A RECONNAISSANCE FOR PHOSPHATE IN THE SALT RIVER RANGE, WYOMING.

By G. R. MANSFIELD.

INTRODUCTION.

Scope of investigation.—In the autumn of 1914 a part of the Salt River Range was examined because of questions relating to certain withdrawn lands on the west flank of that range. The writer was asked to ascertain the presence or absence of important beds of phosphate west of the crest of the range and to procure such other data regarding the stratigraphy and structure of the range as proved practicable.

The examination was begun east of Fairview, Wyo., on September 24, 1914, with P. V. Roundy, of the Geological Survey, as chief assistant. E. L. Jones, jr., and E. H. Finch, of the Geological Survey, later joined the party, and work was continued northward along the range until October 9, when it was stopped because of deep snow on the mountains.

Previous work.—The region described in this report is part of the great area studied by the Hayden Survey, the reports and maps of which still constitute the main source of information on this district. Blackwelder[1] has given an account of the discovery of phosphate in Swift Creek, east of Afton, and Schultz[2] has discussed the geology of the region east of the crest of the Salt River Range.

Results.—The data thus far available indicate that the prosphate deposits of the Salt River Range are probably inferior to those of southeastern Idaho both in thickness and in quality. There is, however, a considerable body of medium-grade rock which may be considered as a valuable reserve deposit. If the plan of grinding and applying phosphate rock directly to the soil without chemical treatment is found to produce beneficial results, some local demand for this rock might be developed, for the westernmost portions of the deposit are readily accessible in the canyons of Dry, Swift, and Willow creeks, and the rock is largely above water level. Under present market conditions, however, and in view of the great body

[1] Blackwelder, Eliot, A reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 460–461, 1911.

[2] Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, 1914.

of high-grade rock in neighboring regions of Idaho, there is little likelihood that the deposits of the Salt River Range will assume any notable importance in the near future.

GEOGRAPHY.

Topography.—The Salt River Range lies near the west boundary of Wyoming, in Lincoln County, east of the broad alluvial valley of Salt River, which is locally known as Star Valley. The range is separated on the north by the Snake River canyon from the Snake River Range. To the south it splits into two ranges that form divides between tributaries of Bear and Green rivers. The range is rugged and high, maintaining an altitude of 9,000 to 10,000 feet, and culminating in Mount Wagner, 10,809 feet high, toward its south end. The trend of the range is north or slightly to the west of north, and many of the ridges and valleys follow the strike of the rocks. The canyons are deep, rough, and picturesque. Some of the harder rock layers descend to the canyon bottoms as veritable walls of rock that project conspicuously above the adjacent weaker beds. Toward the heads of a number of the canyons there are relatively broad, open basins which lie for the most part along the strike of Triassic rocks that offer moderate resistance to erosional activity. Below these basins the canyons cross the disturbed massive limestones of the Carboniferous. Here the canyons tend to close, with steep rocky walls and rock slides that are difficult of passage. There are evidences of two or more physiographic cycles, but the history has not been worked out. Alluvial fans lie at the mouths of many of the canyons along the west base of the range. The town of Afton is located upon a large fan somewhat above the general level of Star Valley.

Drainage.—For most of its length the Salt River Range forms the divide between two large southerly branches of the Snake, Salt River and Grays River, but Grays River cuts across the range in its lower course shortly before entering Snake River. In the portion of the range covered by this report the main streams are all tributary to Salt River except Bear Creek, which heads against McDougal Pass and flows into Grays River, and Corral Creek, which heads against Swift Creek and flows eastward. The main streams that are discussed in this report are Dry Creek, in T. 31 N., R. 118 W.; Swift Creek, in T. 32 N., R. 118 W.; Phillips, Willow, and Dry creeks, in T. 33 N., R. 118 W.; and Strawberry Creek, in T. 34 N., R. 118 W. With the exception of Phillips Creek and the northern Dry Creek, these are all characteristic mountain torrents of good volume and are valuable as sources of water power as well as for irrigation. Large springs occur in a number of the canyons, and one of these in Swift Creek in the NW. ¼ sec. 23 (unsurveyed), T. 32 N., R. 118 W., is intermittent, having a periodic flow said to occur several times daily. This spring

was visited twice on different days. It was inactive on the first visit and just beginning activity on the second. In Strawberry Creek the surface flow is more or less intermittent in the upper and middle courses, but two considerable springs a short distance above the lower and more rocky part of the canyon supply practically the full volume of the creek.

Culture and industries.—The lowland outside of the range is largely taken up as agricultural land and is more or less actively farmed. Star Valley is an important district for the raising of grain and hay and for dairying. Dairies are located at Afton and Thayne. Most of the area directly concerned in this report lies in the Wyoming National Forest, the headquarters of which are at Afton. This part of the range is still largely unsurveyed and uninhabited, but it is extensively used for grazing. Timber and fuel are also cut in the national forest. A sawmill in the forest is maintained on the southern Dry Creek, in unsurveyed sec. 2, T. 31 N., R. 118 W. A sawmill has been operated for many years at the mouth of Willow Canyon, in sec. 14, T. 33 N., R. 118 W., and another sawmill is located at the mouth of Swift Creek canyon, at Afton.

Water power.—A small power plant at the mouth of the canyon of Swift Creek generates electricity for lighting and other uses at Afton. Its capacity is not sufficient, however, to supply much of the surrounding territory. Except at this plant and the sawmills above referred to no use is made of the water power in the creeks mentioned. Strawberry Creek, though admirably adapted for water power, having good volume and velocity, is entirely unutilized in its canyon portion, and Willow Creek, Swift Creek, and the southern Dry Creek are only partly utilized. The sawmill on Dry Creek is about 5 miles above its mouth, and the lower part of the canyon contains favorable power sites.

GEOLOGY.

GENERAL FEATURES.

Parts of the canyons of both Dry creeks and Swift, Phillips, and Willow creeks were traversed, a reconnaissance trip was made along Willow Creek to McDougal Pass and down Strawberry Creek to Bedford, and a similar trip was made down Willow Creek through the narrows below Turnerville to the narrows of Salt River and the region west of that stream.

The part of the Salt River Range examined includes sedimentary rocks ranging in age from early Carboniferous (Madison limestone) to Quaternary. No igneous rocks were seen. On the general map (Pl. XII) an attempt has been made to correlate the several canyon sections by drawing connecting lines from one canyon to the next. These lines, however, are purely hypothetical, for the formations

have not been traced through the areas intervening between the canyons. The accompanying table gives a summary of the rock formations present in the range:

Rock formations of Salt River Range, Wyo.

Age.		Formation.	Character.	Thickness (feet).
Quaternary.		Alluvium.	Unconsolidated sands and gravels.	
Tertiary.		Conglomerates.	Pinkish, calcareous, with subangular fragments of limestones and sandstones as much as 5 inches in diameter.	
Jurassic.		Twin Creek limestone.	Whitish shaly limestone; some massive beds; fossiliferous.	2,000±
Jurassic or Triassic.		Nugget sandstone.	Red sandstones, with some shaly beds and thin beds of purplish limestone.	1,100+
Triassic (Lower Triassic).		Ankareh formation.	Chocolate-colored to dark-red sandstones and shales.	1,000
		Thaynes limestone.	Limestones, sandstones, and calcareous sandy shales, greenish yellow; fossiliferous. Include also 200 to 300 feet of red beds.	2,100+
		Woodside shale.		
Carboniferous.	Permian (?).	Phosphoria formation.	Rex chert member, nodular cherty limestone 250 to 300 feet thick, underlain by phosphate shales 65 to 150 feet thick, containing several beds of phosphate rock; fossiliferous.	450
	Pennsylvanian.	Wells formation.	Siliceous limestone and sandstones; fossiliferous.	2,000+
	Mississippian.	Brazer limestone.	Massive gray limestones, generally light colored; fossiliferous, containing large cup corals.	1,500±
		Madison limestone.	Massive dark-bluish or brownish-gray limestones; fossiliferous.	2,500±

STRATIGRAPHY.

CARBONIFEROUS.

Madison limestone.—The Madison limestone was recognized in Strawberry, Dry, and Willow Creek canyons, in Tps. 34 and 33 N., R. 118 W., and may be present on Swift Creek. The formation consists of massive dark-bluish or brownish-gray, relatively pure limestones, with little or no sandy material. Some of the individual beds are thin, but the formation as a whole is resistant to erosion and forms rugged ledges and slopes where it is exposed in the canyons. Fossils are rather numerous and include small cup corals, gastropods, spiriferoid brachiopods, crinoids, and other types. The rock presents no new or unusual facies and is apparently like the rocks of the same age in other parts of the Idaho field, as described in previous reports. The distinction between the Madison and the Brazer limestone is not everywhere easy, for the two formations are massive and resemble each other lithologically to a certain extent. The relations of the Madison to the formations above and below are not clear, as it seems in this area to be separated from the adjoining formations by faults. Measurements on Willow Creek show 2,400 to 2,500 feet of rock

SECTION A-A'

SECTION B-B'

SECTION C-C'

SECTION D-D'

SECTION E-E'

R. 118 W.

R. 117 W.

T. 34 N.

T. 33 N.

T. 32 N.

T. 31 N.

Cedar Cr.

Strawberry Creek

Bedford

Amby's

Blankenship

Welshman

Turnerville

Dry Creek

Willow Creek

Grover

Afton

Osmond

Smoot

Mc Dougals Pass

CAMP

POWER PLANT

Swift Creek

Phillips Ditch

Fault

Section across phosphate beds

19" 26.00 % $Ca_3(PO_4)_2$
24" 44.16 " "
18" 45.77 " "

Upper bed 1' 68.40 % $Ca_3(PO_4)_2$
Lower bed 2½-3' 48.86 % $Ca_3(PO_4)_2$

Fl. phosphate 72.7 % $Ca_3(PO_4)_2$

Fl. phosphate 69.00 % $Ca_3(PO_4)_2$

LEGEND

Qal	Alluvium	QUATERNARY
Tsl	Conglomerate	TERTIARY
Jtc	Twin Creek limestone	JURASSIC
Trn	Nugget sandstone	JURASSIC OR TRIASSIC
Tra	Ankareh formation	TRIASSIC
Trt-Trw	Thaynes limestone and Woodside shale	TRIASSIC
Cpr, Cpp	Phosphoria formation Rex chert member, Cpr; phosphate shales, Cpp	Permian ?
Cw	Wells formation	Pennsylvanian
Cb	Brazer limestone	Mississippian
Cm	Madison limestone	Mississippian
	Fault	
60°	Dip and strike	
	Vertical bed	
	Axis of anticlinal fold	
	Axis of synclinal fold	
×	Phosphate sample	
	Government corner found	

SECTION SYMBOLS

Qal, Tsl, Jtc, Trn, Tra, Trt, Trw, Cpr, Cpp, Cw, Cb, Cm, D? — 10,000 ft. — 5,000 ft. — 0

RECONNAISSANCE MAP
OF A PORTION OF THE

SALT RIVER RANGE, WYOMING

Showing the geology along several canyons with geologic structure sections

BY G.R. MANSFIELD

Scale 1/62,500

1 0 1 2 Miles

Sketch contours, interval approximately 50 feet

1915

INDEX MAP

PHOTO. LITH. BY A. HOEN & CO., BALTIMORE, MD.

assigned to the Madison, and in Dry Canyon north of Willow Creek the thickness appears to be even greater. A number of folds and faults in these older rocks have been recognized, and allowance has been made for them in measuring the thickness. There may be within the formation, however, unrecognized faults which may have duplicated some of the strata, thus increasing the apparent thickness.

Brazer limestone.—The Brazer limestone is also a massive gray rock but is generally of somewhat lighter color than the Madison. It contains some sandy beds and is more or less cherty in places. Like the Madison, it forms rocky and rough slopes and prominent ledges. Fossils are fairly numerous and conspicuous. Among them are cup corals 4 to 8 inches or more long and 2 or more inches in diameter, with many fine septa, *Productus giganteus* and other brachiopods, Bryozoa, and Syringopora. The Brazer limestone here is similar to the rocks of the same age in Idaho and presents no unusual facies. On account of the faults and folds there has been no good opportunity to measure a complete section. The best exposures seen were in Swift Creek Canyon, where at least 1,500 feet of limestone may be assigned to this formation and the base was not recognized.

Wells formation.—The Wells formation has massive cherty limestones at the base but is more siliceous throughout than either the Brazer or the Madison. A varying portion in the middle or upper part is a sandstone, or in places even a quartzite. The upper 50 to 200 feet is made up of siliceous dense limestone that in places forms prominent ledges. This portion of the formation has sometimes been called the "underlying limestone," or the "lower Productus limestone," as it normally underlies the phosphate shales of the Phosphoria formation just above. The Wells formation as a whole is somewhat less resistant to erosion than the Madison and Brazer and forms rounded slopes. The canyons, too, are wider and less rugged in this formation than in the Brazer and Madison limestones. The limestones of the Wells are somewhat fossiliferous. The lower beds carry *Spirifer rockymontanus*, Schizophoria, Bryozoa, and other forms. The upper limestone is sparingly fossiliferous, the most noticeable forms being species of Productus. Excellent exposures of the Wells are found in all the canyons examined, notably those of Strawberry and Swift creeks. Measurements on Swift Creek show 2,000 feet or more of strata assignable to this formation.

Phosphoria formation.—As in the Idaho field the Phosphoria formation consists here of two members—the phosphate shales below and the Rex chert member above. The thickness of the shales is about 65 to 150 feet and of the chert 250 to 300 feet. A partial section of the shales was obtained from a prospect made by the Survey party in Willow Creek canyon about half a mile above the sawmill. The details of this prospect and the analyses of the samples taken are

given in the discussion of phosphate deposits (p. 339). A number of occurrences of the phosphate shales were noted, including several natural exposures. One of these is described more fully on page 340. The general characteristics of the shales appear to be much the same as in the Idaho field. The Rex chert member is more of a limestone in this region than in many parts of Idaho. It is a very prominent ledge maker where it is well exposed and forms steep walls in a number of places, none more striking than in Swift Creek, where it resembles a stockade nearly 50 feet high, descending the mountain side and crossing the canyon.

TRIASSIC.

Woodside shale and Thaynes limestone.—The Woodside and Thaynes formations were not satisfactorily differentiated in this region. Although a search was made for the Meekoceras zone, the boundary between the two formations, its presence was recognized at only one locality—in the float near the end of the traverse on the northern Dry Creek, about a quarter of a mile east of the northeast corner of unsurveyed sec. 6, T. 33 N., R. 117 W. A very fine section of these two formations is exposed near the crest of the range along the Willow Creek trail, half a mile or less south of McDougals Pass. There was no opportunity to measure this section, but the rock forms prominent cliffs and coarse débris at the locality named. Here silicified fossils, pelecypods, project from the weathered surfaces of rock fragments, as in the upper part of the Thaynes limestone of southeastern Idaho. The massiveness of some of the beds is remarkable. Large fragments, some 8 by 5 by 4 feet, were seen in the rock waste at the bases of the cliffs. Some of the beds are very sandy and form reddish to pinkish sandstones, which in places weather with black, iron-stained surfaces. These rocks resemble some of the sandstones in Dry Valley, Idaho, in T. 8 S., R. 44 E., which proved to belong to the Woodside and Thaynes formations but were at first mistaken for the Wells. In the exposures near McDougals Pass there are 200 to 300 feet of red beds. On Swift Creek measurements of the combined formations, which may not be complete, show 2,100 feet of strata.

Ankareh formation.—The Ankareh formation is represented in this region by a series of chocolate-colored to dark-red sandstones and shales. They are exposed in the canyons of the southern Dry Creek and Swift Creek and also on the headwaters of Willow Creek near McDougals Pass, where they overlie with apparent conformity the Thaynes limestone. The last-named locality furnishes an unusually fine exposure, but it was not practicable to study it at close range. On Dry Creek and Swift Creek the formation as measured is 750 and 1,000 feet thick, respectively. The lower figure on Dry Creek is probably due to partial removal by faulting.

JURASSIC OR TRIASSIC.

Nugget sandstone.—The Nugget sandstone occurs on the lower parts of the southern Dry Creek and Swift, Phillips, and Willow creeks, and also in the low hills west of Turnerville, at the narrows of Willow Creek. In the section south of McDougals Pass above mentioned the Nugget follows the Ankareh, but it was not ascertained if the complete thickness of the formation is present. The Nugget also appears in the upper part of the Swift Creek canyon. The Nugget sections in the lower canyons, where the more detailed observations were made, are all faulted to some extent, but from 800 to 1,100 feet of beds are represented. The rocks are the usual red sandstones with some shaly beds and thin layers of purplish limestone.

JURASSIC.

Twin Creek limestone.—The Twin Creek limestone is exposed in the canyons of the southern Dry Creek, Swift Creek, and Phillips Creek. It also appears to the west of the Nugget sandstone in the narrows of Willow Creek west of Turnerville. So far as observed the Twin Creek limestone is not fully represented in the sections examined but is partly cut out by faults. It is represented chiefly by the chippy and shaly rock that elsewhere seems to occupy the central part of the formation. Sections examined in the southern Dry Creek and Swift Creek indicate thicknesses probably greater than 1,700 and 2,000 feet, respectively. Fossils are not numerous in the more shaly beds of this formation, but Pentacrinus, Ostrea, and other forms occur in the thicker beds.

TERTIARY.

A conglomerate consisting mainly of subangular fragments of Carboniferous limestones and sandstones with some Triassic material of varying shapes and sizes, from a fraction of an inch to 4 or 5 inches in diameter, lies on the lower foothills along Phillips Creek east of Grover, above the narrows of Willow Creek west of Turnerville, and at the mouth of Strawberry Creek. The matrix is calcareous and the general color of the rock is pinkish. The attitude of the rock where observed is nearly horizontal or only slightly inclined. No fossils have yet been found in this rock, and its stratigraphic position is somewhat uncertain. In the field it was tentatively classed with the Salt Lake beds, of probable Pliocene age, as mapped by A. C. Peale, of the Hayden Survey. Some doubt is thrown on this interpretation by observations on similar rock north of Georgetown, Idaho, 30 miles or more to the southwest. It is possible that this conglomerate may prove to be of Wasatch age.

QUATERNARY.

Alluvial and fan deposits of Quaternary age occupy the lowlands along the west base of the range and in the basin west of the mouths of Willow, the northern Dry, and Strawberry canyons. These deposits are coarse bowldery gravels at the mouths of the canyons but consist of finer material farther away from the base of the mountains. The gravels at the mouths of the southern Dry Creek and Swift, Phillips, and Willow creeks and the smaller intervening creeks are abruptly truncated and form terraces 15 or 20 feet high.

STRUCTURE.

The general structure of the region described in this report is complex, and the available data are insufficient to warrant the attempt to carry the structure observed in any one of the several canyons across to the neighboring canyon. It is clear, however, that at least two great folds are involved, one anticlinorial and the other synclinorial, and that each is broken by a number of faults. The trend of both folds and faults is a little west of north. The planes of many of the faults appear to be steeply inclined, and the relations of the formations involved suggest normal faulting, because the structure as a whole does not indicate marked overturning. The folds appear to pitch gently southward, so that older beds are exposed in the northern canyon sections than in the southern sections. The oblique truncation of successive structures along the west base of the range in T. 31 N., R. 118 W., and farther north, together with the relative straightness and steepness of the mountain slope, suggests that the west base of the range is determined by a normal fault that is inclined toward the west and brings in Jurassic or higher formations, now concealed beneath the alluvium of Star Valley. These formations constitute the west wall of Star Valley, some 3 miles or more to the west. Relatively recent movement along such a line is suggested by fairly straight scarps or terraces 15 to 20 feet high in some of the larger alluvial fans along the west base of the range. These scarps, however, may be due to other causes. The map (Pl. XII) shows the broader structural features, and the geologic structure sections along several of the canyons show details and are discussed more fully below in the accounts of the canyons.

PHOSPHATE DEPOSITS.

The Phosphoria formation is involved in the folding and faulting so that it crosses each of the canyons examined except that of Phillips Creek. The canyons of the southern Dry Creek, Swift Creek, and Willow Creek are each crossed by the shales no less than three times between the crest of the range and its western base. The crest of the range was visited only at McDougals Pass, at the heads of Willow

and Strawberry creeks. It was nearly reached, however, on Swift Creek. Crossing the divide at Corral Creek and entering the headwater region of Swift Creek a band of phosphate shales runs along the west side of the crest of the range. This was not followed northward, but it falls in line well with another similar band that in like manner crosses the divide from the southeast at McDougals Pass above Willow Creek and descends northward in the headwater region of Strawberry Creek for a distance of perhaps 2 miles and then reascends toward the crest. It is not yet certain that the Swift Creek band and that of McDougals Pass are identical and continuous, but it seems likely that this will prove to be the case when the intervening territory is traversed. West of this band the phosphate shales are brought in twice by folding in the middle or lower parts of the canyons. The phosphate deposits continue southward from the southern Dry Canyon, but it is doubtful if they extend northward from Strawberry Creek. The extent of the formation in each direction was not determined.

The phosphate shales in this region have a thickness comparable to that of the beds of the same formation in the Idaho field. Phosphate beds of good quality are included in the shales. A section across the shales was measured in a series of prospect pits made by the Survey party near the mouth of Willow Creek, and samples were collected for analysis. The details of the section and the analyses are given in the following table:

Details of Survey prospect in the SW. ¼ NE. ¼ sec. 14, T. 33 N., R. 118 W., on Willow Creek.

[Field No. M 45-14.]

	P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
Phosphoria formation:	*Per cent.*	*Per cent.*	*Ft.*	*in.*
k Phosphate rock, oolitic, dark brown to black, medium grained, folded in small syncline and anticline (end of third trench)—				
Sample 3, upper	11.90	26.00	1	7
Sample 2, lower	20.21	44.16	2	0
j Shale, calcareous, clayey, yellowish, with green tinge; breaks into small pieces with planes irregularly arranged			2	0
i Phosphate rock, oolitic, medium grained. Sample 1	20.95	45.77	1	6
h Limestone, dark gray to blackish, clayey, thin bedded, weathering to a black soil			4	0
g Limestone, dark gray to blackish, clayey, thin bedded (end of second trench)			16	0
f Limestone, dark gray, clayey, with chert bands 1 to 4 inches thick, shale bands and limestone bands 2 to 8 inches thick			6	0
e Shale, dark clayey, much weathered			2	0
d Phosphate shale				1
c Shale, black, not well exposed			5±	
Wells formation (?):				
b Sandstone, fine grained, calcareous (or siliceous limestone), dark gray, broken into small angular pieces (end of first trench)			2	0
a Limestone, fine grained, greenish gray; weathers much lighter; joint planes well developed				10
Wells formation:				
Sandstone, yellow; base of section.				
			43	0

The phosphate band in which the section was made is probably faulted out both north and south of the canyon, but it is readily accessible by road from the valley to the west. The Survey prospect was made in three trenches, planned to cover a continous stratigraphic interval, which aggregated 191 feet in length and ranged from 1 foot to 5 feet 7 inches in depth. The general strike and dip of the rocks, determined from the Wells formation below and the Rex chert member above, were N. 30° E. and 28° E., respectively.

The section shown in the table is not complete, for it proved impracticable to continue the trenching entirely across the phosphate shales. It does, however, include more than half the distance across the shales. By comparison with the apparent thickness of the shales at McDougals Pass and at places on Swift Creek and the southern Dry Creek, the thickness of the shales here seems somewhat less than normal, and this suggests that part of the section may be faulted out. Some deformation in the shales at the Survey prospect is indicated by the brecciation of some of the beds and the presence of folds in other beds.

The analyses show a lower content of phosphoric acid than might be expected from the general appearance of the rock. Some of the deficiency may be due to the presence of infiltered dirt along bedding and joint planes.

At McDougals Pass the phosphate shales strike N. 11° W. and dip 16° W. The breadth of the outcrop is about 225 feet, but the actual thickness of the shales appears to be about 65 feet. Two phosphate beds are hard enough to form low ledges. The lower bed is about 16 feet above the base and is 2½ to 3 feet thick. A sample from this bed yielded on analysis 22.36 per cent of P_2O_5, equivalent to 48.86 per cent of tricalcium phosphate. A second bed about 24 feet above the base and about 1 foot thick yielded on analysis 31.3 per cent of P_2O_5, equivalent to 68.40 per cent of tricalcium phosphate. As it was impracticable to make a trench in the phosphate shales the number of phosphate beds and the thickness of each could not be accurately determined.

In the southern Dry Canyon the phosphate shales are present in apparently normal thickness. They have been prospected on the north side of the canyon, in the westernmost of the three bands that cross the canyon. The prospect, an old tunnel, has caved and has been so covered by slides that no examination or measurements of the shales could be made. A sample of float from the sag on the hill to the south across the canyon was found by analysis to contain 33.31 per cent of P_2O_5, equivalent to 72.7 per cent of tricalcium phosphate.

Phosphate float is found along the base of the ridge on the upper course of Swift Creek, in T. 32 N., R. 117 W., and it seems probable

that the phosphate band which there lies on the west side of the divide continuing northward becomes the band exposed at McDougals Pass. According to Mr. Jewell, of Afton, the phosphate occurs in the head of Corral Creek east of the divide. It appears to cross the divide at the sag between the heads of the two creeks. A sample taken from a large piece of float near the head of Swift Creek yielded 31.59 per cent of P_2O_5, equivalent to 69 per cent of tricalcium phosphate.

From the samples at McDougals Pass, the southern Dry Creek, and Swift Creek it is evident that high-grade rock is present in the phosphate shales of this portion of the Salt River Range. The occurrence at McDougals Pass suggests that this high-grade bed may not exceed 1 foot in thickness. More prospecting and sampling will be necessary to determine the relative importance of the richer material. From the Willow Creek and McDougals Pass section it is evident that there are two beds near enough together to be worked as one bed aggregating 3 to 3½ feet of phosphate rock and yielding from 45 to 50 per cent of tricalcium phosphate.

METALLIFEROUS PROSPECTS.

A number of metalliferous prospects are reported in some of the canyons east of Fairview, in T. 31 N., R. 118 W. The only one of these visited was Nielson's tunnel, in Dry Canyon, about 1½ miles above the mouth of the canyon. The tunnel is located on a minor fault zone in the Twin Creek limestone, about 200 feet east of a larger fault, between the Twin Creek limestone and the Ankereh formation. The tunnel was too badly caved to permit examination of any but the exterior portions. No mineral was seen in the mouth of the tunnel or on the dump.

THE CANYON SECTIONS.

DRY CREEK (T. 31 N., R. 118 W.)

A traverse was carried up the southern Dry Creek canyon as far as the sawmill, a distance of about 5 miles. The geologic features, as observed and interpreted, are shown graphically on the map (Pl. XII) and the accompanying structure, section A–A′. The supposed fault along the west base of the range (see p. 338) is believed to lie at the mouth of the canyon, where it is concealed by alluvium.

The eastward-dipping ledges (Thaynes or, possibly, Woodside) near the mouth of the canyon are succeeded on the east by characteristic Nugget sandstone, which is exposed in ledges at the national forest boundary. The dip of the fault plane between the two formations appears to be 52° E. The boundary is interpreted as a fault because

of the absence of beds that are elsewhere characteristic of the upper Thaynes and of beds assignable to the Ankareh.

Twin Creek beds, almost vertical but inclining east or west, come next to the Nugget. The boundary here also is interpreted as a fault, because of the absence of the light-colored sandstones and red and green shales elsewhere found in the upper part of the Nugget and because of the absence of the lower heavy limestones and the accompanying green band usually found in the lower part of the Twin Creek. East of the Twin Creek are chocolate-colored to red sandy shales assigned on lithologic grounds to the Ankareh, the boundary being a fault because of the absence of the Nugget sandstone. The two faults bounding the Twin Creek in this part of the section are interpreted as normal. An alternative interpretation would consider them as reverse, but this view is regarded as improbable, for reasons stated below.

The Twin Creek limestone reappears east of the Ankareh shale in fault relation, the Nugget sandstone being absent. About 200 feet east of the main contact is a small subsidiary fault on which is located Nielson's tunnel, a metalliferous prospect. Here the fault clay shows beautiful, nearly horizontal slickensides on a surface dipping steeply to the west. The Twin Creek is succeeded up the canyon by the Nugget, again without the usual lower beds of the Twin Creek and upper beds of the Nugget, and hence this boundary also is interpreted as a fault. The faults east and west of the Twin Creek are considered as normal. If they are reverse, the structure of the Twin Creek would appear to be that of an abnormal synclinorium, a sort of flask-shaped fold, overthrust by Ankareh beds on the west and Nugget beds on the east. Such a structure, though possible, does not seem probable, for most of the other folds do not suggest marked overturning, such as might be expected if this Twin Creek belt and the other Twin Creek belt above mentioned had been abnormally folded and overthrust.

The Nugget sandstone is succeeded eastward by chocolate-colored shaly beds assigned on lithologic grounds to the Ankareh, apparently in normal stratigraphic position. East of the Ankareh shale lie the siliceous limestones of the Thaynes and Woodside formations, without observed stratigraphic break. The Meekoceras zone was not recognized, though it may be present, and the two formations were not differentiated. They form a succession of wall-like ledges with narrow gateways. A zone of red rocks more shaly than the inclosing strata and resembling the beds above referred to the Ankareh shale intervenes in the section. These red rocks are overridden on the west by the Thaynes limestone and Woodside shale. At first it was thought that they were part of the Ankareh, but sections in canyons to the north show red beds that are apparently included in

the Thaynes and Woodside formations. Hence the red beds are tentatively considered Woodside, with a fault on the west side that appears to truncate them. East of the red beds are typical calcareous shales of the Woodside.

The Phosphoria formation succeeds the Woodside on the east. The Rex chert member is here more of a cherty limestone than a chert. It is nodular and shows some quartzitic tendencies. Near the base there is a black band of phosphatic chert 2½ to 3 feet thick. About 20 feet beneath this band there is a highly fossiliferous calcareous zone with Productus, Spiriferina, and other forms. A covered zone about 150 feet wide represents the phosphate-shale horizon, and next appears a poorly developed "under limestone," more or less fragmentary, succeeded by a white, calcareous sandstone, almost a quartzite. Excellent phosphate float was found by ascending to the sag on the hill to the south. The zone between the phosphate shales and the top of the Wells may include a minor fault, as shown by the above-noted condition of the "under limestone" east of the phosphate shale.

The anticlinal structure of the formations in this part of the canyon brings the phosphate shales across the canyon again about three-fourths of a mile farther east and some of the succeeding formations recur in ascending order. The fault between the Woodside and the Wells is interpreted as reverse, because of the crumpled condition of the Wells to the east and its apparent position near the apex of a broken anticline. It seems more likely that such a fault was developed by compression associated with the folding, than under later tension. The fault to the east, within the Wells, is believed to have a steep dip and is interpreted as normal. The general relations produced by it are similar to those of the fault near the east border of the anticlinorium in T. 32 N., R. 118 W., and it seems probable that the two faults are continuous. The fault west of the sawmill is considered as reverse, for it seems to descend obliquely westward into the canyon from the northeast.

SWIFT CREEK.

A traverse was carried up Swift Canyon as far as the crossing of the second Phosphoria band, about 6 miles above the mouth, and a reconnaissance trip carried the investigation of the canyon to the head of the creek, some 7 miles farther. The map (Pl. XII) and the accompanying geologic structure, sections B–B′ and C–C′, show the stratigraphic and structural details along the traversed part of the canyon as recognized and interpreted.

For reasons given on page 338 a fault is supposed to occur along the west base of the range and cross the mouth of the canyon. Tertiary conglomerate and eastward-dipping Twin Creek beds, becoming

vertical toward the east, occupy the lower portion of the canyon. The boundary between the Twin Creek limestone and the Nugget sandstone on the east is regarded as a normal fault because of the absence of beds elsewhere characteristic of the upper part of the Nugget and the lower part of the Twin Creek, and because of the supposed steep inclination of the fault plane. It is tentatively assumed that this fault corresponds with a similar fault in the southern Dry Creek section, and the two faults have been provisionally connected, as indicated on the map.

The Ankareh formation, dipping steeply to the west, lies east of the Nugget in apparently normal thickness. The boundary between these beds and the adjacent Thaynes limestone may perhaps be a fault, because the siliceous beds that form the upper part of the Thaynes in some parts of the field do not seem to be present here. There may, however, be local lithologic changes in the formation. The Ankareh band on Swift Creek is tentatively connected with that on Dry Creek to the south because of similar structural relations.

The Thaynes and Woodside formations to the east have not been differentiated, as the Meekoceras zone was not observed, though some search for it was made. Possibly some fault may occur within this group, as in Dry Canyon, but such a fault was not recognized.

The Rex chert member of the Phosphoria appears in unusually prominent wall-like cliffs that form a narrow gateway at the creek. The phosphate shales are concealed here beneath heavy talus on the steep canyon walls. There appears to be room for them, however, and search in this zone along higher levels in the canyon would doubtless be rewarded by the finding of phosphate float.

East of the Phosphoria the canyon becomes wild and rugged in an anticlinorium of Carboniferous quartzites and limestones. About a mile above the Rex ledges the canyon enters the axis of a syncline trending almost due north. The syncline appears on the east side of the canyon with almost diagrammatic clearness when viewed along the axial line from a point to the north. Near the point where the main creek turns eastward the Wells formation in the syncline persists on the west side of the canyon, because the canyon wall is steeper than the dip of the rocks, but on the east side the Wells appears to have been removed from the gentler slope of the canyon wall, which forms an unusually fine dip slope on the Brazer limestone.

In the main canyon east of the forks successive folds in the Brazer limestone and the Wells formation are clearly exposed on the south side of the canyon. Just east of the axial region of the eastern anticline, which is faulted, a small, steep-sided ravine in nearly vertical rocks of the Wells contains the intermittent spring, locally known as "the geyser," which supplies nearly half the volume of the creek.

About half a mile east of the intermittent spring the eastern Phosphoria band crosses the canyon with a steep easterly dip. The Wells and the Rex again form prominent ledges. The phosphate shales are exposed in the trail with some float of phosphate. This is very likely the place from which C. L. Breger collected his samples in 1910, to which reference is made in Blackwelder's report.[1]

East of this locality the canyon lies in rocks younger than the phosphate shales, rising into the Nugget, which occupies the core of a broad syncline. Farther east the formations appear in descending order with westerly dips. Their boundaries were not determined. The head of Swift Creek lies in a rather broadly opened valley in the Woodside and Thaynes formations. East of this valley is a ledge of Rex chert that forms a hogback along the main ridge west of the divide and is succeeded by phosphate shales to the east. The Phosphoria formation continues southward along the range and appears to go through the sag which forms the divide between Swift Creek and Corral Creek. A pedestrian who was encountered on the trail reported "coal" in the sag. The crest of the ridge north of the sag appears to be formed of pre-Phosphoria rocks.

NARROWS OF SALT RIVER.

A reconnaissance in the vicinity of the narrows of Salt River and in the lower valley of Willow Creek, in the western part of T. 33 N., R. 118 W., shows that this part of the region is underlain by the Nugget sandstone and the Twin Creek limestone. These formations are largely concealed by alluvium and Tertiary conglomerate except where the latter are cut through by the deeper canyons. The structure of the Salt River valley a short distance west of sec. 19, where the river enters the narrows, is synclinal in the Twin Creek limestone, which is well exposed. The east side of the valley forms a fine dip slope for a short distance. A fault between the Twin Creek and Nugget, near the southeast corner of sec. 20 is tentatively regarded as the probable continuation of the fault supposed to lie along the west base of the Salt River range to the south.

PHILLIPS CREEK.

The outer slopes of the hills at the mouth of the Phillips Creek Canyon are occupied by white float of the Twin Creek and by red soil of the Nugget. The alluvial deposits at the mouth of the canyon also show a steep slope or terrace, as in the Swift Creek and Dry Creek canyons to the south, but here the edge of the terrace is not so scarplike. These facts, together with the fault in the foot slopes, near the southeast corner of sec. 20, already noted, suggest that this zone may represent the position of the supposed fault along the

[1] Blackwelder, Eliot, op. cit., pp. 460–461.

west base of the Salt River Range. The terrace may, however, have no relation to this fault. East of this zone the Twin Creek continues for nearly half a mile, interrupted by a narrow zone of red débris about midway between the south quarter corner and the southeast corner of sec. 33. There are also on the slopes scattered bowlders, probably the remnants of the Tertiary conglomerate. Near the southeast corner of sec. 33 characteristic sandstone of the Nugget crosses the canyon. The beds elsewhere found in the upper part of the Nugget and lower part of the Twin Creek are missing here, so that the boundary is interpreted as a fault. On the east the series descends to purplish limestone and red shaly sandstone, with strong easterly dip. Beds elsewhere characteristic of the lower part of the Nugget and the Ankareh were not recognized east of these Nugget beds, but ledges of the Thaynes and Woodside formations occupy the lower parts of the slopes, with Tertiary conglomerate above. The dip of the Thaynes and Woodside beds is steeply eastward. Their west boundary is doubtless a fault. About a quarter of a mile to the east all the older beds are concealed by Tertiary conglomerate, which appears to occupy the outer hills and the lower slopes of the higher hills to the east. In ascending these slopes the first rocks of the older series encountered were limestones lithologically resembling some members of the Thaynes and Woodside formations, but possibly older. The rock is much brecciated and does not show fossils or bedding. Float on the hill above seems to be of Wells age or older. A brecciated ledge lithologically resembling the upper part of the Wells formation comes about 200 feet beyond the supposed Thaynes and Woodside formations, and about the same distance eastward is a clear limestone with large cup corals, Syringopora, and crinoid stems, apparently part of the Brazer limestone. The Phosphoria formation does not seem to be represented in the section. If the above interpretations are correct there is a fault between the Thaynes and Woodside and the Wells and probably one also between the Wells and the Brazer. About half a mile to the east, on the higher slopes, are dark, relatively thin-bedded limestones, containing a few cup corals and crinoid stems and lithologically resembling some portions of the Madison limestone. The dips here are westerly instead of easterly, as in the Brazer beds to the west. The structural relations of the intervening area are obscured by vegetation and were not worked out.

WILLOW CREEK.

At the mouth of Willow Creek a pronounced scarp or terrace 15 or 20 feet high occurs in the gravels, as on a number of creeks to the south. Parts of this terrace are underlain by ledges of Nugget sand-

stone with low easterly dips, and up the hillside 1,000 feet or more to the east are massive ledges of the upper part of the Wells formation. A fault doubtless intervenes between the two formations, but its position is concealed by the surface cover. A little less than half a mile up the canyon the Phosphoria formation is exposed. The Thaynes limestone was not recognized in the section, though it may be present. The Woodside shale is cut off by a fault on the east which brings in the Madison limestone. This fault is tentatively regarded as normal, with downthrow on the west. The Madison limestone dips steeply east and is in turn cut by a supposed normal fault that brings in the Wells formation. Only a part of the Wells with the succeeding Phosphoria formation is present. A fault at the horizon of the Phosphoria cuts out much of that formation. The nature of this fault was not determined, but it is tentatively regarded as normal because of the steep inclination of the formations involved. Structure section D–D′, Plate XII, shows the observed and interpreted structural features of the traversed portion of the Willow Creek section.

The trail from Willow Creek to McDougals Pass lies wholly within post-Phosphoria rocks ranging from the Woodside shale to the Nugget sandstone. A specially fine section from the Nugget down to the phosphate shales is exposed along the Willow Creek trail between a point about a mile below the pass and the pass.

The pass itself is occupied by the phosphate shales, which here cross the divide from the southeast and descend to the head of Strawberry Creek. They also turn back north of the pass on the east side of the divide for at least a short distance. The dip of the rocks at the pass is westerly, while farther west, half a mile or more beyond the point where the trail leaves the main canyon of Willow Creek, there is a smooth dip slope in the eastward-dipping beds of the Woodside shale. Thus it seems that the structure west of the divide is synclinal, whereas an anticlinal axis probably lies at the head of Bear Creek east of the divide. According to Peale,[1] this anticline is sharp and probably is complicated by a fault which he thinks may be continued down the head of Glacier (now called Strawberry) Creek.

DRY CREEK (T. 33 N., R. 118 W.).

At the mouth of the Northern Dry Canyon heavy limestones of the Wells formation occur in an anticline that is steep sided, slightly inclined eastward, and faulted on the east limb. The Madison limestone, which lies east of the fault, is also steeply folded in an anticline. This rock in turn appears to be cut by a fault on the east, which brings in a narrow strip of the Brazer limestone, followed on

[1] Peale, A. C., U. S. Geol. and Geog. Survey Terr. Rept. for 1877, pp. 546–547, 1879.

the east by the Wells formation, both with steep easterly dips. The Wells is faulted on the east against the Woodside shale, which here consists of about 200 feet of deep-red and gray shales with shaly sandstone. The Woodside beds have a synclinal structure, the axis running about along the line of the gulch to the north. Phosphate float was found along the west side of this gulch about half a mile north of its mouth. Float pieces of the Meekoceras-bearing rock occur nearly half a mile east of the northeast corner of unsurveyed sec. 6, T. 33 N., R. 117 W. The general structural features of the Dry Creek section as above interpreted are shown in structure section E–E′, Plate XII. Post-Phosphoria rocks appear to continue from the Meekoceras zone up to McDougals Pass. The above-mentioned fault between the Wells and the Woodside is tentatively considered the northward continuation of the similarly located fault in Willow Creek Canyon near the east boundary of T. 33 N., R. 118 W. In each locality post-Phosphoria rocks lie to the east and pre-phosphate rocks to the west of the fault, while the structure east of the fault appears to be synclinal.

STRAWBERRY CREEK.

No traverse was made in Strawberry Canyon, but a reconnaissance trip was made from McDougals Pass down this canyon to Bedford.

The position of the fault thought by Peale to occur at the head of Strawberry Creek was not determined. The headwater region of the creek is a broadly opened trough that appears to lie in a syncline pitching gently to the south. Dip slopes occur on both sides of the creek, but the formations involved were not examined at close range. The phosphate shales continue down the west side of the canyon for 1½ or 2 miles to a point where they cross the creek and ascend the east side of the valley. They form a noticeable black soil in the creek bank and on the adjacent slopes at the point of crossing. Below the point of crossing the rocks in Strawberry Creek are all older than the Phosphoria, and the canyon becomes rougher and more timbered. The course of the creek to the bend, where the creek turns west, appears to continue in the syncline, with the Wells formation at the core. The structure of the axial region where exposed in the hills north of the bend in the creek is complex, and there is some evidence of overturning toward the east. West of the bend the rocks range in age from Wells to Madison and the structure is apparently broadly anticlinorial. Peale[1] recognized two anticlines and an intervening syncline in this part of the canyon. The western anticline, he stated, is sharper than that to the east, and the western members of it pass under the valley of Salt River.

[1] Peale, A. C., op. cit., pp. 546–548.

The Phosphoria formation does not extend as far north as Strawberry Creek west of the great bend. It may turn back along the anticline or perhaps be faulted out. The geology north of Strawberry Creek is not well known, but it seems probable that the rocks will prove to be pre-Phosphoria. Peale reports that nothing younger than Carboniferous appears north of the creek, at least as far north as his station 57 (8 miles north).

On the occasion of Peale's visit to this region, in July, 1877, the head of Strawberry Creek was filled with a huge snow bank, reminding him of a glacier, which extended for several miles down the gorge. On its surface were rocks and earth, and at the bottom a mass of detrital matter resembling a small terminal moraine. Doubtless this occurrence suggested the name Glacier Creek used in his report, though this name is not now in use. He expressed doubts as to the glacial character of the snow bank. On the occasion of the writer's visit, October 1, 1914, there was no snow in the canyon, although a snowstorm occurred two days later. The accumulation of débris noted by Peale was observed. This and the troughlike character of the upper valley from a point perhaps a mile below the great bend indicate the probability of glaciation within comparatively recent geologic time, if not actually at the time of Peale's visit.

West of the mouth of Strawberry Canyon limestones of probable Madison age crop out in a few low knolls along the base of the range. The westernmost exposure of these rocks observed was in the northeast corner of sec. 28, T. 34 N., R. 118 W. Other outlying knolls and part of the lower foot slopes of the range are covered by Tertiary conglomerates. The bottom lands are covered with alluvial deposits, which, from indications in T. 33 N., R. 118 W., may be underlain in part by Nugget or Twin Creek beds. Between these and the older Carboniferous rocks to the east there is probably a concealed fault. The position of the supposed fault is not known, but if present the fault must lie west of the northwest corner of sec. 28, T. 34 N., R. 118 W.