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PRELIMINARY REPORT ON GEOLOGY OF CENTENNIAL RANGE, MONTANA-IDAHO, PHOSPHATE DEPOSITS

by

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ABSTRACT

Phosphate rock is present in the Phosphoria formation of Permian age in the Centennial Range of southwestern Montana and adjoining parts of Idaho. A study was made to map the Phosphoria formation, study its stratigraphy, and to ascertain the reserves and mining problems.

In the Centennial Range the Phosphoria formation is divisible into five members, designated A to E, from the bottom to the top of the formation. The B and D members contain phosphate rock. The B member contains six feet or more of high grade phosphate rock, mostly in one layer, and is the chief potential ore bed. The phosphate rock is of detrital origin and contains some quartz. Lithologic variations in the B member as well as areas where the B member is missing due to pre-member erosion, need more study.

The formation dips gently southward and is overlain by varying amounts of overburden. Underground mining would seem to be the best method of potential exploitation of the deposit, but core drilling and further trenching are needed.

High grade phosphate rock reserves in the Centennial Range may total scores of millions of tons.

INTRODUCTION

Though the presence of phosphate in the Centennial Range, Montana-Idaho, had been known for many years, recent sampling and description of the strata of the Phosphoria formation by members of the United States Geological Survey disclosed one phosphate bed rich enough that it might be minable. During the summer of 1950, the writer, assisted by R. F. Gosman and B. K. Replogle, mapped the area containing the best phosphate deposits. The area, about 15 square miles near the crest of the range, lies chiefly within the SE¼ Lyon quadrangle at 44° 33' mean latitude and 111° 43' mean longitude.

The area is not traversed by roads and is accessible only by foot and horseback. Therefore, the field work had to be done from camps established with the use of packhorses. Mapping was done at a scale of 1 inch equals 1,000 feet on preliminary metal-mounted topographic base sheets, from which the maps of this report were prepared. The land net for the Montana part of the map was included on the base map; that for the Idaho part was transferred from Forest Service reconnaissance base maps and is only approximately located. Aerial photos were used in the field to supplement the topographic maps. Occasional plane-table traverses were made to maintain accuracy of the work.

This preliminary report has been prepared so that the critical information gathered during the study could be release while a more complete report on the geology of the area is being prepared for publication. It is intentionally brief, many important details having

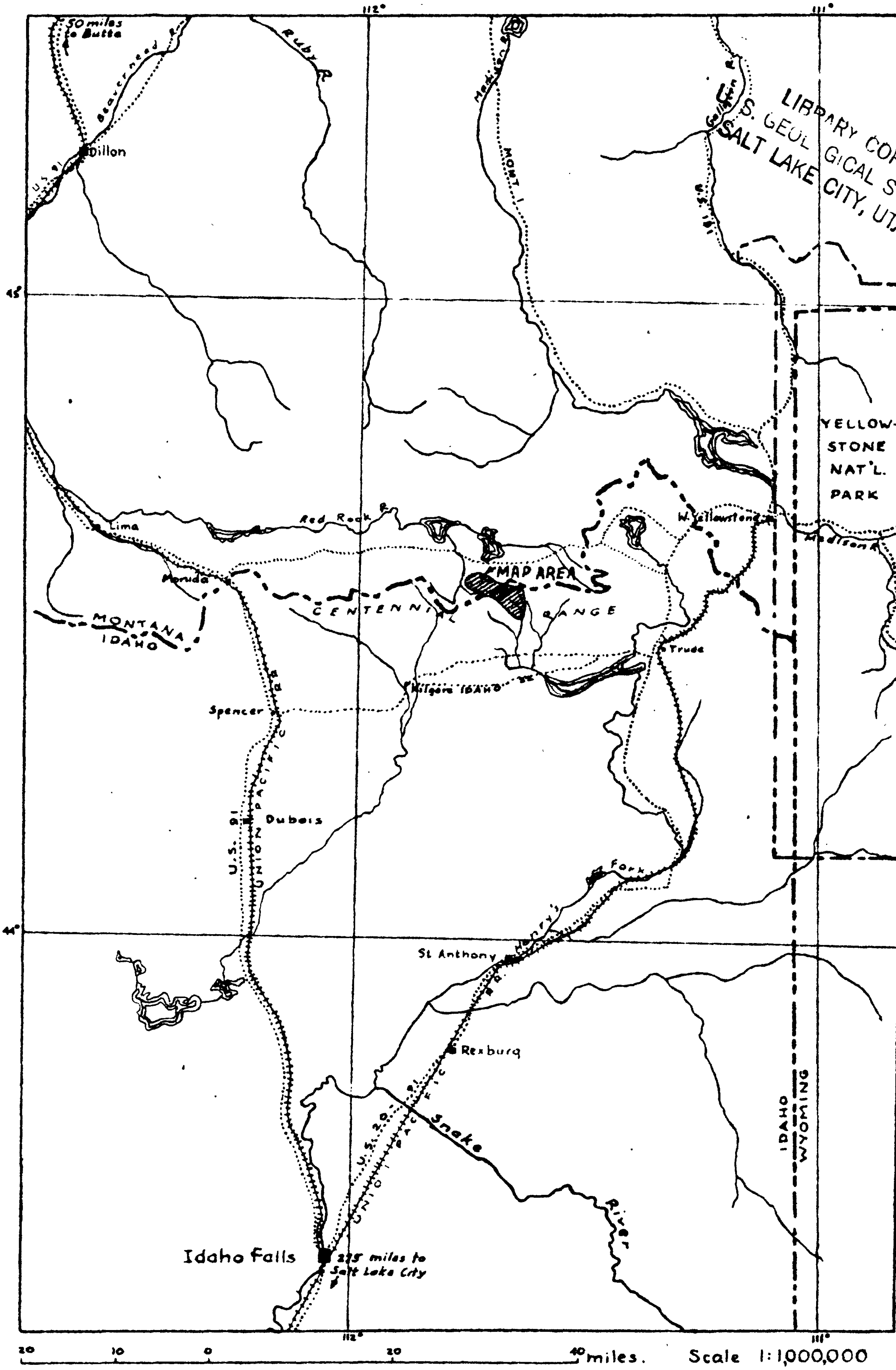

FIGURE 1: Index map of southwestern Montana and southeastern Idaho

been omitted, but it does present the information most critical to economic considerations.

The principal purposes of the investigation were:

1) To map the geology of the Phosphoria formation in the area of best phosphate deposits, with particular emphasis on the structure and on the nature and thickness of overburden above the principal phosphatic horizon.

2) To study and describe the stratigraphy of the Phosphoria formation, particularly lateral variations in the quality and lithology of the phosphatic zone, and to define overlying stratigraphic units that might be useful controls or markers in mining practices.

Previous geologic work in the area includes: a report by Condit and others (1928) that describes briefly the occurrence of phosphate in the Centennial Range; mapping and description of the geology mostly to the north and west, but including a small part of this area, by the author (1947); and mapping of one-third of the Lyon 30-minute quadrangle by G. C. Kennedy. Kennedy (1949) prepared from aerial photos, without the aid of a suitable base, a preliminary map of the principal area of phosphate deposits, which was released on open file. He is now compiling the geology of the SE, NW, and SW quarters of the Lyon quadrangle on topographic base maps for early open file release and is mapping the remainder of the Lyon quadrangle.

This work was supported in part by funds of the Missouri River Basin Division of the U. S. Bureau of Reclamation and the Division of Raw Materials of the U. S. Atomic Energy Commission, which assistance is gratefully acknowledged. Acknowledgement is also made to Montana State University for use of office, library, and laboratory facilities.

The work was done under the supervision of R. W. Swanson and V. E. McKelvey as a part of the investigation of the phosphate deposits of the Phosphoria formation by the Mineral Deposits Branch of the U. S. Geological Survey. The kind assistance of W. R. Lowell, G. C. Kennedy and S. Titensor, packer, were particularly helpful.

GEOGRAPHY

The Centennial Range is located in Beaverhead County, southwestern Montana, and Clark and Fremont Counties, northeastern Idaho. It lies a few miles west of Yellowstone Park along the Continental Divide and is one of the few mountain ranges in the United States having an east-west trend. Access to the main part of the range is by horse or foot from two secondary roads, the Monida-West Yellowstone road through the Centennial Valley in Montana and Idaho State Route 22 east of Kilgore, Idaho. (See index map, figure 1.)

A branch line of the Oregon Short Line Railraod, Union Pacific system, connects West Yellowstone with Idaho Falls and Pocatello and passes through Trude, Idaho. This is the nearest rail point to the Centennial Range phosphate deposits and is about 16 miles due east of the southeast corner of the area at the south side of the range. The Salt Lake City to Butte branch of the same railroad passes through Spencer, Idaho, about 25 miles west and nearly 10 miles south of the same corner. Another station on this branch is at Monida, Montana, 26 miles west of the area on the north side of the range.

The Centennial Range is characterized chiefly by an abrupt north slope rising from the floor of Centennial Valley at an elevation of about 6,650 feet to a mean elevation over 9,000 feet and a maximum elevation of 10,202 feet on Jefferson Peak near the east end. The highest point in the mapped area is 9,864 feet. The north slope culminates in nearly vertical cirque walls at many places, parts of which contain perennial snow. The climate is relatively severe, with long winters and considerable snow. In fact, this range has been recorded by the United States Weather Bureau (see Visher, 1945) as having the longest winters in the United States; and snow flurries, or even snowstorms, may be expected during the summer in the higher parts of the range.

The lower slopes of the range support a good growth of coniferous trees, but the upper slopes include broad, open areas containing chiefly grasses and small flowering plants that bloom throughout the summer season. The range is used for both cattle and sheep grazing, and locally considerable timber is cut.

GENERAL GEOLOGY

The Centennial Range is essentially a large tilted fault block. The steep 3500-foot north face of the range is a strikingly prominent fault scarp that has been scarred by water and ice erosion. To the north the broad, flat Centennial Valley represents the downthrown block. The Paleozoic and Mesozoic strata of the range dip gently—10° to 20°—southward beneath the lava fields of Idaho. North-south faults cut the range in several places. The western half is composed mainly of Cretaceous rocks overlain by younger lavas and the eastern half has chiefly Paleozoic and pre-Cambrian rocks at the crest overlain by Mesozoic and Tertiary rocks to the south. The original deformation that formed the range was the Laramide orogeny of Cretaceous and early

Tertiary time, but movements have occurred intermittently throughout the rest of the Tertiary and in the Quaternary.

The boundary between the east and west halves of the range is marked approximately by Odell Creek, at least part of whose course is along a fault. The stream drains the central part of the range and flows north through a 1500-foot canyon. This course may be due in part to superposition from early Tertiary sediments onto the harder underlying Paleozoic sediments, superposition having occurred in middle or late Tertiary time. This stream marks the western limit of mapping.

Pleistocene mountain glaciation eroded many cirques into the north-facing scarp. At one place a moraine has overridden a beach formed by a Pleistocene lake in the Centennial Valley.

The weak Triassic rocks that cap much of the dip slope east of Odell Creek are subject to much landsliding accompanied by unusual earth cracking in which large cracks, as much as 25 to 30 feet deep and 1,000 feet long, have developed near the crest of the range and generally parallel to it. These cracks seem to be due to tension and open up along joints or shear planes that parallel the range front. They are progressively enlarged by a combination of severe frost action and bedding-plane clay-seam slip below the dip slope which favor development of mass creep and landslide phenomena.

STRATIGRAPHY

Pre-Cambrian metasediments, about 3,700 feet of Paleozoic sediments, nearly 4,000 feet of Mesozoic and early Tertiary sediments, and 600 feet of later Tertiary volcanics and associated sediments crop out in the range. Only the Phosphoria formation was mapped in detail in this study of the Centennial Range phosphate deposits, and the only other rock units mapped are those that were found in contact with the Phosphoria strata. Table I is a generalized list of the formations appearing on the geologic map accompanying this report.

TABLE I

A GENERALIZED LIST OF THE SEDIMENTARY AND VOLCANIC ROCKS
CENTENNIAL RANGE

Age	Formation	Thickness (feet)	Lithology
Quaternary	Alluvium	?	Silts, marls, and gravels.
Pliocene(?)	High level gravels		Gravels, contain quartzites, schists, and volcanics.
	Volcanics & associated sediments	600±	Basalt, agglomerate, volcanic conglomerate, tuff, alluvial beds and rhyolite in general ascending order.
Upper Cretaceous to Lower Eocene	Beaverhead formation	150±	Coarse conglomerate and sandstone blocks, present as erosional remnants; also bedded red and yellow shale or silt, which is present in only one place where it overlies Mississippian rocks.
			Approximately 1,500 to 2,500 feet of Triassic, Jurassic, Cretaceous, and Tertiary(?) sediments are omitted here. These rocks crop out elsewhere in the range but not in the map area.
Lower Triassic	Woodside formation	800	Red shaly siltstone, few white to maroon siltstone, limestones near top.
	Dinwoody formation	470	Thin, flaggy buff to brown alternating limestone, siltstone, and sandstone; fossiliferous.
Permain	Phosphoria	205	Limestone, sandstone, black fissile shale, chert, and oolitic to hard pisolitic phosphate rock.

Age	Formation	Thickness (feet)	Lithology
Lower Pennsylvanian	Quadrant formation	250	Mostly brown sandstone or quartzite, some limestone.
			Approximately 3,250 feet of Cambrian, Devonian, and Mississippian rocks which have not been mapped are omitted here. Basement complex here is pre-Cambrian Cherry Creek(?) group.

Quadrant Formation

The Quadrant formation of Pennsylvanian age underlies the Phosphoria formation. It is composed of sandstone and quartzite with interbedded limestone and dolomite. The rock is generally gray to buff and the unit is commonly a cliffmaker. It is estimated to be about 250 feet thick.

Phosphoria Formation

The Phosphoria formation is of Permian age. It is economically important for its unusual concentration of phosphate. This study is a part of the current intensive study of the entire phosphate field being made by the U. S. Geological Survey. Though three members are recognized at the type locality of the formation in southeastern Idaho (McKelvey, 1949), Lowell (1950) described five members near Dell in southwestern Montana, which he called lower carbonate and siliceous member, lower phosphatic shale member, upper carbonate and siliceous member, upper phosphatic shale member, and upper siliceous member. These were later provisionally termed members A, B, C, D, and E (McKelvey, 1949; Klepper, 1950), which usage is applied in this report.

The B member contains up to six feet or more of high-grade (31 percent P_2O_5) phosphate rock, mostly in one layer which is the chief potential ore bed. The D member contains thin high-grade beds of phosphate rock interspersed through a sequence of black shales.

Abstracts of the stratigraphy of the Phosphoria formation in the Centennial Range may be obtained from the recent open file report by Swanson and others (1951a and b).

A Member: Disconformably overlying the Quadrant formation is a 30-foot unit of interbedded calcareous sandstone and siltstone and sandy limestone and dolomite. Good exposures occur in the bottom of Spring Creek, tributary to Odell Creek, and on the crest of the range. At one place on the crest of the range, a two-foot thick chert pebble conglomerate marks the basal contact. The member is present in all parts of the range but is nowhere topographically conspicuous. The general color is buff, but locally pyrite nodules, which are characteristic of the member, stain the rock with iron oxides. No fossils were found.

B Member: The B member consists of interbedded phosphate rock, shale, calcareous sandstone, sandy limestone, chert, and quartzite, with some marked local lithologic variations. It is well exposed in places along the range crest and also on Taylor Creek ridge. The B member is absent west of a point half a mile east of Odell Creek. It is also absent locally in sec. 33, T. 14 S., R. 1 W. and sec. 4, T. 15 S., R. 1 W., where a conglomerate is present, probably in its stead. The contact between the B and C members is probably disconformable. An average of 20 feet of strata is included in the B member of which an average of six feet is phosphate rock. The thickness of the phosphate rock shows some marked local variations though elsewhere it appears to be fairly uniform. Where trenched locally along the range crest the lowest bed in the member is generally phosphate rock of variable thickness, ranging from six inches to four feet thick. The next higher bed is a lensing calcareous sandstone of highly variable thickness, absent locally and four feet thick in other places. Overlying this is usually at least six feet of high-grade phosphate rock thickening in one place to over 11 feet. This is followed by eight to nine feet of thin-bedded chert, phosphate rock, and mudstone. A massive six-foot thick chert and sandstone bed of the C member overlies these beds. The phosphate rock is one to two feet thicker along the range crest and much of Spring Creek valley than in the Taylor Creek area on the south slope of the range (see Plate 6). Topographic expression of the member is not marked though in general the rock is hard and thick-bedded. The phosphate rock is normally dark-gray or brown to black but weathering imparts a bluish white bloom to it. The phosphate rock is oolitic, nodular, and pisolitic. The upper phosphate bed of the B member is the chief potential ore bed of the formation in the Centennial Range.

C Member: The C member includes a lower fossiliferous limestone, which has a six foot thick chert and calcareous sandstone bed and locally a quartzite conglomerate at its base. The conglomerate is present at the A and C member contact where the B member is missing. This suggests a local area of erosion in B or early C member time. The lower limestone unit is less well exposed than the upper sandstone unit, which is hard and dense, contains numerous rod-like "concretions" and is usually a ridge-maker. The C member is up to 80 feet thick and is characterized by massive bedding. Where separable the lower limestone, which has a light gray color, is mapped as the C_1 unit and the upper sandstone, which has a gray color, is mapped as the C_2 unit. Where the B member is absent the A member is locally included in the C_1 unit because they are usually inseparable. The rod-like structures, or so-called "concretions" are from one to six feet long, about two inches in diameter, resistant to weathering, and composed of calcareous, phosphatic sandstone. A fossiliferous zone in the C_1 unit contains many silicified cephalopods, gastropods, and pelecypods.

D Member: The D member is a soft oolitic phosphate rock that grades upward into black phosphatic shale. It is present throughout the range but is nowhere very well exposed. The black shale is more siliceous toward the top of the member and grades into chert of the E member. The D member averages 20 feet in thickness, of which one to two feet are high-grade phosphate rock. Though the fresh rock is black, the phosphate weathers bluish-white. A few pelecypods were found in the shale.

E Member: The E member is chert grading upward into siltstone, locally mapped as the E_1 unit, chert, and the E_2 unit, siltstone. The member is present throughout the range but the chert forms prominent cliffs only to the west near Odell Creek, and the whole member is less conspicuous to the east. Its average thickness of 55 feet. Both chert and siltstone are thin-bedded and range from buff to gray in color. In several well exposed areas the E member appears to grade into the overlying lower Triassic Dinwoody formation.

Dinwoody Formation

The Dinwoody formation of lower Triassic age is believed to conformably overlie the Phosphoria formation. It is composed of limestone and siltstone that may be cherty, ferruginous, dolomitic, or argillaceous, is thin-bedded, and ranges in color from white to buff to brown. Soft olive-drab colored shales are also present. The formation has an average thickness of 470 feet in the range.

Other Mapped Formations

The following formations will be mentioned very briefly. Though they appear in limited areas on the map they are only incidentally associated with the Phosphate rock in the Centennial Range.

The Woodside formation of lower Triassic age conformably overlies the Dinwoody formation. It includes approximately 800 feet of red shaly siltstones.

In one place on the crest of the range Mississippian rocks are overlain by unctuous red silt and shale. Elsewhere on the dip slope that forms the south side of the range are occasional boulders of coarse conglomerate. Both redbeds and boulders are believed to be remnants of the Upper Cretaceous-Lower Eocene Beaverhead formation (Lowell and Klepper, 1953) that once covered perhaps the entire region.

On the lower slopes of the south side of the range, thin-bedded rhyolite overlaps onto the southward-dipping Paleozoic and Mesozoic strata. Elsewhere in the range other volcanic lithologies are present and alluvial sediments are interbedded with the volcanic rocks. The lavas and interbedded sediments are estimated to be about 600 feet thick and may be late Tertiary in age.

Gravel patches are present on some of the spurs that descend into Spring Creek valley, with quartzite, schist, and volcanic lithologies represented. These also are probably late Tertiary in age. Some of the valley bottoms contain accumulations of Quaternary alluvium which locally effectively mask the bedrock geology.

STRUCTURE

Within the map area the largest faults are (1) in sec. 6, T. 15 S., R. 1 W., and (2) in secs. 11 and 14, T. 14 N., R. 40 E. Both fault traces were mapped for about 4,000 feet but their southern extensions were not checked. The minimum stratigraphic throw on the first fault is about 150 feet with the west side upthrown and the C member of the Phosphoria formation in fault contact with the lower part of the Dinwoody formation. The minimum stratigraphic throw of the second fault is about 225 feet with the east side upthrown and the upper part of the Quadrant formation in fault contact with the lower part of the Dinwoody formation. Both faults have a northeast-southwest trend and are believed to be normal high-angle faults.

A few other smaller faults were mapped. These faults generally trend northeast-southwest or northwest-southeast. Many of the smaller faults are present at the east side of the map area along Taylor Creek Ridge. In the NE¼ SE¼ sec. 19, T. 14 N., R. 41 E. is a small area of deformed and faulted strata and landslides whose structural interpretation is still somewhat uncertain.

The Phosphoria formation contains a local unconformity which is evidenced by the lack of B member phosphate in sec. 33, T. 14 S., R. 1 W., and in sec. 4, T. 15 S., R. 1 W. This may indicate the presence of a local island in the Phosphoria sea either in late B member or early C member time. Also in sec. 34, T. 14 S., R. 1 W. the B member of the Phosphoria formation is well exposed in the ridge which on the map is at the boundary of secs. 34 and 3. Here the B member shows local and very striking lateral changes, including a thickening of the upper phosphate bed from 5 ft. 8 in. to 11 ft. 5 in. within the lateral distance of about 40 feet. These changes indicate, in the least, an uneven sea floor and the possibility of more "islands" with the B member missing. There is also the possibility of unknown thicker accumulations of phosphate rock than the six feet which is an assumed average for the range.

Large cracks, mentioned earlier, are present along the crest of the range, particularly in the Dinwoody formation. The depressions along zones of cracking up to 25 feet deep and 1,000 feet long, are believed due to tension. The rocks at the edge of the north face tend to creep and move down the north face. But the same beds a few hundred feet south dip southward and tend to move south in response to gravity, and tension is set up along the range crest. Snow then fills the resulting cracks and frost action enlarges them. The water from the melting snow seeps into the dipping shales of the Dinwoody formation. This accelerates landslides farther down the dip slope to the south, which in turn removes some of the support of the beds at the range crest and creates more tension, and more cracks.

PHOSPHATE DEPOSITS

General Statement

Phosphate rock is the principle mineral deposit in the mapped area, though the associated black shales in the D member are petroliferous (Bowen, 1918; Condit, 1919). The phosphate deposits are found in the B and D members of the Phosphoria formation. The formation has been sampled in part by the Geological Survey at seven localities within the area (lot nos. 1251, 1252, 1253, 1254, 1255, 1342, and 1343). The basic stratigraphic and analytical data for these lots have been released on open file, (Swanson and others, 1951a and b) will be published soon in Geological Survey Circulars. Besides the seven sample localities, the B member has been partly or wholly trenched and studied in nine trenched exposures and several other stratigraphic sections have been measured.

Geology and Location of Possible Ore Areas

The Phosphoria formation dips 10° to 20° in an average direction of 0° to 20° west of south. It crops out in a northwest-trending belt between Snyder Creek at the east margin of the map and Odell Creek at the west end of the map. Locally the formation extends several thousand feet west of Odell Creek where it is terminated by a fault.

The B member contains the best phosphate deposits, including up to six feet or more of acid-grade rock. It crops out chiefly along the range crest, but other outcrops are on Taylor Creek Ridge and in Spring Creek valley. Good exposures of the B member are uncommon but its presence can be usually ascertained by its distinctive bluish-white float. On the basis of lack of float the B member is considered absent in the western quarter of the mapped area.

The D member is also phosphatic but the phosphate rock is thin (from 1 to 2 feet of high grade rock) and interbedded with poorly phosphatic mudstones, therefore of limited economic interest at the present time. The mudstones (or oil shales) are somewhat petroliferous, however. Minor amounts of vanadium, fluorine, (one part for each 10 of P_2O_5) and other elements are present in the phosphate rock.

Quality and Character of the Phosphate Rock

The B member phosphate rock is composed of phosphatic shell fragments, phosphatic ovulites, and varying amounts of impurities, notably quartz. The quantity of quartz in a phosphate rock bed varies laterally and vertically. The phosphate rock may be in one or several beds. The strata associated with the phosphate rock include phosphatic sandstone, sandstone, impure limestone, chert, and mudstone. Most of the sandstones have some phosphatic content. In the phosphate rock both the detritus and the cement are phosphatic.

The following table lists chemical analytical data for some B-member samples collected in the Centennial Range, (Swanson and others, 1951a and b).

TABLE II

CHEMICAL DATA FOR SOME B-MEMBER SAMPLES

Lot. No.	Bed No.	Lithology	Sample No.	Thickness	Chemical Analysis P_2O_5	Acid Insoluble
1251	B-1	Phosphate rock	FSH-261	6.2	31.3	10.9
1254	B-2	Phosphate rock, argillaceous	OAP-506	1.7	22.8	34.1
	B-1	Phosphate rock	OAP-505	4.6	32.4	8.4
1342	B-4	Phosphate rock	RFG-5562	3.5	30.2	11.4
	B-3	Phosphate rock, calcareous	RFG-5563	0.9	17.0	13.6
1343	B-6	Phosphate rock	BKR-5560	0.7	32.4	7.0
	B-4	Phosphate rock	BKR-5559	1.8	33.9	2.8
	B-3	Phosphate rock	BKR-5558	2.2	33.4	6.3
	B-2	Limestone, sandy	BKR-5557	1.8	3.7	39.7
	B-1	Phosphate rock	BKR-5556	2.4	31.0	9.3

Economic Considerations

A small part of the Centennial Range phosphate reserve might be recovered by surface mining methods, but the severe climate and generally thick cover above the phosphate bed are important limiting factors. The simple structures, including low southward dip and relatively small, widely spaced faults, plus the large reserve above entry level favor considerations of underground mining. Thus, adit-level entries at the south side of the range would favor the mining of large blocks of ground above entry level and shipment by the shortest possible distance to established rail connections. Northward-bearing crosscuts several thousand feet in length would be necessary, however, to reach the phosphate bed.

Variations in the quality and thickness of the phosphate, including lenses of sandstone or limestone that locally split the bed into two or more parts, the complete absence of the phosphate bed locally due to non-deposition or later erosional removal, and character of the footwall and hanging wall rocks are all factors that need further consideration. A program of investigation including surface trenching and drilling would be essential to the establishment of a sound mining program.

Reserves

The presence of a large reserve of phosphate rock in the Centennial Range B member may be inferred from the field and chemical data noted above. Until more attention is given to the problems of split beds and areas of phosphate absence, computations of these reserves cannot be completed, but it is probably safe to say that they involve scores of millions of tons of acid-grade phosphate rock.

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