MINERALOGICAL CHARACTERIZATION OF WEATHERED AND LESS WEATHERED STRATA OF THE MEADE PEAK PHOSPHATIC SHALE MEMBER OF THE PERMIAN PHOSPHORIA FORMATION
Measured Sections E and F, Rasmussen Ridge, and Measured Sections G and H, Sage Creek area of the Webster Range, Caribou County, Idaho

_by_ A. C. Knudsen[1], M. E. Gunter[1], J. R. Herring[2], and R. I. Grauch[2]

Open-File Report 02-392

2002

Prepared in Collaboration With
U.S. Bureau of Land Management
U.S. Forest Service
Agrium U.S. Inc.
Astaris LLC
J.R. Simplot Company
Rhodia Inc.
Monsanto

U. S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

----

[1] Dept. of Geological Sciences, Univ. of Idaho, Moscow, ID 83844-3022
[2] U.S. Geological Survey, Denver Federal Center, Box 25046, MS 973, Denver, CO 80225

CONTENTS

TABLES

ABSTRACT

The Permian Phosphoria Formation of the western U.S. includes one of the largest phosphate deposits in the world. Despite the economic significance of this formation, its fine-grained nature has discouraged detailed mineralogical characterization and quantitative studies. Recently, selenium and other potentially hazardous trace elements in mine wastes have drawn increased attention to these rocks and motivated more extensive study. Part of this effort has focused on a more detailed geological and mineralogical characterization of the rocks. This study uses powder X-ray diffraction (XRD) with Rietveld quantification software to characterize the mineralogy of channel samples from stratigraphic sections measured by the U.S. Geological Survey in the Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation. Measured sections are at the Rasmussen Ridge mine and at the Smoky Canyon mine approximately 15 and 25 miles, respectively, northeast of Soda Springs, Idaho.

The dominant minerals present in these samples are carbonate-fluorapatite, which is the most common phosphatic ore mineral in this and other marine phosphorites, quartz, muscovite, albite, orthoclase, the ammonium feldspar buddingtonite ($NH_4AlSi_3O_8$), dolomite, and calcite. Because of their potential for hosting trace elements such as Se, the presence of minor pyrite and sphalerite is also noteworthy. Analysis of the carbonate content in the carbonate-fluorapatite by Rietveld refinement shows relatively low carbonate contents, generally between 2 – 3% (wt.) CO_3^{2-} in the apatite structure, compared to other marine phosphorites.

INTRODUCTION

Background

U.S. Geological Survey (USGS) geologists studied the Permian Phosphoria Formation in southeastern Idaho and the Western U.S. Phosphate Field (Fig. 1) throughout much of the twentieth century. In response to a request by the U.S. Bureau of Land Management (BLM), a new series of resource and geoenvironmental studies was initiated by the USGS in 1998. Present studies involve many scientific disciplines within the USGS and consist of: (1) integrated, multidisciplinary research directed toward resource and reserve estimations of phosphate in selected 7.5-minute quadrangles; (2) elemental residence, mineralogical, and petrochemical characteristics; (3) mobilization and reaction pathways, transport, and disposition of potentially toxic trace elements associated with the occurrence, development, and use of phosphate rock; (4) geophysical signatures; and (5) improving the understanding of depositional origin.

To carry out these studies, the USGS has formed cooperative research relationships with: the University of Idaho, two Federal agencies, BLM and the U.S. Forest Service (USFS), which are responsible for land management and resource conservation on public lands, and with five private companies currently leasing or developing phosphate resources in southeastern Idaho. The companies are Agrium U.S. Inc. (Rasmussen Ridge mine), Astaris LLC (Dry Valley mine), Rhodia Inc. (Wooley Valley mine-inactive), J.R. Simplot Company (Smoky Canyon mine), and Monsanto (Enoch Valley mine). Because raw data acquired during the project will require time to interpret, the data are released in open-file reports for prompt availability to other workers. The open-file reports associated with this series of resource and geoenvironmental studies are submitted to each of the Federal and industry collaborators for technical comment; however, the USGS and its collaborators are solely responsible for the data contained in the reports.

Location and General Geology

Samples for this study were collected from the Meade Peak Phosphatic Shale Member of the Phosphoria Formation, a major source of phosphate in the Western Phosphate Field (Fig. 1). The samples described in this report are from two active phosphate mines in southeast Idaho. The Rasmussen Ridge mine, the site of measured sections E and F, is located approximately 15 miles northeast of Soda Springs, Idaho. Measured sections G and H were collected at the nearby Smoky Canyon mine, which is approximately 25 miles northeast of Soda Springs (Fig. 2). The Enoch Valley mine, also located on Rasmussen Ridge, provided a pair of more- and less-weathered sections, A and B (Tysdal and others, 1999, Herring and others, 1999, Knudsen and others 2000), as well as a deep least-weathered measured section, section J (Grauch and others, 2001; Herring and others, 2001; Knudsen and others, 2002). The Dry Valley mine was the location of the more- and less-weathered sections C and D, respectively, and was described in Tysdal and others (2000a), Herring and others (2000a), and Knudsen and others (2001).

McKelvey and others (1959) give a detailed discussion of the Phosphoria Formation. Service (1966) provided an evaluation of the western phosphate industry in Idaho and a brief description of the mining history, ore occurrence, and geology. The phosphate mining history is further amplified in Lee (2001). Cressman and Swanson (1964) discussed detailed stratigraphy and petrology of these same rock units in nearby southwestern Montana. Gulbrandsen and Krier (1980) discussed general aspects of the large and rich phosphorus resources in the Phosphoria Formation near Soda Springs. Gulbrandsen (1966, 1975, and 1979) summarized bulk chemical compositional data for various stratigraphic units in the Phosphoria Formation. Desborough and others (1999) provided preliminary mineralogical analysis looking for links between mineralogy and the mobility of Se in Phosphoria strata. Grauch and others (1999) presented a preliminary overview of Se mineral residence, including the dominant occurrence of native selenium in the Meade Peak Phosphatic Shale Member.

Description of Measured Sections

The Phosphoria Formation in southeastern Idaho has been subdivided into three members, which in ascending order are the Meade Peak Phosphatic Shale Member, the Rex Chert Member, and the informally named cherty shale member (McKelvey and others, 1959; Montgomery and Cheney, 1967; Brittenham, 1976; Oberlindacher, 1990). The measured sections of this report are from the Meade Peak Phosphatic Shale Member. The Meade Peak unconformably overlies the Grandeur Tongue of the Permian Park City Formation, and the Triassic Dinwoody Formation overlies the cherty shale member of the Phosphoria (Tysdal and others, 2000b, 2000c).

Stratigraphic sections of the Phosphoria Formation were measured, described, and sampled at the Rasmussen Ridge mine for sections E and F, and at the Smoky Canyon mine for sections G and H. Measurements of paired, more- and less-weathered, stratigraphic sections such as these compare the important effects of weathering and alteration on the chemistry and mineralogy of the rocks. English units of measurement are used in description of the sample depths and intervals in this report to facilitate direct correspondence with units in the extensive historical literature on the Phosphoria and with current industry usage.

Sections E and F were measured on surfaces exposed by mining: section E along a horizontal surface and section F along a steeply inclined face. Section E samples are less-weathered and were taken from about 150 ft. (46 m) below the pre-mining surface. Section F samples are more-weathered and were taken from a site 25 to 40 ft. (7.5 – 12 m) below the pre-mining surface. Description of these samples was provided in Tysdal and others (2000b), and chemical analyses of splits from the samples were reported in Herring and others (2000b).

For each section, measurements of the sample interval reported in the tables represent the true thickness of the strata, having been corrected for apparent thickening of steeply-dipping strata along a horizontal line. In turn the two sections vary in thickness due primarily to the apparent tectonic thinning of the middle waste zone of section E. Moreover, because not all of section F is well exposed, some strata could not be well defined.

Sections G and H from the Smoky Canyon mine were also measured along surfaces exposed by mining. Section G is about 3,000 ft. (900 m) south of section H. The lower third of section G was measured along a horizontal line, and the remainder was measured along a steeply inclined pit-wall. The uppermost strata of the Meade Peak Phosphatic Shale Member were not exposed in section G. Section H was measured along a steeply inclined-pit wall with offsets across three 30 ft. (9 m) benches from the base to the top of the section. Unlike the sections from other mines, these two sections are not separated by nearly as substantial a difference in pre-mining depth. For section G, the pre-mining depth of the samples graded from 175 ft. (53 m) at the lower portions of the section, to 150 ft. (46 m) for the upper portion, while section H graded from 50 ft. (15 m) in the lower portions to 150 ft. (46 m) for upper portions. Additionally, both sections have been extensively fractured and faulted, which has facilitated the infusion of both ground and surface water, leaving both sections moderately to substantially altered. Description of these samples was provided in Tysdal and others (2000c) and chemical analyses of splits from the samples used in this study were reported in Herring and others (2000c).

Strata in the vicinity of sections G and H dip 20° – 30° westward on the limb of an anticlinal fold. Both sections are cut by local low-angle faults, of unknown displacement, that dip at angles near to the dip angles of the bedding. These faults occasionally may cause either thickening or omission of strata. One such fault zone cuts through section G and caused omission of the upper two units of the lower ore zone (Tysdal and others, 2000c) and approximately 25 ft. (7.5 m) of the lowermost strata of the middle waste near the 35 ft. (10.5 m) sample interval. Also, strata between 85 and 105 ft. (26 – 32 m) above the base of the Phosphoria appear thinner than normal, suggesting omission of strata by an unrecognized fault (Tysdal and others, 2000c). In section H, the Cap Rock unit between the lower two lines of correlation [6.5 – 6.2 ft. (1.98 – 1.89 m)] is much thicker than would be expected in this area. The mudstone strata between the two phosphorite sequences of these lower strata contain a thickened, poorly exposed zone that may host a low-angle thrust fault. The fault is nearly parallel to bedding and repeats nearly the entire lower ore zone, although the Fish-scale bed, the lowermost bed of the Meade Peak, is not repeated. The two sections differ in thickness, chiefly because the likely thinning of the middle waste zone in section G, and the thickening of the lower ore zone in section H.

Rather than use of the more general unit names (A, B, C, D) applied to these strata in southeastern Idaho by Hale (1967, p. 152), informal terms such as “lower ore,” “middle waste,” “upper ore, and “upper waste” are used in descriptions of measured sections E, F, G, and H. For the measured sections, contacts in the lower ore and waste units within the Meade Peak were selected by mine personnel, whereas contacts within the middle and upper waste zones generally were picked by USGS personnel to correspond to intervals of consistent lithology as noted and described in the field.

METHODS

Field Sampling

Each measured section was visually divided into intervals for channel sample collection. Channel samples of approximately 0.5 to 1 kg (1 – 2 lbs.) from each interval were collected across the thickness of the interval, providing a single representative sample for mineralogical, geochemical, and petrological analysis. Sampling intervals were chosen with the intention of characterizing strata of relatively uniform lithology. Samples typically were collected over intervals that could be handled by conventional mining equipment in the event that analyses showed that separate handling would be advantageous. Within these broad intervals, samples of thinner intervals were occasionally collected, sometimes as thin as a foot or less, where a distinct lithology was noted from the interval as a whole. Samples were shipped to USGS laboratories in Denver, Colorado for preparation.

Rock Sample Preparation

Samples were air dried and then crushed in a mechanical jaw crusher. From the crushed samples, representative splits were taken and ground in a ceramic plate grinder to <100 mesh (0.15 mm). From the <100 mesh samples, splits were taken using a riffle splitter to ensure similarity with the whole sample, and distributed for analysis to various collaborators.

X-ray Diffraction Analysis

XRD analyses were conducted with a 2-Theta scan from 2° – 62° using Cu radiation on a Siemens D5000 diffractometer operating at 40 kV and 30 mA. XRD scans reveal the major phases, however, the peak to background ratios prevent accurate identification of minor phases, generally those less than 1% abundance, depending on the crystallinity, electron density, and symmetry of a given mineral.

The XRD patterns were subsequently analyzed using the Siroquant program (Taylor 1991). The Siroquant software package uses Rietveld analysis to quantify the mineralogical content in weight percent based on the XRD pattern. First, every phase in a sample must be identified. The program then calculates an XRD pattern based on the known crystal structure of each mineral to match the collected pattern to determine the quantities of each phase. Siroquant refines the calculated pattern for each phase to match the collected pattern, correcting for variable peak shape, preferred orientation, and shifts in cell parameters. The quantity of each phase is reported along with an error value (Tables 1a-d). The overall quality of the match between the calculated and collected patterns is shown by "χ^2", a statistical value reflecting the quality of the fit between the collected and calculated patterns, where lower values represent better matches and any value under 3.0 is considered acceptable.

Estimation of carbonate content in fluorapatite is based on the observations of Smith and Lehr (1966) and McClellan and Lehr (1969) that as CO_3^{2-} enters the fluorapatite structure, the a-cell parameter shrinks, while the c-cell parameter stays relatively constant. Based on this observation, Gulbrandsen (1970) derived a formula comparing the distance between the (004) and (410) diffraction peaks in degrees 2θ as a function of CO_3^{2-}. Because this method compares the shifting a-cell parameter and the relatively constant c-cell parameter, any shifting in the diffraction pattern due to instrumental or preparation error is accounted for, and the need for an internal standard is eliminated. Schuffert and others (1990) further refined this method to come up with the slightly more accurate formula:

$$y = 10.643x^2 – 52.512x + 56.986.$$

Here y is the weight % of CO_3^{2-} present in the fluorapatite and x is the $\Delta 2\theta_{(004)\text{ - }(410)}$. For this project, the method was further improved by calculating the (004) and (410) locations rather than measuring them. Using the Rietveld refinement, the a and c-cell parameters were measured, and then used to calculate the location of the diffraction peaks. This method uses the measured cell parameters that are determined by an average of all diffraction peaks. It reduces the possibility of mismeasurement of the peak locations, which if mismeasured even by fractions of a degree can produce substantial errors.

RESULTS

Quantitative mineral contents for the samples from the two pairs of sections are listed in tables 1a-d. Tables 1 a-d provide background information for each sample including the unit within the Phosphoria Formation, along with a lithology assigned in the field and the sample interval. The lithologies given are those reported by Tysdal and others (2000b, 2000c), and were recorded in the field, and have not been rechecked with other methods. For each sample the χ^2 value is given along with the analysis of 14 mineral species for sections E, F, and G. Section H analysis was done first, and did not include montmorillonite analysis, as little if any of this mineral appeared in any of the samples, although it was later added to analyses on the other sections for completeness. The tables list the weight percent of each mineral species in significant figures as reported by the Rietveld software, with the reported error value in the last significant figure given in parentheses. The reported weight percents are relative to the total diffracting or crystalline portion of each sample. This study did not include analysis of the nondiffracting portion of any sample, which, in preliminary tests, has been shown to be up to about 20% for some samples and considerably higher in carbon seam samples. The nondiffracting phases likely include organics and poorly to noncrystalline mineral-like phases. Analysis of the nondiffracting portion will be considered for these sections and the sections from the other mines in a report in preparation.

The values shown in tables 1a-d are presented graphically in figures 3a-g for the major minerals, apatite, quartz, muscovite + illite, total feldspars (albite + orthoclase + buddingtonite), buddingtonite, dolomite, and calcite. Each figure shows the values for one of these minerals or mineral groups for each of the four measured sections. Mineral concentrations are shown in weight percent of the diffracting portion of each sample over the stratigraphic section in terms of location in feet above the base of the Fish-scale bed.

The extent of carbonate substitution into the apatite structure is also given. Tables 2a-d list the same background information as given in tables 1a-d, along with the measured a- and c-cell parameters for the fluorapatite in each sample which are used to calculate the percent of CO_3^{2-} present in the apatite structure based on the equation of Schuffert and others (1990) given above. The weight percent of apatite in each sample is also repeated from tables 1a-d in tables 2a-d. Samples with less than 5% apatite could not be accurately measured for CO_3^{2-} substitution, and thus were not included. Figure 4 displays the values from tables 2a-d in the same manner in which figures 3 a-g represent the values from tables 1a-d.

Tables 1d and 2d include mineralogical composition data for three special samples that were not collected as part of the channel sampling through the Meade Peak. First there is a composite sample (WPSHG001) of the Grandeur at the location of the section H obtained by collecting approximately 100 g at 1-foot intervals through the upper 75 ft. of thickness of the Grandeur. Second, a composite bag of randomly collected chips from the Fish-scale unit directly overlying the Grandeur at the location of the Grandeur unit composite sample was included. This second sample was included because the Fish-scale unit of the section had lain exposed as a dip slope mining surface for a couple of years and it was conceivable that the mineralogy and chemistry could have been altered compared to fresher samples of the Fish-scale collected in outcrop as part of the channel sampling. Third, there is a 2-foot stratigraphic thickness sub-sample taken of the channel sample that directly overlies the Fish-scale unit; this sub-interval was sampled because of its unusually high radiometric emission (see eU data in Tysdal and others, 2000c).

REFERENCES CITED

Brittenham, M.D., 1976, Permian Phosphoria carbonate banks, Idaho-Wyoming thrust belt, *in* Hill, J.G., ed., Symposium on geology of the Cordilleran hingeline: Rock Mountain Association of Geologists—1976 symposium, Denver, p. 173-191.

Cressman, E.R., and Swanson, R.W., 1964, Stratigraphy and petrology of the Permian rocks of southwestern Montana: U.S. Geological Survey Professional Paper 313-C, p. 275-569.

Desborough, G.A., DeWitt, E., Jones, J., Meier, A., and Meeker, G., 1999, Preliminary mineralogical and chemical studies related to the potential mobility of selenium and associated elements in Phosphoria formation strata, southeastern Idaho: U.S. Geological Survey Open-file Report 99-129, 20 p.

Grauch, R. I., Meeker, G.P., Desborough, G.A., Herring, J.R., Tysdal, R.G. and Johnson, E.A., 1999, Selenium Residence in the Phosphoria Formation: Geological Society of America Abstracts with Programs, v. 31, no. 7, p. A-35,

Grauch, R.I., Tysdal R.G, Johnson, E.A., Herring, J.R., and Desborough, G.A., 2001, Stratigraphic section and selected semiquantitative chemistry, Meade Peak Phosphatic Shale Member of Permian Phosphoria Formation, central part of Rasmussen Ridge, Caribou County, Idaho: U.S. Geological Survey Open-file Report 99-20-E.

Gulbrandsen, R.A., 1966, Chemical composition of phosphorites of the Phosphoria Formation: Geochimica et Cosmochimica Acta, v. 30, no. 8, p. 769-778.

---, 1970, Relation of carbon dioxide content of apatite of the Phosphoria Formation to the regional facies: U.S. Geological Survey Professional Paper 700-B p. 9-13.

---., 1975, Analytical data on the Phosphoria Formation, western United States: U.S. Geological Survey Open-File Report 75-554, 45 p.

---, 1979, Preliminary analytical data on the Meade Peak member of the Phosphoria Formation at Hot Springs underground mine, Trail Canyon trench, and Conda underground mine, southeastern Idaho: U.S. Geological Survey Open-File Report 79-369, 35 p.

Gulbrandsen, R.A., and Krier, D.J., 1980, Large and rich phosphorus resources in the Phosphoria Formation in the Soda Springs area southeastern Idaho: U.S. Geological Survey Bulletin 1496, 25 p.

Hale, L.A., 1967, Phosphate exploration using gamma radiation logs, Dry Valley, Idaho: *in* Hale, L.A., ed., Anatomy of the Western Phosphate Field: Salt Lake City, Intermountain Association of Field Geologists, 15th Annual Field Conference Guidebook, p. 147-159.

Herring, J.R., 1995, Permian phosphorites; a paradox of phosphogenesis: *in*, Scholle, P.A., Peryt, T.M. and Ulmer-Scholle, D.S. (editors), The Permian of northern Pangea; Volume 2, Sedimentary basins and economic resources, p. 292-312.

Herring, J.R., Desborough, G.A., Wilson, S.A., Tysdal, R.G., Grauch, R.I., and Gunter, M.E., 1999, Chemical composition of weathered and unweathered strata of the Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation--A. Measured sections A and B, central part of Rasmussen Ridge, Caribou County, Idaho: U.S. Geological Survey Open-File Report 99-147-A, 24 p.

Herring, J.R., Wilson, S.A., Stillings, L.A., Knudsen, A.C., Gunter, M.E., Tysdal, R.G., Grauch, R.I., Desborough, G.A., and Zielinski, R.A., 2000a, Chemical composition of weathered and less weathered strata of the Meade Phosphatic Shale Member of the Permian Phosphoria Formation—B. Measured sections C and D, Dry Valley, Caribou County, Idaho: U.S. Geological Survey Open-File Report 99-147-B, 34 p.

Herring, J.R., Grauch, R.I., Desborough, G.A., Wilson, S.A., and Tysdal, R.G., 2000b, Chemical composition of weathered and less weathered strata of the Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation—C. Measured sections E and F, Rasmussen Ridge, Caribou County, Idaho: U.S. Geological Survey Open-File Report 99-147-C, 35 p.

Herring, J.R., Grauch, R.I., Tysdal, R.G., Wilson, S.A., and Desborough, G.A., 2000c, Chemical composition of weathered and less weathered strata of the Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation—D. Measured sections G and H, Sage Creek area of the Webster Range, Caribou County, Idaho: U.S. Geological Survey Open-File Report 99-147-D, 38 p.

Herring, J.R., Grauch, R.I., Seims, D.F., Tysdal, R.G., Johnson, E.A., Zielinski, R.A. Desborough, G.A., Knudsen, A.C., Gunter, M.E., 2001, Chemical composition of strata of the Meade Peak Meade Phosphatic Shale Member of the Permian Phosphoria Formation channel-composited and individual rock samples of measured section J and their relationship to measured sections A and B, central part of Rasmussen Ridge, Caribou County, Idaho: U.S. Geological Survey Open-File Report 01-195, 72 p.

Knudsen, A.C., Gunter, M.E., and Herring, J.R., 2000, Preliminary mineralogical characterization of weathered and less-weathered strata of the Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation: Measured sections A and B, central part of Rasmussen Ridge, Caribou County, Idaho: U.S. Geological Survey Open-File Report 00-116, 74 p.

---, 2001, Preliminary mineralogical characterization of weathered and less-weathered strata of the Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation: Measured sections C and D, Dry Valley, Caribou County, Idaho: U.S. Geological Survey Open-File Report 01-072, 72 p.

Knudsen, A.C., Gunter, M.E., and Herring, J.R, Grauch, R.I., 2002, Mineralogical composition of strata of the Meade Peak Meade Phosphatic Shale Member of the Permian Phosphoria Formation channel-composite and individual rock samples of measured section J and their relationship to measured sections A and B, central part of Rasmussen Ridge, Caribou County, Idaho: U.S. Geological Survey Open-File Report 02-0XX, XX p.

Lee, William H., 2001, A history of Phosphate Mining in Southeastern Idaho: U.S. Geological Survey Open-File Report 00-425, CD-ROM.

McClellan, G.H., and Lehr, J.R., 1969, Crystal chemical investigation of natural apatites: American Mineralogist, v. 54, p. 1379-1391.

McKelvey, V.E., Williams, J.S., Sheldon, R.P., Cressman, E.R., Cheney, T.M., and Swanson, R.W., 1959, The Phosphoria, Park City, and Shedhorn Formations in the Western Phosphate Field: U.S. Geological Survey Professional Paper 313-A, 47 p.

Montgomery, K.M., and Cheney, T.M., 1967, Geology of the Stewart Flat quadrangle, Caribou County, Idaho: U.S. Geological Bulletin 1217, 63 p.

Oberlindacher, H.P., 1990, Geologic map and phosphate resources of the northeastern part of the Lower Valley quadrangle, Caribou County, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-2133, scale 1:12,000.

Schuffert, J.D., Dastner, M., Emanuele, G., and Jahnke, R.A., 1990, Carbonate-ion substitution in francolite: A new equation: Geochimica Cosmochimica Acta, v. 54, p. 2323-2328.

Service, A.L., 1966, An evaluation of the western phosphate industry and its resources, Part 3. Idaho: U.S. Bureau of Mines Report of Investigations 6801, 201 p.

Smith, J.P. and Lehr, J.R., 1966, An x-ray investigation of carbonate apatite: Journal of Agricultural Food Chemistry, v. 14, p. 342 – 349.

Taylor, J.C., 1991, Computer programs for standardless quantitative analysis of minerals using the full powder diffraction profile: Powder Diffraction, vol. 6, p. 2-9.

Tysdal, R.G., Johnson, E.A., Herring, J.R., and Desborough, G.A., 1999, Stratigraphic sections and equivalent uranium (eU), Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation, central part of Rasmussen Ridge, Caribou County, Idaho: U.S. Geological Survey Open-File Report 99-20-A.

Tysdal, R.G., Herring, J.R., Desborough, G.A., Grauch, R.I., and Stillings, L.A., 2000a, Stratigraphic sections and equivalent uranium (eU), Meade Peak Phosphatic Shale Member of Permian Phosphoria Formation, Dry Valley, Caribou County, Idaho: U.S. Geological Survey Open-File Report 99-20-B.

Tysdal, R.G., Grauch, R.I., Desborough, G.A., and Herring, J.R., 2000b, Stratigraphic sections and equivalent uranium (eU), Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation, east-central part of Rasmussen Ridge, Caribou County, Idaho: U.S. Geological Survey Open-File Report 99-20-C.

Tysdal, R.G., Herring, J.R., Grauch, R.I., Desborough, G.A., and Johnson, E.A., 2000c, Stratigraphic sections and equivalent uranium (eU), Meade Peak Phosphatic Shale Member of Permian Phosphoria Formation, Sage Creek area of Webster Range, Caribou County, Idaho: U.S. Geological Survey Open-file Report 99-20-D.

Figure 1: Map of the Western United States showing the extent of the Western Phosphate Field (modified from Herring, 1995).

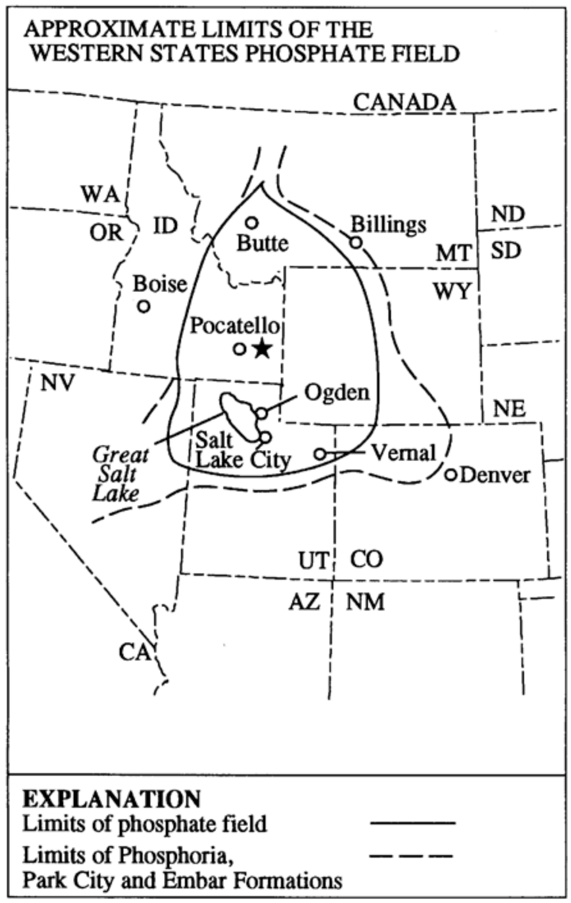

Figure 2: Index map of southeastern Idaho showing locations of measured sections E and F at the Rasmussen Ridge mine and measured sections G and H at the Smoky Canyon mine, Sage Creek area of the Webster Range. The sites of the Enoch Valley mine (measured sections A, B, and J) and the Dry Valley mine (measured sections C and D) are also shown.

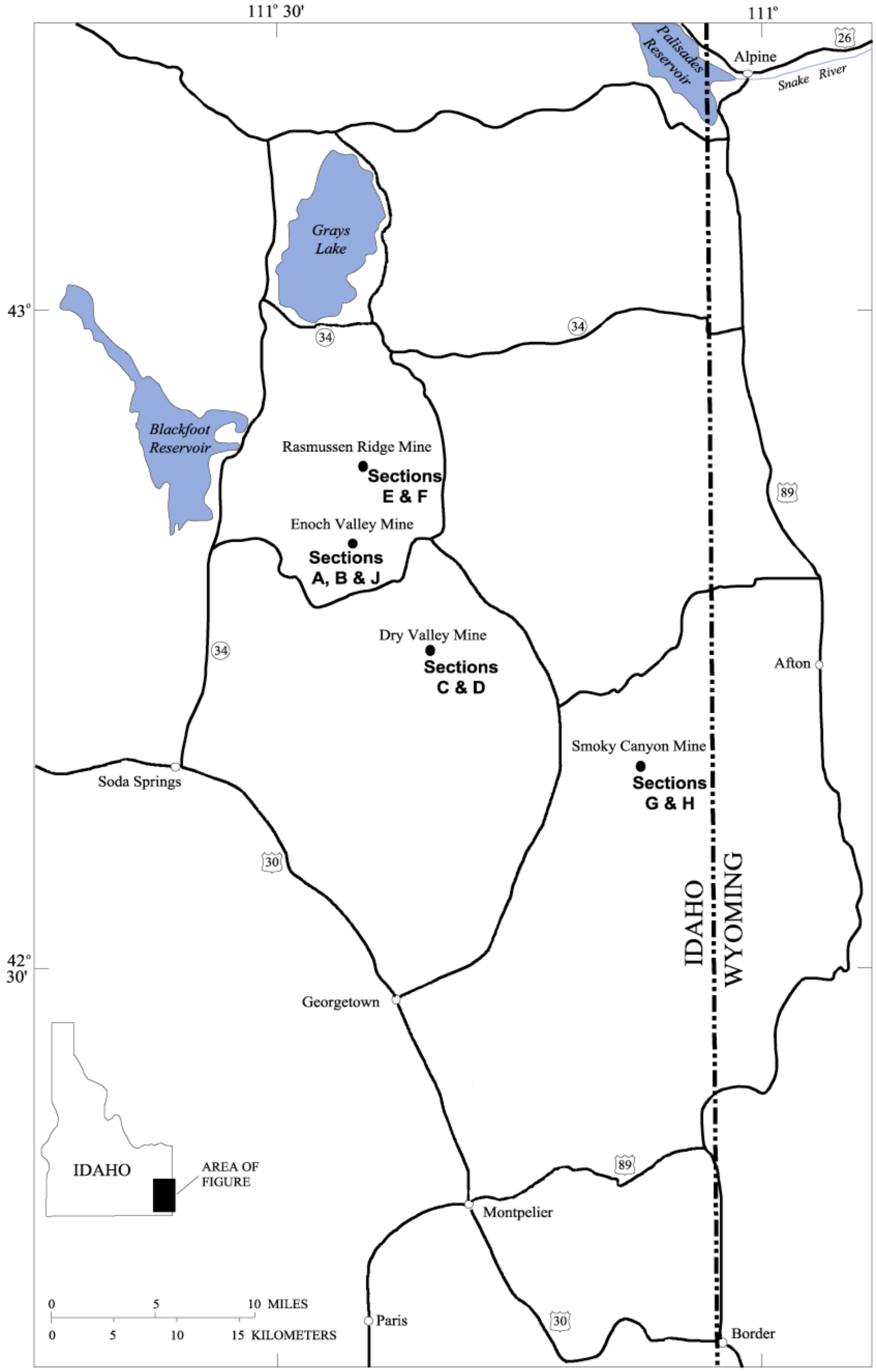

Table 1a: Quantitative mineralogy of samples from measured section E at Rasmussen Ridge calculated using the Rietveld method. The χ^2 value measures the quality of the match between the collected XRD pattern and the calculated Rietveld pattern where any value less than 3 is considered acceptable, with smaller χ^2 values inferring better results. Percents are listed with an accepted error in the last decimal place given in parentheses.

Sample	Lithology	Unit	Interval base	Interval top	χ^2	apt	qtz	musc	ill	alb	orth	budd	dolo	calc	kaol	mont	pyr	sphal	gyp
WPSE131	Carbon Seam	Up. Waste	130.5	131.0	1.96	20.2 (8)	32 (1)	37 (2)	2.6 (9)	0.0 (6)	0.0 (7)	0.0 (7)	0.4 (4)	0.1 (2)	3.7 (5)	0.1 (0)	1.3 (2)	0.0 (1)	2.6 (3)
WPSE126	Mudstone	Up. Waste	124.5	130.5	1.71	2.4 (5)	61 (2)	14 (1)	2.9 (9)	6.6 (7)	1.8 (8)	1.7 (8)	0.0 (4)	0.0 (2)	2.0 (6)	0.1 (1)	6.6 (4)	0.2 (1)	0.1 (4)
WPSE123	Mudstone	Up. Waste	121.3	124.5	1.89	1.2 (5)	42 (1)	11 (1)	0 (1)	4 (1)	2.2 (8)	0.0 (8)	29 (1)	6.0 (9)	0.0 (6)	0.0 (1)	3.4 (3)	0.2 (1)	0.0 (4)
WPSE120	Mudstone	Up. Waste	117.5	121.3	1.65	16.4 (9)	46 (1)	16 (2)	2 (1)	6.7 (8)	0 (1)	0 (1)	3.1 (5)	1.7 (4)	0.0 (7)	0.1 (1)	6.9 (4)	0.4 (1)	1.0 (4)
WPSE117	Dolostone	Up. Waste	116.5	117.5	1.36	1.0 (3)	6.4 (2)	2.6 (7)	0.1 (7)	0.6 (5)	0.1 (5)	0.0 (5)	89 (1)	0.0 (2)	0.0 (4)	0 (0)	0.2 (2)	0.0 (1)	0.0 (3)
WPSE116.5	Siltstone	Up. Waste	116.0	116.5	1.80	6.5 (5)	54 (1)	11 (1)	1.6 (9)	15.0 (7)	3.4 (7)	2 (8)	0.3 (4)	0.3 (3)	1.1 (5)	0.1 (0)	4.1 (3)	0.3 (1)	0.8 (3)
WPSE116	Carbon Seam	Up. Waste	115.3	116.0	1.71	6.3 (8)	54 (2)	15 (2)	3 (1)	8.6 (9)	3 (1)	0 (1)	0.0 (6)	0.3 (5)	0.2 (8)	0.1 (1)	7.8 (4)	0.1 (2)	1.8 (5)
WPSE113	Mudstone	Up. Waste	110.5	115.3	1.47	0.8 (4)	79 (2)	9 (1)	0.1 (7)	0.0 (5)	4.5 (8)	6.9 (9)	0.3 (3)	0.0 (3)	0.0 (5)	0.1 (0)	0.0 (2)	0.0 (1)	0.0 (3)
WPSE109	Mudstone	Up. Waste	107.0	110.5	1.80	4.4 (5)	61 (1)	10 (1)	2.2 (9)	6.5 (8)	6.7 (6)	4 (1)	0.0 (4)	0.0 (3)	1.2 (6)	0 (0)	2.8 (3)	0.2 (1)	0.8 (4)
WPSE106	Phosphorite	Up. Ore	104.3	107.0	1.40	94 (3)	4.4 (3)	0 (2)	0.3 (7)	0.1 (8)	0.1 (9)	0.0 (5)	0.0 (5)	0.0 (4)	0.0 (7)	0.1 (1)	0.0 (3)	0.0 (1)	0.8 (4)
WPSE104	Mudstone	Up. Ore	103.8	104.3	1.88	4.2 (6)	62 (2)	10 (1)	0 (1)	8.8 (7)	3.5 (8)	2.8 (8)	0.0 (4)	0.0 (4)	7.8 (6)	0.0 (1)	0.0 (3)	0.0 (1)	0.6 (4)
WPSE103	Phosphorite	Up. Ore	101.5	103.8	1.39	84 (2)	7.4 (3)	4 (1)	0 (1)	3.3 (7)	0.1 (1)	0.1 (9)	0.0 (4)	0.0 (4)	0.4 (6)	0.1 (1)	0.0 (3)	0.0 (1)	0.8 (4)
WPSE101	Phosphorite	Up. Ore	101.0	101.5	2.21	21.8 (7)	59 (1)	7 (1)	1.2 (9)	4.5 (2)	2.1 (8)	0.6 (6)	0.2 (4)	0.0 (3)	2.1 (6)	0.1 (1)	0.8 (3)	0.0 (1)	0.0 (4)
WPSE100	Phosphorite	Up. Ore	98.8	101.0	1.41	87 (2)	11.1 (4)	1 (1)	1.0 (9)	0.1 (7)	0.1 (1)	0.1 (8)	0.0 (4)	0.0 (3)	0.0 (6)	0.1 (1)	0.0 (3)	0.0 (1)	0.0 (4)
WPSE097	Phosphorite	Up. Ore	95.1	98.8	1.71	65 (2)	17.2 (6)	12 (2)	2 (1)	1.7 (9)	0.1 (1)	1 (1)	0.0 (5)	0.0 (4)	0.4 (8)	0.1 (1)	0.0 (3)	0.0 (1)	1.4 (5)
WPSE093	Phosphorite	Up. Ore	90.7	95.1	1.45	58 (2)	24.2 (8)	10 (2)	0 (1)	0.1 (9)	0.9 (1)	4 (1)	0.3 (5)	0.0 (4)	1.1 (8)	0.1 (1)	0.3 (3)	0.0 (1)	1.0 (5)
WPSE089	Siltstone	Mid. Waste	87.0	90.7	1.56	2.4 (4)	17.8 (4)	8.3 (8)	0.1 (8)	9.5 (5)	0.1 (1)	5.1 (6)	55 (1)	0.0 (3)	0.9 (5)	0 (0)	0.5 (2)	0.0 (1)	0.3 (3)
WPSE086	Siltstone	Mid. Waste	85.0	87.0	1.61	37 (1)	35 (8)	15 (1)	1 (1)	2.9 (4)	1.3 (1)	1.7 (9)	0.0 (5)	0.0 (4)	1.1 (6)	0.1 (1)	3.9 (3)	0.0 (1)	0.6 (4)
WPSE085	Siltstone	Mid. Waste	84.1	85.0	1.54	19.1 (6)	39.2 (9)	20 (1)	0.1 (8)	8.5 (5)	0.2 (1)	10.6 (9)	0.7 (3)	0.0 (2)	0.1 (4)	0 (0)	0.0 (2)	0.0 (1)	1.1 (3)
WPSE083	Siltstone	Mid. Waste	80.3	84.1	1.75	21.6 (8)	40 (1)	18 (1)	0 (1)	5.1 (7)	6.8 (8)	6.7 (8)	0.0 (4)	0.0 (3)	0.8 (6)	0.1 (1)	0.7 (3)	0.0 (1)	0.2 (4)
WPSE080	Phosphorite	Mid. Waste	79.8	80.3	1.40	57 (1)	20.0 (5)	9 (1)	0.1 (8)	3.5 (6)	2.5 (7)	5.9 (7)	0.1 (4)	0.0 (3)	0.4 (5)	0.1 (0)	0.2 (2)	0.0 (1)	1.3 (3)
WPSE79.5	Carbon Seam	Mid. Waste	79.3	79.8	1.65	28 (1)	24.2 (8)	11 (1)	0 (1)	9.2 (8)	5 (1)	18 (1)	0.1 (5)	0.1 (2)	1.0 (7)	0.2 (1)	0.0 (3)	0.0 (1)	2.3 (4)
WPSE079	Phosphorite	Mid. Waste	78.0	79.3	1.53	37 (1)	33.1 (8)	11 (1)	0.1 (9)	5.1 (7)	3.7 (8)	7.8 (8)	0.0 (4)	0.0 (3)	0.1 (6)	0.1 (1)	1.1 (3)	0.0 (1)	1.0 (4)
WPSE077	Phosphorite	Mid. Waste	76.0	78.0	1.51	38.5 (8)	34.4 (6)	6.5 (9)	0.1 (7)	9.4 (6)	3.0 (6)	6.2 (6)	0.8 (3)	0.6 (3)	0.1 (5)	0 (0)	0.0 (2)	0.0 (1)	0.4 (3)
WPSE075	Siltstone	Mid. Waste	74.5	76.0	1.94	6.3 (8)	34.4 (9)	13 (1)	0.1 (8)	15.0 (8)	4.0 (8)	22 (1)	0.4 (4)	0.0 (3)	2.9 (5)	0.2 (0)	0.0 (2)	0.0 (1)	1.8 (3)

Table 1a: (continued)

Sample	Lithology	Unit	Interval base	Interval top	χ^2	apt	qtz	musc	ill	alb	orth	budd	dolo	calc	kaol	mont	pyr	sphal	gyp
WPSE071	Siltstone	Mid. Waste	68.0	74.5	1.44	27.6 (8)	48 (1)	6 (1)	0.1 (9)	3.2 (7)	3.1 (8)	9 (1)	0.4 (4)	0.0 (3)	0.7 (6)	0.1 (1)	0.3 (3)	0.0 (1)	0.7 (4)
WPSE067	Phosphorite	Mid. Waste	67.0	68.0	1.63	5.8 (5)	48 (1)	6 (1)	0.1 (8)	16.4 (7)	5.5 (7)	14.8 (9)	0.0 (3)	0.0 (3)	0.7 (5)	0.1 (0)	0.2 (2)	0.0 (1)	2.3 (3)
WPSE065	Siltstone	Mid. Waste	63.3	67.0	1.55	16.9 (7)	43 (1)	12 (1)	0.1 (9)	9.5 (7)	5.1 (8)	11 (1)	0.6 (4)	0.0 (3)	0.0 (6)	0.1 (1)	0.6 (3)	0.0 (1)	1.3 (4)
WPSE061	Mudstone	Mid. Waste	57.0	63.3	1.59	21.0 (8)	38 (1)	18 (1)	0 (1)	4.9 (8)	2.7 (9)	11 (1)	0.0 (5)	0.5 (4)	1.2 (7)	0.1 (1)	1.0 (3)	0.0 (1)	1.2 (4)
WPSE057	Mudstone	Mid. Waste	56.3	57.0	1.77	4.4 (6)	50 (1)	17 (1)	0 (1)	12 (1)	2.1 (7)	6.2 (9)	0.0 (5)	0.0 (4)	1.1 (6)	0 (0)	5.7 (3)	0.4 (1)	0.8 (4)
WPSE055	Mudstone	Mid. Waste	51.0	56.3	1.80	33 (1)	31 (1)	13 (2)	0 (1)	4.0 (8)	0 (1)	8 (1)	0.3 (5)	0.0 (4)	3.5 (7)	0.1 (1)	1.0 (3)	0.0 (1)	4.2 (4)
WPSE048	Mudstone	Mid. Waste	46.0	51.0	1.52	46 (1)	31.6 (8)	10 (1)	0.9 (9)	2.0 (7)	2.5 (8)	6.1 (8)	0.5 (4)	0.5 (4)	0.0 (3)	0.1 (1)	0.0 (3)	0.0 (1)	0.5 (3)
WPSE046	Mudstone	Mid. Waste	45.3	46.0	1.49	0.2 (6)	42 (1)	1 (1)	0 (1)	21.4 (9)	11 (1)	22 (2)	0.1 (5)	0.2 (4)	1.5 (6)	0.1 (1)	0.0 (3)	0.0 (1)	0.5 (4)
WPSE043	Mudstone	Mid. Waste	41.0	45.3	1.73	16.3 (7)	40 (1)	9 (1)	0 (1)	12 (1)	2.6 (9)	16 (1)	0.6 (4)	0.6 (3)	1.9 (6)	0.1 (0)	0.0 (3)	0.1 (1)	0.5 (4)
WPSE038	Mudstone	Mid. Waste	35.3	41.0	1.57	38 (1)	26.7 (8)	13 (1)	0 (1)	0.1 (9)	6 (1)	13 (1)	0.7 (5)	0.3 (4)	0.3 (8)	0.2 (1)	0.0 (3)	0.0 (1)	2.7 (5)
WPSE033	Phosphorite	Low. Ore	30.7	35.3	1.48	57 (1)	19.0 (5)	13 (2)	1.0 (8)	1.3 (6)	1.0 (7)	5.8 (7)	0.0 (4)	0.0 (3)	1.1 (5)	0.1 (0)	0.0 (2)	0.0 (1)	0.9 (3)
WPSE029	Siltstone	Low. Ore	26.3	30.7	1.43	47 (2)	30 (1)	10 (2)	0 (1)	1.3 (8)	5.3 (9)	2.9 (9)	0.0 (5)	0.3 (4)	0.6 (6)	0.2 (1)	0.0 (3)	0.0 (1)	1.6 (4)
WPSE026	Mudstone	Low. Ore	25.3	26.3	1.46	45 (1)	26.4 (7)	7 (1)	0 (1)	2.8 (7)	9.3 (8)	7.0 (8)	0.4 (4)	1.2 (4)	0.6 (6)	0.1 (1)	0.0 (3)	0.0 (1)	0.7 (4)
WPSE021	Phosphorite	Low. Ore	16.7	25.3	1.38	63 (2)	19.8 (5)	7 (1)	0 (1)	0.7 (7)	4.8 (8)	1.7 (9)	0.0 (4)	0.2 (3)	1.4 (6)	0.1 (1)	0.0 (3)	0.0 (1)	1.7 (4)
WPSE016	Phosphorite	Low. Ore	15.3	16.7	1.36	60 (1)	25.7 (6)	7 (1)	0.1 (9)	0.8 (6)	0.2 (8)	3.3 (8)	0.0 (4)	0.1 (3)	0.9 (6)	0.1 (1)	0.2 (3)	0.0 (1)	1.7 (3)
WPSE012	Phosphorite	Low. Ore	9.5	15.3	1.53	62 (2)	19.8 (6)	8 (1)	0 (1)	0.1 (7)	1.0 (9)	4.3 (9)	0.0 (4)	0.0 (4)	1.7 (6)	0.1 (1)	0.0 (3)	0.2 (1)	2.7 (4)
WPSE008	Mudstone	Low. Ore	5.0	9.5	1.41	65 (2)	20.5 (6)	4 (2)	0 (1)	0.1 (8)	7 (1)	1.2 (9)	0.0 (4)	0.4 (3)	0.0 (6)	0.1 (1)	0.0 (3)	0.0 (1)	1.3 (4)
WPSE006	Mudstone	Low. Ore	6.5	7.0	1.71	47 (1)	18.5 (5)	9 (1)	0 (1)	0.2 (7)	10.1 (6)	4.6 (8)	2.2 (4)	1.5 (3)	4.5 (6)	0.1 (1)	0.0 (3)	0.1 (1)	2.1 (4)
WPSE004	Phosphorite	Low. Ore	3.0	5.0	1.46	67 (2)	19.2 (6)	6 (2)	0 (1)	0.1 (8)	2.2 (9)	3.0 (9)	0.0 (5)	0.2 (4)	1.0 (7)	0.1 (1)	0.0 (3)	0.0 (1)	1.2 (4)
WPSE002	Mudstone	Footwall bed	0.5	3.0	1.62	4.8 (9)	62 (2)	12 (2)	0 (1)	0.8 (9)	10 (1)	6 (1)	0.6 (6)	0.0 (5)	2.8 (8)	0.3 (1)	0.0 (4)	0.0 (2)	1.2 (5)
WPSE00.5	Phosphorite	Fish-scale	0.0	0.5	1.30	81 (3)	5.6 (4)	10 (2)	0 (1)	0.1 (9)	0 (1)	0 (1)	1.0 (5)	0.2 (4)	0.0 (8)	0.1 (1)	0.0 (3)	0.0 (1)	0.9 (5)
WPSE-0.5	Dolostone	Grandeur	-5.0	0.0	1.69	6.8 (8)	5.8 (4)	3 (1)	0 (1)	0.7 (8)	1.7 (9)	4 (1)	76 (2)	0.3 (4)	0.0 (7)	0.0 (1)	0.1 (3)	0.2 (1)	1.6 (5)
WPSE-10	Dolostone	Grandeur	-10.0	-5.0	1.36	2.6 (3)	3.8 (2)	1.7 (8)	0.1 (7)	0.1 (5)	0.4 (5)	0.9 (6)	90 (1)	0.0 (2)	0.0 (2)	0 (0)	0.0 (2)	0.0 (1)	0.7 (3)

Table 1b: Quantitative mineralogy of samples from measured section F at Rasmussen Ridge calculated using the Rietveld method. The χ^2 value measures the quality of the match between the collected XRD pattern and the calculated Rietveld pattern where any value less than 3 is considered acceptable, with smaller χ^2 values inferring better results. Percents are listed with an accepted error in the last decimal place given in parentheses.

Sample	Lithology	Unit	Interval base	Interval top	χ^2	apt	qtz	musc	ill	alb	orth	budd	dolo	calc	kaol	mont	pyr	sphal	gyp
WPSF177	Carbon Seam	Up. Waste	176.5	176.9	1.55	13.1 (8)	57 (2)	18 (2)	5 (1)	0.1 (8)	2.1 (9)	4.0 (9)	0.1 (5)	0.0 (4)	0.8 (7)	0.1 (1)	0.0 (3)	0.0 (1)	0.0 (4)
WPSF167	Carbon Seam	Up. Waste	165.4	170.6	1.81	0.9 (8)	65 (3)	24 (2)	3 (1)	0 (1)	3 (1)	0 (1)	0.3 (7)	0.0 (5)	3.6 (9)	0.1 (1)	0.7 (4)	0.0 (2)	0.0 (6)
WPSF154	Phosphorite	Up. Ore	153.2	155.2	1.35	83 (2)	10.1 (3)	5 (1)	0.3 (9)	0.1 (6)	0.1 (7)	0.1 (8)	0.0 (4)	0.1 (3)	0.4 (6)	0.1 (1)	0.0 (3)	0.1 (1)	0.8 (3)
WPSF141	Phosphorite	Up. Ore	139	142.9	1.47	69 (2)	22.0 (6)	5 (1)	0.1 (8)	0.1 (6)	0.2 (7)	1.5 (7)	0.0 (4)	0.0 (3)	0.2 (6)	0.1 (1)	1.0 (2)	0.0 (1)	0.5 (3)
WPSF121	Phosphorite	Mid. Waste	120.4	121.2	1.73	14 (1)	50 (2)	12 (2)	0 (1)	6 (1)	1 (1)	15 (1)	0.0 (7)	0.0 (5)	1 (1)	0.1 (1)	0.4 (3)	0.0 (2)	0.6 (7)
WPSF097	Phosphorite	Mid. Waste	96.6	97.2	1.55	45 (1)	36 (1)	9 (1)	0 (1)	0.1 (8)	0.9 (9)	5.2 (9)	0.0 (5)	0.0 (4)	0.3 (7)	0.1 (1)	0.6 (3)	0.0 (1)	1.9 (4)
WPSF078	Siltstone	Mid. Waste	76.4	79.4	1.64	13.6 (5)	37.8 (8)	10.2 (8)	0.1 (7)	13.8 (7)	8.5 (8)	13 (1)	1.6 (3)	0.2 (3)	0.8 (4)	0 (0)	0.0 (2)	0.0 (1)	0.6 (3)
WPSF061	Phosphorite	Mid. Waste	60	62	1.93	5.0 (6)	38 (1)	7 (1)	0.5 (9)	10.3 (7)	9 (1)	26 (1)	0.0 (4)	0.4 (3)	3.1 (5)	0 (0)	0.3 (2)	0.0 (1)	1.1 (4)
WPSF045	Mudstone	Low. Ore	40.5	47	1.53	57 (2)	20.9 (7)	6 (1)	1 (1)	0.3 (8)	7 (2)	5 (1)	0.1 (5)	0.3 (4)	1.1 (7)	0.2 (1)	0.3 (3)	0.1 (1)	1.1 (5)
WPSF040	Mudstone	False Cap	39.6	40.5	1.54	47 (2)	24 (1)	8 (2)	0 (1)	0.1 (9)	4 (1)	14 (2)	0.4 (5)	0.7 (4)	1.3 (7)	0.1 (1)	0.0 (3)	0.0 (1)	1.1 (5)
WPSF035	Phosphorite	Low. Ore	34.8	36	1.46	74 (2)	11.4 (4)	7 (2)	0 (1)	0.1 (7)	3.8 (9)	0.7 (8)	0.0 (4)	0.0 (4)	0.6 (6)	0.1 (1)	0.0 (3)	0.0 (1)	1.9 (4)
WPSF031	Mudstone	Low. Ore	29.25	31.9	1.65	18 (1)	42 (2)	6 (1)	0 (1)	0.1 (9)	22 (2)	8 (2)	0.5 (5)	1.0 (4)	1.1 (8)	0.1 (1)	0.0 (3)	0.0 (1)	0.1 (5)
WPSF020	Phosphorite	Low. Ore	19.2	20.5	1.49	78 (2)	13.9 (4)	2 (1)	0 (1)	0.1 (7)	2 (8)	0.1 (9)	1.1 (4)	0.1 (4)	0.8 (6)	0.1 (1)	0.2 (3)	0.0 (1)	1.8 (4)
WPSF015	Mudstone	Low. Ore	4.5	13.2	1.5	61 (2)	21.8 (6)	7 (1)	0 (1)	0.1 (8)	2.5 (9)	2.7 (9)	0.3 (5)	0.3 (4)	1.9 (7)	0.1 (1)	0.4 (3)	0.0 (1)	2.2 (4)
WPSF004	Phosphorite	Low. Ore	4	4.5	1.42	88 (2)	5.7 (3)	3 (2)	0 (1)	0.1 (8)	0.1 (9)	0.7 (9)	0.0 (5)	0.0 (4)	0.9 (7)	0.1 (1)	0.0 (3)	0.0 (1)	0.8 (4)
WPSF001	Mudstone	Footwall	1	4	1.91	0.2 (5)	50 (2)	32 (1)	1.6 (9)	0.0 (7)	2.5 (7)	4.8 (7)	0.0 (4)	0.0 (3)	5.7 (6)	0.1 (1)	0.0 (3)	0.0 (1)	3.7 (4)

Table 1c: Quantitative mineralogy of samples from measured section G from the Smoky Canyon mine, Sage Creek area of the Webster Range calculated using the Rietveld method. The χ^2 value measures the quality of the match between the collected XRD pattern and the calculated Rietveld pattern where any value less than 3 is considered acceptable, with smaller χ^2 values inferring better results. Percents are listed with an accepted error in the last decimal place given in parentheses.

Sample	Lithology	Unit	Interval base	Interval top	χ^2	apt	qtz	musc	ill	alb	orth	budd	dolo	calc	kaol	mont	pyr	sphal	gyp
WPSG115	Phosphorite	Up. Ore	113	117	1.9	40 (1)	19.9 (7)	11 (3)	0.1 (9)	8.8 (7)	1.5 (8)	4.2 (9)	4.3 (4)	0.8 (3)	3.3 (6)	0 (0)	2.6 (2)	0.0 (1)	3.1 (4)
WPSG113	Mudstone	Up. Ore	112.5	113	1.72	5.6 (6)	60 (2)	4 (2)	4.2 (9)	15.6 (9)	8.2 (8)	1.7 (9)	0.0 (5)	1.1 (4)	0.7 (6)	0 (0)	0.0 (3)	0.0 (1)	0.0 (4)
WPSG112.5	Mudstone	Up. Ore	111.5	112.5	1.89	3.3 (6)	54 (1)	10 (1)	3 (1)	17.5 (9)	6.4 (9)	2.5 (9)	0.0 (5)	0.3 (4)	2.8 (7)	0.0 (1)	0.0 (3)	0.0 (1)	0.0 (4)
WPSG110	Phosphorite	Up. Ore	106	111.5	1.51	64 (1)	20.6 (5)	4 (1)	1.2 (9)	6.0 (7)	2.3 (7)	0.9 (8)	0.0 (4)	0.4 (3)	0.6 (6)	0.0 (1)	0.0 (3)	0.1 (1)	0.3 (4)
WPSG105	Phosphorite	Up. Ore	102.5	106	1.36	93 (2)	5.0 (3)	1 (1)	0 (1)	0.1 (7)	0.1 (8)	0.1 (8)	0.0 (4)	0.0 (3)	0.0 (6)	0.1 (1)	0.0 (3)	0.0 (1)	0.5 (4)
WPSG101	Mudstone	Up. Ore	100	102.5	1.76	6.6 (5)	54 (1)	14 (1)	2.9 (9)	5.5 (6)	3.4 (7)	1.4 (8)	5.2 (4)	0.0 (3)	0.7 (6)	0 (0)	5.0 (3)	0.1 (1)	1.6 (3)
WPSG098	Mudstone	Mid. Waste	95	100	1.48	72 (1)	11.2 (4)	14 (2)	0 (1)	0.1 (7)	0.1 (8)	0.0 (5)	0.0 (4)	0.0 (3)	0.0 (6)	0.1 (1)	0.0 (3)	0.0 (1)	0.0 (4)
WPSG097	Mudstone	Mid. Waste	93.5	100	1.74	48 (1)	29.3 (9)	10 (2)	2 (1)	7.6 (7)	0.1 (9)	2.0 (9)	0.0 (5)	0.1 (4)	0.0 (7)	0.1 (1)	0.9 (3)	0.0 (1)	0.0 (4)
WPSG093	Dolostone	Mid. Waste	91.5	93.5	1.84	1.5 (5)	48 (2)	13 (1)	0.1 (9)	21.5 (9)	3 (1)	13 (2)	0.0 (4)	0.0 (3)	0.0 (6)	0.1 (1)	0.0 (2)	0.1 (1)	0.5 (3)
WPSG090	Mudstone	Mid. Waste	86	91.5	1.61	32.3 (9)	35.8 (9)	9 (1)	0 (1)	10.8 (6)	2.7 (8)	5.0 (8)	0.0 (4)	0.7 (3)	1.1 (6)	0.1 (1)	0.0 (3)	0.2 (1)	1.9 (4)
WPSG085	Phosphorite	Mid. Waste	84	86	1.7	54 (1)	20.6 (6)	12 (2)	3.2 (9)	3.3 (6)	0.1 (8)	1.0 (8)	0.0 (4)	0.0 (3)	2.2 (6)	0.0 (1)	1.7 (3)	0.0 (1)	1.7 (3)
WPSG083	Mudstone	Mid. Waste	82.5	84	2.2	0.0 (5)	45 (1)	10 (1)	0 (1)	12.2 (8)	4.3 (6)	26 (1)	0.0 (5)	0.4 (3)	0.7 (6)	0 (0)	0.0 (3)	0.0 (1)	1.1 (4)
WPSG82.5	Phosphorite	Mid. Waste	82	82.5	1.46	72 (2)	11.1 (3)	5.0 (8)	0 (1)	5.2 (9)	0.1 (8)	3.5 (8)	0.1 (4)	0.0 (3)	0.9 (6)	0.1 (1)	0.0 (3)	0.0 (1)	2.1 (4)
WPSG082	Mudstone	Mid. Waste	81	82	1.92	0.2 (5)	43 (1)	9 (1)	0.1 (9)	19.4 (8)	4.0 (6)	20 (1)	0.8 (4)	0.4 (3)	1.8 (6)	0.0 (1)	0.0 (3)	0.0 (1)	1.2 (4)
WPSG080	Phosphorite	Mid. Waste	80	81	1.46	48 (1)	23.7 (5)	6 (1)	0.1 (9)	8.2 (6)	5.8 (7)	4.8 (7)	0.0 (4)	0.2 (3)	1.1 (6)	0.1 (1)	0.0 (3)	0.0 (1)	1.7 (3)
WPSG079	Mudstone	Mid. Waste	78.5	80	1.85	2.3 (5)	47 (1)	10 (1)	0.1 (9)	19.8 (8)	11.0 (8)	6 (1)	0.0 (4)	0.0 (3)	2.0 (5)	0 (0)	0.0 (3)	0.0 (1)	2.0 (3)
WPSG078	Phosphorite	Mid. Waste	76.5	78.5	1.67	35 (1)	27 (1)	23 (2)	3 (1)	7.4 (9)	1 (1)	2 (1)	0.0 (5)	0.7 (4)	0.1 (8)	0.2 (1)	0.3 (4)	0.2 (1)	0.0 (5)
WPSG077	Mudstone	Mid. Waste	70	80	1.92	24 (1)	24.5 (9)	25 (2)	0 (1)	12.2 (9)	1 (1)	8 (1)	0.0 (5)	2.7 (4)	1.8 (7)	0.1 (1)	0.0 (3)	0.0 (1)	1.6 (4)
WPSG073	Mudstone	Mid. Waste	70	76.5	1.71	18 (1)	13.0 (6)	21 (2)	0 (1)	4.8 (9)	1 (1)	5 (1)	1.5 (5)	32 (1)	1.5 (8)	0.1 (1)	0.0 (4)	0.6 (2)	1.7 (5)
WPSG069	Mudstone	Mid. Waste	67	70	1.77	15.2 (8)	19.8 (7)	9 (1)	0 (1)	7 (1)	4 (1)	12 (1)	3.0 (5)	27 (1)	0.8 (7)	0.1 (1)	1.1 (3)	0.1 (1)	0.8 (5)
WPSG065	Dolostone	Mid. Waste	60	67	1.58	1.1 (4)	32 (7)	4.1 (9)	0.1 (8)	2.6 (6)	1.6 (6)	12.8 (6)	29.7 (8)	13.6 (6)	0.8 (5)	0 (0)	0.0 (2)	0.0 (1)	1.4 (3)
WPSG057	Mudstone	Mid. Waste	55	60	1.98	9.4 (8)	32 (1)	17 (1)	0 (1)	15.8 (9)	8 (1)	8 (1)	2.5 (5)	4.3 (4)	1.5 (7)	0.0 (1)	0.0 (3)	0.0 (1)	2.0 (4)
WPSG052	Mudstone	Mid. Waste	50	55	1.64	13.0 (7)	32.0 (9)	13 (1)	3 (1)	12.0 (8)	4.6 (9)	8.2 (9)	0.0 (5)	12.1 (6)	1.3 (7)	0.1 (1)	0.1 (3)	0.0 (1)	1.8 (4)
WPSG047	Dolostone	Mid. Waste	45	50	2.03	30 (1)	21.4 (7)	13 (1)	1 (1)	9 (1)	3.2 (8)	10 (1)	4.6 (5)	4.6 (4)	0.8 (7)	0.1 (1)	0.0 (3)	0.0 (1)	3.5 (5)
WPSG042	Dolostone	Mid. Waste	40	45	1.62	33.0 (8)	14.9 (4)	10 (1)	0.1 (9)	7.0 (6)	1.9 (4)	8.0 (7)	1.3 (4)	22.5 (7)	1.0 (6)	0.1 (1)	0.0 (3)	0.0 (1)	0.6 (3)

Table 1c: (continued)

Sample	Lithology	Unit	Interval base	Interval top	χ^2	apt	qtz	musc	ill	alb	orth	budd	dolo	calc	kaol	mont	pyr	sphal	gyp
WPSG037	Dolostone	Mid. Waste	35	40	1.63	43 (1)	14.4 (6)	8 (2)	0 (1)	6.6 (8)	5.0 (9)	8 (1)	4 (1)	7.6 (9)	0.8 (7)	0.1 (1)	0.0 (3)	0.0 (1)	2.7 (5)
WPSG033	Mudstone	Low. Ore	30	35	1.54	52 (2)	10.9 (6)	5 (1)	0 (1)	3 (1)	2 (1)	6 (1)	5.3 (6)	16 (1)	0.2 (9)	0.2 (1)	0.0 (4)	0.0 (2)	0.0 (6)
WPSG028	Phosphorite	Low. Ore	26.8	30	1.52	63 (2)	14.7 (5)	6 (2)	0 (1)	1.0 (8)	1.9 (8)	1.7 (9)	5.3 (6)	4.5 (4)	0.3 (7)	0.1 (1)	0.0 (3)	0.0 (1)	0.7 (4)
WPSG026	Dolostone	Low. Ore	24.5	26.8	1.66	41 (1)	18.2 (5)	6 (1)	0 (1)	7.1 (7)	2.6 (8)	3.3 (8)	15 (1)	3.8 (8)	0.9 (6)	0.1 (1)	0.3 (3)	0.1 (1)	1.4 (4)
WPSG024	Mudstone	Low. Ore	23.3	24.5	1.58	39 (1)	27.1 (8)	6 (2)	0 (1)	4.4 (7)	5.1 (8)	4.9 (8)	9.4 (6)	2.5 (3)	0.0 (6)	0.0 (1)	0.0 (3)	0.0 (1)	1.7 (4)
WPSG023	Dolostone	Low. Ore	22	23.3	1.65	6.4 (6)	39 (1)	4 (1)	0 (1)	7 (1)	8.3 (9)	0.1 (9)	22 (1)	7.8 (8)	2.7 (7)	0.0 (1)	0.0 (3)	0.1 (1)	2.7 (4)
WPSG020	Phosphorite	Low. Ore	18.3	22	1.53	67 (1)	18.7 (4)	5 (1)	0.1 (9)	3.0 (6)	1.4 (7)	0.1 (8)	1.3 (4)	0.0 (3)	1.8 (6)	0.1 (1)	0.0 (3)	0.0 (1)	1.6 (4)
WPSG016	Siltstone	Low. Ore	15	18.3	1.84	36.6 (8)	38.1 (8)	7 (1)	0.1 (8)	8.4 (6)	3.2 (7)	0.1 (7)	2.9 (4)	0.0 (3)	2.0 (5)	0.1 (1)	0.0 (2)	0.1 (1)	1.4 (3)
WPSG014	Dolostone	Low. Ore	14	15	1.58	4.9 (6)	21.8 (5)	5.1 (8)	0.1 (9)	5.4 (6)	1.9 (7)	0.9 (8)	7.0 (4)	47 (1)	4.3 (6)	0.1 (0)	0.0 (3)	0.2 (1)	1.6 (4)
WPSG013	Phosphorite	Low. Ore	11.9	14	1.53	73 (2)	12.6 (5)	10 (2)	0 (1)	4.1 (8)	0.1 (9)	0.2 (9)	0.3 (5)	0.0 (4)	0.0 (7)	0.1 (1)	0.0 (3)	0.0 (1)	0.0 (4)
WPSG011	Dolostone	Low. Ore	11	11.9	1.53	32 (1)	17.8 (6)	4 (1)	0 (1)	0.1 (9)	1 (1)	2 (1)	1.5 (6)	39 (1)	1.6 (8)	0.1 (1)	0.0 (4)	0.3 (2)	1.4 (5)
WPSG008	Phosphorite	Low. Ore	1.5	11	1.45	83 (2)	9.5 (3)	4 (1)	0 (1)	0.1 (7)	0.5 (8)	0.8 (8)	0.0 (4)	1.4 (2)	0.6 (6)	0.1 (1)	0.0 (3)	0.0 (1)	0.1 (4)

Table 1d: Quantitative mineralogy of samples from measured section H from the Smoky Canyon mine, Sage Creek area of the Webster Range calculated using the Rietveld method. The χ^2 value measures the quality of the match between the collected XRD pattern and the calculated Rietveld pattern where any value less than 3 is considered acceptable, with smaller χ^2 values inferring better results. Percents are listed with an accepted error in the last decimal place given in parentheses.

Sample	Lithology	Unit	Interval base	Interval top	χ^2	apt	qtz	musc	ill	alb	orth	budd	dolo	calc	kaol	mont	pyr	sphal	gyp
WPSH180	Chert	Rex Chert	178	180	1.84	1.6 (3)	84 (1)	0.1 (7)	0.1 (6)	0.0 (4)	1.0 (5)	2.1 (5)	0.6 (3)	11.0 (3)	0.0 (4)	.	0.0 (2)	0.0 (1)	0.0 (2)
WPSH176	Dolostone	Up. Ore	174	178	1.6	1.6 (3)	79 (1)	0.1 (7)	0.4 (6)	0.0 (4)	2.3 (5)	1.3 (5)	5.8 (3)	9.6 (5)	0.5 (4)	.	0.0 (2)	0.1 (1)	0.0 (2)
WPSH172	Dolostone	Up. Ore	170	174	1.72	22.9 (7)	47 (1)	9.4 (9)	0.1 (9)	5.9 (6)	3.4 (7)	2.1 (7)	0.3 (4)	7.3 (3)	0.7 (5)	.	0.2 (2)	0.0 (1)	0.3 (3)
WPSH165	Dolostone	Up. Ore	159.5	170	1.83	1.6 (6)	48 (1)	13 (1)	5 (1)	14.2 (9)	5.6 (9)	0.1 (9)	3.1 (5)	5.9 (8)	1.8 (7)	.	1.1 (3)	0.0 (1)	0.3 (4)
WPSH158	Mudstone	Up. Ore	156	159.5	1.64	8.8 (6)	39.3 (9)	12 (1)	3.2 (8)	12.3 (7)	2.7 (7)	0.1 (7)	3.5 (4)	14.6 (6)	1.5 (6)	.	1.0 (2)	0.1 (1)	0.8 (3)
WPSH155	Phosphorite	Up. Ore	153	156	1.62	32 (1)	23.4 (7)	5 (1)	0 (1)	6.3 (9)	2.9 (8)	0.5 (9)	24 (1)	4.3 (4)	0.9 (7)	.	0.0 (3)	1.0 (1)	0.4 (4)
WPSH151	Mudstone	Up. Ore	148.5	153	2.24	1.7 (4)	44 (1)	18 (1)	2.4 (5)	13.3 (5)	11.6 (7)	0.5 (8)	1.9 (8)	3.6 (5)	1.8 (5)	.	0.0 (2)	0.3 (1)	1.6 (3)
WPSH147	Phosphorite	Up. Ore	145.5	148.5	1.41	87 (2)	8.5 (3)	2 (1)	1.4 (8)	0.8 (6)	0.1 (8)	0.1 (8)	0.0 (4)	0.0 (1)	0.5 (6)	.	0.0 (2)	0.0 (1)	0.3 (4)
WPSH143	Mudstone	Up. Ore	141.5	145.5	1.88	22.5 (8)	31.0 (8)	11 (1)	3.0 (7)	13.2 (8)	4.0 (6)	4.6 (9)	7 (1)	0.6 (1)	2.0 (6)	.	0.0 (3)	0.0 (1)	0.9 (4)
WPSH140	Phosphorite	Up. Ore	137	141.5	1.46	68 (1)	17.8 (4)	3 (1)	0.1 (8)	5.1 (6)	0.3 (7)	0.5 (7)	1.2 (4)	2.0 (3)	0.6 (5)	.	0.1 (2)	0.1 (1)	0.6 (3)
WPSH136	Dolostone	Up. Ore	135.5	137	1.67	29.2 (7)	28.9 (7)	5 (1)	0.5 (7)	10.5 (7)	2.7 (6)	1.2 (6)	1.2 (6)	3.9 (9)	15.9 (6)	.	1.4 (2)	0.2 (1)	0.0 (3)
WPSH134	Phosphorite	Up. Ore	132	135.5	1.46	89 (2)	7.3 (2)	3 (1)	0.1 (8)	0.2 (6)	0.1 (7)	0.1 (7)	0.0 (4)	0.5 (3)	0.4 (5)	.	0.0 (2)	0.0 (1)	0.1 (3)
WPSH125	Phosphorite	Up. Ore	121	132	1.65	61 (1)	26.6 (5)	5.0 (9)	0.1 (7)	2.8 (6)	0.1 (6)	3.5 (7)	0.1 (3)	0.1 (3)	0.4 (5)	.	0.0 (2)	0.0 (1)	0.0 (3)
WPSH119	Dolostone	Mid. Waste	118	121	1.81	2.6 (4)	19.3 (4)	6 (1)	0.1 (7)	13.0 (5)	1.8 (1)	9.3 (6)	46.7 (9)	1.2 (3)	0.0 (5)	.	0.0 (2)	0.0 (1)	0.0 (3)
WPSH115	Mudstone	Mid. Waste	111	118	1.44	86 (3)	4.7 (3)	9 (3)	0 (1)	0.1 (7)	0.1 (8)	0.1 (8)	0.0 (4)	0.3 (3)	0.1 (6)	.	0.0 (3)	0.1 (1)	0.0 (4)
WPSH110	Dolostone	Mid. Waste	109	111	1.9	31.8 (7)	37 (7)	6.6 (4)	0.1 (7)	5.1 (6)	7.8 (6)	6.4 (7)	2.3 (8)	2.4 (3)	0.4 (5)	.	0.0 (2)	0.0 (1)	0.1 (3)
WPSH107	Mudstone	Mid. Waste	105	109	1.62	30.4 (8)	47 (1)	2.9 (2)	0.1 (9)	8.9 (9)	2 (1)	8.1 (9)	0.0 (4)	0.0 (6)	0.7 (6)	.	0.1 (3)	0.0 (1)	0.0 (4)
WPSH097	Mudstone	Mid. Waste	97	105	1.88	17.4 (6)	42 (1)	7 (1)	0.1 (8)	11.4 (8)	4.9 (9)	15 (1)	0.3 (4)	0.0 (3)	1.7 (5)	.	0.0 (2)	0.0 (1)	0.7 (3)
WPSH096	Phosphorite	Mid. Waste	94.5	97	1.64	57 (2)	19.9 (6)	3 (2)	2 (1)	4 (1)	1.6 (8)	3.3 (1)	0.0 (5)	0.0 (4)	1.4 (7)	.	1.6 (3)	0.0 (1)	6.1 (4)
WPSH093	Dolostone	Mid. Waste	90.5	94.5	1.7	20.0 (6)	19.0 (4)	3.7 (9)	0.1 (8)	9.0 (5)	1.5 (6)	2.4 (7)	32.0 (8)	7.7 (6)	0.0 (5)	.	3.5 (2)	0.1 (1)	1.5 (3)
WPSH090	Mudstone	Mid. Waste	87	90.5	1.54	24.4 (9)	37 (1)	7 (2)	0 (1)	11.7 (8)	4 (1)	10 (2)	0.0 (4)	0.1 (3)	0.0 (6)	.	3.6 (3)	0.2 (1)	1.4 (4)
WPSH085	Mudstone	Mid. Waste	84	87	1.73	1.4 (4)	29.0 (8)	6.7 (9)	0.1 (8)	13.3 (7)	3 (1)	12 (1)	28.2 (9)	3.7 (6)	0.5 (5)	.	0.8 (2)	0.0 (1)	1.3 (3)
WPSH083	Mudstone	Mid. Waste	82	84	1.58	30 (1)	19.5 (8)	12 (3)	1 (1)	5.3 (7)	1.8 (9)	0.1 (9)	5.1 (5)	20 (1)	0.2 (7)	.	3.8 (3)	0.5 (1)	1.4 (4)
WPSH080	Phosphorite	Low. Ore	78	82	1.81	22 (1)	18.3 (8)	17 (3)	0.5 (9)	6.3 (6)	1.8 (8)	5 (1)	3.3 (4)	21 (1)	2.3 (5)	.	2.1 (2)	0.0 (1)	1.1 (4)
WPSH071	Dolostone	Low. Ore	69	78	1.74	6.7 (6)	19.0 (7)	12 (3)	0.1 (7)	3.0 (5)	0.8 (7)	23 (1)	24 (1)	7.4 (4)	2.3 (4)	.	0.0 (2)	0.0 (1)	0.6 (3)

Table 1d: (continued)

Sample	Lithology	Unit	Interval base	Interval top	χ^2	apt	qtz	musc	ill	alb	orth	budd	dolo	calc	kaol	mont	pyr	sphal	gyp
WPSH066	Mudstone	Low. Ore	61.5	69	1.77	12.8 (6)	36 (1)	9 (1)	0.1 (9)	14.1 (8)	3 (1)	13 (1)	0.2 (4)	4.1 (3)	2.3 (6)	.	2.1 (2)	0.1 (1)	3.2 (3)
WPSH060	Phosphorite	Low. Ore	58.5	61.5	1.77	13.3 (6)	33.6 (9)	14 (1)	0.1 (9)	8.2 (6)	2.3 (8)	16 (1)	3.0 (9)	4.0 (7)	1.5 (5)	.	3.6 (2)	0.6 (1)	0.4 (4)
WPSH058	Dolostone	Low. Ore	57	58.5	1.61	22.6 (7)	19.0 (5)	7.9 (9)	0.1 (8)	4.6 (9)	0.1 (8)	10.4 (8)	5.4 (4)	27.7 (8)	0.2 (5)	.	2.0 (2)	0.0 (1)	0.1 (4)
WPSH053	Phosphorite	Low. Ore	50	57	1.61	38.5 (9)	12.3 (4)	5.5 (4)	1.8 (9)	3.0 (7)	3.8 (8)	3.3 (9)	3.0 (5)	23.9 (8)	1.5 (6)	.	0.7 (3)	0.0 (1)	2.6 (4)
WPSH047	Phosphorite	Low. Ore	44	50	1.52	77 (2)	9.2 (4)	3.6 (5)	1 (1)	0.1 (8)	0.5 (9)	1.3 (1)	1.2 (5)	4.9 (2)	0.8 (7)	.	0.1 (3)	0.0 (1)	0.9 (5)
WPSH042	Mudstone	Low. Ore	40	44	1.59	10.0 (6)	8.2 (3)	0.1 (3)	0.1 (8)	3.0 (6)	3.1 (7)	1.9 (7)	64 (1)	7.8 (6)	0.0 (6)	.	0.0 (2)	0.0 (1)	1.5 (3)
WPSH038	Mudstone	Low. Ore	34.5	40	1.69	27.4 (8)	27.9 (7)	8 (1)	0.1 (8)	5.5 (6)	6.5 (7)	4.4 (7)	15.0 (9)	0.2 (3)	1.5 (5)	.	2.1 (2)	0.0 (1)	1.7 (3)
WPSH034	Dolostone	Low. Ore	32.5	34.5	1.97	14.5 (9)	10.4 (4)	4 (2)	0 (1)	3 (1)	0.5 (3)	2.1 (8)	37 (1)	25 (1)	1.4 (7)	.	0.5 (3)	0.3 (1)	2.0 (4)
WPSH031	Mudstone	Low. Ore	29	32.5	1.72	34 (1)	20.9 (6)	11 (1)	0 (1)	7.0 (7)	5.6 (8)	2.9 (8)	11.8 (9)	0.9 (3)	0.3 (6)	.	4.0 (4)	0.0 (1)	1.6 (4)
WPSH027	Dolostone	Low. Ore	25	29	1.34	6.5 (6)	9.2 (3)	0 (1)	2.7 (9)	2.0 (6)	2.5 (7)	1.0 (8)	11.9 (9)	63 (1)	0.6 (6)	.	0.0 (2)	0.0 (1)	0.7 (4)
WPSH022	Phosphorite	Low. Ore	20	25	1.54	68 (2)	16.1 (5)	5 (1)	0 (1)	1.4 (7)	3 (1)	0.1 (9)	4.6 (5)	0.0 (4)	0.7 (6)	.	0.1 (3)	0.0 (1)	1.2 (4)
WPSH019	Phosphorite	Low. Ore	18	20	1.55	9.4 (6)	15.7 (4)	3 (1)	1.0 (9)	4.9 (6)	2.6 (7)	0.8 (7)	12.6 (9)	47 (1)	1.5 (6)	.	0.0 (2)	0.5 (1)	0.6 (4)
WPSH015	Phosphorite	Low. Ore	13	18	1.4	87 (2)	10.2 (3)	0 (1)	0.1 (9)	0.1 (7)	0.9 (7)	0.1 (8)	0.4 (4)	0.0 (3)	0.0 (6)	.	0.0 (2)	0.0 (1)	0.4 (4)
WPSH011	Limestone	Low. Ore	10	13	1.46	40 (1)	15.8 (4)	3 (1)	1.1 (8)	0.1 (6)	0.5 (7)	0.1 (8)	7.6 (9)	29.5 (9)	2.5 (6)	.	0.0 (2)	0.0 (1)	0.5 (4)
WPSH008	Phosphorite	Low. Ore	7	10	1.44	69 (1)	19.3 (5)	3.1 (3)	1.6 (9)	0.1 (7)	1.6 (8)	0.5 (9)	0.0 (5)	0.6 (8)	2.9 (6)	.	0.9 (3)	0.0 (1)	0.4 (4)
WPSH006	Dolostone	Low. Ore	6	7	1.52	19.3 (6)	6.8 (3)	0.1 (6)	2.6 (9)	0.4 (6)	1.1 (9)	0.0 (6)	61 (1)	7.3 (2)	0.4 (6)	.	0.0 (2)	0.3 (1)	0.6 (4)
WPSH003	Phosphorite	Low. Ore	0.5	6	1.56	88 (3)	3.5 (4)	5 (2)	1 (1)	0.1 (9)	0 (1)	0 (1)	0.0 (5)	0.8 (4)	0.7 (8)	.	0.7 (3)	0.0 (1)	0.8 (5)
WPSH00.5	Phosphorite	Low. Ore	0	0.5	1.54	70 (2)	23.0 (7)	4 (2)	1 (1)	0.1 (7)	0.5 (8)	0.3 (8)	0.2 (4)	0.0 (4)	0.1 (6)	.	0.1 (3)	0.0 (1)	0.0 (4)
Nonchannel samples, see text:																			
WPSHG001	Uraniferous (?) sample				1.57	0.5 (6)	22.7 (6)	0.1 (4)	1 (1)	0.3 (4)	4.6 (9)	0.1 (9)	62 (1)	6.8 (6)	0.5 (7)	0.0 (1)	0.1 (3)	0.0 (1)	1.3 (4)
WPSHG002	Grandeur Tongue, composite sample near sect. H				1.42	80 (2)	2.7 (3)	0.8 (5)	0.2 (9)	0.1 (4)	2 (1)	2 (2)	2.5 (2)	8.6 (6)	1.3 (7)	0.2 (1)	0.0 (3)	0.0 (1)	0.6 (4)
WPSHU001	Fish-scale chips from near sample WPSHG001				1.34	88 (3)	3.3 (2)	7 (3)	0.2 (9)	0.8 (7)	0.1 (8)	0.1 (8)	0.0 (4)	0.3 (3)	0 (6)	0.1 (1)	0.0 (3)	0.1 (1)	0.1 (4)

Figure 3a: Apatite content of samples from measured sections E and F at Rasmussen Ridge, and measured sections G and H from the Smoky Canyon Mine, Sage Creek area of the Webster Range. Due to a lack of stratigraphic uniformity, the three sections cannot be directly compared unit-to-unit, however, the recognized ore and waste zone boundaries are shown for reference.

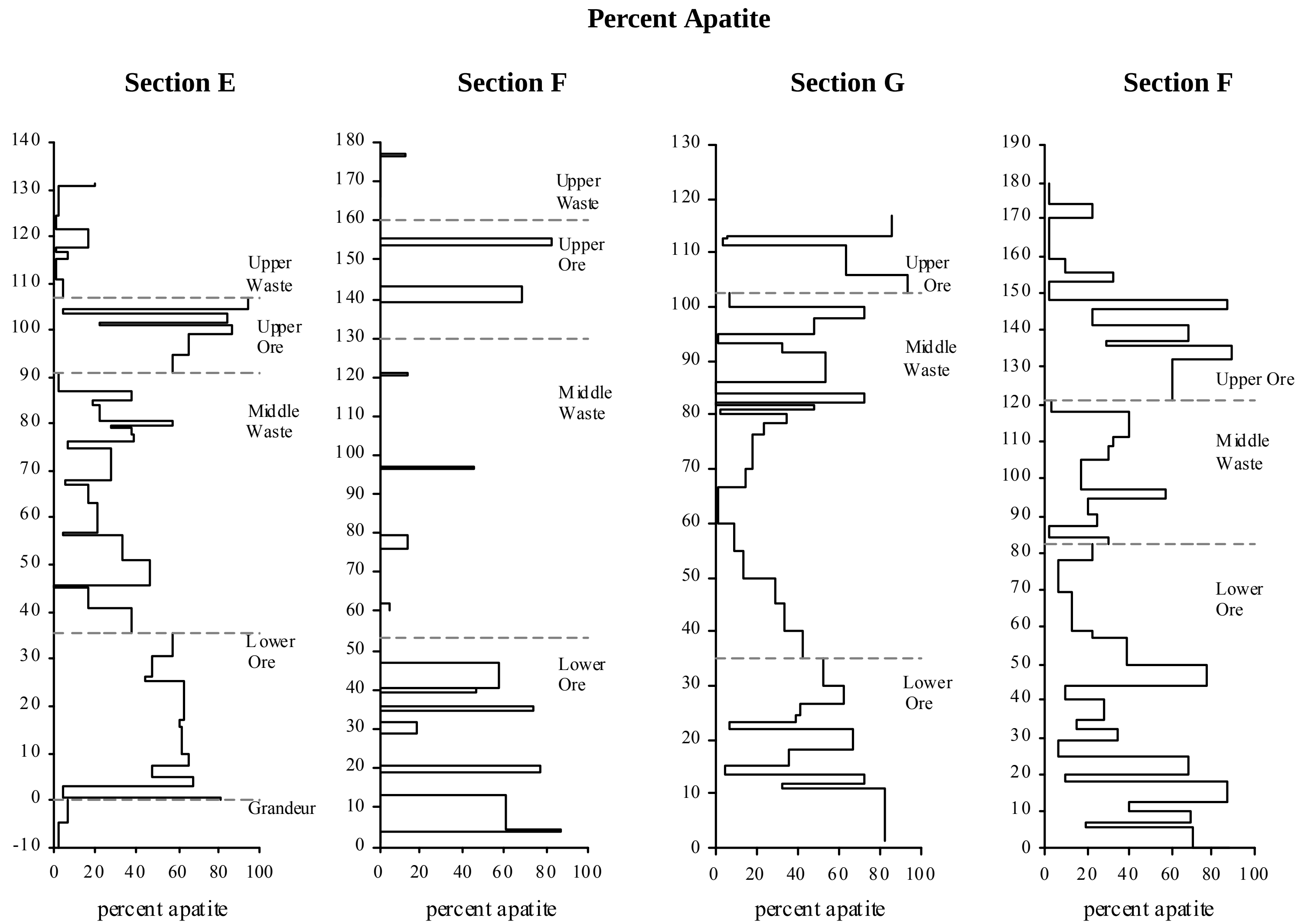

Figure 3b: Quartz content of samples from measured sections E and F at Rasmussen Ridge, and measured sections G and H from the Smoky Canyon Mine, Sage Creek area of the Webster Range. Due to a lack of stratigraphic uniformity, the three sections cannot be directly compared unit-to-unit, however, the recognized ore and waste zone boundaries are shown for reference.

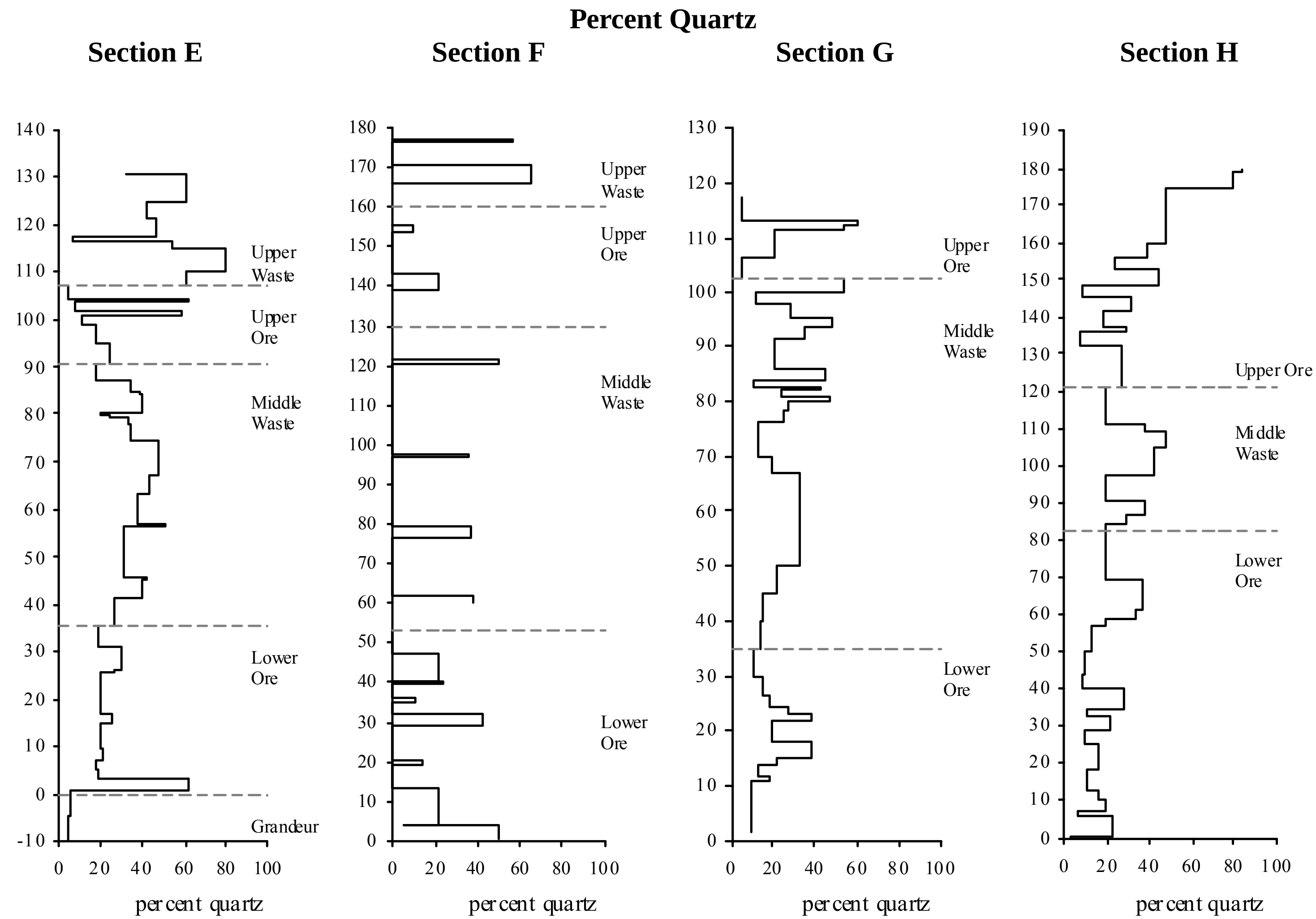

Figure 3c: Muscovite + illite content of samples from measured sections E and F at Rasmussen Ridge, and measured sections G and H from the Smoky Canyon Mine, Sage Creek area of the Webster Range. Due to a lack of stratigraphic uniformity, the three sections cannot be directly compared unit-to-unit, however, the recognized ore and waste zone boundaries are shown for reference.

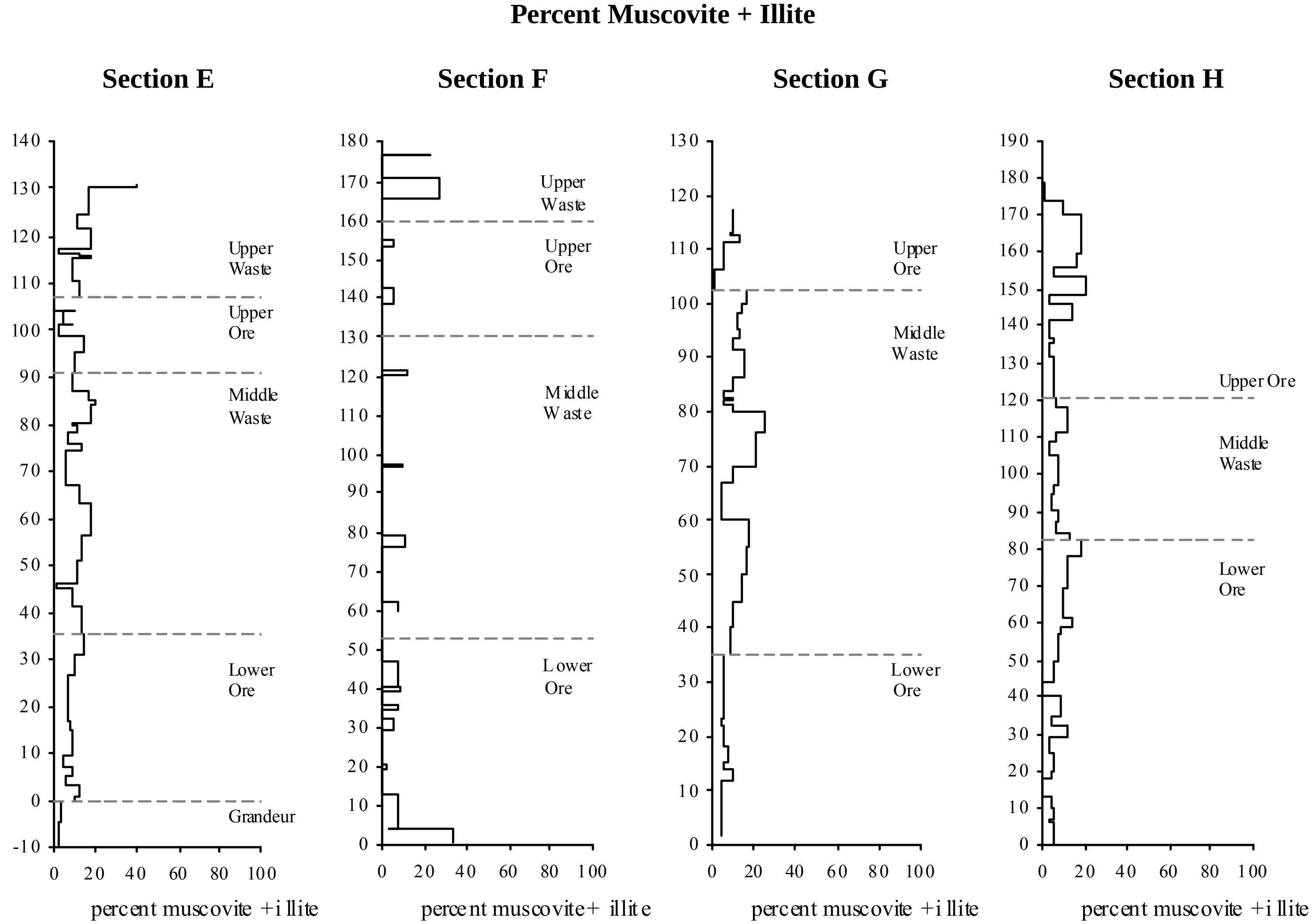

Figure 3d: Total feldspar (albite + orthoclase + buddingtonite) content of samples from measured sections E and F at Rasmussen Ridge, and measured sections G and H from the Smoky Canyon Mine, Sage Creek area of the Webster Range. Due to a lack of stratigraphic uniformity, the three sections cannot be directly compared unit-to-unit, however, the recognized ore and waste zone boundaries are shown for reference.

Percent Feldspars (Albite + Orthoclase + Buddingtonite)

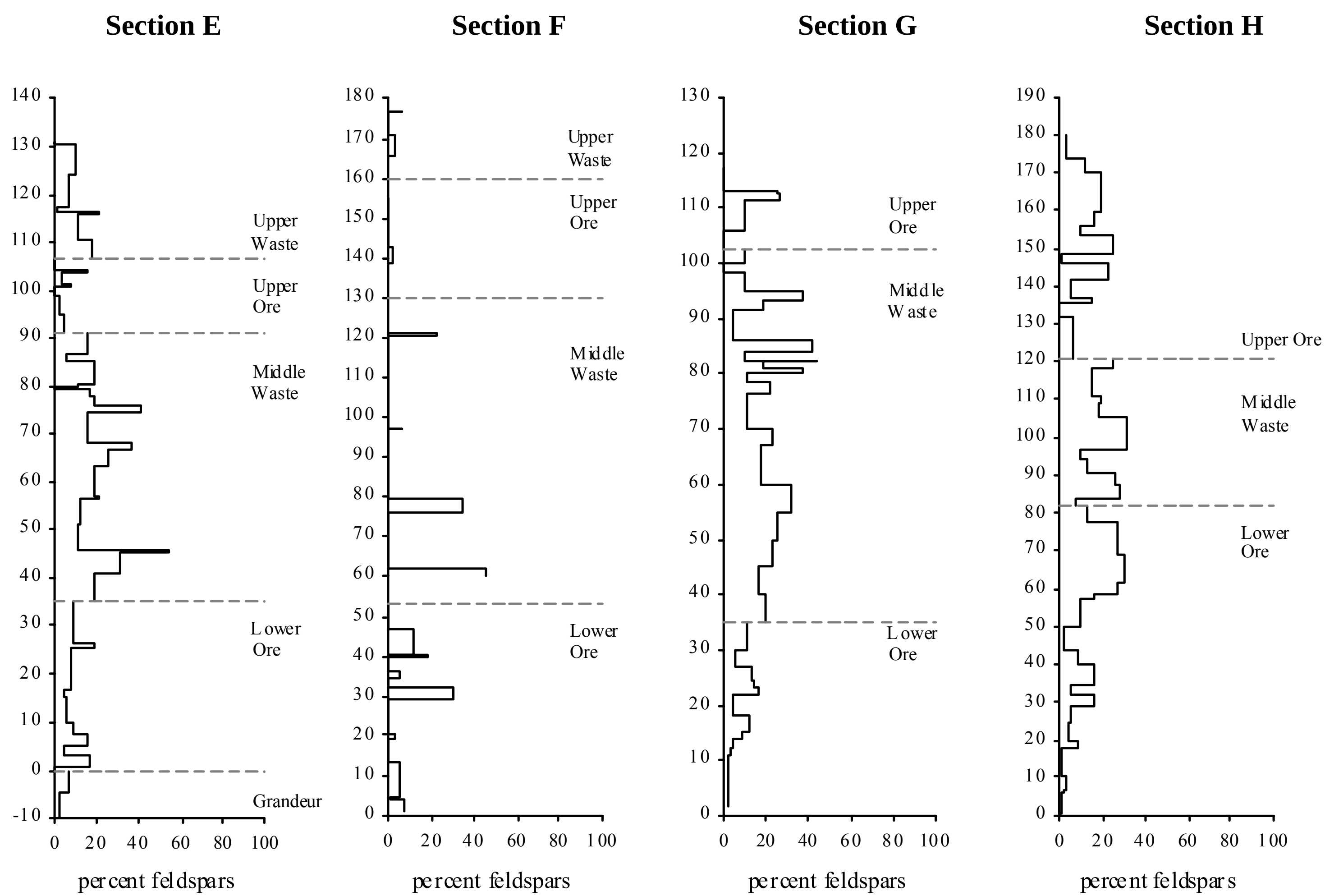

Figure 3e: Buddingtonite content of samples from measured sections E and F at Rasmussen Ridge, and measured sections G and H from the Smoky Canyon Mine, Sage Creek area of the Webster Range. Due to a lack of stratigraphic uniformity, the three sections cannot be directly compared unit-to-unit, however, the recognized ore and waste zone boundaries are shown for reference.

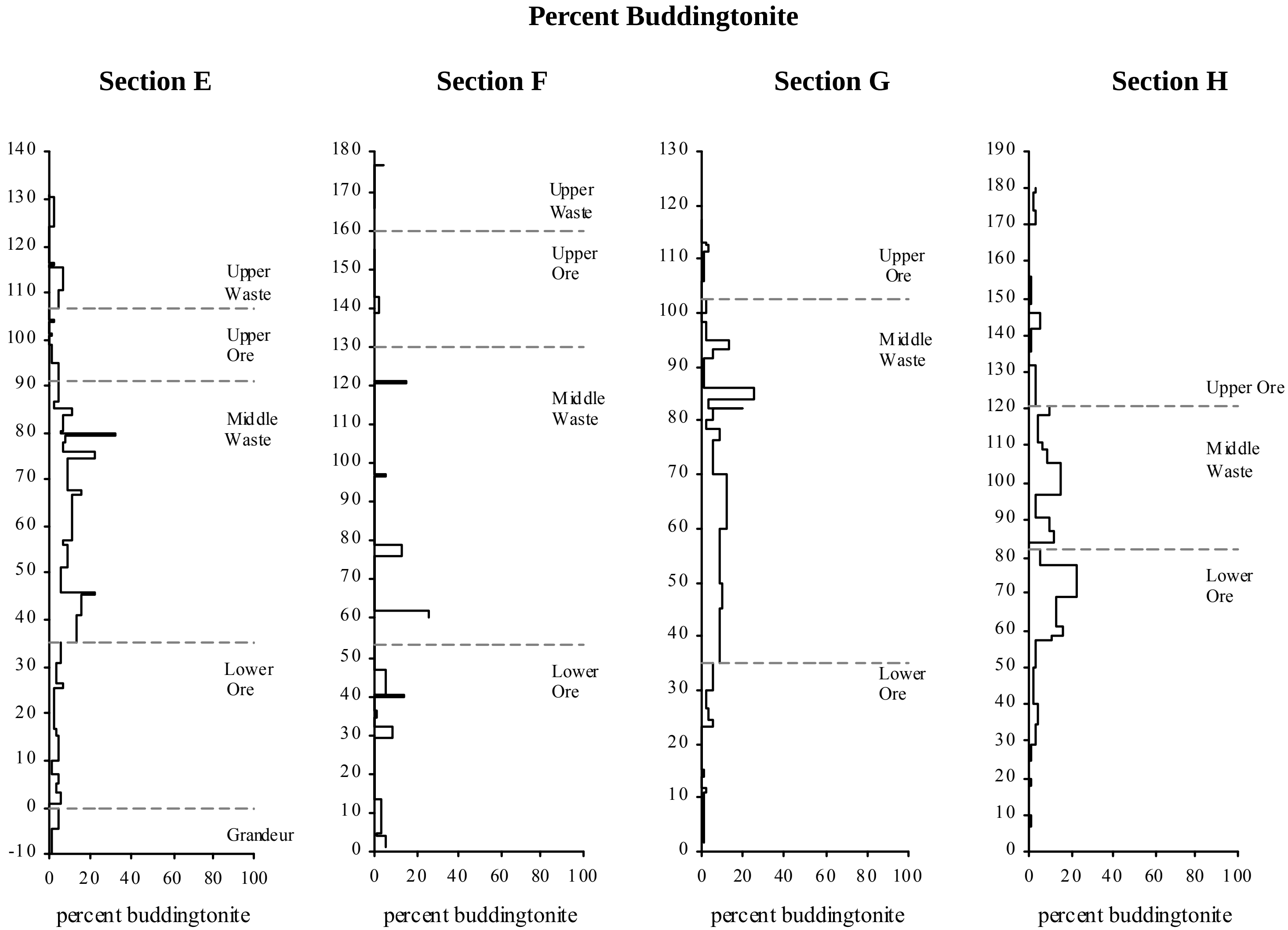

Figure 3f: Dolomite content of samples from measured sections E and F at Rasmussen Ridge, and measured sections G and H from the Smoky Canyon Mine, Sage Creek area of the Webster Range. Due to a lack of stratigraphic uniformity, the three sections cannot be directly compared unit-to-unit, however, the recognized ore and waste zone boundaries are shown for reference.

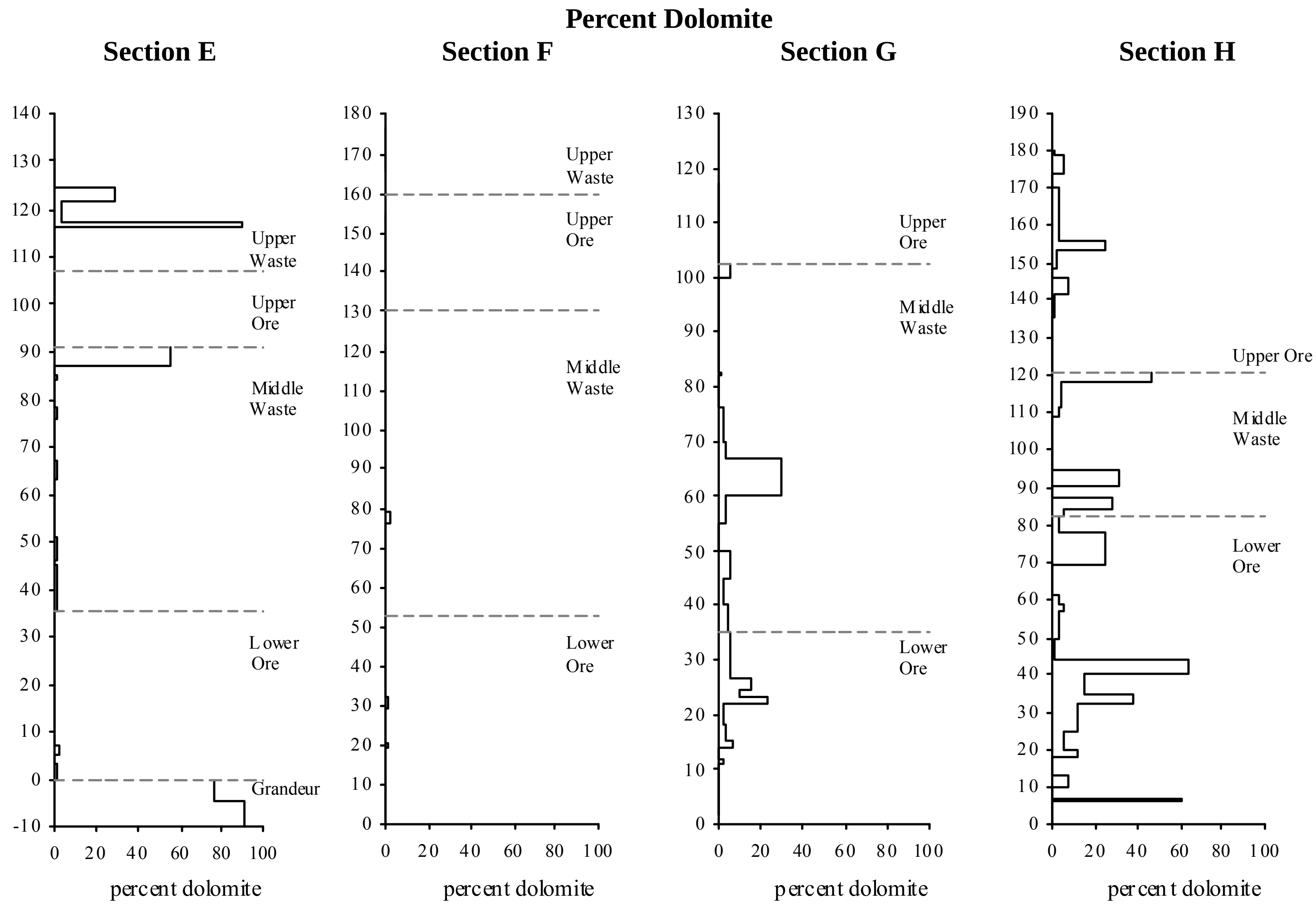

Figure 3g: Calcite content of samples from measured sections E and F at Rasmussen Ridge, and measured sections G and H from the Smoky Canyon Mine, Sage Creek area of the Webster Range. Due to a lack of stratigraphic uniformity, the three sections cannot be directly compared unit-to-unit, however, the recognized ore and waste zone boundaries are shown for reference.

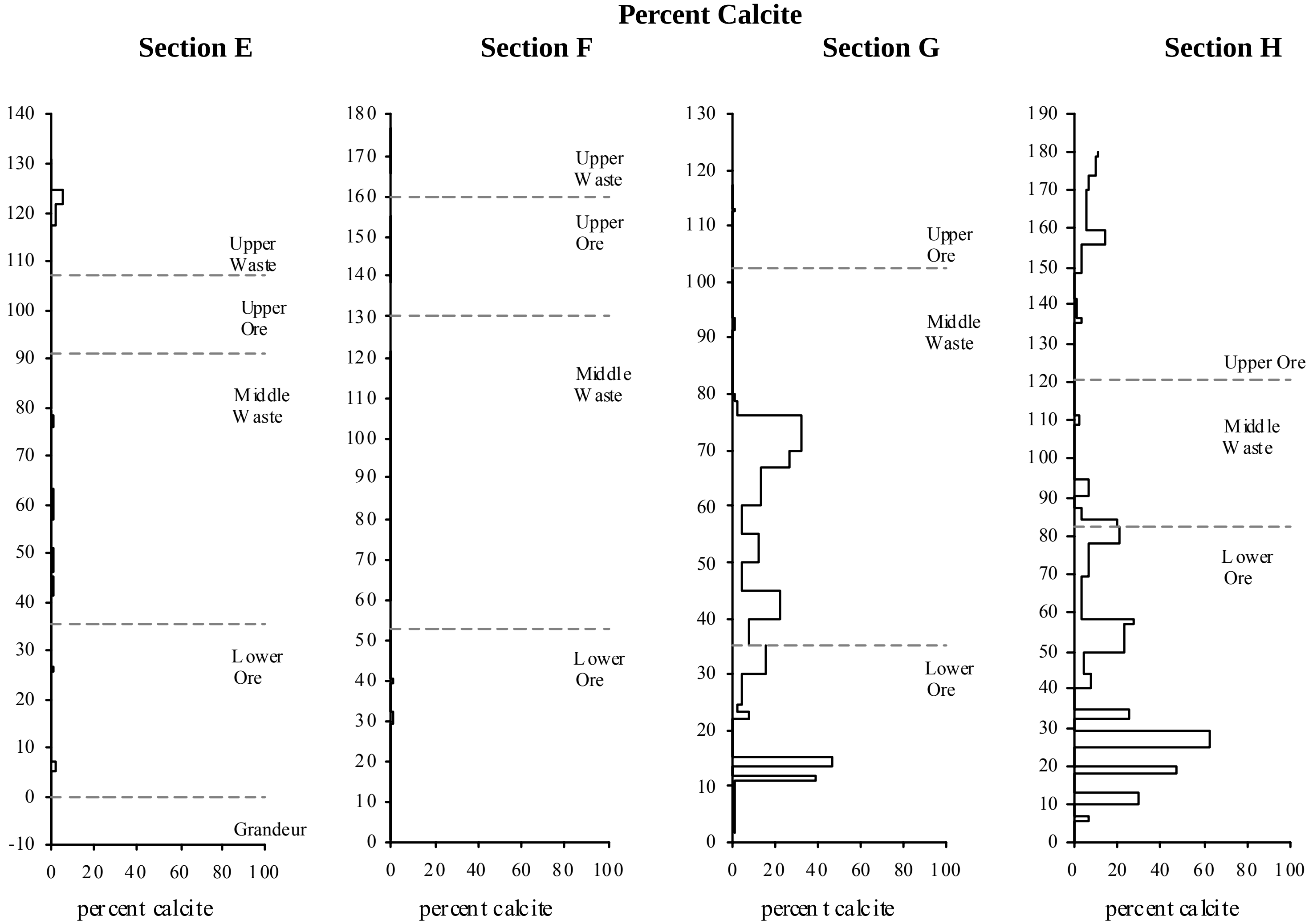

Table 2a: Extent of substitution of CO_3^{2-} for PO_4^{3-} in fluorapatite for measured section E samples based on the equation by Schuffert and others (1990).

$$y = 10.643x^2 - 52.512x + 56.986$$

where y = the wt. % CO_3^{2-}, and x = $\Delta 2\theta_{(004)-(410)}$ for fluorapatite, as calculated by cell parameters obtained from Rietveld analysis.

Sample	Lithology	Unit	Interval base	Interval top	% apt	A-cell	C-cell	% CO_3^{2-}
WPSE131	Carbon Seam	Up. Waste	130.5	131.0	20.2	9.3624	6.8908	2.04
WPSE126	Mudstone	Up. Waste	124.5	130.5	2.4	.	.	.
WPSE123	Mudstone	Up. Waste	121.3	124.5	1.2	.	.	.
WPSE120	Mudstone	Up. Waste	117.5	121.3	16.4	9.3604	6.8919	2.47
WPSE117	Dolostone	Up. Waste	116.5	117.5	1			
WPSE116.5	Siltstone	Up. Waste	116.0	116.5	6.5	9.3639	6.8936	2.33
WPSE116	Carbon Seam	Up. Waste	115.3	116.0	6.3	9.3715	6.9024	2.93
WPSE113	Mudstone	Up. Waste	110.5	115.3	0.8	.	.	.
WPSE109	Mudstone	Up. Waste	107.0	110.5	4.4	9.3717	6.8804	-0.65
WPSE106	Phosphorite	Up. Ore	104.3	107.0	94	9.3577	6.8898	2.44
WPSE104	Mudstone	Up. Ore	103.8	104.3	4.2	.	.	.
WPSE103	Phosphorite	Up. Ore	101.5	103.8	84	9.3610	6.8912	2.28
WPSE101	Phosphorite	Up. Ore	101.0	101.5	21.8	9.3587	6.8916	2.63
WPSE100	Phosphorite	Up. Ore	98.8	101.0	87	9.3598	6.8907	2.34
WPSE097	Phosphorite	Up. Ore	95.1	98.8	65	9.3567	6.8919	2.94
WPSE093	Phosphorite	Up. Ore	90.7	95.1	58	9.3586	6.8909	2.52
WPSE089	Siltstone	Mid. Waste	87.0	90.7	2.4	.	.	.
WPSE086	Siltstone	Mid. Waste	85.0	87.0	37	9.3582	6.8918	2.73
WPSE085	Siltstone	Mid. Waste	84.1	85.0	19.1	9.3618	6.8895	1.89
WPSE083	Siltstone	Mid. Waste	80.3	84.1	21.6	9.3617	6.8909	2.14
WPSE080	Phosphorite	Mid. Waste	79.8	80.3	57	9.3599	6.8897	2.15
WPSE79.5	Carbon Seam	Mid. Waste	79.3	79.8	28	9.3575	6.8918	2.82
WPSE079	Phosphorite	Mid. Waste	78.0	79.3	37	9.3598	6.8921	2.58
WPSE077	Phosphorite	Mid. Waste	76.0	78.0	38.5	9.3599	6.8891	2.05
WPSE075	Siltstone	Mid. Waste	74.5	76.0	6.3	9.3693	6.9071	4.06
WPSE071	Siltstone	Mid. Waste	68.0	74.5	27.6	9.3598	6.8911	2.41
WPSE067	Phosphorite	Mid. Waste	67.0	68.0	5.8	9.3632	6.8896	1.74
WPSE065	Siltstone	Mid. Waste	63.3	67.0	16.9	9.3605	6.8905	2.22
WPSE061	Mudstone	Mid. Waste	57.0	63.3	21	9.3573	6.8897	2.47
WPSE057	Mudstone	Mid. Waste	56.3	57.0	4.4	.	.	.
WPSE055	Mudstone	Mid. Waste	51.0	56.3	33	9.3599	6.8921	2.57
WPSE048	Mudstone	Mid. Waste	46.0	51.0	46	9.3610	6.8923	2.47

Table 2a: (continued)

Sample	Lithology	Unit	Interval base	Interval top	% apt	A-cell	C-cell	% CO_3^{2-}
WPSE046	Mudstone	Mid. Waste	45.3	46	0.2	.	.	.
WPSE043	Mudstone	Mid. Waste	41	45.3	16.3	9.3624	6.89	1.9
WPSE038	Mudstone	Mid. Waste	35.3	41	57	9.3614	6.8932	2.57
WPSE033	Phosphorite	Low. Ore	30.7	35.3	47	9.3619	6.8917	2.25
WPSE029	Siltstone	Low. Ore	26.3	30.7	38	9.3596	6.8897	2.19
WPSE026	Mudstone	Low. Ore	25.3	26.3	45	9.3602	6.8915	2.43
WPSE021	Phosphorite	Low. Ore	16.7	25.3	63	9.3634	6.8928	2.26
WPSE016	Phosphorite	Low. Ore	15.3	16.7	60	9.3626	6.8908	2.01
WPSE012	Phosphorite	Low. Ore	9.5	15.3	62	9.3615	6.8898	1.98
WPSE008	Mudstone	Low. Ore	5	9.5	65	9.3596	6.89	2.24
WPSE006	Mudstone	Low. Ore	6.5	7	47	9.3624	6.8908	2.04
WPSE004	Phosphorite	Low. Ore	3	5	67	9.3559	6.8905	2.79
WPSE002	Mudstone	Footwall bed	0.5	3	4.8	.	.	.
WPSE00.5	Phosphorite	Fish-scale	0	0.5	81	9.36	6.8929	2.7
WPSE-0.5	Dolostone	Grandeur	-5	0	6.8	9.3784	6.8851	-0.65
WPSE-10	Dolostone	Grandeur	-10	-5	2.6	.	.	.

Table 2b: Extent of substitution of CO_3^{2-} for PO_4^{3-} in fluorapatite for measured section F samples based on the equation by Schuffert and others (1990).

$$y = 10.643x^2 - 52.512x + 56.986$$

where y = the wt. % CO_3^{2-}, and x = $\Delta 2\theta_{(004)-(410)}$ for fluorapatite, as calculated by cell parameters obtained from Rietveld analysis.

Sample	Lithology	Unit	Interval base	Interval top	% apt	A-cell	C-cell	% CO_3^{2-}
WPSF177	Carbon Seam	Up. Waste	176.5	176.9	13.1	9.3554	6.8841	1.75
WPSF167	Carbon Seam	Up. Waste	165.4	170.6	0.9	.	.	.
WPSF154	Phosphorite	Up. Ore	153.2	155.2	83	9.3584	6.8903	2.44
WPSF141	Phosphorite	Up. Ore	139	142.9	69	9.3557	6.8907	2.85
WPSF121	Phosphorite	Mid. Waste	120.4	121.2	14	9.3616	6.8989	3.57
WPSF097	Phosphorite	Mid. Waste	96.6	97.2	45	9.3597	6.8923	2.63
WPSF078	Siltstone	Mid. Waste	76.4	79.4	13.6	9.3629	6.8889	1.66
WPSF061	Phosphorite	Mid. Waste	60	62	5	9.3622	6.8861	1.28
WPSF045	Mudstone	Low. Ore	40.5	47	57	9.3629	6.8900	1.84
WPSF040	Mudstone	False Cap	39.6	40.5	47	9.3595	6.8901	2.27
WPSF035	Phosphorite	Low. Ore	34.8	36	74	9.3661	6.8897	1.41
WPSF031	Mudstone	Low. Ore	29.25	31.9	18	9.3599	6.8870	1.70
WPSF020	Phosphorite	Low. Ore	19.2	20.5	78	9.3616	6.8900	2.00
WPSF015	Mudstone	Low. Ore	4.5	13.2	61	9.3622	6.8886	1.69
WPSF004	Phosphorite	Low. Ore	4	4.5	88	9.3581	6.8906	2.53
WPSF001	Mudstone	Footwall	1	4	0.2	.	.	.

Table 2c: Extent of substitution of CO_3^{2-} for PO_4^{3-} in fluorapatite for measured section G samples based on the equation by Schuffert and others (1990).

$$y = 10.643x^2 - 52.512x + 56.986$$

where y = the wt. % CO_3^{2-}, and x = $\Delta 2\theta_{(004)-(410)}$ for fluorapatite, as calculated by cell parameters obtained from Rietveld analysis.

Sample	Lithology	Unit	Interval base	Interval top	% apt	A-cell	C-cell	% CO_3^{2-}
WPSG115	Phosphorite	Up. Ore	113	117	86	9.3608	6.8922	2.47
WPSG113	Mudstone	Up. Ore	112.5	113	5.6	9.3618	6.8834	0.89
WPSG112.5	Mudstone	Up. Ore	111.5	112.5	3.3	.	.	.
WPSG110	Phosphorite	Up. Ore	106	111.5	64	9.3597	6.8913	2.45
WPSG105	Phosphorite	Up. Ore	102.5	106	93	9.3587	6.8921	2.72
WPSG101	Mudstone	Up. Ore	100	102.5	6.6	9.3647	6.8863	1.02
WPSG098	Mudstone	Mid. Waste	95	100	72	9.3607	6.8915	2.37
WPSG097	Mudstone	Mid. Waste	93.5	100	48	9.3570	6.8905	2.65
WPSG093	Dolostone	Mid. Waste	91.5	93.5	1.5	.	.	.
WPSG090	Mudstone	Mid. Waste	86	91.5	32.3	9.3613	6.8900	2.04
WPSG085	Phosphorite	Mid. Waste	84	86	54	9.3612	6.8921	2.41
WPSG083	Mudstone	Mid. Waste	82.5	84	0	.	.	.
WPSG82.5	Phosphorite	Mid. Waste	82	82.5	72	9.3542	6.8928	3.42
WPSG082	Mudstone	Mid. Waste	81	82	0.2	.	.	.
WPSG080	Phosphorite	Mid. Waste	80	81	48	9.3591	6.8918	2.62
WPSG079	Mudstone	Mid. Waste	78.5	80	2.3	.	.	.
WPSG078	Phosphorite	Mid. Waste	76.5	78.5	35	9.3652	6.8900	1.57
WPSG077	Mudstone	Mid. Waste	70	80	24	9.3626	6.8947	2.69
WPSG073	Mudstone	Mid. Waste	70	76.5	18	9.3652	6.8947	2.36
WPSG069	Mudstone	Mid. Waste	67	70	15.2	9.3663	6.8960	2.45
WPSG065	Dolostone	Mid. Waste	60	67	1.1	.	.	.
WPSG057	Mudstone	Mid. Waste	55	60	9.4	9.3624	6.8876	1.50
WPSG052	Mudstone	Mid. Waste	50	55	13	9.3596	6.8931	2.78
WPSG047	Dolostone	Mid. Waste	45	50	30	9.3611	6.8894	1.96
WPSG042	Dolostone	Mid. Waste	40	45	33	9.3646	6.8931	2.16
WPSG037	Dolostone	Mid. Waste	35	40	43	9.3578	6.8916	2.74
WPSG033	Mudstone	Low. Ore	30	35	52	9.364	6.8963	2.79
WPSG028	Phosphorite	Low. Ore	26.8	30	63	9.3587	6.8914	2.60
WPSG026	Dolostone	Low. Ore	24.5	26.8	41	9.3597	6.8903	2.28
WPSG024	Mudstone	Low. Ore	23.3	24.5	39	9.3549	6.8924	3.26
WPSG023	Dolostone	Low. Ore	22	23.3	6.4	9.3623	6.8866	1.35
WPSG020	Phosphorite	Low. Ore	18.3	22	67	9.3589	6.8907	2.45
WPSG016	Siltstone	Low. Ore	15	18.3	36.6	9.3578	6.8918	2.78
WPSG014	Dolostone	Low. Ore	14	15	4.9	9.3652	6.8940	2.24
WPSG013	Phosphorite	Low. Ore	11.9	14	73	9.3687	6.8969	2.31

Table 2c: (continued)

Sample	Lithology	Unit	Interval base	Interval top	% apt	A-cell	C-cell	% CO_3^{2-}
WPSG011	Dolostone	Low. Ore	11	11.9	32	9.3707	6.8938	1.55
WPSG008	Phosphorite	Low. Ore	1.5	11	83	9.357	6.8904	2.63

Table 2d: Extent of substitution of CO_3^{2-} for PO_4^{3-} in fluorapatite for measured section H samples based on the equation by Schuffert and others (1990).

$$y = 10.643x^2 - 52.512x + 56.986$$

where y = the wt. % CO_3^{2-}, and x = $\Delta 2\theta_{(004)-(410)}$ for fluorapatite, as calculated by cell parameters obtained from Rietveld analysis.

Sample	Lithology	Unit	Interval base	Interval top	% apt	A-cell	C-cell	% CO_3^{2-}
WPSH180	Chert	Rex Chert	178	180	1.6	.	.	.
WPSH176	Dolostone	Up. Ore	174	178	1.6	.	.	.
WPSH172	Dolostone	Up. Ore	170	174	22.9	9.3589	6.8922	2.71
WPSH165	Dolostone	Up. Ore	159.5	170	1.6	.	.	.
WPSH158	Mudstone	Up. Ore	156	159.5	8.8	9.3707	6.8924	1.32
WPSH155	Phosphorite	Up. Ore	153	156	32	9.3565	6.8912	2.84
WPSH151	Mudstone	Up. Ore	148.5	153	1.7	.	.	.
WPSH147	Phosphorite	Up. Ore	145.5	148.5	87	9.3641	6.8944	2.45
WPSH143	Mudstone	Up. Ore	141.5	145.5	22.5	9.3626	6.8945	2.65
WPSH140	Phosphorite	Up. Ore	137	141.5	68.2	9.3628	6.8931	2.38
WPSH136	Dolostone	Up. Ore	135.5	137	29.2	9.3684	6.8860	0.55
WPSH134	Phosphorite	Up. Ore	132	135.5	89	9.3621	6.8941	2.64
WPSH125	Phosphorite	Up. Ore	121	132	61	9.3632	6.8941	2.51
WPSH119	Dolostone	Mid. Waste	118	121	2.6	.	.	.
WPSH115	Mudstone	Mid. Waste	111	118	40	9.3604	6.8908	2.28
WPSH110	Dolostone	Mid. Waste	109	111	31.8	9.3649	6.8910	1.77
WPSH107	Mudstone	Mid. Waste	105	109	30.4	9.3622	6.8908	2.06
WPSH097	Mudstone	Mid. Waste	97	105	17.4	9.3642	6.8960	2.72
WPSH096	Phosphorite	Mid. Waste	94.5	97	57	9.3626	6.8915	2.13
WPSH093	Dolostone	Mid. Waste	90.5	94.5	20	9.3607	6.8905	2.19
WPSH090	Mudstone	Mid. Waste	87	90.5	24.4	9.3629	6.8923	2.23
WPSH085	Mudstone	Mid. Waste	84	87	1.4	.	.	.
WPSH083	Mudstone	Mid. Waste	82	84	30	9.3643	6.8862	1.05
WPSH080	Phosphorite	Low. Ore	78	82	22	9.3646	6.8875	1.23
WPSH071	Dolostone	Low. Ore	69	78	6.7	9.3573	6.8980	3.97
WPSH066	Mudstone	Low. Ore	61.5	69	12.8	9.3625	6.8917	2.18
WPSH060	Phosphorite	Low. Ore	58.5	61.5	13.3	9.3579	6.8924	2.87
WPSH058	Dolostone	Low. Ore	57	58.5	22.6	9.3618	6.8862	1.34
WPSH053	Phosphorite	Low. Ore	50	57	38.5	9.3593	6.8919	2.61
WPSH047	Phosphorite	Low. Ore	44	50	77	9.3594	6.8908	2.41
WPSH042	Mudstone	Low. Ore	40	44	10	9.3626	6.8909	2.03
WPSH038	Mudstone	Low. Ore	34.5	40	27.4	9.3556	6.8918	3.06
WPSH034	Dolostone	Low. Ore	32.5	34.5	14.5	9.3602	6.8912	2.38
WPSH031	Mudstone	Low. Ore	29	32.5	34	9.3557	6.8901	2.74

Table 2d: (continued)

Sample	Lithology	Unit	Interval base	Interval top	% apt	A-cell	C-cell	% CO_3^{2-}
WPSH027	Dolostone	Low. Ore	25	29	6.5	9.3673	6.8932	1.85
WPSH022	Phosphorite	Low. Ore	20	25	68	9.3576	6.8891	2.33
WPSH019	Phosphorite	Low. Ore	18	20	9.4	9.3698	6.8953	1.91
WPSH015	Phosphorite	Low. Ore	13	18	87	9.3627	6.8921	2.22
WPSH011	Limestone	Low. Ore	10	13	40	9.3622	6.8937	2.56
WPSH008	Phosphorite	Low. Ore	7	10	69	9.3561	6.8904	2.75
WPSH006	Dolostone	Low. Ore	6	7	19.3	9.3382	6.8692	1.30
WPSH003	Phosphorite	Low. Ore	0.5	6	88	9.3552	6.8906	2.90
WPSH00.5	Phosphorite	Low. Ore	0	0.5	70	9.3577	6.8902	2.51

Figure 4: Carbonate substitution for phosphate in fluorapatite reported in weight percent for samples from measured sections E and F at Rasmussen Ridge, and measured sections G and H from the Smoky Canyon mine, Sage Creek area of the Webster Range. While the sections cannot be directly correlated stratigraphically, recognized ore and waste zones are noted for reference. Carbonate content is determined by the measured unit cell parameters of fluorapatite, based on the equation determined by Schuffert and others 1990: $y = 10.643x^2 - 52.512x + 56.986$
Where y = the wt. % CO_3^{2-}, and $x = \Delta 2\theta_{(004)-(410)}$ for fluorapatite, as calculated by cell parameters obtained from Rietveld analysis.

Percent Carbonate in Fluorapatite