Minor Elements in Bedrock Soil, and Vegetation at an Outcrop of the Phosphoria Formation on Snowdrift Mountain Southeastern Idaho

By FREDERICK B. LOTSPEICH *and* ELLEN L. MARKWARD

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MINOR ELEMENTS IN BEDROCK, SOIL, AND VEGETATION AT AN OUTCROP OF THE PHOSPHORIA FORMATION ON SNOWDRIFT MOUNTAIN, SOUTHEASTERN IDAHO

By FREDERICK B. LOTSPEICH and ELLEN L. MARKWARD

ABSTRACT

In southeastern Idaho, the Phosphoria Formation of Permian age contains measurable though minor amounts of barium, chromium, copper, manganese, nickel, strontium, vanadium, and zinc. On the western slope of Snowdrift Mountain north of Montpelier, Idaho, this formation has been covered by a thin colluvium derived from the Grandeur Tongue of the Park City Formation (also of Permian age, although older), which is poorer in these metals. In this environment, conditions are favorable for studying the movement of the elements by analysis of samples of bedrock, soil, and vegetation.

In the unweathered rock, there seems to be a definite positive correlation of strontium content and a rough positive correlation of vanadium content with phosphorus content, irrespective of lithology. Zinc shows a generally positive correlation with phosphorus in rock units in which silty constituents are high. An inverse correlation seems evident between manganese and phosphorus, and there seems to be a rough inverse correlation between barium and phosphorus.

In a comparison made between the metal content of samples of fresh phosphatic shale and that of weathered phosphatic shale in the twelve lithologic units studied, barium, chromium, and vanadium show an increase with weathering in 8, 8, and 10 units respectively; zinc shows a decrease with weathering in 9 units. For copper, manganese, nickel, phosphorus, and strontium, results are neither consistent nor conclusive; that is, a few units of fresh rock have the higher content of the metal measured, a few units of weathered rock have the higher content, and in the remaining units differences are nil or negligible. In distribution, amount, and general relations with other elements, in all lithologic units except one, copper and nickel are similar.

Minor-element content of the source of the colluvium is about the same as that of most soil-forming material. The soil above the phosphatic shale contains more phosphorus, zinc, vanadium, chromium, and strontium, and slightly more copper, than that above the Grandeur Tongue of the Park City Formation. The barium content of soil over the two formations is about the same. Manganese, barium, nickel, and strontium are more concentrated in the upper soil horizons than in the lower.

Analysis of plants shows wide variations in metal content among different species of plants growing under similar conditions. Such variations are demonstrated by analytical results on samples from three shrub species and are probably related to the rooting habit and physiology of each species. Different types of plant tissue also vary widely in minor-element content, as do the same types of tissue when of different ages.

INTRODUCTION

Although geochemical techniques for locating hidden ore deposits are currently in common use, further fundamental studies must be made before the full potentialities of geochemical methods of exploration can be utilized. Still important is the need, emphasized by Hawkes (1950), for fundamental research in the relative mobility of metallic elements in the zone of weathering.

This study is an attempt to relate, in accordance with Goldschmidt's enrichment principle (Goldschmidt, 1954), the metal content of bedrock to the metal content of an overlying colluvial soil of extraneous origin and to the metal content of vegetation growing in the soil. In addition, by comparing samples of weathered rock with samples of corresponding units of fresh rock and by studying the soil and the vertical distribution of elements between bedrock and surface, some information has been obtained on the behavior of several metallic elements during the weathering processes. Such information allows better interpretation of geochemical data and points the way to proper sampling.

The Phosphoria Formation, of Permian age, is well suited in southeastern Idaho to this type of investigation for the following reasons: the phosphatic shale beds of this formation contain several metals in measurable quantity; the shale beds are remarkably persistent and are nearly uniform in both lithology and chemical composition for tens of miles; in many places the outcrops have been covered by colluvium derived from another rock unit; and in some of these places, soil has developed from the colluvium, and a considerable plant cover is growing from the soil.

For the work reported here, samples were collected during the summers of 1954 and 1955 at a site about 20 miles north of Montpelier, Idaho (fig. 1). At this locality trenches had been dug in 1948 by the U.S. Geological Survey in its investigation of phosphate deposits of the northwestern United States, and underground workings had been started by the Central Farmers Fertilizer Co. about the same time. The site is at an altitude of approximately 8,300 feet. The mean annual temperature at Montpelier is 41.6° F (the range is from −34° to 102°), and the mean annual precipitation is about 22 inches. Although comparable data are not available for the work site, the mean annual temperature is thought to be about 3° F lower there because of the higher elevation.

In the area studied, the Phosphoria Formation is made up of two members. The lower, the Meade Peak Phosphatic Shale Member, consists of about 180 feet of rock commonly called phosphatic shale, which may be subdivided into three types: the so-called phosphate rock, a highly phosphatic shale; argillaceous phosphate rock, which contains less phosphate and more silt and clay; and phosphatic mudstone, a hard well-indurated rock, some of which is nodular and some of which is highly calcareous. The upper member, the Rex Chert Member, is about 250 feet thick and consists of massive chert, siliceous shale, and, locally, lenses of calcareous mudstone. The Meade Peak is underlain by the Grandeur Tongue of the Park City Formation, a sequence of carbonate rocks and sandstone units more than 5,000 feet thick. The Rex is overlain by the Dinwoody Formation of Early Triassic age.

The Phosphoria beds studied lie in the western limb of the anticline that forms Snowdrift Mountain and are exposed locally on the western slope of the mountain. The beds strike N. 10° E. and dip 70° W. Because of the anticlinal structure, the older rocks (those of the Grandeur Tongue of the Park City Formation) crop out on the mountain at an altitude higher than that of outcrops of the Meade Peak phosphatic shale member. Above the phosphatic shale beds of the Phosphoria Formation, the slope of the land surface is only 10° W.; but above the Park City Formation, it is about 25° W. The topography has permitted movement of colluvium from the Park City Formation downward across the exposure of the phosphatic shales.

At the work site, the sandy texture of the soil is a clue to the source of the colluvium. It is believed that the colluvium can not have been derived from the phosphatic shale, because the phosphatic shale beds contain very little sand (McKelvey, Davidson, O'Malley, and Smith, 1953). Furthermore, large chunks of limestone and dolomite in the colluvium resemble the carbonate rocks of the Park City Formation; no rocks of their type or appearance are associated with the phosphatic shale. This evidence, together with the position of the Park City exposure topographically higher than that of the Phosphoria Formation and with the presence of the steeper slope above the Park City, strongly suggests that through weathering and subsequent movement the colluvium has been derived from the Park City Formation. Frost action may have played an important role in the transport of this material, although the presence of incipient soil horizons rules out recent mixing action.

At the contact between the colluvium and the phoshatic shale, the truncated edges of the shale beds are overturned, having been rolled and dragged downslope by movement of the colluvium above them.

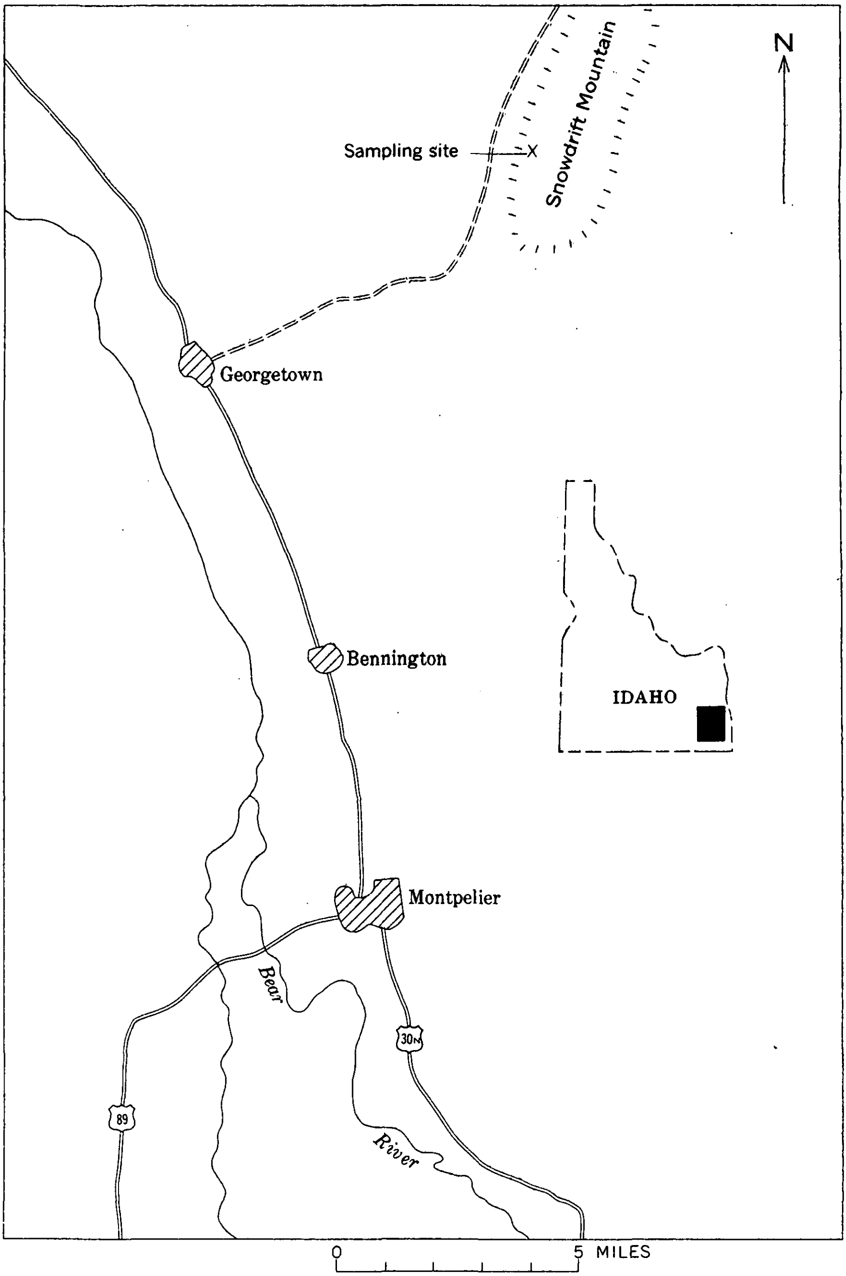

FIGURE 1.—Index map showing location of sampling site on west side of Snowdrift Mountain, northeast of Georgetown, Idaho.

Figure 2, a photograph, and figure 3, a diagrammatic section of the site where samples were collected, show the contact relation of the shale beds to the overlying colluvial soil. Although the dragged beds have been thinned and the attitude of their layering has been changed from a 70° dip to one roughly parallel to the surface slope of 10°, the identity of some individual beds has been preserved to the extent that these beds are recognizable 40 feet or more downslope from their former position.

Soil horizons, though identifiable, are not well developed, as is indicated in the generalized soil-profile description (table 1). Among characteristics of the several soil horizons, the main variable is color, whose changes seem to be due to the degree to which the yellow of the parent material is masked by organic matter. The coloring effects of organic matter are especially noticeable in the horizons near the surface. Typical structures of the soil units are only incipiently developed, except for the weak granular structure in the upper horizons and the subangular blocks in the deeper horizons. The yellow material of the C horizon is somewhat vesicular and the vesicles have a darker color than that of the matrix.

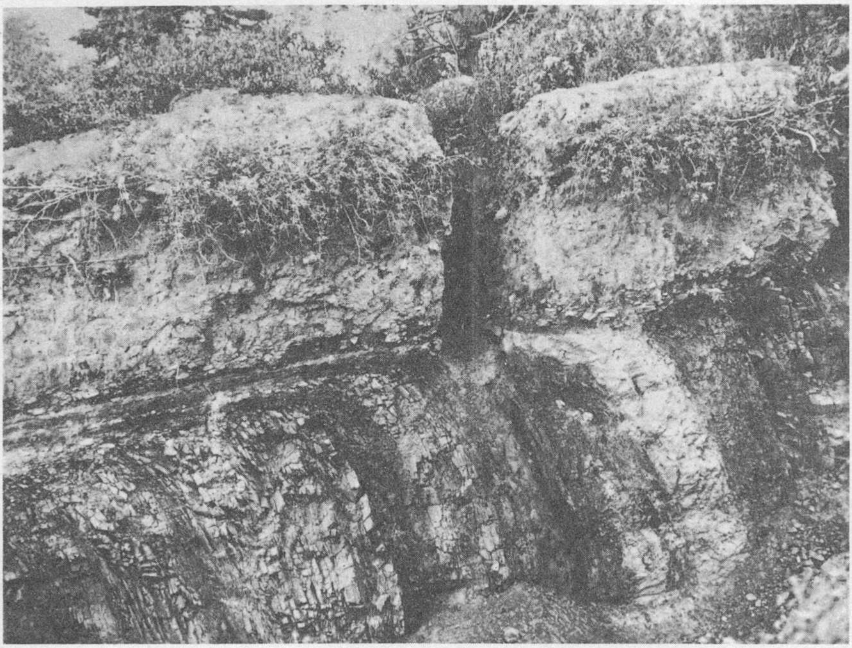

FIGURE 2.—Photograph of side of trench 1 at sampling site near Georgetown in southeastern Idaho. Photograph shows truncated beds of phosphatic shale in Meade Peak Member of Phosphoria Formation which have been dragged by movement of overlying colluvium. Samples were taken from small excavation at center.

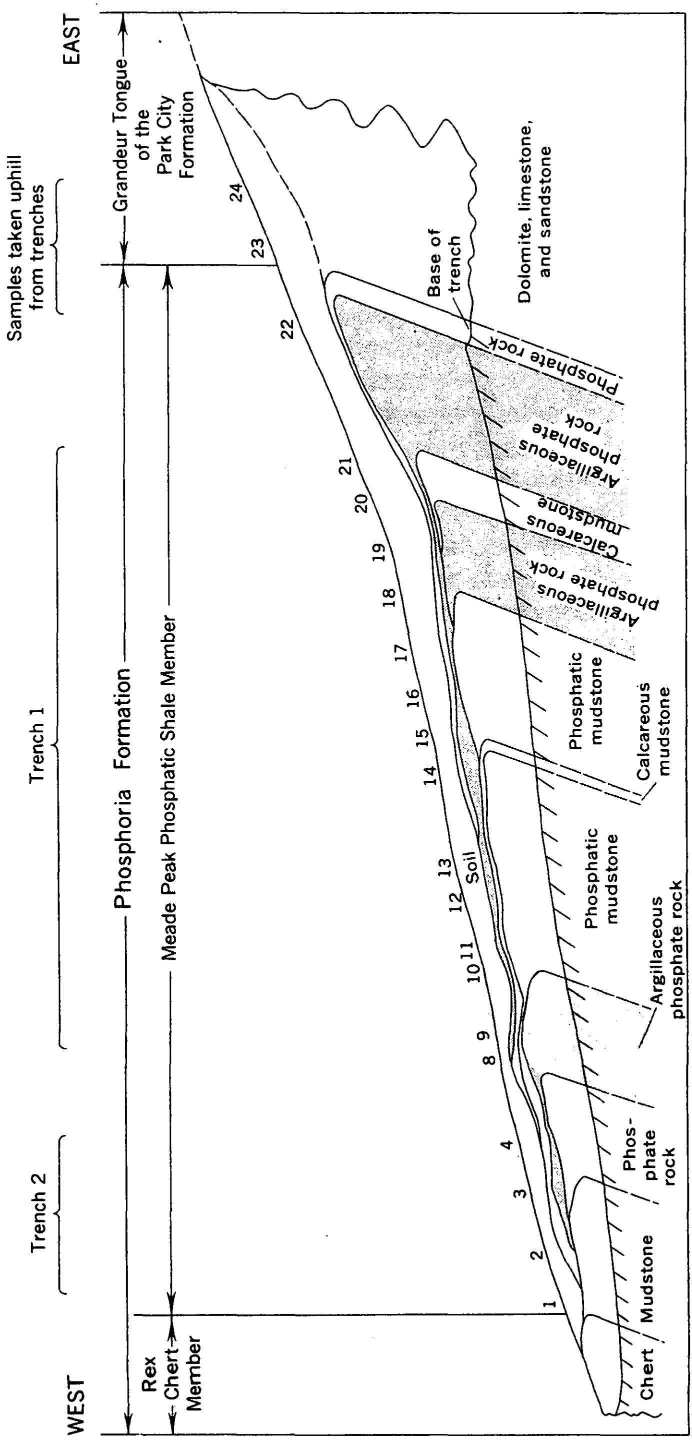

FIGURE 3.—Diagrammatic longitudinal section composited of trenches 1 and 2, showing major groups of beds and numbered sites of complete profile sampling near Georgetown, southeastern Idaho. Relative thickness of soil is correct.

TABLE 1.—*Soil profile description (generalized)*

[From the surface as reference (designated 0), soil horizons are measured both upward and downward. Soil colors are from "Soil Color Charts," published by Munsell Color Co., Inc., Baltimore, Md.]

Horizon	Depth (inches)	Description
A_{00}	4–2	Dry leaves and other vegetal material, somewhat matted but not visibly decayed.
A_0	2–0	Partially decomposed plant material; leaves have lost their identity.
Ground surface	0	
A_{11}	0–6	Dark grayish-brown (10*YR* 4/2, dry) silt loam; single-grained to weak crumb structure; many roots; this is the horizon having maximum content of organic matter.
A_{12}	6–12	Dark-brown (10*YR* 4/3, dry) silt loam; single-grained to weak crumb structure; roots are numerous and organic matter content appears to be high; separation of this horizon from A_{11} is arbitrary.
AC	12–16	Yellowish-brown (10*YR* 5/4, dry) silt loam; weak blocky structure; roots are still numerous, although organic-matter content has decreased; this is a transition horizon having arbitrary boundaries above and below.
C	16–36	Yellowish-brown (10*YR* 5/6, dry) silt loam; subangular blocks; number of roots decreases with depth; this horizon may contain numerous limestone, sandstone, and dolomite boulders, ranging in size from 6 to 24 inches in greatest dimension, that have a weathered skin; sharp boundary with underlying, colluvially dragged layers of phosphatic shale.

In southeastern Idaho, the mountain slopes support forest growth, including both trees and shrubs; the broad valleys support only brushy plant cover. The tree species most abundant in the general region is quaking aspen (*Populus tremuloides*); Douglas-fir (*Pseudotsuga taxifolia*) and lodgepole pine (*Pinus contorta* var. *latifolia*) are next in abundance. At altitudes above 8,000 feet, Engelmann's spruce (*Picea engelmanni*), subalpine fir (*Abies lasiocarpa*), and limber pine (*Pinus flexilis*) are common members of the forest community. The most numerous of the shrubby species that cover the lower slopes are mountain mahogany (*Cercocarpus* sp.), snowbrush (*Ceanothus velutinus*), snowberry (*Symphoricarpos oreophilus*), and mountain lover (*Pachistima myrsinites*). Sagebrush (*Artemisia tridentata*), which is plentiful in certain areas, in some places extends to an altitude of 9,000 feet although it is usually restricted to the valley bottoms. In the immediate vicinity of the outcrop studied at East Georgetown, the trees in the order of their abundance are Douglas-fir, spruce, subalpine fir, aspen, and willow, and the chief shrubs are snowbrush, snowberry, and mountain lover.

In this report, the senior author is responsible for planning the investigation, for the field work, for some of the analyses, and for the major part of interpretation of analytical results. The contribution of the junior author lies in the organization and presentation of material and in the checking of data.

Special thanks are due the Central Farmers Fertilizer Co. of Chicago for permitting collection of samples from their property and for the trenching they did for the benefit of the Geological Survey field party.

METHODS OF INVESTIGATION AND RESULTS

For study of the behavior of several chemical elements during the weathering process and of the movement of these elements from their source in the bedrock to their present position, data were obtained from analytical determinations made on different types of material during two phases of investigation. In one phase, a comparative study was made of samples of weathered bedrock and samples of fresh bedrock. In the second phase, to supply information on what happens in the vertical zone between bedrock and surface, complete profile sampling was done—that is, samples were taken from bedrock in place, from shale layers that had been dragged by moving colluvium, from soil developed in the colluvium, and from plants growing in the soil.

The surface and near-surface samples came from the trenches shown in figures 2 and 3, and in figure 4, a diagrammatic sketch of the area in plan. Trench 1, referred to here as the main trench, had been scooped out with a bulldozer in 1948. For purposes of the present work, this main trench was cleaned out and then deepened along its full length by an additional excavation 2 feet wide and 1½ feet deep; exposures were therefore available of soil, colluvially dragged layers, and phosphatic shales in place to depths of 8 to 20 feet. Trench 2, a smaller trench, was dug about 100 feet north of the main trench, as part of the work reported here, in order to provide fresh exposures of the soil and vegetation, which had been stripped away along the top of trench 1. Figure 3, the diagrammatic logitudinal section, is a composite of both trenches.

STUDY OF WEATHERED AND UNWEATHERED BEDROCK

The trenches furnished samples of the phosphatic shale beds in the weathering zone; a channel sample weighing between 8 and 12 pounds was taken from each lithologic unit studied. Samples of the same units at depth were taken from the Central Farmers Fertilizer Co.

mine about 800 feet down dip from rock exposed in the trench. Beds that are noticeably weathered near the surface appear unweathered in the mine.

Phosphorus is the only major rock-forming constituent of the phosphatic shales chemically determined in this study; the phosphorus content was estimated by means of a semiquantitative wet chemical colorimetric method, which, on the basis of the reactions described by Snell and Snell (1949, p. 672), had been developed in the laboratories of the U.S. Geological Survey for field use. The zinc content of the shale samples was also determined by use of a wet chemical semiquantitative field method. The shale samples were also analyzed by semiquantitative spectrographic methods for copper, nickel, manganese, vanadium, chromium, barium, and strontium; these analyses were made in a truck-mounted spectrograph. Analyses of individual samples are reported in table 2, and averages of groups of analyses representing the respective rock units are diagrammatically presented on plate 1.

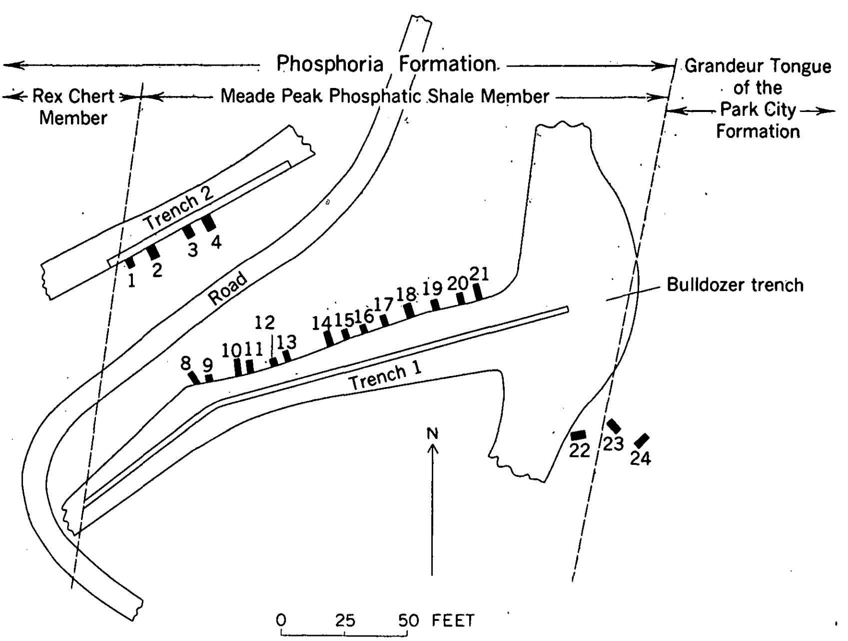

FIGURE 4.—Diagrammatic sketch map of area on west side of Snowdrift Mountain, northeast of Georgetown, Idaho. Trenches are outlined. Sites of complete profile sampling are numbered.

TABLE 2.—*Phosphorus and minor-element content of samples from the Meade Peak Phosphatic Shale Member of the Phosphoria Formation*

[Phosphorus is expressed in percent, trace elements in parts per million. Zinc and phosphorus were determined, by semiquantitative field methods, by R. R. Beins and G. C. Campbell; other elements, by semiquantitative spectrographic methods, by U. Oda]

Sample		Constituents								
Lab. No.	Field No.	P	Zn	Cu	Ni	Mn	V	Cr	Ba	Sr
SAMPLES OF UNWEATHERED ROCK, FROM MINE										
Phosphate rock										
54-5751	657	7.50	400	15	75	200	750	750	75	3,500
5752	658	10.00	1,000	35	75	150	1,500	750	75	3,500
5753	659	1.50	200	35	20	500	350	350	100	350
5754	660	7.50	1,000	35	10	350	500	500	75	1,000
5755	661	2.00	1,000	75	75	350	750	750	150	750
5756	662	7.50	1,750	100	150	200	1,500	1,500	150	3,500
5757	663	7.50	1,000	35	75	200	1,500	750	100	2,000
5758	664	15.00	1,000	35	75	100	2,000	1,000	75	3,500
5759	665	4.25	3,500	100	150	200	1,500	1,500	100	2,000
5760	666	1.00	300	15	<5	100	750	150	<10	750
5761	667	15.00	1,500	75	75	75	1,500	750	50	3,500
5762	668	7.50	2,000	75	100	100	2,000	750	50	3,500
Argillaceous phosphate rock										
54-5763	669	0.75	500	15	<5	150	500	150	<10	500
5764	670	7.50	7,000	100	350	100	5,000	1,500	100	1,500
5765	671	7.50	3,500	100	350	75	3,500	1,500	100	2,000
5766	672	5.00	3,500	150	200	100	3,500	2,000	150	2,000
5767	673	4.25	2,000	75	150	75	1,500	1,500	100	2,000
5768	674	3.75	3,000	100	150	100	2,000	2,000	150	2,000
5769	675	1.50	750	35	35	150	200	350	75	500
5770	676	.50	300	15	20	150	50	200	75	350
5771	677	4.25	2,000	150	200	100	500	1,500	200	750
Phosphatic mudstone										
55-3923	736	5.0	400	100	75	200	200	500	150	750
3924	737	5.0	600	75	100	200	200	750	150	750
3925	738	4.0	400	75	50	200	200	500	150	500
3926	739	1.0	200	50	20	200	200	350	75	350
3927	740	2.5	1,500	150	200	200	350	1,500	150	500
3928	741	2.5	1,500	100	150	200	350	1,000	200	350
Nodular phosphatic mudstone										
55-3929	742	1.0	600	50	50	150	350	750	150	500
3930	743	2.0	600	75	75	150	500	750	350	750
3931	744	1.0	400	75	75	200	750	750	350	500
3932	745	1.0	1,500	100	100	200	750	1,500	350	500
3933	746	1.5	1,000	75	100	200	500	1,000	200	500
3934	747	1.5	1,500	75	100	200	750	1,500	350	500
3935	748	1.0	600	75	75	200	500	750	200	500
3936	749	1.0	300	75	50	350	350	350	200	350
3937	750	2.5	700	150	200	150	500	1,500	500	500
3938	751	3.0	2,000	150	350	100	500	1,500	200	500
Calcareous mudstone										
55-3939	752	10.0	1,000	75	200	50	1,000	1,500	100	3,500

TABLE 2.—*Phosphorus and minor-element content of samples from the Meade Peak Phosphatic Shale Member of the Phosphoria Formation*—Continued

Sample		Constituents								
Lab. No.	Field No.	P	Zn	Cu	Ni	Mn	V	Cr	Ba	Sr
SAMPLES OF UNWEATHERED ROCK, FROM MINE—Continued										
Nodular phosphatic mudstone										
55-3940	753	1.0	200	35	50	350	500	200	100	200
3941	754	3.0	100	20	35	200	150	150	150	500
3942	755	.5	50	15	10	200	100	100	50	200
3943	756(a)	.1	20	15	5	200	100	75	50	350
3944	756(b)	1.5	70	35	20	200	200	150	100	350
3945	757	6.0	300	35	75	100	350	500	200	750
3946	758	12.5	300	35	35	100	500	1,500	75	3,500
3947	759	10.0	300	35	35	75	200	350	100	2,000
3948	760	5.0	300	50	50	150	350	500	150	750
3949	761	7.5	1,500	100	150	100	350	1,500	100	750
3950	762	3.0	700	100	150	200	350	1,000	150	500
3951	763	6.0	3,000	150	350	100	1,000	2,000	200	1,000
3952	764	2.0	600	75	50	100	350	500	150	350
Phosphatic mudstone										
55-3953	765	4.0	2,000	150	350	100	750	2,000	75	500
3954	766	3.0	1,000	75	150	75	500	1,500	150	750
3955	767	2.5	1,000	150	200	100	500	1,500	200	750
3956	768	3.0	1,500	100	150	75	350	2,000	100	750
3957	769	2.5	1,500	75	150	100	350	2,000	200	1,000
3958	770	.1	100	10	<5	75	35	150	<5	350
3959	771	1.0	200	15	10	100	75	200	50	350
3960	772	.1	70	15	5	150	75	150	5	350
3961	773	1.0	1,500	75	150	150	500	1,500	350	500
3962	774	2.5	1,000	75	100	200	350	1,000	350	750
Argillaceous phosphate rock										
55-3963	775	0.5	200	20	20	150	200	350	200	500
3964	776	1.5	400	35	35	150	200	750	350	750
3965	777	1.0	400	35	35	150	200	500	150	500
Argillaceous phosphate rock										
55-3966	778	5.0	1,000	100	100	150	200	2,000	350	750
3967	779	2.0	400	50	35	150	100	500	200	750
3968	780	4.0	1,500	50	75	100	200	1,500	200	1,000
3969	781	5.0	600	35	75	100	350	1,000	100	1,000
Calcareous mudstone										
55-3970	782	2.0	400	50	20	200	200	500	150	500
3971	783	2.5	1,500	75	100	150	200	1,500	200	1,500
3972	784	3.0	1,500	75	150	50	350	1,000	100	750
54-5772	678	2.00	1,500	75	150	150	200	1,000	200	750

TABLE 2.—*Phosphorus and minor-element content of samples from the Meade Peak Phosphatic Shale Member of the Phosphoria Formation*—Continued

Sample		Constituents								
Lab. No.	Field No.	P	Zn	Cu	Ni	Mn	V	Cr	Ba	Sr
SAMPLES OF UNWEATHERED ROCK, FROM MINE—Continued										
Argillaceous phosphate rock										
54-5773	680	2.00	1,000	20	20	75	350	350	35	500
5774	681	0.75	300	15	10	100	200	150	10	200
5775	682	3.75	750	100	100	100	350	750	150	750
5776	683	2.50	1,250	75	75	100	350	500	150	350
5777	684	7.50	750	75	75	50	500	750	75	1,000
5778	685	5.00	5,000	75	150	75	3,500	750	75	1,000
5779	686	7.50	3,000	100	150	75	3,500	750	150	1,500
5780	687	7.50	2,500	100	100	75	3,500	750	150	1,000
5781	688	1.50	2,500	15	35	100	1,000	350	75	350
5782	689	5.00	1,500	150	150	75	2,000	750	150	1,000
5783	690	7.50	2,500	75	150	50	2,000	750	150	1,000
5784	691	7.50	3,500	100	150	50	2,000	750	100	750
5785	692	7.50	2,500	100	150	35	2,000	750	100	750
5786	693	3.75	1,500	75	150	50	1,500	750	150	750
5787	694	2.00	1,250	20	75	75	350	500	75	350
5788	695	0.15	750	<1	<5	75	100	50	<10	100
5789	697	3.75	1,500	75	150	75	750	750	100	750
Phosphate rock										
54-5790	698	10.00	1,500	75	50	10	3,500	500	75	2,000
5791	699	7.50	1,500	150	100	20	3,500	750	75	1,500
5792	700	15.00	2,000	100	75	15	5,000	750	75	2,000
5793	701	7.50	2,500	75	75	15	3,500	750	75	1,500
SAMPLES OF WEATHERED ROCK, FROM TRENCH										
Phosphate rock										
54-5639	158	6.00	700	15	10	50	750	750	75	1,500
5640	159	1.50	2,500	15	75	75	500	500	200	150
5641	160	15.00	500	15	<5	<10	750	750	75	3,500
5642	161	3.00	2,500	15	75	350	500	500	350	350
5643	162	7.50	1,000	20	20	150	750	750	150	750
5644	163	4.25	2,500	20	35	200	500	500	200	350
5645	164	10.00	750	15	15	150	500	500	150	1,500
5646	165	7.50	1,500	15	15	20	500	500	150	750
5647	166	7.50	750	15	15	75	500	500	150	3,500
5648	167	15.00	750	15	<5	<10	500	500	50	3,500
5649	168	7.50	1,000	35	5	10	3,500	750	75	1,500
5650	169	7.50	2,500	75	75	75	3,500	1,000	350	750
5651	170	5.00	2,500	75	20	10	3,500	750	150	750
5652	171	2.50	750	15	2	<10	3,500	750	75	3,500
Argillaceous phosphate rock										
54-5653	172	7.50	1,500	75	75	75	3,500	1,500	150	1,500
5654	173	4.25	2,500	150	100	75	3,500	1,500	100	750
5655	174	.40	750	15	<5	<10	500	150	<10	750
5656	175	7.50	2,500	150	100	75	5,000	1,500	150	3,500
5657	176	4.25	2,500	150	150	50	3,500	1,500	150	1,500
5658	177	7.50	2,500	150	150	20	1,500	1,500	150	2,000
5659	178	5.00	1,500	150	150	100	1,500	1,500	150	1,500
5660	179	3.75	2,500	150	150	20	1,500	1,500	200	1,500
5661	180	2.00	1,500	75	150	150	1,500	1,000	200	750
5662	181	.85	1,500	75	350	1,000	1,500	750	750	750
5663	182	5.00	1,500	150	350	100	1,000	3,500	350	1,000
5664	183	4.25	1,500	150	350	150	750	1,500	150	750
5665	184	5.00	1,500	150	150	75	500	1,500	350	1,000

TABLE 2.—*Phosphorus and minor-element content of samples from the Meade Peak Phosphatic Shale Member of the Phosphoria Formation*—Continued

Sample		Constituents								
Lab. No.	Field No.	P	Zn	Cu	Ni	Mn	V	Cr	Ba	Sr
SAMPLES OF WEATHERED ROCK, FROM TRENCH—Continued										
Phosphatic mudstone										
54-5666	185	10.00	750	75	50	100	200	750	100	3,500
5667	186	.85	1,500	75	350	1,000	750	1,000	750	750
5668	187	3.75	500	100	150	200	350	500	150	750
5669	188	3.75	500	75	50	20	200	1,500	350	1,000
5670	189	3.00	500	75	35	20	200	750	150	200
5671	190	2.00	750	100	100	200	350	750	350	500
5672	191	1.50	750	150	150	75	500	2,000	750	500
5673	192	3.75	500	100	75	50	750	2,000	500	1,000
5674	193	5.00	500	100	75	75	500	2,000	350	1,500
5675	194	3.75	500	150	100	20	750	2,000	350	750
5676	195	1.50	500	150	75	15	750	1,500	500	500
5677	196	2.00	500	75	75	15	500	750	500	750
5678	197	3.00	400	150	75	15	1,000	3,500	500	1,000
5679	198	5.00	300	150	75	15	750	2,000	350	750
Nodular phosphatic mudstone										
54-5680	199	0.60	400	100	75	15	500	750	500	750
5681	200	3.00	1,000	150	350	350	500	750	350	750
5682	201	3.75	1,000	150	200	150	1,500	1,500	350	750
5683	202	1.25	1,000	150	150	75	1,000	1,500	500	500
5684	203	2.00	1,000	100	150	75	1,000	1,500	750	1,000
5685	204	1.00	750	75	150	75	500	750	750	350
5686	205	.40	750	50	100	75	500	350	750	200
5687	206	.40	750	150	100	75	350	1,500	500	350
5688	207	4.25	500	150	100	75	1,000	2,000	150	750
5689	208	.75	750	150	150	75	1,500	750	500	350
5690	209	4.25	1,000	200	350	350	1,500	5,000	350	750
5691	210	7.50	750	150	150	100	750	1,500	150	3,500
5692	211	4.25	750	200	200	100	1,500	1,500	150	750
5693	212	7.50	750	75	150	100	350	750	100	1,000
5694	213	5.00	750	75	350	1,000	750	150	350	150
5695	214	5.00	750	75	75	150	500	750	150	750
Calcareous mudstone										
54-5696	215	0.25	750	75	350	1,500	750	500	350	200
Nodular phosphatic mudstone										
54-5697	216	2.50	380	75	50	50	350	750	350	750
5698	217	7.50	750	75	350	750	350	1,000	150	1,000
5699	218	4.25	300	150	10	50	200	1,500	100	750
5700	219	2.00	300	150	50	50	500	1,500	350	500
5701	220	3.75	750	200	75	75	350	1,500	150	500
5702	221	.75	1,250	150	200	75	350	1,000	500	350
5703	222	2.00	1,000	150	200	20	750	1,500	350	500
5704	223	4.25	1,250	350	350	20	750	2,000	200	750
5705	224	2.00	1,250	100	150	100	750	1,000	100	750
5706	225	3.00	2,500	150	350	350	1,000	1,500	350	1,500
5707	226	2.00	2,500	100	350	500	500	1,500	350	750

695-901 O—63——3

TABLE 2.—*Phosphorus and minor-element content of samples from the Meade Peak Phosphatic Shale Member of the Phosphoria Formation*—Continued

Sample		Constituents								
Lab. No.	Field No.	P	Zn	Cu	Ni	Mn	V	Cr	Ba	Sr
SAMPLES OF WEATHERED ROCK, FROM TRENCH—Continued										
Phosphatic mudstone										
54-5708	227	0.15	250	10	100	100	20	150	<10	350
5709	228	.75	1,250	75	100	100	200	750	200	150
5710	229	.25	750	75	100	100	150	350	50	150
5711	230	.25	750	50	75	200	50	150	35	150
5712	231	.75	1,000	75	150	50	500	750	350	350
5713	232	.50	750	150	150	15	1,000	1,000	500	150
5714	233	3.00	2,000	150	750	3,500	1,500	1,500	750	750
5715	234	.40	1,000	100	150	350	500	1,000	500	350
5716	235	.50	750	75	100	15	350	500	500	350
5717	236	.75	400	100	75	10	350	750	500	350
5718	237	3.00	750	150	150	75	350	1,500	200	750
5719	238	.40	400	100	75	15	500	350	500	200
5720	239	.40	200	35	50	10	350	350	500	350
Argillaceous phosphate rock										
54-5721	240	2.00	400	200	75	10	750	2,000	200	2,000
5722	241	5.00	300	200	350	10	1,000	3,500	150	2,000
5723	242	4.25	300	150	75	<10	750	1,000	150	1,500
5724	243	2.50	750	350	350	10	1,500	2,000	150	2,000
5725	244	4.25	300	200	75	10	500	1,500	150	2,000
5726	245	1.25	2,000	350	350	15	1,500	1,500	350	350
5727	246	7.50	300	350	75	<10	1,000	2,000	100	3,500
5728	247	.25	400	350	350	20	3,500	5,000	350	500
5729	248	3.00	750	500	75	10	3,500	1,500	150	500
5730	249	7.50	750	350	100	10	3,500	1,500	100	750
5731	250	3.00	750	150	150	20	1,500	1,000	150	750
5732	251	2.00	1,250	150	350	350	500	500	150	350
Calcareous mudstone										
54-5733	252	2.00	400	50	35	100	350	350	35	150
5734	253	5.00	1,000	150	150	75	750	750	200	500
5735	254	.75	750	7	5	100	100	150	35	100
Argillaceous phosphate rock										
54-5736	255	7.50	750	100	50	15	1,000	750	75	500
5737	256	7.50	1,500	150	35	10	3,500	1,000	150	750
5738	257	4.25	1,500	100	100	150	3,500	750	150	750
5739	258	5.00	1,250	100	100	20	2,000	500	150	350
5740	259	7.50	1,500	100	75	10	2,000	750	150	750
5741	260	2.00	750	20	20	150	750	350	20	350
5742	261	7.50	1,250	100	150	10	2,000	750	75	500
5743	262	7.50	1,250	75	100	75	1,500	750	75	500
5747	529	5.00	750	75	75	75	350	500	75	350
5748	530	5.00	1,000	100	100	20	1,000	750	100	750
5749	531	2.00	1,250	100	150	500	1,000	350	75	150
5750	532	7.50	1,250	150	100	200	1,500	1,000	150	750
Phosphate rock										
54-5795	722	15.00	1,500	75	35	20	3,500	750	75	2,000
5796	723	15.00	1,500	100	75	200	3,500	1,000	75	1,500
5797	724	15.00	1,000	75	20	15	3,500	750	75	1,500

For the elements reported, ranges of concentration in the samples listed in table 2 are as follows (phosphorus expressed in percent, other elements in parts per million):

	In unweathered rock	*In weathered rock*
Phosphorus	0.1–15	0.1–15
Zinc	20–7,000	200–2,500
Copper	<1–150	7–500
Nickel	<5–350	<5–750
Manganese	10–500	<10–3,500
Vanadium	35–5,000	20–5,000
Chromium	50–2,000	150–5,000
Barium	<5–500	<10–750
Strontium	100–3,500	100–3,500

When analyses of the samples of unweathered rock listed in table 2 are arranged in the numerical sequence of the phosphorus values obtained, several possibilities are disclosed for initial relations among individual elements and also between certain elements and certain rock types. It must be remembered, however, that although the lithologic designation of each rock unit given in table 2 and plate 1 is applicable to the unit as a whole, single samples within a group may vary somewhat, lithologically, from the majority of samples taken from the unit.

In the 93 samples of unweathered rock that were analyzed in this study, the lowest phosphorus content, 0.1 percent, was in 3 samples of phosphatic mudstone; the highest, 15 percent, was in 3 samples of phosphate rock. The median phosphorus content is 3 percent, which was the content of 6 samples of mudstone, 2 of which are nodular and 1 of which is highly calcareous. The first quartile value is 1.5 percent, which was the content of 7 samples, 3 of which were taken from nodular phosphatic mudstone, and 4 of which were taken from argillaceous phosphate rock. The third quartile value is 7.5 percent, which was the content of 16 samples, 8 from argillaceous phosphate rock, 7 from phosphate rock, and 1 from nodular phosphatic mudstone.

The nine highest zinc values determined—ranging from 3,000 to 7,000 ppm (parts per million)—were in argillaceous rocks that contained 3.75 to 7.5 percent phosphorus, values that are above the median but well below the maximum concentration of phosphorus measured. The two lowest zinc values determined—20 and 50 ppm—were for samples that had the two minimum phosphorus values. Only one sample that had a zinc value of less than 200 ppm had a phosphorus content above the first quartile value, and none of the samples that had contained less than 200 ppm zinc had a phosphorus value above the median of 3 percent.

The distributions of nickel and chromium—and, to some extent, of barium—are similar to the distribution of zinc in that most of the minimal values of these elements are in rocks having the lowest phosphorus values, and the maximal values are in argillaceous rocks having only moderately high phosphorus values. From these facts it seems that in the unweathered shale beds of the Meade Peak Member of the Phosphoria Formation, zinc, nickel, chromium, and possibly barium have a rough positive correlation with phosphorus in rocks of high argillaceous content.

Both vanadium and strontium, especially the latter, seem to show positive correlation with phosphorus regardless of lithology. The four minimum values of each of these two elements were determined in rocks which had a phosphorus content less than the first-quartile phosphorus value of 1.5 percent. The eight high values of each were in rocks of high phosphorus content—maximal vanadium in rocks having from 5 to 15 percent phosphorus, and maximal strontium in rocks having 7.5 to 15 percent phosphorus.

An inverse correlation between manganese and phosphorus seems possible; with one exception the highest manganese values were in rocks whose phosphorus content was 2 percent or less, whereas the five lowest manganese values were in rocks whose phosphorus content was 7.5 percent or more.

No definite relations are obvious between content of phosphorus and the contents of other elements, which seem to be randomly distributed relative to phosphorus.

On plate 1, histograms of average values computed from analytical results on groups of samples from the mine are shown beside histograms of average values computed from analytical results on corresponding groups of samples from the trench. Each group averaged represents a lithologic unit. Inspection of this figure shows that for the section as a whole there seem to be no consistent or significant differences between unweathered and weathered rock in content of zinc, managanese, vanadium, and strontium. In most of the rock units studied, weathering apparently has concentrated chromium, barium, copper, and possibly nickel.

The effect of weathering on the mobility of elements seems to be related to the character of the rock being weathered. In the 12-inch marker bed of highly calcareous mudstone 84 feet from the chert, amounts of manganese, barium, and nickel have greatly increased during weathering, but strontium, chromium, and phosphorus have decreased. The only weathered rock unit strikingly enriched in phosphorus is the high-grade phosphate rock 159 feet from the chert; this unit shows little or no enrichment in other elements. Barium shows its greatest increase with weathering in the mudstone units, including the calcareous unit mentioned above. Chromium shows some increase in all the weathered mudstone units except the highly calcareous ones, but its maximum increase is in the argillaceous phosphate rock in the interval 116 to 121 feet from the chert—a unit which also shows considerable enrichment in strontium, nickel, and copper. The adjoining unit 121 to 128 feet from the chert, also argillaceous phosphate rock, shows a great enrichment in vanadium, considerable enrichment in copper, and some in nickel and chromium.

STUDY OF SAMPLES FROM COMPLETE PROFILES

From short trenches dug into the banks of trenches 1 and 2 (figs. 2–4), complete profile samples were collected at 19 sites over the phosphatic shale beds of the Meade Peak Member of the Phosphoria Formation. The locations of these short trenches were determined by the availability of the plant species that had been chosen for study. In the aggregate, the samples from these sites provide data across the entire section of phosphatic shales exposed in the region. The technique used to sample the colluvially dragged shales and the soils was described by the U.S. Soil Survey Staff (1951, p. 330).

For purposes of comparison, soil and vegetation samples were also collected at three sites over the carbonate rock of the Grandeur Tongue of the Park City Formation upslope from the outcrop of the phosphatic shales, where it is believed that metal from the shales can not have enriched the colluvium. One representative sample—sample 785—was taken from the outcropping weathered carbonate bedrock to learn in what amounts the elements determined in the colluvial soil had been present in the source rock from which the colluvium was derived.

Data from the analyses are reported in table 3, in which the complete profile at each site (including analytical results on shrubs) is shown as a unit. In this table, the lowermost part of the C horizon is the bottom of the soil; DSh designates the colluvially dragged layers of shale, and BR designates bedrock in place.

BEDROCK

Of the bedrock samples included in the complete profiles from the 19 sites over the phosphatic shales, all but 2 (those at sites 1 and 22) have already been reported in table 2 and plate 1. To the information in the previous section, therefore, little is added here toward clarification of relations between elements within the Meade Peak Member of the Phosphoria Formation. Only one new figure is supplied by the results from analysis of these two bedrock samples: a different maximum for phosphorus in the weathered shales studied is the 18 percent of phosphorus in the bedrock sample from site 22.

The analysis of the sample of weathered carbonate bedrock from the Grandeur Tongue of the Park City Formation indicates the probable metal content of the colluvium from which the soil was derived. The values for the respective metals in general are near the minimum of the ranges in the phosphatic shale samples.

TABLE 3.—*Phosphorus and minor-element content of samples of 22 complete profiles and one bedrock exposure near Montpelier, Idaho*

[Type of sample: S, P, and C denote shrub species *Symphoricarpos*, *Pachistima*, and *Ceanothus*; Y and O show type of growth, young and old; A_{00} and A_0 are layers of unconsolidated organic material (humus) on the ground surface, which in column headed "Depth" is designated by 0; A_1, A_{11}, A_{12}, AC, C_1, C_2, C_3, and C_4 are soil horizons, DSh is dragged shale, and BR is bedrock. Depth of sample: Asterisk indicates plant sample; no depth recorded. Phosphorus content is expressed in percent; trace elements are in parts per million. Leaders mean not determined]

Sample				Constituent								
Lab. No.	Field No.	Type	Depth (inches)	Cu	Zn	V	Cr	Mn	Ni	Sr	Ba	P
PROFILES ABOVE PHOSPHORIA FORMATION												
Profile at site 1												
55-598	68	S-Y	*	------	------	24	50-100	200-500	20-50	750	350	2.0-4.0
599	69	S-O	*	4	70	85	100-200	1,000-2,000	50	1,500	1,000	1.0-2.0
600	70	P-Y	*	------	------	24	20-50	100-200	50-100	750	75	2.0-4.0
601	71	P-O	*	3	90	55	50-100	100-200	20-50	1,500	200	0.5-1.0
247	84	A_{00}	3-2	28	200	<55	------	------	------	------	------	------
248	85	A_0	2-0	24	460	60	------	------	------	------	------	------
811	86	A_{11}	0-4	10	750	350	350	350	20	350	350	3
812	87	A_{12}	4-9	20	850	500	350	350	50	350	350	3
813	88	AC	9-13	15	850	750	500	350	20	750	350	5
814	89	C_1	13-18	26	1,150	750	350	200	50	500	200	5
815	90	C_2	18-24	50	1,250	200	350	200	50	200	200	2
1058	91	DSh	24-32	20	1,000	100	350	100	50	500	500	.5
1059	92	DSh	32-40	40	1,000	200	350	350	75	150	350	.01
1060	93	DSh	40-49	30	700	100	350	200	50	100	350	.2
1069	276	BR	49-60	50	1,000	200	350	200	75	200	350	1.0
Profile at site 2												
55-602	72	C-Y	*	3	30	42	20-50	200-500	20-50	750	100	1.0-2.0
603	73	C-O	*	1	11	44	50-100	200-500	20-50	2,000	200	1.0-2.0
249	263	A_{00}	3-1.5	19	190	>59	135	190	27	------	------	.8
250	264	A_0	1.5-0	22	520	122	216	500	50	------	------	1.2
816	265	A_{11}	0-6	12	600	150	200	200	15	200	350	.5
817	266	A_{12}	6-9	15	550	200	200	350	20	200	350	2.0
818	267	C	9-14	36	750	200	350	200	50	350	200	3.0
1061	268	DSh	14-18	80	700	200	750	75	50	350	150	5.0
1062	269	DSh	18-23	120	1,400	1,500	1,000	50	50	1,000	100	4.0
1063	270	DSh	23-28	50	1,200	1,000	750	200	50	750	100	13.0
1064	271	DSh	28-30	30	1,400	1,000	500	350	50	750	200	10.0
1065	272	DSh	30-35	50	1,200	1,000	750	200	75	750	150	10.0
1066	273	DSh	35-42	40	1,200	750	500	150	50	750	100	1.0
1067	274	DSh	42-49	50	1,400	200	350	350	75	350	200	3.0
1068	275	DSh	49-59	30	1,200	200	350	150	100	150	200	1.0
54-5629	148	BR	>59	15	1,500	350	350	75	50	200	750	2.00

TABLE 3.—*Phosphorus and minor-element content of samples of 22 complete profiles and one bedrock exposure near Montpelier, Idaho*—Continued

Sample				Constituent								
Lab. No.	Field No.	Type	Depth (inches)	Cu	Zn	V	Cr	Mn	Ni	Sr	Ba	P
PROFILES ABOVE PHOSPHORIA FORMATION—Continued												
Profile at site 3												
55-604	74	S-Y	*	2	20	29	50-100	200-500	20-50	1,000	350	1.0-2.0
605	75	S-O	*	3	80	75	50-100	1,000-2,000	20-50	1,000	1,000	1.0-2.0
606	76	C-Y	*	4	30	60	50-100	200-500	20-50	750	150	1.0-2.0
607	77	C-O	*	4	10	44	20-50	200-500	20-50	1,500	350	1.0-2.0
251	277	A_{00}	2.5-1.5	20	150	>46	105	140	21	------	------	.6
253	279	A_0	1.5-0	22	210	28	66	490	9	------	------	.5
819	280	A_{11}	0-5	10	550	50	75	200	10	150	500	.5
820	281	A_{12}	5-10	10	600	50	75	200	20	150	200	.8
821	282	C	10-18	8	400	75	75	200	35	200	500	.5
1070	283	DSh	18-26	100	700	500	1,500	75	50	750	200	6.0
1071	284	DSh	26-32	100	1,000	350	1,500	200	100	750	200	4.0
1072	285	DSh	32-40	80	700	200	500	75	50	500	200	5.0
1073	286	DSh	40-51	100	1,200	1,500	1,500	75	75	750	100	10.0
1074	287	DSh	51-58	80	1,400	1,000	750	100	35	500	75	10.0
1075	288	DSh	58-70	100	1,400	1,000	750	100	20	750	100	10.0
1076	289	DSh	70-73	70	2,000	750	750	500	100	350	150	5.0
54-5642	161	BR	>73	15	2,500	500	500	350	75	350	350	3.00
Profile at site 4												
55-608	78	S-Y	*	------	------	21	50-100	100-200	20-50	750	200	2.0-4.0
609	79	S-O	*	6	80	100	100-200	1,000-2,000	20-50	1,000	2,000	1.0-2.0
254	290	A_{00}	3-1.5	14	180	30	30	250	10	------	------	.22
255	291	A_0	1.5-0	24	360	38	69	690	23	------	------	.03
822	292	A_{11}	0-5	50	575	50	75	500	<5	200	750	.3
823	293	A_{12}	5-10	12	600	100	75	350	5	350	750	.3
824	294	AC	10-14	18	475	100	75	200	10	200	500	.3
825	295	C	14-24	10	600	150	75	200	20	<50	150	.6
1077	296	DSh	24-32	70	1,000	1,500	1,000	100	75	500	100	9.0
1078	297	DSh	32-41	100	800	500	1,000	50	75	350	100	4.0
1079	298	DSh	41-52	100	1,000	350	1,500	50	75	750	150	8.0
1080	299	DSh	52-58	120	1,200	1,000	1,000	200	150	500	150	5.0
1081	300	DSh	58-65	120	1,200	1,500	1,000	75	100	750	100	6.0
1082	301	DSh	65-68	120	2,000	3,500	2,000	100	150	750	100	5.0
1083	302	DSh	68-78	100	1,000	1,500	750	75	35	750	75	17.0
54-5653	172	BR	>78	75	1,500	3,500	1,500	75	75	1,500	150	7.5
Profile at site 8												
55-614	94	C-Y	*	2	30	58	50-100	200-500	50-100	1,500	150	1.0-2.0
615	95	C-O	*	<1	20	37	50-100	200-500	50-100	3,500	350	0.5-1.0
260	334	A_{00}	3-2	26	400	>140	450	450	96	------	------	4.47
261	335	A_0	2-0	24	350	>117	265	370	53	------	------	1.60
834	336	A_1	0-4	12	750	200	200	350	5	350	500	3.0
835	337	AC	4-9	20	850	350	350	350	20	750	750	3.0
836	338	C	9-12	26	850	350	500	200	20	500	500	4.0
1103	339	DSh	12-20	160	1,400	1,500	1,000	50	75	500	150	4.0
1104	340	DSh	20-27	120	1,400	3,500	1,000	50	100	750	75	6.0
1105	341	DSh	27-37	40	1,400	2,000	750	200	50	500	150	8.0
1106	342	DSh	37-43	60	700	2,000	1,000	350	50	750	100	14.0
54-5651	170	BR	>43	75	2,500	3,500	750	10	20	750	150	5.00
Profile at site 9												
55-617	97	C-O	*	3	20	46	50-100	200-500	50-100	350	350	0.5-1.0
262	343	A_{00}	1.5-0	24	380	>147	470	200	67	------	------	4.70
837	344	A_1	0-4	18	675	150	350	350	10	750	750	2.0
838	345	AC	4-12	20	675	200	500	350	20	750	750	1.0
839	346	C	12-21	40	550	200	750	100	35	750	500	5.0
1107	347	DSh	21-26	160	1,000	500	1,000	100	100	500	150	4.0
1108	348	DSh	26-32	100	1,000	750	1,500	150	100	750	200	4.0
1109	349	DSh	32-40	160	1,400	1,500	2,000	75	100	750	150	5.0
1110	350	DSh	40-47	160	1,700	2,000	1,500	100	150	750	100	5.0
1111	351	DSh	47-54	160	2,000	5,000	1,500	75	100	750	100	6.0
54-5656	175	BR	>54	150	2,500	5,000	1,500	75	100	3,500	150	7.5

TABLE 3.—*Phosphorus and minor-element content of samples of 22 complete profiles and one bedrock exposure near Montpelier, Idaho*—Continued

Sample				Constituent								
Lab. No.	Field No.	Type	Depth (inches)	Cu	Zn	V	Cr	Mn	Ni	Sr	Ba	P
PROFILES ABOVE PHOSPHORIA FORMATION—Continued												
Profile at site 10												
55-618	98	S-Y	*	------	------	36	20-50	200-500	20-50	1,500	200	1.0-2.0
619	99	S-O	*	4	80	100	100-200	1,000-2,000	20-50	1,500	1,500	0.5-1.0
263	352	A_0	1.5-0	19	440	89	200	520	52	------	------	1.12
840	353	A_{11}	0-4	15	600	75	150	350	10	350	750	.8
841	354	A_{12}	4-10	15	625	50	150	350	10	350	750	.8
842	355	AC	10-17	18	550	75	200	200	10	350	500	1.0
843	356	C	17-26	15	475	100	350	100	10	500	350	4.0
1112	357	DSh	26-33	60	700	350	1,000	75	75	350	150	3.0
1113	358	DSh	33-40	120	500	350	2,000	20	75	750	150	4.0
1114	359	DSh	40-46	70	700	150	750	50	50	500	150	4.0
1115	360	DSh	46-54	100	700	150	1,000	50	100	350	150	6.0
1116	361	DSh	54-60	160	1,000	500	1,500	50	150	500	150	8.0
54-5662	181	BR	>60	75	1,500	1,500	750	1,000	350	750	750	.85
Profile at site 11												
55-620	100	S-Y	*	3	30	64	50-100	200-500	50-100	1,000	150	1.0-2.0
621	101	S-O	*	5	50	110	100-200	2,000-5,000	20-50	750	1,000	1.0-2.0
264	362	A_{00}	3-1.5	12	120	36	55	130	13	------	------	.28
265	363	A_0	1.5-0	16	280	49	98	343	34	------	------	.74
844	364	A_1	0-5	15	550	50	100	350	5	350	750	.5
845	365	AC	5-13	8	450	50	100	200	<5	200	750	.3
846	366	C	13-19	8	300	200	200	100	20	350	500	2.0
1117	367	DSh	19-25	80	700	1,000	2,000	50	100	750	200	8.0
1118	368	DSh	25-33	80	1,000	200	1,000	200	75	500	150	3.0
1119	369	DSh	33-42	50	700	150	500	200	75	500	200	1.0
1120	370	DSh	42-48	100	500	500	1,000	35	75	200	150	3.0
1121	371	DSh	48-55	50	500	350	1,000	50	100	350	150	4.0
54-5667	186	BR	>55	75	1,500	750	1,000	1,000	350	750	750	.85
Profile at site 12												
55-622	102	C-Y	*	2	36	60	20-50	200-500	100-200	750	150	1.0-2.0
623	103	C-O	*	1	15	39	20-50	200-500	50-100	2,000	350	1.0-2.0
624	104	P-Y	*	5	34	70	50-100	200-500	50-100	1,500	150	2.0-4.0
625	105	P-O	*	3	50	68	50-100	200-500	20-50	1,500	350	.5-1.0
266	372	A_{00}	4-2	26	390	>99	225	320	45	------	------	1.36
267	373	A_0	2-0	22	360	60	150	740	35	------	------	.74
847	374	A_{11}	0-7	10	500	50	150	200	5	350	750	.5
848	375	A_{12}	7-13	10	475	75	150	350	20	500	750	.4
849	376	AC	13-19	10	300	100	150	200	20	350	750	.5
850	377	C	19-29	10	200	75	100	200	10	200	750	.2
1122	378	DSh	29-36	60	700	200	750	50	50	350	150	6.0
1123	379	DSh	36-39	100	1,400	350	1,000	200	100	500	150	5.0
1124	380	DSh	39-42	70	700	350	1,000	100	50	500	200	3.0
1125	381	DSh	42-45	20	700	350	500	500	100	500	350	1.0
1126	382	DSh	45-48	120	500	350	1,000	100	50	750	200	5.0
1127	383	DSh	48-53	40	500	350	500	50	75	350	350	.6
1128	384	DSh	53-58	80	300	350	1,000	20	35	350	150	4.0
1129	385	DSh	58-61	100	700	350	1,000	50	75	200	150	3.0
54-5675	194	BR	>61	150	500	750	2,000	20	100	750	350	3.75

TABLE 3.—*Phosphorus and minor-element content of samples of 22 complete profiles and one bedrock exposure near Montpelier, Idaho*—Continued

Sample				Constituent								
Lab. No.	Field No.	Type	Depth (inches)	Cu	Zn	V	Cr	Mn	Ni	Sr	Ba	P
PROFILES ABOVE PHOSPHORIA FORMATION—Continued												
Profile at site 13												
55-626...	106	S-Y	*	3	15	31	10-20	200-500	20-50	1,000	75	1.0-2.0
628...	108	P-Y	*	------	------	50	50-100	500-1,000	20-50	1,500	200	1.0-2.0
629...	109	P-O	*	5	56	64	50-100	200-500	20-50	2,000	350	0.5-1.0
268...	386	A_{00}	3-1	22	380	>70	160	480	32	------	------	1.0
269...	387	A_0	1-0	23	400	56	170	850	40	------	------	.8
851...	388	A_{11}	0-7	15	600	100	350	350	20	500	750	1.0
852...	389	A_{12}	7-14	15	525	100	350	350	35	350	750	.8
853...	390	AC	14-20	8	225	75	100	350	10	200	500	.3
854...	391	C	20-32	10	125	100	150	350	20	200	750	.2
1130..	392	DSh	32-41	80	500	1,000	750	75	50	500	150	9.0
1131..	393	DSh	41-44	80	1,000	200	750	50	50	350	200	4.0
1132..	394	DSh	44-47	80	1,200	200	750	200	150	350	200	2.0
1133..	395	DSh	47-49	30	700	200	350	500	100	500	350	2.0
1134..	396	DSh	49-52	120	500	750	2,000	200	50	750	200	6.0
1135..	397	DSh	52-61	80	800	350	1,000	75	75	500	500	1.0
54-5680..	199	BR	>61	100	400	500	750	15	75	750	500	.60
Profile at site 14												
55-630...	110	C-Y	*	1	24	26	20-50	500-1,000	50-100	1,500	150	1.0-2.0
631...	111	C-O	*	<1	11	26	20-50	200-500	20-50	3,500	500	0.5-1.0
632...	112	P-Y	*	------	------	46	50-100	500-1,000	20-50	1,500	350	2.0-5.0
633...	113	P-O	*	3	70	81	50-100	500-1,000	20-50	2,000	500	1.0-2.0
270...	398	A_{00}	4-2.5	24	290	>100	230	320	46	------	------	1.4
271...	399	A_0	2.5-0	19	180	29	120	585	39	------	------	.6
855...	400	A_{11}	0-6	15	550	200	350	500	20	350	500	1.0
856...	401	A_{12}	6-12	75	600	500	1,000	50	100	1,000	200	5.0
857...	402	AC	12-16	20	525	350	350	350	20	350	750	2.0
858...	403	C	16-24	22	550	350	350	350	20	350	500	2.0
1136..	404	DSh	24-34	40	700	350	750	200	50	500	350	3.0
1137..	405	DSh	34-42	60	700	200	500	200	50	350	350	2.0
1138..	406	DSh	42-51	60	1,000	350	750	100	75	500	500	1.0
1139..	407	DSh	51-54	30	800	500	750	500	150	350	350	.6
1140..	408	DSh	54-59	160	700	500	1,500	50	75	750	150	6.0
54-5691..	210	BR	>59	150	750	750	1,500	100	150	3,500	150	7.50
Profile at site 15												
55-634...	114	S-Y	*	18	55	13	10-20	200-500	20-50	1,500	350	1.0-2.0
635...	115	S-O	*	3	38	78	50-100	1,000-2,000	20-50	1,500	1,500	0.5-1.0
636...	116	P-Y	*	<1	50	49	20-50	500-1,000	20-50	1,500	350	1.0-2.0
637...	117	P-O	*	4	50	67	50-100	200-500	10-20	1,500	750	1.0-2.0
272...	409	A_{00}	3-1.5	20	200	>62	83	190	28	------	------	.8
273...	410	A_0	1.5-0	19	150	32	64	220	22	------	------	.5
859...	411	A_{11}	0-6	15	525	150	200	500	5	200	500	.8
860...	412	A_{12}	6-13	18	525	150	200	350	20	200	500	.6
861...	413	AC	13-20	20	450	150	350	350	50	200	500	.8
862...	414	C	20-29	40	500	350	500	200	75	500	500	2.0
1141..	415	DSh	29-35	50	800	200	1,000	200	150	500	200	1.0
1142..	416	DSh	35-42	200	800	500	3,500	200	150	750	350	3.0
1143..	417	DSh	42-47	70	800	200	2,000	75	100	500	200	4.0
54-5700..	219	BR	>47	150	300	500	1,500	50	50	500	350	2.00

TABLE 3.—*Phosphorus and minor-element content of samples of 22 complete profiles and one bedrock exposure near Montpelier, Idaho*—Continued

Sample				Constituent								
Lab. No.	Field No.	Type	Depth (inches)	Cu	Zn	V	Cr	Mn	Ni	Sr	Ba	P
PROFILES ABOVE PHOSPHORIA FORMATION—Continued												
Profile at site 16												
55-638	118	S-Y	*	6	42	21	10-20	200-500	20-50	1,500	350	1.0-2.0
639	119	S-O	*	2	36	72	50-100	500-1,000	10-20	1,500	1,500	1.0-2.0
274	418	A_{00}	3.5-2.5	22	300	>81	185	260	55	------	------	1.0
275	419	A_0	2.5-0	17	320	77	64	450	32	------	------	1.0
863	420	A_{11}	0-6	12	500	100	75	350	5	200	500	.6
864	421	A_{12}	6-12	10	425	200	100	350	20	200	750	.5
865	422	AC	12-16	10	425	100	75	350	35	150	500	.4
866	423	C	16-25	12	300	200	75	200	35	200	500	.4
1144	424	DSh	25-30	30	500	1,000	500	200	50	500	500	5.0
1145	425	DSh	30-38	70	800	750	1,000	100	75	500	200	6.0
1146	426	DSh	38-45	120	800	500	1,500	50	75	750	200	6.0
1147	427	DSh	45-53	60	1,200	350	1,000	100	100	500	350	2.0
1148	428	DSh	53-58	60	1,600	200	750	500	100	350	150	2.0
1149	429	DSh	58-64	200	2,000	200	1,000	500	150	750	200	8.0
54-5707	226	BR	>64	100	2,500	500	1,500	500	350	750	350	2.00
Profile at site 17												
55-640	120	P-Y	*	------	40	27	10-20	500-1,000	10-20	1,000	200	1.0-2.0
641	121	P-O	*	2	50	72	50-100	200-500	20-50	3,500	750	0.5-1.0
276	430	A_{00}	3-1.5	17	120	>62	105	150	21	------	------	.6
277	431	A_0	1.5-0	20	210	45	62	620	30	------	------	.6
867	432	A_{11}	0-6	10	400	200	75	75	8	350	500	1.0
868	433	A_{12}	6-12	8	400	200	75	500	10	200	500	.5
869	434	AC	12-16	10	275	150	50	350	5	150	500	.3
870	435	C	16-31	8	425	150	75	350	15	100	150	.5
1150	436	DSh	31-41	70	1,400	1,500	1,000	75	75	500	150	8.0
1151	437	DSh	41-46	200	800	1,000	1,500	20	50	750	150	5.0
1152	438	DSh	46-50	70	800	350	1,000	20	50	500	150	6.0
1153	439	DSh	50-55	50	1,000	350	1,000	50	75	500	200	2.0
1154	440	DSh	55-61	80	1,200	1,000	1,000	50	150	350	200	1.0
54-5710	229	BR	>61	75	750	150	350	100	100	150	50	.25
Profile at site 18												
55-642	122	S-Y	*	------	32	11	Trace	200-500	10-20	1,000	350	1.0-2.0
643	123	S-O	*	3	38	99	50-110	1,000-2,000	20-50	1,500	1,500	1.0-2.0
278	441	A_{00}	3-1.5	9	110	>35	80	100	16	------	------	.5
279	442	A_0	1.5-0	14	120	28	42	200	20	------	------	.4
871	443	A_{11}	0-7	8	375	100	35	350	<5	200	500	.5
872	444	A_{12}	7-13	10	300	100	35	200	<5	150	500	.5
873	445	AC	13-18	10	250	100	75	200	10	150	500	.4
874	446	C	18-35	10	550	200	75	150	20	100	200	1.5
1155	447	DSh	35-44	60	1,200	2,000	750	150	75	500	100	6.0
1156	448	DSh	44-50	80	1,000	1,500	1,000	100	100	350	100	6.0
1157	449	DSh	50-54	200	500	1,000	1,500	20	35	750	100	6.0
1158	450	DSh	54-60	70	700	500	500	35	35	750	200	4.0
1159	451	DSh	60-64	60	700	350	1,000	75	75	500	200	3.0
1160	452	DSh	64-69	70	700	200	1,000	35	35	500	200	3.0
54-5717	236	BR	>69	100	400	350	750	10	75	350	500	.75

TABLE 3.—*Phosphorus and minor-element content of samples of 22 complete profiles and one bedrock exposure near Montpelier, Idaho*—Continued

Sample				Constituent								
Lab. No.	Field No.	Type	Depth (inches)	Cu	Zn	V	Cr	Mn	Ni	Sr	Ba	P
PROFILES ABOVE PHOSPHORIA FORMATION—Continued												
Profile at site 19												
55-644	124	C-Y	*	2	22	21	10-20	200-500	20-50	750	150	1.0-2.0
645	125	C-O	*	1	8	22	20-50	200-500	10-20	1,500	350	1.0-2.0
280	453	A_{00}	4.5-2	11	110	37	44	160	16	------	------	.7
281	454	A_0	2-0	8	100	28	20	60	10	------	------	.1
875	455	A_{11}	0-7	8	300	75	50	500	<5	150	500	1.0
876	456	A_{12}	7-13	8	300	50	35	200	10	200	750	.2
877	457	AC	13-18	8	150	50	35	150	10	100	500	.2
878	458	C_1	18-30	8	125	50	35	200	5	100	500	.1
879	459	C_2	30-50	10	550	75	75	150	15	50	150	.4
1161	460	DSh	50-57	70	1,000	1,500	750	200	100	350	75	6.0
1162	461	DSh	57-63	60	1,000	1,500	750	20	35	500	100	5.0
1163	462	DSh	63-71	60	1,000	500	500	100	50	500	75	4.0
1164	463	DSh	71-79	250	700	1,000	2,000	10	50	750	75	6.0
1165	464	DSh	79-90	100	1,400	350	1,500	20	150	500	100	6.0
1166	465	DSh	90-100	60	800	350	1,000	10	50	500	150	3.0
54-5714	233	BR	>100	150	2,000	1,500	1,500	3,500	750	750	750	3.00
Profile at site 20												
55-646	126	S-Y	*	6	42	13	Trace	500-1,000	10-20	1,000	350	1.0-2.0
647	127	S-O	*	5	50	86	50-100	1,000-2,000	10-20	1,000	1,500	0.5-1.0
282	466	A_{00}	2-1.5	11	87	>57	40	180	18	------	------	.8
283	467	A_0	1.5-0	13	240	87	58	410	18	------	------	.9
880	468	A_{11}	0-6	8	375	75	75	200	<5	350	750	.5
881	469	A_{12}	6-11	10	275	50	50	200	<5	200	500	.5
882	470	AC	11-18	8	325	100	75	200	5	200	750	.4
883	471	C_1	18-29	10	475	100	100	200	20	75	200	.2
884	472	C_2	29-51	10	375	75	75	150	15	75	75	.5
1167	473	DSh	51-58	60	800	1,000	750	350	150	500	100	7.0
1168	474	DSh	58-64	60	1,200	1,500	750	100	75	500	100	6.0
1169	475	DSh	64-73	80	1,200	1,000	750	50	75	500	100	6.0
1170	476	DSh	73-80	60	1,400	2,000	1,500	75	150	500	150	6.0
54-5720	239	BR	>80	35	200	350	350	10	50	350	500	.40
Profile at site 21												
55-648	128	P-Y	*	4	30	18	20-50	200-500	10-20	1.000	350	2.0-5.0
649	129	P-O	*	4	50	42	20-50	500-1,000	10-20	1,500	750	1.0-2.0
284	477	A_{00}	3-1	13	160	>62	56	190	19	------	------	.8
285	478	A_0	1-0	16	140	72	40	280	20	------	------	.6
885	479	A_{11}	0-6	10	325	100	150	350	5	350	750	1.0
886	480	A_{12}	6-12	10	350	100	100	200	5	150	350	1.0
887	481	C_1	12-23	10	150	75	100	200	20	100	500	.2
888	482	C_2	23-43	12	600	75	150	200	20	50	100	.4
1171	483	DSh	43-49	60	800	2,000	1,000	750	100	750	150	16.0
1172	484	DSh	49-56	60	800	750	1,500	750	150	750	150	6.0
1173	485	DSh	56-63	100	1,400	1,500	1,000	100	100	500	150	6.0
1174	486	DSh	63-68	70	1,200	1,500	1,000	35	75	750	150	6.0
1175	487	DSh	68-74	80	1,400	2,000	500	50	20	500	100	7.0
54-5736	255	BR	>74	100	750	1,000	750	15	50	500	75	7.50
Profile at site 22												
55-650	130	S-Y	*	<1	24	<10	0	200-500	5-10	750	350	1.0-2.0
651	131	S-O	*	4	48	59	20-50	5,000-10,000	10-20	1,500	2,000	1.0-2.0
286	496	A_{00}	1-0.5	13	140	28	19	280	13	------	------	.3
287	497	A_0	0.5-0	14	240	45	40	400	31	------	------	.4
889	488	A_{11}	0-5	15	300	75	100	350	15	200	350	.2
890	489	A_{12}	5-10	10	250	50	75	350	10	200	350	.3
891	490	AC	10-16	8	325	50	75	350	<5	150	200	.2
892	491	C_1	16-26	8	375	50	50	350	5	150	200	.3
893	492	C_2	26-37	8	275	75	100	500	10	150	350	.2
894	493	C_3	37-56	10	675	100	200	150	20	50	150	2.0
895	494	C_4	56-74	26	1,300	100	350	150	50	75	150	1.5
1176	495	B-R	>84	70	800	2,000	500	20	20	750	75	18.0

TABLE 3.—*Phosphorus and minor-element content of samples of 22 complete profiles and one bedrock exposure near Montpelier, Idaho*—Continued

Sample				Constituent								
Lab. No.	Field No.	Type	Depth (inches)	Cu	Zn	V	Cr	Mn	Ni	Sr	Ba	P
PROFILES ABOVE PARK CITY FORMATION												
Profile at site 23												
55-652	132	S-Y	*	5	20	<10	20-50	200-500	10-20	750	200	1.0-2.0
653	133	S-O	*	4	24	39	20-50	5,000-10,000	10-20	1,500	1,500	1.0-2.0
288	498	A_{00}	4-3	12	75	5	8	180	4	------	------	.1
289	499	A_0	3-0	19	110	16	16	350	12	------	------	.2
896	500	A_1	0-8	10	300	50	75	350	<5	350	750	.2
897	501	AC	8-15	10	300	100	150	350	50	200	500	.3
898	502	C_1	15-25	8	250	50	75	350	5	200	500	.2
899	503	C_2	25-38	8	325	75	150	200	35	100	200	.5
900	504	C_3	38-55	8	300	75	100	150	<5	150	150	.5
901	505	C_4	55-69	10	850	50	350	100	50	100	200	1.0
Profile at site 24												
55-654	134	S-Y	*	6	24	<10	10-20	200-500	10-20	750	350	1.0-2.0
655	135	S-O	*	2	38	29	20-50	2,000-5,000	10-20	750	1,500	1.0-2.0
290	506	A_{00}	4-3	13	65	10	10	320	6	------	------	.2
291	507	A_0	3-0	13	85	19	14	200	8	------	------	.1
902	508	A_1	0-8	8	300	35	35	200	<5	100	500	.1
903	509	AC	8-15	10	300	75	75	350	10	75	500	.1
904	510	C_1	15-25	10	300	50	50	350	10	100	500	.1
905	511	C_2	25-40	8	375	100	100	200	15	75	200	.3
Profile at site 27												
55-769	569	P	*	6	40	32	20-50	500-1,000	10-20	1,500	750	0.5-1.0
728	570	C	*	2	4	23	10-20	200-500	5-10	1,500	500	0.5-1.0
3973	729	A_{00}	3-0	18	100	35	5	350	<5	200	350	Tr.
3974	730	A_1	0-6	14	140	75	35	500	20	500	750	.01
3975	731	AC	6-15	9	100	50	35	75	10	150	500	.025
3976	732	C_1	15-23	10	140	50	35	50	20	150	500	.025
3977	733	C_2	23-32	16	120	50	35	50	20	50	350	.005
3978	734	C_3	32-43	15	150	35	35	50	50	50	200	.005
3979	735	C_4	43-54	10	300	100	50	350	75	50	150	.025
BEDROCK FROM EXPOSED PARK CITY FORMATION												
61-4101	785	BR	0	10	350	100	70	50	20	100	10	0.45

COLLUVIALLY DRAGGED LAYERS OF SHALE

Methods used for analyzing samples from layers of colluvially dragged shale are the same as those used for analysis of samples of shale in place. An individual layer of the dragged shale could commonly be identified with the bed from which it was mainly derived, although some samples contained rock fragments from as many as three beds.

Layers of bedrock having a high vanadium content retain a high concentration of vanadium as dragged layers, except when there has been significant dilution with material of low vanadium content.

Dragged layers containing abundant chromium are derived from shale beds that are high in chromium, but the chromium concentration in some dragged layers that can be traced are greater than the contents of equivalent bedrock in place. For example, two samples from site 15 that contain 3, 500 and 2, 000 ppm chromium, respectively, are derived from beds containing 2,000 and 1,500 ppm chromium.

Zinc is more evenly distributed through the dragged layers than the other elements and ranges from 500 to 2, 000 ppm. In general, dragged layers contain less zinc than the beds from which they are derived. Nonetheless the dragged layers that contain the most zinc are derived from the shale beds of highest zinc content.

Strontium in dragged layers is less than that in the source beds. In a single sample of the dragged shale, this element has a value of 1,000 ppm; otherwise, its range is from 100 to 750 ppm. In bedrock, strontium content is as high as 3,500 ppm.

The maximum barium content in dragged layers is 500 ppm, which is the content of four samples, whereas the maximum in bedrock samples is 750 ppm. The decrease in the barium content of dragged layers—perceptible, but not so pronounced as that of strontium—indicates that barium compounds are commonly less soluble than those of strontium. Dragged layers high in barium, however, are derived from layers of bedrock that are high in barium.

The relation of phosphorus content of bedrock to that of dragged layers requires consideration of the data in table 2 as well as study of values in table 3, which alone might be misleading. In table 3, only one phosphorus value above 7.5 percent is shown for bedrock as compared to 17 values above 7.5 percent phosphorus in the dragged layers. Actually the phosphorus content of the dragged layers is lower than that of their respective beds in place, when analyses of equivalent beds are compared.

Thin beds relatively rich in copper retain their copper content as dragged layers for tens of feet downhill. Sample 463, which was taken at site 19 from a layer 30 to 40 feet downslope from the bed from which it was derived, contains 250 ppm copper, the maximum among samples of dragged layers of shale. Vertical migration of copper seems to have been insignificant, because although dragged layers are only 4 to 6 inches thick, samples from material both above and below these dragged layers contain less copper. Although table 3 shows a maximum copper content of only 150 ppm in the bedrock samples included, table 2 shows that the greatest concentration of copper is 500 ppm, found in one sample of weathered bedrock that is also high in organic matter (11 percent carbon) and rather high in phosphate.

What happens to nickel during weathering is not clear. Several dragged layers derived from beds in the lower part of the shale section have a higher nickel content than that of beds in place, whereas others have a nickel content that is much lower than that of the beds in place.

Maximum manganese content in dragged layers is considerably less than that in bedrock. The two highest values for manganese in the dragged layers are 750 and 500 ppm as compared to 3,500 and 1,000 ppm in the bedrock.

SOIL

The pH of soil was determined on a soil-water paste of each sample by use of a Beckman pH meter having a glass electrode. Particle size distribution was estimated by the method of Kilmer and Alexander (1949). To obtain an estimate of the organic content of each sample, a split from each was oven-dried and weighed. After the split was treated with 30 percent H_2O_2, it was weighed again. From the difference in the weights, the approximate weight of organic matter included in the sample was computed. Soil samples were prepared for analytical study by being air dried, disaggregated, and screened through a sieve having a 2-mm mesh. No attempt was made to crush rock particles, and all material that stayed on the sieve was discarded.

The samples were analyzed for phosphorus by the chemical semiquantitative field method used in analysis of the shale samples. Vanadium content also was determined by use of a rapid chemical semiquantitative field method. Copper content of soil samples was determined by use of the biquinoline analytical method described by Almond (1955), and zinc content was determined by use of a modification of the dithizone analytical method described by Holmes (1945). The samples were analyzed semiquantitatively also by means of the truck-mounted spectrograph.

The pH ranges from 4.6, in the A horizon of profile 19, to 7.7, in the horizons of profile 23. Free carbonates are not present. Overall acidity is greatest in the horizons that have the most organic matter, the pH ranging from 4.6 to 6.2; in the mineral soil the range is from 6.0 to 7.7.

The relative amount and distribution of sand (2–0.05 mm), silt (0.05–0.002 mm), and clay ($<$ 0.002 mm) within a soil profile gives information on soil-forming processes and on the sources from which the soil is derived. The great amount of sand in all profiles studied (40–60 percent) is believed to indicate that the soil has been derived from the sandy Grandeur Tongue of the Park City Formation.

The vertical distribution of clay is similar in all profiles. The general range in the clay content of the soils is from 10 to 15 percent, although the C horizon of profile 4 contains 20 percent, and a few profiles have horizons that contain only 7–8 percent of clay. Such small variations in clay content within the profiles suggest that there has been little or no eluviation of clay by soil-forming processes and that the variations observed may be ascribed to mixing during colluvial movement of the parent material of the soil.

Organic matter is most abundant in horizons near the surface; in the soils studied, the organic content decreases rapidly with depth. Samples from profile 1 contain the most organic matter—as much as 4.3 percent at the surface; samples from all other profiles average from 1.5 to 2 percent.

The generalized description in table 1 is representative, with minor variations, of all the soil profiles examined. Thicknesses of soil in individual profiles range from 12 to 74 inches. The C horizons of some profiles contain rock fragments of considerable size; others contain few or none. There is little or no difference in color between soil horizons over the Phosphoria Formation and corresponding soil horizons above the Park City.

Vanadium content of soil sampled ranges from 5 to 750 ppm. Inspection of table 3 demonstrates that the vanadium content of soil developed over the Park City Formation (profiles at sites 23, 24, 27) is markedly lower than that of soil developed over the phosphatic shales. The higher vanadium content of the soil over the shale units almost certainly reflects movement of vanadium from the shale into the soil. It is interesting to note that vanadium seems to be in generally lower concentrations in thick soil.

The relative distribution of chromium in soil is similar to that of vanadium. Thus the chromium content of soil over the Park City Formation (35–350 ppm) is less than that of soil over the shales (35–1,000 ppm). Chromium content, like vanadium content, tends to be less in thick profiles.

Zinc content of soil ranges from 125 to 1,300 ppm over the Phosphoria and from 65 to 850 ppm over the Park City Formation.

The barium content of soil ranges from 75 to 750 ppm and is about the same in soil over the phosphatic shale beds as in soil over the Park City Formation. The barium in the soil, therefore, is probably derived directly from the barium in the colluvium.

Strontium content of soil samples ranges from 50 to 1,000 ppm, but samples from most profiles contain between 100 and 400 ppm. Strontium content is nearly as high in soil overlying the Park City Formation as in soil overlying the phosphatic shales.

Phosphorus is the only element under discussion commonly considered of major importance in plant nutrition. In comparison with the underlying dragged shale layers, the soil is generally low in phosphorus content. Samples from the soil profiles overlying the shales are higher in phosphorus, however, than are normal agricultural soils, whose phosphorus content seldom exceeds 0.1 percent by weight. Samples from several soil profiles overlying the shales contain as much as 5.0 percent phosphorus (profiles 1, 9, and 14), although the average for all profiles is much lower. Phosphorus content of soil samples varies greatly but seems to be less in samples from profiles over the Park City Formation, ranging from 0.005 to 1.0 percent in profiles 23, 24, and 27. The soil overlying the phosphatic shales has probably been enriched in phosphorus.

Copper content of the soil is low, ranging from 8 to 75 ppm; most samples contain less than 30 ppm. There seems to be no relation between the copper content of the dragged phosphate layers and the overlying soil. Soil overlying the Park City contains nearly as much copper as that overlying the Phosphoria, even though the shale units contain much more copper than does the carbonate rock that is the parent material of the soil.

Nickel in the soil is similar to copper in content and distribution. Like copper, there is no appreciable difference between the nickel content of soil overlying the Park City and that of soil overlying the Phosphoria.

Manganese content of the soil is rather high, especially in the upper soil horizons—that is, in the A_{00}, A_0, and A horizons. Over both the Phosphoria and the Park City Formations, the upper soil horizons not only contain more manganese on the average than either the AC or the C soil horizons, but they are very similar in manganese content to most of the lithologic units of the phosphatic shale (pl. 1). The manganese content of the soil overlying the Park City Formation differs very little from that of most of the profiles over the phosphatic shales.

VEGETATION

Three shrub species were chosen for study: *Symphoricarpos* (snowberry), *Ceanothus* (snowbrush), and *Pachistima* (mountain lover). Of these three, as many species were sampled as were growing at each site where profile samples were taken. At seven sites only two of the species were present, at 15 sites only one was present. Two samples were collected from each shrub; one was of new growth and the other of older growth.

Three species of conifer—the Douglas-fir, subalpine fir, and Engelmann's spruce—were also sampled, as well as one deciduous tree—

the willow. Samples were collected from the north, south, east, and west sides of every tree. The new growth (branch tips) of each conifer sample was segregated from the older growth, the twigs and leaves were separated, and all sample material was air dried.

At site 21, a Douglas-fir was sampled on the north, south, east, and west, both near ground level and about 10 feet above the ground; the different types of material were separated as described in the previous paragraph. Four samples of cones were also taken, and a sample of branch wood was collected at each height on each side. Forty-four samples in all were collected from this single tree.

After the air-dried vegetation was digested by means of a perchloric-nitric acid mixture, quantitative determinations for copper and zinc were made on all samples. Vanadium content of the plant samples was measured by a quantitative spectrographic method. Semiquantitative spectrographic methods were used to estimate other elements. All plant material analyzed spectrographically was ashed before analysis.

MINOR ELEMENTS IN SHRUBS

Table 4 summarizes minor-element content both of shrubs growing over the Phosphoria Formation and of shrubs growing over the Park City Formation. The data show that there are marked differences in the minor-element content of samples, not only from different plant species but also from tissues of different age from a single specimen.

SNOWBERRY

Snowberry bushes growing over the Phosphoria Formation contain more vanadium, chromium, zinc, and nickel than those growing over the Park City Formation. The snowberry growing over the Park City, however, contains more barium; in the old tissue, it contains more manganese. The average values of strontium in samples of snowberry growing over the Phosphoria Formation are about the same as those in samples of this plant growing over the Park City. Copper content seems slightly higher in snowberry above the Phosphoria Formation, but the content is so low that differences may not be significant.

Young tissue of snowberry contains more nickel—but less zinc, vanadium, chromium, manganese, strontium, and barium—than older tissue contains. Phosphorus content of young tissue is higher than that of old tissue of snowberry plants growing over the Phosphoria Formation, but phosphorus content of old and young tissue is the same in plants of the same species above the Park City. Above both formations, the young tissue of snowberry contains slightly more copper than the old tissue.

TABLE 4.—*Summary of minor-element content of shrubs*

[All analyses are in parts per million except phosphorus, which is in percent. Copper and zinc in the air-dried plant material were determined quantitatively by F. B. Lotspeich, Charles Thompson, and Harry Nakagawa. Other analyses are spectrographic determinations made on plant ash by George Boyes. Vanadium is by quantitative and all other elements are by semiquantitative spectrographic analyses]

Formation under shrub	Material (tissue)	Content	Cu	Zn	V	Cr	Mn	Ni	Sr	Ba	P
					***Symphoricarpos* (snowberry)**						
Phosphoria	Young	Max	18	55	80	100	1,000	100	1,500	350	4.0
		Min	2	20	11	Trace	100	10	750	75	1.0
		Avg	6	34	26	------	------	------	1,100	270	------
	Old	Max	6	80	110	200	5,000	50	1,500	2,000	2.0
		Min	2	36	50	50	500	10	750	1,000	0.5
		Avg	4	58	90	------	------	------	1,250	1,280	------
Park City	Young	Max	6	24	<10	50	500	20	750	350	2.0
		Min	1	20	<10	0	200	5	750	200	1.0
		Avg	4	23	<10	------	------	------	750	300	------
	Old	Max	4	48	59	50	10,000	20	1,500	2,000	2.0
		Min	2	24	29	20	2,000	10	750	1,500	1.0
		Avg	3	38	42	------	------	------	1,250	1,670	------
					***Ceanothus* (snowbrush)**						
Phosphoria	Young	Max	3	36	60	100	1,000	200	1,500	150	2.0
		Min	1	22	21	10	200	20	750	100	1.0
		Avg	2	29	45	------	------	------	1,000	140	------
	Old	Max	3	20	46	100	500	100	3,500	500	2.0
		Min	1	8	22	20	200	10	350	200	0.5
		Avg	1.3	14	37	------	------	------	2,300	350	------
Park City	------	------	2	4	23	15	350	7	1,500	500	0.7
					***Pachistima* (mountain lover)**						
Phosphoria	Young	Max	5	50	70	100	1,000	100	1,500	350	5.0
		Min	<1	30	18	10	100	10	750	75	1.0
		Avg	3	38	41	------	------	------	1,270	240	------
	Old	Max	5	90	81	100	1,000	50	3,500	750	2.0
		Min	2	50	42	20	100	10	1,500	200	0.5
		Avg	3	60	64	------	------	------	1,930	520	------
Park City	------	------	6	40	32	35	750	15	1,500	750	0.7

SNOWBRUSH

Snowbrush shrubs growing over the Phosphoria Formation contain more zinc, vanadium, chromium, nickel, and phosphorus than those growing over the Park City; barium is higher in these plants above the Park City. There is no significant difference in content of either manganese or copper between snowbrush growing over the Phosphoria and snowbrush over the Park City.

Differences between metal content of young tissue and of old tissue of snowbrush are not as marked as those of snowberry. Only small differences in vanadium, chromium, manganese, nickel, and phosphorus content exist between young and old tissue. In young tissue of snowbrush, however, the zinc content is definitely higher and the strontium content lower than that in old tissue. There seems to be no significant variation in copper content.

MOUNTAIN LOVER

Young tissue of the shrub mountain lover contains more manganese, nickel, and phosphorus than old tissue. Old tissue, however, contains more zinc, vanadium, chromium, strontium, and barium. Young and old tissue contain about the same amount of copper.

Old tissue from mountain lover growing over the Phosphoria Formation contains more vanadium, chromium, zinc, nickel, and phosphorus but less manganese and barium than that from mountain lover growing over the Park City Formation. In samples of mountain lover, copper concentrations are too low to permit definite conclusions. There seems to be no consistent pattern of distribution of strontium.

MINOR ELEMENTS IN TREES

Table 5 presents data showing the minor-element content of leaves (or needles) and twigs taken from four species of trees, some of which were sampled over the Phosphoria Formation and some over the Park City Formation. For this table, analytical results on young and old tissue of leaves or twigs have been averaged for each species for purposes of comparison of concentrations in these tissues over the two formations.

To learn whether significant differences in metal content exist between the same plant tissue of different ages and in different places on a single tree, 44 samples from a Douglas-fir at site 21 (fig. 4) were collected and analyzed. The results (table 6) show that some of these differences are considerable.

DOUGLAS-FIR

Both needles and twigs of Douglas-fir growing over the phosphatic shales contain considerably more strontium and slightly more vanadium than needles and twigs of Douglas-fir growing over the Park City Formation. Zinc, barium, and manganese are higher in both needles and twigs of the Douglas-fir growing over the Park City Formation. Chromium, phosphorus, copper, and nickel content of both needles and twigs are nearly the same in samples from trees over both formations. The data in table 5 show that in Douglas-fir trees vanadium and barium tend to be more highly concentrated in twigs and that manganese is more highly concentrated in needles.

The data in table 6 show that among samples from the same Douglas-fir tree, not only does the content of a given element differ appreciably in needles and twigs, but the content similarly differs between old needles and young needles.

Vanadium concentration, for example, is greatest in cones and lowest in branch wood 10 feet above the ground. The second highest vanadium content is in young needles near the ground. Old twigs, however, contain more vanadium than either old needles or young twigs.

TABLE 5.—*Comparison of minor-element composition of leaves (or needles) and twigs from four species of trees growing over the Phosphoria Formation and Park City Formation*

[All analyses are in parts per million except phosphorus, which is in percent. Copper and zinc in the air-dried plant material were determined quantitatively by F. B. Lotspeich, Charles Thompson, and Harry Nakagawa. Other analyses are spectrographic determinations made on plant ash by George Boyes. Vanadium is by quantitative and all other elements are by semiquantitative spectrographic analyses]

Element	Douglas-fir				Subalpine fir				Engelmann's spruce				Willow	
	Phosphoria		Park City		Phosphoria		Park City		Phosphoria		Park City		Phos-phoria	Park City
	Leaves	Twigs	Leaves	Twigs	Leaves	Twigs	Leaves	Twigs	Leaves	Twigs	Leaves	Twigs		
Vanadium	31	48	14	43	22	48	12	29	33	116	13	52	16	40
Chromium	20–50	20–50	10–20	20–50	20–50	50–100	Tr.	10–20	10–20	100–200	10–20	20–50	10–20	Tr.
Zinc	36	37	53	41	68	51	55	26	108	76	44	62	145	81
Barium	1,380	1,620	1,880	2,120	3,880	6,200	3,380	3,000	3,000	6,200	2,220	3,500	550	420
Strontium	6,250	6,500	4,250	3,500	1,500	1,250	1,310	810	1,880	3,100	1,620	1,500	1,600	1,060
Phosphorus	.2–.5	.5–1.0	.2–.5	.5–1.0	.5–1.0	1.0–2.0	.2–.5	1.0–2.0	1.0–2.0	1.0–2.0	.2–.5	.2–.5	.5–1.0	.2–.5
Copper	2	4	3	4	2	4	4	5	2	4	1	4	3	4
Nickel	10–20	10–20	5–10	10–20	5–10	10–20	2–5	5–10	5–10	20–50	2–5	5–10	10–20	2–5
Manganese	1,000–2,000	500–1,000	2,000–5,000	1,000–2,000	1,000–2,000	1,000–2,000	2,000–5,000	1,000–2,000	2,000–5,000	2,000–5,000	2,000–5,000	1,000–2,000	200–500	200–500

TABLE 6.—*Minor-element composition of Douglas-fir tree at site 21*

[All elements expressed in parts per million except phosphorus, which is in percent. Copper and zinc were determined quantitatively in the air-dried plant material by F. B. Lotspeich, Charles Thompson, and Harry Nakagawa. Other analyses are spectrographic determinations made on plant ash by George Boyes. Vanadium is by quantitative and all other elements are by semiquantitative spectrographic analyses]

Element	Near ground				10 feet above ground				Branch wood		
	Young		Old		Young		Old		Near ground	10 feet above ground	Cones
	Leaves	Twigs	Leaves	Twigs	Leaves	Twigs	Leaves	Twigs			
Vanadium	71	39	37	51	45	42	34	43	20	14	112
Chromium	50–100	50–100	20–50	20–50	20–50	20–50	20–50	20–50	20–50	10–20	50–100
Zinc	32	56	33	62	30	44	24	48	22	12	8
Barium	1,300	1,440	1,120	1,500	1,000	750	1,060	1,310	1,320	1,620	500
Strontium	3,500	3,500	3,870	4,250	2,380	2,120	3,100	3,500	3,880	3,500	750
Phosphorus	2–4	2–4	1–2	1–2	1–2	1–2	1–2	1–2	2–4	0.5–1	2–4
Copper	4	13	5	6	4	7	2	4	4	2	3
Nickel	20–50	20–50	5–10	20–50	20–50	20–50	5–10	20–50	5–10	5–10	20–50
Manganese	500–1,000	200–500	1,000–2,000	500–1,000	1,000–2,000	500–1,000	1,000–2,000	500–1,000	200–500	200–500	200–500

Chromium is rather evenly distributed. The old leaves and twigs, the young leaves and twigs 10 feet above the ground, and the branches near the ground have about the same content; young leaves and twigs near the ground have a slightly higher chromium content, as do cones; branch wood 10 feet above the ground is slightly lower in chromium.

The zinc content of twigs is higher than that of leaves, and old twigs contain more zinc than young twigs. Samples at the 10-foot height contain less zinc than those at ground level. Both branch wood and cones are lower in zinc than either leaves or twigs. Distribution of copper is about the same as that of zinc.

Barium content is higher in twigs than it is in leaves, except for the young twigs sampled 10 feet above the ground. The highest barium content, however, is in branch wood at a height of 10 feet.

Old tissue contains more strontium than young tissue, and strontium content of all samples tends to be higher at ground level than at 10 feet above ground. Branch wood has about the same strontium content as twigs and leaves; cones contain the least amount of strontium.

Phosphorus content is higher in new tissue than in old tissue in samples from ground level, but in samples of new and old tissue from 10 feet above ground there is no difference in phosphorus content. Branch wood from ground level contains more phosphorus than a similar sample from 10 feet above ground. Cones contain as much phosphorus as young leaves and twigs.

Nickel content of young leaves is the same as that of young twigs; in older tissue, twigs contain more nickel than leaves, and cones contain as much nickel as twigs. The nickel content of branch wood is low.

Regardless of age of tissue or position of tissue on the tree, leaves contain about twice as much manganese as twigs. Branch wood and cones have about the same manganese content, nearly one-half the content of twigs.

SUBALPINE FIR

Analyses of vanadium, chromium, zinc, barium, strontium, and nickel are definitely lower in samples from subalpine fir trees growing over the Park City Formation than in samples from trees of the same kind growing over the Phosphoria, whereas copper content tends to be slightly higher in trees over the Park City. Phosphorus content of needles is about the same, whether the sample came from a tree over the Phosphoria or over the Park City, and phosphorus content of twigs is also the same in samples from trees over both formations. Manganese content of needles is higher in samples from trees over the Park City, but manganese content of twigs from trees over the Park City is the same as that of twigs from trees over the Phosphoria. In twigs, vanadium, chromium, and phosphorus concentrations are higher than in needles; zinc, barium, and strontium concentrations, however, are higher in needles than in twigs.

ENGELMANN'S SPRUCE

Samples from a spruce tree growing over the Phosphoria Formation contain more vanadium, zinc, barium, strontium, phosphorus, and nickel than samples from the same species of trees growing over the Park City Formation. Twigs contain more vanadium, chromium, barium, and nickel than needles. Results for the other elements show no significant variations.

WILLOW

In samples from a willow tree growing over the Phosphoria Formation, chromium, zinc, barium, strontium, phosphorus, and nickel contents were higher than in samples from a willow tree growing over the Park City Formation. Vanadium content, however, is higher in samples from the tree growing over the Park City. In copper content the difference between the trees is negligible. Samples from the willow growing over the Phosphoria Formation have the highest zinc content of all the vegetation samples analyzed for this study.

DISCUSSION AND SUMMARY OF DATA ON MINOR ELEMENTS

In considering the data amassed in this investigation, certain plant-substrate relations (Goldschmidt, 1954) should be kept in mind. Roots of plants extract from the substrate the elements that are then translocated to stems, leaves, flowers, and fruits; after these plant parts die, fall to the ground, and are decomposed, the elements enter and enrich the soil.

The soil at every profile-sampling site over the Phosphoria Formation, except site 22, is underlain by one or more colluvially dragged layers of phosphatic shale, and many of the plants sampled were rooted in these metal-rich dragged layers. Where the soil is less than 24 inches thick, the roots of the snowberry and mountain lover shrubs penetrate the dragged shale. Snowbrush, however, has a root system that in some places penetrates bedrock at depths of 8 to 10 feet. The roots of the trees also may extend considerable distances both vertically and laterally.

BARIUM

In the unweathered phosphatic shale beds of the Meade Peak Member of the Phosphoria Formation, barium probably has a random distribution in relation to phosphorus content, although plate 1 shows a possible rough inverse correlation of barium with both phosphorus and strontium. The highest barium contents are in layers having considerable muddy or silty constituents. Plate 1 shows a slight general increase of barium with increase of weathering in most of the rock units studied; the greatest increase is in the mudstone units, especially the marker bed of calcareous mudstone near the middle of the section. Barium content is lower in the colluvially dragged layers, however, than in bedrock.

Table 3 shows that the barium content of the weathered carbonate rock of the Park City Formation is much lower than that of the phosphatic shales of the Phosphoria Formation. Nevertheless, the barium content of the soil is about the same over the two formations. Inasmuch as the barium content of the soil is higher in the upper horizons than in the lower and the barium content of shrubs and soil seems not to be influenced by barium content of either underlying dragged shale layers or bedrock, it seems probable that the plants are obtaining barium from the colluvium and are concentrating it in the upper horizons of the soil.

CHROMIUM

The distribution of chromium in unweathered shale units is similar to that of nickel and zinc and to a certain extent to that of barium. The chromium content of the unweathered shale is greatest in argillaceous rocks having a phosphorus content of 2.5 to 6 percent. Plate 1 shows that most rock units, especially mudstone, have undergone chromium enrichment with weathering. The greatest increase in chromium content has taken place in a unit of argillaceous phosphate rock in the interval 116 to 121 feet from the chert; a notable, but exceptional, decrease with weathering has occurred in the highly calcareous mudstone marker bed near the middle of the section.

The maximum chromium content of the phosphatic shale beds is 2,000 ppm for bedrock and 3,500 ppm for dragged layers; the chromium content of dragged layers generally is slightly higher than that of bedrock (table 3). The chromium content of the carbonate rock in the Park City Formation is 70 ppm.

Chromium content of all soil horizons is noticeably higher for soils over the Phosphoria Formation than those over the Park City. The same is true of chromium content of plants.

COPPER

Distribution of copper in the unweathered shale is somewhat similar to that of chromium (except that the amounts are less) and very similar to that of nickel, except in the thin marker bed of calcareous mudstone mentioned previously. Most of the minimum copper values are for rocks having the lowest content of phosphorus, and most of the maximum values are for argillaceous rocks of high organic content but only moderately high phosphorus content—2.5 to 7.5 percent.

In most rock units the copper content of weathered rock equals or exceeds that of unweathered rock (pl. 1). In two units of phosphate rock, weathered rock contains less than unweathered rock, but the differences—25 and 50 ppm—seem negligible. Two weathered units of argillaceous phosphate rock show copper enrichment of 250 and 150 ppm respectively.

The copper content of weathered rock from the Park City Formation was measured as less than 10 ppm. The range of copper values in the weathered shales in place is 7 to 500 ppm as shown in table 2; table 3 shows only 15 to 150 ppm. The range of copper content in the dragged shales is 20 to 250 ppm; the maximum copper content is in a layer at site 19 that could be traced to where it is a bed in place 30 to 40 feet away.

The copper content of soil over the Phosphoria is low but is slightly more than that of soil over the Park City—a range of 8 to 75 ppm as compared to a range of 8 to 19 ppm. The range of copper content of shrubs over the Phosphoria is less than 1 to 18 ppm; that of shrubs over the Park City is 2 to 6 ppm.

MANGANESE

The range of manganese content for fresh bedrock of the Phosphoria Formation examined in this study is 10 to 500 ppm. In the distribution of elements in the unweathered Meade Peak Member, there is a rough inverse correlation of manganese with phosphorus; the four minimum manganese values were for rocks having a phosphorus content of 7.5 percent or more, and the five maximum manganese values were for rocks having a phosphorus content of 2 percent or less.

In the weathered shale units, the range of manganese content is from less than 10 to as much as 3,500 ppm; minimum and maximum manganese values seem to be randomly distributed in relation to phosphorus. In most of the lithologic units studied, differences in manganese content are negligible between unweathered and weathered phosphatic shales. In the six units shown on plate 1 in which the manganese content is greater in the fresh rocks, 140 ppm is the maximum difference between unweathered and weathered material; in four of the six units in which manganese concentration is higher in the weathered rocks, the difference is less than 75 ppm. In only one rock unit is the contrast striking; the thin marker bed of highly calcareous mudstone previously mentioned contains only 50 ppm manganese where unweathered, but 1,500 ppm manganese where weathered.

The manganese content of the bedrock sample from the Park City Formation is 50 ppm.

Table 3 shows the samples of dragged shale to be generally lower in manganese content (10 to 750 ppm) than the shale in place (10 to 3,500 ppm). Manganese content of soil is rather high, and is about the same over both formations except in the organic horizons A_{00} and A_0, which have manganese contents that are definitely greater over the Phosphoria Formation that over the Park City. Apparently plants concentrate the manganese and enrich these horizons, and possibly the A horizon as well.

NICKEL

In distribution, amount, and general relations with other elements and with all the lithologic units except one, nickel content is similar to copper content of the phosphatic shale. In unweathered rocks having a phosphorus content of 1 percent or less, all but one of the samples having minimum nickel contents are from the same layers that have minimum copper contents. The maximal values of nickel like those of copper are for rocks having muddy constituents and intermediate phosphorus content. In weathered rocks, nickel, like copper, shows random distribution in relation to phosphorus content. The range of nickel content in the shale is from less than 3 to as much as 550 ppm in unweathered rock and from less than 5 to as much as 750 ppm in weathered rock. The nickel content of the sample from the Park City Formation was 20 ppm.

Plate 1 shows little difference in nickel content between fresh and weathered rock units. In high grade phosphate rock and in the marker unit of calcareous mudstone, nickel content is greater in unweathered rock; the nickel content of most mudstones and other argillaceous rocks is a little higher in unweathered rock. Table 3 shows that the nickel content of shales in place is slightly more (20 to 750 ppm) than of dragged layers (20 to 150 ppm).

The C and the AC horizons of soil have about the same nickel content over the Phosphoria Formation as over the Park City. In the upper horizons—the A_{00}, A_0, and A—as well as in the shrubs, nickel content is greater over the Phosphoria. It seems that plant uptake of nickel must be responsible for the concentration of nickel at the upper levels of the soil.

STRONTIUM

The range of strontium values is the same in both fresh and weathered phosphatic shales: 100 to 3,500 ppm. In the unweathered rocks there is a definite positive correlation between strontium and phosphorus regardless of lithology; the maximum values of both elements occur in the same layers and the minimum values coincide as well. There is a rough positive correlation between strontium and phosphorus content in weathered rocks also.

Weathering has not caused any obvious consistent changes in strontium content of the several rock units. In 5 of the 12 lithologic units of shale, however, weathering has resulted in a change of strontium content of 500 ppm or more. Three of these units contain substantially more strontium where they are unweathered than where weathered, but in the other 2 units of the 5, strontium content is higher in the weathered rock. The most notable change has occurred in the thin marker bed of calcareous mudstone, in which weathering seems to have decreased the strontium content from 3,500 to 200 ppm and the phosphorus content from 10 percent to 0.25 percent. Weathering apparently has increased strontium content from 600 to 1,800 ppm in a unit of argillaceous phosphate rock in the interval 116 to 121 feet from the chert. In the other 7 units of the 12 studied, differences are negligible. The sample of bedrock from the Park City Formation contained 100 ppm strontium.

Strontium content of dragged layers of shale is not as high as that of equivalent bedrock layers. In the soil over both formations, strontium content increases progressively upward from the deepest horizon, C, through the A horizon. Both soil and shrub samples collected over the Phosphoria Formation contain more strontium than those collected over the Park City. Again, increases in the metal content in the upper soil horizons may be the result of concentration by plants.

VANADIUM

Vanadium content of the shales ranges from 35 to 5,000 ppm in the unweathered shale and 20 to 5,000 ppm in the weathered shale. There seems to be a rough positive correlation of vanadium with phosphorus and strontium. In 10 of the 12 lithologic units studied, the vanadium content is higher in weathered rock than in unweathered rock. In most of the weathered units the increase in vanadium is between 100 and 300 ppm; in two units of argillaceous phosphate rock, however, the difference is greater—600 and 1,600 ppm. The vanadium content of the bedrock sample from the Park City Formation was 100 ppm.

In general, vanadium content of the dragged shale is about the same as in the bedrock. The mineral horizons of the soil over the Phosphoria Formation contain substantially more vanadium (50 to 750 ppm) than do the analogous horizons over the Park City (35 to 100 ppm). The vanadium content of organic horizons of the soil over the Phosphoria Formation range from 28 to 147 ppm, as compared with a range from 5 to 35 ppm over the Park City Formation. Vanadium content of shrubs ranges from 10 to 110 ppm over the Phosphoria and from 10 to 39 ppm over the Park City.

In 15 of the 22 profiles studied, vanadium content of the lower soil horizons (C and AC) is greater than that of the upper horizons (A, A_0, and A_{00}). In four profiles (2, 13, 16, 19) maximum values of vanadium in lower and upper horizons are equal, and in three profiles (14, 17, 21) the vanadium content of the upper horizons exceeds that of the lower. In soils whose total thickness is 40 inches or more, maximum vanadium content is 100 ppm; for those profiles wherein the underlying shales have a high vanadium content, one might expect a correlation between soil thickness and vanadium content of soil. Some profiles seem to support this premise, but data for an equal number of profiles seem to disprove it. Illustrative examples follow.

In profile 1, in which vanadium content of soil is greatest, 750 ppm, the thickness of the soil is 24 inches and the highest vanadium content of the shale is only 200 ppm. In profile 4, in which the thickness of soil is the same as that of profile 1, vanadium content of the shale ranges from 350 to 3,500 ppm, but the range of vanadium in the soil is only 30 to 150 ppm. In profile 2, in which soil thickness is 14 inches, there is a maximum vanadium content of 1,500 ppm in the shales but a maximum of only 200 ppm in the overlying soil. In the 18-inch soil of profile 3, the highest vanadium value is only 75 ppm, although vanadium content of underlying shale has a maximum of 1,500 ppm. In profiles 14 and 15, however, having soil thickness of 24 and 29 inches, respectively, the maximum vanadium content of shale at both sites is 500 ppm, but vanadium content of the one overlying soil is 500 ppm and of the other is 350 ppm.

ZINC

In unweathered shale in place, the range in zinc content is 20 to 7,000 ppm. The maximum value is for a sample from a bed of argillaceous phosphate rock having a phosphorus content of 7.5 percent; all the high zinc values (3,000 to 7,000 ppm) are for muddy or silty rocks having phosphorus contents ranging from 3.75 to 7.5 percent. Rocks of the minimum phosphorus contents have minimum zinc contents. Evidently there is a direct correlation between zinc and phosphorus in shales of high silty content; in the weathered shale, however, this relation is not apparent.

In general, the effect of weathering seems to equalize zinc distribution; the range of zinc content is much less in weathered shale than in unweathered shale.

For 9 of the 12 lithologic units shown on plate 1, average zinc content is higher in the unweathered rock than in the weathered; for one unit, average zinc content is the same in both; in the remaining two units, zinc content of the weathered rock is the higher. The range of zinc content of weathered shale is 200 to 2,500 ppm; in the dragged layers the range is 300 to 2,000 ppm. The zinc content of the sample from the Park City is 350 ppm.

All soil horizons above the Phosphoria have higher zinc contents respectively than comparable horizons above the Park City. The zinc content of the shrubs over the Phosphoria is higher also than that over the Park City.

CONCLUSIONS

Both metal-poor colluvium and the soil developed on it can be enriched by metallic elements from the substrata, if the metal content of the underlying beds is sufficient and in an available form. It is believed that the metabolic processes of vegetation growing in the soil constitute an important if not a necessary factor of the mechanism through which the enrichment is accomplished. The metal content of either plants or soil, therefore, may be evidence of a metal-rich substratum if proper sampling has been done. To obtain a comprehensive picture by plant sampling, material for analysis must be collected not only from different species, but also from tissues of different type and age. Comparisons of metal content, however, should be made only between analytical results on plant samples of the same species and age and on analogous tissue.

Before soil samples are collected, consideration must be given to the stage of development of the soil to be sampled. In the area studied, although little difference was noted in the metal content of adjacent horizons of the poorly developed soils, it is a well-substantiated fact that a noticeable difference exists in the metal content of adjacent horizons of soils in which soil development is advanced. It follows that in pedogeochemical investigations of regions with mature soils, the investigator must take the samples to be compared from the same soil horizons, if comparisons of their metal content are to be valid.

Where a surface slopes, even very gently, an investigator seeking the source of a metal anomaly should remember three facts documented by this study: (1) that colluvium may move, without much internal mixing, for great distances downhill; (2) that upended metal-rich layers of rock can be dragged by moving colluvium for tens or even hundreds of feet downslope as identifiable units with little mixing and almost no significant change in characteristics except thinning; and (3) that anomalous concentrations of metal in the colluvium, in the soil developed on it, or in plants growing on the soil may have been derived from such displaced metal-rich layers rather than from the bedrock directly beneath the colluvial mantle.

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