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Depositional History and Petroleum Geology of the Permian Phosphoria, Park City, and Shedhorn Formations, Wyoming and Southeastern Idaho

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards or stratigraphic nomenclature

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ABSTRACT

Integrated studies of over 500 subsurface control sections and over 200 measured surface sections indicate that paleostructural growth of late Paleozoic structural elements, penecontemporaneous with deposition, markedly influenced the distribution of Permian cyclic lithofacies and carbonate reservoir belts in Wyoming and southeastern Idaho. Major paleostructural features include the Antler orogenic belt, Sublett basin, and Bannock high of southeastern Idaho, the Cortez-Uinta axis, the Wyoming shelf margin, and several paleostructures on the Wyoming shelf, some of which may represent early growth of features that later were involved in Laramide orogenic movements. Identification of paleostructural growth is based on interpretations of depositional environments of Permian facies, along with thickness patterns of Permian as well as pre- and post-Permian stratigraphic units.

The Phosphoria Formation and the equivalent beds of the Park City Formation are divisible into two main depositional cycles, comprising the Franson and Ervay Members, which in turn are separated into subcycles, based on a marker-bed correlation framework, applicable throughout most of the Wyoming shelf province. Marker beds are thin sandy and shaly units that represent widespread clastic deposition across the shelf during low sea level stages at the termination of each subcycle. Reservoir beds are associated with early diagenetic dolomitization of coarse-grained skeletal carbonate mound belts, concentrated along paleostructural high areas of the shelf. Dolomitization of these beds is believed to have been caused by seepage-reflux of high-magnesium waters, with a westward shelf-to-basin gradient during low sea-level stages at the termination of depositional cycles. Deposition of phosphorite and organic-rich dark shale occurred at the time of the maximum regressive and early transgressive stages of the two main cycles. Carbonate-mound buildup of bryozoan, crinoid, brachiopod, oolite-pellet, phylloid algae, and other skeletal debris occurred during maximum transgressive stages when optimum normal seawater circulation systems were present across the shelf.

Thick, organic-rich, dark shale petroleum source-rock beds are present in the Meade Peak and Retort Members of the Phosphoria Formation, with maximum thickness in southeastern Idaho and westernmost Wyoming. A substantial thickness of dark shale is also present in the Green River, Wind River, and Bighorn basins. Isopach maps of post-Permian strata suggest that burial depths in the western area were sufficient for generation of petroleum from the Phosphoria beds to begin as early as Jurassic time. At that time an eastward migration gradient existed across west-central Wyoming, perhaps as far east as the Bighorn Mountains and Casper arch. Late in Mesozoic time, generation and migration should have begun from the source-rock facies farther east in the Green River, Wind River, and Bighorn basins, with a migration gradient into local reservoir belts.

The nature and distribution of stratigraphic facies in the overlying Dinwoody Formation suggest that cyclical depositional patterns characteristic of the Permian continued into the Triassic. The striking difference between the

Phosphoria and Dinwoody sediments is interpreted to have resulted from the worldwide decline and extinction by Triassic time of major elements of the Paleozoic marine biotic assemblages which were largely responsible for the deposition of organic carbonate mound buildups and associated organic-rich sedimentary facies in the Permian and earlier Paleozoic beds.

INTRODUCTION

Permian rocks outcrop extensively in the mountain ranges of Wyoming and southeastern Idaho (Map 0) and are present in the subsurface throughout all of that area. Carbonate reservoirs of Permian age have yielded substantial amounts of petroleum, mostly oil, in the Bighorn and Wind River basins of Wyoming (Map 0). The highly organic phosphatic black shales of the Phosphoria Formation are considered to be the source rocks for this petroleum (Stone, 1967), as well as a major part of that found in other upper Paleozoic reservoirs in Wyoming. Because of petroleum interest, extensive exploratory drilling has been completed in the Permian and underlying Tensleep Sandstone, especially since World War II. Likewise, because of interest in the large Permian phosphorite deposits of western Wyoming and southeastern Idaho, comprehensive outcrop studies of these rocks have been completed by the U.S. Geological Survey and others during the post-war years. Among the more significant publications are those by McKelvey and others (1959), Sheldon (1963, 1967), Sheldon and others (1967), Maughan (1966, 1975), Yochelson (1968), Boyd and Maughan (1973), Gulbrandsen (1966), Burk and Thomas (1956), and Thomas (1934).

The purpose of the present work is to integrate outcrop data and subsurface information in order to relate Permian sedimentary history with reservoir distribution, source rock facies, and potential migration patterns of petroleum accumulation. Information taken from about 250 surface stratigraphic sections and over 500 boreholes was analyzed for detailed stratigraphic, lithologic, biotic, and porosity data. Field work was begun in 1967, under NSF Grant GA 12948, and the subsurface study has continued after 1975 under the Branch of Oil and Gas Resources of the U.S. Geological Survey. The work was completed in 1977, and the report does not incorporate subsurface data made available since that time.

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REGIONAL STRUCTURE AND PALEOSTRUCTURE

The area of study includes the Overthrust Belt of southeastern Idaho and western Wyoming, the adjacent part of the Basin and Range province to the west in southeastern Idaho, and the Wyoming Rocky Mountain foreland structural province to the east as far as the Laramie Range and Bighorn mountains (Map A). A large volume of work has been published on the regional and local structure and structural styles of the Wyoming Rocky Mountain foreland structural province (e.g., Berg, 1962; Blackstone, 1963; Prucha and others, 1965; Sales, 1968; Stone, 1969; Stearns, 1971). Interpretations of structural styles and tectonic history of the overthrust belt have been summarized by Armstrong and Oriel (1965). Other informative work, and in some cases somewhat different interpretations on overthrust belt structure are presented by Eardley (1969, 1972), Crittenden (1961, 1972), Crosby (1970), Royse and others (1975), and Lowell (1977).

Table 1.--List of selected stratigraphic sections

No.	Name	Location	Source of data	Fig. No.
1.	Paris Canyon	sec. 8, T. 14 S, R. 43 E, Bear Lake Co., Idaho	McKelvey and others, 1959	6
2.	Laketown Canyon	sec. 32, T. 13 N., R. 6 E., Cache Co., Utah	Cheney and others, 1953	3
3.	Brazer Canyon	T. 11 N., R. 8 E., Cache Co., Utah	Smith and others, 1952	3
4.	Amerada, Chicken Creek No. 1	sec. 30, T. 22 N., R. 117 W., Lincoln Co., Wyoming	American Stratigraphic Co.	3
5.	South Mountain Pit	secs. 8, 9, T. 23 N., R. 116 W., Lincoln Co., Wyoming	Sheldon, 1963	3, 6, 12
6.	Carter, Meridian Ridge No. 1	sec. 10, T. 26 N., R. 115 W., Lincoln Co., Wyoming	American Stratigraphic Co.	3
7.	Deadline Ridge	sec. 7, T. 27 N., R. 114 W., Sublette Co., Wyoming	Sheldon, 1963	3
8.	Mobil, Tiptop 32-19	sec. 19, T. 28 N., 113 W., Sublette Co., Wyoming	American Stratigraphic Co., Sheldon, 1963	3
9.	Composite - Mtn. Fuel, Bruff No. 1 and Steele Butte	sec. 22, T. 19 N., R. 112 W., Lincoln Co., Wyoming, and sec. 36, T. 33 N., R. 108 W., Sublette Co., Wyoming	American Stratigraphic Co. Measured and sampled by Peterson and Ahlstrand, 1971	3 3
10.	So. Fork Little Wind River	sec. 18, T. 1 S., R. 2 W., Fremont Co., Wyoming	Measured and sampled by Peterson and Ahlstrand, 1971	3
11.	Stanolind B-1, Sage Creek	sec. 4, T. 1 N., R. 1 W., Fremont Co., Wyoming	American Stratigraphic Co.	3
12.	Sinclair, No. 1 Indian, S. Pilot	sec. 4, T. 2 N., R. 1 W., Fremont Co., Wyoming	American Stratigraphic Co.	3
13.	Shell, Pavillion 33x-10	sec. 10, T. 3 N., R. 2 E., Fremont Co., Wyoming	American Stratigraphic Co.	3
14.	Black Rock Ridge	sec. 23, T. 6 N., R. 3 E., Fremont Co., Wyoming	Measured and sampled by Peterson and Ahlstrand, 1971	3
15.	Red Creek	sec. 8, T. 8 N., R. 3 E., Fremont Co., Wyoming	Measured and sampled by Peterson and Cole, 1970	3
16.	Argo Oil, Govt. No. 51, Hamilton Dome	sec. 14, T. 44 N., R. 98 W., Hot Springs Co., Wyoming	American Stratigraphic Co.	3
17.	Pioneer-Phillips, Golden Eagle No. 1	sec. 12, T. 45 N., R. 97 W., Hot Springs Co., Wyoming	American Stratigraphic Co.	3
18.	Phillips No. 1A, Mesa	sec. 27, T. 46 N., R. 96 W., Hot Springs Co., Wyoming	American Stratigraphic Co.	3
19.	Anderson-Pritchard, No. 1 Blue Ridge	sec. 33, T. 47 N., R. 95 W., Washakie Co., Wyoming	American Stratigraphic Co.	3, 6, 10
20.	Tiger Oil, No. 1 Holly Sugar	sec. 26, T. 47 N., R. 93 W., Washakie Co., Wyoming	American Stratigraphic Co.	3
21.	Tenneco, Frisby Fed. No. 1	sec. 24, T. 47 N., R. 92 W., Washakie Co., Wyoming	American Stratigraphic Co.	3
22.	Pan American No. 37 Cottonwood Creek	sec. 9, T. 47 N., R. 91 W., Washakie Co., Wyoming	American Stratigraphic Co.	3, 6

Table 1.--List of selected stratigraphic sections--Continued

No.	Name	Location	Source of data	Fig. No.
23.	Stanolind, Govt. Elliott No. 1	sec. 29, T. 48 N., R. 90 W., Washakie Co., Wyoming	American Stratigraphic Co.	3
24.	Gulf, S. Nowood No. 1	sec. 31, T. 48 N., R. 89 W., Washakie Co., Wyoming	American Stratigraphic Co.	3
25.	Tensleep Canyon	T. 48 N., R. 88 W., Washakie Co., Wyoming	J. McCune, 1953 Measured and sampled by Peterson and Gilmour, 1967	3
26.	Crazy Woman Cr.	T. 49 N., R. 83 W., Johnson Co., Wyoming	Hose, 1954	3
27.	Pure Schoonover No. 1	sec. 20, T. 48 N., R. 76 W., Johnson Co., Wyoming	American Stratigraphic Co.	3
28.	Texas, Adon No. 1	sec. 2, T. 52 N., R. 72 W., Campbell Co., Wyoming	American Stratigraphic Co.	3
29.	Rock Canyon-Fort Hall	T. 4 to 6 S., R. 37, 38 E., Bannock Co., Idaho	Smart and others, 1954 O'Malley and others, 1953	4, 5
30.	Fall Creek	sec. 17, T. 1 N., R. 43 E., Bonneville Co., Idaho	Sheldon, 1963 Measured and sampled by Peterson and Brittenham, 1967	5
31.	Argument Ridge	T. 4 N., R. 42, 43 E., Madison Co., Idaho	Gere, Schell and Moore, 1966	5
32.	Patterson Creek Ridge	sec. 34, T. 4 N., R. 44 E., Teton Co., Idaho	Gere, Schell and Moore, 1966	5
33.	Mahogany Ridge	sec. 22, T. 4 N., R. 44 E., Teton Co., Idaho	Gere, Schell and Moore, 1966	5
34.	Forellen Peak-Jackson Lake	T. 47 N., R. 116 W., Grand Teton National Park, Wyo.	Sheldon, 1963	5, 6
35.	Red Creek	Approx. T. 49 N., R. 113 W., Yellowstone Natl. Park, Wyo.	Sheldon, 1963	5
36.	Continental Oil, No. 1 S. Shoshone	sec. 25, T. 50 N., R. 105 W., Park Co., Wyoming	American Stratigraphic Co.	5, 9
37.	South Sage Creek	T. 9 S., R. 45 E., Caribou Co., Idaho	Brittenham, 1973	4, 6
38.	Bradley Mtn.-Wolf Creek	T. 37 N., R. 117 W., Lincoln Co., Wyoming	Wanless and others, 1955	4
39.	Steer Creek	sec. 9, T. 36 N., R. 116 W., Lincoln Co., Wyoming	Sheldon, 1963	4
40.	Buck Creek-E. Cream Puff Mtn.	secs. 1, 12, T. 38 N., R. 115 W., Teton Co., Wyoming	Sheldon, 1963	4
41.	Dell Creek-E. Shoal Creek	secs. 17, 20, T. 39 N., R. 112 W., Sublette Co., Wyo.	Sheldon, 1963	4
42.	Rock Creek	sec. 12, T. 38 N., R. 111 W., Sublette Co., Wyoming	Sheldon, 1963, 1972	4
43.	Sheep Mountain	sec. 36, T. 39 N., R. 109 W., Sublette Co., Wyoming	Sheldon, 1963	4
44.	Dinwoody Lakes	sec. 6, T. 4 N., R. 5 W., Fremont Co., Wyoming	Sheldon, 1963; measured and sampled by Peterson and Ahlstrand, 1971	2, 4

Table 1.--*List of selected stratigraphic sections*--Continued

No.	Name	Location	Source of data	Fig. No.
45.	Union Oil and Carter, Heath - Govt. No. 1	sec. 35, T. 22 N., R. 115 W., Lincoln Co., Wyoming	American Stratigraphic Co.	12
46.	Continental 23-1 Hams Fork	sec. 23, T. 20 N., R. 116 W., Lincoln Co., Wyoming	American Stratigraphic Co.	12
47.	Mountain Fuel Co. Church Buttes 21	sec. 28, T. 16 N., R. 112 W., Sweetwater Co., Wyoming	American Stratigraphic Co.	6, 12
48.	Mountain Fuel Co. No. 4 UPRR	sec. 11, T. 19 N., R. 104 W., Sweetwater Co., Wyoming	American Stratigraphic Co.	6, 12
49.	Texaco No. 15 Table Rock	sec. 2, T. 18 N., R. 98 W., Sweetwater Co., Wyoming	American Stratigraphic Co.	6, 12
50.	Tenneco No. 1 USA	sec. 26, T. 19 N., R. 90 W., Carbon Co., Wyoming	American Stratigraphic Co.	12
51.	Dry Bread Hollow and Hardy Hollow	sec. 14, T. 7 N., R. 3 E., and sec. 2, T. 5 N., R. 2 E., Weber Co., Utah	Measured and sampled by W. Gere and E. Schell, 1964	6
52.	California Co. Rawhide No. 1	sec. 4, T. 48 N., R. 101 W., Park Co., Wyoming	American Stratigraphic Co.	6
53.	Goose Egg Post Office	sec. 12, T. 32 N., R. 81 W., Natrona Co., Wyoming	Burk and Thomas, 1956	6
54.	Sublett Range	T. 12 S., R. 29 E., Cassia Co., Idaho	McKelvey and others, 1959	2
55.	Deep Creek Mtns.	T. 9, 10 S., R. 31, 32 E., Power and Bannock Cos., Idaho	Trimble and Carr, 1976 Sando, 1967	2
56.	Chesterfield Range	T. 7 S., R. 40 E., Bannock Co., Idaho	Sando, 1967 Armstrong, 1953	2
57.	Snowdrift Mtn.	T. 9, 10 S., R. 45 E., Caribou Co., Idaho	Montgomery and Cheney, 1967 Cressman, 1964	2
58.	Salt River Range	T. 34 N., R. 117 W., Lincoln Co., Wyoming	Sando, 1967	2
59.	Hoback Canyon	T. 39 N., R. 115 W., Teton Co., Wyoming	Wanless and others, 1955 Strickland, 1960	2
60.	Mobil F14-44S	sec. 4, T. 50 N., R. 103 W., Park Co., Wyoming	American Stratigraphic Co.	9
61.	Richfield, Front Ridge No. 1	sec. 6, T. 50 N., R. 101 W., Park Co., Wyoming	American Stratigraphic Co.	9
62.	Marathon, Hallone No. 7	sec. 29, T. 51 N., R. 100 W., Park Co., Wyoming	American Stratigraphic Co.	9
63.	Fundamental Oil, Fed. No. 1	sec. 15, T. 50 N., R. 100 W., Park Co., Wyoming	American Stratigraphic Co.	9
64.	Sohio, Simms No. 1	sec. 13, T. 50 N., R. 100 W., Park Co., Wyoming	American Stratigraphic Co.	9
65.	CRA, Inc., Chorney State No. 1	sec. 16, T. 49 N., R. 99 W., Park Co., Wyoming	American Stratigraphic Co.	9
66.	Husky, Torgenson No. 1, Five Mile	sec. 29, T. 49 N., R. 93 W., Big Horn Co., Wyoming	American Stratigraphic Co.	9

Table 1.--List of selected stratigraphic sections--Continued

No.	Name	Location	Source of data	Fig. No.
67.	Pure, Worland No. 1	sec. 18, T. 48 N., R. 92 W., Washakie Co., Wyoming	American Stratigraphic Co.	9
68.	Stanolind, Cottonwood Cr. No. 1	sec. 2, T. 47 N., R. 91 W., Washakie Co., Wyoming	American Stratigraphic Co.	9
69.	Ohio, Tensleep OPC No. 5	sec. 31, T. 48 N., R. 90 W., Washakie Co., Wyoming	American Stratigraphic Co.	9
70.	Gulf, No. 1 Mills	sec. 31, T. 48 N., R. 89 W., Washakie Co., Wyoming	American Stratigraphic Co.	9
71.	Hamilton Dome Oil, No. 11-A	sec. 18, T. 44 N., R. 97 W., Hot Springs Co., Wyoming	American Stratigraphic Co.	10
72.	Argo Oil, No. 51 Hamilton Dome	sec. 14, T. 44 N., R. 97 W., Hot Springs Co., Wyoming	American Stratigraphic Co.	10
73.	Phillips, No. 1 Golden Eagle	sec. 12, T. 45 N., R. 97 W., Hot Springs Co., Wyoming	American Stratigraphic Co.	10
74.	Phillips, No. 1-A Blue Mesa	sec. 27, T. 46 N., R. 96 W., Hot Springs Co., Wyoming	American Stratigraphic Co.	10
75.	Baldwin Creek	T. 33 N., R. 101 W., Fremont Co., Wyoming	King, 1957; measured and sampled by Peterson and Ahlstrand, 1968	11
76.	Woodson Oil, Tribal 1-7651	sec. 13, T. 2 S., R. 1 E., Fremont Co., Wyoming	American Stratigraphic Co.	11
77.	Atlantic Oil, No. 4, Tribal	sec. 36, T. 1 S., R. 4 E., Fremont Co., Wyoming	American Stratigraphic Co.	11
78.	Continental Oil, Tribal 12-2	sec. 12, T. 1 S., R. 5 E., Fremont Co., Wyoming	American Stratigraphic Co.	11

Almost all petroleum produced from the Phosphoria and equivalent beds has been found in anticlinal structures around the borders of the Bighorn basin and along the southern and western flanks of the Wind River basin. These accumulations are primarily oil, rather than gas, and in most cases, fields producing from the Phosphoria also produce from the underlying Tensleep Sandstone (Map O).

Structural evolution of the overthrust belt extended from late Mesozoic through early Tertiary time, with maximum intensity in the early Tertiary (Armstrong and Oriel, 1965; Oriel and Armstrong, 1966). The present-day configuration of the ranges and basins of the Wyoming Rocky Mountain foreland structural province evolved mainly during middle to late Tertiary time. Structural growth of the Basin and Range province occurred mainly during the late Tertiary. Thus, the present-day structure of the area is largely the result of late Mesozoic and Tertiary tectonic growth of the northern Rocky Mountains. There is, however, increasing evidence for earlier paleostructural growth of many of the "Laramide" structural elements. Some of these paleostructures may have influenced sedimentary patterns across the Wyoming shelf province through much of Paleozoic time. The presence of an active paleostructural framework during the Pennsylvanian and Permian is indicated by interpretations of sedimentary environments, early diagenetic processes, distribution of facies, and thickness patterns. The major elements which appear to have directly or indirectly influenced sedimentary facies and cyclic depositional patterns in Wyoming and southeastern Idaho during the late Paleozoic are shown on Map B. Important regional features are the Antler orogenic belt, the Cortez-Uinta axis, the Sublett basin, the Wyoming shelf, and the Transcontinental arch. A more regional discussion of many of these features and their relation to Paleozoic paleostructure and sedimentation in the western United States is given by Roberts and others (1965), Roberts (1968), Bissell (1962), Hintze (1973), Peterson (1973, 1977), and Stewart and Poole (1974).

The Phosphoria depositional basin is a late stage of the long-subsiding Paleozoic Sublett basin of south-central Idaho and adjacent area in which a great thickness of Paleozoic sediments was deposited. Phosphoria deposition is differentiated by the distinctive sedimentary facies of dark shale, phosphatic shale, phosphorite and bedded chert of Permian age that contrast with the underlying Paleozoic sediments which are mostly shallow water carbonates, sandstone, and some shale. The Cortez-Uinta axis separates the Sublett or Phosphoria basin from the Oquirrh basin of Utah.

Rapid westward thickening of Paleozoic sediments occurs along a north-south belt approximately coincident with the Wyoming shelf margin, near the Wyoming-Idaho border, although shelf-type sediments are present for variable distances to the west. This line of thickening is generally referred to as the "Wasatch Line" (Kay, 1951), or the "Wasatch-Teton Line" (Grose, 1972). Crustal shortening related to Laramide thrusting, however, exaggerates the rapidity of westward thickening as shown by palinspastic reconstructions presented in this report and elswhere (e.g., Hintze, 1973; Peterson, 1977). Estimates of thrust movement in the Idaho-Wyoming overthrust belt are given by Armstrong and Oriel (1965), Royse and others (1975), and in numerous other publications on local structures. Thrust displacement distances used in this report are taken largely from the maps and cross-sections by Royse and others (1975).

Evidence for pre-Laramide Cretaceous growth of Laramide uplifts in Wyoming is discussed by Stearns and others (1975), and Royse and others (1975). Stratigraphic evidence for pre-Cretaceous growth is difficult to obtain because: (1) pre-Laramide structural movements on the Wyoming shelf were much less intense than those of the Laramide, and (2) much of the pre-Cretaceous stratigraphic section has been removed by post-Laramide erosion. However, detailed analyses of sediment thickness and facies patterns suggest the presence of paleostructural elements, several of which coincide closely with uplifts and basins of Laramide age. The influence of these paleostructural features is best shown on Maps K and L, isopach maps of the interval between Permian marker P-30 (base of Meade Peak Shale Member) and the top of the Mississippian Madison Limestone. This interval, which includes the Lower Permian, Pennsylvanian, and part of the uppermost Mississippian, is largely composed of clastic sedimentary rocks, and thickness patterns tend to reflect the influence of late Paleozoic structural heterogeneities on the Wyoming shelf. Thickness maps by Mallory (1967), Mallory and others (1972), Foster (1958), Bates (1955), Maughan (1964, 1966), and others indicate patterns similar in general to those of Map L, allowing for some difference in interpretation of isopach data. The interval isopached on Maps K and L underlies the Franson Member and provides evidence for the paleostructural system present on the Wyoming shelf at the time of Franson and Ervay carbonate mound growth. Regional mid-Permian land areas and paleostructural features of the northern Rocky Mountains are discussed by Maughan (1966), who proposed a rectilinear system of northwest-southeast and northeast-southwest trending faults and folds that affected Permian sediment distribution and facies relations. Further substantiation for parts of these regional paleostructural trends is shown on several of the illustrations in this report (fig. 3; Maps C, D, G, H, L).

The more important paleostructural features are designated as "highs", "lows", or "troughs" rather than "uplifts", "highlands", or "downwarps" because there is no evidence that they underwent strong tectonic movements during Permian time. The "low" or "troughs" were more rapidly subsiding deeper-water areas of the shelf and the "highs" were less rapidly subsiding shallower-water areas that became low-lying islands during low sea-level stages. High areas are recognized by thinning and sometimes increased grain size in clastic sediments and by thickening and increase in percentage of skeletal content in carbonate facies. A brief discussion of individual features for which there is sedimentological evidence for late Paleozoic paleostructural activity follows. More detailed analyses of their effects on facies distribution are included with discussions of individual Permian stratigraphic units.

The Bannock high is located in the vicinity of the Bannock and Bear River ranges in southeastern Idaho which contain exposures of lower Paleozoic and Precambrian rocks. This area, called the "Cache Uplift" by Eardley (1968), appears to be in part related to the feature described earlier by Williams (1962), in studies of Pennsylvanian rocks, as the "Bannock Highland". West of this feature the Paleozoic section thickens very rapidly into the Sublett basin. Further evidence of the paleostructural validity of this feature, in modified form, is described in this report, and the name "Bannock High" is retained. Stratigraphic and sedimentological evidence for the antiquity of this area as a major shelf margin province during most of Paleozoic time is discussed by Peterson (1973, 1977). Evidence for Mesozoic ancestry of the Bear River Range is presented by Armstrong and Oriel (1965), and Royse and others (1975). The Permian expression of the Bannock high appears to have been the site of a secondary shelf or platform about 100 miles (160 km) west of the main Wyoming shelf margin. The presence of this secondary platform is especially evident when palinspastic adjustments are made to account for eastward tectonic transport of the stratigraphic sections used in construction of isopach and facies maps and cross-sections.

The Moxa high (Map K) occupies a portion of the Wyoming shelf margin and lies generally along the western side of the Green River basin. Evidence of the paleostructural nature of this feature is discussed by Wach (1977), Stearns and others (1975), and Thomaidis (1973).

The Green River trough lies east of the Moxa high approximately in the position of the Laramide Green River basin.

The Rock Springs high lies along the eastern side of the Green River trough and coincides closely with the Laramide Rock Springs uplift.

The Washakie low approximately coincides with the Laramide Washakie basin.

The Wind River high coincides with the Laramide Wind River Range but is displaced slightly northeast of its present-day axis.

The Absaroka-Owl Creek high coincides approximately with the Laramide Absaroka Range and Owl Creek Mountains belt.

The Yellowstone high trends northwest-southeast across Yellowstone Park and projects southeastward along the west and southwest flanks of the Bighorn basin. This feature may be related to the Devonian high designated as the Yellowstone Park Uplift by Sandberg and Mapel (1967).

The Wind River trough follows the general shape and trend of the Laramide Wind River basin.

The Bighorn high extends northwest-southeast and occupies generally the area covered by the present-day southwest flank of the Bighorn Mountains and the northeast flank of the Bighorn Basin. This feature may be the northwestern part of a mid-Permian structural trend called the "Horn Fault lineament" by Maughan (1966). Thinning of Pennsylvanian rocks along this trend is shown by Mallory (1967) and Tenney (1966).

The Casper high occupies the area of the Casper arch (platform) and falls along the Horn Fault lineament of Maughan (1966).

The Sweetwater high coincides closely with the present-day Sweetwater uplift. This paleostructure is in the vicinity of one designated by Mallory (1967) as the "Pathfinder uplift" of Pennsylvanian age which apparently includes an area encompassing that of the present-day Sweetwater uplift (Granite Mountains), the Casper arch, and the northern part of the Laramie Range.

The Laramie high follows approximately the present-day trend of the Laramie Range. Thinning of Pennsylvanian rocks in this area is shown by Tenney (1966), Mallory (1967), and Mallory and others (1972).

The Laramie trough follows generally the trend of the present-day Laramie and Hanna basins.

The Front Range high coincides with the north end of the Front Range uplift of late Paleozoic age described by several authors, including Mallory (1967), Mallory and others (1972), Maughan (1966, 1978), and Tenney (1966).

The Powder River trough extends northwest-southeast across northeastern Wyoming about 50 miles northeast of the present-day axis of the Powder River Basin. This feature is prominent on thickness maps of Pennsylvanian rocks and has been described as the "Lusk embayment" (Bates, 1955; Tenney, 1966).

REGIONAL STRATIGRAPHY AND DEPOSITIONAL SETTING

Nomenclature

The Phosphoria Formation and equivalent beds of Wyoming and southeastern Idaho were deposited in the northern part of the broad ancestral Rocky Mountain shelf (Wyoming shelf) and the adjacent Cordilleran Miogeosyncline (Map B). The formation was defined by Richards and Mansfield (1912) as a sequence of dark-gray to black phosphatic shale, phosphorite, chert, and some carbonate rock, which occurs between the underlying Wells Formation and the overlying Triassic Dinwoody Formation, exposed at Phosphoria Gulch, north of Montpelier, Idaho. Cheney and others (in McKelvey and others, 1959) subsequently separated dolomite and sandstone beds of the upper part of the Wells into the Grandeur Member of the Park City Formation of Permian age (fig. 1). The Phosphoria was defined primarily on the basis of its phosphatic shale and chert content, but later work showed that the formation changes facies rapidly eastward and in places along the Wyoming-Idaho border is made up primarily of carbonate rock and dark phosphatic shale, with minor chert. Carbonate rocks are common in parts of the section across much of western and central Wyoming, and sandstone dominates the unit in part of southwestern Montana (Shedhorn Formation). McKelvey and others (1959) separated these three facies of the Phosphoria and equivalents into three lithologic units, a western dark phosphatic shale and chert facies (Phosphoria Formation), a northern sandstone facies (Shedhorn Sandstone), and a central carbonatic facies (Park City Formation). The Park City Formation had been defined earlier by Boutwell (1907) for a thick carbonate rock section of Permian age in the Wasatch Range east of Salt Lake City, Utah. The Park City terminology applies to the broad belt of shelf carbonate rocks extending northward through central and western Wyoming, but the name has generally not been widely used in Wyoming by industry geologists, who commonly assign to the Phosphoria Formation the interval of carbonate rock, chert, dark shale, and minor sandstone lying between the Tensleep Sandstone or the Wells Formation and the Triassic Dinwoody Formation. To the east the Phosphoria or Park City beds grade into the dominantly redbed and evaporite section of the Goose Egg Formation (figs. 1, 3).

Nomenclature problems of the Phosphoria and equivalents stem largely from the complexly intertonguing nature and varied lithology of the sequence across the Wyoming shelf. While the main distinguishing feature is the generally phosphatic nature of the unit, intertonguing of carbonate, dark shale, phosphorite, sandstone, chert, green shale, redbeds, and anhydrite are prevalent in different areas of the Wyoming shelf province (fig. 6). However, the relatively distinctive and varied lithology of the Phosphoria serve to separate it rather prominently from the more consistent lithology of the underlying Tensleep Sandstone and the overlying Dinwoody Formation.

Tectonic Setting

Distribution of Permian facies is strongly influenced by the regional paleotectonic-paleogeographic setting of the northern Rocky Mountains (Map B). The Phosphoria depositional basin represents the latest Paleozoic expression of the Sublett basin of southeastern Idaho, a regional subsiding foreland basin of the Cordilleran Miogeosyncline lying between the Antler orogenic belt and the Wyoming shelf during most of Paleozoic time. The Wyoming shelf, a segment of the ancestral Rocky Mountain shelf province, is used informally to designate the broad area of shelf carbonate and clean marine and eolian sand deposition lying between the Sublett basin, or Cordilleran Miogeosyncline, on the west and the ancestral Williston basin and Alliance or Julesberg basin on the east, along the border of the Paleozoic Transcontinental arch. The Wyoming shelf is commonly depicted as a broad relatively featureless shelf of shallow water marine deposition. During much of early and middle Paleozoic time, this may have been the case. However, during late Paleozoic time, stratigraphic evidence suggests that the Wyoming shelf was characterized by significant relief, related to ancestral growth of paleostructural features that may have evolved into the later system of Laramide structures. The influence of these ancestral high and low areas had a marked effect on depositional processes and the development of porous reservoir beds in the shelf area.

The central part of the Phosphoria basin was apparently the site of predominantly dark shale and dark cherty shale deposition during Late Permian Leonardian and Guadalupian time (McKelvey and others, 1956, 1959). Along the eastern and southern margins of the basin, phosphatic deposits accumulated in upwelling areas, a result of the prevailing northerly wind direction of the time (Sheldon and others, 1967). Most of the basin was not enclosed by marginal land areas, rather the boundaries were made up of more slowly subsiding paleostructural features that probably had been inherited from older Paleozoic structures. The basin was bounded on the north by the Lemhi uplift, on the east by the Wyoming shelf margin, on the south by the Permian expression of the Cortez-Uinta axis, and on the west by the Antler orogenic belt (Map B).

PHOSPHORIA STRATIGRAPHY AND DEPOSITIONAL SETTING

Stratigraphic Framework

The Phosphoria and Park City Formations are divided into several lithologic members, (some of which are locally called tongues) of relatively wide distribution. In general, these are concentrations or lateral extensions of the five main Permian facies: dark shale and phosphorite, chert, carbonate, sandstone, and redbed-evaporites. Carbonate beds are the most laterally widespread of the facies, with tongues extending eastward, some as far as the Williston basin and Black Hills of North and South Dakota (Minnekahta, Forelle, Ervay Members). These carbonate tongues, particularly the Minnekahta, are excellent key-bed correlation units in the Goose Egg (and equivalent) redbed-evaporite facies across the Powder River and Williston basins (fig. 3). To the west, however, where the carbonate tongues merge with the main carbonate facies, their usefulness as correlative marker beds diminishes. The Park City carbonate beds are abundantly fossiliferous in many places, but in general, detailed correlations within the Phosphoria are difficult across central and western Wyoming and southeastern Idaho because of the non-zonal nature of the fossil assemblages and the complex facies interrelations. However, detailed outcrop and subsurface studies indicate the presence of widespread clastic marker-bed horizons within the main carbonate and chert facies across the Wyoming shelf. These markers, some of which coincide with lithologic unit boundaries, are associated with southward extending tongues of the Shedhorn Sandstone facies and are recognizable in both subsurface and outcrop sections (figs. 1, 4, 5, 6, 9, 10, 11, 12). The most useful and widespread marker horizons are believed to represent surfaces of increased clastic sediment influx, combined with emergence and erosion in topographically high areas, during times of regressive, low sea-level. In deeper water areas of depositon the marker beds are represented by thick, commonly very argillaceous carbonate or evaporite rocks or dark shale and siltstone. On the basis of these marker-beds, the Phosphoria and equivalent units are separated into cycles and subcycles. Each marker-bed is believed to be approximately contemporaneous and represents a single event of depositional history, defined as follows (oldest to youngest):

First Cycle:

P-10 - A disconformity at the base of the Grandeur Member, or the top of the Tensleep or Wells Formation.

Second Cycle:

P-30 - A disconformity at the base of the Meade Peak Member.

P-35 - The top of the Meade Peak Member, or base of the lower Franson Member.

P-40 - A disconformity and sandy interval at the top of the lower Franson Member, or base of the middle Franson Member.

P-50 - A disconformity and sandy interval marking the base of the upper Franson Member, or top of the middle Franson Member.

Third Cycle:

P-70 - A disconformity at the top of the Franson Member, or base of the Retort Member.

P-75 - The top of the Retort Member, or base of the Tosi Member.

P-80 - A disconformity marking the base of the Ervay Member.

P-90 - A disconformity at the top of the Ervay Member, or base of the lower Dinwoody Formation (the Permian-Triassic unconformity).

Origin and Distribution of Phosphoria Facies

The cyclic nature of Permian deposits in western North America has been discussed by several authors, including McKelvey and others (1959), Sheldon (1963), McKee and others (1967), Peterson (1969, 1971), Meissner (1970), Boyd and Maughan (1973), and Maughan (1975). Permian and late Paleozoic cyclicity is recognized in many parts of the world, but expression of the cycles differs in various areas, depending not only on local and regional paleotectonic activity, but also on the dominant sedimentary facies of the area--clastic, carbonate, evaporite, or combinations of these. Causes of late Paleozoic cyclicity are a subject of some controversy, involving eustatic, tectonic, and climatic factors (Moore, 1950; Wanless, 1950, 1967; Weller, 1964; Coogan, 1969; Jacka and others, 1967; Meissner, 1970). Most authors emphasize some degree of eustatic sea-level change that may be modified by local and regional tectonic movements in the depositional and sediment-source provinces.

Permian deposits in the northern Rocky Mountains comprise a highly variable facies complex that falls into three main depositional cycles, the first cycle (P10-P30), second cycle (P30-P70), and third cycle (P70-P90). Each cycle is bounded by marker beds and contains variable amounts of all of the principal facies (dark shale, phosphorite, chert, carbonate rock, sandstone, redbeds, and evaporites), with the fullest cyclic development expressed in the upper or third (P70-P90) cycle. Each main cycle begins with a widespread phosphatic unit that grades upward into cherty beds, with fossiliferous shelf carbonate at the top. Smaller, incomplete cycles, or subcycles, are identifiable within each major cycle.

The basal dark shale and phosphorite unit achieves maximum development in the western part of the shelf province. Across most of the shelf area, the dark shale and phosphatic unit lies disconformably on the underlying beds and in places contains phosphatic sandstone or sandy bioclastic beds at the base. The dark shale generally grades upward into chert or cherty carbonate beds, and finally to skeletal carbonate beds that show carbonate mound buildup and prograde laterally outward from the topographically higher parts of the submergent shelf. In most shallow-water areas, e.g., on paleostructural highs, the upper beds of the cycle are overlain disconformably by the basal beds of the next cycle, commonly with evidence of erosion and scour.

The three main cycles are believed to be related primarily to transgressive-regressive sea-level changes, with the transgressions proceeding farther east across the Wyoming shelf with each succeeding cycle. Thus, the various major facies of the Third (P70-P90) cycle tend to occur farther east than the equivalent facies of the second (P30-P70) cycle, and the facies of the first (P10-P30) cycle are less extensive and may not have been deposited completely across the Wyoming shelf. The first cycle contains a large percentage of sandstone beds, and is underlain disconformably by the thick quartzose sandstone section of the Tensleep, Quadrant or Wells Formation. During each of the two succeeding cycles, skeletal carbonate becomes increasingly more abundant in the shallow water areas of the shelf, culminating in the substantial Ervay carbonate-mound or biohermal accumulations that contain the major share of Permian carbonate reservoirs in Wyoming.

FIRST (P10-P30) CYCLE (GRANDEUR MEMBER)

The Grandeur Member represents the lowermost major transgressive-regressive cycle of Permian sedimentation in the northern Rocky Mountains. Rocks of this cycle are dominated by sandy dolomite, sandstone (or quartzite), and chert, with minor gray shale and rare phosphorite along the border of the western basin. In shallow-water depositional areas of the Wyoming shelf, these beds lie with marked unconformity on the Pennsylvanian Tensleep Sandstone surface, in most places overlying sandstone or quartizite of probable Desmoinesian age (figs. 3, 4, 5, 6). The unconformable surface commonly is prominently undulating or channeled, and there is a sharp contrast between the relatively evenly bedded Grandeur sandy dolomite and carbonatic sandstone and the underlying highly cross bedded Tensleep Sandstone. In basinal areas of the shelf, however, this contrast is not as great and the contact between the Grandeur and Tensleep may be difficult to locate. Because adequate paleontological data are lacking, the magnitude of the hiatus represented by the unconformity is difficult to determine, but it may represent a substantial part of Late Pennsylvanian and Early Permian time, during which halite and gypsum beds in the Wolfcampian and Leonardian upper Minnelusa Formation or the lower part of the Opeche Shale were deposited in western Nebraska and north-eastern Colorado. The hiatus, in part, also represents non-deposition or erosion of Missourian and Virgilian strata, particularly in central Wyoming.

To the west, in southeastern Idaho and westernmost Wyoming, the Grandeur becomes gradational with the underlying Wells Formation, although they may be differianted in some places by the thicker and more dominant dolomite and chert beds in the Grandeur. Phosphatic beds are not prominent in the Grandeur, but some thin phosphorite and dark shale occurs in the basal part of the unit in northern Utah, and scattered thin phosphorite, phosphatic shale, or sandy beds are also present locally in western Wyoming, southeastern Idaho, and northern

Utah (McKelvey and others, 1956, 1959; Cheney, 1957; Sheldon, 1963).

The Grandeur is probably early Leonardian in age (Yochelson, 1968) and appears to represent a single major transgressive-regressive cycle. However, precise correlations within the unit have not been made, and the abundant evidence of erosion and sharp bedding contacts within the unit on the Wyoming shelf, suggest the possible presence of minor cycles.

The Grandeur Member represents a transition from the dominantly clean, well-sorted sandstone facies of the Tensleep, Quadrant, Wells, or Weber Formation upward to the predominantly clean shelf-carbonate facies of the Park City or Phosphoria Formation. Increase in carbonate deposition is probably related to more widespread marine inundation of the shelf, coupled with a probable decrease in supply of quartzose sand from the northern source provenance.

SECOND (P30-P70) CYCLE

The second cycle represents the second major transgressive-regressive sequence of Permian sedimentation that includes the Meade Peak Phosphatic Shale and Rex Chert Members of the Phosphoria Formation, the Franson carbonate member of the Park City Formation, and the Opeche Shale, Minnekahta Limestone, Glendo Shale, and Forelle Limestone Members of the Goose Egg Formation (fig. 1). The second cycle is further divided on the basis of clastic marker beds into four subcycles.

P30-P35 Subcycle (Meade Peak Member)

The phosphorite and dark shale beds of the Meade Peak Phosphatic Shale Member contrast sharply with the sandy carbonate, sandstone, and chert of the underlying Grandeur Member. In the basin slope area of southeastern Idaho and westernmost Wyoming, the Meade Peak contains a lower and an upper interval of thick phosphorite beds. Both phosphorite intervals thin eastward approximately along the western margin of the Wyoming shelf. East of the shelf margin area, the basal Meade Peak beds are somewhat sandy and oolitic or bioclastic in topographically high depositional areas, and they are silty to sandy and less phosphatic in basinal low areas of the Wyoming shelf (fig. 3). In the Wind River Range and Owl Creek Mountains, and over a broad area south of Yellowstone National Park, the basal beds commonly contain a thin phosphatic sandstone. On the outcrop in these areas the contact with the underlying Grandeur is consistently sharp and undulating, and in places clasts of carbonate or chert and rarely quartzite are common in the lower few inches of the Meade Peak beds. In these areas a second erosion surface, less prominent than that at the base of the Meade Peak, is present in the upper part of the member, suggesting a secondary regression during deposition of the Meade Peak sequence (figs. 4, 5). In depositional position, the maximum thickness of phosphorite occurs in a more or less arcuate pattern in southeastern Idaho at least 80 km (50 mi) basinward (west) of the main shelf margin (Map E). From here the net thickness of phosphorite decreases westward into the Phosphoria basin as well as eastward toward the shelf. Between the upper and lower phosphorite intervals, the Meade Peak consists mainly of dark shale, with interbeds of dark fine-grained argillaceous carbonate, chert and some phosphorite. Most of the Meade Peak beds are dark brownish gray to brownish black and are exceptionally high in organic carbon content. Maximum thickness of the member is in southeastern Idaho, approximately coinciding with the area of maximum phosphorite content. The unit thins somewhat along the Idaho-Wyoming border, but thickens again in the Green River basin. In the central and eastern Wind River Range, the Meade Peak beds are thin and somewhat sandy to oolitic, grading eastward into green and then red shale and siltstone in the Wind River and Bighorn basins.

The basal Meade Peak disconformity is interpreted to represent a regional regression associated with falling sea level which followed the transgressive phase of the lower cycle. During this time, the topographically high areas of the Wyoming shelf were probably emergent, dry, and swept by northerly winds, which covered the exposed Grandeur surface with a veneer of fine-grained eolian quartz sand, silt, and clay. Weathering and solution of the emergent carbonate and sandstone beds were probably minimal because of the extremely dry climate. As maximum regression and lower sea level were attained, the Phosphoria basin to the west became restricted in circulation and reached maximum concentration of dissolved matter, including phosphate. In the slope area along the shelf margin, phosphorite beds formed in an elongate north-south belt where upwelling currents were dominant (for further discussion of this process, see McKelvey and others, 1959; Sheldon, 1963; Brongersma-Sanders, 1948). Maximum phosphorite deposition occurred along the western borders of the Bannock high, a feature that may have persisted through much of Paleozoic time (figs. 3, Map E).

In southeastern Idaho and westernmost Wyoming, the basal Meade Peak contains abundant bioclastic phosphatic brachiopod beds high in P_2O_5 content (the "fish scale" phosphorites). Concentration of probable planktonic phosphatic brachiopod debris in this area may be related not only to increased phosphate concentration by upwelling of basin waters but also to near-emergence of the basin margin during lowered sea level, with accompanying submarine winnowing and reworking of accumulating shell and other phosphatic sediment. Increased restriction of the basin may also have resulted in periodic extinction of basin edge organic communities during times of excessive upwelling or algal bloom. Additional reworking of the accumulating shell debris probably formed the basal "fish scale" phosphorites during maximum low sea level west of the partially emergent Wyoming shelf. Similarly, some phosphatic brachiopod material from the shelf edge could have been carried farther into the basin and reworked as sea level lowered. Finally as the basin reached maximum restriction at lowest sea level stage, the upwelling area then became a toxic zone of mass mortality where fecal material and the remains of phosphatic organisms and plankton were concentrated.

Phosphatic deposition along the eastern slope of the basin continued as sea level began to rise, but the locus of maximum phosphate deposition shifted eastward as rising sea level inundated the Wyoming shelf. At the same time, in southeastern Idaho, phosphorite accumulation was replaced by deposition of dark organic-rich mud, dark carbonate mud, and siliceous mud in the middle part of the Meade Peak. Occasional regressive fluctuations in sea level probably resulted in the temporary return of phosphorite deposition to the Bannock high shelf area, accounting for the interbedded thin phosphorites in the middle Meade Peak. As transgression progressed across the Wyoming shelf, the deposition of organic-rich muds shifted eastward and succeeded phosphorite deposition. The dark shale facies extends eastward as far as west-central Wyoming where the Meade Peak is dominated by sandy and oolitic phosphatic beds deposited in shallow water areas. Following deposition of the major part of the Meade Peak in western Wyoming and southeastern Idaho, a secondary regression and fall of sea level occurred and parts of the shelf were temporarily exposed. During this regression and the early phases of the subsequent transgression, the upper phosphorite beds of the Meade Peak were deposited. Meanwhile, the Phosphoria depositional basin remained relatively restricted, and unusually high concentrations of organic carbon were deposited.

The upper Meade Peak transgression was apparently relatively rapid, and the entire Wyoming shelf area was quickly inundated. At this time the Phosphoria basin became less restricted, open circulation was partly restored, and the basin water chemistry became more nearly normal marine. Phosphorite deposition again shifted eastward on to the shelf area and was followed by deposition of dark mud and dark siliceous mud and finally by skeletal shelf carbonate beds as sea level continued to rise and basin-to-shelf circulation patterns were restored. These events resulted in the gradational upper contact between the Meade Peak and the overlying carbonate or chert beds of the Franson or Rex Members, with the sedimentary facies grading both upward and laterally from shale to shaly chert to shelf carbonate rocks of the lower Franson (figs. 3, 4, 5).

P35-P40 Subcycle (Lower Franson Member)

The Franson Member is divisible into lower, middle, and upper marker-defined units, identifable in the subsurface as well as in outcrop sections (figs. 1, 6). The Franson facies is present across most of central and western Wyoming and extends northward into southwestern Montana. A short distance west of the Idaho-Wyoming border, the carbonate rocks of this member grade rapidly into and intertongue with the bedded chert facies of the Rex Chert Member in southeastern Idaho and in extreme southwestern Montana (figs. 3 and 4; Maps C, D). Carbonate bioherms occur within the cherty facies west of the main transition from carbonate to chert (Brittenham, 1976).

The maximum thickness of the Franson Member occurs as a northward trending carbonate belt near the southern Wyoming-Idaho border. These beds are composed largely of crinoid, bryozoan, and brachiopid debris and are extensively dolomitized, particularly in the central and eastern parts of the belt (fig. 3; Maps C, D). Much of the dolomite facies is porous, with as much as 20 to 30 ft (6 to 9 m) of beds of greater than 10 percent porosity.

The lower part of the Franson is generally more cherty than the upper part which contains much more abundant skeletal crinoid and bryozoan debris. Thin tongues of the lower Rex Chert Member extend eastward in the lower Franson. Skeletal carbonates are prevalent in the northwestern Wind River Range and adjacent area, but except for the upper part, the unit grades into argillaceous carbonate rocks and green carbonatic shale in the remainder of central and north central Wyoming. The carbonate rock content increases in percentage along the northeast flanks of the Wind River Range and the Owl Creek Mountains and in general around the borders of the Bighorn, Wind River, and Green River basins (figs. 9, 10, 11). Subsurface sequences in the central part of these basins generally are made up of dark argillaceous limestone and dark shale beds. The Franson grades into predominantly redbeds and anhydrite or gypsum beds of the Goose Egg Formation along a north-south belt through central Wyoming. Tongues of carbonate rock, the Minnekahta and Forelle Members, extend eastward within the redbed-evaporite facies as far as eastern Wyoming and the Dakotas.

The main shelf carbonate buildup in the lower Franson is concentrated approximately along the shelf margin, although some shelf carbonate beds are also present farther east, higher on the shelf (figs. 3, 4, 5, 6, 7). Carbonate deposition also spread far to the east to deposit the Minnekahta Member in eastern Wyoming and the Dakotas. Initial growth of skeletal bioherms or carbonate mounds on the Bannock high may also have occurred during the maximum sea-level rise of this subcycle.

The close of lower Franson deposition is marked by a minor regression as evidenced by the presence of a thin, relatively widespread sandy unit (P-40 marker) that is phosphatic in places, especially to the west along the shelf edge. Evidence of minor erosion in the basal part of the clastic unit is found in the commonly undulatory and sharp contact between this unit and the underlying rock. During this erosion period, the higher parts of the shelf apparently were briefly emergent, and northerly-derived eolian sand spread across the emergent surface, to be reworked by the advancing strand line of the succeeding subcycle. Some phosphorite, although minor in thickness, was deposited at this time along the western margin of the shelf, and probably the halite and gypsum beds of the lower Spearfish Formation were deposited in eastern Wyoming and western Nebraska.

P40-F50 Subcycle (Middle Franson Member)

The sequence of deposits in the middle Franson approximately repeats the sequence in the lower Franson except: (1) carbonate bioherms or mound buildups are prominent along the western borders of the Bannock high, and (2) in general there is considerably less bedded chert in the shelf facies of this subcycle.

The carbonate bioherms in southeastern Idaho have been studied in some detail by Brittenham (1973, 1976). These skeletal buildups are unusual in several respects: (1) their thickness (up to 200 ft or 60 m), (2) their direct association with the bedded Rex Chert Member facies (in some cases the thick chert sequence changes facies to fossiliferous carbonate beds in a distance of only a few hundred yards or meters), (3) their isolated occurrence in southeastern Idaho, along the western margin of the Bannock high, and (4) their general coincidence with the maximum thickness and maximum phosphorite content of the underlying Meade Peak (fig. 4; Maps C, E).

The bioherms consist mainly of a great abundance of crinoid, brachiopod, and bryozoan debris and seem obviously to have formed in shallow water, suggesting by their close association with the bedded Rex Chert Member facies that the chert also must have formed in relatively shallow water. The reasons for their isolated and seemingly anomalous occurrence have been discussed by others (Yochelson, 1968; Brittenham, 1973, 1976). Yochelson suggests that they are fossil banks that co-existed during chert deposition and were localized on a firmer and slightly shallower part of the sea bottom. Brittenham suggests that they formed along a shelf margin basinward of the main Franson carbonate facies. A consideration of the paleogeography of the Phosphoria depositional basin suggests a genetic relationship between the carbonate bodies and their areal coincidence with maximum phosphorite and maximum shale (Mead Peak) development. Palinspastic maps (Maps C, E) indicate that the biohermal as well as the phosphatic maxima occur along the western boundary of the Bannock high, suggesting that the western margin of this paleostructural feature formed a hingeline break in slope between the main basin and the outer shelf margin and provided the requisite conditions for localization of these facies along a major belt of upwelling at succeeding stages of the depositional cycle. Maximum phosphate formed here because of upwelling conditions at the slope break during a phase of lower sea level, higher phosphate concentration, and restricted circulation which was succeeded by organic carbonate and chert deposition when more normal seawater circulation systems were restored in the basin during the rising sea-level stages.

It is of interest to note that the maximum thickness of Rex Chert Member also occurs at approximately the same geographic position as the bioherms and the belt of maximum phosphate deposition (Maps D, F). Upwelling along the shelf edge may have stimulated the growth of siliceous sponge communities and thereby established the main belt of chert deposition. Offshore upwelling here may also have aided the growth of siliceous microorganisms which could have contributed significantly to accumulation of the chert.

Middle Franson deposition closed with a second marine regression and partial emergence of the Wyoming shelf during which a clastic unit similar to that overlying the previous subcycle was deposited. Part of the halite and gypsum beds of the Spearfish Formation were deposited in eastern Wyoming and western Nebraska during this regression which appears to have been of somewhat shorter duration than the previous one, with less of the shelf emergent (fig. 7). The overlying clastic marker unit is somewhat phosphatic in places and contains minor thin phosphorite layers and some pebbly layers derived from the underlying carbonate and chert beds.

P50-P70 Subcycle (Upper Franson Member)

The upper Franson represents the final transgressive stage of the second major cycle, with skeletal shelf carbonate mounds widespread in the shallow water areas of the Wyoming shelf. The carbonate buildups are larger than those of previous subcycles, and during this time the main bioherm building in southeastern Idaho probably occurred as basin and shelf circulation reached a maximum, and relatively normal marine conditions were approached.

Upper Franson carbonate beds are commonly dolomitized and contain most of the better porosity of the Franson Member. The porous dolomite facies is best developed in four areas: (1) along the east side of the shelf margin carbonate facies belt in the vicinity of the Idaho-Wyoming border, (2) along the north or northeast side of the Wind River Range, (3) along the north side of the Owl Creek Mountains, and (4) along the east side of the Bighorn basin. Each of these trends is believed to be the site of ancestral structural highs on the Wyoming shelf where the carbonate mounds reached maximum growth and were probably exposed and dolomitized at the close of each cycle. The isolated bioherms in southeastern Idaho, described by Brittenham (1976), however, are composed entirely of fossiliferous limestone rather than dolomite and consequently, although oil-stained, lack significant porosity. The absence of evidence for significant erosion at the top of these bioherms indicates that they probably remained submergent at the lowest sea-level stage of the cycle and thus escaped dolomitization.

In the deep subsurface of the Green River and Wind River basins, Franson beds are predominantly dark argillaceous carbonate rock and shale, with a single anhydrite bed at the top of the interval. In the Bighorn basin, the Franson sequence is dominated by redbeds, evaporites, and dolomite in the central part of the basin, grading westward to gray shale, limestone or dolomite, and sandstone. The character of the basin facies indicates that the ancestral basin areas of the shelf, as well as the main Phosphoria basin, including the biohermal belt, were not emergent during the lowest sea-level stage of the cycle.

Completely normal marine conditions probably were never achieved in the Phosphoria sea, as judged, not only from the character of lithofacies, but also from the paucity of normal marine Permian faunas. The upper Franson shelf carbonates beds, as well as those of the succeeding Ervay limestone Member of the overlying major cycle, are characterized by accumulations of crinoids, bryozoans, spiriferid and productid brachiopods, phosphatic brachiopods, mollusks, and some phylloid algae. Important elements of the Permian biota, which occur in carbonate facies in other parts of the Cordilleran miogeosyncline (fusulinids, small foraminifera, corals, trilobites) are either absent or very rare in the Franson and Ervay carbonate facies. The reasons for this have been considered by Yochelson (1968) who suggests that low water temperature may have been the major cause. Several factors of Permian paleogeography and facies distribution offer further possibilities. For example, the Phosphoria sea was located near the predicted Permian equatorial belt, the climate was very dry, temperature and evaporation rates very high, wind direction was apparently generally from the north or northeast across the shelf area, a phosphatic-rich foreland basin lay to the west, and a major evaporite area to the east. These conditions should have resulted in the wind-transfer of surface waters across the shelf from the eastern evaporite basins. Intermixing of saline waters from the east should have resulted in higher than normal salinity at times. Dry climate and high evaporation rates would tend to further increase the salinity on the shelf area, with a consequent adverse effect on marine biota.

The effect of temperature on biotic assemblages may have been of major importance, and cooler waters brought onto the shelf by upwelling must have occurred at times, especially during high sea-level stages. This may explain the absence of corals, small foraminifera, and fusulinids in the more fossiliferous shelf carbonate beds. However, the presence of numerous coral specimens, some foraminifera, and abundant spiriferid brachiopods in the biohermal facies in southeastern Idaho (Brittenham, 1973, 1976) suggests a normal warm-water environment in that area, where maximum upwelling in the Phosphoria sea must have occurred. Upwelling onto the main expanse of the Wyoming shelf should have been less effective than along the main break in slope of the western shelf margin, thus decreasing the possibility of cool-water invasion of the shelf as an environmental factor. The near-equatorial position and the shallowness of the water on the shelf as well as the intermixing of abnormally warm waters from the eastern evaporite area should have increased water temperatures on the shelf. These interpretations suggest that high, rather than low water temperatures, coupled with probable higher salinity, may at times have been factors influencing the nature of life assemblages on the Wyoming shelf.

A major part of the Franson carbonate facies, including the bioherms in southeastern Idaho, were deposited during the upper part of the cycle. The cycle closed with a major regression, general emergence of the shelf area, deposition of halite and gypsum in the lower Spearfish Formation of eastern Wyoming and western Nebraska, and increased restriction and phosphate concentration in the basin to the west. The succeeding cycle was in general a repetition of the Franson deposition except for an overall increase in quartz sand content and a general eastward or northeastward shift of the dark shale, chert and shelf carbonate facies across the Wyoming shelf.

THIRD (P70-P90) CYCLE

The third major cycle of Permian sedimentation contains essentially the same facies as those of the Franson, but with differences in geographic position, thickness and volume, and in some cases lateral extent of the various facies. This cycle includes the Retort Phosphatic Shale, Tosi Chert, and Ervay Carbonate Rock Members of western and central Wyoming, the upper cherty shale member of southeastern Idaho, and the Ervay Carbonate Rock and Difficulty Shale Members of eastern Wyoming (fig. 1).

P70-P75 Subcycle (Retort Member).

The Retort Member is grossly similar to that of the Meade Peak except that the locus of phosphorite deposition is shifted farther north and northeast to fall more or less along the Wyoming shelf border, and extending northward into southwestern Montana. The basal beds also contain much more quartz sand than those of the Meade Peak, especially in northwestern Wyoming and adjacent areas of Idaho (figs. 5, 6). An increasing influx of quartzose sand from the northern Shedhorn facies characterizes most of the sediments deposited during the upper cycle. The regression which closed Franson deposition probably resulted in the accumulation of a substantial amount of windblown quartz sand across much of the northern part of the emergent portion of the Wyoming shelf. The advancing Retort seaway then reworked most of the wind-deposited clastics into an extensive basal deposit of longshore marine sand that can be traced from southwestern Montana to west-central Wyoming. Considerable phosphorite deposition also occurred during the early phases of this advancing seaway. Phosphatic sandstone as much as 6-9 m (20-30 ft) thick makes up the basal beds of the Retort in northwestern Wyoming and adjacent Idaho (fig. 5; Maps I, J). The basal sandstone represents an increased supply of quartzose sand in the Shedhorn facies to the north, which was probably derived from the Canadian Shield or Alberta shelf (Milk River uplift of Maughan, 1966; and Sheldon, and others, 1967). The basal sandstone commonly contains phosphatic brachiopod shell material, in places quite abundant. The unit grades upward into oolitic, pelletal, and sandy phosphorite that extends across at least the western half of the Wyoming shelf. The phosphorite beds in turn grade upward to dark-gray to brownish-black shale which in some places contains thin beds of phosphorite in its middle and upper part. The upper phosphorite sequence at most localities grades into overlying dark shale that is overlain by interbedded dark shale and chert, or shaly chert and thin-bedded chert (the main body of the Tosi Chert Member). Farther eastward, chert beds grade both laterally and upward into fossiliferous shelf carbonate rocks that are part of the Ervay Carbonate Rock Member. Along the western shelf margin a similar lateral gradation from basinal dark shale to shaly chert, bedded chert, and, finally, to carbonate rock can also be demonstrated (figs. 4, 5, 7).

The occurrence of phosphorite beds in the upper part of the Retort Member probably represents a temporary regression at the close of the subcycle and the initial deposition of the overlying subcycle. These relationships are very similar to those previously described for the Meade Peak-lower Franson units. Thus, the Retort facies is the result of two transgressive-regressive subcycles developed during the early rising sea-level phase of the major cycle.

Maximum occurrence of phosphorite in the Retort is in southwestern Montana, and the belt of high phosphorite extends southeastwardly into western Wyoming approximately through the Jackson area. This phosphorite trend occurs near the western margin of the Wyoming shelf, in contrast with that of maximum Meade Peak phosphorite which, in palinspastic depositional position, is about 165 km (100 mi) farther southwest, along the margin of the Bannock high in Idaho (Map E). The northeastward shift of phosphorite occurrence in the Retort appears to be related to at least two factors: (1) a greater overall rise of sea level and possible westward tilting of the shelf margin, resulting in greater eastward transgression during the Retort-Tosi transgression; the resultant locus of maximum upwelling shifted eastward from the margin of the Bannock high in southeastern Idaho onto the Wyoming shelf where two areas of phosphorite deposition occurred, one approximately along the shelf margin and the other along the Wind River high, and (2) probable erosion of much of the Retort facies from the general area of the shelf margin during the regressive lower sea-level event following deposition of the Phosphoria cycles and prior to deposition of the basal Dinwoody beds. The relative importance of these two factors in explaining the present-day patterns of Retort phosphatic facies distribution is difficult to assess because almost all post-Franson Permian beds have been removed along the Wyoming shelf margin (Maps G, I).

P75-P80 Subcycle (Tosi Member).

Tosi deposition began with renewed transgression following the upper regressive phase of the Retort Member. With rising sea level and restoration of basin-to-shelf circulation patterns, the depositional facies rapidly changed upward to dominantly shaly chert and bedded chert. Laterally, the facies of this subcycle change from dark shale and cherty shale in the west (on the outer shelf and basin slope) to interbedded shaly chert and chert on the shelf to the east in west-central Wyoming (figs. 4, 5). The chert facies of the shelf grades into skeletal shelf-carbonate rock on depositionally high areas of the shelf. East of the skeletal carbonate province, the carbonate facies grades into and intertongues with the eastern redbed-anhydrite facies (figs. 3, 9, 12; Map H).

Organic and oolitic-pelletal carbonate mound deposits in the Tosi-equivalent beds are concentrated along a belt extending from the eastern Bighorn basin southward to the Rock Springs uplift, with northwestward extension along the Wind River high and the Absaroka-Owl Creek high. These carbonate beds are largely composed of crinoid, bryozoan, brachiopod, and phylloid algae material that grades eastward to carbonate mound deposits composed largely of oolitic pellets and phylloid algae. At many places the carbonate rocks are somewhat cherty and thin- to medium-bedded. Eastward, the carbonate mound facies commonly grades to fine-grained laminated stromatolitic and mudcracked tidal flat carbonate rocks interbedded with redbeds and anhydrite. The chert facies is widespread, but carbonate deposition predominated wherever the biotic communities of the shelf were able to flourish in areas of shallow, clear water, generally along the trend of paleostructural highs.

The predominance of chert in this subcycle may be related to the shelf water chemistry during the early stages of the main cycle. The high organic carbon content of the Retort-Tosi facies may have resulted in bottom waters of higher acidity which enhanced concentration and precipitation of silica. Likewise, the higher concentration of silica may have provided a favorable environment in which sponges and other siliceous skeletal communities flourished on the seaward borders of the Shedhorn sand facies and within deeper parts of the shelf. Similar reasons seem to explain the chert distribution in the lower Franson and Rex Chert beds in southeastern Idaho and westernmost Wyoming, where the main chert facies occupies the basin slope or Bannock high area.

The precise upper boundary of the Tosi subcycle is somewhat difficult to determine. However, a thin clastic, often phosphatic, unit with sharp and often undulating lower contact (the P-80 marker horizon) is present in most outcrop sections and can be correlated through the subsurface across most of the shelf. This unit is believed to represent a brief regression and partial exposure of the shelf prior to the final maximum rising sea-level phase of the third cycle.

P80-P90 Subcycle.

The P80-P90 subcycle represents the maximum transgressive phase and the main Ervay carbonate deposition of the third cycle and shows many characteristics similar to those of the upper Franson, with respect to the nature of the carbonate buildup. However, there are at least three major differences in facies distribution between the upper Franson and the upper Ervay units: (1) Ervay Carbonate Rock Member beds are absent in most of the belt of maximum Franson carbonate buildup in westernmost Wyoming, southeastern Idaho, and southwestern Montana, (2) the maximum development of the Ervay carbonate facies occurs much farther east on the Wyoming shelf, and (3) the Shedhorn Sandstone facies occurs farther south and dominates a large part of the shelf extending from southwestern Montana into northwestern Wyoming south of Yellowstone National Park. Eastward shift of the shelf carbonate facies is related in part to the extent of sea-level rise, shifting the optimum environment for shallow water organic production farther eastward than for the upper Franson. In northwestern Wyoming, the western extent of the Ervay is limited by the presence of the southward extending Shedhorn Sandstone facies which dominated the depositional environments there and precluded the growth of biotic communities necessary to produce the carbonate buildups. The prominent influx of Shedhorn sand from the north may be related to two factors; (1) an increase of quartz-sand supply in the source area, or (2) the northward transgression of the Ervay shoreline to rework and redistribute the major supply of sand that may have accumulated in central and western Montana during the emergence of that area in Late Pennsylvanian and Early Permian time. In either case, an increased supply of sand was transported southward and southeastward by longshore current and wave systems of the Ervay seaway. This condition is similar to that observed at the close of upper Franson deposition when a significantly increased supply of sand moved from the north to intertongue with carbonate sediments of the upper Franson.

The upper Ervay carbonate buildups contain abundant bryozoan, crinoid, and brachiopod remains and, in some cases, a significant percentage of phylloid algal remains. Oolitic and pelletal carbonate beds are also prominent in places, particularly along the eastern and southern borders of the Bighorn basin (figs. 3, 4, 9, 10, 11, 11, 12; Map H). The upper Ervay carbonate facies prograded significantly westward during the maximum transgressive stage of the cycle. These beds grade into the upper part of the Tosi Chert Member facies or into the Shedhorn Sandstone facies along a line approximately coincident with the eastern border of Yellowstone National Park and extending southward across western Wyoming, just east of the overthrust belt. The sand facies prograded southward across the Yellowstone high during this time and grades into either the carbonate facies (Ervay) or the Chert facies (upper Tosi) a short distance south and southeast of the Park.

The third cycle closed with widespread emergence of the Wyoming shelf, and probably most of the area of the Rocky Mountain shelf. The boundary between the Dinwoody Formation and the underlying Permian strata is generally sharp and seems to be disconformable, although evidence is lacking for considerable erosion of the underlying rocks during this time. The contact apparently marks the Permian-Triassic boundary, although determination of the ages of these rocks has been hampered by the lack of diagnostic fossils, particularly in the lower Dinwoody beds (Newell and Kummel, 1941; Yochelson, 1968; Boyd and Maughan, 1973).

LOWER DINWOODY FORMATION

The lower Dinwoody sequence shows a gross similarity to the main depositional cycles of the Phosphoria-Park City facies, although in detail there are many differences. In the basin area of southeastern Idaho, the Dinwoody is composed of gray to green-gray shale and gray, shaley, silty, fine-grained carbonate rocks. Eastward, carbonate rocks become more dominant, reaching a maximum approximately in the vicinity of the Wyoming shelf margin. Predominantly gray, argillaceous or silty fine-grained limestone makes up much of the Dinwoody along the shelf margin, grading eastward to dominantly green shale, siltstone, and interbedded silty limestone (fig. 7). The entire unit grades farther east into redbeds and some gypsum or anhydrite in central and eastern Wyoming. Thus, most of the basin-to-shelf facies relations observed in the Permian cycles also occur in the Dinwoody, and the regional depositional geometry and paleogeography appear to have changed little at the beginning of the Triassic. In this sense, the Dinwoody depositional environments demonstrate a repetition or continuation of those characteristic of the Permian. However, there are many differences in details, some of which are listed as follows:

1. Evidence of basal Dinwoody unconformity: Considerably greater evidence for unconformity can be shown for the contact between the Dinwoody and the underlying Phosphoria-Park City-Shedhorn beds. Part of this analysis is related to the following statements and will be further discussed later.

2. Marked decrease in phosphate content: Some minor basal Dinwoody phosphatic units are found in westernmost Wyoming and southeastern Idaho, but as discussed below, these beds in large part may be the result of reworking of Retort phosphatic shale beds.

3. Marked decrease in organic carbon content: The Dinwoody gray shale facies is markedly lower in organic carbon content than that of the Permian.

4. Total absence of chert: Chert or cherty carbonate rock, prevalent in the Phosphoria Formation, is not present in the Dinwoody Formation, although carbonate beds are commonly silty and often appear to be siliceous.

5. Marked change in carbonate lithology: The Dinwoody carbonates are very fine-grained, not abundantly fossiliferous, and show little or no evidence of mound or biohermal buildup.

6. Marked change in fossil content: The Dinwoody carbonate beds contain very few fossil groups, mainly linguloid brachiopods, a few species of clams, and some ammonoids. These very limited faunal assemblages contrast sharply with the Permian shelf carbonate faunas, which contain abundant broyzoans, crinoids, brachiopods, mollusks, and several other kinds of fossil remains.

7. The redbed-evaporite facies: This facies extends farther west across the Wyoming shelf than similar Permian rocks and occurs farther west progressively upward in the Dinwoody section, until above the Dinwoody all of the Wyoming shelf and adjacent area is covered by redbeds.

8. Decrease in quartz sand (vs. silt) content: Some sandstone units are found in the Dinwoody, but the amount of quartz sand is significantly less than in the underlying Permian Shedhorn Sandstone.

All of these factors are closely related to the analysis of the Permian-Triassic boundary problem but explanations are difficult to document conclusively. However, a consideration of the nature of basin-to-shelf facies and their interrelations, along with regional aspects of Permian and Triassic stratigraphy, paleogeography, climate, and biotic evolution, provide a reasonably adequate basis for analysis. In overview, most of the lithologic changes observed in the Dinwoody beds can be attributed to biotic changes in the composition of the sediments. The marked absence in the Dinwoody of the abundant skeletal carbonate rocks characteristic of the Permian Franson and Ervay beds is most striking. These contrasts must be related to the extinction or marked decrease of most skeletal-producing and mound-building organisms, such as crinoids, bryozoans, brachiopods and other marine invertebrates, that occurred during the closing stages of Permian time. Without such assemblages present in the shelf-margin facies, coarse-grained carbonate mounds could not have built up. Absence of chert also may be related to associated decimation of siliceous sponge assemblages at the close of the Paleozoic. Likewise, extinction of upper Paleozoic marine planktonic assemblages may explain the sparsity of black, organic-rich shale in the Triassic, in contrast to the Permian and older Paleozoic beds. These upper Paleozoic events of biotic change had a profound effect on the nature of Triassic shelf facies, despite the fact that the basic paleogeography and physical sedimentary environment patterns of the shelf and basin provinces were relatively unchanged.

DOLOMITIZATION

Dolomite is common in much of the Permian carbonate facies in the northern Rocky Mountains, particularly in the carbonate beds within and adjacent to the redbed-evaporite facies. Much of the carbonate mound facies is also heavily dolomitized in west-central and western Wyoming. In all cases, dolomitization and reservoir development in the mound facies are most pronounced on the eastern or northeastern side of the facies belts (figs. 3, 4, 7, 10, 11, 12; Maps C, D, H). Distribution patterns of the mound facies, as well as the associated dolomite and porosity patterns, coupled with the paleogeographic and paleostructural system prevalent on the Wyoming shelf, suggests that dolomitization by seepage-reflux (Adams and Rhodes, 1960), was the prevalent mechanism for dolomitization and associated development of porosity. The paleostructural, paleogeographic, and facies relations on the shelf are compatible with a system of seepage-reflux of high-magnesium waters westward through the mound facies during low sea-level evaporitic stages at the close of each cycle. The presence of anhydrite beds at these stratigraphic positions in some outcrops and in wells drilled in the southern Green River Basin, the eastern half of the Wind River and Bighorn basins, and throughout all of the Powder River Basin provide evidence for the presence of large areas of hypersaline water near the end of each cycle. Dolomitization of the shallow water mound facies is most complete along a belt extending from the Rock Springs uplift in south-central Wyoming northward across the southeastern border of the Wind River basin and the east side of the Bighorn basin (Maps D, H). Dolomitization is prevalent here because of the proximity of the belt of skeletal carbonate mounds to the eastern evaporite facies. Also, these carbonate beds were probably the first to be exposed and subjected to seepage-reflux effects as sea level lowered and the shelf gradually became drained of normal sea water, subjecting the area to reflux dolomitization processes for a longer period of time than the sediments farther west. Likewise, during the subsequent transgression these mounds were the last to be submerged as sea level gradually rose across the shelf area. Thus, more time was available for the seepage-reflux process to more completely dolomitize the eastern mound facies. Dolomitization is less complete on the southwestern flank of the Bighorn basin and is relatively minor on the west and north sides of the basin (fig. 9; Maps D, H). On the north side of the basin, an efficient reflux system probably did not develop because the northern shelf was closely adjacent to the land area to the north. On the west side of the Bighorn basin, reflux may have been inhibited by several factors, including greater distance from the source of high-magnesium evaporitic waters, greater distance from a deeper water trough to the west, and a possible barrier effect of the fine-grained, calcareous Shedhorn Sandstone facies immediately to the west of the Ervay carbonate facies. On the southwest flank of the basin, the northeastern part of the mound belt along the Absaroka-Owl Creek high was rather thoroughly dolomitized (figs. 3, 10; Maps D, H). Seepage-reflux here would have been toward the southwest from the low, evaporitic area of the Bighorn trough through the carbonate mound belt and into the subsiding Wind River trough. The pattern of dolomitization along the southwestern flank of the Wind River basin is somewhat similar to that in the Bighorn basin, with more complete dolomitization in the eastern part of the mound belt. The seepage-reflux system here probably was directed across the carbonate mound belt toward the southwest into the ancestral Green River trough (figs. 3, 7; Maps D, H). Reflux in the mound belt along the Rock Springs uplift was directed westward from the eastern evaporitic area into the Green River trough (fig. 12; Maps C, H). The carbonate buildup along the margin of the Wyoming shelf (on the west side of the Green River basin) was not completely dolomitized, although because of its size a large volume of dolomite is present there. Reflux circulation in this area was probably westward from the Green River trough through the mound facies and into the marine Phosphoria basin to the west (figs. 3, 7; Maps C, G, H). The reflux circulation process may have been very effective here, despite the large size of the Franson carbonate buildup, because of the probable steeper westward slope off the mound belt into the open basin to the west.

In summary, the main dolomitization and reservoir patterns are believed to be associated with several seepage-reflux systems, generated during low sea-level regressive stages of the Permian cycles, directly related to the position of paleostructural high and low features of the shelf, which also had determined the depositional position of the carbonate mound facies. Dolomitization did not take place, or was greatly limited, in subsiding ancestral basin areas of the shelf, partly because very fine-grained or argillaceous low-porosity carbonate beds and clastic muds were deposited in the low areas, and also because a sufficient seepage-reflux head could not be established in the bottoms of the ancestral basins. Furthermore, these beds probably remained submergent and were covered with impermeable muds or gypsum during the low-water evaporative stages of the cycles and subcycles.

STRATIGRAPHIC EVIDENCE FOR PERMIAN PALEOSTRUCTURAL GROWTH

Evidence of paleostructural growth correlated with Permian thickness and facies distribution patterns is found not only within the Permian section, but also in the stratigraphic sections below and above. Maps K and L are isopach maps of the interval between the P-30 Permian marker (base of the Meade Peak Shale Member) and the top of the Mississippian Madison Limestone. Several thickness trends on this map coincide generally with trends of Permian facies

1. The north-south belt of thinning (Moxa high) in the overthrust belt which coincides generally with the overlying Franson carbonate bank facies.

2. Northwest-southeast thinning trends in the vicinity of the Wind River Range and Bighorn Mountains where Permian mound belts are mapped. Both thinning belts are parallel with but slightly offset from the axes of the Laramide mountain ranges. A thinning area occurs in the vicinity of the Absaroka Range and continues eastward from there as a general flattening of isopach gradient along the Owl Creek Mountains.

3. Areas of thinning occur along the Rock Springs uplift, the Sierra Madre and Medicine Bow uplifts (Front Range high), and approximately coincident with the Laramie Range.

4. Thickening of the interval is observed in the area of the Green River, Washakie, Wind River, Laramie-Hanna, and the Powder River basins. The paleo-axes of all these thickening belts are offset to some degree from the present day axes of the basins, and similarly the axes of paleo-high areas are offset slightly from the present day axes.

Within the Permian sequence, evidence of paleostructural growth is found in the distribution of shallow and deeper water carbonate and clastic facies, as well as evaporite and phosphorite facies, as judged by interpretations of depositional environments for specific facies. Shallow-water carbonate-mound belts and dolomitized carbonate belts, as well as quartzose sandstone tongues, occur along paleostructural highs. Evidence of erosion such as conglomerate beds and undulating scour surfaces likewise are more prevalent in these areas. Wells drilled in the deeper parts of the Green River and Wind River basins have encountered argillaceous (rather than mound) carbonates, mostly limestone rather than dolomite, and a high percentage of dark shale beds, along with anhydrite beds that in some cases occur at the stratigraphic position of conglomeratic beds or erosion surfaces in outcrop areas. Phosphorite beds are more prevalent on the western sides of paleostructural high features, e.g., the Bannock high, the Wyoming shelf margin, and the ancestral Wind River high (figs. 3, 11), in keeping with the principle of upwelling origin on the downwind seaward side of shallow water shelf or platform areas. The cross-section of figure 3 is constructed on a hypothetical Permian sea-level datum in order to best illustrate the distribution of shelf sedimentary environments, all of which are related to water depth. The effects of using other datum surfaces, and some possible misconceptions involved, are shown schematically on figure 8.

Evidence for continued paleostructural growth during the Mesozoic is found in the thickness patterns of Maps M and N, which in general follow the trends of Laramide ranges and basins.

SUMMARY OF DEPOSITIONAL HISTORY

Origin and distribution of the Phosphoria-Park City-Shedhorn sedimentary facies of the northern Rocky Mountains region is the result of marine deposition of transgressive-regressive cyclic sequences of complexly intertongued chemical and clastic sediments across the northern Rocky Mountain or Wyoming shelf. Cyclic deposition is believed to result primarily from eustatic rise and fall of sea level. Evidence indicates that much of the facies distribution, especially of carbonates, is associated with paleostructural features of the shelf that represent late Paleozoic growth of high and low areas that may have been ancestral to Laramide structural features in Wyoming and southeastern Idaho. Skeletal and oolitic carbonate mound facies dominated the high or shallow-water areas of the shelf during the higher stands of sea level when maximum water circulation was achieved. At the same time, dark fine-grained argillaceous carbonate muds and shales were dominant in the deeper-water ancestral basins or troughs on the shelf; chert, dark shale, and phosphorite dominated in the western basin; and redbed-evaporite facies dominated the sedimentation to the east. Sand tongues projected southward from the Shedhorn facies during regressive and early rising sea-level stages of the cycles. Sandstone and siltstone tongues from a southern or south-eastern source are also present in southwestern and south-central Wyoming.

Transgressive-regressive cyclic sequences are best developed in the second and third cycles. The main cycles are divisible into subcycles correlated on the basis of widespread clastic marker beds. Each of the two main cycles begins with phosphatic deposition and terminates with transgressive carbonate mound beds that are overlain by a disconformity on the shelf. The sequence of events that produced the main cyclic sequences is interpreted as follows (fig. 7 and Map B):

1. The cycle began following regression and lowering of sea level and emergence of the higher parts of the shelf, deposition of gypsum in the low areas, and redbed-gypsum and halite to the east in central and eastern Wyoming. During this time, eolian sand or dust, derived from the north, accumulated on emergent high areas of the shelf. To the west, marine erosion and reworking took place along and immediately west of the shelf margin in westernmost Wyoming and southeastern Idaho. Skeletal phosphorites of the Meade Park Member accumulated farther west in an offshore upwelling belt along the margin of the Bannock high, which remained shallowly submerged during the maximum regressive stage that preceded the cycle.

2. Rising sea level shifted the area of upwelling and phosphate deposition progressively higher onto the shelf, the previously exposed high areas of the shelf became awash, and the eolian sand veneer was reworked into a basal marine phosphatic sand. In places this sand incorporated carbonate or chert clasts loosened from the underlying, partly consolidated beds.

3. Continued rise of sea level deepened the water over the high areas, and because of the influence of northerly winds on upwelling systems, pelletal phosphorite was deposited on the margin of the shelf along the Wyoming-Idaho border, and oolitic to pelletal phosphorites were deposited in the central shelf area along the westward-facing borders of ancestral uplifted features such as the Wind River high and Rock Springs high. Phsophorite deposition also occurred in the lower part of the Meade Peak along the north flank of the Cortez-Uinta axis as far west as northeastern Nevada.

4. Continued rise of sea level deepened the water across the entire shelf, basin-to-shelf circulation systems began to develop, and the entire basin and western shelf area was circulated with nearly normal sea water. Sponge communities developed to the west in the deeper waters of the western shelf, and some carbonate-producing invertebrate assemblages began to flourish in the shallow-water, high areas of the shelf. Deposition of spicular chert became prevalent to the west, grading laterally into intermixed skeletal carbonate and chert on the high areas of the shelf (lower Franson and Tosi beds).

5. Sea level gradually rose to the maximum level of the transgressive cycle, normal marine circulation was restored across the shelf, skeletal or oolitic carbonate mounds built up in the shallow-water high areas, argillaceous fine-grained carbonates and some chert were deposited in the low areas of the shelf, and bedded chert and some carbonate beds formed along the eastern border of the Phosphoria basin. As sea level reached its highest stage and normal sea water circulation reached optimum, organic growth flourished in the bank areas and skeletal carbonate mound facies continued to build and to prograde laterally across the underlying deeper water beds, covering the flanks as well as the crests of paleostructural high areas. To the east of the carbonate mound belt in central Wyoming, a broad expanse of very fine-grained tidal and supratidal carbonate beds were deposited, intermixing with red eolian-derived silt and dust and, in places, with gypsum beds. These carbonate units are the eastward projecting carbonate tongues of the Park City facies.

6. Falling sea level began, the larger carbonate mounds became energent, progradation of the mound facies continued on the flanks of paleostructural highs, and finally mound-building assemblages died out as normal seawater circulation diminished and water salinity increased.

7. Sea level continued to fall toward the minimum level, the entire area of carbonate banks became emergent, water salinity across the shelf continued to increase, with high concentration of magnesium salts. Seepage-reflux systems developed; early lithification, leaching, and dolomitization of the carbonate mound facies occurred, and finally gypsum was deposited in low areas of the shelf which had remained submerged throughout the regressive low sea-level stage. To the west, the foreland basin became restricted in circulation and refluxing saline waters from the shelf increased salinity sufficiently to kill off the siliceous sponge assemblages and other skeletal marine organisms. Organic chert and carbonate deposition ceased, and reworking by basin-edge wave action occurred along the shelf margin, with deposition of skeletal phosphatic beds.

8. Rising sea level began, initiating the succeeding cycle.

PETROLEUM GEOLOGY

Almost all known petroleum accumulations in Permian reservoirs of central and western Wyoming occur in anticlinal or domal traps on the east and west flanks of the Bighorn basin and the southwest flank of the Wind River basin. Most structural fields with Permian production also produce from the underlying Tensleep Sandstone which in almost all cases contains much greater reserves than do the Permian carbonate reservoirs (Map O). An exception to this generality is the largest of the Phosphoria fields, Cottonwood Creek (fig. 9). This field is a major stratigraphic trap on the east flank of the Bighorn basin (McCaleb and Willingham, 1967), which has only minor production from the Tensleep Sandstone.

Thus far, the main Permian accumulations have been found in regional trends of dolomite porosity occurring within belts of carbonate mounds that appear to be associated with paleostructural growth on basin flanks. This statement also applies in general to Tensleep productions; i.e., the main Tensleep production is found also in structures along trends where the overlying Permian carbonate section contains a dolomitized carbonate-mound porosity belt.

Porosity values for construction of reservoir distribution maps were calculated from neutron, sonic, and density logs, using methods devised by logging company engineers. Porosity patterns on the maps of Maps C, D, G, and H represent data from about 500 well logs, compiling net feet of porous rocks with greater than 10 percent porosity. Log-porosity determinations were augmented and confirmed wherever possible by lithologic log descriptions.

Reservoir and Source Rock Distribution

Good porosity in the Permian section of the northern Rocky Mountains is developed primarily in dolomitized carbonate mounds of the Franson and Ervay Members that occur along relatively well-defined facies belts. Porosity is also present in sandstone beds in the Grandeur Member at places in central and north-central Wyoming. However, the Grandeur in these areas is difficult to separate in the subsurface from the underlying Tensleep Sandstone, and for this reason porous Grandeur beds are commonly assigned to the Tensleep. The Grandeur carbonate beds are almost entirely dolomite, usually sandy to silty or cherty and normally of low porosity and permeability. Some porous sandstone tongues of Shedhorn Sandstone occur in the Park City beds above the Grandeur in wells drilled in the northwestern part of the Bighorn basin (fig. 9). However, these are mostly calcareous-cemented, fine-grained sandstone of relatively low permeability.

FRANSON MEMBER

Porous dolomite in the Franson Member is best developed in the uppermost beds of the unit. These reservoirs are related to maximum carbonate-mound buildups at the top of the Franson Member that were penecontemporaneously dolomitized during the low sea-level evaporitic stage at the close of the second cycle. Some porous dolomite is also present in the middle and lower Franson units, usually in the uppermost beds of these subcycles, but in general these reservoirs account for only a small part of the total Franson carbonate reservoir porosity. Major porous belts in the Franson tend to coincide very closely with the maximum dolomitized carbonate-mound facies and the trends of incipient paleostructural highs on the Wyoming shelf. Thus far, all wells drilled in the deeper interior of the Bighorn, Wind River, Green River, and Washakie basins have encountered thinner, usually argillaceous, carbonate beds of low porosity, in comparison with wells on the basin margins where skeletal carbonate beds are more dominant. The greatest porosity in the Franson Member occurs along a north-south dolomitized carbonate-mound buildup on the east flank of the Bighorn basin where the carbonate-rock portion of the unit is entirely dolomite (figs. 3, 9). This belt of high porosity decreases toward the trough of the southeastern Bighorn basin, but the trend of dolomitized carbonate rock may continue southward across the eastern part of the Wind River and Great Divide basins and along the Rock Springs uplift. A band of dolomite and associated high porosity extends northwestward along the east flank of the Wind River Range, coinciding with the ancestral Wind River high.

The broad tongue of porous Franson dolomite that extends northward from the Park City facies of Utah along the western border of the Green River basin is the largest area of porous dolomitized carbonate rock delineated on Maps C and D. The true size of this porous belt is best shown on the palinspastic map of Map C. This carbonate facies contains a large volume of porous beds that, as of this date, are relatively unexplored.

In contrast to the substantial belt of porosity in the Franson Member along the Idaho-Wyoming border, the biohermal mounds to the west, along the Bannock high, show very little porosity on the outcrop, although some oil staining has been noted. These mounds are composed of limestone and were not dolomitized probably because they remained submerged during low sea-level stages of the second cycle.

ERVAY MEMBER

The Ervay Member is the most productive of the Permian carbonate units in Wyoming. Several reasons for this may be noted: (1) it contains the largest carbonate banks of the Permian cyclic units, (2) it is the stratigraphically highest and most widespread of the porous carbonate units and therefore occupies the highest structural position in both structural and stratigraphic traps, and (3) it is underlain by and intertongues with the Retort Phosphatic Shale Member, the most widespread black shale organic-rich source-rock unit of the Phosphoria.

Porosity belts in the Ervay Carbonate Rock Member follow approximately the same general trends as porous belts in the Franson, and are coincident with the paleostructurally high areas of the Wyoming shelf (Maps G, H). Like the Franson, maximum total porosity in the unit occurs on the eastern and southwestern flanks of the Big Horn basin where the largest petroleum reserves have been found thus far in the Cottonwood Creek, Worland, Hamilton Dome, Gebo, Golden Eagle, Little Buffalo, and other fields (Map O). This porous dolomite belt extends southward, across the Great Divide basin and the Rock Springs uplift, following more or less the same trend as that of the Franson, although the Ervay porous facies extends much farther east. To the east, however, the dolomite facies becomes anhydritic, and because of anhydrite sealing, the permeability of these rocks decreases markedly. A similar situation exists along this belt in the Franson dolomite facies, but the eastward transition from carbonate-mound facies to evaporites is more abrupt in the Franson and the transition belt occurs some distance west of that in the Ervay.

Porosity in the Ervay is well developed along the southwestern flank of the Bighorn basin, where significant oil production is obtained from these beds. However, in this area the Ervay is not entirely dolomitized and the total porosity is less than on the east side of the basin. This belt of porous carbonate rock extends to the northwest along the basin flank but limestone content progressively increases, with consequent lowering of total porosity. Oil accumulations in the Permian in the northwestern part of the basin are generally relatively small. The Ervay thins and overlaps the Franson pinchout along the north flank of the Bighorn basin into Montana, where the sequence is largely composed of limestone, and porosity is generally low.

Porosity in the Ervay is well developed along the southwest flank of the Wind River basin where several important oil fields in the Permian as well as in the Tensleep Sandstone are located. Porosity here is not as great as it is on the east flank of the Bighorn basin, apparently because of less complete dolomitization. A relatively narrow band of Ervay dolomite porosity extends north-south along the west flank of the Green River basin, approximately coinciding with the east side of the porous belt in the Franson. Compared with the Franson, however, the porous belt in the Ervay is relatively narrow. The Ervay thins rapidly westward here, is absent over much of the area of Franson carbonate bank buildup, and farther west it changes facies to cherty shale in southeastern Idaho.

SOURCE ROCKS

The Meade Peak and Retort black shale beds are high in organic-carbon content and are widely identified as the source rocks for most of the upper Paleozoic oil in the Bighorn and Wind River basins (Cheney and Sheldon, 1959; Sheldon, 1967;

Stone, 1967; Maughan, 1975; and Claypool and others, 1978). Total thickness of black shale in the main cycles is shown on Maps E, F, I, J). In general, thickness is greatest in the western miogeosyncline and in basins on the shelf, rapidly diminishing in the vicinity of the redbed-evaporite facies to the east. Retort dark shale beds extend some distance farther east than those of the Meade Peak, a consequence of greater transgression of the shelf area by western basin waters during the later cycle. Overall, black shales of the Retort are slightly higher in organic carbon and have a wider distribution than those of the Meade Peak. In general, the Retort beds have not been buried as deeply as those of the Meade Peak, but in most places where porous carbonate facies are present burial has been sufficient for petroleum generation.

Migration Patterns and Depth of Burial

The main area of thickest organic-rich dark shale facies occurs in the Meade Peak Phosphate Shale Member in southeastern Idaho and westernmost Wyoming (Maughan, 1975), an area where subsidence and burial rates were substantially greater than those on the Wyoming shelf. As suggested by Sheldon (1967), Claypool and others (1978), and other investigators, petroleum generation should have occurred much earlier there, when organic-rich beds reached the temperature regime necessary for hydrocarbon generation at burial depths of about 2,000 m (6,500 ft). By mid-Jurassic time, Phosphoria beds should have been buried to these depths in much of the Wyoming shelf margin and slope area, and by Early Cretaceous time they should have been as much as 4,500 m (15,000 ft) or more (Map M). Migration gradients at this time would have been directed toward the shelf, and substantial amounts of petroleum should have first accumulated in the Franson dolomite reservoirs along the Idaho-Wyoming border. Subsequently, most of this reservoir belt has been buried to great depths, probably over 7,500 m (25,000 ft), and much of the hydrocarbons should have reached degradation temperatures sufficient for destruction or conversion to gas.

Burial depths across most of western and central Wyoming by the end of Early Cretaceous time ranged from about 600 to 1,800 m (2,000 to 6,000 ft) (Map M). It is probable that only in the western area sufficient burial temperatures had been reached for petroleum generation to begin at this time. Because of paleostructural subsidence of the Green River trough, however, these fluids were prevented from migrating any farther east than the Wyoming shelf margin. From here, the migration gradient would have been directed northward, along the shelf margin, toward an area of shallower burial bordering the northwestern part of the Green River basin, within the porous Franson dolomite facies and perhaps the underlying Grandeur or Wells sandstone beds. Some of these early hydrocarbons then may have migrated from here eastward along paleostructural belts on the margins of the ancestral Bighorn and Wind River basins, perhaps as far as the Casper arch. Of significance in this respect is the area of high organic carbon content of both the Meade Peak and Retort Shale Members in Idaho and Wyoming (Maughan, 1975), which extends eastward across the northwestern border of the Green River basin (Maps M, N). Subsidence in this area was much less rapid than that to the west and southwest, and probably hydrocarbon generation temperatures were not reached until mid-Cretaceous time. This area of high organic carbon in the Meade Peak and Retort probably presisted for a long time as a major source area and accessway for Permian oils migrating toward the Bighorn and Wind River basins.

Near the end of the Early Cretaceous, burial depths in the western geosynclinal area should have reached the point of hydrocarbon degradation, and generation may have ceased in that area. However, by that time, the thick, dark shale beds in the Retort, Meade Peak and Franson Members in the Green River trough should have reached burial depths of at least 1,800-2,500 m (6,000-8,000 ft), sufficient to begin petroleum generation (Map N). Migration paths for these hydrocarbons should have been to the east and northeast, toward the ancestral Wind River, Rock Springs, Sweetwater, and Casper highs, with continued migration toward the east and northeast through the main accessway on the northwest flank of the Green River basin. Some time before the end of the Cretaceous, perhaps during Mesaverde deposition, burial depths in the Wind River and Bighorn basins should have been sufficient to begin hydrocarbon generation from the substantial thickness of Permian dark shale beds in these areas, primarily those of the Retort Member, bringing the more local source rock facies of these basins into the migration system. By this time, through the continuing evolution of the temperature-hydrocarbon generation regime, large quantities of petroleum may have been accumulated in dolomite (Phosphoria) and sandstone (Tensleep) reservoirs in broad paleostructural belts along the margins of both basins. Some of these may have been stratigraphic traps along the Permian facies transition belt between porous dolomite and redbed-anhydrite facies, including early entrapment in the Cottonwood Creek Field area. The final migration and accumulation system then evolved through Laramide structural growth during Cenozoic time. Important to the final result of this series of paleostructural events is the fact that Laramide growth of the Wind River Range, and the Owl Creek and Bighorn Mountains occurred along structural axes that were somewhat offset from the late Paleozoic and early Mesozoic paleostructural axes. Because of this, much of the early petroleum accumulation in the Phosphoria and Tensleep is still preserved. However, much of the petroleum in the more blanket-like and highly porous Tensleep Sandstone probably has been lost to Cenozoic erosion in the Wind River Range and Bighorn Mountains and other major areas of Laramide uplift.

A consideration of the above factors of paleostructural and burial-depth history, along with the distribution patterns of reservoir and source rock facies, suggests that the Phosphoria and Tensleep hydrocarbons of the Bighorn and Wind River basins may represent a combination of those derived by middle Mesozoic migration from distant source rock facies and late Mesozoic-Cenozoic migration from more local intra-basin source rock facies. Present-day burial depths, as shown on Map O, suggest that around the margins of the basins, the generation process may still be in operation.

CONCLUSIONS

Permian cyclic lithofacies and carbonate reservoir trends appear to be related primarily to paleostructural growth contemporaneous with deposition on the Wyoming shelf. Carbonate mound buildups, composed of bryozoan, crinoid, brachiopod, oolite-pellet, phylloid algae, and other bioclastic debris, are most commonly located along apparent paleostructural features related to late Paleozoic ancestral growth of major Laramide structures. Wells drilled in paleostructural basin areas on the shelf, however, have encountered a much more shaly section, increased content of dark shale, anhydrite, and finer grained to shaly carbonates of low reservoir porosity. Porosity trends, related to dolomitization of the coarse-grained buildups, also occur along the paleostructural belts. A seepage-reflux system with a westward gradient, penecontemporaneous with deposition, is believed to account for most of the reservoir development, as an early diagenetic process.

The main area of dark organic shale potential source rock facies is in southeastern Idaho and westernmost Wyoming. Subsurface lithologic studies, however, indicate the presence of a substantial thickness of dark shale in the Green River, Wind River, and Bighorn basins. Thickness maps of Mesozoic rocks suggest that burial depths were sufficient for generation of Phosphoria petroleum to take place in southeastern Idaho and western Wyoming as early as Jurassic time, with a migration gradient toward carbonate reservoir belts in the overthrust belt and along the ancestral Wind River Range and the Owl Creek and Bighorn Mountain paleostructures, and perhaps as far east as the Casper arch. The main migration pathway for this petroleum should have been eastward across west-central Wyoming. Near the end of the Mesozoic, generation and migration of petroleum from source rock facies in the basin areas of the shelf should have begun.

The pattern of cyclic deposition characteristic of the Phosphoria Formation continued into the Triassic Dinwoody Formation. The striking difference between cycles in Dinwoody and Phosphoria time is believed to be primarily biotic, related to disappearance of skeletal mound building and other marine organisms at the close of the Paleozoic.

SELECTED REFERENCES

Adams, J. E., 1967, Semi-cyclicity in the Castile Anhydrite, in Cyclic sedimentation in the Permian Basin: West Texas Geological Society, p. 198-203.

Adams, J. E., and Rhodes, M. L., 1960, Dolomitization by seepage refluxion: American Association of Petroleum Geologists Bulletin, v. 44, p. 1912-1920.

Agatston, R. S., 1952, Tensleep Formation of the Big Horn Basin, in Wyoming Geological Association Guidebook 7th Annual Field Conference: p. 44-48.

______1954, Pennsylvanian and Lower Permian of northern and eastern Wyoming: American Association of Petroleum Geologists Bulletin, v. 38, no. 4, p. 508-583.

Ahlstrand, D. C., 1970, Permian carbonate facies, Wind River Mountains and western Wind River Basin, Wyoming: University of Montana, Missoula, Master's thesis.

Ahlstrand, D. C., and Peterson, J. A., 1978, Permian carbonate facies, Wind River Basin, Wyoming, in Resources of the Wind River Basin: Wyoming Geological Association, Guidebook 30th Annual Field Conference, p. 89-100.

Albee, H. F., 1964, Preliminary geologic map of the Garns Mountain NE quadrangle, Teton County, Idaho: U.S. Geological Survey Mineral Investigations Field Studies Map MF-274.

Albee, H. F., and Cullins, H. L., 1965, Preliminary geologic map of the Poker Peak and Palisades Reservoir quadrangles, Bonneville, County, Idaho, and Lincoln County, Wyoming: U.S. Geological Survey Open-File 65-2.

Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1954, Occurrence of uranium in phosphate deposits: U.S. Geological Survey Report TEI-440, p. 157-160, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tennessee.

Altschuler, Z. S., et al, 1954, Uranium in Apatite: Geological Society of America Bulletin, v. 65, p. 1225-1226.

______1954, Occurrence of uranium in phosphate deposits: U.S. Geological Survey Report TEI-490, p. 202-204, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tennessee.

______1955, Occurrence of uranium in phosphate deposits: U.S. Geological Survey Report TEI-540, p. 197-199, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tennessee.

______1958, Geochemistry of uranium in apatite and phosphorite: U.S. Geological Survey Professional Paper 314-D, p. 45-90.

Armstrong, F. C., 1953, Generalized composite stratigraphic section for the Soda Springs Quadrangle and adjacent areas in southeastern Idaho, in Intermountain Association of Petroleum Geology Guidebook, 4th Annual Field Conference.

Armstrong, F. C., and Cressman, E. R., 1963, The Bannock thrust zone, southeastern Idaho: U.S. Geological Survey Professional Paper 374-J, p. J1-J22.

Armstrong, F. C., and Oriel, S. S., 1965, Tectonic development of Idaho-Wyoming thrust belt: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 1847-1866.

Arro, E., 1972, Stratigraphic trap potential, Permian Phosphoria Formation of central Wyoming [abs.]: American Association of Petroleum Geologists Bulletin, v. 56, p. 601.

Baker, A. A., and Williams, J. S., 1940, Permian in parts of Rocky Mountain and Colorado Plateau regions: American Association of Petroleum Geologists Bulletin, v. 24, no. 4, p. 617-635.

Bates, R. L., 1955, Permo-Pennsylvania formations between Laramie Mountains, Wyoming and Black Hills, South Dakota: American Association of Petroleum Geologists Bulletin, v. 39, no. 10, p. 1979-2002.

Berg, R. R., 1962, Mountain flank thrusting in Rocky Mountain foreland: American Association of Petroleum Geologists Bulletin, v. 48, p. 2019-2032.

Bissell, H. J., 1962, Permian rocks of parts of Nevada, Utah and Idaho: Geological Society of America Bulletin, v. 73, p. 1083-1110.

Blackstone, D. L., Jr., 1963, Development of geologic structure in central Rocky Mountains, in Backbone of Americas: American Association of Petroleum Geologists Memoir No. 2, p. 160-179.

Blackwelder, E., 1911, A reconnaissance of the phosphate deposits in western Wyoming: U.S. Geological Survey Bulletin 470, p. 452-481.

Boutwell, J. M., 1907, Stratigraphy and structure of the Park City mining district, Utah: Journal of Geology, v. 15, p. 434-458.

______1912, Geology and ore deposits of the Park City district, Utah: U.S. Geological Survey Professional Paper 77, 231 p.

Bowen, C. F., 1918, Phosphatic oil shales near Dell and Dillon, Beaverhead County, Montana: U.S. Geological Survey Bulletin 661-I, p. 315-328.

Boyd, D. W., 1958, Observations on the Phosphoria reservoir rock, Cottonwood Creek Field, Washakie County, Wyoming: American Association of Petroleum Geologists, Petroleum Information, Geological Record, p. 45-53.

Boyd, D. W., and Maughan, E. K., 1973, Permian-Triassic boundary in the Middle Rocky Mountains, in Logan, A., and Hills, L. V., eds., The Permian and Triassic systems and their mutural boundary: Canadian Society of Petroleum Geologists Memoir 2, p. 284-317.

Boyd, D. W., and Newell, N. D., 1972, Taphonomy and diagenesis of a Permian fossil assemblage from Wyoming: Journal of Paleontology, v. 46, no. 1, p. 1-14.

Branson, C. C., 1930, Paleontology and stratigraphy of the Phosphoria Formation: Missouri University Studies, v. 5, no. 2, p. 1-99.

______1933, The fish fauna of the middle Phosphoria Formation: Journal of Geology, v. 41, p. 173-184.

______1934, The Permian sharks of Wyoming and east Greenland: Science, v. 79, p. 431.

Branson, E. B., 1916, The lower Embar of Wyoming and its fauna: Journal of Geology, v. 24, p. 639-644.

Branson, E. B., and Branson, C. C., 1941, Geology of the Wind River Mountains, Wyoming: American Association of Petroleum Geologists Bulletin, v. 24, no. 1, p. 120-151.

Brittenham, M. D., 1973, Permian Phosphoria bioherms and related facies, southeastern Idaho: University of Montana, Missoula, Master's thesis, 213 p.

______1976, Permian Phosphoria carbonate banks, Idaho-Wyoming thrust belt, in Geology of the Cordilleran Hingeline--A symposium: Rocky Mountain Association of Geologists, p. 173-192.

Brongersma-Sanders, M., 1948, The importance of upwelling water to vertebrate paleontology and oil geology: Koninkl. Nederlandsche Akademie Van Wetensch, Afd., Natuurk, Tweede Section, Deel XLV, no. 4, 112 p.

Burk, C. A., and Thomas, H. D., 1956, The Goose Egg Formation (Permo-Triassic) of eastern Wyoming: Wyoming Geological Survey Report Investigation, no. 6, p. 1-11.

Campbell, C. V., 1956, The Phosphoria Formation in the southeastern Big Horn Basin, Wyoming: Stanford University, Palo Alto, Ph. D. thesis.

______1962, Depositional environments of Phosphoria Formation (Permian) in southeastern Bighorn Basin, Wyoming: American Association of Petroleum Geologists Bulletin, v. 46, no. 4, p. 478-503.

Carr, W. J., and Trimble, D. E., 1961, Upper Paleozoic rocks in the Deep Creek Mountains, Idaho, in Short papers in the geologic and hydrologic sciences: U.S. Geological Survey Professional Paper 424-C, p. C181-184.

______1963, Geology of the American Falls quadrangle, Idaho: U.S. Geological Survey Bulletin 1121-G, p. G1-G44.

Carswell, L. D., and Sheldon, R. P., 1954, Geology of the Stewart Flat quadrangle, Idaho: U.S. Geological Survey Report TEI-490, p. 189-190, issued by the Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

Cheney, T. M., 1955, Facies and oil possibilities of the Phosphoria Formation and equivalent strata in eastern Utah and southwestern Wyoming, in Wyoming Geological Association Guidebook, 10th Annual Field Conference: p. 65-67.

______1957, Phosphate in Utah and an analysis of the stratigraphy of the Park City and Phosphoria formations, Utah: Utah Geological and Mineralogical Survey Bulletin 59, 54 p.

Cheney, T. M., McKelvey, V. E., and Gere, W. C., 1956, Fusulinid-bearing rocks in Sublett Range, Idaho; American Association of Petroleum Geologists Bulletin, v. 40, no. 7, p. 1716-1719.

Cheney, T. M., and Montgomery, K. M., 1967, Geology of the Stewart Flat quadrangle, Caribou County, Idaho: U.S. Geological Survey Bulletin 1217, 63 p.

Cheney, T. M., and Sheldon, R. P., 1959, Permian stratigraphy and oil potential, Wyoming and Utah, in Intermountain Association of Petroleum Geologists Guidebook, 10th Annual Field Conference: p. 90-100.

Cheney, T. M., Sheldon, R. P., Waring, R. G., and Warner, M. A., 1954, Stratigraphic sections of the Phosphoria Formation in Wyoming, 1951: U.S. Geological Survey Circular 324.

Cheney, T. M., Smart, R. A., Waring, R. G., and Warner, M. A., 1953, Stratigraphic sections of the Phosphoria Formation in Utah, 1949-51: U.S. Geological Survey Circular 306, 40 p.

Ciriacks, K. W., 1963, Permian and Eotriassic bivalves of the middle Rockies: American Museum of Natural History Bulletin, v. 125, art. 1, p. 1-100, pl. 1-16.

Clabaugh, P. S., 1946, Map of Permian phosphate deposits of Montana, Wyoming, Idaho, and Utah: U.S. Geological Survey Strategic Minerals Investigations Preliminary Map 3-198.

Claypool, G. E., Love, A. H., and Maughan, E. K., 1978, Organic geochemistry, incipient metamorphism, and oil generation in black shale members of Phosphoria Formation, western interior United States: American Association of Petroleum Geologists Bulletin, v. 62, p. 98-120.

Cole, G. P., 1969, Permian carbonate facies, southern Big Horn Basin-Owl Creek Mountains area, north-central Wyoming: University of Montana, Missoula, Master's thesis.

Collier, A. J., 1920, Anticlines near Maverick Springs, Fremont County, Wyoming: U.S. Geological Survey Bulletin 711, p. 149-166.

Condit, D. D., 1916, Relations of the Embar and Chugwater formations in central Wyoming: U.S. Geological Survey Professional Paper 98-O, p. O263-O270.

______1918, Relations of late Paleozoic and early Mesozoic formations of southwestern Montana and adjacent parts of Wyoming: U.S. Geological Survey Professional Paper 120-F, p. F111-F121.

______1919, Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U.S. Geological Survey Bulletin 711-B, p. B15-B40.

______1924, Phosphate deposits in the Wind River Mountains, near Lander, Wyoming: U.S. Geological Survey Bulletin 764, 39 p.

Coogan, A. H., 1969, Recent and ancient carbonate cyclic sequences, in Cyclic sedimentation in the Permian Basin: West Texas Geological Society Publication 69-56, p. 5-16.

Cramer, H. R., 1971, Permian rocks from the Sublette Range, southern Idaho: American Association of Petroleum Geologists Bulletin, v. 55, no. 10, p. 1787-1801.

Cressman, E. R., 1953a, Northwest phosphate--Areal geologic mapping, Dry Valley quadrangle, Idaho: U.S. Geological Survey Report TEI-280, p. 40-41, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

______1953b, Uranium in phosphates--Snowdrift Mountain quadrangle, Idaho: U.S. Geological Survey Report TEI-390, p. 169-170, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

______1954, The Phosphoria Formation in north-central Idaho: U.S. Geological Survey Report TEI-490, p. 191, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

______1955, Geology of the Snowdrift Mountain quadrangle, Idaho: U.S. Geological Survey Report TEI-590, p. 278-279, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

______1957, Preliminary goelogic map of the Snowdrift Mountain quadrangle, Caribou County, Idaho: U.S. Geological Survey Mineral Investigations Field Studies Map MF-118.

______1964, Geology of the Georgetown Canyon-Snowdrift Mountain area, southeastern Idaho: U.S. Geological Survey Bulletin 1153, 105 p.

Cressman, E. R., and Carswell, L. D., 1954a, Interpretation of data on uranium content of the Phosphoria Formation: U.S. Geological Survey Report TEI-440, p. 146-147, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

______1954b, Geology of the Snowdrift Mountains quadrangle and adjacent areas, Idaho: U.S. Geological Survey Report TEI-490, p. 189, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

Cressman, E. R., and Gulbrandsen, R. A., 1953, Uranium in phosphates--Geology of Dry Valley quadrangle, Idaho: U.S. Geological Survey Report TEI-390, p. 171-172, issued by the U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

______1955, Geology of Dry Valley quadrangle, Idaho: U.S. Geological Survey Bulletin 1015-I, p. 257-270.

Crittenden, M. D., Jr., 1961, Magnitude of thrusting in northern Utah: U.S. Geological Survey Professional Paper 424-D, p. D128-D132.

______1972, Willard Thrust and the Cache Allochthon, Utah: Geological Society of America Bulletin, v. 83, p. 2871-2880.

Crosby, G. W., 1970, Radial movements in the western Wyoming salient of the Cordilleran overthrust belt: Geological Society of America Bulletin, v. 80, p. 1061-1078.

Davidson, D. F., Smart, R. A., Pierce, H. W., and Weiser, J. D., 1953, Stratigraphic sections of the Phosphoria Formation in Idaho, pt. 2: U.S. Geological Survey Circular 305, 28 p.

Deiss, C. F., 1949, Phosphate deposits of the Deer Creek Wells Canyon area, Caribou County, Idaho: U.S. Geological Survey Bulletin 955-C, p. C61-C101.

Duncan, H., 1961, Corals from Permian rocks of the northern Rocky Mountain region, in Short papers in the geologic and hydrologic sciences: U.S. Geological Survey Professional Paper 424-B, p. B235-B236.

Dutro, J. T., Jr., and Sando, W. J., 1963, New Mississippian formations and faunal zones in Chesterfield Range, Portneuf Quadrangle, southeast Idaho: American Association of Petroleum Geologists Bulletin, v. 47, no. 11, p. 1963-1986.

Eardley, A. J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geological Society of America Bulletin, v. 55, p. 819-894.

______1968, Major structures of the Rocky Mountains of Colorado and Utah: Rolla, University of Missouri Journal, p. 79-100.

______1969, Charting the Laramide structures of western Utah, in Guidebook of Northern Utah: Utah Geological and Mineralogical Survey Bulletin 82, p. 51-70.

______1972, Willard Thrust and Cache Allochthon, Utah: Geological Society of America Bulletin, v. 83, p. 2881.

Emigh, G. D., 1958, Petrography, mineralogy, and origin of phosphate pellets in the Phosphoria Formation: Idaho Bureau of Mines and Geology Pamphlet 144, 60 p.

Finks, R. M., Yochelson, E. L., and Sheldon, R. P., 1961, Stratigraphic implications of a Permian sponge occurrence in the Park City Formation of western Wyoming: Journal of Paleontology, v. 35, no. 3, p. 564-568.

Foster, D. I., 1958, Summary of the stratigraphy of the Minnelusa Formation, Powder River Basin, Wyoming in Guidebook, 13th Annual Field Conference: Wyoming Geological Association, p. 39-44.

Foster, H. L., 1947, Paleozoic and Mesozoic stratigraphy of northern Gros Ventre Mountains and Mount Leidy Highlands, Teton County, Wyoming: American Association of Petroleum Geologists Bulletin, v. 31, p. 1537-1593.

Fox, J. E., Lambert, P. W., Mast, R. F., and others, 1975, Porosity variation in the Tensleep and its equivalent the Weber Sandstone, western Wyoming--A log and petrographic analysis, in Bolyard, D. W., ed., Symposium on deep drilling frontiers of the central Rocky Mountains: Rocky Mountain Association of Geologists, p. 185-216.

Gale, H. S., and Richards, R. W., 1910, Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U.S. Geological Survey Bulletin 430-II, p. II457-II535.

Gardner, L. S., 1944, Phosphate deposits of the Teton Basin area, Idaho and Wyoming: U.S. Geological Survey Bulletin 944-A, p. A1-A36.

______1961, Preliminary geologic map, columnar sections, and trench sections of the Irwin quadrangle, Caribou and Bonneville Counties, Idaho, and Lincoln and Teton Counties, Wyoming: U.S. Geological Survey Open-File map.

Garvin, R. F., 1971, Paleoenvironments of Phosphoria Formation, Cottonwood-No Water Creek fields, Washakie County, Wyoming [abs.]: American Association of Petroleum Geologists Bulletin, v. 55, p. 1392.

Gere, W. C., 1964, Phosphate rock, in Mineral and water resources of Idaho: Report of U.S. Geological Survey in collaboration with Idaho Bureau of Mines and Geology and Idaho Department of Reclamation, U.S. 88th Congress, 1st session, p. 152-161. (Also published as Idaho Bureau of Mines and Geology Special Report No. 1, 1964).

Gere, W. C., Schnell, E. M., and Moore, K. P., 1966, Stratigraphic sections and phosphate analyses of Permian rocks in the Teton Range and parts of the Snake River and Gros Ventre Ranges, Idaho and Wyoming: U.S. Geological Survey Open-File Report, 71 p.

Girty, G. H., 1910, The fauna of the phosphate beds of the Park City Formation in Idaho, Wyoming, and Utah: U.S. Geological Survey Bulletin 436, 82 p.

______1927, Descriptions of carboniferous and Triassic fossils, in Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geological Survey Professional Paper 152, p. 78-81.

Gordon, M., 1966, Permian coleoid cephalopods from the Phosphoria Formation in Idaho and Montana: U.S. Geological Survey Professional Paper 550-B, p. B28-B35.

Grose, L. T., 1972, Tectonics, in Geologic Atlas of the Rocky Mountain Region: Rocky Mountain Association of Geologists, p. 35-44.

Gulbrandsen, R. A., 1958, Petrology of the Meade Peak phosphatic shale member of the Phosphoria Formation, Coal Canyon, Wyoming: U.S. Geological Survey Open-File Report, 196 p.

______1960, Petrology of the Meade Peak phosphatic shale member of the Phosphoria Formation at Coal Canyon, Wyoming: U.S. Geological Survey Bulletin 111-C, p. C71-C146.

______1966, Chemical Composition of Phosphorites of the Phosphoria Formation: Geochimica et Cosmochica Acta, v. 30, p. 769-778.

______1969, Physical and chemical factors in the formation of marine apatite: Economic Geology, v. 64, p. 365-382.

______1971, Relation of carbon dioxide content of apatite of the Phosphoria Formation to regional facies: Mountain Geologist, v. 8, p. 81-84.

Harris, R. A., and others, 1954, Bibliography of the geology of the western phosphate field: U.S. Geological Survey Bulletin 1018, 89 p.

Hayes, K. H., 1976, A discussion of the geology of the southeastern Canadian Cordillera and its comparison to the Idaho-Wyoming Fold and Thrust Belt, in Symposium, Geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists, p. 59-82.

Hintze, L. F., 1973, Geologic history of Utah: Brigham Young University Geologic Studies, v. 20, pt. 3, 181 p.

Hood, A., and Castano, 1974, Organic metamorphism--Its relationship to petroleum generation and application to studies of authigenic minerals: Coordinating Committee Offshore Prospecting Technical Bulletin, v. 8, p. 85-118.

Hood, A., Gutjahr, C. C. M., and Heacock, R. L., 1975, Organic metamorphism and the generation of petroleum: American Association of Petroleum Geologists Bulletin, v. 59, no. 6, p. 986-996.

Hose, R. K., 1954, Geology of the Crazy Woman Creek area, Johnson County, Wyoming: U.S. Geological Survey Map OM 142.

Howe, D. M., 1971, Early Permian unconformity in southeastern Wyoming and north-central Colorado !abs.1: American Association of Petroleum Geologists Bulletin, v. 55, no. 8, p. 1392.

Jacka, A. D., Thomas, C. M., Beck, R. H., Williams, K. W., and Harrison, S. C., 1967, Guadalupian depositional cycles, Delaware Basin and northwest shelf, in Cyclic sedimentation in the Permian Basin: West Texas Geological Society, p. 152-197.

Jobin, D. A., 1964, Geology of the Irwin quadrangle, Bonneville County, Idaho: U.S. Geological Survey Mineral Investigations Field Studies Map MF-287.

Jobin, D. A., and Schroeder, M. L., 1964, Geology of the Conant Valley quadrangle, Bonneville County, Idaho: U.S. Geological Survey Mineral Investigations Field Studies Map MF-277.

Jobin, D. A., and Soister, P. E., 1964, Geologic map of the Thompson Peak quadrangle, Bonneville County, Idaho: U.S. Geological Survey Mineral Investigations Field Studies Map MF-284.

Kay, G. M., 1951, North American geosynclines: Geological Society of America Memoir 48, 113 p.
Kazakov, A. V., 1937, The phosphorite facies and the genesis of phosphorites: Transactions Scientific Institute Fertilizers and Insecto Fungicides, No. 142 (published for the 17th International Geological Congress), Leningrad, p. 95-113.
Keefer, W. R., 1957, Geology of the DuNoir area, Fremont County, Wyoming: U.S. Geological Survey Professional Paper 294-E, p. E155-E221.
Keefer, W. R., 1969, Geology of petroleum in Wind River Basin, central Wyoming: American Association of Petroleum Geologists Bulletin, v. 53, p. 1839-1865.
Keller, W. D., 1941, Petrography and origin of the Rex chert: Geological Society of America Bulletin, v. 52, p. 1279-1298.
Kentta, H., and Abrassart, C., 1952, Surface cross section of the Phosphoria Formation, southeast Big Horn Basin, in Wyoming Geological Association Guidebook, 7th Annual Field Conference: p. 54.
Ketterer, W. P., and Swirczynski, R. P., 1952, Preliminary lithofacies study of the Phosphoria Formation, Big Horn Basin, Wyoming, in Wyoming Geological Association Guidebook, 7th Annual Field Conference: p. 53-54.
King, R. H., 1947, Phosphate deposits near Lander, Wyoming: Wyoming Geological Survey Bulletin 39, 84 p.
______1957, Stratigraphy of the Phosphoria Formation in the Wind River Mountains, in Wyoming Geological Association Guidebook, 12th Annual Field Conference: p. 35-38.
Kirkham, V. R. D., 1924, Geology and oil possibilities of Bingham, Bonneville, and Caribou Counties, Idaho: Idaho Bureau of Mines and Geology Bulletin 8, 116 p.
Koch, W. J., 1976, Lower Triassic facies in the vicinity of the Cordilleran hingeline, western Wyoming, southeastern Idaho, and Utah, in Symposium on Geology of the Cordilleran Hingelines: Rocky Mountain Association of Geologists, p. 203-218.
Kummel, B., 1953, Regional relationships of Triassic formations in eastern Idaho and adjacent areas, in Guide to the Geology of northern Utah and southeastern Idaho, 4th Annual Field Conference: Intermountain Association of Petroleum Geologists, p. 48-53.
______1954, Triassic stratigraphy of southeastern Idaho and adjacent areas: U.S. Geological Survey Professional Paper 254-H, p. H165-H194.
Lane, D. W. 1973, The Phosphoria and Goose Egg formations in Wyoming: Geological Survey of Wyoming, Preliminary Report no. 12, 24 p.
Lehman, N. E., 1966, Geology and mineralogy of the Fort Hall phosphate deposits, Idaho: University of Arizona thesis.
Love, J. D., Keefer, W. R., Duncan, D. C., Berquist, H. R., and Hose, R. K., 1951, Geologic map of the Spread Creek-Gros Ventre River area, Teton County, Wyoming: U.S. Geological Survey Oil and Gas Investigations Map OM-118.
Love, J. D., Reed, J. C., Jr., Christiansen, R. L., and Stacy, J. R., 1973, Geologic block diagram and tectonic history of the Teton region, Wyoming-Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-730.
Lowell, J. D., 1977, Underthrusting origin for thrust fold belts with application to the Idaho-Wyoming Belt, in Rocky Mountain Thrust Belt, Geology and Resources: Wyoming Geological Association, p. 449-456.
Lowell, W. R., 1952, Phosphate rocks in the Deer Creek-Wells Canyon area, Idaho: U.S. Geological Survey Bulletin 982-A, p. A1-A52.
McCaleb, J. A., and Willingham, R. W., 1967, Influence of geologic heterogeneities on secondary recovery from Permian Phosphoria reservoir, Cottonwood Creek field, Wyoming: American Association of Petroleum Geologists Bulletin, v. 51, p. 2122-2132.

McKee, E. D., Oriel, S. S., MacLachlan, M. E., and others, 1959, Paleotectonic maps of the Triassic system: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-300.

McKee, E. D., Oriel, S. S., Berryhill, H. J., Jr., Cheney, T. M., Cressman, E. R., Crosby, E. J., Dixon, G. H., Fix., G. E., Hallgarth, W. E., Ketner, K. B., MacLachlan, M. E., Maughan, E. K., McKelvey, V. E. Mudge, M. R., Myers, D. A., and Sheldon, R. P., 1967, Paleotectonic maps of the Permian System: U.S. Geological Survey Miscellaneous Investigations Series Map I-450.

McKelvey, V. E., 1946, Preliminary report on stratigraphy of phosphatic shale member of the Phosphoria Formation in western Wyoming, southeastern Idaho, and northern Utah: U.S. Geological Survey Open-File Report, 162 p.

______1949, Geological studies of the western phosphate field: American Institute of Mining Metallurgical Engineers Transactions, v. 4, p. 270-280; Mining Eng., v. 1, p. 270-279.

______1959, Relation of upwelling marine waters to phosphorite and oil [abs.]: Geological Society of America Bulletin, v. 70, p. 1783-1784.

McKelvey, V. E., Armstrong, F. C., Gulbrandsen, R. A., and Campbell, R. M., 1953, Stratigraphic sections of the Phosphoria Formation in Idaho 1947-1948, pt. 2: U.S. Geological Survey Circular 301, 58 p.

McKelvey, V. E., Davidson, D. F., O'Malley, F. W., and Smith, L. E., 1953, Stratigraphic sections of the Phosphoria Formation in Idaho, 1947-1948, pt. 1: U.S. Geological Survey Circular 208, 49 p.

McKelvey, V. E., and Nelson, J. M., 1950, Characteristics of marine uranium bearing sedimentary rocks: Economic Geology, v. 45, p. 35-53.

McKelvey, V. E., Smith, L. E., Hoppin, R. A., and Armstrong, F. C., 1953, Stratigraphic sections of the Phosphoria Formation in Wyoming, 1947-1948: U.S. Geological Survey Circular 210, 33 p.

McKelvey, V. E., and Strobell, J. D., Jr., 1955, Preliminary geologic map of the Paris-Bloomington vanadium area, Bear Lake County, Idaho: U.S. Geological Survey Mineral Investigations Field Studies Map MF-41.

McKelvey, V. E., Swanson, R. W., and Sheldon, R. P., 1953, The Permian phosphorite deposits of western United States, in Saint Guilhem, P. L. R., ed., Origine des gisements des phosphates des chaux: International Geological Congress, 19th Algiers, 1952, Comptes rendus, sec. 11, fasc. 11, p. 45-64.

McKelvey, V. E., Williams, J. S., Sheldon, R. P., Cressman, E. R., Cheney, T. M., and Swanson, R. W., 1956, Summary description of Phosphoria, Park City, and Shedhorn formations in western phosphate field: American Association of Petroleum Geologists Bulletin, v. 40, no. 12, p. 2826-2863.

______1959, The Phosphoria, Park City, and Shedhorn formations in the western phosphate field: U.S. Geological Survey Professional Paper 313-A, p. A1-A47.

Mallory, W. W., 1967, Pennsylvanian and associated rocks in Wyoming: U.S. Geological Survey Professional Paper 554-G, p. G1-G31.

Mallory, W. W., Bachman, G. O., Maughan, E. K., McKee, E. D., Prichard, G. E., and Wilson, R. F., 1972, Regional synthesis of the Pennsylvanian System, in Geologic Atlas of the Rocky Mountain Region: Rocky Mountain Assocation of Geologists, p. 111-127.

Mansfield, G. R., 1916, A reconnaissance for phosphate in the Salt River Range, Wyoming: U.S. Geological Survey Bulletin 620-O, p. O331-O349.

______1920, Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U.S. Geological Survey Bulletin 713, 152 p.

______1927, Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geological Survey Professional Paper 152, 453 p.

______1929, Geography, geology, and mineral resources of the Portneuf quadrangle, Idaho: U.S. Geological Survey Bulletin 803, 110 p.

______1952, Geography, geology, and mineral resources of the Ammon and Paradise Valley quadrangles: U.S. Geological Survey Professional Paper 238, 92 p.

Maughan, E. K., 1964, The Goose Egg Formation in the Laramie Range and adjacent parts of southeastern Wyoming: U.S. Geological Survey Professional Paper 501-B, p. B53-B60.

______1966, Environment of deposition of Permian salt in the Williston and Alliance basins, in Symposium on Salt, 2d, v. 1, Geology, Geochemistry and Mining: Cleveland, Ohio, Northern Ohio Geological Society, p. 35-47.

______1975, Organic carbon in shale beds of the Permian Phosphoria Formation of eastern Idaho and adjacent states--a summary report: Wyoming Geologic Association, 27th Annual Field Conference, Capser, Wyoming, p. 107-115.

______1978, Pennsylvanian (upper Carboniferous) System of Wyoming: U.S. Geological Survey Open-File Report 78-377, 32 p.

Meissner, F. F., 1970, Cyclic sedimentation in Mid-Permian strata, in Cyclic sedimentation in the Permian Basin (2nd Ed.): West Texas Geological Society, p. 203-232.

Miller, A. K., and Cline, L. M., 1934, The cephalopods of the Phosphoria Formation of northwestern United States: Journal of Paleontology, v. 8, p. 281-302.

Miller, A. K., Furnish, W. M., and Clark, D. L., 1957, Permian ammonoids from western United States: Journal of Paleontology, v. 31, no. 6, p. 1057-1068.

Miller, A. K., and Unklesbay, A. G., 1942, Permian nautiloids from western United States: Journal of Paleontology, v. 16, p. 719-738.

Monley, L. E., 1971, Petroleum potential of Idaho-Wyoming Overthrust Belt, in American Association of Petroleum Geologists Memoir 15, Future Petroleum Provinces of the U.S., v. 1, p. 506-529.

Montgomery, K., and Cheney, T. M., 1967, Geology of the Stewart Flat quadrangle, Caribou County, Idhao: U.S. Geological Survey Bulletin 1217.

Moore, R. C., 1950, Late Paleozoic cyclic sedimentation in central United States: 18th International Geological Congress, Rept. 4, p. 5-16.

Mullens, T. E., and Izett, G. A., 1964, Geology of the Paradise quadrangle, Cache County, Utah: U.S. Geological Survey Bulletin 1181-S, p. S1-S32.

Mullens, T. E., and Laraway, W. H., 1964, Geology of the Devils Slide quadrangle, Morgan and Summit Counties, Utah: U.S. Geological Survey Mineral Investigations Field Studies Map MF-290.

Murata, K. J., Friedman, I., and Gulbrandsen, R. A., 1972, Geochemistry of carbonate rocks in Phosphoria and related formations of the western phosphate field: U.S. Geological Survey, Professional Paper 800-D, p. D103-D110.

Newell, N. D., Rigby, J. K., Fischer, J. K., Whiteman, A. S., Hickox, J. E., and Bradley, J. S., 1953, The Permian reef complex of the Guadalupe Mountain region, Texas and New Mexico: San Francisco, W. H. Freeman Co., 136 p.

Newell, N. D., and Kummel, B., Jr., 1941, The Permo-Triassic boundary in Idaho, Montana and Wyoming: American Journal of Science, v. 239, p. 204-208.

______1942, Lower Eo-Triassic stratigraphy, western Wyoming and southeast Idaho: Geological Society of America Bulletin, v. 53, no. 6, p. 937-995.

O'Malley, F. W., Davidson, D. F., Hoppin, R. A., and Sheldon, R. P., 1953, Stratigraphic sections of the Phosphoria Formation in Idaho, 1947-1948, pt. 3: U.S. Geological Survey Circular 262, 43 p.

Oriel, S. S., 1965, Preliminary geologic map of the SW¼ of the Bancroft quadrangle, Bannock and Caribou Counties, Idaho: U.S. Geological Survey Mineral Investigations Field Studies Map MF-299.

Oriel, S. S., and Armstrong, F. C., 1966, Times of thrusting in Idaho-Wyoming thrust belt, Reply: American Association of Petroleum Geologists Bulletin, v. 50, p. 2614-2621.

Partridge, J. F., Jr., 1958, Oil occurrence in Permian, Pennsylvanian, and Mississippian rocks, Bighorn Basin, Wyoming, in Habitat of Oil: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 293-306.

Pedry, J. J., 1957, Cottonwood Creek field, Washakie County, Wyoming, carbonate stratigraphic trap: American Association of Petroleum Geologists Bulletin, v. 41, p. 823-838.

Peterson, J. A., 1968, Permian carbonate mound facies, western United States phosphate province [abs.]: Geological Society of America Special Paper 121, p. 236.

______1969, Cyclic carbonate mound facies, Permian Franson and Ervay formations, western Wyoming and adjacent area: Geological Society of America Abstracts with Programs, p. 63.

______1971, Permian unconformity cycles, northern Rocky Mountains, United States: Geological Society of America Abstracts with Programs, p. 404.

______1973, Paleozoic shelf margins, northern Rocky Mountains, U.S.: Geological Society of America Abstracts with Programs, v. 5, no, 3, p. 501.

______1977, Paleozoic shelf margins and marginal basins, western Rocky Mountains-Great Basin, U.S., in Rocky Mountain Thrust Belt, geology and resources: Wyoming Geological Association, p. 135-154.

Peterson, J. A., Gosman, R. F., and Swanson, R. W., 1954, Stratigraphic sections of the Phosphoria Formation in Montana, 1951: U.S. Geological Survey Circular 326, p. 1-27.

Powell, T. G., Cook, P. J., and McKirdy, O. M., 1975, Organic geochemistry of phosphorites--Relevance to petroleum genesis: American Association of Petroleum Geologists Bulletin, v. 49, no. 4, p. 618-632.

Prucha, J. J., Graham, J. A., and Nickelson, R. P., 1965, Basement-controlled deformation in Wyoming province of Rocky Mountain foreland: American Association of Petroleum Geologists Bulletin, v. 49, p. 966-992.

Richards, R. W., and Mansfield, G. R., 1912, Preliminary report on portion of the Idaho phosphate reserve, in Phosphates: U.S. Geological Survey Bulletin 470-H.

______1914, Geology of the phosphate deposits northeast of Georgetown, Idaho: U.S. Geological Survey Bulletin 577, 76 p.

Richardson, G. B., 1941, Geology and mineral resources of the Randolph quadrangle, Utah and Wyoming: U.S. Geological Survey Bulletin 923.

Rioux, R. L., Hite, R. J., Dyni, J. R., and Gere, W. C., 1966, Preliminary geologic map of the Upper Valley quadrangle, Caribou County, Idaho: U.S. Geological Survey Open-File Report.

Roberts, R. J., 1968, Tectonic framework of the Great Basin, in A Coast to Coast Tectonic Study of the United States: Rolla, University of Missouri Jouronal, Ser. 1, v. 1, p. 101-117.

Roberts, R. J., Crittenden, M. D., Tooker, E. W., Morris, H. T., Hose, R. K., and Cheney, T. M., 1965; Pennsylvanian and Permian basins in northwestern Nevada and south-central Idaho: American Association of Petroleum Geologists Bulletin, v. 49, p. 1926-1956.

Rohrer, W. L., 1973, Geologic map of the phosphate reserve in the Lander area, Fremont, Wyoming: U.S. Geological Survey Mineral Investigations Field Studies Map MF-305.

Rogers, J. P., 1971, Characteristics of tidal sedimentation in Phosphoria (Permian) strata at Cottonwood Creek Field, Big Horn Basin, Wyoming [abs.]: American Association of Petroleum Geologists Bulletin, v. 55, no. 8, p. 1893.

Rooney, L. F., 1956, Organic carbon in Phosphoria Formation: American Association of Petroleum Geologists Bulletin, v. 40, no. 9, p. 2267-2271.

Royse, F., Warner, M. A., and Reese, D. L, 1975, Thrust Belt structural geometry and related stratigraphic problems, Wyoming-Idaho-northern Utah, in Symposium on deep drilling frontiers, central Rocky Mountains: Rocky Mountain Association of Geologists, p. 41-54.

Rubey, W. W., 1958, Geology of the Bedford quadrangle, Wyoming: U.S. Geological Survey Geologic Quadrangle Map GQ-109.

Sales, J. K., 1968, Crustal mechanics of Cordilleran foreland deformation: A regional and scale-model approach: American Association of Petroleum Geologists Bulletin, v. 52, p. 2016-2044.

Sandberg, C. A., and Mapel, W. J., 1967, Devonian of the northern Rocky Mountains and Plains, in Oswald, D. H., ed., International Symposium on the Devonian System: Alberta Society of Petroleum Geologists, v. 1, p. 843-877.

Sando, W. J., 1967, Mississippian depositional provinces in the northern Cordilleran region, in Geological Survey research 1967: U.S. Geological Survey Professional Paper 575-D, p. D29-D38.

Schell, E. M., 1969, Summary of the geology of the Sheep Creek Canyon geological area and vicinity, Daggett County, Utah, in Lindsay, J. B., ed., Geologic guidebook of the Uinta Mountains: Salt Lake City, Utah, Intermountain Association of Geologists, p. 143-152.

Schell, E. M., and Yochelson, E. L., 1966, Permian-Triassic boundary in eastern Uintah County, Utah, and western Moffat County, Colorado: U.S. Geological Survey Professional Paper 550-D, p. D48-D64.

Schroeder, M. L., 1974, Geologic map of the Camp Davis quadrangle, Teton County, Wyoming: U.S. Geological Survey Geologic Quadrangle Map GQ-1160.

Schultz, A. R., 1914, Geology and geography of a portion of Lincoln County, Wyoming: U.S. Geological Survey Bulletin 543, 141 p.

______1918, A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U.S. Geological Survey Bulletin 680, 84 p.

Schultz, A. R., and Richards, R. W., 1911, A geologic reconnaissance of southeastern Idaho, in Phosphates: U.S. Geological Survey Bulletin 530-F, p. F267-F284.

Sears, R. S., 1955, Phosphate deposits in the Caribou Range, Bonneville County, Idaho [abs.]: Geological Society of America Bulletin, v. 66, no. 12, pt. 2, p. 1680.

Sheldon, R. P., 1955, Stratigraphy of the Phosphoria Formation in the Wyoming and Wind River Ranges, in Wyoming Geological Association Guidebook, 10th Annual Field Conference: p. 64.

______1956, Stratigraphy of the Phosphoria Formation in the Jackson Hole region, Wyoming, in Wyoming Geological Association Guidebook, 11th Annual Field Conference: p. 66-69.

______1957, Physical stratigraphy of the Phosphoria Formation in northwestern Wyoming: U.S. Geological Survey Bulletin 1042-E, p. E105-E185.

______1959, Geochemistry of uranium in phosphorites and black shales of the Phosphoria Formation: U.S. Geological Survey Bulletin 1084-D, p. D83-D113.

______1963, Physical stratigraphy and mineral resources of Permian rocks in western Wyoming: U.S. Geological Survey Professional Paper 313-B, 273 p.

______1967, Long-distance migration of oil in Wyoming: The Mountain Geologist, v. 4, no. 2, p. 53-65.

______1972, Phosphate deposition seaward of barrier islands at edge of Phosphoria sea in northwestern Wyoming [abs.]: American Association of Petroleum Geologists Bulletin, v. 56, no. 3, p. 653.

Sheldon, R. P., Cressman, E. R., Carswell, L. D., and Smart, R. A., 1954, Stratigraphic sections of the Phosphoria Formation in Wyoming, 1952: U.S. Geological Survey Circular 325, 24 p.

Sheldon, R. P., Maughan, E. K., and Cressman, E. R., 1967, Environment of Wyoming and adjacent states--Interval B, in Paleotectonic maps of the Permian of the Permian System: U.S. Geological Survey Miscellaeous Investigations Series Map I-450, p. 48-54.

Sheldon, R. P., Waring, R. G., Warner, M. A., and Smart, R. A., 1953, Stratigraphic sections of the Phosphoria Formation in Wyoming, 1949-1950: U.S. Geological Survey Circular 307, 45 p.

______1954, Stratigraphic sections of the Phosphoria Formation in Wyoming, 1952: U.S. Geological Survey Circular 325, 24 p.

Sheldon, R. P., Warner, M. A., Thompson, M. E., and Pierce, H. W., 1953, Stratigraphic sections of the Phosphoria Formation in Idaho, 1949, pt. 1: U.S. Geological Survey Circular 304, 30 p.

Smart, R. A., Waring, R. G., Cheney, T. M., and Sheldon, R. P., 1954, Stratigrpahic sections of the Phosphoria Formation in Idaho, 1950-1951: U.S. Geological Survey Circular 327, 22 p.

Smith, L. E., Hosford, G. F., Sears, R. S., Sprouse, D. P., and Stewart, M. D., 1952, Stratigraphic sections of the Phosphoria Formation in Utah, 1947-48: U.S. Geological Survey Circular 211, 48 p.

Staatz, M. H., and Albee, H. F., 1963, Preliminary geologic map of Garns Mountain SE quadrangle, Bonneville and Teton Counties, Idaho: U.S. Geological Survey Mineral Investigations Field Studies Map MF-262.

Stearns, D. W., 1971, Mechanism of drape folding in the Wyoming Province, in Wyoming Geological Association Guidebook, 23rd Annual Field Conference: p. 125-143.

Stearns, D. W., Sacrison, W. R., and Hanson, R. C., 1975, Structural history of southwestern Wyoming as evidenced from outcrop and seismic, in Symposium on Deep Drilling Frontiers in the Central Rocky Mountains: Rocky Mountain Association of Geologists, p. 9-20.

Stewart, J. H., and Poole, F. G., 1974, Lower Paleozoic and uppermost Precambrian Cordilleran Miogeocline, Great Basin, western U.S., in Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication No. 22, p. 28-57.

Stokes, W. D., 1976, What is the Wasatch Line?, in Symposium on geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists, p. 11-25.

Stone, D. S., 1967, Theory of Paleozoic oil and gas accumulation in Big Horn Basin, Wyoming: American Association of Petroleum Geologists Bulletin, v. 51, no. 3, p. 2056-2114.

Stone, D. S., 1969, Wrench faulting and Rocky Mountain tectonics, in Earth Science Bulletin: Wyoming Geological Association, p. 27-45.

Swanson, R. W., Carswell, L. D., Sheldon, R. P., and Cheney, T. M., 1956, Stratigraphic sections of the Phosphoria Formation, 1953: U.S. Geological Survey Circular 375, 30 p.

Tebbutt, G. E., 1964, Lithogenesis of a distinctive Permian carbonate fabric, Big Horn and Washakie Counties, Wyoming: Laramie, University of Wyoming, Master's thesis.

Tebbutt, G. E., Conley, C. D., and Boyd, D. W., 1965, Lithogenesis of a distinctive carbonate fabric, in Contributions to geology: Laramie, University of Wyoming, v. 4, p. 1-13.

Tenney, C. S., 1966, Pennsylvanian and lower Permian deposition in Wyoming and adjacent areas: American Association of Petroleum Geologists Bulletin, v. 50, p. 227-250.

Thomaidis, N. D., 1973, Church Buttes Arch, Wyoming and Utah, in Guidebook, 25th Annual Field Conference: Wyoming Geological Association, p. 35-39.
Thomas, H. D., 1934, Phosphoria and Dinwoody tongues in lower Chugwater of central and southern Wyoming: American Association of Petroleum Geologists Bulletin, v. 18, p. 1655-1697.
______1948, Summary of Paleozoic stratigraphy of the Wind River Basin, Wyoming, in Wyoming Geological Association Guidebook, 3rd Annual Field Conference: p. 79-95.
Thomas, H. D., and Krueger, M. L., 1946, Late Paleozoic and early Mesozoic stratigraphy of Uinta Mountains, Utah: American Association of Petroleum Geologists Bulletin, v. 30, p. 1255-1293.
Thompson, M. E., 1953, Distribution of uranium in rich phosphate beds of the Phosphoria Formation: U.S. Geological Survey Bulletin 988-D, p. 45-67.
______1954, Further studies in the distribution of uranium in rich phosphate beds of the Phosphoria Formation: U.S. Geological Survey Bulletin 1009-D, p. 107-123.
Todd, T. W., 1963, Post-depositional history of Tensleep Sandstone (Pennsylvanian), Bighorn Basin, Wyoming: American Association of Petroleum Geologists Bulletin, v. 47, no. 4, p. 599-616.
Tourtelot, H. A., 1952, Marine and evaporite facies of Permian and Triassic strata in the southern part of the Big Horn Basin and adjacent areas, central Wyoming, in Wyoming Geological Association Guidebook, 7th Annual Field Conference, p. 49-52.
Trimble, D. E., and Carr, W. J., 1976, Geology of the Rockland and Arbon quadrangles, Power County, Idaho: U.S. Geological Survey Belletin 1399, 115 p.
Wach, P. H., 1977, The Moxa Arch, an overthrust model?, in Rocky Mountain Thrust Belt Resources: Wyoming Geological Association, 20th Annual Field Conference, p. 651-664.
Wanless, H. R., 1950, Late Paleozoic cycles of sedimentation in the United States: 18th International Geologic Congress Report, pt. 4, p. 17-28.
______1967, Eustatic shifts in sealevel during the deposition of Late Paleozoic sediments in the central United States, in Cyclic sedimentation in the Permian Basin: West Texas Geological Society, p. 41-54.
Wanless, H. R., Belknap, R. L., and Foster, H., 1955, Paleozoic and Mesozoic rocks of Gros Ventre, Teton, Hoback, and Snake River Ranges, Wyoming: Geological Society of America Memoir 63, 90 p.
Warner, M. A., 1956, The origin of the Rex Chert: Madison, University of Wisconsin, Ph. D. thesis.
Weeks, F. B., and Ferrier, W. F., 1907, Phosphate deposits in western United States: U.S. Geological Survey Bulletin 315, p. 449-462.
Weller, J. M., 1964, Development of the concept and interpretation of cyclic sedimentation, in Symposium on cyclic sedimentation: Kansas Geological Survey Bulletin 169, v. 2, p. 605-621.
Wilkinson, B. H., 1967, Paleoecology of the Permian Ervay Member of the Park City Formation in north-central Wyoming: Laramie, University of Wyoming, Master's thesis.
Williams, G. A., and Holstein, H. J., 1967, Geology of the southeastern Idaho central phosphate region, in Hale, L. A., ed., Anatomy of the Western Phosphate Field: Salt Lake City, Intermountain Association of Geologists, p. 45-60.
Williams, J. S., 1948, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geological Society of America Bulletin, v. 59, p. 1121-1164.
______1953, Pennsylvanian and Permian rocks, in Intermountain Association of Petroleum Geologists 4th Annual Field Conference: p. 38-40.

______1962, Pennsylvanian System in central and northern Rocky Mountains, in Pennsylvanian System in the United States: Tulsa, Okla., American Association of Petroleum Geologists, p. 159-187.

Yochelson, E. L., 1956, Permian Gastropoda of the southwestern United States; 1, Euomphalacea, Trochonematacea, Pseudophoracea, Anomphalacea, Craspedostomatacea, and Platyceratacea: American Museum of Natural History Bulletin, v. 110, art. 3, p. 173-276.

______1968, Biostratigraphy of the Phosphoria, Park City and Shedhorn Formations: U.S. Geological Survey Professional Paper 313-D, p. 571-660.

Youngquist, W. L., and Haegele, J. R., 1955, Fusulinid-bearing rocks in Sublett Range, southern Idaho: American Association of Petroleum Geologists Bulletin, v. 39, no. 10, p. 2078-2084.

Youngquist, W. L., Hawley, R. W., and Miller, A. K., 1951, Phosphoria conodonts from southeastern Idaho: Journal of Paleontology, v. 25, no. 3, p. 356-364.