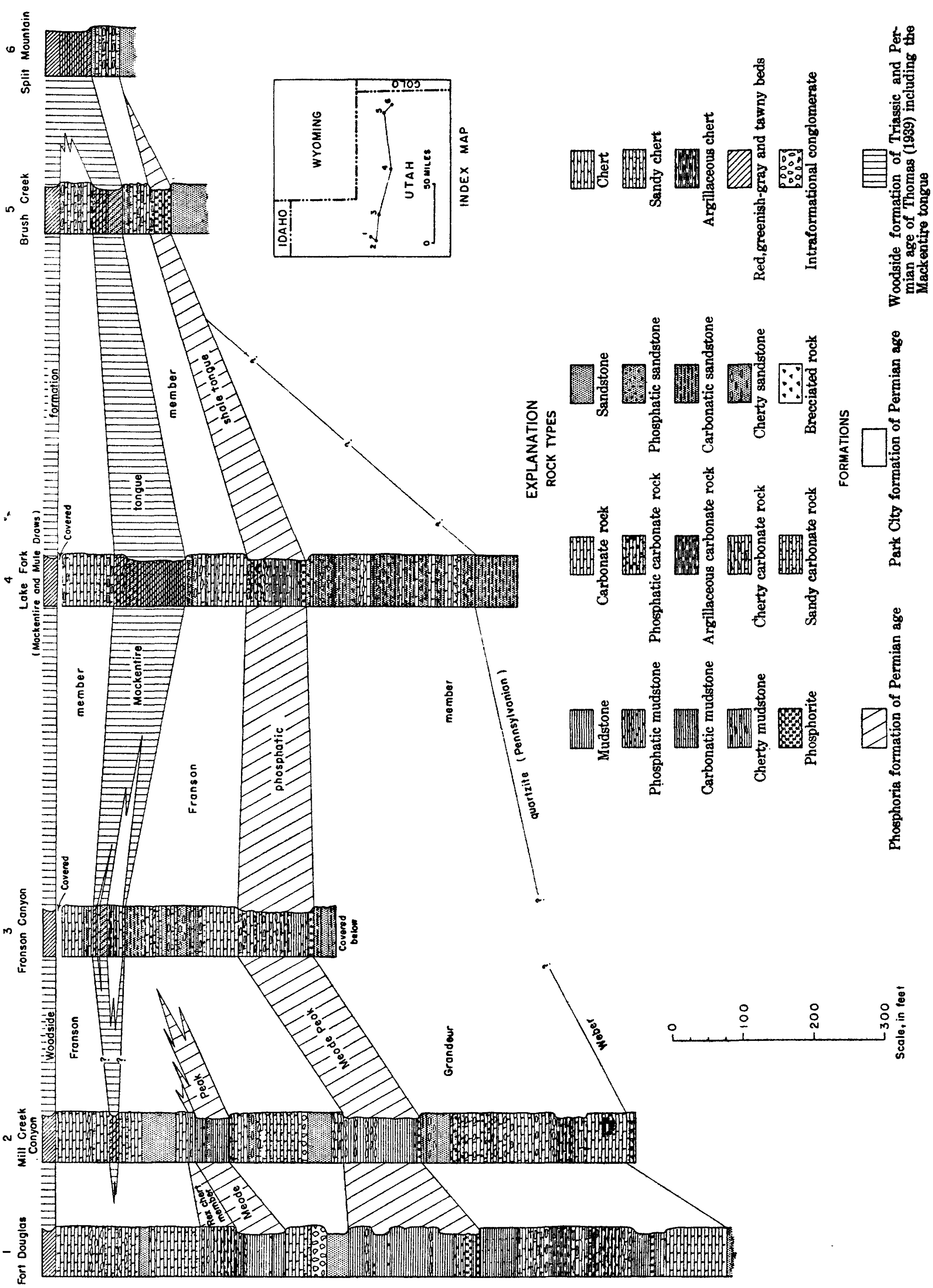
	Ft
Meade Peak phosphatic shale tongue of the Phosphoria formation (lower bed only):	
Phosphorite, argillaceous, calcareous, finely to coarsely pelletal, hard, light-gray, thin-bedded	1.0
Grandeur member of the Park City formation:	
Sandstone, calcareous, fine-grained, light-gray, thick-bedded	8.0
Chert, sandy (?), hard, light-gray, massive	1.5
Sandstone (60 percent) and chert (40 percent): cherty fine-grained hard light-gray massive sandstone interbedded with layers and nodules of chert as much as 0.5 ft thick	12.5
Sandstone, very fine grained, grayish-brown, thick- and massive-bedded; slightly calcareous in lower one-third of unit	17.0

TABLE 1. *Type stratigraphic section of the Grandeur member of the Park City formation in sec. 36, T. 1 S., R. 1 E., on the north side and near the mouth of Mill Creek Canyon, Salt Lake County, Utah*—Continued

	Ft
Grandeur member of the Park City formation—Con.	
Dolomite (80 percent) and chert (20 percent): sandy hard light-gray thick- to massive-bedded dolomite interbedded with 20 percent chert, as dark-gray layers and nodules as much as 0.8 ft thick. Light-gray fossil fragments, some phosphatic, are concentrated in beds immediately underlying chert layers	18.5
Dolomite, silty, sandy(?), light-gray; about 40 percent of unit contains 20–50 percent chert as gray nodules as much as 0.5 ft thick	22.9
Dolomite, sandy, silty, hard, light brownish-gray, massive, laminated in part. Phosphatic fossil fragments comprise 3–5 percent of unit but are concentrated in two thin beds. Laminae composed of phosphatic fossil fragments are in upper part of unit	11.4
Dolomite, argillaceous, hard, light-gray, massive. Unit contains both phosphatic and nonphosphatic fossil fragments	2.5
Dolomite (60 percent) and chert (40 percent): silty very pale brown thin- and thick-bedded dolomite and black chert as layers, and layers of nodules, which average about 0.2 ft thick	12.5
Dolomite, silty(?), hard, very pale brown, massive(?); less than 5 percent calcareous fossil fragments	5.0
Dolomite (70 percent) and chert (30 percent): cherty dense hard dark-gray thin to thick irregular beds of dolomite interbedded with black chert as layers of nodules and stringers	15.0
Dolomite, dense, slightly argillaceous, medium-hard and hard, pale-brown, very thin to massive bedded; some phosphatic fossil fragments in lower one-third of unit	30.0
Dolomite (70 percent) and chert (30 percent): dense hard dark-gray irregular thin and thick beds of dolomite and black chert as nodules in layers as much as 0.6 ft thick	6.5
Dolomite, dense to coarsely crystalline, hard, light-gray, massive; contains about 1 percent chert, as nodules as much as 0.3 ft in diameter, and large splotches of secondary calcite	14.0
Dolomite: about half is silty and light brownish-gray, and half is cherty, dense, hard, and light-gray. Unit contains a few stringers of chert 0.05 ft thick	7.0
Limestone, argillaceous, silty, black, very thin to massive bedded; shaly in part. A few thin layers contain abundant small (<3 mm) black phosphatic casts of pelecypods and gastropods. Fish scales and phosphatic and nonphosphatic brachiopods are also present in some beds	20.0
Phosphorite, carbonatic, very finely pelletal, black; upper and lower contacts gradational	.3
Limestone, argillaceous, slightly phosphatic(?), pale-brown, massive	1.0
Phosphorite, calcareous, slightly silty, very finely and finely pelletal, dark-gray, massive	1.1
Limestone, argillaceous, silty, medium-hard, black, very thin and thick bedded, shaly in part. Some layers contain abundant phosphatic casts of small (average size 3 mm) gastropods and pelecypods; other phosphatic and nonphosphatic fossils and fossil fragments abundant in some beds; pyrite, chalcocite, and bornite present in a few beds	14.0
Limestone, argillaceous, hard, dark-gray and black, thick-bedded. Upper 0.2 ft is finely to coarsely pelletal phosphate rock; phosphatic internal casts of small fossils present in 0.2-foot thick bed near middle of unit	2.0
Limestone, argillaceous, pale-brown, very thin to thin-bedded. Lower 0.3 ft contains 10–30 percent fine to medium pellets of phosphate	1.5
Dolomite, argillaceous, dense, dark-gray, massive. About 30 percent of unit is fossil fragments 1/16–10 mm in size	8.5
Limestone, thick- and massive-bedded, dark-gray. About 50 percent of rock is calcareous fossils and fossil fragments (mostly articulate brachiopods)	45.0
Total thickness of Grandeur member of Park City	277.7
Weber quartzite (upper bed only):	
Limestone, sandy, fine- to medium-grained, light-gray, massive	8.5

The Grandeur member is present at all outcrops of the Park City formation in the Uinta Mountains except those east of Lake Fork on the south flank, and it ranges in thickness from a featheredge to about 350 feet. In the western Uinta Mountains the upper part of the Weber contains some carbonate rock and the Grandeur member of the Park City contains considerable sandstone. The contact between the two, which is gradational in many places, is placed arbitrarily at the horizon above which carbonate rock is dominant, but the lighter color, lesser magnitude of cross-bedding, and brecciated character of sandstone in the Grandeur member in comparison with the sandstone of the Weber serve to distinguish the two in places. M. N. Bramlette (written communication, 1951) has suggested that the upper part of the Weber in the eastern Uintas is equivalent to part of the Grandeur member of the Park City to the west. This implies that part of the Grandeur member of the Park City and part of the Weber quartzite intertongue in the western Uintas—a possibility that should be investigated in further work.

In the southeastern Wind River Mountains, a cherty and sandy carbonate rock unit about 40 feet thick occupies the same stratigraphic position as the Grandeur



Sections at Mill Creek, Split Mountain, the upper part at Fort Douglas, Lakefork, and Brush Creek by T. M. Cheney. Grandeur member at Lakefork from unpublished data of J. W. Huddle. Other data from Cheney and others (1953, p. 18, 25) and Smith and others (1952, p. 31, 35)

FIGURE 4.—Stratigraphic sections of Park City and Phosphoria formations in Utah.

member of the Park City in Utah (fig. 5). Data from a few scattered test wells in southwestern Wyoming suggest that the two carbonate units are laterally continuous. For example, a cherty carbonate rock just above the Weber quartzite was penetrated by the Mountain Fuel Supply Company unit No. 1 (sec. 21, T. 16 N., R. 104 W.) in the South Baxter basin gas field in the Rock Springs uplift and in several wells in Uinta and Lincoln Counties, Wyo.

The upper siliceous limestone of the Wells formation of Mansfield (1927, p. 72) in southeastern Idaho and western Wyoming is here assigned to the Grandeur tongue of the Park City formation. The name "Wells formation" is thus restricted to the underlying sandstones, red beds, and carbonate rocks. The Wells formation was subdivided by Mansfield into a lower carbonate sequence, a middle sandstone sequence, and the upper siliceous limestone referred to above; the Geological Survey has mapped these subdivisions in the Aspen Range-Dry Ridge area, and perhaps the other two units should also be recognized by separate names. We have not done so here, however, because our work on the Wells as a whole has been limited to a restricted area and any such action ought to take cognizance of regional relationships yet to be studied.

The Grandeur tongue of the Park City in Idaho and western Wyoming has not been studied as much as have other sections, but it has been examined in reconnaissance fashion in connection with the phosphate studies and has been mapped in several areas as well. From these studies, it is known to range in thickness from about 10 feet in the Salt River Range to about 200 feet in the Sublett Range and to consist of dolomite, cherty dolomite, and chert.

In southeastern Idaho, the Grandeur tongue of the Park City generally forms a prominent ledge stratigraphically below the covered interval that characterizes the Meade Peak member of the Phosphoria. The top of the Grandeur, marked by a fish-scale-bearing phosphorite bed at the base of the Meade Peak, is commonly exposed, but the contact with the underlying sandstone is seldom exposed; both upper and lower contacts are conformable. The Grandeur tongue also crops out in western Wyoming, but there it is less conspicuous because the quartzites below it are harder and more resistant than the underlying sandstones in southeastern Idaho.

In southwestern Montana the Grandeur consists of interbedded cherty carbonate rock (largely dolomite), red to greenish-gray dolomitic siltstone, and light-colored locally crossbedded quartz sandstone (fig. 6, columns 1 and 2). In preliminary reports on the phosphate studies in Montana these strata have been tentatively identified as the A member of the Phosphoria formation, after the usage applied by A. P. Butler and C. W. Chesterman (written communication, 1944). The Grandeur generally thins east and north of Lima, Mont., where it is about 350 feet thick, though it reaches a thickness of 385 feet at Hogback Mountain in the Snowcrest Range. In most of the area north of Dillon, where neither the Meade Peak nor the Rex chert members are present, the Grandeur and the Franson members of the Park City formation cannot be separated readily.

East of the Madison River the Meade Peak member of the Phosphoria is not present, but the Grandeur and Franson members of the Park City formation may be distinguished by the character of the associated sandstone; clean quartz sandstone interbeds occur in the lower member whereas sandstone interbedded with the Franson contains many chert grains, apatite pellets, and fossil fragments. The upper part of the Quadrant formation contains intercalated beds of carbonate rock in this area, and the contact between the Quadrant and the Grandeur is gradational in some localities; the contact in these localities is arbitrarily placed at the horizon separating dominant sandstone below and dominant dolomite above.

Although the Grandeur member of the Park City is dominantly carbonate rock, it is characteristically a heterogenous unit. Alternations in the physical and chemical environment of deposition are suggested by the thin beds of phosphate rock and the abundant chert, argillaceous material, quartz silt, and sand present in the Grandeur member. The greater thickness and variety of rock types in the Wasatch Mountains and southwesternmost Montana suggest greater tectonic instability in those areas than in central and western Wyoming, eastern Utah, and the eastern part of the field in Montana.

FRANSON MEMBER

By T. M. Cheney

The light-gray and grayish-brown carbonate rock, cherty or sandy carbonate rock, and calcareous sandstone that overlie the Meade Peak phosphatic shale member of the Phosphoria and underlie the Woodside formation of Triassic age on the north side of Franson Canyon near its mouth are designated the Franson member of the Park City formation (table 2). The Utah portion of this member was classed previously as the upper member of the Park City formation, the stratigraphy of which has been described by J. Stewart Williams (1939), Baker and J. Steele Williams (1940), Thomas and Krueger (1946, p. 1263–1267), and Cheney and others (1953). The Franson is also present in

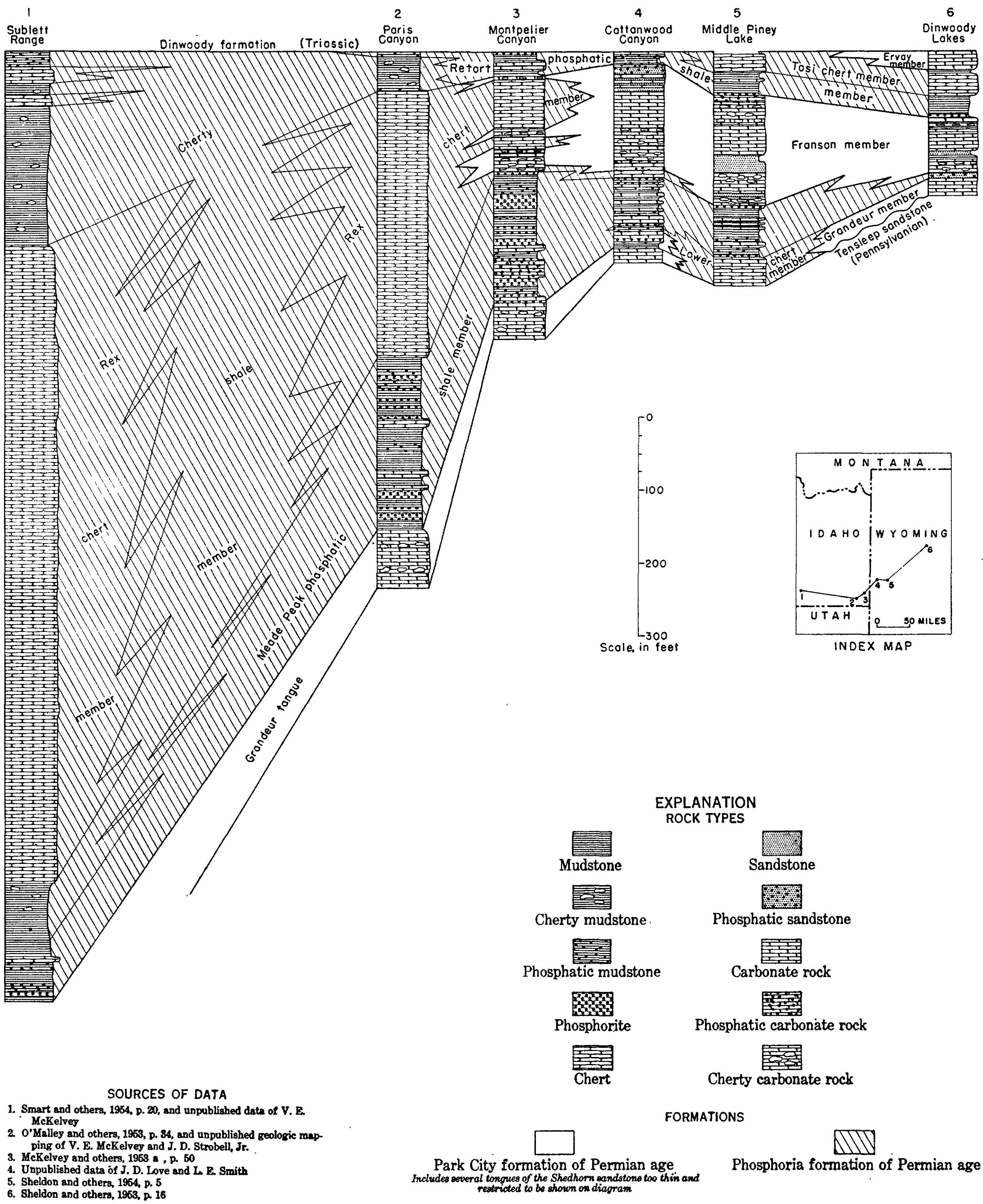


FIGURE 5.—Stratigraphic sections of Phosphoria and Park City formations in southern Idaho and western Wyoming.

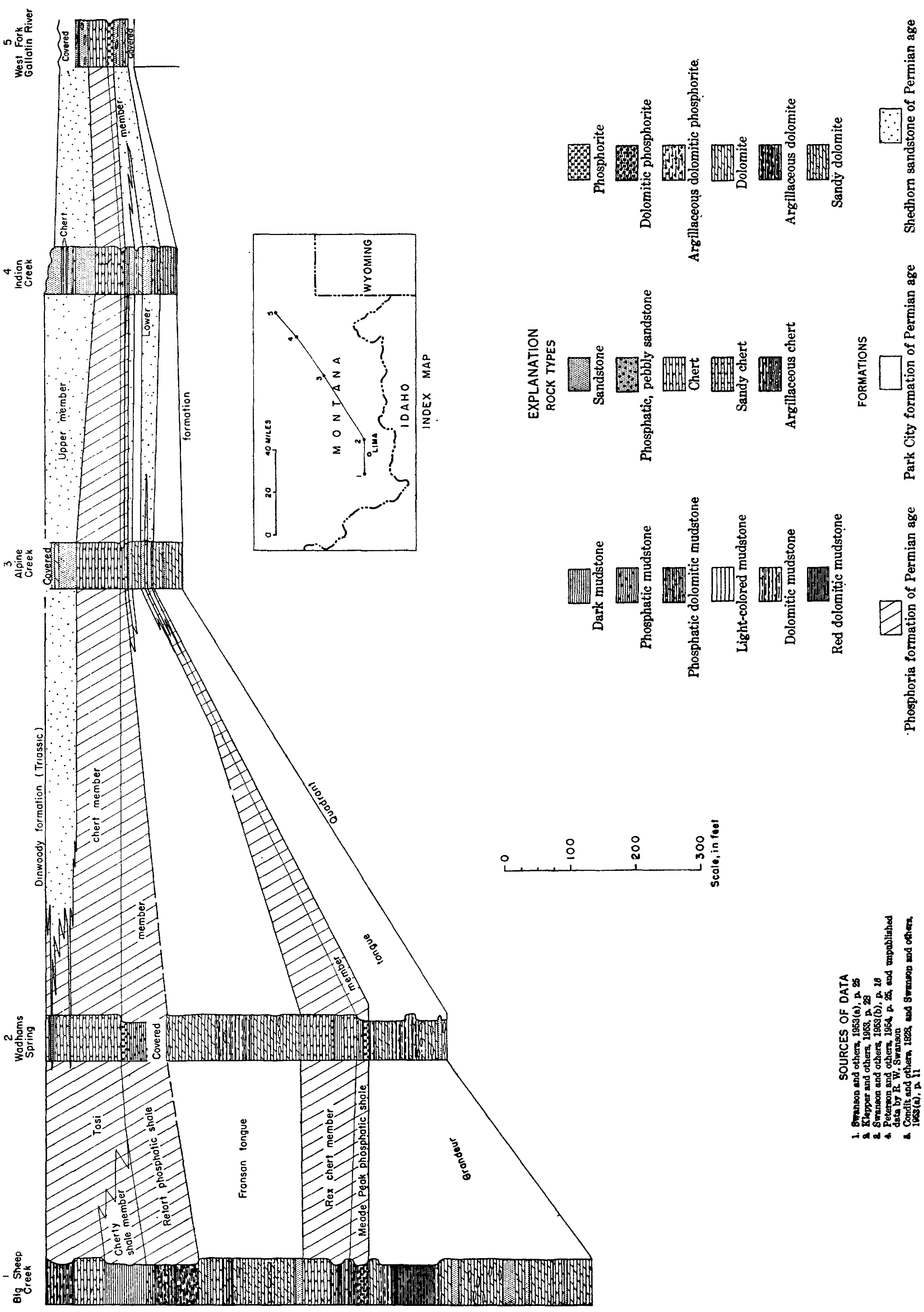


FIGURE 6.—Stratigraphic sections of Phosphoria, Park City, and Shedhorn formations in Montana.

Montana, Wyoming, and Idaho, and its beds in those states were considered to be a part of the Rex chert member or the C member of the Phosphoria formation (Klepper, 1951, p. 61).

TABLE 2.—*Stratigraphic section of Franson member at the north side and near the mouth of Franson Canyon, sec. 14, T. 1 S., R. 6 E., Summit County, Utah*

[Measured and described by M. A. Warner, R. A. Smart, R. G. Waring, and T. M. Cheney in 1951 (Cheney and others, 1953, p. 18)]

	Ft
Woodside formation:	
Basal part of Woodside is red calcareous shaly mudstone and siltstone; greenish-gray streaks in some beds.	
Franson member of the Park City formation (includes thin beds of the Mackentire(?) tongue of the Woodside formation of Thomas (1939), indicated by "Mk:" in front of description):	
Covered; probably white dolomite	5–10
Dolomite, dense, medium-hard, pale-pink and white (mottled), medium-gray and yellowish-gray, thin- and massive-bedded; lower contact gradational	15.0
Dolomite, medium-hard, light purplish-gray, thick-bedded, slightly argillaceous. Phosphatic fossils and fossil fragments comprise 10 percent of some beds. Some calcareous, glauconitic, and cherty fossils and fossil fragments are also present	6.1
Dolomite, argillaceous, medium-hard, thin-bedded; upper 1.2 ft purplish gray, lower 2.9 ft reddish gray	4.1
Limestone, argillaceous, slightly sandy(?), hard, light brownish-gray. Contains bryozoans and a few chert pebbles	1.9
Dolomite, hard, light brownish-gray, thick- and irregular-bedded, slightly argillaceous; contains chert concretions	2.1
Dolomite, argillaceous, dense, hard, purplish-gray, massive, knotty; lower 0.4 ft soft, greenish gray, glauconitic	2.4
Dolomite, dense, hard, light brownish- and yellowish-gray, thick-bedded; upper 4.7 ft is sandy	11.9
Mk: Dolomite, dense, medium-hard and soft, reddish-gray, thin-bedded; middle part contains calcite geodes	4.3
Dolomite, dense, hard, yellowish-gray, thick-bedded	3.1
Mk: Sandstone, calcareous, soft, crumbly, pale brownish-red	7.2
Dolomite, argillaceous, dense, hard, light-gray, thick-bedded; lower 1.2 ft is not argillaceous	13.6
Mk: Dolomite, argillaceous, silty, brecciated, soft, crumbly, greenish-gray and brick-red (banded)	.7
Limestone, oolitic, medium-hard, yellowish-gray; lower contact gradational	8.1
Mk: Dolomite, argillaceous, soft, brownish-red and brick-red	3.9
Sandstone, fine-grained, slightly calcareous, hard, yellowish-gray, thick- and massive-bedded	10.9
Sandstone, calcareous, fine-grained, medium-hard, pinkish-white, massive; contains some chert as lenses and nodules	12.9

TABLE 2.—*Stratigraphic section of Franson member at the north Side and near the mouth of Franson Canyon, sec. 14, T. 1 S., R. 6 E., Summit County, Utah*—Continued

	Ft
Franson member of the Park City formation—Con.	
Dolomite, argillaceous, hard, light brownish-gray, thick-bedded; contains chert as lenses and nodules	5.3
Mudstone, dolomitic, medium-hard, brownish-gray, thin-bedded; some chert and carbonate concretions and inarticulate brachiopod fragments. Upper and lower 0.2 ft are moderately pelletal and nodular phosphorite	3.7
Sandstone, calcareous, fine- to medium coarse-grained, hard, pale yellowish-orange, massive; phosphatic, cherty bed 0.3 ft thick near base of unit	3.4
Sandstone, calcareous, medium-hard, yellowish-white, thick-bedded; lower 3.0 ft is sandy limestone	8.6
Sandstone, calcareous, fine-grained, medium-hard, light-gray, massive, crossbedded	4.3
Chert, hard, yellowish-gray, thin-bedded. Upper 1.9 ft contains about 60 percent calcareous fine-grained medium-hard yellowish-gray thin-bedded sandstone	3.8
Sandstone, dolomitic, medium-grained, hard, yellowish-gray, thick-bedded; very fine grained, cherty bed 1.9 ft thick in middle of unit; lower 1.7 ft slightly sandy dolomite	4.1
Dolomite, slightly sandy and silty, medium-hard, light-gray and light brownish-gray, thin-bedded; phosphatic fossils and fossil fragments in lower 1.9 ft; lower contact gradational	7.3
Chert (50 percent) and sandstone (50 percent): sandy hard medium-gray massive chert that contains abundant sponge spicules interbedded with calcareous fine- and medium-grained hard light-gray massive sandstone	13.4
Limestone, sandy, medium-coarsely crystalline, medium-hard, light-gray, massive; contains fine to coarse rounded quartz grains and rounded calcite grains	3.6
Chert, slightly calcareous, hard, yellowish-gray, thick-bedded; contains abundant spicules	3.7
Dolomite (60 percent) and chert (40 percent): sandy hard light-gray massive dolomite interbedded with hard dark-gray chert; chert contains spicules	3.8
Limestone, cherty, dense, hard, light yellowish-gray, massive; contains irregular masses of chert	5.4
Chert, sandy, slightly calcareous, hard, yellowish-gray; contains abundant siliceous sponge spicules; lower contact gradational	1.2
Limestone, sandy, dense, hard, yellowish-gray, massive	5.2
Dolomite, slightly argillaceous, medium-hard, yellowish-gray and light brownish-gray, massive. Zone 4.3 ft thick 6 ft above base is sandy; chert masses in lower 1.4 ft	15.7
Dolomite, silty, soft and medium-hard, light brownish-gray; contains phosphatic inarticulate brachiopod fragments	2.2

TABLE 2.—*Stratigraphic section of Franson member at the north side and near the mouth of Franson Canyon, sec. 14, T. 1 S., R. 6 E., Summit County, Utah*—Continued

	Ft
Franson member of the Park City formation—Con.	
Covered; probably limestone	7.6
Limestone, hard, very pale brown, massive; contains abundant fossil fragments; chert concretions in zone 5.6 ft above base	15.4
Limestone, slightly argillaceous, hard, yellowish-gray; contains phosphatic inarticulate brachiopod fragments	1.7
Total thickness of Franson member	230–235
Meade Peak phosphatic shale tongue of the Phosphoria formation (upper beds only):	
Dolomite, argillaceous, medium-hard, very pale brown; contains black chert masses	2.3
Dolomite, argillaceous, soft, light greenish-gray, slightly phosphatic	.5

At the type locality the Franson member is about 235 feet thick and consists of a lower unit about 65 feet thick composed of dominantly light-gray and grayish-brown carbonate rock, a middle unit about 85 feet thick of dominantly light-gray and brownish-gray carbonatic sandstone containing chert as beds and nodules, and an upper unit about 85 feet thick of dominantly white and light-gray carbonate rock. Some of the beds in the upper unit are reddish brown and are probably laterally continuous with the Mackentire tongue of the Woodside formation of Thomas (1939).[4] The lower contact is gradational but is placed at the top of the gray and greenish-gray cherty, phosphatic thin-bedded carbonate rock of the upper part of the Meade Peak and beneath the pale-brown massive sandy carbonate rock of the basal part of the Franson member. Most of the apatite is in the form of internal casts of small fossils. At the type locality, as well as at many other localities in Utah, a limestone containing phosphatic inarticulate brachiopods is present near the base of the member.

The Franson member is one of the most extensive units of the rocks of Phosphoria age in the western field (pl. 3). In most of Utah, western Wyoming, and parts of Montana, the Franson is generally underlain by a tongue of the Phosphoria formation, either the Meade Peak or the Rex; however, in eastern Utah and northwestern Colorado it is underlain by the Weber sandstone; in parts of western Montana and central Wyoming, where the Meade Peak and Rex are absent, it is difficult to distinguish the Franson member from the Grandeur member of the Park City. In northernmost Utah, eastern Idaho, western Wyoming, and southwestern Montana, the Franson interfingers with the Rex, Tosi, and Meade Peak members of the Phosphoria formation, and in Utah it intertongues with the red and greenish-gray shales of the Woodside formation of Thomas (1939). In the southern Wasatch Mountains the Franson member is overlain unconformably by the Woodside formation (Baker and Williams, 1940, p. 624); however, in most of Utah, as at the type localities of the Park City and the Franson, the Woodside is conformable on the Franson. In eastern Utah the Franson is overlain by the red and gray shales of the Woodside formation. In western Wyoming, Montana, and northeastern Idaho, the Franson is overlain by the Retort phosphatic shale member of the Phosphoria formation.

The Franson member of the Park City formation reaches a maximum thickness of 830 feet in the southern Wasatch Mountains, but over most of its extent it ranges from 50 to 200 feet in thickness (pls. 2 and 3; figs. 4–6). It is composed mainly of light-colored hard massive carbonate rock, but calcareous or dolomitic sandstone forms as much as one-third of the total thickness in some places. The carbonate rock is dolomite, calcite, or mixtures of the two. Dolomite, generally dense to fine grained, is the most abundant carbonate in Montana and Utah. Limestone, mostly bioclastic, is present in all areas and it is the dominant carbonate in much of Wyoming. Chert is common as nodules and stringers. Apatite and glauconite are common minor constituents. The Franson often forms ledges and cliffs. Soft or shaly beds are uncommon.

The general conditions of carbonate deposition were discussed previously in this report. Suffice it to say here that the carbonate rocks of the Franson were deposited in relatively shallow water intermediate between chert, basinward, and greenish-gray shales, red beds, evaporites, and sandstone, shoreward. The effects of wave action and currents on the Franson sediments are seen in carbonate oolites, quartz silt and sand, fragmented fossils, and the general lack of argillaceous material in the carbonate rocks.

ERVAY CARBONATE ROCK MEMBER

By R. P. SHELDON

Thomas (1934, p. 1666) applied the name "Ervay" to a limestone 16 feet thick at the top of the Permian sequence of interbedded red shale and carbonate rock in the Rattlesnake Hills, Wyo. He considered it a tongue of the Phosphoria formation because its lithology is similar to that of the Phosphoria formation (as the name was used then) in the southern Wind River

[4] The Woodside formation as used by Thomas includes rocks of Permian and Triassic age in the eastern Uintas.

Mountains; he correlated the Ervay with the uppermost limestone of the Phosphoria formation in the Wind River Mountains. In this report the beds in the Wind River Mountains that Thomas called Phosphoria are designated in part as the Park City formation, and the Ervay is thus considered a member of the Park City formation. The Ervay carbonate rock member is a widespread unit of the Park City formation in western Wyoming (pl. 2). It extends to the northern Wind River Mountains where it is about 30 to 40 feet thick; north and west of the Wind River it grades into the upper member of the Shedhorn sandstone. To the west of the southern Wind River Mountains, the Ervay tongue extends as far as General Petroleum's Lakeridge No. 1 well (sec. 19, T. 29 N., R. 114 W.), 20 miles west of Big Piney, Wyo., where it is about 30 feet thick. West of this well the Ervay grades into the Tosi chert member of the Phosphoria formation. A carbonate rock unit at the top of the Franson member in Utah contains a fauna similar to that of the Ervay and may be a correlative of it. The Ervay is mostly limestone in its western area and dolomite in its eastern area.

PHOSPHORIA FORMATION

GENERAL DESCRIPTION

By V. E. McKelvey

The Phosphoria formation of Permian age was named for Phosphoria Gulch, Bear Lake County, Idaho (Richards and Mansfield, 1912, p. 684), a locality that is still representative of the formation as it is known today. In the vicinity of its type locality (table 3), the formation ranges from 250 to 450 feet in thickness and consists mainly of dark chert, phosphatic and carbonaceous mudstone, phosphorite, cherty mudstone, and minor amounts of dark carbonate rock. Sandstone is absent, and light-colored carbonate rock is either absent or present only in local lenses. The Phosphoria in this area is underlain by the Grandeur tongue of the Park City and overlain by the Dinwoody formation of Triassic age. The lower boundary of the Phosphoria is marked by a thin phosphorite bed which contains abundant fish scales and bones and overlies the light-colored cherty fossiliferous carbonate rock of the Grandeur tongue of the Park City. The upper boundary of the Phosphoria is rarely exposed but is marked by a nodular phosphorite which contains casts of sponge spicules(?) and is readily separable in good exposures from the tan calcareous siltstone of the basal part of the Dinwoody.

TABLE 3.—*Stratigraphic section of the Phosphoria formation on Snowdrift Mountain, Caribou County, Idaho*

[The Meade Peak phosphatic shale member measured in a bulldozer trench in the NW¼NW¼ sec. 8, T. 10 S., R. 45 E., by T. M. Cheney, J. A. Peterson, R. G. Waring, R. A. Smart, and E. R. Cressman. (See Smart and others, 1954, p. 15.) Lower part of Rex chert member measured by V. E. McKelvey in artificial and natural exposures adjacent to opencut mine of the Central Farmers Fertilizer Cooperative in the NW¼SW¼ sec. 8; upper part of Rex and the cherty shale member measured by McKelvey in natural and artificial exposures in canyon in the NE¼NE¼ sec. 18]

	Ft
Dinwoody formation (lower beds only):	
Limestone, argillaceous, hard (forms natural outcrop), brownish-gray to pale-brown, thin-bedded; lower 0.7 ft consists of grayish-brown mudstone containing scattered black phosphatic pellets.	
Cherty shale member of the Phosphoria formation (includes a tongue of the Retort, indicated by "Rt:" in front of the description):	
Rt: Phosphorite, cherty(?), nodular, grayish-brown, hard; contains casts of sponge spicules(?)	1.0
Rt: Mudstone, soft, brownish-black, fissile	1.3
Rt: Phosphorite, cherty, hard, black, pelletal	1.3
Rt: Mudstone, soft, brownish-gray, fissile	3.0
Rt: Dolomite, hard (forms natural outcrop), brownish-gray, massive. Weathered surface is pale brown and deeply etched	1.7
Rt: Mudstone, soft, black to grayish-brown, fissile	22.0
Chert, argillaceous, hard (forms natural outcrop), black, thick-bedded	3.5
Cherty mudstone and mudstone: hard black and brownish-gray thin-bedded cherty mudstone (80 percent) and soft brownish-gray mudstone (20 percent)	13.0
Mudstone, slightly dolomitic, medium-hard, dark-gray, fissile	6.3
Mudstone, cherty, medium-hard, brownish-gray, thin-bedded	10.0
Dolomite, hard, dark-gray, massive; contains chert nodules in upper 0.2 ft. Weathered surface is pale brown and deeply etched	1.0
Mudstone, cherty, locally dolomitic, medium-hard, brownish-gray, thin-bedded. Some fracture surfaces are stained reddish brown and moderate orange	24.2
Dolomite, argillaceous, hard, brownish-gray; contains deeply weathered parts that are soft and pale reddish brown	4.0
Mudstone, locally dolomitic or cherty, medium-hard, brownish-gray fresh and pale-brown to moderate yellowish-orange weathered, thin-bedded	4.4
Total thickness of cherty shale member	96.7
Rex chert member of the Phosphoria formation (includes a tongue of the cherty shale member, designated by "CS:" in front of the description):	
Chert and mudstone: hard (forms natural outcrop) dark-gray nodular thin-bedded chert (75 percent) and interbedded thin zones of cherty soft to medium-hard brownish-gray (stained pale brown to moderate yellowish orange on fractures) fissile and thin-bedded mudstone (25 percent)	21.6

TABLE 3.—*Stratigraphic section of the Phosphoria formation on Snowdrift Mountain, Caribou County, Idaho*—Continued

	Ft
Rex chert member—Continued	
Chert, hard (forms conspicuous natural outcrop), black and dark-gray (weathers reddish gray), thick-bedded; contains irregular chert pebbles and nodules	11.3
Chert, hard (forms conspicuous natural outcrop), dark-gray (weathered surface has conspicuous light-gray bands), thick-bedded	21.2
Chert, hard (forms natural outcrop), dark-gray (reddish-gray and moderate-orange weathered), thin- and thick-bedded; contains abundant irregular cylindrical concretions as much as 0.3 ft wide and 1.0 ft long, mostly inclined in relation to bedding planes; unit not observed in nearby sections	10.2
CS: Chert and cherty mudstone: cherty medium-hard (poorly exposed) brownish-gray (moderate yellowish-brown and reddish-brown coatings on weathered surfaces and joints), thin-bedded mudstone (35 percent) interbedded with hard thin-bedded nodular chert (65 percent)	15.9
Chert, hard (forms upper part of prominent cliff) dark-gray (light-gray and reddish-gray weathered), thick- and massive-bedded, nodular	9.2
Chert, hard (forms prominent cliff), dark-gray (light-gray weathered), thick- and massive-bedded; beds pinch and swell	26.5
Chert, hard, black (moderate-orange to reddish-gray on weathered surfaces and joints), thick-bedded; contains abundant spicules	23.7
Chert and limestone: hard black thin- and thick-bedded finely laminated chert (70 percent) interbedded with and irregularly replacing hard black (pale-brown and yellowish-brown weathered) thin- and thick-bedded finely laminated limestone (30 percent). In nearby sections this unit is as much as 45 ft thick	16.0
Total thickness of Rex chert member	155.6
Meade Peak phosphatic shale member of the Phosphoria formation:	
Mudstone, medium-hard, grayish-brown, commonly spheroidally weathered; nodular phosphorite about 0.5 ft thick at top of unit; another bed approximately 1 ft thick about 3 ft above base	25.3
Upper phosphate zone: coarsely oolitic medium-hard brownish-gray thin- and thick-bedded phosphorite and interbedded thin layers of soft yellowish-brown slightly phosphatic mudstone; pisolitic phosphorite at top, hackly fractured oolitic phosphorite at base	15.5
Phosphorite, argillaceous, soft, grayish-brown; increasingly vanadiferous toward top. In fresh sections, rocks of this zone are only moderately phosphatic and contain abundant carbonate lenses as much as 1 ft thick	9.4
Upper nodular zone: medium-hard pale-brown (grayish-black with greenish-yellow stains in fresh sections) thick-bedded mudstone and interbedded thin layers of nodular grayish-brown phosphorite; hard massive limestone 2 ft thick ordinarily present at top but here weathered to mudstone	16.4
Mudstone, soft, brownish-gray, thin-bedded; contains some phosphatic layers	7.3
Lower nodular zone: soft to medium-hard brownish-gray (hard and grayish-black in fresh sections) thick-bedded mudstone and interbedded thin layers of nodular grayish-brown phosphorite; greenish-yellow stains abundant	22.5
Mudstone, soft, brownish-black, thin-bedded, phosphatic in upper half; chert bed about 0.5 ft thick 10 ft above base. Fresh sections contain abundant lenses of carbonate rock	28.4
Mudstone, phosphatic, soft, grayish-brown, thin-bedded	26.6
Mudstone, soft, grayish-brown, phosphatic in upper two-thirds. In fresh sections upper and lower 2 ft are carbonate beds; the lower one is known as the "false cap"	7.5
Phosphorite, argillaceous, brownish-gray, thin-bedded. Rock from this zone is used in electric furnace manufacture of phosphorus	22.0
Mudstone, phosphatic, soft, grayish-brown. Where unweathered this bed is phosphatic, argillaceous limestone, known as the "cap lime"	1.4
Lower phosphate zone: medium-hard thin-bedded brownish-black phosphorite. Rock from this zone is used to make superphosphate and triple-superphosphate fertilizer	7.0
Carbonate rock, argillaceous, medium-hard, dark-gray, thick-bedded; bed of bioclastic phosphorite 0.7 ft thick at base contains abundant fish scales	10.6
Total thickness of the Meade Peak phosphatic shale member	199.9
Park City formation (upper bed only of Grandeur tongue): Dolomite, siliceous, hard, light brownish-gray, thick-bedded.	

The Phosphoria is typically developed in southeastern Idaho, adjacent parts of Utah and Wyoming, and western Beaverhead County, Mont. Four members are recognizable at the type locality: the Meade Peak phosphatic shale member, the Rex chert member, the cherty shale member, and the Retort phosphatic shale member. Two other members, the lower chert member (laterally continuous with the lower beds of the Meade Peak) and the Tosi chert member (laterally continuous with the upper part of the Retort and cherty shale members), are not present at the type locality but are present in the broader area of typical development of the Phosphoria. Eastward, parts of the Phosphoria grade laterally into sandstone of the Shedhorn and carbonate rock of the Park City but other parts extend as tongues over most of the field. The Phosphoria thickens to about 1,300 feet in south-central Idaho.

LOWER CHERT MEMBER

By R. P. Sheldon

The lower chert member of the Phosphoria formation is defined as the resistant dominantly cherty and slightly phosphatic beds that underlie the nonresistant medium-gray to black phosphatic shale of the Meade Peak phosphatic shale member and that overlie the light-colored nonphosphatic massive sandstone and carbonate rock of the Tensleep sandstone or the Grandeur member of the Park City formation. These beds have been previously included with the Phosphoria by some authors (Gardner, 1944, p. 29; Sheldon, 1957) and with the Wells by others (Cheney and others, 1953, p. 4; Sheldon and others, 1954, p. 4). A typical section of the lower chert member is at Middle Piney Lake in the Wyoming Range (fig. 5), where the unit overlies massive sandstone of the Wells formation and consists of 23 feet of medium-gray chert overlain by 9 feet of dolomite. The unit is overlain by black shale of the Meade Peak.

The lower chert member is confined to a narrow northward-trending belt in the Wyoming, Snake River, Gros Ventre, and Teton Ranges, and the eastern part of the Salt River Range (pl. 3). It has a maximum thickness of about 40 feet in the southern Wyoming Range, thins to the north to about 10 feet in the southwestern Teton Range, and pinches out in the northern Gros Ventre Range. The unit grades westward into phosphatic mudstone of the Meade Peak, which contains thin interbeds of chert in the Salt River and Caribou Ranges, and grades into sandy and cherty carbonate rock eastward in west-central Wyoming and into carbonate rock and phosphatic mudstone southward in Rich County, Utah (pl. 3 and fig. 1). It pinches out in northwestern Wyoming. The environment of deposition of the chert of the lower chert member was probably similar to that of the Rex chert member.

MEADE PEAK PHOSPHATIC SHALE MEMBER

By V. E. McKelvey

The phosphatic shale member of Richards and Mansfield (1912, p. 683)[5] is here named the Meade Peak phosphatic shale member of the Phosphoria formation. It derives its name from Meade Peak, the highest point on Snowdrift Mountain, about 2½ miles south of Phosphoria Gulch, and its type area is the same as that of the Phosphoria formation. The trench in which the phosphatic shale member of Richards and Mansfield was exposed no longer exists, but several sections near the former trench have been measured in recent years by Geological Survey field parties. The section described in table 3 is on the west flank of Snowdrift Mountain about 1 mile north of the section described by Richards and Mansfield. The zones and key beds described in this section are recognizable over almost all southeastern Idaho, although their composition and thickness vary locally because of the effects of deformation and weathering.

As shown by the description in table 3, the Meade Peak phosphatic shale member in its type area is composed mainly of dark carbonaceous, phosphatic, and argillaceous rocks. Mudstone and phosphorite are the chief end-member rock types; dark dolomite and limestone are subordinate types. Common mixed-rock types and distinctive textural varieties include both slightly and highly carbonaceous mudstone (the latter pyritic in fresh exposures); finely pelletal phosphatic mudstone; dense, structureless phosphorite, fine-grained pelletal phosphorite, oolitic phosphorite, pisolitic phosphorite, nodular phosphorite, and bioclastic phosphorite generally composed of fish scales or brachiopod shells; and finely crystalline argillaceous and phosphatic (pelletal) dolomite or limestone. The vertical sequence of these rocks in the type area is symmetrical—upper and lower halves are almost mirror images of each other (McKelvey, 1949, fig. 10). Thus, the sequence from the base upward consists of bioclastic phosphorite, mudstone, high-grade pelletal phosphorite becoming progressively more argillaceous upward, and slightly phosphatic mudstone; then the reverse sequence to the top of the member.

The Meade Peak phosphatic shale member is seldom exposed, but its position usually is marked by a swale between resistant rocks of the Grandeur tongue of the Park City and the Rex chert member of the Phosphoria. Near-surface sections generally show considerable effects of weathering: the rocks are soft and brown, or lighter, in color; carbonate rock is leached to mudstone; and nearly all the rocks are enriched in phosphate. Rocks in unweathered sections are uniformly dark gray or black, hard, and more calcareous and less phosphatic. The Meade Peak in southeastern Idaho ranges from 125 to 225 feet in thickness. Much of this variation may be the effect of deformation and weathering.

The Meade Peak thickens somewhat to the south and is about 300 feet thick in the central Wasatch Mountains, where it is split by a tongue of the Franson. It thins to the north, east, and southeast, and pinches out in southwestern Montana, western Wyoming, and eastern Utah (pl. 3). It also thins westward; in Cassia County, Idaho, it is about 85 feet thick. Its westernmost extent is unknown. A phosphatic shale unit, 50–

[5] The Montana and northwestern Wyoming part of this member was formerly known also as the B unit or member of the Phosphoria, the Utah part as the middle shale member of the Park City.

680 feet thick, believed to be laterally continuous with the Meade Peak, is present in several mountain ranges in western Utah and northeastern Nevada (Cheney and others, 1956, p. 1716–1719).

The Meade Peak also changes somewhat in lithology away from its type area. Dark carbonate rock progressively takes the place of mudstone and phosphorite southward to the central Wasatch Mountains. Eastward in central Wyoming the upper and lower parts pass into chert and carbonate beds, leaving a core of sandy phosphorite as the Meade Peak tongue (fig. 5). The unit thins northward and eastward from southwestern Montana, leaving sandy phosphorite as the last trace of the tongue in that area (fig. 6). In the Sublett Range of south-central Idaho, the member is mainly carbonaceous mudstone and contains only minor amounts of phosphorite (fig. 5). Finely pelletal phosphorites are most abundant in the type area, but oolitic, pisolitic, and bioclastic phosphorites are most abundant in fringe areas. Glauconite and fluorite are minor constituents of phosphorite in fringe areas.

In its type area, the lower and upper contacts of the Meade Peak are defined, respectively, as the base and top of the sequence of dark carbonaceous or phosphatic beds. Throughout southeastern Idaho and adjacent areas the lowest bed of the Meade Peak is a thin phosphorite bed containing abundant fish scales, bones, and small nodules. This bed is highly distinctive in appearance and generally is exposed or is conspicuous in float. The highest bed, seldom exposed, generally consists of a thin nodular phosphorite, commonly containing a gastropod resembling *Omphalotrochus*. Locally in southeastern Idaho the Meade Peak may include a foot or two of soft mudstone above this bed.

Eastward and southward from the type area, where the upper and lower parts of the member pass into cherty and carbonatic beds, the contacts are not always sharp. Zones of thin-bedded dark chert and carbonate rock, containing thin phosphorites in many places, separate typical Meade Peak from typical Grandeur and from Rex and Franson. In west-central Wyoming, the lower chert beds are thick enough to be recognized as a separate member; they are described in the previous section. Elsewhere, the assignment of the transitional beds is arbitrary at best, for they contain characteristics of both the Meade Peak and the Grandeur or Rex. Locally, mapping requirements may make some other course preferable, but, in general, our policy is to include transitional beds at the base in the Meade Peak, because they are more characteristic of the Phosphoria formation as a whole than they are of the underlying units, but to include transitional beds at the top in the Rex or Franson, with which the upper transitional beds are more closely allied lithologically.

The source of the Meade Peak sediments and the physical and chemical conditions attending their deposition have been subjects of much interest and discussion (see Blackwelder, 1915; Mansfield, 1927, p. 184–188, 361–367; Condit and others, 1928, p. 172–176; McKelvey and others, 1953; Cressman, 1955, p. 22–29; Sheldon, 1957, p. 146–154). The variety of rock types in the Meade Peak and their vertical and lateral sequences show that the environment of deposition was by no means uniform, either in time or in space. Moreover, the associations of the rocks indicate that some of the constituents of the Meade Peak were deposited over a significant range in depth (Cressman, 1955, p. 28). The fine grain of the mudstones, the high content of carbonaceous matter in many of them, the presence of pyrite, the lack of abrasion of their contained fossils (J. E. Smedley, written communication, 1955), and their general absence in fringe areas indicate that they were deposited below wave base at considerable distance from land and that reducing conditions prevailed on the bottom or in the unconsolidated bottom sediments. The range in texture and composition of the phosphorites, from unsorted pellets in carbonaceous mudstone to noncarbonaceous well-sorted coarse oolitic and pisolitic phosphorites that may contain abraded fossils (idem) or glauconite, suggests that they may have accumulated both above and below wave base and that the redox potential on the bottom may have been either positive or negative. According to Krumbein and Garrels (1952, p. 26), most of the phosphorites probably were deposited when the pH of the water was slightly less than 7.8 (Sheldon, 1957, p. 147), but the presence of phosphate in some carbonates suggests that phosphate deposition may also have taken place at a pH slightly above 7.8. The dark fine-grained limestones and dolomites, in contrast to the light-colored coarse-textured carbonates of the Park City, show little effect of wave action and most are interbedded with mudstones; they probably accumulated below wave base under reducing conditions at a pH above 7.8.

The lateral sequence of the Meade Peak member indicates that the depth of the Meade Peak sea decreased from central and eastern Idaho and southwestern Montana (where the Meade Peak contains much carbonaceous mudstone, fine-grained phosphorites, and little carbonate rock) to the north, east, south, and southwest (where the Meade Peak contains coarser grained phosphorites and proportionately more carbonate and less mudstone, and where it intertongues with light-colored carbonate, chert, and sandstone). The vertical sequence indicates that the sea increased in depth with time toward some maximum represented by the mudstones near the middle of the member, from which point it shoaled rather steadily. The interbedding indicates either that the vertical movement of the bottom was not a constant one or that the conditions affecting sedimentation, such as pH and turbulence, fluctuated, possibly as the result of climatic variations. The common interbedding of phosphorite and phosphatic mudstone, the vertical gradation of phosphate into phosphatic mudstone, the presence of silt and clay inclusions in apatite pellets of phosphorites that contain little or no detritus in the matrix, as well as the abraded character of the fossils in the phosphorite compared to those in the mudstone (Smedley, written communication, 1955), suggest that some of the high-grade phosphorites were formed as the result of reworking of phosphatic mudstones (Sheldon, 1957, p. 122), perhaps during storms.

The Meade Peak deposits are all probably of shallow-water deposition but the actual depth cannot yet be given with certainty. Kazakov (1937, p. 112) believed the zone of phosphorite deposition to be below the zone of photosynthesis, probably at depths of 50 to 200 meters. The fine grain of many phosphorites, the presence of fine-grained pellets in carbonaceous mudstone, the general absence of wave marks and crossbedding in the Meade Peak, and the common occurrence of phosphatic sediments at depths of 400 to 1,000 meters on the present sea bottom (Twenhofel, 1932, p. 555) indicate (McKelvey and others, 1953b, p. 59) that the zone of phosphorite formation might have been somewhat deeper, possibly between 200 and 1,000 meters. Rogers and others (1956) and Van Vloten (1955, p. 137) have presented physical and faunal evidence, however, indicating that the phosphorites of the somewhat similar La Caja formation in Zacatecas, Mexico, formed in much shallower water. A similar conclusion was reached with respect to the Meade Peak by Mansfield (1927, p. 365), Condit and others (1928, p. 172), and Honkala (1953), who suggested that the lenticular character of the main phosphate bed of the Meade Peak in the Centennial Mountains and its lateral gradation over short distances from a coquina of *Lingulidiscina* to leanly phosphatic quartz sand imply deposition along a beach. Smedley (written communication, 1955) also has concluded, mainly because of the presence of *Lingula* and related brachiopods, that some Meade Peak sediments were deposited in water less than 40 meters deep. Because some beds of the Meade Peak were deposited in extremely shallow water, it seems best to reserve final judgment on the range in depth over which the rocks of the Meade Peak were deposited until the relationships of the Meade Peak sediments and fauna to those found on the present ocean bottom are more fully analyzed. In the meantime, the data now available serve to indicate the relative depth at which the major types of sediments were deposited (Cressman, 1955, p. 28).

The Meade Peak provides good clues to the physical and chemical nature of the bottom on which the sediments were buried but their sorting suggests that some may have been formed elsewhere. The phosphatic shells in the "bars" described by Condit and others (1928, p. 172) were obviously formed elsewhere, and the carbonaceous matter may also have been transported by surface currents seaward from its zone of formation (McKelvey and others, 1953b, p. 60). It is possible that much of this carbonaceous matter was formed by the same organisms that secreted the silica and carbonate now preserved in other parts of the Phosphoria. Thus, the lateral zonation of sediments within the Phosphoria may have originated, at least in part, in the physical sorting, by wave action and currents, of biochemical and chemical precipitates formed in a less heterogeneous surface-water environment than might be imagined on first thought. In this connection, it should be noted that although the bottom of the Meade Peak sea may have been "foul," the upper waters were of optimum character most of the time for the growth of organisms. The mass mortalities described by Brongersma-Sanders (1948) as occurring in modern upwelling waters once or twice during the summer indicate, however, that at times surface waters also were unfavorable for the existence of larger organisms.

Considering now the source and mode of precipitation of the sediments of the Meade Peak, it seems likely that the phosphate, carbonaceous matter, and other chemical sediments were derived, as Kazakov (1937, p. 111) first postulated, from cold oceanic waters upwelling onto a shoaling bottom (see also Macpherson, 1945, p. 34–41). Such waters are rich in phosphate, nitrogen, and carbon dioxide and have a relatively low pH. As they are warmed, their carbon dioxide content decreases, their pH rises, and they approach and reach saturation, first with respect to calcium fluorophosphate and then with respect to calcium carbonate (McKelvey and others, 1953b, p. 59). The abundant nutrients literally fertilize the sea and stimulate growth of tremendous blooms of plankton and nekton. The organic productivity of these waters is abetted, perhaps even permitted, by the saturation or near-saturation of the water with nutrient elements, for it reduces the competition that organisms must wage with hydrogen ions in the acquisition of their constituent elements. (The effects of such competition may be observed by comparing the abundance and character of calcium carbonatesecreting invertebrates in the cold and warm waters of the Atlantic). Organisms were, of course, the source of the carbonaceous matter in the Meade Peak; they are also plainly the source of some phosphorite. The fish-scale beds, for example, may have originated in mass-mortalities of fish (Blackwelder, 1915) which are a common feature of areas of upwelling (Brongersma-Sanders, 1948), but the distribution of these beds in the Meade Peak in the vertical or lateral sequence of sediments suggests that such mass-mortalities were restricted to shallower water and that they did not contribute directly to the formation of other phosphorites.

In addition to the phosphate in the bioclastic beds, it is possible that some of the phosphate now in the form of cement and in pellets, oolites, and nodules was first precipitated organically. Several authors (Branner and Newsom, 1902; Moore, 1939; Dietz and others, 1942, p. 839) favor a fecal origin for the pellets, but if the pellets were formed by excretion they probably were formed by deposit-eating organisms that merely shaped preexisting sediment (Moore, 1939). Van Vloten (1955, p. 141) postulates that organic phosphorus is resorbed by bottom water on the decay and disintegration of organisms and precipitated into concretions if the concentration of phosphate is high enough. The replacement of some calcerous and siliceous skeletal matter in the Phosphoria shows secondary migration and deposition of phosphate, but the presence of interfering pellets, of pellets clearly formed in place in the rock, and of apatite cement is clear evidence that some, perhaps most, of this secondary migration and deposition took place diagenetically (Sheldon, 1957, p. 123).

The fine-grained, structureless phosphorites probably were the products of direct chemical precipitation and some or much of the phosphate in the colloform phosphorites may be reorganized chemical precipitate. The dark fine-grained carbonates are also probably direct chemical precipitates, though the presence of laminated argillaceous limestone lenses indicates that penecontemporaneous migration and redeposition may have played an important part in their origin. The fine-grained dolomites may have been formed by penecontemporaneous action of sea water on unconsolidated lime muds, as shown by the concentration of dolomite in the upper part of some layers (R. A. Gulbrandsen, oral communication); diagenetic movement of interstitial water from compacting muds below may have been a contributory source of magnesium.

A prerequisite to the formation of a phosphorite formation like the Meade Peak is the nondeposition of diluting carbonates (Rubey *in* McKelvey and others, 1953b, p. 59) and clastics (Kazakov, 1937, p. 103). The sand in rocks of Phosphoria age in Montana seems to have come from all sides of the basin in that area (Cressman, 1955, p. 23) and the fine-grained detritus in the Meade Peak probably did also. The surrounding lands, however, must have been low and it is not unlikely that an arid climate prevailed, as it does in many similar areas of upwelling (Brongersma-Sanders, 1948, p. 95).

In conclusion, the sediments of the Meade Peak probably accumulated on a gently shoaling bottom that received cold, phosphate-rich waters from the open ocean. The general setting of the Meade Peak sea probably was analogous to that in some of the modern areas of upwelling (Brongersma-Sanders, 1948, p. 19–34). The distribution of the Meade Peak and its shoalward facies suggests, however, that it was deposited in a large embayment, and that its environment was more similar to that in the Arabian Sea than to that of areas of upwelling along the western margin of the continents.

REX CHERT MEMBER

By V. E. McKelvey

According to Richards and Mansfield (1912, p. 684), "the name of the Rex chert member is derived from Rex Peak in the Crawford Mountains, Rich County, Utah. * * * This locality has been described by Gale * * * and the selection of the name for the member was originally made by him." Neither Gale nor Richards and Mansfield, however, published a description of a section of the Rex from the Crawford Mountains; the only section of the Rex described by Richards and Mansfield is one measured in sec. 12, T. 10 S., R. 44 E., a few miles west of Phosphoria Gulch. Because Richards and Mansfield chose to describe the section near Phosphoria Gulch (which has chert as the dominant constituent), in preference to the Crawford Mountain section (where beds of Rex age are mainly carbonate rock), it is reasonable to assume that they intended that the Phosphoria Gulch area be the type locality of the Rex chert member as well as of the Phosphoria formation as a whole. Adoption of the alternate interpretation—that they meant Rex Peak to be the type locality of the Rex—would require displacing the name "Rex" with a new name for the chert member in southeastern Idaho, if the usual rules of stratigraphic nomenclature were adhered to strictly. Because the Rex is known internationally as the name of the main chert in the Phosphoria, its displacement by a new name seems undesirable.

Richards and Mansfield (1912, p. 684) described the Rex of the Phosphoria Gulch area as consisting of

100 feet of gray limestone and black chert in the lower part,[6] 60 feet of red-stained black chert in the middle, and 80 feet of dark cherty shale in the upper part. The latter unit has been recognized over a wide area and in recent reports has been separated from the Rex and termed "the upper shale member" (McKelvey, 1949, p. 272). The separation is continued here. The name "Rex" is restricted to the hard resistant dark chert above the Meade Peak phosphatic shale member.

In the type area and at most other localities where the Rex is exposed it includes a wide variety of cherty rocks that range from almost pure vitreous translucent chert to impure dull opaque chert to mudstone, phosphorite, and carbonate rock that contain discrete masses of chert. Major impurities in the chert are argillaceous and carbonaceous matter, quartz sand, calcite, dolomite, or apatite; minor impurities include pyrite or glauconite. The rocks of the Rex range in color value (lightness) from black to nearly white; intermediate shades are mostly low in chroma. The bedding of the cherts ranges from even to wavy or lenticular and from an inch to as much as 2 feet in thickness. Some beds are structureless (massive) but many are composed of lenses, elliptical nodules, cylindrical masses, or highly irregular masses. The cylindrical masses are either parallel to each other and steeply inclined with respect to the bedding planes, or nonparallel and flat lying; the latter type gives bedding surfaces a fucoidal appearance. Some of the chert beds contain sparse to abundant sponge spicules (Keller, 1941, p. 1292; Cressman, 1955, p. 11) which are composed of chalcedony or microcrystalline quartz and which range in preservation from poor to good; they can be seen with a hand lens or even with the naked eye. Many other beds have spicules that are visible under high magnification or dark-field illumination; still other beds contain no recognizable organic remains. Stylolites, some with a vertical relief of 4 inches, are present in many beds, particularly in relatively pure spicular cherts.

Three sections of the Rex and upper shale in the Phosphoria Gulch area have been measured recently; the units described in table 3 are recognized in all of them. The cherty mudstone zone, 10 to 15 feet thick, in the middle of the Rex is probably an eastern tongue of the cherty shale member; it is not found in adjacent areas, where the Rex consists of an uninterrupted sequence of chert. The basal zone containing lenses and layers of carbonate is recognizable at most localities in southeastern Idaho, though it ranges in thickness from 5 to 65 feet.

[6] More recent work shows limestone to be a subordinate component of the Rex, even in the Phosphoria Gulch area (table 3).

Extensive lenses of coarse light-gray bioclastic limestone occur near the middle of the Rex at several localities in southeastern Idaho, notably Wood Canyon, North Stewart Canyon, Timber Creek, Deer Creek, Sage Creek, South Canyon, and the ridge north of Hot Springs. These lenses are as much as a mile in outcrop length and range from 0 to as much as 50 feet in thickness; northwest of Timber Creek they seem to constitute nearly the whole of the Rex interval. Their lithology is highly distinctive and closely resembles that of the Franson member of the Park City in western Wyoming; no observations suggest they were ever physically continuous with the Franson, but they are outliers of the same facies.

Northward, eastward, and southward from its type area the upper part of the Rex chert member passes into carbonate rock of the Franson member of the Park City formation. The lower part of the Rex persists as far as southwestern Montana, western Wyoming, and north-central Utah, where it also passes into carbonate rock of the Franson. A few miles west-northwest of the type area the Rex passes into cherty mudstone (designated as a separate member), which composes the entire upper part of the Phosphoria formation in the Portneuf quadrangle and the Fort Hall Indian Reservation. In the Sublett Range area of south-central Idaho, however, thick beds of hard resistant chert are interbedded with cherty mudstone above the Meade Peak (figs. 3, 4, and 8). The chert in the Sublett Range was probably once continuous with the chert of southeastern Idaho in a semicircular belt extending around southern Idaho and northern Utah and parallel to the strike of other facies in that area (Cheney, 1955, fig. 2; 1957, p. 17–19); hence, it also is designated Rex.

The upper and lower boundaries of the Rex correspond to the limits of hard resistant chert. The lower contact is formed by rocks progressively older eastward from the type region, and the upper contact is formed by rocks progressively older to the north and to the south (pl. 3).

The problem of the environment of deposition of the Rex cannot be considered without reference to the source of the silica and the manner of formation of the chert. Microcrystalline quartz and chalcedony, which largely compose the cherts of the Phosphoria, form by progressive reconstitution of amorphous opaline silica (Lawson, 1914, p. 5; Pettijohn, 1949, p. 324). A wide variety of sources of the silica has been proposed[7] but there seems general agreement that sea

[7] For a more comprehensive review of the different theories presented on the origin of chert than can be given here, the reader is referred to Davis (1918, p. 292, 343 et seq.), Rubey (1929, p. 165), Tarr and Twenhofel (1932), Bramlette (1946, p. 41) and Pettijohn (1949, p. 328–332).

water was the immediate source of the amorphous silica from which the extensive bedded cherts were formed. Some writers believe that the sea was enriched in silica derived from a local source such as submarine lava flows (Lawson, 1895, p. 425–426; Davis, 1918, p. 383–384, 402–404; Taliaferro, 1933, p. 52) or volcanic ash, which in places is associated with the chert (Rubey, 1929, p. 166–169; Bramlette, 1946, p. 39–41). Others (for example, Tarr and Twenhofel, 1932, p. 525) believe the silica to be derived from chemical weathering of the continents. Most of the authors cited believe that the bulk of the silica was deposited by direct chemical precipitation, but Bramlette and many earlier writers have shown that in some deposits the silica was precipitated by organisms and rearranged later by diagenetic processes. Significant evidence has been presented recently on this subject by Krauskopf (1956), who finds that the sea is so far undersaturated with silica that its direct chemical precipitation under normal conditions today is impossible.

Meager traces of volcanic material have been found in the Phosphoria. Weaver (1955, p. 168) reported the occurrence of some lath-shaped quartz grains and suggests they may be paramorphic after tridymite. Gulbrandsen (1958) found an expandable clay mineral in a single sample, and Sheldon (written communication, 1956) reported a bed of phosphatic siltstone that contains abundant sand-size broken crystals of zoned plagioclase. But the volume of this volcanic material appears small and thus the source of the silica in the cherts of the Phosphoria cannot reasonably be assigned to local volcanism or to tuffs deposited in the basin of deposition. It seems more likely that the silica in the Phosphoria was that normally dissolved in the sea. The largest amounts of silica in the sea now are in the cold waters which are also rich in phosphate and nitrogen (compare Sverdrup and others, 1946, figures 47, 48, 52, 53, 54, 55, and 198). Moreover, some of the areas of large and frequent diatom blooms are the areas of phosphate-rich upwelling water (Brongersma-Sanders, 1948, p. 20–21) previously mentioned in connection with the origin of the phosphate deposits (p. 24). In other formations as well as in the Phosphoria the close association among bedded chert, phosphorite, and black shale (Pettijohn, 1949, p. 332; McKelvey and others, 1953b, p. 61) makes it seem probable that the rocks of this association are genetically related and that the common denominator is the nutrient-rich water from which they are derived.

Although diagenetic rearrangement of the silica in the Rex accounts in large measure for the form of the chert now, the carbonate rocks interbedded with chert at certain horizons (the bioclastic coarse-textured limestone lenses, for example) and the carbonate beds in the lower part of the Rex in southeastern Idaho, indicate that the silica did not migrate across layers to any appreciable extent (Keller, 1941, p. 1293). Field examinations of such strata give the impression that the silica within individual layers or zones, even though it is in replacement relation to the enclosing rock or shows other evidence of reorganization, was derived from silica originally dispersed within those layers or closely adjacent ones.

According to M. W. de Laubenfels (oral communication, 1957), who examined many thin sections of cherts from the Phosphoria, nearly all the spicules in the Phosphoria were derived from sponges of the class Demospongia and from species that probably lived in waters less than a few tens of meters in depth. Although sponges may grow on spicule oozes, they generally require a firm point of attachment. The uniform size of the spicules within each chert specimen and their commonly observed uniform orientation suggest that they have been subjected to considerable current action which may have transported the spicules from another environment to the area in which the Rex accumulated (Cressman, 1955, p. 27; Bramlette, 1946, p. 9–10, 13). The greater effect of winnowing processes during marine regression, may explain the deposition of the Rex (and of most other large masses of chert associated with phosphorite formations) during the regressive phase of the depositional cycle described on page 5. As with other rocks of the Phosphoria, it is difficult to estimate exactly the depth of deposition, but probably it was below wave base, and intermediate between that at which most of the phosphatic mudstone and most of the sandstone and bioclastic carbonate rocks accumulated (Cressman, 1955, p. 28).

The evidence presented by Bramlette, Krauskopf, and others, and the abundance of spicules in many cherts in the Rex, suggest that the nondetrital silica was precipitated by organisms and subsequently rearranged by diagenetic processes after burial. The important role of these diagenetic processes in the formation of the chert as we see it today is shown by the fact that even the rocks that on first inspection seem wholly composed of sponge spicules contain a larger amount of silica in the matrix and in spicule canal-fillings than in the spicules alone; by the abundance of irregularly bedded, lenticular, and nodular chert; by the presence of lenses and irregular nodules and masses of chert, many of which are plainly replacements, in other rock types; and by the presence of stylolites in spicular cherts. It seems unlikely that the larger spicules (megascleres) supplied much of this matrix and replacement silica, particularly in the spongoliths in which they are so well preserved (see Rubey, 1929, p. 167, with respect to Radiolaria); but the silica may have been derived from microscleres—small spicules typically present in sponges, but never observed in cherts of the Phosphoria (M. W. de Laubenfels, oral communication, 1957)—or from other silica-precipitating organisms whose remains have been totally destroyed. Paragenetic relationships seen in the field show that some of the redistrbution of silica took place before lithification, and some took place later—a relation also found in the Monterey formation of Miocene age in California (Bramlette, 1946, p. 50–51).

The presence of carbonaceous matter and pyrite in some cherts and their relative absence in others indicate that the redox potential of the bottom on which the chert accumulated may have been either positive or negative (Sheldon, 1957, p. 151). The intimate association of chert with both apatite and carbonate shows that the silica accumulated over at least a moderate range of pH, an observation in accord with the recent findings of Krauskopf (1956) that pH has little effect on the solubility of amorphous silica.

CHERTY SHALE MEMBER

By V. E. McKelvey

In the area between the Blackfoot River Reservoir and Fort Hall, Idaho, the Phosphoria formation above the Meade Peak member consists of about 500 feet of nonresistant thin-bedded black (brown or yellowish-brown where weathered) cherty mudstone, mudstone, and subordinate thin-bedded argillaceous chert. These rocks were formerly classed as Rex by Mansfield (1929, p. 29), but because they are much different from the hard, resistant chert of the Rex,[8] they are assigned to the cherty shale member. The best exposure of this member is on the east side of Grizzly Creek, sec. 30, T. 5 S., R. 40 E., where numerous outcrops and much float are found in the lower half of the member. A completely exposed section is not yet known in this area.

The lithology of the cherty shale is not as well known as that of the other units because of poor exposures in the area of its major development. The mudstone, which makes up a large part of the unit, is harder, more siliceous, and less carbonaceous than that of the Meade Peak. The chert is mostly thin-bedded and argillaceous. The cherty mudstone is thin-bedded and hard; its siliceous nature is due to disseminated chert and to quartz silt, which is much more prominent than microcrystalline quartz and chalcedony in some thin sections. Joint surfaces of the cherty mudstone are often etched in a manner resembling stylolites of low relief; no bedding-plane stylolites, however, have been observed.

Because the cherty shale member is not well exposed in most localities, its stratigraphic relationships are not completely known. The lower part of the member intertongues with and grades laterally into the hard Rex chert member both eastward and westward from its typical area (figs. 1, 5) but the upper part extends as a tongue above the Rex over much of southeastern Idaho. Chert and cherty mudstone in the Retort member in western Wyoming may represent a still more easterly extent of this facies, and soft noncherty mudstone and phosphorite in the upper part of the interval in the Aspen Range area represent westerly tongues of the Retort. In the Big Sheep Canyon area of southwestern Montana the cherty mudstone that overlies the Retort and intertongues with the Tosi chert member toward the east, north, and west (pl. 3) is believed to be a northward extension of the upper part of the cherty mudstone of southeastern Idaho.

The differences between the cherty shale member and the Retort are subtle and gradational; in fact, because both are shaly units they might be grouped under the same name. They are separated, however, because they differ in total aspect. The cherty shale contains more chert, less carbonaceous matter, and less phosphate and is more resistant to weathering than the Retort; moreover, it might be a disservice to those interested in the economic value of the rocks to group the cherty shale member, a good source of road metal but not of phosphate or oil shale, with the Retort, which has much phosphate and oil shale but no road metal.

The lower contact of the cherty shale is placed at the top of the hard chert of the Rex where the latter is present. Where the Rex is absent, the lower contact is not exposed, though it can be located approximately by a minor break in slope at the top of the soft rocks of the Meade Peak. The upper contact in the Portneuf-Fort Hall area is nowhere exposed. In eastern Caribou and Bear Lake Counties a tongue of the Retort, consisting of 10 to 30 feet of soft carbonaceous mudstone, dolomite, and two thin phosphorite beds (one at the other near the top) overlies the cherty shale member. The contact of the two is not exposed; although the separation can be made arbitrarily at the top of the uppermost cherty mudstone or chert where the beds are exposed artificially, the tongue of the Retort must be grouped with the cherty shale in mapping.

[8] Mansfield (1929, p. 29) noted that "the principal exposures show the flinty shale that is characteristic of the [Rex] member in much of the general region, but locally, as in sec. 10, T. 6 S., R. 39 E., the chert forms massive ledges." The hard chert in the area named bears little resemblance to the Rex in other areas. It seems likely that it is not Rex at all but silicified fault breccia within the Brazer limestone of Mississippian age.

Because the cherty mudstone is, in part, a basinward facies of the Rex, it probably was deposited in somewhat deeper water than the Rex. The absence of coarse-textured partings and the uniformly fine-grained size indicate that the bottom was continuously below wave base. The presence of carbonaceous matter suggests accumulation under slightly reducing or only weakly oxidizing conditions, possibly in waters too cold for the precipitation or accumulation of appreciable amounts of phosphate and carbonate.

RETORT PHOSPHATIC SHALE MEMBER

By R. W. SWANSON

The upper phosphatic shale member of the Phosphoria formation, provisionally called the D member in recent preliminary reports on areas in Montana and Wyoming, is here named the Retort phosphatic shale member after Retort Mountain in section 23, T. 9 S., R. 9 W., about 10 miles south of Dillon in Beaverhead County, Mont. A natural exposure of the Retort which occurs near the head of Small Horn Canyon just northwest of Retort Mountain is designated the type locality. One and one-half miles to the north in section 14 the shale horizon was prospected for coal by a 150-foot tunnel, and from this tunnel Bowen (1918) obtained a sample that yielded on dry distillation 24 gallons of oil to the ton. Condit (1919, p. 23) noted that a retort capable of treating 50 tons of shale per day was being installed. No significant production was obtained and only the foundations of the old retort remain today.

At its type locality the Retort phosphatic shale member is 60 feet thick and consists of a sequence of thin-bedded soft dark brownish-gray carbonaceous mudstone and pelletal phosphorite (table 4). These two lithologic types occur together in nearly all proportions. Some beds are moderately calcareous; many yield on distillation a significant quantity of oil, nearly 10 percent by weight of some samples. At this locality the Retort phosphatic shale member can be divided into three principal zones: a lower phosphatic zone 26 feet thick; a middle, somewhat calcareous mudstone 15 feet thick, the lower 10 feet of which includes the richest oil shale beds; and an upper phosphatic zone 19 feet thick. These three zones are identifiable in southwest Montana over a considerable area south of Dillon, though correlation of boundaries is questionable and phosphate and oil yield are lower than at the type locality. Thin beds of dark carbonate rock occur locally but seldom can be traced from one locality to another. The thickness of the member in this area ranges from 55 to 80 feet, and both bottom and top contacts appear conformable; the top contact is commonly gradational and the bottom contact is occasionally so. Northward from Retort Mountain the Retort thins progressively to about 30 feet near Melrose, 20 feet near Philipsburg, 10 feet near Maxville, and 3 to 5 feet in the Garrison region where it is composed almost wholly of phosphorite. East of the Ruby River the member thins abruptly to generally less than 10 feet, though locally it is as thick as 15 feet, and in the Centennial Mountains it is about 20 feet thick. In many of these areas conglomeratic material occurs at the base, and the lower part of the member is absent; the contact is accordant, however. The contact with the Tosi chert member in these areas is generally somewhat gradational and in some areas the two members intertongue.

TABLE 4.—*Generalized stratigraphic section of the Retort phosphatic shale member near Retort Mountain, SW¼ sec. 23, T. 9 S., R. 9 W., Beaverhead County, Mont.*[1]

	Ft
Tosi chert member of the Phosphoria formation (lower bed only):	
Sandstone, phosphatic	0.8
Retort phosphatic shale member of the Phosphoria formation:	
Mudstone, phosphatic, soft, dark brownish-gray	4.5
Mudstone, soft, dark brownish-gray	4.0
Mudstone, phosphatic, and argillaceous phosphorite, soft, dark brownish-gray	4.5
Phosphorite, argillaceous, and mudstone, soft, dark brownish-gray to black	5.65
Mudstone, medium-hard, brownish-black, fissile	5.9
Mudstone, medium-hard, brownish-black, fissile; yields about 15 gal of oil per ton	9.55
Phosphorite, argillaceous, soft, dark-brown, thin-bedded	4.1
Phosphorite, argillaceous, and mudstone, medium-hard, dark brownish-gray; upper 6½ ft yields about 10 gal of oil per ton	15.3
Mudstone and phosphorite, medium-hard, dark brownish-gray	6.4
Total thickness of Retort phosphatic shale member	59.9
Franson tongue of the Park City formation (upper bed only):	
Sandstone, argillaceous	2.9

In the Jackson Hole region of Wyoming the Retort phosphatic shale member is generally 35 feet or less in thickness. It thins markedly to the north, probably in large part by a facies change to chert, and to the southwest in adjacent Idaho where it intertongues with and grades laterally into the cherty shale member. Southward in Wyoming it maintains a fairly constant thickness of 25 to 30 feet but it thickens westward to nearly

[1] See Swanson and others, 1953a, p. 16, for more detailed description and analyses of beds.

60 feet in Sublette Ridge near the Idaho border. A thin tongue is recognized above the cherty shale in southeastern Idaho. Eastward from the Jackson Hole region the Retort thickens to 55 or 60 feet in the Wind River Mountains. Interbeds of both chert and carbonate rock are common. In most of the Wyoming area the upper and lower contacts of the Retort appear to be conformable.

The Retort phosphatic shale member contains rocks similar to those of the Meade Peak, although the proportions of these rocks are different; in general the proportion of dark mudstone and siltstone to dark dolomite and phosphorite is greater in the Retort. The sedimentation and depositional environments described for rocks of the Meade Peak also apply for rocks of the Retort. An important difference, however, is the configuration and location of the basin of deposition. The Retort basin was situated farther north and east than the Meade Peak basin; thus, the Retort is of maximum thickness in northwestern Wyoming and southwestern Montana and is the only phosphatic shale in the northern and east-central parts of the field, but it is absent in northeast Utah where the Meade Peak is well developed. The Retort thins to the west so that in the Salt River and Caribou Ranges it is only a few feet thick and is in places represented by only a thin nodular phosphorite. West of this the unit thickens and grades into the cherty shale member. Thus, it seems possible that the sea at this time was split into two basins by a linear submarine high near the present Salt River and Caribou Ranges.

TOSI CHERT MEMBER

By R. P. Sheldon

The widespread thin dark- to light-colored chert beds that lie above the Retort phosphatic shale member of the Phosphoria formation in Wyoming, Montana, and in a limited area in Idaho and Utah, are here designated the Tosi chert member of the Phosphoria formation. The type locality is at Tosi Creek, Sublette County, Wyo., on the east nose of the Tosi Creek anticline. The member is well exposed along the banks of Tosi Creek.

At the type locality the Tosi member is 33 feet thick. It is composed of a lower brownish-gray to brownish-black chert unit, 25 feet thick, that contains abundant columns of chert several inches in diameter and 1–2 feet long, oriented obliquely to the bedding; and an upper light-gray sandy chert unit, 8 feet thick. A detailed section is given in table 5. The member grades from the Retort below, the gradation zone consisting of interbedded fissile mudstone and thin-bedded chert. The contact with the upper tongue of the Shedhorn is also gradational. The Tosi chert is a resistant unit which forms ledges and cliffs; at the type locality on Tosi Creek it forms a series of small waterfalls and riffles.

Table 5.—*Type stratigraphic section of Tosi chert member of the Phosphoria formation at Tosi Creek, SE¼ sec. 17, T. 39 N., R. 110 W., Sublette County, Wyo.*

[Section measured by M. A. Warner in 1950 (Sheldon and others, 1953, p. 18)]

	Ft
Upper tongue of the Shedhorn sandstone (lower bed only):	
Sandstone, cherty, carbonaceous, hard, light-gray, massive; sand is very fine grained; gradational contact with unit below	2.5
Tosi chert member of the Phosphoria formation:	
Chert, sandy, contains glauconite and collophane grains, hard, light-gray, thin-bedded; sand is very fine grained and well sorted	2.1
Chert, medium crystalline, hard, light-gray, thin-bedded; bedding planes are undulant	2.8
Chert, medium crystalline, brecciated, hard, medium-gray, thick-bedded; bedding planes are undulant	3.1
Chert, dolomitic, hard, brownish-black, thick-bedded; bedding planes are undulant	4.2
Chert, dolomitic, hard, brownish-gray, thick-bedded; contains silt; bedding planes are undulant	14.0
Chert, hard, brownish-gray, thick-bedded	4.1
Chert, hard, brownish-gray, thin-bedded; grades from unit below	2.4
Total thickness of Tosi chert member	32.7
Retort phosphatic shale member of the Phosphoria formation (upper beds only):	
Dolomite, argillaceous, medium-hard, dusky-brown, thin-bedded	2.0
Phosphorite, cherty, finely pelletal, hard, brownish-black, thin-bedded	.2

The Tosi chert is a prominent member of the Phosphoria formation in southwestern Montana and northwestern Wyoming, and has been included in the E unit or member in recent reports on that area. It is also the most extensive tongue of the Phosphoria formation in the Park City formation in central Wyoming and in the Shedhorn sandstone in Wyoming and Montana. Southwest of the type locality the Tosi grades into dark-gray mudstone which is included in the Retort phosphatic shale member of the Phosphoria formation. North of the type locality the unit thickens to about 40 feet in Yellowstone Park and to as much as 145 feet in western Beaverhead County, Mont. In southwestern Montana, in the Big Sheep Canyon area, the Tosi grades into the cherty shale member. The Tosi extends also to the southeastern Wind River Mountains, where at Baldwin Creek it is about 70 feet thick; to the Conant Creek anticline; and to the Owl Creek Mountains, Wyo., where it is about 15 feet thick. At Brazer Canyon, Rich County, Utah, the Tosi is about 40 feet thick.

The Tosi chert contains intercalated beds of mudstone, sandstone, carbonate rock, and a few thin phosphorites. The lower part of the Tosi chert member grades from the Retort phosphatic shale member. The contact progressively falls to lower horizons north and east of Tosi Creek, and in the vicinity of Yellowstone Park the Tosi is separated from the lower member of the Shedhorn sandstone by a phosphorite bed 0.5 foot thick. The Tosi chert member of the Phosphoria is overlain by the Dinwoody formation of Triassic age in the Wyoming Range in Wyoming and in western Beaverhead County, Mont. At Brazer Canyon, Utah, it is overlain by a thin tongue of the Franson. East and north of these areas the Tosi is overlain by units of the Shedhorn and Park City formations. In the Teton and Gros Ventre Ranges, in Yellowstone Park, Wyo., and in southwestern Montana, exclusive of western Beaverhead County, the upper member of the Shedhorn sandstone overlies the Tosi. In the Owl Creek and Wind River Mountains and in the Conant Creek anticline, Wyoming, the Ervay member of the Park City formation overlies the Tosi. What has been said about the depositional environment of the Rex chert member applies also to the Tosi chert member.

SHEDHORN SANDSTONE

By E. R. Cressman and R. W. Swanson

The dominantly sandy rocks of Phosphoria age within Yellowstone National Park and adjacent parts of southwestern Montana and northwestern Wyoming are named the Shedhorn sandstone for Shedhorn Creek in the Madison Range of Montana. The type section is exposed in cliffs on the north side of Indian Creek (table 6; fig. 6, section 4).

Table 6.—*Stratigraphic section of the Shedhorn, Phosphoria, and Park City formations measured in SW¼ sec. 20, T. 8 S., R. 2 E., Madison County, Mont., about ¼ mile west of mouth of Shedhorn Creek*

[Measured by J. A. Peterson and R. F. Gosman in 1951 (Peterson, Gosman, and Swanson, 1954, p. 25) and by R. W. Swanson in 1956]

	Ft
Dinwoody formation (lower beds only):	
Carbonate rock (probably largely dolomite), hard, thick-bedded, dense, pale-brown; weathers to darker brown; basal 0.5 ft shaly to sandy; contact sharp but gently transgressive	40.0
Upper member of the Shedhorn sandstone:	
Sandstone, hard, thick-bedded, fine-grained, pale-brown; contains small chert nodules and thin streaks of very finely sandy to cherty carbonate rock; top 1 ft light gray; thin lenticular layer of light bluish-gray chert at top	12.8
Chert, hard, wavy-bedded, white	1.0
Sandstone, hard, massive, fine- to medium-grained, light brownish-gray; contains nodules and columns of yellowish-gray chert	5.6

Table 6.—*Stratigraphic section of the Shedhorn, Phosphoria, and Park City formations measured in SW¼ sec. 20, T. 8 S., R. 2 E., Madison County, Mont., about ¼ mile west of mouth of Shedhorn Creek*—Continued

	Ft
Upper member of the Shedhorn sandstone—Continued	
Chert and sandstone interbedded: hard, sandy, very spicular white chert dominant in middle; sandstone is hard, fine grained, very pale brown and contains many dark grains	1.8
Sandstone, hard, massive, fine- to coarse-grained, light brownish-gray; contains lenses and flat pebbles of dense carbonate rock, silicified fossils, and many dark grains of phosphorite	6.5
Chert, thin- to thick- and wavy-bedded, light brownish-gray; contains concentric banded columns; top part shaly to carbonatic	6.4
Chert and sandstone: fine-grained sandstone underlain by laminated white chert	1.0
Sandstone, hard, massive, fine-grained, pale-brown; contains dark phosphorite and solid hydrocarbon(?) grains, and columns of chert	28.4
Total thickness of upper member of the Shedhorn	63.5
Tosi chert tongue of the Phosphoria formation:	
Chert, thin- to medium-bedded, dark-gray; grades upward to thicker brownish-gray beds in top 10 ft	42.0
Retort phosphatic shale tongue of the Phosphoria formation:	
Phosphorite, mudstone, and carbonate rock interbedded; medium-hard, dark brownish-gray; phosphorite pelletal to oolitic; basal bed contains fluorite	6.5
Lower member of the Shedhorn sandstone:	
Sandstone, hard, thick-bedded, fine- to medium-grained; basal part sandy carbonate rock with many sandstone columns	4.1
Chert, thin-bedded, brownish-gray; may be a tongue of the Rex chert	2.4
Sandstone, hard, massive, fine- to medium-grained, light brownish-gray; contains chert concretions and quartzite pebble zone in lower third; some chert concretions are columnar	9.3
Mudstone, sandy, soft, fissile to thin-bedded, pale-brown	4.0
Franson tongue of Park City formation:	
Carbonate rock (dolomite?), sandy, hard, massive, finely crystalline, yellowish-gray; contains phosphatic shell fragments and chert, quartzite, and carbonate rock pebbles at several horizons; some chert pebbles rich in sponge spicules; basal contact irregular	7.5
Lower member of the Shedhorn sandstone:	
Sandstone, carbonatic, hard, massive, fine-grained, yellowish-gray; contains phosphate as pellets and shell fragments	14.2
Chert, locally sandy, laminated to massive, yellowish white; thin beds of hard fine- to medium-grained very pale brown sandstone containing phosphatic shell fragments are present in lower half; may be a tongue of the Rex chert	6.0

TABLE 6.—*Stratigraphic section of the Shedhorn, Phosphoria, and Park City formations measured in SW¼ sec. 20, T. 8 S., R. 2 E., Madison County, Mont., about ¼ mile west of mouth of Shedhorn Creek*—Continued

	Ft
Lower member of the Shedhorn sandstone—Continued	
Sandstone, hard, thick-bedded, fine-grained, yellowish-gray; contains thin layers of laminated carbonate rock	2.9
Chert, sandy, laminated, spicular, yellowish-white; contains laminae of cherty sandstone; thin layers of fine-grained sandstone contain phosphate as pellets, spicule canal fillings, and shell fragments; may be a tongue of the Rex chert	3.9
Sandstone, hard, thick-bedded, fine-grained, yellowish-gray; contains grains of spicular chert and light-brown phosphate; thin carbonate layers near base, and small chert and quartzite pebbles at middle	1.0
Total thickness of lower member of Shedhorn sandstone, including Franson tongue of Park City formation	55.3
Grandeur tongue of the Park City formation:	
Dolomite, hard, massive, dense, yellowish-gray	2.7
Sandstone, hard, massive, cross-bedded in part, fine-grained, pale-orange; contains streaks of coarse-grained sand	4.5
Dolomite, hard, massive, finely crystalline, yellowish-gray; contains poorly preserved fossils in lower half	3.0
Sandstone, hard, massive, fine-grained, yellowish-white; coarse-grained at base with many chert pebbles	5.3
Dolomite, hard, thick-bedded, dense, yellowish-gray	3.0
Sandstone, hard, massive, fine-grained, very pale orange	3.7
Dolomite, silty, hard, dense, very pale orange; basal part soft and poorly exposed	2.0
Total thickness of Grandeur tongue of Park City formation	24.2
Quadrant formation (upper beds only):	
Sandstone, hard, massive, very fine to medium-grained, yellowish-gray; overgrowths on quartz grains	8.2
Sandstone and dolomite, interbedded, hard, yellowish-gray, fine-grained and dense	3.8

At the type locality the lower member of the Shedhorn sandstone is 48 feet thick but is divided into two parts by a 7.5-foot tongue of the Franson member of the Park City formation. The upper member is 64 feet thick where measured in detail at one locality but thickens to about 80 feet within a few hundred yards. Tongues of the Retort and Tosi members of the Phosphoria formation aggregating 45–50 feet in thickness occur between the two members of the Shedhorn. Between the lower member of the Shedhorn and the Quadrant formation there is a series of alternating sandstone and dolomite beds that is considered a tongue of the Grandeur member of the Park City formation, though it contains more sand than ordinarily observed in that unit. As in most of the Madison Range, the upper part of the Quadrant contains interbedded dolomite, and the Quadrant-Park City contact is difficult to define. It has been arbitrarily placed here at the top of the highest thick bed of sandstone. The Shedhorn is overlain by carbonate rock of the Dinwoody formation of Early Triassic age. The local variation in thickness of the upper member of the Shedhorn points to unconformable relations at the Shedhorn-Dinwoody contact. The thickness of the upper Shedhorn at the type locality is not significantly different from that at other localities in this area, however, and it is probable that no more than a small part of the upper part of the Shedhorn was removed by pre-Dinwoody erosion.

The Shedhorn is composed of medium- to very fine-grained quartz sandstone that contains small amounts of black chert and phosphate grains and amber to white phosphatic shell and bone fragments. Some of the sandstone is slightly glauconitic. In the Madison Range and adjacent areas the Shedhorn sandstone is medium- to brownish-gray, in sharp contrast to the light-gray quartz sandstone in the underlying Quadrant formation. The difference in color between the sandstones of the two formations is generally apparent even at considerable distance from the outcrop.

In Montana the Shedhorn extends eastward to the Yellowstone River, northward into the Garnet Range west of Drummond, and westward to Dalys Spur. Thin tongues of the Shedhorn extend southeastward in Wyoming to the Wyoming and Salt River Ranges.

The Shedhorn sandstone is the most shoreward facies of rocks of Permian age in southwestern Montana. It was deposited under marine conditions in a tectonically stable area that was subsiding but slightly. The presence of only the most stable detrital minerals and the conspicuous amount of chert grains both suggest that the sand was reworked from an older sedimentary sequence. The gross distribution of the formation indicates that the immediate source may have been in central Montana.

LOWER MEMBER

At the type locality in the Madison Range of Montana the lower member of the Shedhorn sandstone consists of 48 feet of sandstone, cherty sandstone, and chert divided by a 7.5-foot thick tongue of the Franson member of the Park City formation. It thickens to the southeast so that at Red Creek in the southern part of Yellowstone National Park it is nearly 110 feet thick. Farther to the south and west in Wyoming, and also immediately west of the type locality in Montana, the member interfingers with and eventually grades into carbonate rock of the Franson member of the Park City formation and chert of the Rex chert member of the Phosphoria formation. The member extends throughout the Madison and Gallatin Ranges in Montana, but it thins eastward by transgressive overlap so that it is only 3 feet thick at Cinnabar Mountain near the north boundary of Yellowstone Park, though it is nearly 40 feet thick 14 miles to the south at Quadrant Mountain in the Park.

The lower member rests disconformably on the Quadrant formation in Montana and the Tensleep sandstone of Pennsylvanian age in northwestern Wyoming. It is everywhere overlain with apparent conformity by the Retort phosphatic shale tongue of the Phosphoria formation.

UPPER MEMBER

The upper member of the Shedhorn sandstone extends from 13 miles west of Drummond, Mont., more than 250 miles southeastward to Tosi Creek in the Gros Ventre Range, Wyo., and from Cinnabar Mountain, Mont., 100 miles westward to Dalys Spur. It interfingers with the Tosi chert member of the Phosphoria formation to the west and south and grades into the Ervay tongue of the Park City formation to the southeast.

The upper member at the type section of the Shedhorn sandstone consists of 60 to 80 feet of sandstone with some interbedded chert. At Hogback Mountain, 35 miles to the southwest, it consists of 95 feet of cherty sandstone and contains some thin tongues of the Tosi chert member of the Phosphoria formation. In the Philipsburg and Garrison regions of Montana, where the member is truncated by pre-Ellis erosion, it ranges from 0 to more than 70 feet in thickness; at Cinnabar Mountain, in Montana, the most easterly exposure, the upper member is 75 feet thick; at Forellen Peak in the Teton Range of Wyoming it is 40 feet thick; and at Tosi Creek, the southeasternmost exposure, it is 28 feet thick.

The member is fairly uniform in lithologic character over the region. At the type locality it consists of medium-gray fine-grained well-sorted quartz sandstone that contains small but conspicuous amounts of glauconite grains and dark chert and phosphate grains. The chert and phosphate grains are universally present, but not all sandstone of the member is glauconitic, and the color in weathered sections is lighter. In some localities much of the sandstone is cemented by chert and in many sections chert occurs as beds, irregular nodules, and masses in the sandstone. In parts of the member over much of the area of its distribution, columnar bodies of sandstone or chert as much as several inches in diameter and several feet long are arranged perpendicularly to the bedding of the enclosing sandstone.

Over most of the area the upper member rests conformably and gradationally on the Tosi chert tongue of the Phosphoria formation, but in parts of the Snowcrest Range in southwestern Montana and the Snake River Range in Wyoming and Idaho, it immediately overlies the Retort. In the southern two-thirds of the region in which it is exposed, the upper member of the Shedhorn is overlain conformably by the Dinwoody formation of Early Triassic age (Kummel, 1954, p. 168); in the northern part of the exposure area, in the Three Forks region, and north of Butte, Mont., it is truncated by erosion and is unconformably overlain by beds of the Ellis group of Jurassic age.

NOMENCLATURE OF OTHER UNITS OF PARK CITY AGE

By T. M. Cheney and R. P. Sheldon

Rocks similar in lithology and age to some of those in the Park City and Phosphoria formations, crop out in several areas in western Utah and northeastern Nevada. The nomenclature currently in use for this large area and the general stratigraphic relationships are reviewed briefly below.

The Gerster formation of Permian age at its type locality in the Gold Hill area, Utah, is about 600 feet thick and consists mostly of richly fossiliferous limestone (Nolan, 1930, p. 39–42). It contains a "*Puncto-spirifer*" *pulcher* fauna similar to that found in the upper part of the Franson member of the Park City in the Wasatch mountains. The Gerster is underlain by about 800 feet of mostly dolomite and cherty dolomite which are in turn underlain by a phosphatic, cherty, and shaly unit about 100 feet thick. These two units were included in the upper part of the Oquirrh formation of Pennsylvanian and Permian age by Nolan.

Limestone and dolomite, in the Confusion Range, Utah, that contain a Phosphoria fauna were called the Phosphoria formation by Newell (1948). However, recent work there by Hose and Repenning (in press) has shown that the strata of Park City age are mostly dolomite and limestone similar to the carbonate rocks at the type locality of the Park City formation. Hose and Repenning have divided these rocks, approximately 2,300 feet thick, into three distinct conformable formations on the basis of differences in lithology of the carbonate rocks; from oldest to youngest they are as follows: (1) The Kaibab limestone, about 500 feet thick, consisting dominantly of bioclastic limestone. (2) The Plympton formation, about 700 feet thick, consisting mainly of dolomite and cherty dolomite, and less abundant beds of chert and siltstone, some of which is reddish-brown, and, at one locality, a bed of gypsum. About 150 feet above the base of the Plympton there is a unit of chert and dark-gray dolomitic siltstone that contains a few stringers and thin beds of phosphorite. These beds are probably laterally continuous with the Meade Peak phosphatic shale member of the Phosphoria formation. (3) The Gerster limestone, about 1,100 feet thick, consisting mainly of a sequence of bioclastic limestones, identical lithologically and faunally to the Gerster at its type locality (Nolan, 1930, p. 39–42). Hose and Repenning (in press) designate the Kaibab, Plympton, and Gerster as the Park City group because of their general similarity to and correlation with the Park City formation. In the Confusion Range the Park City group is underlain by sandstone and shales of the Arcturus limestone of Permian age and overlain by the chocolate-weathering limestones and greenish-gray and gray shales and siltstones of the Thaynes limestone of Triassic age.

The carbonate rocks typical of the Park City group in the Confusion Range intertongue northward with the chert, phosphatic shale, and cherty mudstone of the Phosphoria in the Sublett Range, Idaho. Dolomite and limestone similar in stratigraphic position and composition to the formations defined by Hose and Repenning (in press), but with thin tongues of chert and phosphatic shale typical of the Phosphoria, crop out in the Gold Hill quadrangle, Utah, and in the Pequop and East Humboldt Ranges, Nev. In the Hogup Mountains, Utah, and northeast Elko County, Nev., as at Nine Mile Ridge, Leach Mountains, and Goose Creek Mountains, the same general carbonate rock units are recognizable but there thick tongues of chert, cherty shale, and phosphatic shale (typical Phosphoria lithologies) are also prominent; the strata laterally continuous with the Park City formation are about half carbonate rock and half chert, phosphatic shale, and cherty shale. In the vicinity of Trapper and Trout Creeks, in the Cassia Mountains, Idaho, the strata appear to be nearly all chert, sandstone, and phosphatic shale, with the exception of the lowermost unit which is much like the Grandeur member of the Park City formation elsewhere. Application of formal nomenclature to the rocks of Park City age in the area between the Confusion Range and the Sublett Range will be delayed until the completion of stratigraphic studies now in progress in that area.

In central and southern Wyoming and eastern Utah red and greenish-gray calcareous shale tongues interfinger with the carbonate rock tongues of the Park City. Thomas (1934, p. 1670; 1939, p. 1249–1250) designated the red-bed units in Wyoming as tongues of the Chugwater formation and those in Utah as tongues of the Woodside formation. In 1956, however, Burk and Thomas separated the lower red beds and evaporites from the Chugwater formation in Wyoming and named them the Goose Egg formation. They considered the carbonate rock tongues in the Goose Egg formation to be members of that formation rather than tongues of the Phosphoria formation as had been done previously (Thomas, 1934). Rioux (1957, p. 44–45), however, called the carbonate rock units in the Big Horn Basin tongues of the Park City formation, after McKelvey and others (1956), thus slightly modifying the definition of the Goose Egg formation.

The greenish-gray shales are probably an intermediate facies between the light-colored carbonate rocks and the red beds. Where greenish-gray shales are minor in importance they may be grouped arbitrarily with either the carbonate rock or the red-bed tongues; but in some areas, as at the Conant Creek anticline in Fremont County, Wyo., they constitute major parts of the rocks of Park City age and in others, as in the southern Wind River Mountains and the Uinta Mountains, they comprise prominent tongues within the Franson member. In order that these greenish-gray beds may have a temporary place in the nomenclature, previous usage has been followed: those in Wyoming have been classified with the carbonate-rock tongues (Thomas, 1934; Burk and Thomas, 1956), and those in Utah have been grouped with the red beds (Thomas and Krueger, 1946, p. 1264, fig. 3; Kinney and Rominger, 1947). It is possible that others who study these beds in the future will find the greenish-gray shales thick enough and sufficiently widespread to merit a separate formational name.

We have not studied the red and greenish-gray beds except the Mackentire tongue of the Woodside formation (Thomas, 1939). The Mackentire received attention because it extends into the phosphate field in Utah. In Mackentire Draw near the Lake Fork River in Duchesne County, Utah, a sequence of red beds 100 feet thick splits the Franson member of the Park City formation into two parts. Farther west, in the vicinity of Wolf Creek, James Steele Williams identified Permian fossils (J. W. Huddle, written communication, 1954) in thin beds of limestone within the lower part of the red beds mapped as Woodside by Huddle and McCann (1947). These limestones probably represent the featheredges of the upper part of the Franson member, as shown diagrammatically on plate 3. Red beds, greenish-gray shale, sandstone, and evaporites are present in the Franson farther west in the Uintas and in part of the Wasatch Mountains as well. In the eastern part of the Uintas the upper part of the Franson feathers out, so that in Dinosaur National Monument and in northwestern Colorado the lower part of the Franson is overlain by tawny, greenish-gray, and red beds.

The problem of nomenclature of these beds is complex. J. Stewart Williams, who first recognized the red beds at Mackentire Draw, named them the Mackentire tongue of the Phosphoria (1939, p. 91). Thomas (1939) and Thomas and Krueger (1946, p. 1263–1270) later classed them as the Mackentire tongue of the Woodside formation, the red-bed unit from which they are inseparable in that part of the western Uintas where the upper part of the Franson is absent. Kinney and Rominger (1947) and Kinney (1955, p. 56) classed the greenish-gray and red beds above the Franson in the eastern Uintas as part of the Moenkopi formation of Triassic age; this name was introduced because the absence of the Thaynes formation in the eastern Uintas makes it difficult to separate the Woodside and Ankareh, as the red beds of the same interval farther west are called. Genetically the Mackentire, Woodside, and Ankareh all appear to be tongues of the greenish-gray shale and red-bed unit that lies between the Franson member of the Park City and the Shinarump member of the Chinle formation of Triassic age in eastern Utah and northwestern Colorado (Kummel, 1954, pl. 34). This relationship would be correctly emphasized if the Mackentire were designated as a tongue of the main red-bed and greenish-gray-shale unit rather than as a tongue of the Woodside formation of Thomas (1939); however, because the name "Chugwater", or more recently the name "Goose Egg", has been used for the red beds of Permian and Triassic age in south-central Wyoming, it is possible that red beds in northeastern Utah and northwestern Colorado should be called Chugwater or Goose Egg instead of Moenkopi. As a consequence, the greenish-gray shale part of the sequence probably would be designated by a different name. Because we have not studied the regional relationships of the greenish-gray and red beds, we feel it best to refer to future workers the problem of nomenclature of these rocks in the eastern Uinta Mountains. In this report we have followed Thomas (1939) and Thomas and Krueger (1946, p. 1263–1270) in designating the rocks above the Franson in northeastern Utah as Woodside and in considering the Mackentire as a tongue of the Woodside.

The Mackentire at the type locality (table 7 and section 4, fig. 4) is defined as the soft, dominantly reddish-brown shale and sandstone which are overlain and underlain by tongues of the Franson member (J. Stewart Williams, 1939, p. 91). Thin beds of purple, greenish-gray, yellowish-orange, and gray shale and siltstone are present in the Mackentire at the type locality. East of Lake Fork the Mackentire tongue is dominantly greenish-gray and pale yellowish-orange (tawny) siltstone, though some red beds are generally present.

The Mackentire thins to the north, east, and west of the type locality. The thickness of the Mackentire at Wolf Creek is not known; the strata were not described or measured above the lower part of the Franson; hence, the relationships are shown diagramatically on plate 3. The upper and lower contacts, commonly gradational, are marked by the red, purple, greenish-gray, or pale yellowish-orange color and soft shaly slope-forming character of the Mackentire in contrast to the light-gray to white color and hard massive-bedded cliff-forming character of the upper and lower parts of the Franson member.

TABLE 7.—*Stratigraphic section of the Mackentire tongue (as used by Thomas, 1939) in Mule Draw, 1/4 mile southeast of Mackentire Draw, in sec. 26, T. 2 N., R. 5 W., Duchesne County, Utah*

[Section measured and described by John W. Huddle]

	Ft
Upper part of the Franson member of the Park City formation (lower bed only):	
Sandstone, fine-grained, dolomitic, hard, tan; 50 percent chert as light-gray beds and lenses	14.7
Mackentire tongue of the Woodside formation as used by Thomas (1939):	
Chert (70 percent) and shale (30 percent); red, gray, green, purple, and buff thin to thick irregular beds of chert and calcareous silty red and light-gray shale; contains calcite geodes up to 0.8 ft in diameter	15.9
Shale, silty, reddish-brown; contains thin lenses of limestone	.3
Limestone, dense, light-gray, and cream; contains masses of yellow dolomitic limestone	2.1
Mudstone, slightly calcareous, yellow to light-gray; forms notch in cliff face	.6
Siltstone, slightly calcareous, reddish-brown, shaly in places; contains streaks of grayish-green shale	15.1
Siltstone or sandstone, slightly calcareous, very fine grained, reddish-brown, massive; more calcareous beds contain round white masses	50.0
Sandstone, calcareous, very fine grained, purplish-brown, flaggy	1.5
Siltstone, calcareous, light orange-brown, massive. Light yellowish-gray mottling in lower 1 ft	14.0
Total thickness of Mackentire tongue	99.5
Lower part of the Franson member (upper bed only):	
Sandstone, calcareous, fine- to medium-grained, light brownish-gray, soft; contains grains of chert as well as quartz	5.0

FAUNA, AGE, AND CORRELATION OF ROCKS OF PARK CITY AGE

By James Steele Williams

Studies of the faunas of the Phosphoria, Park City, and Shedhorn formations, based on large collections obtained during the present and past field investigations, are in progress. These studies have not reached an advanced stage, but enough data exist to indicate the general age of the sequence and to provide a basis for its approximate correlation with standard units in the United States and elsewhere. Detailed faunal knowledge with which to distinguish and correlate the individual stratigraphic units defined in the accompanying reports by McKelvey and associates is not yet available, but the type of fauna that characterizes the Phosphoria and Park City is described in the following pages. The collections from the Shedhorn have not yet been completely studied and the fauna is unknown.

PARK CITY FORMATION

GRANDEUR MEMBER

A fauna containing *Dictyoclostus ivesi* (Newberry) (*s. l.*) was found by A. A. Baker and the writer (Baker and Williams, 1940) in the Grandeur member of the Park City formation in the Hobble Creek area of Utah, 42 miles from the type locality but separated from it by a major fault. This fauna has Kaibab affinities and is inferred to be of Leonard (Permian) age; faunas of the same age have been found in the Grandeur at other localities.[9] Frenzel and Mundorff (1942) described *Pseudoschwagerina montanensis* and *Schwagerina laxissima* Dunbar and Skinner from a tongue of the Grandeur near Three Forks, Mont. L. G. Henbest (written communication, 1954) identified *Pseudoschwagerina*, *Pseudoschwagerina* or *Schwagerina*, and *Pseudoschwagerina* or *Parafusulina* from beds thought to be in the Grandeur in the same area.

In southeastern Idaho rocks that underlie the Grandeur tongue have yielded early Permian fusulinids, a circumstance that helps define the age of the Grandeur in this area. Henbest (written communication, 1954) identified *Schubertella kingi* Dunbar and Skinner, *Triticites notus* Thompson, and *T. ventricosus* (Meek and Hayden) var., which he considered to indicate an early Wolfcamp age, from the upper part of the Wells formation in Caribou County, Idaho.[10] He also identified (written communication, 1948) two species of *Schwagerina* and a possible species of *Paraschwagerina* from beds mapped as Wells by A. M. Piper 4.5 miles N. 70° E. of Juniper, Oneida County, Idaho.[11]

These several collections indicate that the Grandeur member in western Montana, Idaho, and Utah is of Permian age. In certain areas in Utah, Pennsylvanian fossils have been reported from beds referred by their collectors to the lower (Grandeur) member of the Park City. For example, a Pennsylvanian fauna was described by Boutwell (1933, p. 39) as from the lower member of the Park City in Dry Creek.[12] This fauna, quoted as listed but with authors of species added, includes *Orbiculoidea utahensis* (Meek), *Marginifera splendens* (Norwood and Pratten), *Chonetes* cf. *C. granulifera* Owen, "*Productus costatus*" Sowerby, *Hustedia mormoni* (Marcou), *Spirifer cameratus* Morton, and "*Worthenia*" *tabulata* (Conrad). *Chonetes mesolobus* Norwood and Pratten (*Mesolobus mesolobus* of authors), *Spirifer occidentalis* Girty and other fossils characteristic of the Middle Pennsylvanian have also been found in beds referred to the Park City. In some areas the Grandeur member is fairly sandy, and locally sandy limestone occurs in the upper part of the underlying Weber quartzite, which is of Pennsylvanian age. It is possible that in some places limestones in the upper part of the Weber quartzite have been mistaken for the Grandeur member of the Park City and that this error may account for the discrepancy in age determinations. However, other explanations may be found.

According to published data, fossils are rare in the Grandeur member of the Park City near Lander, Wyo., and those that occur in it are nondiagnostic: *Orbiculoidea utahensis* (Meek), a *Grammysia*-like pelecypod and a few other long-range pelecypod gen-

[9] Productoid brachiopods near the top of the Grandeur member at the Ballard mine, Caribou County, Idaho (NW¼ sec. 7, T. 7 S., R. 43 E.) have been identified as *Dictyoclostus* cf. *D. ivesi* (Newberry) by J. T. Dutro, Jr. (written communication, 1958). Brachiopods collected from the lowermost limestone beds at the type section of the Grandeur in Mill Creek Canyon are similar to those in the Grandeur at Hobble Creek and indicate a Leonard age for these strata (Mackenzie Gordon, Jr., oral communication, 1958). This information and that in subsequent footnotes have been added since Mr. Williams' death, Jan. 16, 1957.

[10] Several additional collections from the Wells formation in southeastern Idaho studied by R. C. Douglass (written communication, 1958) show that the lower part of the Wells and a few feet of what is now called the upper part of the Wells, as mapped in recent years by Geological Survey parties in the area, is of Atoka and Des Moines (Middle Pennsylvanian) age; and that most of the lower beds of the upper part of the Wells are of Wolfcamp age. The fusulinids from the lower part of the Wells and basal beds of the upper part of the Wells in these collections are *Millerella* sp., *Staffella?* sp., *Staffella* sp., *Fusulinella* sp., *Fusulina* sp., *Fusulina* sp. aff. *F. leei* Skinner, *Wedekindellina* sp., and *Endothyra* sp. Those from the upper part of the Wells are *Pseudofusulinella* sp., *Schwagerina* sp. aff. *S. elkoensis* Thompson and Hansen, and *Millerella* sp.

[11] Youngquist and Haegele (1955) have also identified fusulinids of Wolfcamp age in beds an unknown distance below the Phosphoria formation in the Sublett Range, Cassia County, Idaho.

[12] Boutwell stated that this collection comes from Cephalopod Gulch; however, this gulch, as located on the recent Fort Douglas quadrangle topographic map, is cut in the Thaynes limestone, so the locality Boutwell refers to must be on the left fork of Dry Creek. Fossils collected in 1958 from the basal beds of the Grandeur member at Dry Creek are definitely of Permian age, according to G. Arthur Cooper of the U.S. National Museum, and E. L. Yochelson; therefore, the fauna listed by Boutwell must have come from older beds.

era—*Edmondia*, *Schizodus*, *Deltopecten*, *Allorisma*—and *Pleurophorus*, *Plagioglypta canna* (White), and a euphemitid gastropod. Fish scales are abundant locally. Recent Survey collections from this member have not yet been studied.

FRANSON MEMBER

The Franson probably is the most fossiliferous zone in the Park City; it contains a fossil assemblage widely known as the "*Spiriferina pulchra*" fauna from the brachiopod that was long known by that name. This fauna characterizes the upper part of the Park City in the type area and also is known generally as the Rex chert fauna.

Brachiopods are the most abundant element of the Franson fauna, but bryozoans are also important and a few pelecypods, gastropods, scaphopods, cephalopods, and other invertebrates are present. There are also fish remains. The more significant brachiopods are: "*Punctospirifer*" *pulcher* (Meek) [*Spiriferina pulchra* and *Spiriferinella pulchra* of authors], *Neospirifer pseudocameratus* (Girty), *Dictyoclostus* (*Muirwoodia*) *multistriatus* (Meek), *Linoproductus* (*Cancrinella*) *phosphaticus* (Girty), *Pustula nevadensis* (Meek), *Avonia subhorrida* (Meek), *Waagenoconcha montpelierensis* (Girty), *Aulosteges hispidus* Girty, *Leiorhynchoidea weeksi* (Girty), *Dielasma phosphoriensis* Branson, *Punctospirifer kentuckyensis* (Shumard), *Rhynchopora taylori* Girty, *Hustedia phosphoriensis* Branson, and Compositas. Pelecypods are relatively uncommon. The principal ones are species of *Edmondia*, *Nucula*, *Yoldia*, *Leda*, *Schizodus*, *Allorisma*, *Myalina*, *Aviculopecten*, *Streblochondria*, and *Pleurophorus*. When the Franson pelecypods are carefully restudied some of them may prove to be diagnostic of individual zones. It is possible, however, that their distribution was influenced by ecological conditions and that differences in the content of assemblages reflect differences in facies rather than in age.

Fusulinids, corals, and ostracods are as yet unknown in the Franson. Sponge spicules, echinoid fragments, and crinoid columnals are locally abundant but material suitable for species identification has not been found. Bryozoans are common in the Franson and more species occur than are listed in print. The scaphopod, *Plagioglypta canna* (White), is a conspicuous fossil, but it occurs in both older and younger beds. Gastropods include types referred to *Bellerophon*, *Pleurotomaria*, and *Strophostylus*. A few Foraminifera and conodonts are known. A large fish fauna from this member in Wyoming was described by C. C. Branson in 1933. He described or mentioned species under the following genera: *Helodus*, *Cladodus*, *Janassa*, *Campodus*, *Ctenacanthus*, *Dolophonodus* (later referred to *Arctacanthus*), *Hamatus*, *Ancistriodus* and *Edestes?*.

ERVAY CARBONATE ROCK MEMBER

The fauna of the Ervay member near its type locality is listed by H. D. Thomas (1934, p. 1675). Additional forms from beds near Lander, Wyo., now referred to the Ervay, are listed by C. C. Branson in his 1930 report. These are mostly in Branson's *Hustedia*, and *Aulosteges* (top limestone) zones (1930, p. 19, 20). Other species identified by Girty have been listed in papers by Darton and Siebenthal (1909, p. 21), Blackwelder (1913, p. 178), Condit (1924, p. 11), and Lee (1927, p. 75–76). A strong molluscan element is a conspicuous feature of this fauna but the brachiopods are nearly as abundant and are perhaps the most significant forms. At least 2 genera of crinoids, 1 of echinoids, 7 of bryozoans, 2 of scaphopods, 7 of gastropods, and 2 of cephalopods are included in the invertebrate fauna. Especially important brachiopods are *Orbiculoidea utahensis* (Meek), *Plicatoderbyia magna* (Branson), *Pustula nevadensis* (Meek), *Avonia subhorrida* (Meek), *Aulosteges hispidus* Girty, "*Punctospirifer*" *pulcher* (Meek), *Punctospirifer kentuckyensis* (Shumard), *Dielasma phosphoriensis* Branson, *Hustedia phosphoriensis* Branson, and Compositas. Some of the pelecypods are unknown from older beds of the Park City. These include two species described as Cyrtorostras by C. C. Branson. This genus is close to *Oxytoma* and may be found to overlap it. Other pelecypod species are described under the genera: *Yoldia*, *Solenomya*, *Leda*, *Pseudomonotis*, *Myalina*, *Parallelodon*, *Edmondia*, *Schizodus*, *Pinna*, *Aviculopecten*, *Deltopecten*, *Mytilus*, and *Pleurophorus*. The scaphopod *Plagioglypta canna* (White) is a common fossil. Gastropods include the Permian species *Euphemites subpapillosus* (White), which has also been found in older members of the Park City, and species belonging to *Pleurotomaria*, *Omphalotrochus?*, *Arthonema*, and *Naticopsis?*. Miller and Cline have described one species of cephalopod, the nautiloid *Coelogasteroceras thomasi*, from the Ervay; and C. C. Branson described a species that is now known as *Stearoceras phosphoriense* and another form which is either a *Coloceras* or another *Stearoceras*. It might seem that the fauna of this member is quite distinct from those of other members and that the member could be recognized widely by its fauna throughout the field; however, some of the apparently distinctive forms occur only in one or a few localities, and others have been found in other members during this investigation. The influence of facies and other ecological factors remains to be satisfactorily evaluated. Miller and Unklesbay

(1942) mentioned other nautiloids that may have come from the Ervay.

PHOSPHORIA FORMATION

MEADE PEAK PHOSPHATIC SHALE AND LOWER CHERT MEMBERS

The Meade Peak phosphatic shale member of the Phosphoria formation has yielded a large fauna. Most of the described forms came from the so-called cap lime. This unit is a thin phosphatic limestone 1 to 3 feet thick that caps the lowest minable phosphate beds over a wide area in southeastern Idaho. Some of the mudstones and phosphorites of the Meade Peak are also fairly fossiliferous. In general the thin muddy carbonate rocks and carbonatic mudstone of the Meade Peak contain molluscan assemblages, whereas many of the purer phosphorite beds have almost nothing but Orbiculoideas and Lingulas and perhaps some fish bones, plates, or scales. There are exceptions to the above generalizations, however, as Foraminifera, conodonts, and other nonmolluscs are present in certain beds in certain areas.

Brachiopods common or significant in the Meade Peak include Orbiculoideas of one or more species, *Chonetes ostiolatus* Girty and two varieties thereof, "*Productus*" (*Muirwoodia*) *geniculatus* Girty, *Linoproductus* (*Cancrinella*) *phosphaticus* (Girty), *Waagenoconcha montpelierensis* (Girty), *Leiorhynchoidea weeksi* (Girty), *L. weeksi* var. *nobilis* (Girty), *Wellerella osagensis* (Swallow), *Rhynchopora taylori* Girty, *Ambocoelia* (or *Crurithyris*) *arcuata* (Girty), and Compositas. Pelecypods are fairly abundant in some beds. Genera identified include: *Grammysia?*, *Edmondia?*, *Cardiomorpha?*, *Nucula*, *Yoldia*, *Leda*, *Schizodus*, *Aviculopecten*, *Streblochondria* and *Pleurophorous*. *Plagioglypta canna* (White) occurs in several zones in the Meade Peak member. The cap limestone and some other beds contain large numbers of gastropods. Forms that were referred to species of *Omphalotrochus* (now reassigned to *Babylonites* by Yochelson, 1956, p. 202) are perhaps the most conspicuous gastropod element. Less abundant are individuals that have been referred to the genera *Pleurotomaria*, *Euphemites*, *Naticopsis*, *Soleniscus*, and *Microdoma*.

The cephalopods of the Meade Peak are a significant element in the fauna of the Phosphoria. The most varied cephalopod fauna occurs in beds about 60 feet below the top of the Meade Peak member in Raymond Canyon, Wyo., and at other nearby localities on Sublette Ridge. Cephalopods were first described by Girty (1910, p. 52–54) from beds exposed at Thomas Fork (Raymond Canyon?). Later, Miller and Cline (1934) restudied the cephalopods described by Girty as well as other cephalopods they collected on Sublette Ridge. They identified *Vidrioceras*, *Stacheoceras s. s.*, and certain species of the genus *Pseudogastrioceras*. In addition to the three genera of cephalopods mentioned above, representatives of "*Orthoceras*" and *Peritrochia* have been listed from the Meade Peak.[13]

Conodonts from the Meade Peak member of the Phosphoria were described by Youngquist, Hawley, and Miller in 1951. They recognized species of *Gondolella*, *Prioniodus?*, and *Streptognathodus*, among the approximately 100 specimens that they obtained. Branson and Branson (1941) have also collected *Gondolella* and *Hindeodella* and other conodonts from this member in Wyoming. Girty (1910, p. 55–58) described the ostracodes *Hollina emaciata* var. *occidentalis*, *Jonesina carbonifera*, and *Cytherella benniei* Jones, Kirkby, and Brady from phosphatic shales now placed in the Meade Peak. Also present are "onychites" (belemnoid arm hooks) identified by J. E. Smedley. Trepostomatous bryozoa are also present in some carbonate beds.

Fish remains, some of which belong to *Lissoprion*, a genus closely related to if not identical with *Helicoprion*, are common at certain zones in the Meade Peak phosphatic shale member at Montpelier and Fort Hall, Idaho, and in Utah. Fish scales, teeth, and bones not identifiable as to genus also are found in the Meade Peak member. Conularias of one and possibly more genera are also present.

The Meade Peak member in Montana, Utah, and Wyoming is, generally speaking, much less fossiliferous than it is in Idaho. The brachiopod *Orbiculoidea utahensis* (Meek) is common but other brachiopods are rare. A few conodonts have been found, but they are not diagnostic of any particular zone in the Permian. A few generalized types of pelecypods are also present as is the scaphopod *Plagioglypta canna* (White). A very few gastropods and a few Foraminifera are known. Fish remains were reported by St. John (1883) and a large fish fauna from the Meade Peak in western Wyoming was described by E. B. Branson (1916); additional information on this fauna was published by C. C. Branson (1930).

The fauna of the lower chert member has not yet been studied.

REX CHERT AND CHERTY SHALE MEMBERS

Orbiculoidea utahensis (Meek) and Lingulas are the most common brachiopods in the Rex. Crinoid colum-

[13] In a paper published after Mr. Williams' death, Miller, Furnish, and Clark (1957) listed the following ammonoids from the Meade Peak in the southeastern Idaho-western Wyoming area: *Peritrochia girtyi* (Miller and Cline), *Stacheoceras bransonorum* Miller and Cline, *S. sexlobatum* Miller and Cline, *Pseudogastrioceras simulator* (Girty) and varieties, *Spirolegoceras fischeri* Miller, Furnish, and Clark. They also identified *Pseudogastrioceras* sp. from the Meade Peak tongue of the Phosphoria at Hobble Creek, Utah.

nals and some bryozoans and other brachiopods occur in the lenticular limestone; sponge spicules and possibly spicules from other organisms are present in the cherty beds. Some chert beds in the Rex consist almost entirely of sponge spicules, and long spicules or spines are common also in the cherty shale; some of the latter are productoid and echinoid spines. Productoids with long spines attached are included in collections made in beds of Park City age near Montello, Nev., by T. M. Cheney and Jane Wallace of the U. S. Geological Survey in 1955. Radiolaria have also been reported from the Rex but not described.

RETORT PHOSPHATIC SHALE AND TOSI CHERT MEMBERS

Both these members contain *Hustedia phosphoriensis* Branson. The Retort fauna also contains *Punctospirifer kentuckyensis* (Shumard), *Pustula nevadensis* (Meek), and perhaps other brachiopods, molluscs, and fish. Pelecypods of the Retort have been referred to *Nucula* and to *Leda;* gastropods to *Bellerophon*, *Strophostylus*, and *Pleurotomaria. Plagioglypta canna* (White) is also in the Retort fauna. Fish recognized in the Retort have been referred to *Helodus*, *Janassa*, and *Hamatus*, a genus that may be related to *Helicoprion.* Many of the molluscs are represented by small individuals.

The Tosi chert member contains also a large and varied bryozoan fauna and a varied brachiopod fauna. The brachiopod element includes, in addition to the *Hustedia* mentioned above, *Plicatoderbyia magna* (Branson), *Dielasma phosphoriensis* Branson, "*Punctospirifer*" *pulcher* (Meek), *P. kentuckyensis*, *Aulosteges hispidus* (Girty) and *Composita.* One species of *Myalina* and two species of *Aviculopecten* are present, as are also echinoid spines and plates.

UNDERLYING AND OVERLYING ROCKS

The beds of Park City age are underlain by formations of several ages. Some of them, such as the Weber quartzite and Tensleep sandstone, are probably no younger than the lower half of the Pennsylvanian in most areas of their outcrop.[14] Others, such as the Quadrant, Casper, and Wells, are largely of Pennsylvanian age but the Casper and the Wells contain beds of early Permian age in their upper parts. The Diamond Creek sandstone is probably of Wolfcamp (Permian) age.

Throughout most of their extent the rocks of Park City age are overlain by Triassic rocks, though it seems clear that the lower part of the overlying formation at the east end of the Uinta Mountains and in parts of central Wyoming is Permian.

REGIONAL AND INTERCONTINENTAL CORRELATION OF ROCKS OF PARK CITY AGE

The Grandeur member of the Park City formation in the Hobble Creek area of Utah and probably also in many other parts of the western phosphate field is of Leonard (Permian) age. The Grandeur near Threeforks, Mont., was considered of Wolfcamp (Permian) age by Frenzel and Mundorff, although Thompson and others (1946) believe that the fusulinids there may be younger than fusulinids from the type section of the Wolfcamp, and Henbest (written communication, 1954) believes that the fusulinids may be as young as early Leonard.

The cephalopods found in the Meade Peak have furnished the most useful data for age determination of this member. The species of *Vidrioceras* cited by Miller and Cline (1934) from what is now called the Meade Peak phosphatic shale member is said by them to be close to, if not identical with, a species from the Sosio beds of Italy which have been correlated with the Word formation of Texas. *Stacheoceras* s. s. had previously been found in North America only in the Word and Wichita formations of Permian age and in Timor in beds that are probably the equivalent of the Leonard in age. Certain species of the genus *Pseudogastrioceras* of the Meade Peak are abundant and widespread in the United States and Mexico only in beds of Word age (Miller and Cline, 1934).[15]

Youngquist, Hawley, and Miller (1951) assigned a post-Wolfcamp age to the beds of the Meade Peak, partly on the basis of the supposed evolutionary stage of the conodonts found there. However, the conodonts of the Permian are not well known and have not been adequately described, and therefore precise correlations cannot be based on them.

The fish fauna of the Meade Peak also has been used for regional correlations and for speculations regarding possible intercontinental correlations. Authorities differ as to whether the form referred to *Lissoprion* is a genus distinct from *Helicoprion.* Although *Helicoprion* is considered by some to be an index fossil of the Permian, it actually ranges in age from late Carboniferous to the top of Artinskian (lower Permian) (Licharew, 1939, p. 208; Gorsky and others, 1939, p. 150). If the Meade Peak genus is *Helicoprion*, its presence does not tell much about the age of the enclosing beds. The large fish fauna found in the Meade Park member in western Wyoming, described by E. B. Branson in 1916,

[14] The upper Tensleep in the southern Bighorn Basin, Wyo., is of early Permian age but elsewhere in western Wyoming it is of Pennsylvanian age (Verville, 1957, p. 350).

[15] Miller, Furnish, and Clark (1957) now consider the ammonoid assemblage in the Meade Peak of southeastern Idaho and the central Wasatch Mountains of Utah to be of Leonard age.

originally was thought to be of Pennsylvanian age. In 1941 E. B. and C. C. Branson referred it to the Permian, and considered it probably of pre-Word age.

The faunas of the parts of the Park City above the Meade Peak member are not definitely known to be younger than the Word, but some may be younger. The significant species found in these uppermost beds are mostly brachiopods that have also been reported from the Meade Peak or from older beds of the Park City, or that are limited geographically to this area. Girty (numerous references including 1910 and *in* Mansfield, 1927), Branson (1930), King (1930), and others have suggested correlations of the Phosphoria based in large part on brachiopods. Most of the brachiopods common to the provincial Permian section in Texas and the uppermost part of the Park City occur in the Word formation in Texas, and few if any of these occur in Texas in beds that are younger than the Word. The widespread appearance above the Word of reef facies and of other beds not of normal marine facies could account for the absence in Texas of faunas that may have continued into post-Word time in the Rocky Mountain and Great Basin regions.

Deposits of Park City age are widespread in western North America from Alaska to Mexico. West and northwest of the area of the Phosphoria the writer has made collections of approximately the same age from the Clover Creek greenstone (Permian) at Baker, Ore., and the Seven Devils volcanics in Idaho. Though not fossiliferous, the Casto volcanics, which are exposed near Challis, Idaho, are thought to be of approximately the same age. Fossils from the Gerster and Edna Mountain formations in eastern Nevada suggest Phosphoria age. Newell (1948) cited faunal evidence that indicates Phosphoria age for the Gerster in the Confusion Range in western Utah. Faunas of Park City age occur in the Nosoni, McCloud, Owenyo, and other formations in California and also in Oregon,[16] Washington, Nevada, and Canada.

Faunas of Phosphoria age that were collected in Mexico by Robert King in 1926 have been described by a group of paleontologists (King and others, 1944). Deposits at El Antimonio, described by W. D. Keller in 1928, were studied in detail by Cooper and associates in the 1940's, and the fauna collected was described by a group of specialists (Cooper and others, 1953).

In the writer's opinion (J. Steele Williams, 1954) the Permian age of the Park City depends on its correlation with beds in the type area of the Permian in Russia. Direct correlation with the type area is only partly satisfactory. In Russia, as in many other places, the youngest Permian rocks are largely of continental origin and, with the exception of a few beds, lack normal marine fossils. Most intercontinental correlations of relatively thin sedimentary units are speculative. The insecure identification of species (often without adequate comparative material) and problems of migration, paleogeography, and differing facies complicate these correlations and often make them controversial.

In Russia, as elsewhere, there are different classifications of the Permian. Some of them are unique and are the opinion of one or two men. The classification that seemed to the writer when he visited Russia in 1937 (J. Steele Williams, 1939) to be most favored by working geologists was that published by Licharew and others in 1939 and apparently officially sanctioned by the Central Geological and Prospecting Institute (see also Gorsky and others, 1939). This Permian classification which has two divisions, Upper and Lower, was agreed upon by a group of Permian specialists working under the sponsorship of that organization. The Lower Permian consisted of the Artinskian overlain by the Kungurian. Some Russian geologists in 1937 assigned certain pre-Artinskian beds, believed by Gorsky and others (1939) to be Upper Carboniferous, to a Sakmarian division, which they considered lowest Permian. The Upper Permian consisted of the Kazanian and Tartarian beds. Scandinavian geologists place the Kungurian in the Upper Permian, but this usage has not received general acceptance in Russia.[17]

The beds of the Park City that are of Wolfcamp age would best be correlated with the so-called Schwagerina beds of the U. S. S. R., which are placed in the Sakmarian division. These beds are included in the Permian in this report, in deference to the usage of many North American geologists and because of the increased use in foreign literature in the last few years of Sakmarian as a subdivision of the Permian.

Field observations of the brachiopod faunules in the type area of the Permian, together with cursory office studies, suggest that the brachiopods of the Meade Peak member of the Phosphoria and of the upper beds of the Park City have a greater resemblance to the Irghina brachiopods than to those of any other faunal division in the Russian type area. The writer's impressions are based on the general character of the fauna and its con-

[16] G. A. Cooper has described the brachiopods from the Coyote Butte formation of central Oregon and evaluated their significance in correlation. He regards the productid *Muirwoodia,* which occurs also in the Gerster and the Phosphoria, as indicative of post-Leonard age and tentatively correlates the Oregon Permian with the limestone No. 1 of the Word formation (1957, p. 18).

[17] Since this section was written, the Ministry of Geology and Mineral Resources of the USSR published (1956) a "Stratigraphic Dictionary of the USSR." Licharew prepared the annotations for subdivisions and stages of the Permian. He indicates that the present concept of the Lower Permian encompasses the Sakmarian, Artinskian, and Kungurian stages (p. 666). The Upper Permian series (p. 212) includes the Ufimian, Kazanian, and Tartarian stages.

tained genera and on related rather than on identical and restricted genera or species. Possible facies factors and their influence on correlation remain to be evaluated. The Irghina beds are placed near the top of the Artinskian (Lower Permian of Russian usage).

Evidence from elasmobranchian and actinopterian fossil fishes in the Franson member suggests a correlation with certain beds in Greenland (C. C. Branson, 1934); these beds have in turn been correlated with beds in the type section, one such correlation having been with the Kungurian. Westoll (1941) has summarized and evaluated the evidence for and against these correlations.

Other correlations of the Phosphoria with beds younger than the Artinskian have been made by indirect methods. These methods have generally taken the form of correlating the Phosphoria with certain beds in regions other than the type Permian region, which beds have in turn been correlated with the type Permian. These correlations have been based on different classes of fossils and different types of evidence. Their validity depends upon the reliability of many factors, such as the correctness of the correlation of the third unit with the Phosphoria and with the type Permian. Few if any of the correlations made by this method are adequately supported in all their aspects by incontrovertible evidence from fossils. For example, Gerth (1950), in his excellent summary of the Permian of most of the world, correlated the Phosphoria with the Kungurian (Lower Permian of the type area) because the Phosphoria has been considered to be the age equivalent of the Sosio beds which Gerth believes to be of the age of certain beds in Asia. His interpretation is based mainly on evidence from cephalopods. These beds in Asia he considers to be of Kungurian age. The writer knows of no cephalopods in the type Kungurian.

As early as 1929, Rosenkrantz (cited *in* Dunbar, 1955, p. 49) listed species of brachiopods he considered of Zechstein (late Permian) age in limestone blocks in Triassic conglomerates in Greenland. Other workers (Frebold, 1931; Miller and Furnish, 1940; Newell, 1955; and Dunbar, 1955) have suggested late Permian age for the Greenland beds that have been correlated with the Phosphoria on evidence of fossil fishes. Dunbar (1955) has given a summary of the evidence for this viewpoint.

Other correlations have been suggested and other writers have discussed the above correlations. Further work with the immense Park City collections remaining to be studied may provide data for further discussion of the relations of the Phosphoria to beds in the type area, and may throw further light on the various correlations postulated by the indirect methods.

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INDEX

A

Page

Acknowledgments 1-2
Age, Park City formation 36-38
Phosphoria formation 38-39
rocks underlying and overlying beds of Park City age 39
Ankareh formation 35
Apatite 19, 24, 25
Artinskian beds 40, 41

B

Baldwin Creek, Tosi chert member near 30
Big Cottonwood Canyon, type locality of Park City formation 11-12
Blackfoot Dam area, phosphatic shale in 2
Brazer Canyon in Utah, Tosi chert member 30, 31

C

Cartographic units, selection 9, 11
Casto volcanics 40
Cheney, T. M., Franson member 15-19
and Sheldon, R. P., Nomenclature of other units of Park City age 33-36
Park City formation, general description 11-12
Peterson, J. A., Waring, R. G., Smart, R. A., and Cressman, E. R., section measured by 20-21
section measured by 12-13
Swanson, R. W., Sheldon, R. P., and McKelvey, V. E., Park City formation, Grandeur member 12-15
with McKelvey, V. E., Cressman, E. R., and Sheldon, R. P., Nomenclature 5-11
with Waring, R. G., Warner, M. A., and Smart, R. A., section measured and described by 18-19
Cherty shale member of Phosphoria formation. age 38-39
definition 28
description 28-29
fossils 38-39
subdivision of the Phosphoria 9
Chugwater formation 3, 8, 11, 34, 35
Cinnabar Mountain in Montana, Shedhorn sandstone 33
Clover Creek greenstone 40
Conant Creek anticline, rocks exposed 31, 34
Condit, D. D., quoted 7
Confusion Range of Utah, rocks 8, 9, 33-34
Contacts, Park City formation 15, 19
Phosphoria formation 20, 22, 23, 26, 31
Shedhorn sandstone 32, 33
Correlation, Park City formation 13, 20, 39-41
Phosphoria formation 21, 23, 26, 39-41
Shedhorn sandstone 32-33
Cressman, E. R., and Swanson, R. W., Shedhorn sandstone 31-33
with Cheney, T. M., Peterson, J. A., Waring, R. G., and Smart, R. A., section measured by 20-21
with McKelvey, V. E., Sheldon, R. P., and Cheney, T. M., Nomenclature 5-11

D

Deer Creek in Idaho, limestone near 26
Distribution, Park City formation 13, 15, 19, 20
of Phosphoria formation 21, 22, 29, 30
Shedhorn sandstone 11, 32-33
Dolomite 12, 30, 34

E

East Humboldt Range in Nevada, rocks 34
Edna Mountain formation 40
Embar formation, use of name 1, 7-8, 10, 11
Environment of deposition, Park City formation 12
Phosphoria formation 23-25, 26-27, 29
Shedhorn sandstone 32

Page

Ervay carbonate rock member, age 37-38
by R. P. Sheldon 19-20
definition and description 19-20
fossils 37-38
subdivision of the Park City 9
Ervay tongue 7-8

F

Facies, regional relationship 2-5
Fauna, age, and correlation of rocks of the Park City age, by James Steele Williams 36-41
Fieldwork 1-2
Fish scales, in phosphorite beds 15, 36-37, 38, 39-40
Fluorite 23
Forellen Peak in Wyoming, Shedhorn sandstone on 33
Forelle tongue 7-8
Fort Hall area, phosphatic shale in 2
Fossils, collected in Mexico 40
Ervay carbonate rock member 37-38
Franson member 19, 37, 41
Gerster formation 33
Grandeur member 36-37
Meade Peak member 23, 24, 25, 38, 39-40
Park City formation 12, 36-38
Phosphoria formation 38-39
Rex chert member 26, 27
Retort phosphatic shale 39
rocks of Park City age 12, 36-38
Tosi chert member 39
Word formation 40
Franson Canyon, stratigraphic section 15, 18-19
Franson member, age 37
Franson member, by T. M. Cheney 15-19
definition 15, 18
distribution 19
fossils 37
lithologic character 19
stratigraphic section 18-19
subdivision of the Park City 9
thickness 19
type locality 15, 19
Freezeout Hills, rocks of Phosphoria age 2

G

Gerster formation, age 40
description 8, 33-34
fossils 33
Glauconite 12, 19, 23, 26, 32
Goose Creek Mountains, rocks 34
Goose Egg formation, use of name 7-8, 34, 35
Gosman, R. F., and Peterson, J. A., section measured by 31-32
Grandeur member, age 8, 36-37
definition 12
distribution 12, 13-14
environment of deposition 15
fossils 36-37
stratigraphic section 12-13, 32
subdivision of Park City 9
thickness 12
Grandeur tongue of the Park City formation, definition and description 15
distribution 15
Grizzly Creek, exposures of cherty shale member of Phosphoria formation along 28
Gros Ventre Range, rocks exposed 22, 31
Gypsum 2, 12

H

Hogback Mountain, rocks of 15, 33
Hobble Creek area, Utah, fossils from 36

Page
Hogup Mountains, rocks 34
Huddle, John W., section measured by 35

I

Irghina beds 41

J

Jackson Hole region 29–30

K

Kaibab limestone 33–34
Kazanian beds 40
Kungurian beds 41

L

Lander, Wyo., fossils from 36–38
Leach Mountains, rocks 34
Leonard age, rocks 39
Limestone, in Park City formation 12
near Wolf Creek in Utah 34–35
Literature cited 41–42
Lower chert member, age 38
by R. P. Sheldon 22
description 22
fossils 38
stratigraphic section 20
subdivision of the Phosphoria 9
Lower member of the Shedhorn sandstone 9, 32–33

M

McCloud formation 40
Mackentire Draw, Utah, rocks 34–35
Mackentire tongue 34–35
Madison Range of Montana, Shedhorn sandstone 31, 32
Mansfield, G. R., and Richards, R. W., quoted 25
Meade Peak 22
Meade Peak phosphatic shale member, age 38
definition 22
environment of deposition 23–24
fossils 23, 24, 25, 38, 39–40
lithologic character 22–23
mode of precipitation of sediments 24–25
phosphorite 23–25
stratigraphic section 21
subdivision of the Phosphoria 9
Middle Piney Lake 22
Mill Creek Canyon, stratigraphic section of Grandeur member 12–13
Montello, Nev 2
Mule Draw in Utah, stratigraphic section in 35

N

Nine Mile Ridge, rocks 34
Nomenclature, by V. E. McKelvey, E. R. Cressman, R. P. Sheldon and T. M. Cheney 5–11
history 5–8
of other units of Park City age, by T. M. Cheney and R. P. Sheldon 33–36
plan of 9–10
justification 10–11
summarized 1
problems 8–9
North Stewart Canyon in Idaho, rocks 26
Nosoni formation 40

O

Oil 10
Oil shale 29
Oquirrh formation 33
Owenyo formation 40
Owl Creek Mountains, Tosi chert member 30

P

Park City age, rocks of, regional and intercontinental correlation 39–41
Park City district, Utah, type locality of Park City formation 7
Park City formation, correlated with beds of Permian age in Russia 40–41
definition 1, 9, 11–12
environment of deposition 12
Ervay carbonate rock member 19–20
fossils 12, 36–38
Franson member 15–19
general description, by R. P. Sheldon and T. M. Cheney 11–12
Grandeur member 12–15

Page
Park City formation, stratigraphic section 31–32
subdivisions 9, 12
use of name 7, 8, 11
Park City group, description 34
Permian rocks, in Russia 40–41
Peterson, J. A., and Gosman, R. F., section measured by 31–32
with Cheney, T. M., Waring, R. G., Smart, R. A., and Cressman, E. R., section measured by 20–21
Phosphoria formation, cherty shale member 28–29
correlated with beds of Permian age in Russia 41
definition 20
diagram of sequence of rocks 6
distribution 2
fossils 38–39
general description 20–21
lithologic character 2–5, 20–21
lower chert member 22
mappability 9
Meade Peak phosphatic shale member 22–25, 38–39
Retort phosphatic shale member 29–30
Rex chert member 25–28
stratigraphic section 20–21, 31
subdivisions 9
thickness 2, 4
Tosi chert member 30–31
use of name 1, 7–8, 9–11, 33
Phosphoria Gulch, Idaho, 7, 20, 25–26
Phosphoria sea, depth of, as a control of deposition 5
sequence of rocks deposited along 5
Phosphorite 2, 5, 10, 12, 15, 20–25, 27, 29, 30
Pierce, W. G., and Andrews, D. A., quoted 8
Plympton formation 33–34
Powell, J. W., quoted 10
Pyrite 23, 26, 28

Q

Quadrant formation, use of name 5, 7
Quadrant Mountain, Shedhorn sandstone in 33
Quadrant quartzite. *See* Quadrant formation.

R

Red beds 2, 5, 19, 34–35
Retort Mountain, stratigraphic section near 29
Retort phosphatic shale member, age 39
by R. W. Swanson 29–30
definition and description 29
environment of deposition 30
fossils 39
stratigraphic section 29
Rex chert member of Phosphoria formation, age 38–39
environment of deposition 26–27
definition 25–26
fossils 37–38
lithologic character 26
organic precipitation 27–28
stratigraphic section 20–21
subdivision of the Phosphoria 9
use of name 7
Rex Peak 7, 25
Richards, R. W., and Mansfield, G. R., quoted 25
Road metal, cherty shale member 28
Russian classification of Permian rocks 40

S

Sage Creek in Idaho, limestone near 26
Salt River Range, Phosphoria formation 15, 22, 30
Schwagerina beds 40
Seven Devils volcanics, age 40
Shedhorn Creek, stratigraphic section near 31–32
Shedhorn sandstone, by E. R. Cressman and R. W. Swanson 31–33
definition 1, 9, 31
distribution 11, 32–33
environment of deposition 32
lithologic character 32
lower member 32–33
stratigraphic section 31–32
subdivisions 9
upper member 33

Page

Sheldon, R. P., Ervay carbonate rock member ... 19–20
lower chert member ... 22
Tosi chert member ... 30–31
and Cheney, T. M., Nomenclature of other units of Park City age ... 33–36
Park City formation, general description ... 11–12
with Cheney, T. M., Swanson, R. W., and McKelvey, V. E., Park City formation, Grandeur member ... 12–15
with McKelvey, V. E., Cressman, E. R., and Cheney, T. M., Nomenclature ... 5–11
Silica, in Rex chert ... 26–28
Small Horn Canyon, type locality of Retort phosphatic shale member ... 29
Smart, R. A., with Cheney, T. M., Peterson, J. A., Waring, R. G., Smart, R. A., and Cressman, E. R., section measured by ... 20–21
with Warner, M. A., Waring, R. G., and Cheney, T. M., section measured and described by ... 18–19
Snake River Range ... 22
Snowdrift Mountain, section ... 20–21
Sosio beds ... 41
Stratigraphy, regional ... 2–5, 33–36
Stratigraphic section, Franson member ... 18–19
Grandeur member ... 12–13
Mackentire tongue ... 35
Phosphoria formation ... 20–21
Retort phosphatic shale ... 29
Shedhorn sandstone ... 31–32
Tosi chert member ... 30
Sublett Range, character of rocks ... 2, 15, 23, 26
Swanson, R. W., Retort phosphatic shale member, Phosphoria formation ... 29–30
and Cressman, E. R., Shedhorn sandstone ... 31–33
with Cheney, T. M., Sheldon, R. P., and McKelvey, V. E., Park City formation, Grandeur member ... 12–15
Sybille tongue ... 7–8

T

Tartarian beds ... 40
Teton formation, use of name ... 1, 5, 7, 10
Teton Range of Wyoming, rocks exposed ... 5, 22, 33
Thickness, Park City formation ... 12, 19
Phosphoria formation ... 21, 22, 26, 29, 30
Shedhorn sandstone ... 32–33
Thomas, H. D., quoted ... 11
Three Forks, Mont., fossils ... 36
Timber Creek in Idaho, limestone near ... 26

Page

Tosi chert member, age ... 39
by R. P. Sheldon ... 30–31
description ... 30
definition ... 30
distribution ... 30–31
fossils ... 39
subdivision of the Phosphoria ... 9
Type locality, Park City formation ... 7, 12
Phosphoria formation ... 20, 21

U

Uinta Mountains, rocks ... 13, 31–35
Upper member, subdivision of the Shedhorn sandstone ... 9, 33

V

Volcanic material, in Phosphoria formation ... 27

W

Warner, M. A., section measured by ... 30
Waring, R. G., with Cheney, T. M., Peterson, J. A., Smart, R. A., and Cressman, E. R., section measured by ... 20–21
with Warner, M. A., Smart, R. A., and Cheney, T. M., section measured and described by ... 18–19
Smart, R. A., Waring, R. G., and Cheney, T. M., section measured and described by ... 18–19
Wasatch Mountains, outcrops of Grandeur member ... 12
Weber quartzite ... 7, 13, 15, 36
Weed, W. H., quoted ... 5, 7
Wells formation, assigned to Grandeur tongue of the Park City ... 15
diagram of sequence of rocks ... 6
red beds ... 2, 15
use of name ... 1, 7, 15
Williams, James Steele, Fauna, age, and correlation of rocks of the Park City age ... 36–41
Wind River Mountains, rocks ... 2, 13–14, 30–31, 34
Wolfcamp age, rocks ... 39, 40
Wolf Creek area in Utah, limestone ... 34–35
Wood Canyon in Idaho, rocks ... 26
Woodside formation ... 34–35
Word formation ... 39, 40
Wyoming, oil in rocks of Phosphoria age ... 10
Wyoming Range, Phosphoria formation ... 2, 22

Y

Yellowstone National Park, Shedhorn sandstone ... 32–33
Tosi chert in ... 30–31

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