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Geology of the Johnson Creek Quadrangle, Caribou County, Idaho

GEOLOGICAL SURVEY BULLETIN 1042-A

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GEOLOGY OF THE JOHNSON CREEK QUADRANGLE, CARIBOU COUNTY, IDAHO

By R. A. GULBRANDSEN, K. P. McLAUGHLIN, F. S. HONKALA, and S. E. CLABAUGH

ABSTRACT

The Johnson Creek 7½-minute quadrangle in southeastern Idaho has been mapped at a scale of 1:24,000. The quadrangle is in the southeastern Idaho region in which the Phosphoria formation contains some of the richest and thickest phosphate deposits of the western field. Principal efforts have been devoted to a detailed definition of structural features.

Most of the area of the quadrangle is occupied by the northwestward-trending Aspen Range that is bounded on the west by Bear River valley and on the east by Slug Creek valley. The Aspen Range forms a part of the divide between the Columbia River drainage basin to the north and Great Basin drainage area to the southwest.

The quadrangle contains only sedimentary rocks and these range in age from Mississippian to Triassic and from Tertiary to Recent. Formations present are the Brazer limestone of Mississippian age, the Wells formation of Pennsylvanian and Permian (?) age, the Phosphoria formation of Permian age, and the Dinwoody and Thaynes formations of Triassic age. Rocks of Tertiary and Quarternary age are present also but have not been designated by formation names.

The Johnson Creek syncline and the Aspen Range anticline are the principal structural features of the quadrangle. They trend west of north and are modified and partly obscured in places by many minor folds and by faults that have broken the area into large and small blocks. Most of the faults strike parallel to the trend of the folds, though a few are normal to it. The western front of the Aspen Range is the most intensely folded and faulted part, as shown by the magnitude of overturned strata and the large apparent displacement of the faults.

Phosphate rock is the only important mineral resource at this time. It occurs as bedded rock at different levels in the Phosphoria formation. There are two principal zones of economic importance: one, about 20 feet thick, is near the base of the formation, the other, about 5 feet thick, is 100 to 150 feet above the lower zone. Though the phosphate zones appear to be continuous over the region as a whole, their grade and thickness differ from place to place. Phosphate rock was being mined from the area in 1955.

INTRODUCTION AND ACKNOWLEDGMENTS

The Johnson Creek 7½-minute quadrangle (fig. 1) was mapped as part of an investigation of the phosphate deposits in the Phosphoria formation of Permian age. The quadrangle lies in the Peale Mountains of southeastern Idaho where some of the largest and richest

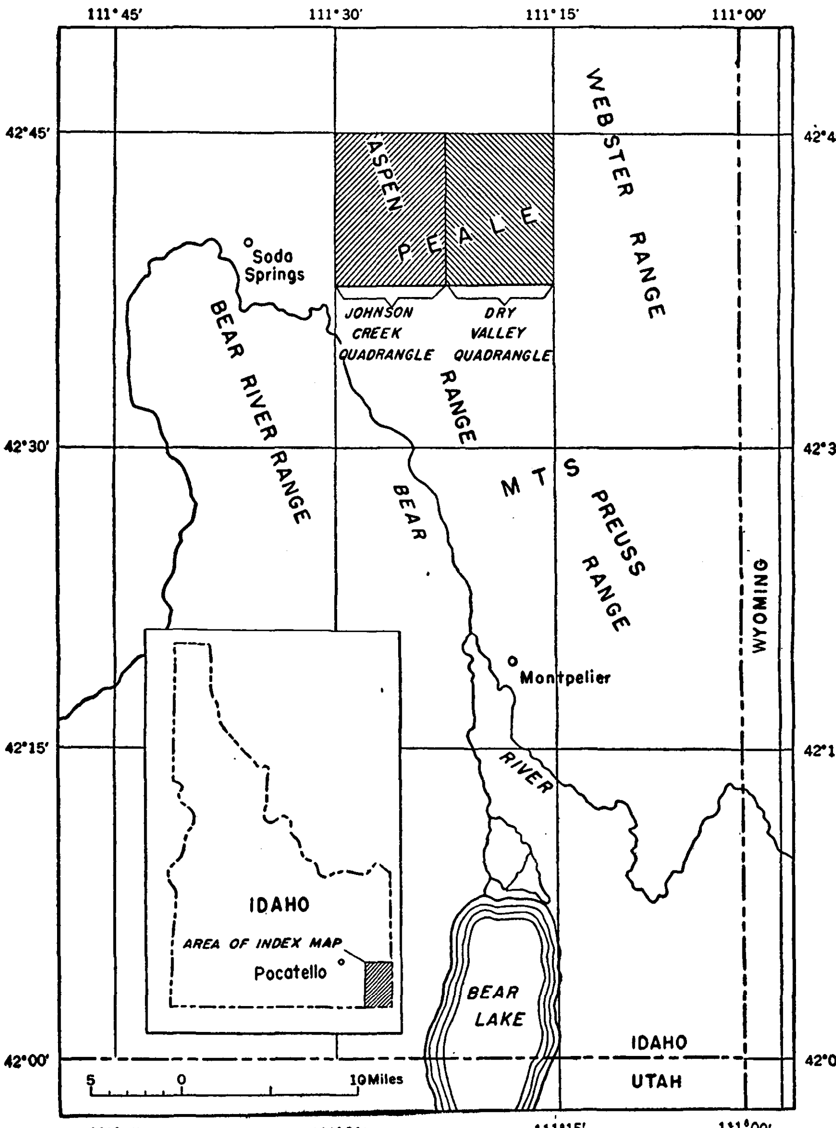

FIGURE 1.—Location of Johnson Creek quadrangle, Caribou County, Idaho.

phosphate deposits of the western field occur (Swanson, McKelvey, and Sheldon, 1953). The Johnson Creek quadrangle, as the northwest quarter of the Slug Creek 15-minute quadrangle, was mapped previously by Mansfield and others (Mansfield, 1927) at a scale of 1:62,500 and has been remapped at a scale of 1:24,000 in order to obtain detailed geologic data that will aid in the appraisal of the phosphate deposits there (pl. 1). The Dry Valley quadrangle, recently mapped by Cressman and Gulbrandsen (1955), adjoins the eastern border of the Johnson Creek quadrangle.

Preliminary work in the Johnson Creek quadrangle began in 1948 when F. C. Armstrong, N. K. Flint, S. Tuttle, and R. Harris examined and mapped outcrops of the Phosphoria formation and adjacent strata in parts of the area. Mapping on a topographic base was done in 1949 and 1950 by R. A. Gulbrandsen, K. P. McLaughlin, F. S. Honkala, S. E. Clabaugh, K. B. Krauskopf, E. R. Cressman, and J. W. Hill under the general supervision of V. E. McKelvey and R. W. Swanson. Field verifications were made in 1951 and 1952. Gulbrandsen is chiefly responsible for the text and map compilation.

Besides the comprehensive description of the geology of the Slug Creek quadrangle and of the regional geology of southeastern Idaho compiled by Mansfield (1927), earlier reports of studies concerning this area were made by Gale and Richards (1910), Richards and Bridges (1911), and Richards and Mansfield (1911 and 1912).

Helpful cooperation was extended to the field parties by the Anaconda Copper Mining Co., and residents of the area allowed free access to their properties. Also, thanks are due R. W. Swanson, V. E. McKelvey, and E. R. Cressman for suggestions and advice given during the preparation of this report. The cost of the work was partly borne by the Division of Raw Materials of the United States Atomic Energy Commission.

GEOGRAPHY

The principal physiographic feature of the quadrangle is the northwestward-trending Aspen Range, one of the ranges composing the Peale Mountains (Mansfield, 1927, p. 24). The Aspen Range is bounded on the east by Slug Creek valley, part of which lies within the quadrangle, and on the west by Bear River valley which lies entirely outside the quadrangle. Valleys within the range trend northwestward and northeastward. Some that lie parallel to the range are broad, but nearly all those perpendicular to it are narrow.

The Aspen Range forms a part of the divide between the Columbia River drainage basin on the north and the Great Basin drainage area on the southwest. Slug Creek, Trail Creek, and Johnson Creek are the largest perennial streams in the quadrangle. Other perennial streams are in South Sulphur Canyon, Wood Canyon, and in the canyon west of the Jougelard Ranch. The highest point in the quadrangle is Sulphur Peak, 8,302 feet. The maximum relief is 2,600 feet, but local relief between ridge and valley is generally about 1,000 feet.

No towns are present in the Johnson Creek quadrangle, but Soda Springs, the Caribou County seat, Monsanto, and Conda are situated a few miles west of the quadrangle. Soda Springs is served by the Union Pacific Railroad and U. S. 30 N. Dirt roads enter the quadrangle from the west through Trail, Wood, and Sulphur Canyons and make all parts except the southern part of the southeast quarter reasonably accessible.

STRATIGRAPHY

The Johnson Creek quadrangle contains only sedimentary rocks. They total from 7,000 to 9,000 feet in thickness and range in age from Mississippian to Triassic and from Tertiary to Recent. Formations present are the Brazer limestone of Mississippian age, the Wells formation of Pennsylvanian and Permian(?) age, the Phosphoria formation of Permian age, and the Dinwoody and Thaynes formations of Triassic age. Formational names have not been given to the rocks of Tertiary and Quaternary age in this quadrangle, though Mansfield (1927) designated the rocks he considered of Tertiary age as the Salt Lake formation. Limestone, quartz sandstone, and quartz siltstone are the most abundant rock types. Phosphate rock is the only rock of economic importance at this time, though chert of the Rex chert member of the Phosphoria formation is used locally as road metal on secondary roads.

MISSISSIPPIAN ROCKS

BRAZER LIMESTONE

The name Brazer was applied by Richardson (1913) to a sequence of rock of late Mississippian age, 800 to 1,400 feet thick, in Brazer Canyon in the Crawford Mountains of northern Utah. There the formation consists of thick-bedded limestone in the upper part and thin-bedded limestone and shale in the lower. Locally the formation contains beds of calcareous sandstone and nodules and thin beds of chert.

The Brazer limestone is incompletely exposed in the Johnson Creek quadrangle but in areas nearby it is thicker and somewhat different in composition from its type locality. In Wells Canyon (see section, p. 5) about 15 miles southeastward from Middle Sulphur Canyon, the Brazer is more than 1,900 feet thick and consists mostly of thick-bedded limestone in the upper part and interbedded limestone and sandstone in the lower part. At Little Flat Canyon (see section, pp. 6–7) about 18 miles northwestward from Middle Sulphur Canyon, the Brazer is about 1,800 feet thick and consists of about 1,000 feet of thick-bedded limestone in the upper part and about 800 feet of calcareous sandstone and some limestone in the lower part. Locally, a thin black shale unit occurs at the top or bottom of the Brazer in areas outside the Johnson Creek quadrangle. Black shale occurs at the top of the Brazer in Fossil Canyon a few miles south of this quadrangle. Shale at the top of the Brazer at Little Flat Canyon is varicolored (brown, red, and gray) rather than black, presumably the result of weathering. Black shale at the base of the Brazer near Laketown, northern Utah, contains some phosphate rock.

Section of the Brazer limestone, north side of Wells Canyon, SW¼SW¼ sec. 11, SE¼ sec. 10, T. 10 S., R. 45 E., Caribou County, Idaho; generalized from section measured by T. M. Cheney.

	Thickness of unit (feet)	*Cumulative thickness (feet)*
Limestone, gray, fine-grained, thick-bedded; contains chert nodules and lenses, brachiopods, and pelecypods; sandy and some cross-bedding at base	9	1966
Limestone, gray, fine- to coarse-grained, thick-bedded; contains horn corals, brachiopods, and many fossil fragments	169	1957
Dolomite and limestone, light-brown to pink, fine-grained, thin- to thick-bedded	6	1788
Limestone, gray, fine- to medium-grained, thick-bedded	40	1782
Covered	48	1742
Limestone, light-brown to gray, fine- to coarse-grained; mostly thick-bedded; contains horn corals and other fossil fragments; sandy in middle part	41	1694
Covered	19	1653
Limestone, gray, fine-grained, thick-bedded, contains ferruginous splotches; thin purple to light-red sandstone in middle part	188	1634
Limestone and sandstone, interbedded gray fine- to coarse-grained thick-bedded limestone; and light-brown thick-bedded sandstone; some siltstone at top of unit; and oolites in limestone at top of unit	326	1446
Sandstone and limestone, interbedded light-brown to red thick-bedded sandstone; and gray fine- to coarse-grained thick-bedded limestone; oolites in limestone at top of unit; horn corals and other fossils and fossil fragments in limestone	140	1120
Limestone, gray and brown, fine- to coarse-grained, mostly thick-bedded; contains many chert nodules and lenses in middle part, and contains horn corals, brachiopods, and fossil fragments	236	980
Covered, limestone and chert float	23	744
Limestone, brown, fine- to medium-grained, thick-bedded; contains chert nodules and lenses in middle part	56	721
Limestone and sandstone, interbedded gray fine- to medium-grained thick-bedded limestone; and light-brown thick-bedded sandstone; oolites and some chert nodules and lenses in limestone	203	665
Limestone, gray, fine- to coarse-grained, mostly thick-bedded; sandy in part; oolites at top of unit; contains chert nodules and horn corals and fossil fragments	264	462
Limestone and sandstone, interbedded gray fine-grained thick-bedded limestone; and light-brown thick-bedded sandstone; some siltstone in middle part of unit; fossil fragments in limestone in middle part of unit	170	198
Covered, limestone float	12	28
Limestone, gray, fine-grained, thick-bedded; contains lenses of oolitic limestone	16	16

Base of formation not exposed.

Section of the Brazer limestone measured on the south side of Little Flat Canyon, in the S½ sec. 17, N½ sec. 20, T. 7 S., R. 40 E., Bannock County, Idaho, measured by R. A. Gulbrandsen, L. Carswell, and R. Smart.

	Thickness of unit (feet)	Cumulative thickness (feet)
Shale, varicolored (brown, red, and gray); appears highly weathered; contains some black sandstone; exposed by excavation on north side of canyon	10	1830
Covered	10	1820
Carbonate rock, medium- and dark-gray on fresh fracture, light- and medium-gray on weathered surface, coarse- and fine-grained, thick-bedded, fossiliferous; contains horn corals, brachiopods, and gastropods(?)—mostly silicified	55	1810
Mostly covered, some dark-gray and medium-gray carbonate rock with black chert lenses	20	1755
Carbonate rock, medium- and dark-gray, fine- and coarse-grained, thick-bedded, fossiliferous; contains horn corals and brachiopods—mostly silicified; contains sandy carbonate lenses that weather brown	20	1735
Carbonate rock, medium-gray, mostly coarse-grained, thick-bedded, fossiliferous; contains mostly fragments of brachiopods and crinoid stem plates, some silicified; contains black chert lenses—some fossiliferous	85	1715
Carbonate rock, medium-gray and light brownish-gray, fine-grained, thick-bedded; fossiliferous in places; contains black and light-olive chert nodules and lenses	110	1630
Carbonate rock, light brownish-gray, fine-grained, thick-bedded; fossiliferous in places; contains some reddish and brownish beds colored by iron oxide, and some chert lenses	65	1520
Covered	135	1455
Carbonate rock, dark-gray and light brownish-gray, fine-grained, thick-bedded; contains silicified corals	30	1320
Carbonate rock, dark-gray, coarse-grained, thick-bedded, fossiliferous; contains silicified horn corals and crinoid stem plates	55	1290
Carbonate rock, dark- and medium-gray, coarse- and fine-grained, thick-bedded, fossiliferous; contains silicified horn corals and colonial pipestem corals—individuals of the latter measure as much as ½ inch in diameter and 1 foot in length	115	1235
Carbonate rock, dark- and medium-gray, coarse- and fine-grained, thick-bedded, oolitic	350	1120
Carbonate rock, light yellowish-brown on fresh surface, pale-brown on weathered surface, fine-grained, thin-bedded, sandy—very fine grained quartz	2	770
Carbonate rock, fine-grained; contains many lenses of black chert	5	768
Carbonate rock, pale-brown and light yellowish-brown and medium-gray, fine-grained, thin- and thick-bedded; contains interbeds of sandy carbonate rock, some chert lenses in upper part, and a thin zone of horn corals	113	763
Sandstone, light yellowish-brown and light olive-brown, fine-grained thin-bedded, carbonatic; contains bed of very coarse grained carbonate rock and a bed of fine-grained deep-red carbonatic sandstone	30	650

	Thickness of unit (feet)	Cumulative thickness (feet)
Sandstone, light-gray, medium-grained, thin- and thick-bedded	90	620
Carbonate rock, light-gray, mostly coarse-grained, thin- and thick-bedded; contains some interbeds of pale brown fine-grained carbonatic sandstone	130	530
Mostly covered, contains float and some outcrops of brown and gray fine-grained thin-bedded carbonatic sandstone	400	400

In the Johnson Creek quadrangle the composition of the upper half of the Brazer, the only part represented, compares well with the composition of the Brazer in the southeastern Idaho region. In the Middle Sulphur Canyon area, where the principal exposures occur, about 1,000 feet of Brazer consists largely of thick-bedded limestone but contains a small amount of sandstone in the lowest exposures. Here the characteristically thick-bedded limestone is medium to dark gray on fresh surfaces and weathers to lighter shades of gray. Grain size ranges from very fine to coarse; the coarse grains are of sand size and are composed mostly of crinoid stem plates, oolites, and shell fragments. Chert occurs in small amounts as nodules, lenses, and thin beds in the limestone. Some of the limestone presents a mottled appearance because of irregularly shaped segregations of finely disseminated iron oxides which are the specks of "siderite" referred to by Mansfield (1927, p. 63). In the lowermost exposures the fresh calcareous sandstone is brownish gray and grayish brown, but on weathered surfaces it is dark brown and reddish brown.

Fossils are abundant in the limestone of the formation. Large silicified horn corals occur in great number at several horizons, and many beds are composed largely of crinoid stem plates and brachiopods.

The top of the Brazer in this quadrangle is taken at the top of the uppermost cliff-forming thick-bedded limestone. The break between the Brazer and the overlying Wells formation is not distinct, however, because the thin black shale unit referred to previously is not present.

PENNSYLVANIAN AND PERMIAN(?) ROCKS

WELLS FORMATION

The Wells formation was named by Richards and Mansfield (1912, p. 689) for its occurrence in Wells Canyon, Idaho, about 10 miles southeast of this quadrangle. At Wells Canyon the formation includes 2,400 feet of thick-bedded sandstone and limestone lying between the Brazer limestone of Mississippian age and the Phosphoria formation of Permian age. Richards and Mansfield (1912) and Mansfield (1927) considered the formation to be largely of Pennsylvanian age. Work by other members of the group investigating the western phosphate deposits and Baker, Huddle, and Kinney (1949), however, suggest that a significant part of the upper half of the Wells may be of Permian age and correlatable with the lower member of the Park City formation in Utah. J. S. Williams (1955, oral communication) states that the upper member of the Wells contains fusilinids of probable Permian age. Considerably more work is necessary, though, before a definite Permian age can be assigned to some of the Wells formation.

In this quadrangle the formation is lithologically similar to the type section in Wells Canyon and to the section which follows, measured by A. F. Holzle in Deer Creek Canyon, about 2 miles northwest of Wells Canyon. The three principal lithologic divisions described by Mansfield (1927, p. 72) are recognizable in this quadrangle as well as in the general area of the Peale Mountains. They are "a lower sandy and cherty limestone facies, a middle sandy facies, and an upper siliceous limestone." The thicknesses of Mansfield's units are, respectively, 750, 1,600, and 50 feet. Though the formation is compositionally uniform over a large area, its differences in thickness are noteworthy. The Wells Canyon section is 2,400 feet thick, the Deer Creek Canyon section is about 1,700 feet thick, and an average thickness in the Johnson Creek quadrangle is about 2,000 feet.

Section of the Wells formation, north side of Deer Creek Canyon, in the S½ sec. 33, T. 9 S., R. 45 E., Caribou County, Idaho; generalized from section measured by A. F. Holzle.

	Thickness of unit (feet)	*Cumulative thickness (feet)*
Dolomite, brownish-gray to light-gray, fine-grained, thick-bedded; contains distinctive white-weathering chert nodules and lenses, and silicified fossil fragments in upper part	15	1668
Limestone, light-brown to dark-brown, fine- to coarse-grained, thin- to thick-bedded; white sandstone at top	42	1653
Covered, white and reddish-brown sandstone float	130	1611
Sandstone, reddish-brown, white and gray, fine-grained, thick-bedded; limestone bed in lower part	79	1481
Covered	30	1402
Sandstone, yellowish-white, fine-grained, thick-bedded	27	1372
Covered, yellowish-white sandstone float	40	1345
Sandstone and limestone, interbedded buff, fine-grained, thick-bedded sandstone; and reddish-gray, fine-grained, limestone	45	1305
Covered, yellowish-brown and light-gray sandstone float	65	1260
Sandstone, yellowish-white and yellowish-brown, fine-grained, thick-bedded	36	1195
Covered, light-brown-weathering sandstone float	55	1159
Sandstone, yellowish-brown, fine-grained, thick-bedded	18	1104
Covered, gray and brown sandstone float	110	1086
Sandstone, light-reddish to yellowish-gray, fine-grained, thick-bedded	35	976
Covered, sandstone float	160	941
Sandstone, reddish-gray, fine-grained, thick-bedded	15	781
Covered, sandstone float. (Approximately the contact between the upper and lower members of the formation.)	85	766
Limestone, light-brown and brownish-gray, fine-grained, thick-bedded, cherty and sandy in part, fossiliferous in middle part; contains chert nodules and interbeds of chert in middle part	121	681

	Thickness of unit (feet)	*Cumulative thickness (feet)*
Covered, brown sandstone float	12	560
Limestone, gray, fine- to coarse-grained, thick-bedded, sandy; contains a few sandstone interbeds, and chert nodules in middle part of unit	91	548
Covered, gray sandstone float	30	457
Limestone, light-gray to brownish-gray, fine-grained, thick-bedded, sandy; contains chert nodules in lower part of unit	34	427
Covered, gray sandy limestone float	300	393
Limestone, gray and light-brown, fine- to coarse-grained, thick-bedded, sandy in upper part; contains few chert nodules in middle part of unit	28	93
Covered, approximate contact with Brazer limestone	65	65
Next lower outcrop is part of Brazer limestone.		

The formation has been divided into two members for mapping purposes. The contact between them is taken as the zone of gradation from interbedded sandstone and limestone below (Mansfield's sandy and cherty limestone facies) to a dominantly sandstone sequence above (Mansfield's middle sandy and upper siliceous limestone facies).

The lower member, which is about 800 to 900 feet thick, contains gray and brownish-gray interbedded limestone and sandstone that occur as thick-bedded units, generally several feet thick. Many of the limestone beds contain abundant fossil fragments and oolites. The sandstone is commonly fine to medium grained and calcareous.

The upper member, about 1,100 to 1,300 feet thick, consists mostly of sandstone, though some limestone is also present. The sandstone is gray on fresh surfaces but weathers to shades of brown and reddish brown. Some of the sandstone is cemented with silica, some is distinctly crossbedded, and all is typically thick bedded. A thin unit of gray calcareous porous friable sandstone occurs about 200 or 300 feet from the top of the member. In outcrop areas this rock contains many cavities, both large and small. Another thin unit composed of red calcareous sandstone, rarely exposed, overlies the porous sandstone. The porous sandstone and red sandstone are correlative in stratigraphic position with "pink" sandstone and anhydrite in the upper part of the Wells formation in Bear Lake County, Idaho, according to the core log reported by Zeni (1953) from the Sheep Creek test well. The contact of the upper member with the overlying Phosphoria formation is sharp and is taken at the top of about 30 feet of thick-bedded gray dolomite that contains nodules, lenses, and thin beds of black and light bluish-gray chert. Some of the dolomite beds contain abundant silicified brachiopods (*Squamularia*?), and others contain silicified rough-surfaced white rods that are considered to be of organic origin. The lithology and fossils of these beds make an excellent marker, and they have great value in defining the proximity of the Phosphoria formation.

Exposures of the Wells formation make up large parts of the areas along the western, southern, and eastern margins of the quadrangle. The formation's general outcrop pattern outlines a northward-plunging syncline, though the eastern limb is partly obscured by faulting. In the south-central part of the quadrangle at the head of Johnson Creek part of the upper member of the formation is exposed in a small transverse anticline.

PERMIAN ROCKS

PHOSPHORIA FORMATION

The Phosphoria formation was named by Richards and Mansfield (1912, p. 684) for its occurrence in Phosphoria Gulch in the southeast corner of the Slug Creek quadrangle, Idaho. The formation is of Permian age, though what part of the Permian is represented has not yet been satisfactorily determined. The phosphatic shale member is thought by some paleontologists to be of Guadalupe age, and possibly Leonard as well (Miller and Cline, 1934; Newell, 1948; and Thompson, Wheeler, and Hazzard, 1948, p. 8). Licharew (*in* Williams, 1938, p. 772) considers the Phosphoria to be probably of Artinskian age.

In its type section the formation is about 415 feet thick and is divided into two members; a lower member composed dominantly of phosphatic shale, and an upper member, named the Rex chert member, composed of chert and limestone. The formation in this quadrangle as described by McKelvey, Armstrong, Gulbrandsen, and Campbell (1953) is similar in character and average thickness to that of the type section and is likewise divided into two distinct members, the phosphatic shale member and the Rex chert member (pl. 2).

The thickness of the formation in the Johnson Creek quadrangle ranges from about 150 or 200 feet to a maximum of around 500 feet. In general, the formation is thicker along its outcrop at the western part of the quadrangle than in the eastern or southern parts; this is especially true for the phosphatic shale member. The thickness of the Rex chert member is not well defined because the upper contact is generally covered.

The phosphatic shale member is generally from 100 to 200 feet thick and consists of mudstone, phosphate rock, and carbonate rock. Where fresh, the mudstone and phosphate rock are dark shades of gray and the carbonate rock is a lighter gray. Weathered rock is brownish gray, brown, and gray. The beds are typically thin bedded and generally less than a foot and frequently less than an inch in thickness. The carbonate rocks tend to be thicker bedded than the others. The phosphate rock is characteristically pellety or oolitic, and the abundance of pellets and oolites provides a good estimate of the amount of phosphate in the rock. Most of the phosphate rock occurs in two zones, one near the base and one near the top of the member. The phosphate content of these zones is shown by the analyses on page 19. Parts of the phosphatic shale member are rarely exposed in natural outcrop, and the whole member has been exposed only in bulldozer trenches.

The Rex chert member consists of chert and limestone, chert making up the greater part of the unit. The chert is black, medium gray, and pale red, and massive in the lower half and shaly above. The shaly impure chert is also called siliceous mudstone. Limestone occurs in two zones: in the lower part as dense dark-gray limestone that weathers gray, and at the top of the massive chert as a coarse gray limestone that contains abundant fossil fragments—mostly crinoid stem plates. The upper limestone is laterally discontinuous. It occurs in this quadrangle only in the Wood Canyon area as a large lens several square miles in area. In regions outside the quadrangle, however, there are similar occurrences of the limestone at this horizon. The Rex chert member is generally from 200 to 300 feet thick.

The major outcrop areas of the Phosphoria are in two bands, one in the western part of the quadrangle and one in the eastern part. The formation is exposed also around part of the southern tip of the Trail Creek syncline and in the transverse anticline at the head of Johnson Creek. Its other occurrences are in many small fault blocks. Usually the massive chert of the Rex chert member is well exposed, in contrast to the less competent shaly chert and the rocks of the phosphatic shale member.

TRIASSIC ROCKS

DINWOODY FORMATION

The Dinwoody formation of Early Triassic age (Newell and Kummel, 1941) has its type locality at Dinwoody Canyon in the Wind River Mountains of western Wyoming. The name Dinwoody is applied in this quadrangle, following Kummel (1953 and 1954), to the rock strata lying above the Phosphoria formation and below the *Meekoceras*-bearing limestone at the base of the Thaynes formation, the same strata referred to by Mansfield (1927, p. 86) as the Woodside shale. Kummel (1953 and 1954) redefined the Woodside to include only the red facies of these Triassic strata. Since red beds are not present in this quadrangle, the whole interval is mapped as Dinwoody.

Olive-gray and dusky-yellow calcareous siltstone and gray limestone are characteristic of the Dinwoody rock types throughout a large area. The rock strata are shaly in the lower half and thick bedded (commonly from 1 to 2 feet thick) in the upper half. The total thickness of the formation averages about 2,000 feet, but there are large local differences. Generally the formation seems to be thicker in the northern half of the mapped area and markedly thinner in the southern part by as much as several hundred feet. A complete section of the Dinwoody formation was measured by Kummel (1954) on Dry Ridge, a few miles east of this quadrangle.

Two members are mapped. The lower member, which is about 1,000 to 1,400 feet thick, is composed largely of dusky-yellow and light olive-gray calcareous shale. Thin ribs of fossiliferous limestone that weather to a distinctive brownish gray or dark purple are characteristic of the lower part of the member. In the upper part of the member irregularly bedded and thin-bedded calcareous siltstones are interbedded with even- and thick-bedded calcareous siltstone. The latter siltstone weathers typically to brownish gray or shiny black.

A zone of transition between the shale and siltstone of the lower member and siltstone and limestone of the upper member is taken as the contact between the two members of the Dinwoody. This zone is characterized by what is interpreted to be slump structures—bedded rock fragments whose bedding is bent and twisted and is discordant to the bedding of the containing rock mass. Also, on the rock of this zone, differential weathering has produced marked surface irregularities that reflect a small-scale alternation of siltstone and limestone layers. The contact between the Phosphoria and this lower member is rarely exposed. However, the topographic expression that is the result of a change from the resistant unit that represents the upper part of the Rex chert member to the weak unit that represents the lower part of the Dinwoody, along with marked soil and float changes, serves to locate it approximately.

The upper member, 800 to 1,200 feet thick, is characterized by thick-bedded limestone that weathers light gray, and by interbeds of calcareous siltstone and calcareous shale. Many of the limestone beds contain an abundance of poorly preserved shells of pelecypods and brachiopods. The contact with the Thaynes formation is taken at the base of the *Meekoceras*-bearing limestone.

Outcrops of the Dinwoody occur mostly in the central and northern parts of the mapped area where its distribution is controlled by the attitude of the Trail Creek syncline. Other exposures occur in the crest of a small anticline between Trail and Wood Canyons, in fault blocks in the southwest corner of the mapped area, and in the northeast part of the quadrangle.

THAYNES FORMATION

The Thaynes formation of Early Triassic age has been redefined recently by Kummel (1954, p. 173). In the region of the Peale Mountains, Kummel divides the formation into seven members that are, from bottom to top: lower limestone, lower black limestone, tan silty limestone, upper black limestone, sandstone and limestone, Portneuf limestone, and Timothy limestone. Formerly Mansfield (1916 and 1927) had included three formations—Ross Fork limestone, Fort Hall formation, and Portneuf limestone—in a Thaynes group. Kummel (1954), on the basis of his regional study, reduces the Thaynes group to formational rank and retains Mansfield's Portneuf limestone only as a member of the formation. In addition, Kummel includes the Timothy sandstone as a member of the Thaynes, whereas the Timothy had formerly been a formation.

Kummel's (1954) Sheep Creek section of the Thaynes, which is about 8 miles northeast of the Johnson Creek quadrangle, is about 3,550 feet thick. In the Johnson Creek quadrangle only about the lower two-thirds of the formation is present. The topmost beds are probably equivalent to the lower part of Kummel's Portneuf member, but few and poor exposures make the correlation uncertain. Four units of the Thaynes are mapped in this quadrangle (pl. 1). They were chosen as the units most suitable for mapping in the quadrangle and correspond only in part with Kummel's members.

The lowest member is composed of calcareous shale and limestone, estimated to be 500 to 800 feet thick. The base is marked by the distinctive *Meekoceras*-bearing gray limestone containing interbeds of calcareous siltstone. The abundance of fossils in a few feet of strata serves as an excellent marker throughout the whole of southeastern Idaho. Overlying beds are composed of fissile and thin-bedded medium-gray calcareous shales that weather gray and brown. Some black brittle thin-bedded limestone that weathers to a characteristic medium bluish gray is present in the central part of the member.

The second member is composed dominantly of thin-bedded olive-gray calcareous siltstone that weathers characteristically into large smooth thin dusky-yellow plates. The plates are thick and rough surfaced in the upper part of the sequence. Dark-gray fissile shale occurs at the top. The overall thickness is estimated to be 600 to 800 feet.

The third member, which is about 500 to 900 feet thick, is typically thin bedded and irregularly bedded. It is composed largely of calcareous siltstone or very fine grained sandstone that contains nodules and thin beds of gray limestone. The limestone nodules give a large-scale mottled appearance to the rock.

The fourth member is very poorly exposed. It contains distinctive thick-bedded gray limestone that is fossiliferous in part, and fine-grained sandstone that weathers brown. Along the axis of the Trail Creek syncline the unit has a maximum thickness of about 500 feet.

The Thaynes formation is confined to the central and north-central part of the mapped area. It occurs in the trough of the Trail Creek syncline and represents the youngest of all the beds making up the syncline.

TERTIARY AND QUATERNARY ROCKS

Tertiary and Quaternary rocks are not differentiated, except Quaternary alluvium, though rocks of both ages are believed to occur in the quadrangle. It was found that their limited distribution, poorness of exposure, and lack of fossils made attempts at differentiation too tenuous to be useful. However, Mansfield (1927) did map rocks in this quadrangle that he considered to be of Tertiary age as the Salt Lake formation.

The unit mapped as Tertiary and Quaternary is composed of gravel, conglomerate, and travertine, but gravel is most abundant at least as observed at the surface. The gravel included here is of local derivation, but it occurs in physiographic positions in which it could not have been deposited by processes prevailing in Recent time. Travertine occurs along fault zones and is the cementing material for some of the conglomerate.

Patches of Tertiary and Quarternary sediments are found mostly along the higher margins of Johnson Creek valley and the valley just east of Trail Creek. Other small patches occur in the northwest corner of the quadrangle near the Jougelard Ranch, in the extreme southwest corner, in the east-central margin area, and along the west side of Dry Fork Canyon in the southeast part of the quadrangle.

QUATERNARY ROCKS

Quaternary alluvium makes up the valley floors. Generally it is composed of fine-grained sediments, but along the edges of the valleys and in their narrower parts the sediments are coarser, in places gravel.

STRUCTURAL GEOLOGY

The structure of the quadrangle is complex. It consists of two major north-northwestward-trending folds that include many minor folds. The folds, in addition, are modified and obscured by faults which have broken the area into large and small blocks. Most of the faults strike parallel to the trend of the folds, though a few are transverse to them.

The Trail Creek syncline and the Aspen Range anticline (Mansfield, 1927) are the largest folds in the quadrangle and are the basic structural elements of the area. The Trail Creek syncline is the better defined of the two, though it is partly obscured by faulting and much minor folding. The Aspen Range anticline is complexly faulted; minor folding is present but is less common than in the Trail Creek syncline.

The Trail Creek syncline makes up the central part of the quadrangle, extends the full length of the area, and plunges gently to the north. The west limb is generally better defined and dips more steeply than the east limb, particularly in the southern half of the quadrangle. The southern end of the syncline is not well defined because of the occurrence of many faults and the small transverse anticline at the head of Johnson Creek. The rocks in the Trail Creek syncline have been crumpled on a small scale throughout a large area. Most of this folding is of too small a scale to be indicated on the map but is reflected there by some of the seemingly erratic dips and strikes.

The Aspen Range anticline adjoins the Trail Creek syncline on the east. Its anticlinal form is not clearly defined, for it is bounded on the west by a large normal fault and is sliced up by other transverse and longitudinal faults; parts of the area that are not disturbed by faults, however, show the crest of the anticline and its gently dipping limbs. The large ridge between Trail and Slug Creeks is thought to be the northern continuation of the anticline, though that continuity is not clearly shown because of the great amount of faulting.

Folds of lesser magnitude than those just described are common and are similar in character. Nearly all trend north-northwestward, parallel to the larger folds, though at the head of Johnson Creek two small transverse anticlines plunge northeastward. Overturned folds are not common, and those that have been found are mostly near the western front of the Aspen Range where much large-scale faulting has occurred.

The coincidence of the range front and the position of overturned strata and complex faults is striking. This relation is well illustrated by the overturned moderately dipping Phosphoria formation and adjacent strata on the south side of South Sulphur Canyon. Other occurrences of this coincidence are northward from there. Overturned strata along the front of the Aspen Range are not restricted to this quadrangle; the feature is found also on the north side of Swan Lake Gulch about 2 miles south of this quadrangle. The same phenomenon has been noted by Williams (1948) along the western front of the Bear River Range near Logan, Utah. Williams attributes the overturning there to drag from a large thrust fault that cut the rock strata at an angle greater than the slope angle of the range front. In this quadrangle the complex faulting associated with the overturning makes an explanation more difficult, and as yet the mechanism and sequence of events that are involved are not known.

Normal faults are the largest and most abundant of the many faults in the quadrangle. Though two large tear faults probably associated with the normal faults occur in the northern half of the quadrangle, transverse and reverse or thrust faults are of minor importance. The faults are not well defined in many places because of poor exposures, but generally they dip westward at medium to high angles. Most of the normal faults that dip eastward are on the east limb of the Trail Creek syncline.

Faults along the western border of the quadrangle are especially complex. A large normal fault can be traced southward from Shield Canyon to the area between North and South Sulphur Canyons where its identity is lost in a complex of faults. This fault was mapped by Mansfield (1927) as two faults, both as branches of the Bannock overthrust, but his interpretation is not supported here. The position and attitude of the Phosphoria and Wells formations on the west side of the fault are more simply explained as thrown down rather than thrust up. In the normal fault interpretation the rock mass on the west side of the fault was derived from the west limb of the Trail Creek syncline; in Mansfield's interpretation the thrust block came out of Bear River valley. At both ends of the fault, as traced in this quadrangle, are large outcrops of the Brazer limestone that are nearly bounded by faults, the largest of which represents a minimum stratigraphic displacement of more than 3,000 feet. The masses of Brazer appear to have been points of resistance that deflected the faulting to all sides.

Two other complexly faulted areas occur in the eastern half of the quadrangle, the area of Burchertt Canyon and the area just north of the junction of the Mill Fork and Wood Canyon roads. These areas show an intricate pattern of faults, mostly of small displacement and length, such as might result from a general but rather small-scale shattering of the strata.

Two major tear faults are present in the northern half of the mapped area. They strike nearly eastward and are the only large faults that cut across and displace the northward-trending folds. The block on the north side of each fault shows an apparent westward horizontal displacement of 1,000 to 2,000 feet from the block on the south side. Mansfield (1927) states that the Bannock overthrust underlies the whole of the Johnson Creek quadrangle, and therefore no direct observations relating to the question of the existence of the Bannock could have been or can be made here. Mansfield did map some thrusts along the western margin of this quadrangle that he considered to be branches of the Bannock overthrust, but it was found in the course of this mapping that the thrusts do not exist or are better interpreted as normal faults. Another instance of this relates to the thrust shown by Mansfield as extending southward from the northwest corner of the quadrangle to the area between Trail and Wood Canyons. There the existence of the thrust was based on the supposed absence of the *Meekoceras* zone at the base of the Thaynes formation; during the course of the present mapping, however, the *Meekoceras* zone was found along the entire line of outcrop.

The relation of faulting to folding in the quadrangle is complex; yet in general the major faulting and folding appear to have occurred in different periods. The major folds, the Trail Creek syncline and Aspen Range anticline, were formed first. Minor faulting was associated with the folding, such as the breaking and thinning of strata at the southern tip of the Trail Creek syncline. The major faulting occurred after the folding, as indicated by displaced and broken folds. During this period the large normal faults were formed. They generally trend parallel to the folds, and most commonly the blocks on the west side of the faults were dropped.

MINERAL DEPOSITS

The phosphate deposits of this quadrangle are among the thickest and richest of the entire western phosphate field (Swanson, McKelvey, and Sheldon, 1953), but the largest part of the deposits is deeply buried. The phosphate rock occurs as beds at different horizons in the Phosphoria formation and is composed of carbonate-fluorapatite and varying proportions of quartz, dolomite, calcite, and carbonaceous material. The carbonate-fluorapatite occurs most commonly as pellets or oolites of fine to coarse sand size. The phosphate and associated rocks of the phosphatic shale member contain important concentrations of many minor elements; but, except for vanadium, the economic utilization of the minor elements awaits the development of efficient processes of concentration and extraction.

As part of a regional program, the U. S. Geological Survey trenched and sampled the phosphatic shale member of the Phosphoria formation in Trail Canyon, trench 1206, in the NW¼ sec. 30, T. 8 S., R. 43 E., and on the outcrop just north of the point where Johnson Creek enters Slug Creek valley, trench 1209, in the SE¼ sec. 23, T. 8 S., R. 43 E. Brief rock descriptions and chemical analyses for P_2O_5 and the acid insoluble of all samples; Al_2O_3, Fe_2O_3, F, and loss on ignition for some samples; and semiquantitative spectrographic analyses for a large number of elements for some samples have already been published (McKelvey, Armstrong, Gulbrandsen, and Campbell, 1953).

In addition to the surface trenching, three diamond-drill holes were drilled for the Geological Survey by the U. S. Bureau of Mines. They are: diamond-drill hole 1274 on the south slope of Middle Sulphur Canyon, sec. 8, T. 9 S., R. 43 E.; diamond-drill hole 1278 on the north slope of Middle Sulphur Canyon, sec. 8, T. 9 S., R. 43 E.; and diamond-drill hole 1276 on the valley bottom of the south fork of Johnson Creek, sec. 9, T. 9 S., R. 43 E. The sections obtained from this drilling program were incomplete, but descriptions and chemical analyses for P_2O_5 and the acid insoluble of the core samples have been published (McKelvey, Davidson, O'Malley, and Smith, 1953). The diamond core drilling was part of an experimental program that is described by Long (1949).

Studies of the phosphatic shale member throughout the southeastern Idaho region (Swanson, McKelvey, and Sheldon, 1953) have revealed that the lower and upper phosphate zones are exceptionally continuous as a whole; but local differences are marked and are critical from the economic point of view, as shown in the table, which summarizes the P_2O_5 content of the beds exposed in the Trail Canyon and the Johnson Creek trenches. The table indicates the problems of areal differences in grade of phosphate rock and faulting that must be considered in the appraisal of a deposit for development.

At Trail Canyon the lower phosphate zone, near the base of the member, is 6.6 feet thick and averages 32.8 percent P_2O_5. No such zone is found in the Johnson Creek section. Overlying this rich zone at Trail Canyon is the furnace-grade shale zone, 14.8 feet of phosphate rock that averages 25.1 percent P_2O_5; again, no comparable zone is found at Johnson Creek. Other parts of the phosphatic shale member at the two localities are comparable, and, moreover, the lower phosphate zone and the furnace-grade shale zone have been identified at other localities to the east. The absence of these zones in the Johnson Creek section, therefore, is believed to be due to faults that occurred at low angles to the bedding planes. Faults of this type are difficult to recognize in small exposures and may account for other occurrences of the phosphatic shale member that are anomalously thin.

At Trail Canyon the upper phosphate zone, which underlies the top of the phosphatic shale member, is 5.1 feet thick and averages 29.4 percent P_2O_5. The same zone at Johnson Creek is 5.2 feet thick and averages 34.2 percent P_2O_5. This relatively small difference in grade is critical because the rock is acid grade at Johnson Creek and furnace grade at Trail Canyon. Differences in grade of this kind, but possibly not the magnitude of the above example, are likely to be due to differences in weathering of the rock. Generally the rock that has undergone the most weathering will contain the most phosphate, because carbonaceous material and carbonate are removed

Summary of the phosphate content of the phosphatic shale member

Zones	Trail Canyon section			Johnson Creek section		
	P_2O_5 content (percent)	Thickness (feet)	Cumulative thickness [1] (feet)	P_2O_5 content (percent)	Thickness (feet)	Cumulative thickness [1] (feet)
Undifferentiated	4.3	13.2	13.2	5.5	14.2	14.2
Upper phosphate	29.4	5.1	18.3	34.2	5.2	19.4
				10.8	1.6	21.0
Middle mudstone	8.3	165.7	184.0	25.2	4.3	25.3
				8.9	119.8	145.1
Furnace-grade shale	25.1	14.8	198.8	-----	-----	-----
Lower phosphate	32.8	6.6	205.4	-----	-----	-----
Undifferentiated	10.2	5.6	211.0	-----	-----	-----

[1] Cumulative thickness measured from top of phosphatic shale member.

from the rock more rapidly by solution and oxidation than is phosphate. Differences in grade with depth is likewise a function of weathering. Generally, but depending on specific conditions, the grade of phosphate rock will decrease with depth. The amount of decrease probably is small in most cases, but it may be important.

The Anaconda Copper Mining Co. is the only company now actively engaged in mining phosphate rock in this quadrangle. Most of its work has been done in the development of the Conda mine, which is 2 miles west of the quadrangle but whose workings extend to the outcrop of the Phosphoria in the northwest corner of the quadrangle. A portal is located in the W½ sec. 13, T. 8 S., R. 42 E. The Conda mine has been in operation since the early 1920's and is the only underground phosphate mine in southeastern Idaho which has had any sustained period of production. Most of its production has been from the lower part of the phosphatic shale member of the formation. In 1952 Anaconda began exploratory strip-mining operations in the southwestern part of this quadrangle on a high spur, in the E½ sec. 17, T. 9 S., R. 43 E., that is capped by nearly flat lying Phosphoria formation strata.

Though exploration for rich deposits of phosphate in the Phosphoria formation has been under way for many years, that activity has recently been accelerated by the increasing demand for phosphate fertilizer and elemental phosphorus. Particular attention has been directed toward areas that possibly could be exploited by strip mining. Besides the exploratory strip mining begun by the Anaconda company, several areas, including the upper part of the south fork of Johnson Creek, along Burchertt Canyon, and north of the junction of Dry Fork and Petterson Canyons, have been extensively explored by bulldozer trenching. Though many trenches were dug, they were not deep enough for a proper evaluation of the deposits. Thus the potential of those areas is still unknown.

The part of the Trail Creek syncline south of the Johnson Creek road in which the phosphatic shale member of the Phosphoria formation is covered only by the Rex chert member or the Rex chert and the lower part of the Dinwoody formation is possibly of value for shallow underground mining. The marked thinning or absence of the phosphatic shale member in that area, however, makes any estimate of its potential uncertain.

The long line of outcrop in the northeast quarter of the quadrangle has not been prospected, probably because it is notably thinner than either the Trail Canyon or Johnson Creek sections; however, it is not known whether the phosphate zones of the section are present there. The line of outcrop along the west limb of the Trail Creek syncline from the summit of Middle Sulphur Canyon to the northwest corner of the quadrangle seems to be comparatively free from structural complexities for some distance on either side of the Phosphoria. If the grade and amount of phosphate found in the Trail Canyon section is characteristic of this outcrop, it is of high economic importance. A limited amount of strip mining may be possible southward from the Middle Sulphur Canyon area along this line of outcrop. Other small areas of outcrop are in fault blocks throughout the quadrangle but these rocks generally can be rejected from economic considerations because of their structural complexity and limited downward extension.

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