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PROGRESS REPORT ON INVESTIGATIONS OF WESTERN PHOSPHATE DEPOSITS

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

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ILLUSTRATIONS

ABSTRACT

A comprehensive investigation of the western phosphate deposits has been in progress since 1947. Most of the field work is now completed but final reports will not be completed for some years. The scope of the investigations and preliminary conclusions, however, are summarized in this report.

The principal phosphate deposits are found in the Phosphoria and Park City formations over an area of about 135,000 square miles in Montana, Idaho, Wyoming, and Utah. The rocks composing these formations in the western part of the field are chiefly dark phosphatic shales and cherts that were deposited near the margin of the Paleozoic Cordilleran miogeosyncline; those to the east are thinner, were deposited on the stable continental platform, and include conspicuous limestones and sandstone that grade eastward into redbeds in Wyoming and Utah. Complex structures characterized by parallel-trending tight folds and thrust faults were developed subsequently in the area of the miogeosyncline, whereas simpler structures characterized by random orientation were developed in the platform area.

Two black phosphatic shale members characterize the Phosphoria formation. The lower, and more important, of these members is thickest and most phosphatic in southeast Idaho and pinches out in southern Montana, central Wyoming, and eastern Utah. The upper member is best developed in southwestern Montana but is prominent also in western Wyoming. Chert characterizes the intervening member, but limestone and sandstone are important constituents to the north and east. Also toward the north and east, chert and sandstone above the upper phosphatic shale are important.

The Bear River region of southeastern Idaho and adjacent parts of Wyoming and Utah contains the greatest total amount of phosphate as well as the thickest beds of high-grade phosphate, although some high-grade beds of minable thickness occur in other parts of the field, particularly in western Montana. Several valuable deposits were discovered during this investigation, most noteworthy of which are a 6-foot bed of acid-grade rock in the Centennial Mountains at the Montana-Idaho State line, a 12-foot bed of 33 percent P_2O_5 rock in the Caribou Range, Idaho, several strippable deposits of acid- and furnace-grade rock in southeastern Idaho, and a 12-foot bed of 20 percent P_2O_5 rock at the top of the formation north of Cokeville, Wyo.

INTRODUCTION

In anticipation of an increased demand for phosphate, a comprehensive investigation of the western phosphate field (fig. 1) was begun in 1947. Most of the field investigations planned as a part of the investigation (McKelvey, 1949) are now completed. Although the results will not be fully synthesized and analyzed for some years, it is appropriate to describe what has been done and to indicate some of the important findings and conclusions, particularly those of economic significance.

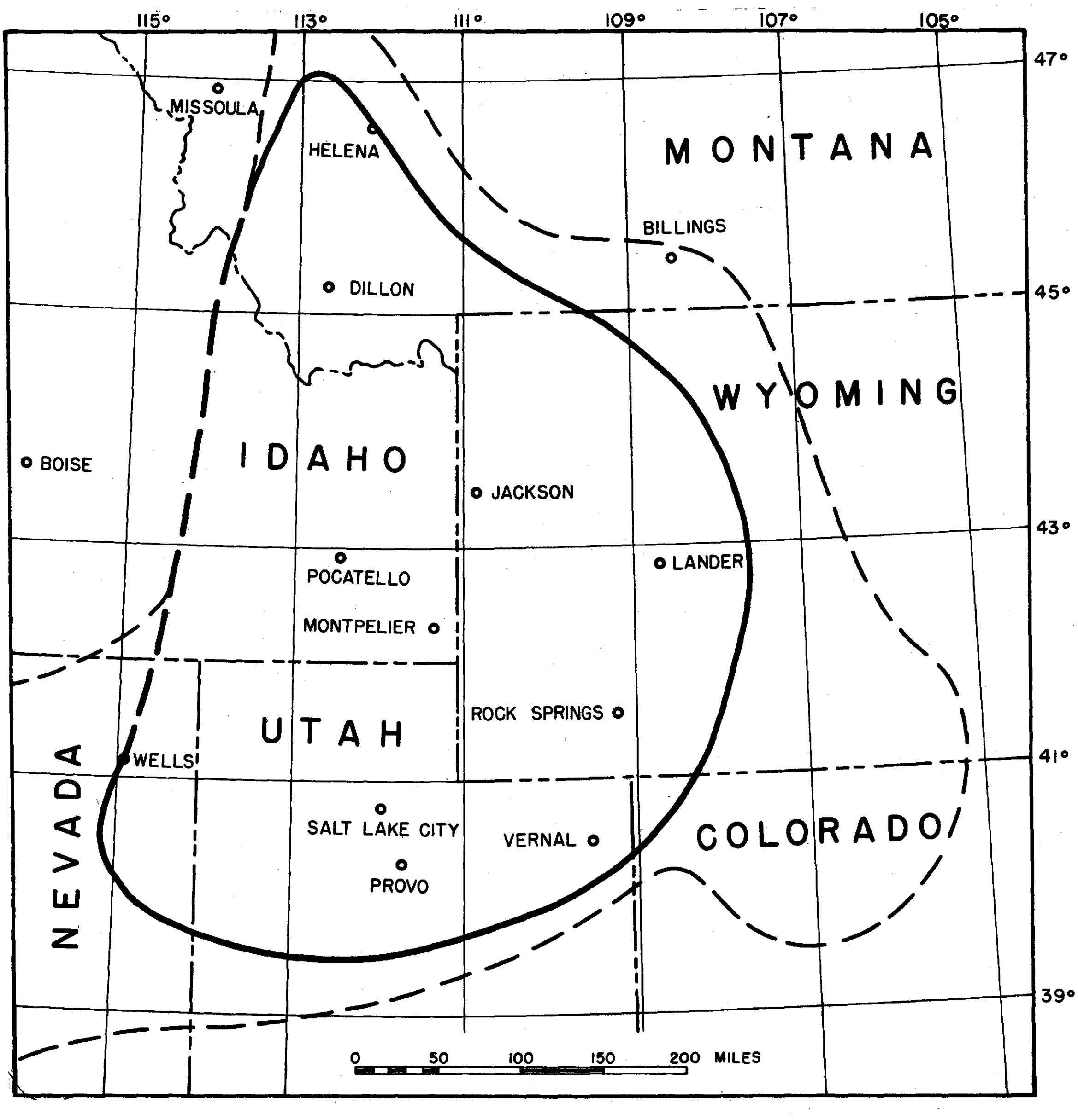

Figure 1.—Index map of the western phosphate field showing limits of the Phosphoria formation and its stratigraphic correlatives in the Park City and Embar formations (dashed line) and their phosphate deposits (solid line).

This program has been supported in part by the Atomic Energy Commission and is part of the program of the Department of the Interior for development of the Missouri River Basin. Many people have assisted in the collection of data and others have contributed much in the way of advice and criticism in the field. Although it is not possible to acknowledge individually the help of all these persons, their part in the program is described in the individual reports being released on various aspects of the investigation.

STATUS OF INVESTIGATIONS

Investigation of the western phosphate deposits was undertaken to acquire more data on their thickness, composition and quality, structure, and distribution—data that would help industry select deposits suitable for mining, permit estimation of resources of phosphate and potential byproduct elements such as uranium and vanadium, and establish the origin of the deposits.

The two major aspects of the field investigations have been stratigraphic studies and geologic mapping. The stratigraphic studies have included measurement, description, and sampling of the phosphatic and associated beds over nearly the entire field. In the more important parts of the field, Phosphoria strata have been measured and sampled at intervals of 3 to 6 miles; in the marginal areas the interval between localities has been 10 to 20 miles.

About 9,000 channel samples have been collected from more than 160 localities during the course of this work (figs. 2-5). The analytical data are being prepared for publication, but data on nearly 9,000 samples have been placed on open file (McKelvey and others, 1953a, b, d; Swanson and others, 1951, 1953; Sheldon and others, 1951; O'Malley and others, 1953; Smith and others, 1953; and Cheney and others, 1952, 1953). These data are not adequate, for the appraisal of individual deposits—such was not their purpose—but they show the areas in which the best deposits lie and, through the stratigraphic correlation they make possible, they permit the estimation of potential resources over large areas.

Although the mapping program has been restricted to a relatively small part of the total field, a considerable area has been mapped in the course of these and other Geological Survey investigations (fig. 6). An area of 450 square miles in southeastern Idaho, where earlier studies by Mansfield and others (see particularly Gale and Richards, 1910; Richards and Mansfield, 1912; and Mansfield, 1927) had shown the presence of some of the thickest, richest, and most accessible phosphate deposits of the western field, has been remapped topographically at a scale of 1:12,000 and is being remapped geologically at the same scale. The topographic maps have been published and preliminary geologic maps of two 7½-minute quadrangles have been placed on open file (Cressman, 1952; Gulbrandsen and others, 1952).

The Soda Springs, Idaho, 15-minute quadrangle, bounding the Aspen Range-Dry Ridge area on the southwest, contains some of the structure that must be understood before an adequate understanding of the structure of the Aspen Range-Dry Ridge area can be achieved. About two-thirds of the quadrangle was mapped at a scale of 1:48,000 before the work was recessed in favor of more pressing investigations stemming from the present national emergency. A report on the work done to date is in preparation.

In southwestern Montana, where previously only broad-scale reconnaissance had been undertaken, several areas totalling more than 1,400 square miles have been mapped at a scale of 1:62,500 or larger. These areas include the western half of the Willis 30-minute quadrangle west of Dillon and part of the eastern half south of Dillon; a small part of the Dell 30-minute quadrangle near Lima; more than three-fourths of the Lyon 30-minute quadrangle west of Yellowstone Park; and parts of the Virginia City and Eldridge 30-minute quadrangles northwest of Yellowstone Park. Part of the Lyon quadrangle in the Centennial Mountains along the Idaho-Montana border, in which rich phosphate deposits have been found, has also been mapped at a scale of 1:12,000. Geologic maps of some of these areas have already been placed on open file (Kennedy, 1949; Lowell, 1950, 1953; Swanson, 1951; Myers, 1952; and Honkala, 1953) and others will be released shortly.

Geologic mapping has also been undertaken in Montana, Wyoming, and Utah in connection with other Survey investigations, chiefly oil and gas. As may be seen from figure 6, the recent and earlier mapping cover nearly half the quadrangles that contain phosphate in the western field.

Several other studies are being carried on as part of these investigations. The mineralogy and petrography of the rocks are being studied in some detail to establish the identity and properties of the components of western phosphate rock and to supplement the field description of strata sampled at various localities. Geochemical studies have been directed chiefly toward an evaluation of the marine conditions that probably prevailed while the Phosphoria sediments were accumulating (Krauskopf, 1952). Paleontologic collections have been made from most of the localities measured and sampled on the sampling program. These extensive collections are being used for descriptive paleontological and paleoecological studies.

Preliminary reports on the different aspects of these investigations are being prepared and released as rapidly as possible. Most reports are placed on open file as soon as prepared in order to make the information available as promptly as possible.

REVIEW OF GEOLOGY OF THE WESTERN PHOSPHATE FIELD

Geologic setting and structure

The most important phosphate deposits in the western field are part of the marine Phosphoria formation of Permian age and its partial stratigraphic equivalent in Utah, the Park City formation. These formations were deposited over an area of some 135,000 square miles in Montana, Idaho, Wyoming, Utah, and Nevada. The rocks in the western part of this area are part of the Paleozoic Cordilleran miogeosyncline (Kay, 1947), an accumulation of sediments 20,000 to 40,000 feet or more in thickness that were deposited along the margin of the stable

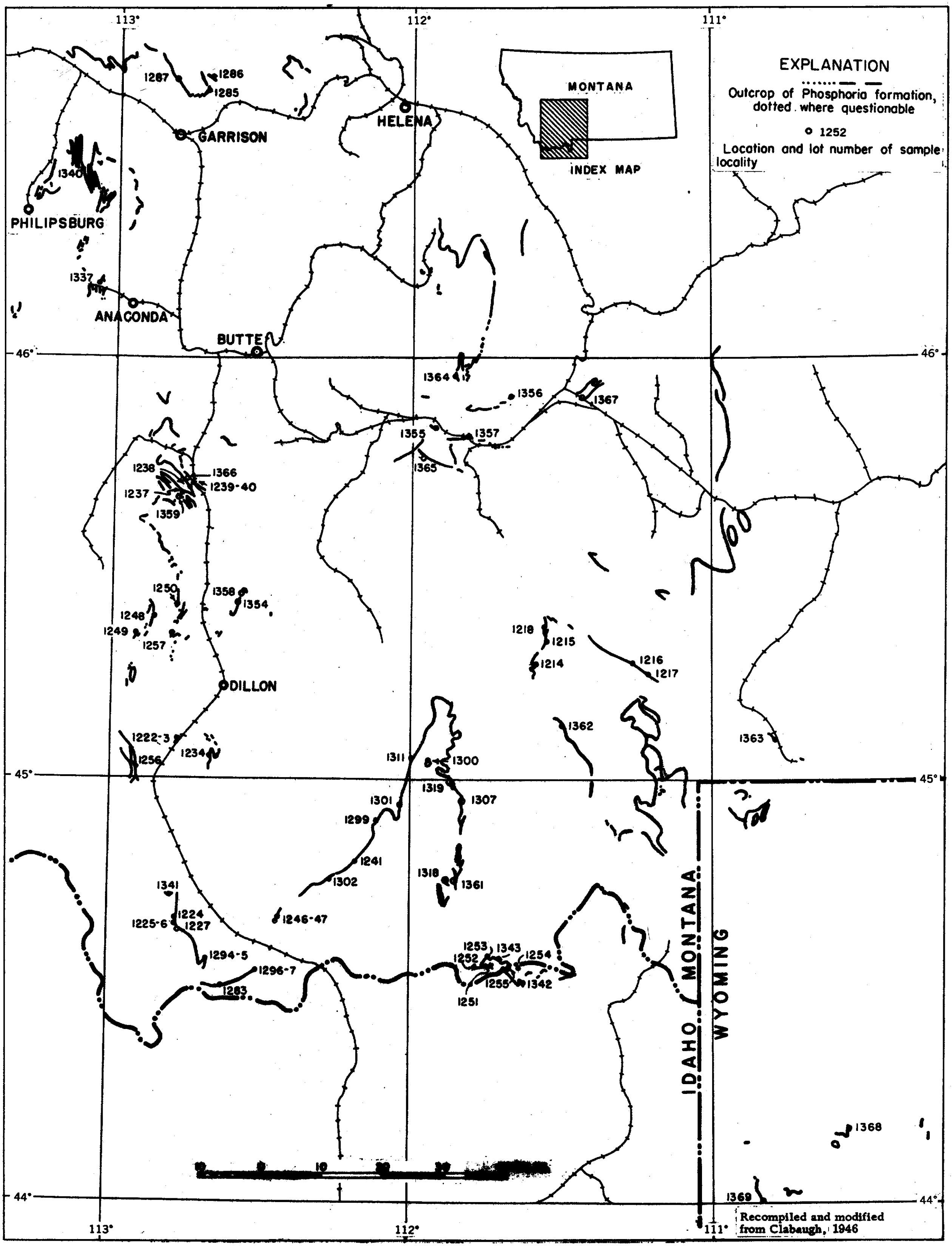

Figure 2. —Outcrops of the Phosphoria formation in Montana and localities sampled.

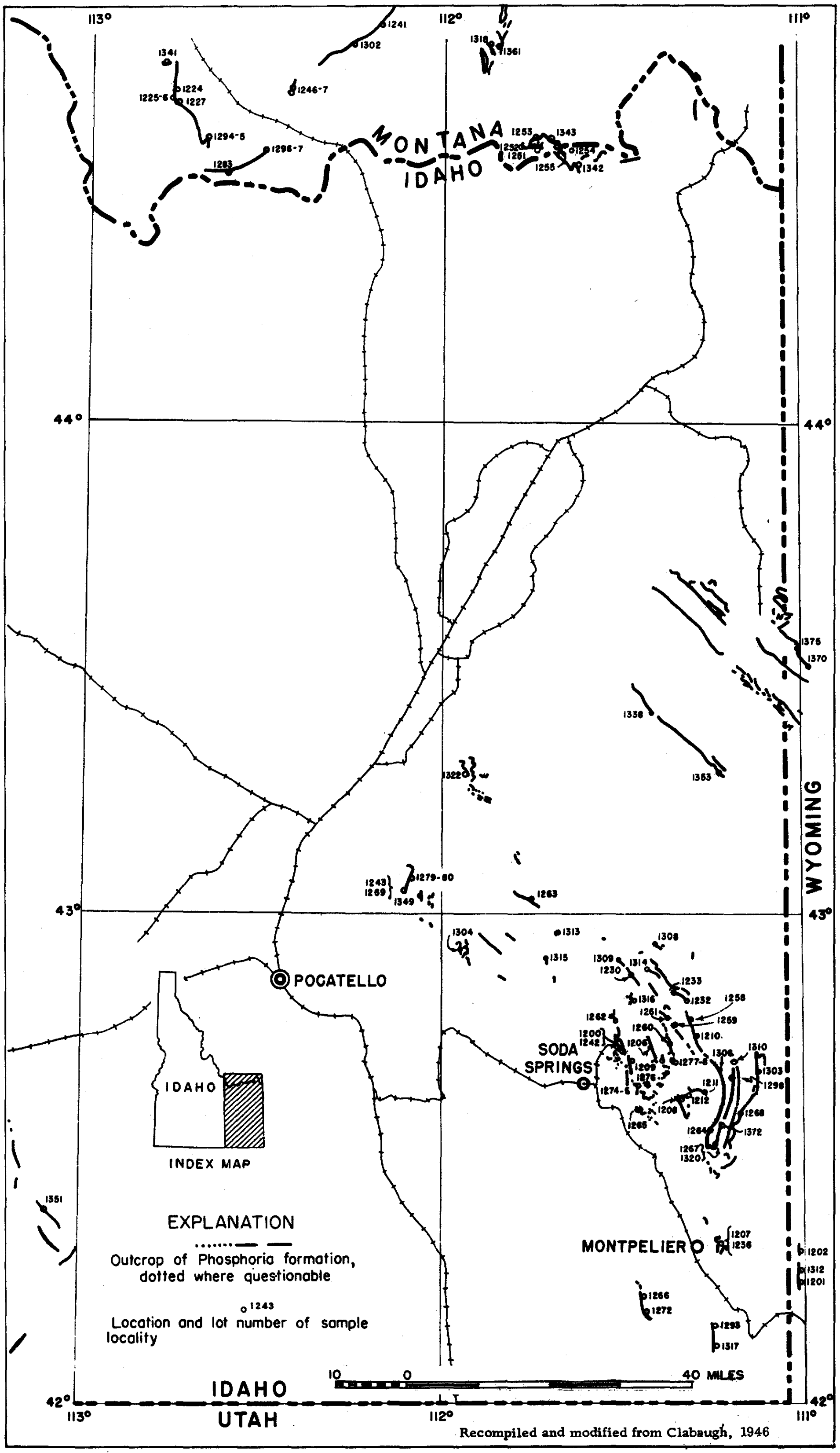

Figure 3.—Outcrops of the Phosphoria formation in Idaho and Montana and localities sampled.

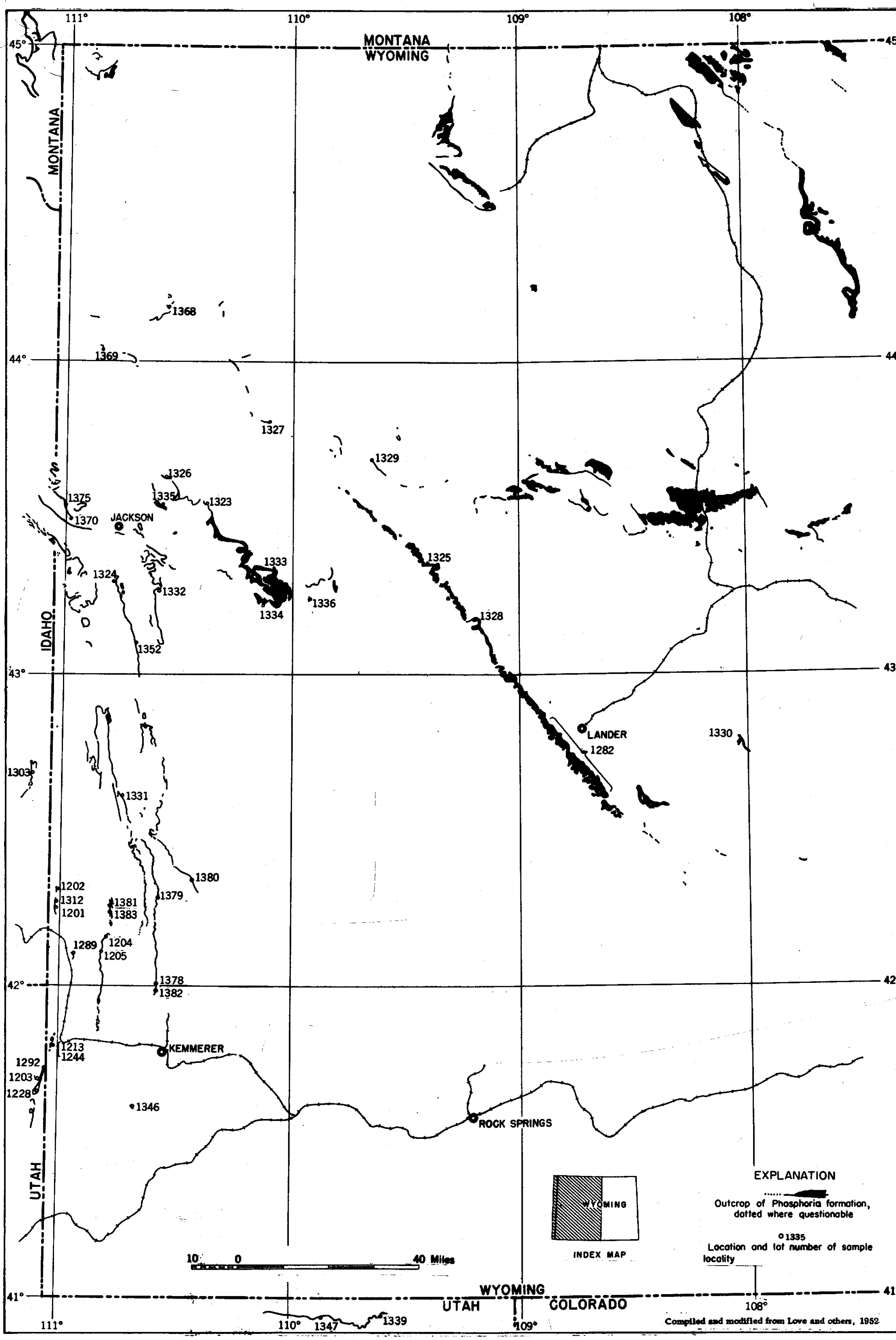

Figure 4. —Outcrops of the Phosphoria formation in Wyoming and localities sampled.

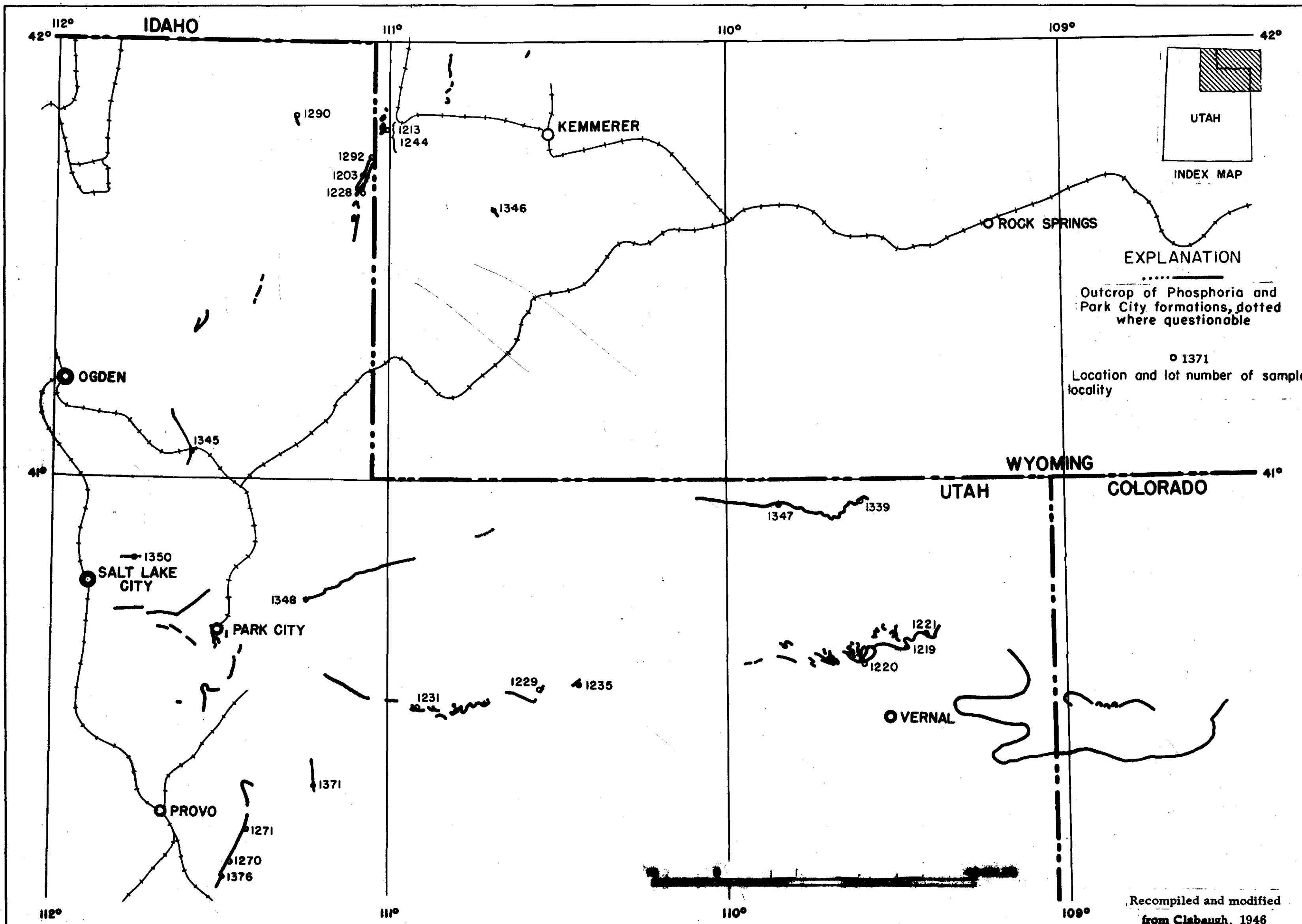

Figure 5. —Outcrops of the Phosphoria and Park City formations in Utah and localities sampled.

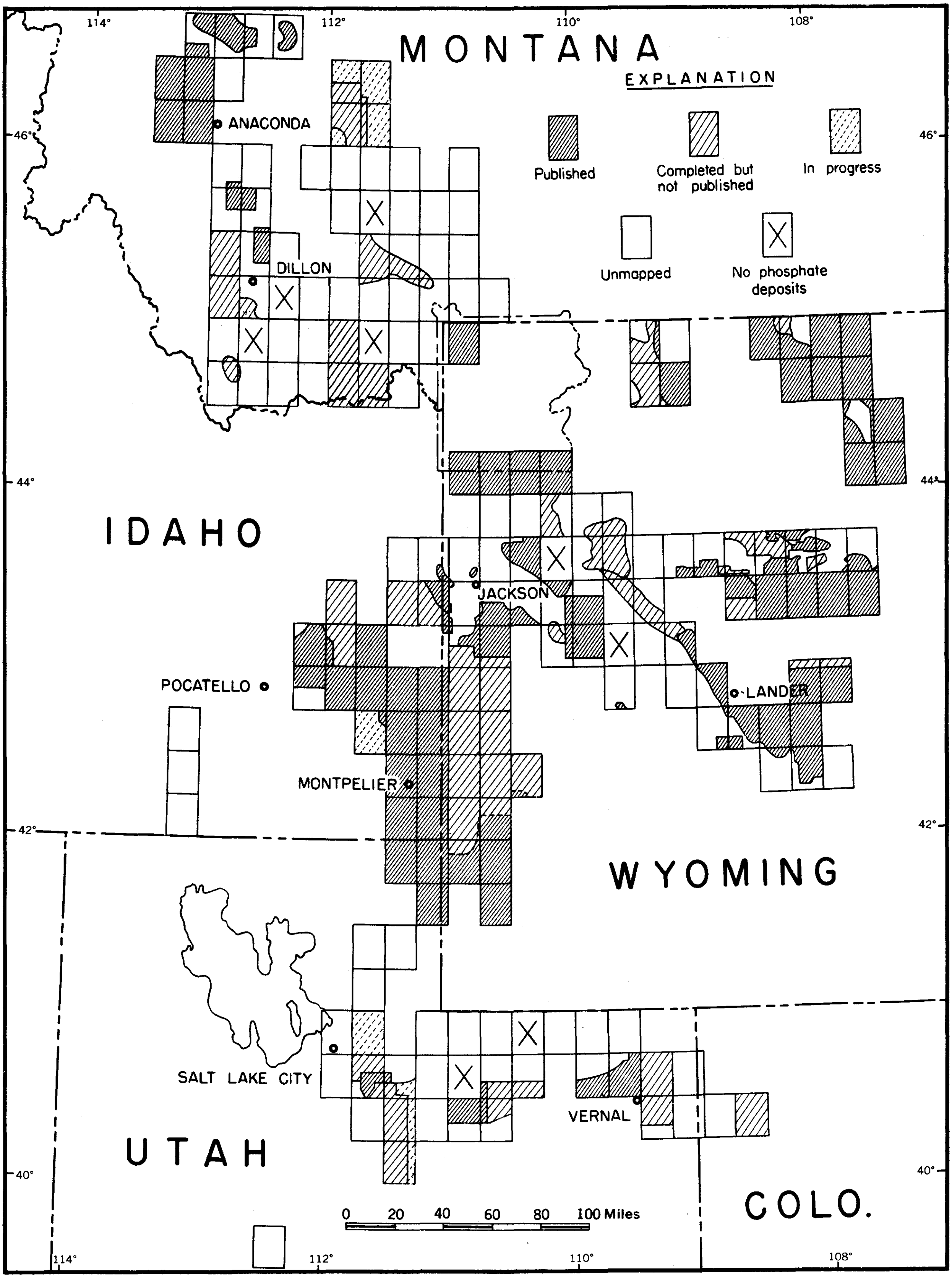

Figure 6.—Status of geologic mapping by the U. S. Geological Survey (1:125,000 or larger) in quadrangles containing outcrops of the Phosphoria formation and its partial stratigraphic correlatives.

continental platform (figs. 1 and 7). Rocks of comparable age that accumulated on the platform are only a few hundred to a few thousand feet thick.

The facies of the Phosphoria and other formations in the miogeosynclinal zone differ from those on the platform. The rocks in the miogeosynclinal zone are generally finer grained and thicker than their platform equivalents. Dark shales and cherts are more abundant in the miogeosyncline. Redbeds are almost wholly restricted to the platform. One of the most conspicuous differences between rocks of the two zones lies in the vertical continuity of sedimentation. Unconformities are much more abundant and prominent on the platform than in the miogeosynclinal zone.

Differences in the geologic structure of the eastern and western part of the field are even more pronounced. The structure in the miogeosynclinal zone is complex. The folds are tight, overturned, and mashed in many places; they generally trend north, and are broken by many overthrust and normal faults of large and small displacement. On the other hand, the structure on the platform in the eastern part of the field, where the phosphate beds are thin and of low quality, is relatively simple. The folds are broad, of diverse orientation, and over large areas are unbroken by faults.

The phosphate beds now occur in all attitudes from flat to vertical to overturned, and range in location from small remnants on the tops of high mountain ranges to deposits buried at great depth beneath overlying strata of Mesozoic age, or in some places—as the Snake River plains southwest of Yellowstone Park—beneath unknown thicknesses of continental deposits and volcanic rocks. Maps showing distribution of outcrops, therefore (figs. 2-5), present a very broken and irregular pattern and point to the great diversity of environments in which mining might be undertaken.

Stratigraphy of the Phosphoria formation

The Phosphoria formation may be roughly divided into a miogeosynclinal facies and a platform facies, prominent in the western and eastern parts of the field respectively (fig. 7). Many problems are unsolved in the correlation of component parts of these facies over the field but, primarily as the result of Sheldon's work in northwestern Wyoming, correlation of the gross units has been established (pl. 1).

The miogeosynclinal facies is best known near its eastern limits in the Bear River region of southeastern Idaho, westernmost Wyoming, and north-central Utah (secs. 7, 8, and 9, fig. 7). In this area the Phosphoria formation consists of a lower phosphatic shale member, 150 to 200 feet thick, overlain by the Rex chert member of comparable thickness, and in most places capped by an upper shale member, 25 to 75 feet thick, which also contains some phosphatic beds. The Phosphoria formation in this area is composed of three principal constituents or mixtures thereof—phosphate rock, carbonaceous mudstone, and chert. Carbonate rock is a minor constituent. In the Bear River region the Phosphoria overlies limestone of the Wells formation. Whether or not these beds are Pennsylvanian in age, as formerly thought (Mansfield, 1927, p. 71), or Permian, as seems to be the case in Utah (Baker and Williams, 1940), is not yet known.

The Park City formation in the Wasatch Mountains in Utah consists of a lower carbonate member, 650 feet thick and of Leonard age, that may correspond to the upper part of the Wells formation in Idaho; a middle shale member, 200 feet thick, that corresponds to the phosphatic shale member of the Phosphoria formation; and an upper cherty-carbonate member, 900 feet thick, that corresponds to the Rex chert member. The lower member overlies the Pennsylvanian Weber sandstone or quartzite. An even thicker section of the Park City has been found recently in the western part of the Wasatch near Fort Douglas, Utah (sec. 10, fig. 7) but its correlation with the section elsewhere is uncertain.

The Phosphoria formation is not well known to the west; but, judged from sections in the Goshute Range, eastern Nevada, and the Sublette Mountains, Cassia County, Idaho, its thickness increases markedly, and black carbonaceous mudstone and chert become the dominant rock types.

In the Beaverhead County region, southwestern Montana (secs. 2 and 3, fig. 7), the Phosphoria formation consists of five units, provisionally termed members A, B, C, D, and E, from oldest to youngest (Klepper, 1950). Member A, which overlies quartzite of the Pennsylvanian Quadrant formation, is 20 to 380 feet thick and consists predominantly of carbonate rocks. It is probably equivalent to the upper part of the Wells formation in southeastern Idaho and perhaps to the lower member of the Park City formation in Utah. Member B, 5 to 70 feet in thickness, consists of phosphate rock, carbonaceous mudstone, and chert; it is probably the equivalent of the phosphatic shale member in Idaho. Member C, 100 to 250 feet thick, is composed mainly of carbonate rocks, cherty carbonate rocks, and sandstone; it is probably the equivalent of the Rex chert member. Member D, 50 to 80 feet thick, is mainly carbonaceous mudstone and phosphate mudstone; it is probably equivalent, at least in part, to the upper shale. Member E, 100 to 150 feet thick, is mainly chert, sandstone, and mudstone; it may have no counterpart in southeastern Idaho.

The platform facies borders the geosynclinal facies on the east and north. It ranges in total thickness from about 100 to nearly 400 feet. The formation becomes progressively less phosphatic eastward and northward and carbonate rocks and sandstone make up an increasing proportion of the formation (secs. 1, 4, 5, 6, and 11, fig. 7). In central Wyoming, eastern Utah, and south-central Montana the Phosphoria strata tongue out into redbeds of the Opeche and Spearfish formations (Condit, 1924; Thomas, 1934; Thomas and Krueger, 1946; Tourtelot, 1952). The A, B, and C members become progressively thinner and disappear to the north and particularly to the northeast in Montana. At least the upper part of the Wells formation in Idaho and the lower member of the Park City formation in Utah disappear eastward—in central Wyoming and eastern Utah the Phosphoria and Park City rest directly on the Pennsylvanian Tensleep and Weber sandstones respectively.

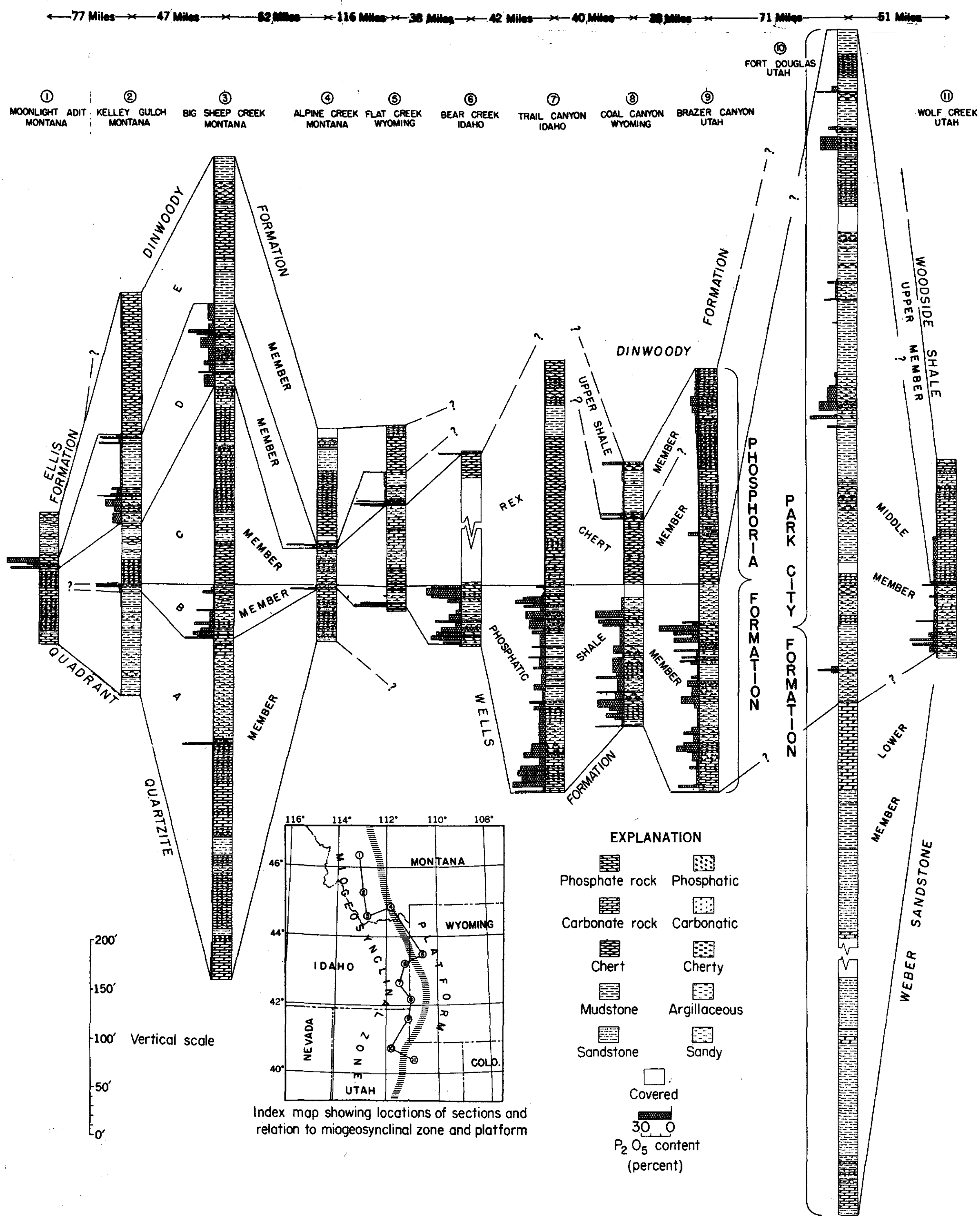

Figure 7.—Typical stratigraphic sections of the western phosphate field showing facies of the miogeosynclinal zone and the platform.

REGIONAL VARIATIONS IN THICKNESS AND QUALITY OF PHOSPHATE ROCK

Now that most of the analytical work on recently collected samples **is** complete, the regional variations in thickness and quality of phosphate rock in the western field can be indicated fairly reliably. This is done by means of a map (fig. 7) showing regional variations in the total amount of phosphate present in the formation, figure 8 showing total phosphate (in feet times percent P_2O_5), and by other maps (figs. 9-11) showing variations in the thickness of beds containing more than 18, 25, and 31 percent P_2O_5. Attention is called to the fact that on each of these maps the thickness indicated represents the total thickness of all layers containing more than the amount of P_2O_5 stipulated for that map and therefore is not necessarily minable thickness. As a general rule, however, the total thickness of minable layers of a given P_2O_5 content increases as the total thickness of all layers of that quality in the whole formation increases.

The data synthesized on these maps show that the greatest volume of P_2O_5, as well as the greatest thickness of beds containing more than any given P_2O_5 content, is in the Bear River region of southeastern Idaho and adjacent parts of Wyoming and Utah. Other parts of the field, particularly western Montana, contain minable thicknesses of acid-grade and furnace-grade rock (31 and 25 percent P_2O_5). Minable beds of both qualities possibly may be found elsewhere, particularly in the upper shale member in western Wyoming.

NEWLY DISCOVERED DEPOSITS

Recent field reconnaissance by the Montana Bureau of Mines and Geology and the Geological Survey has disclosed the presence of the Phosphoria at many localities where it was unknown previously. The newly discovered lines of outcrop are mainly in southwestern Montana, part of which had not been mapped previously and part of which, mainly in the Philipsburg area, had been mapped before the discovery of phosphate in the western field. About 250 miles of outcrops of the Phosphoria formation are shown on figure 2 that were unrecorded previously.

Because many of these newly reported lines of outcrop have not been adequately explored the value of deposits contained in them is not yet known. Lying as they do in areas of complex structure, many of them probably will be too crushed and broken to be minable. Deposits in the vicinity of Maxville, Elliston, and Anaconda at the north end of the field, however, deserve further exploration for both acid-grade and furnace-grade rock. The deposits between Dillon and Anaconda may contain furnace-grade rock.

In addition to these newly discovered outcrops, several important deposits have been found by mapping and trenching. One of the most promising deposits found thus far is in the Centennial Mountains along the Montana-Idaho State line (Kennedy, 1949; Honkala, 1953). Phosphate deposits were first reported in this area by Condit, Finch, and Pardee (1928), but their potentialities were not recognized until recent sampling and mapping showed the presence of large reserves—perhaps 50 million tons or more—of phosphate rock that range from 4 to 6 feet in thickness and contain about 31 percent P_2O_5. The best of these deposits crop out along the crest of the range, which is nearly inaccessible from the north, but as they dip 12° to 20° southward they could be entered from the southern toe of the range by crosscuts 1 to 2 miles in length, the portals of which would be less than 25 miles from the railroad at Trude siding between West Yellowstone and Idaho Falls.

Another important deposit was discovered in 1951 in the Caribou Range of Idaho, sec. 31, T. 1S., R. 45E., 3 or 4 miles south of the Palisades dam site on the Snake River. Preliminary analyses of samples from this deposit indicate an average grade of 33 percent P_2O_5 over a thickness of about 12 feet—the largest thickness of rock of such quality known anywhere in the country. Details of the way the complicated structure in this area affects the deposit have not been determined, but it appears that a considerable tonnage may be anticipated above entry level. The rocks where sampled are nearly vertical.

A 12-foot bed of phosphate containing 22 percent P_2O_5 was found in 1952 at the top contact of the formation on Basin Creek, secs. 12 and 13, T. 26N., R. 117½W., in western Wyoming about 15 miles northeast of Cokeville. The beds, where sampled, dip 45° W. Reconnaissance of the adjoining area indicates that the deposit is of rather limited areal extent, but it is noteworthy for both the thickness and the quality of phosphate at this stratigraphic horizon. This occurrence, as well as facies relationships which indicate that mudstones of the lower phosphatic shale member in south-central Idaho pass laterally into phosphatic mudstones and phosphate rocks in southeastern Idaho (McKelvey, Swanson, and Sheldon, 1952), suggest that important phosphate deposits may be found at this and other horizons in the upper shale member further east.

One of the most significant developments in mining in the western field has been the initiation of strip-mining techniques by the San Francisco Chemical Co. at Montpelier, Idaho and Leefe, Wyo.; and by the Simplot Co. at Fort Hall, Idaho, the Monsanto Chemical Co. at its Ballard mine near Soda Springs, Idaho, and the Anaconda Copper Mining Co. at Conda, Idaho. Because of the complex structure and steep dips in the Bear River region, deposits suitable in attitude for strip-mining are the exception rather than the rule, but private companies and Geological Survey parties have found a number of strippable deposits of sufficient volume to support mining operations for some years. All of these are on private land already under lease. The largest undeveloped deposits appear to be those along the western margin of the Trail syncline, near Soda Springs, and along the east limb of the Webster syncline south of Wells Canyon, Idaho.

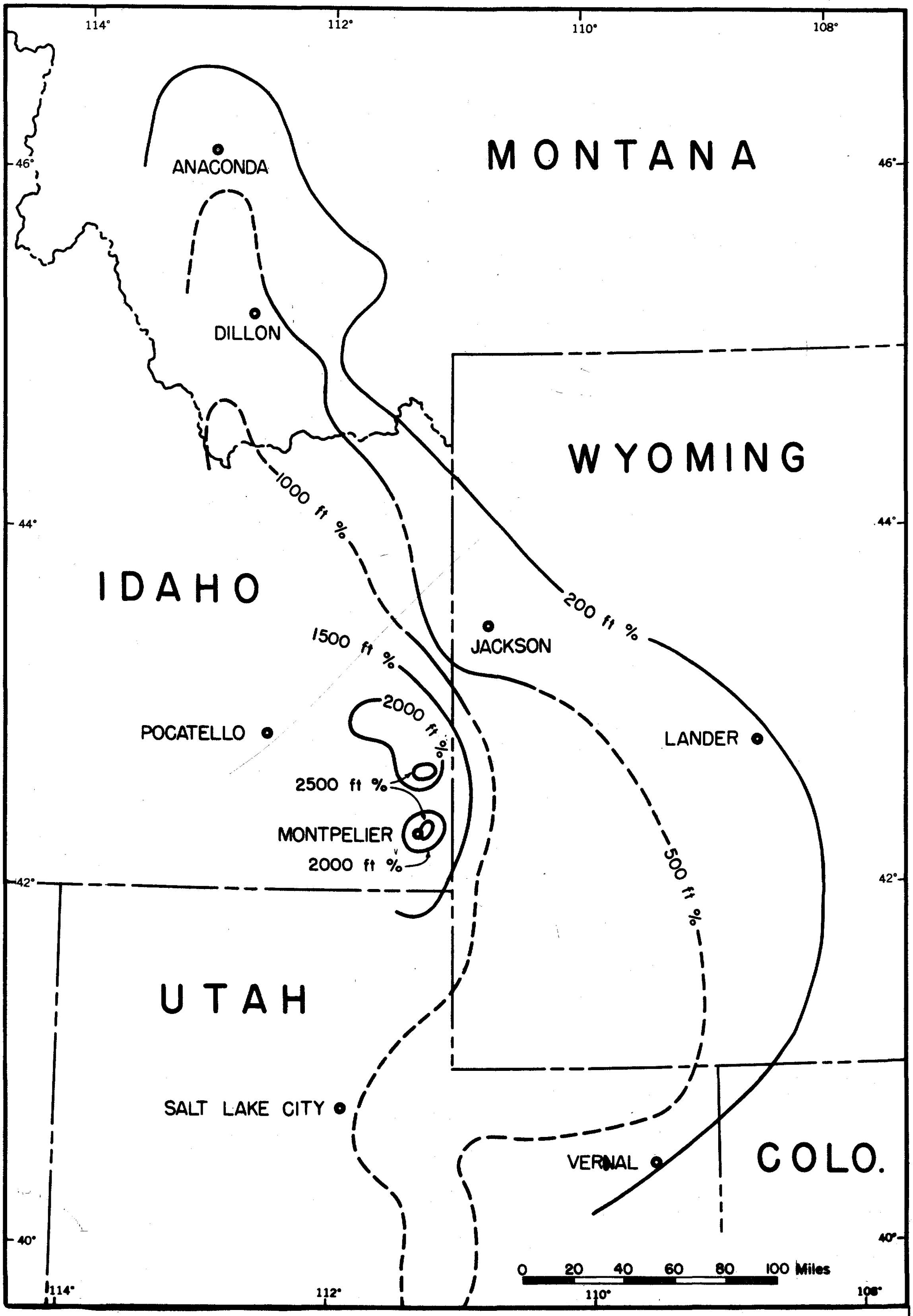

Figure 8.—Total phosphate (in feet times percent P_2O_5) in phosphatic portions of the Phosphoria and Park City formations.

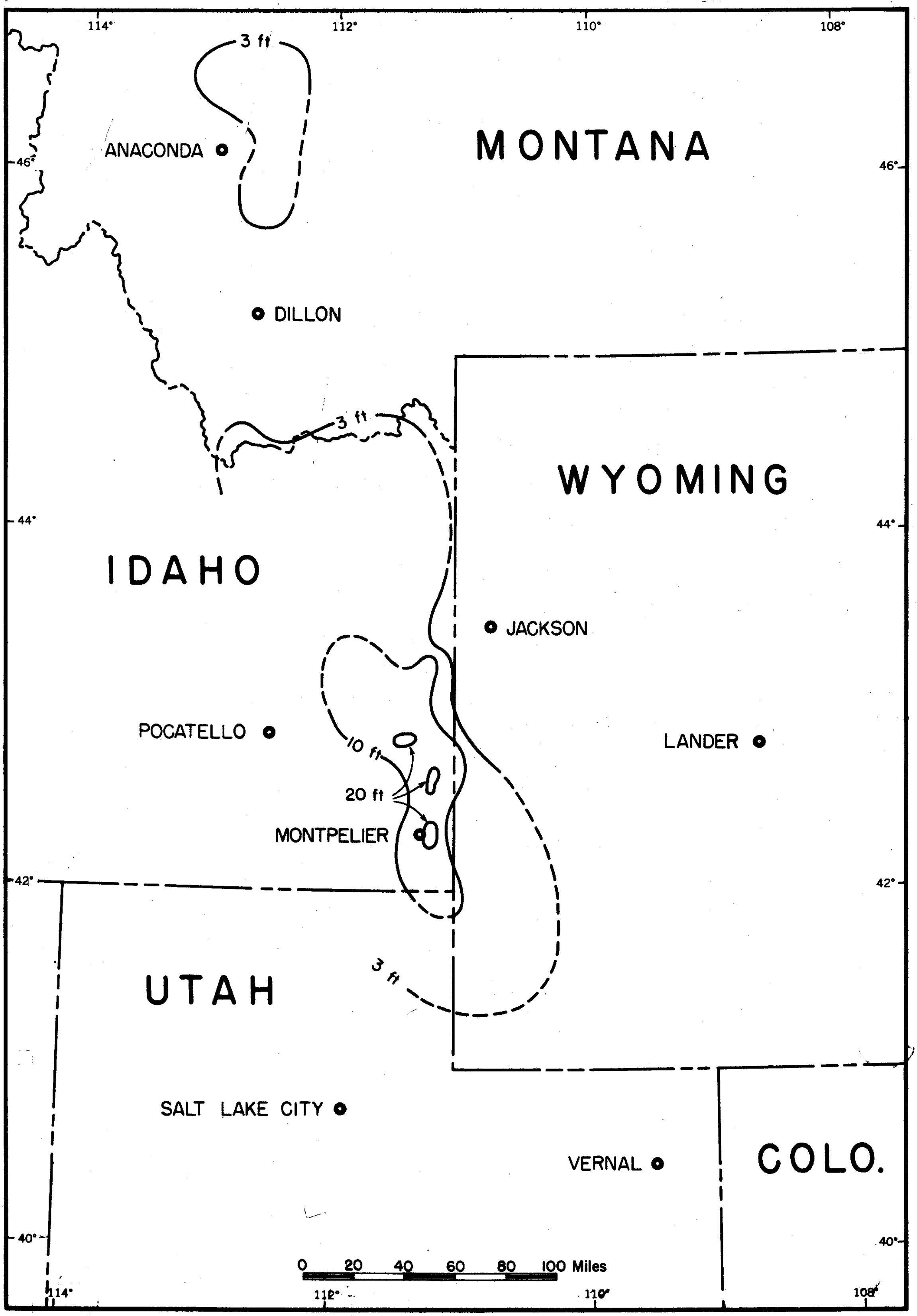

Figure 9. —Total thickness (in feet) or rocks in the Phosphoria and Park City formations containing more than 31 percent P_2O_5.

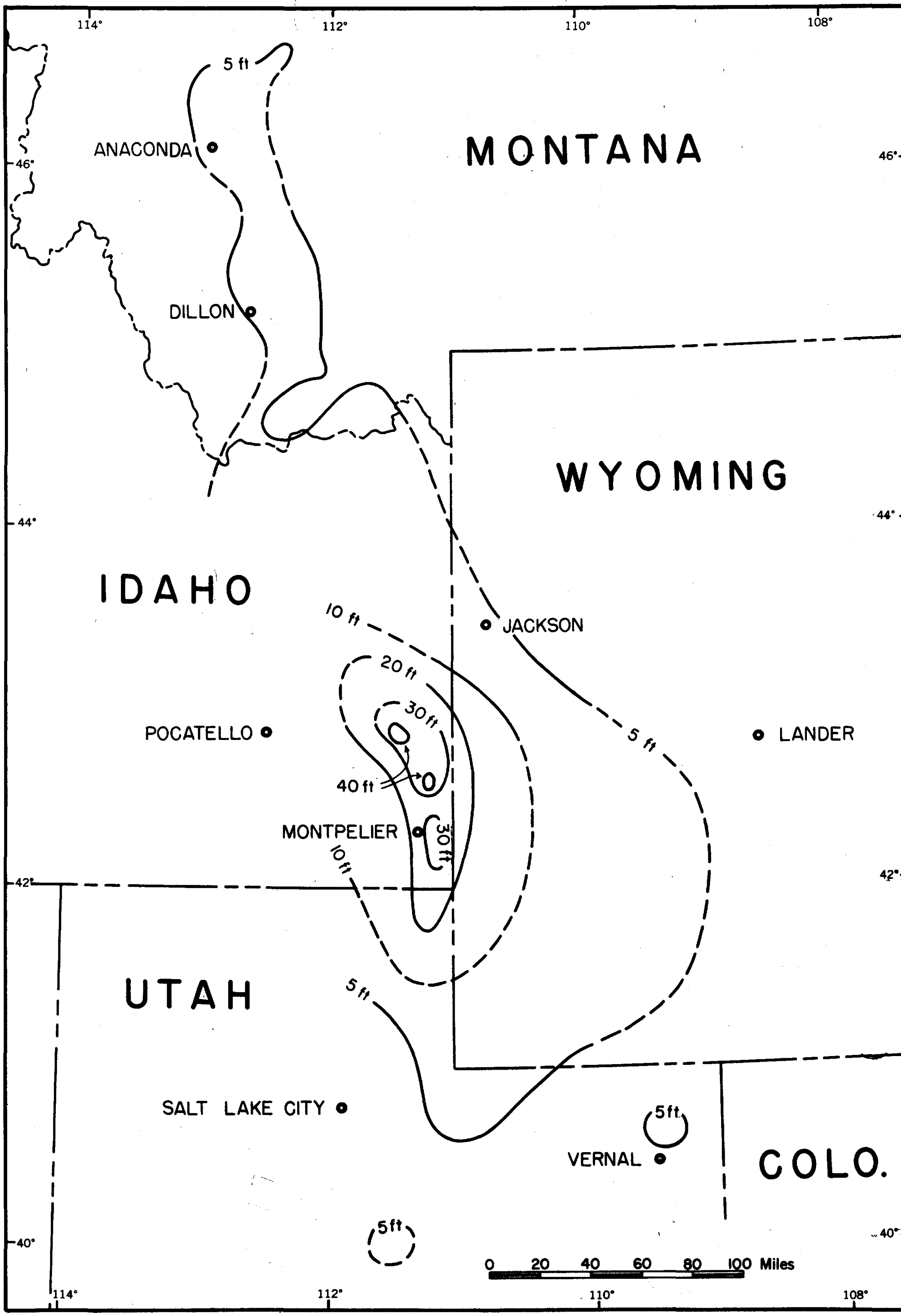

Figure 10.—Total thickness (in feet) of rocks in the Phosphoria and Park City formations containing more than 25 percent P_2O_5.

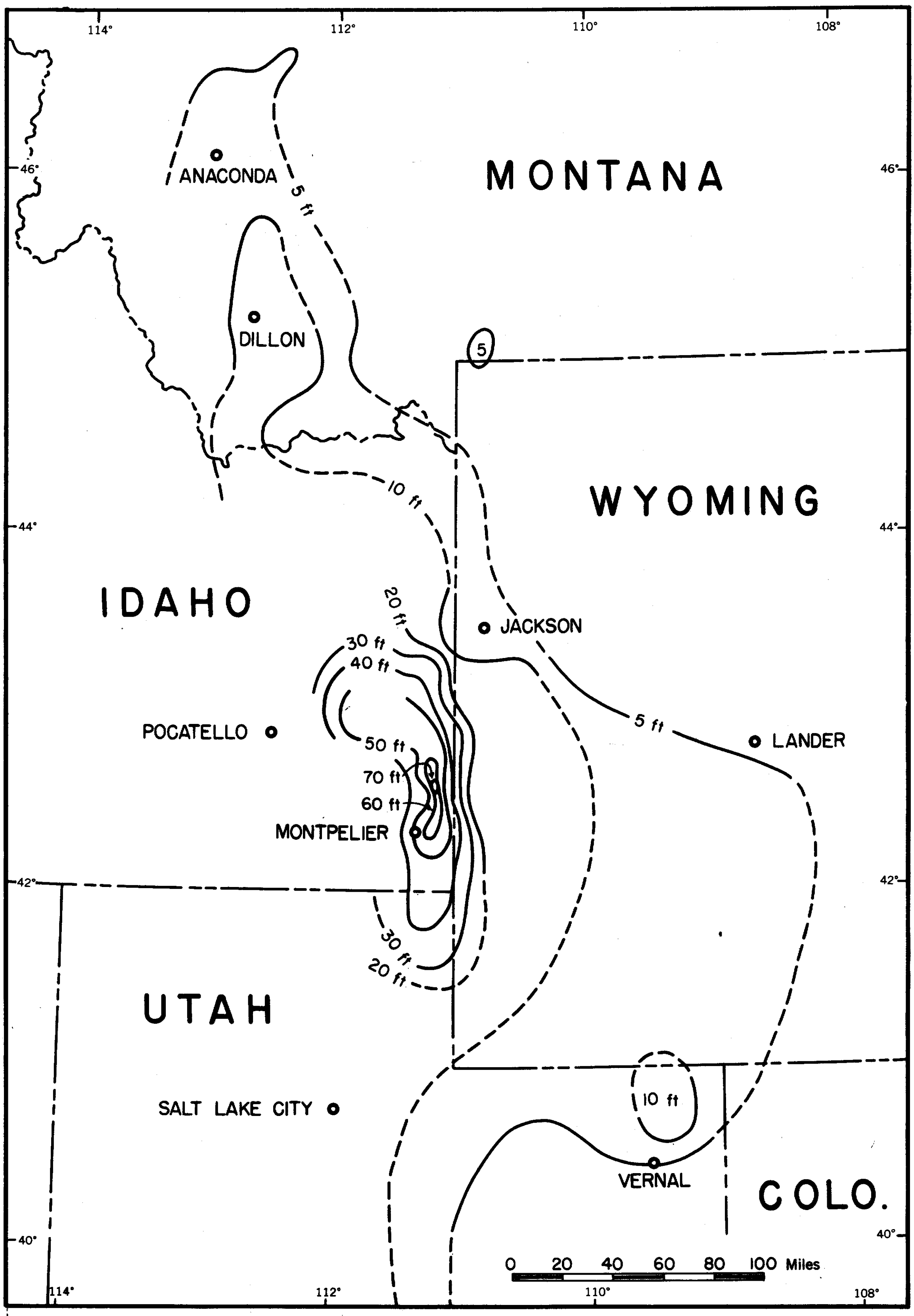

Figure 11. —Total thickness (in feet) of rocks in the Phosphoria and Park City formations containing more than 18 percent P_2O_5.

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