A Normative-Calculation Procedure Used
to Determine Mineral Abundances in
Rocks from the Montpelier Canyon Section
of the Phosphoria Formation, Idaho:
A Tool in Deciphering the Minor-Element
Geochemistry of Sedimentary Rocks

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Chapter A

A Normative-Calculation Procedure Used to Determine Mineral Abundances in Rocks from the Montpelier Canyon Section of the Phosphoria Formation, Idaho: A Tool in Deciphering the Minor-Element Geochemistry of Sedimentary Rocks

By M.D. MEDRANO and D.Z. PIPER

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By M.D. Medrano and D.Z. Piper

Abstract

We have analyzed samples of the Phosphoria Formation in Montpelier Canyon, Idaho, for major and minor elements. A normative calculation, using major-element-oxide ratios, was performed to quantify the rock components. Calcite, dolomite, apatite, biogenic/diagenetic silica, and organic matter represent the marine component, whereas the detrital fraction represents the nonmarine component. The CaO/P_2O_5 ratio in apatites is 1.38, and the organic-matter/organic-carbon ratio in the rocks is 1.7. In the detrital fraction, the SiO_2/Al_2O_3 ratio is 3.8, the Fe_2O_3/Al_2O_3 ratio is 0.31, the MgO/Al_2O_3 ratio is 0.15, the CaO/Al_2O_3 ratio is 0.26, the K_2O/Al_2O_3 ratio is 0.26, the TiO_2/Al_2O_3 ratio is 0.03, and the P_2O_5/Al_2O_3 ratio is 0.01. A simple correlation of major rock components with minor elements shows that most of the minor elements are strongly associated with either organic matter or the detrital fraction, or both.

INTRODUCTION

The Phosphoria Formation, which was deposited on a Permian continental shelf (the then-west edge of the North American Continent) extending over four Western States, was studied extensively by U.S. Geological Survey geologists (see McKelvey and others, 1953a, and references therein) from the 1950's through the 1970's. It was mapped extensively, and its stratigraphy was determined. Major-element-oxide contents were determined by wet chemical analysis, and mineralogy by optical microscopy and X-ray-diffraction (XRD) spectroscopy. Minor elements, however, were not extensively examined in these early studies. The improved resolution of today's analytical techniques with respect to minor elements may further

contribute to our understanding of the geochemical environment within which this formation was deposited. For this purpose, we use a normative-calculation procedure.

This report presents a step-by-step explanation of a normative-calculation procedure that does not follow the Cross, Iddings, Pirsson, and Washington (CIPW) normative scheme used in igneous petrology, whereby the minerals calculated are fictitious and used only for comparison and classification purposes. Instead, we determine from major-element-oxide ratios in sedimentary-rock-forming components or phases the actual abundance of each mineral in each sample. Leinen (1977), Isaacs (1980), and Isaacs and others (1983) pioneered this approach in sedimentary processes. For example, Leinen developed a normative-calculation technique to determine the opal content of deep-sea sediment. First, she derived an equation for calculating the nonbiogenic-silica abundance, using linear regression analysis; this value was then subtracted from the total silica content to give the opal abundance. Isaacs (1980), in her exhaustive study of the Monterey Formation, determined the abundance of calcite, the SiO_2 content of aluminosilicates, and the aluminosilicate fraction directly from major-element-oxide analyses, using proportionality constants. The abundances of biogenic silica and detrital quartz were determined by peak intensities on XRD traces. Later, Isaacs and others (1983) derived proportionality constants for detrital quartz, dolomite, and apatite. Both Leinen (1977) and Isaacs and others (1983) used other methods as checks on their calculations, supporting the validity of this technique.

The purpose of our procedure is twofold. First, by determining quantitatively the mineral abundances in each rock sample, we can differentiate between the proportion of the rock that is of terrigenous origin and that which is of marine origin. Assuming that we can assign a fraction of the minor-element content to the terrigenous component,

we can calculate the marine component of the minor elements, which can then be compared with the marine mineral abundances. These comparisons allow us to distinguish between initial multiple marine sources and current host mineral phases for minor elements: Initial sources relate to the aqueous and organic chemistry of the depositional environment, and current phases to the pore-water and crystalline chemistry of early diagenesis (Piper, 1991).

Second, by determining quantitatively the mineral abundances and their stoichiometries for several sections of the Phosphoria Formation, we can look for possible chemical variations across the basin. For example, the terrigenous component most likely varies across the basin as a function of the distance from source, whereas the marine component may vary owing to both areal and depth-related variations in seawater chemistry.

ANALYTICAL TECHNIQUES

Laboratory-prepared powders of samples, which were collected by McKelvey and others (1953b), were analyzed for major-element oxides and minor elements (table 1). The samples are from the section of the Phosphoria Formation exposed in Montpelier Canyon, southeastern Idaho (fig. 1). Most samples are from the Meade Peak Phosphatic Shale Member (fig. 2), three are from the upper shale member (equivalent to either the cherty shale member or the Retort Phosphatic Shale Member; see McKelvey and others, 1959), and one is from the Rex Chert Member (McKelvey and others, 1959; see McKelvey and others, 1953a, for sample descriptions).

Major-element oxides (except SiO_2) in 45 samples were measured by inductively coupled plasma (ICP) atomic-emission spectroscopy after acid digestion (Lichte and others, 1987). Precision, based on multiple analyses of U.S. Geological Survey standard reference materials, is ±10 percent for concentrations greater than 10 times the lower limit of detection. Limits of detection, in weight percent, are as follows: Al_2O_3 (0.09), CaO (0.07), Fe_2O_3 (0.07), K_2O (0.1), MgO (0.08), Na_2O (0.1), P_2O_5 (0.02), and TiO_2 (0.02).

Major-element oxides (including SiO_2) in aliquots from 21 samples were measured by wavelength-dispersive X-ray-fluorescence (XRF) spectroscopy (Taggart and others, 1987) and loss on ignition (LOI). Samples were fused with lithium tetraborate, the melts cast into polished point molds, and the resulting glass disks weighed and then analyzed. Precision is better than ±5 percent and, depending on the element, as low as ±0.2 percent. ICP and XRF analyses, along with several wet chemical analyses originally reported by McKelvey and others (1953b), are listed in table 1.

Comparisons of the XRF, wet chemical, and ICP data (fig. 3) show only slight differences between the three

methods for major-element oxides. The ICP data for Al_2O_3 are about 4 percent higher, on average, than the XRF data (fig. 3A); the ICP data for P_2O_5 are virtually the same as both the XRF and wet chemical data (fig. 3B); the ICP data for Fe_2O_3 are as much as 9 percent lower than the XRF and wet chemical data (fig. 3C); and the ICP data for CaO are about 2.5 percent lower than the XRF data (fig. 3D). These plots confirm the accuracy and precision of the XRF and ICP analyses reported by Lichte and others (1987) and Taggart and others (1987), with the possible exception of Fe_2O_3.

Minor elements in all samples were determined by ICP spectroscopy (table 2), including the following (limit of detection in parts per million in parentheses): Ag (2), As (10), Au (8), Ba (1), Be (1), Bi (10), Cd (2), Ce (4), Co (1), Cr (1), Cu (1), Eu (2), Ga (4), Ho (4), La (2), Li (2), Mn (10), Mo (2), Nd (4), Ni (2), Pb (4), Sc (2), Sn (10), Sr (2), Ta (40), Th (4), U (100), V (2), Y (2), Yb (1), and Zn (2). Precision, based on multiple analyses of U.S. Geological Survey standard reference materials, is ±10 percent for concentrations greater than 10 times the lower limit of detection, (Lichte and others, 1987). The 20 elements listed in table 2 are those for which at least half the measurements were above the limit of detection. A zero was substituted for those analyses below the limit of detection to facilitate calculations.

Inorganic and total carbon were determined by combustion (table 1); the difference gives the fraction of organic carbon. Precision is from 5 to 10 percent, based on an analysis of aliquots to which $CaCO_3$ was added in an amount that approximately doubled the original carbon content.

NORMATIVE CALCULATIONS

Mineral Components

The major-element oxides must be partitioned into mineral phases to determine the mineral abundances in the rock samples. In the Phosphoria Formation, Gulbrandsen (1967) identified quartz, muscovite-illite, feldspar, iron oxide, organic matter, and apatite as ubiquitous phases and calcite, dolomite, microcrystalline quartz, and gypsum as present only in some of the rocks. Plots of major-element oxides and inorganic and organic carbon confirm that apatite, calcite, dolomite, organic matter, and biogenic/diagenetic silica (microcrystalline quartz) are major minerals in the Montpelier Canyon section. The plot of Fe_2O_3 versus Al_2O_3 content (fig. 4B) also indicates that a few samples contain iron in excess of that contributed by aluminosilicates. Because at most 2 weight percent Fe (present now as an oxide but possibly pyrite originally) is present, its abundance was not calculated. Because the plot of SiO_2 versus Al_2O_3 content (see fig. 7C) shows a strongly
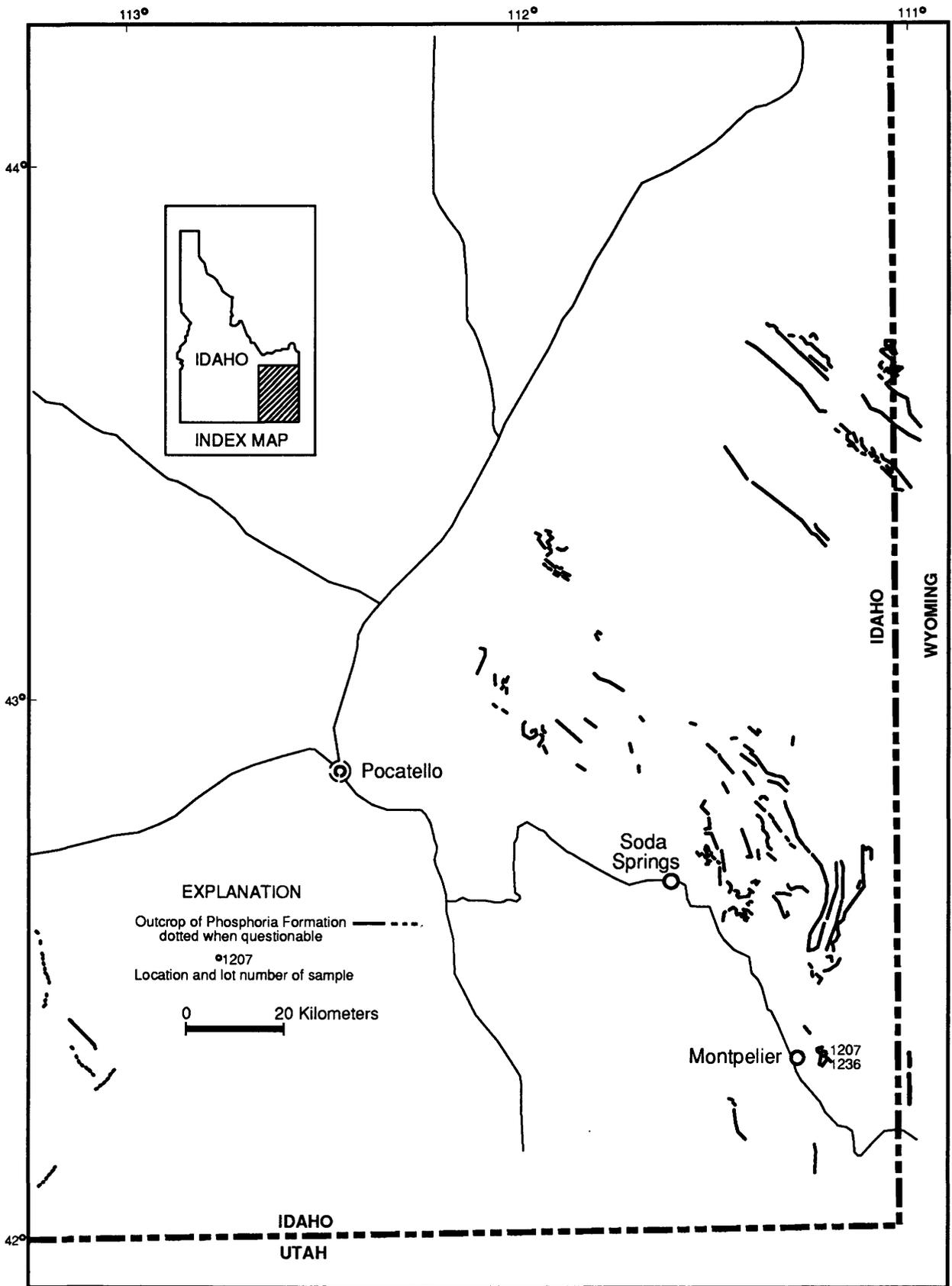
Figure 1. Sketch map of southeastern Idaho, showing locations of outcrops of the Phosphoria Formation and of samples from Montpelier Canyon. After McKelvey and others (1953a).
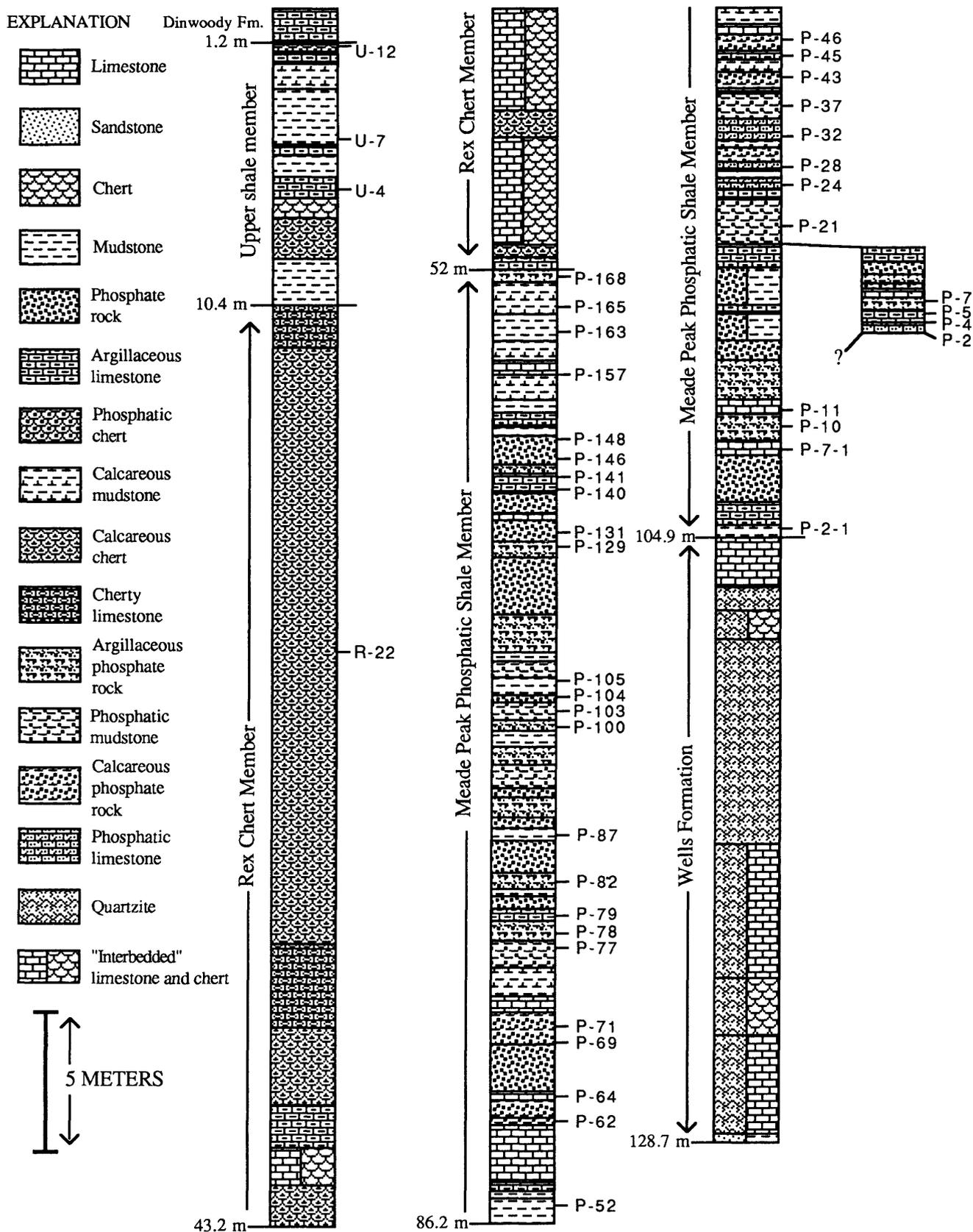
Figure 2. Stratigraphic column of the Phosphoria Formation in Montpelier Canyon, showing locations of samples analyzed. Compiled from McKelvey and others (1953a).

defined minimum and Fe_2O_3, K_2O, and TiO_2 (fig. 4) correlate strongly with Al_2O_3 but not with any other major-element oxide, Gulbrandsen's quartz, muscovite-illite, and feldspar phases (quartz and aluminosilicates) were combined into a single detrital fraction, assumed to have a constant Al_2O_3 content. Isaacs (1980) and Isaacs and others (1983) also chose to combine all the aluminosilicates and detrital quartz into a single detrital fraction. They determined independently the abundances of the mineral phases that compose this fraction, including detrital quartz, and concluded that the relative proportions of the mineral phases of the detrital fraction in fine-grained rocks vary only slightly, owing to the absence of mineral fractionation as the detrital material was transported to and deposited in a marine basin.

Following the format of Isaacs (1980) and Isaacs and others (1983), we assign the major-element-oxide contents, not accommodated in the detrital fraction, to biogenic/diagenetic silica, apatite, dolomite, calcite, and organic matter, by assuming a constant composition for each. The rocks may be sufficiently complex that our simple assumptions used to calculate their components are invalid. For example, we use the MgO content, in excess of that accommodated in the detrital fraction, to calculate dolomite. Similarly, we use the P_2O_5 content to calculate the apatite content. If these rocks contained other mineral phases in which MgO and P_2O_5 were present, these calculations would be far more complex and much less accurate.

Mineral Compositions

Our initial assumption is that each mineral component has a constant composition throughout the stratigraphic column. Implicit in this assumption is that all the samples are closely associated. The plots of major-element oxides and organic and inorganic carbon strongly support the assumption that the minerals have constant major-element-oxide ratios.

The number and approximate composition of the major components must be known to partition the major-element oxides. For calcite and dolomite, partitioning of CaO, MgO, and CO_2 is relatively straight forward: We assume stoichiometric phases. As shown below, extremums in the plots of CaO and MgO versus inorganic-carbon content support this assumption. Apatite varies slightly from place to place in composition, owing to substitution of CO_3^{2-} and SO_4^{2-} for PO_4^{3-} and of Na^+ and Mg^{2+} for Ca^{2+} (McClellan, 1969). Gulbrandsen (1966), however, reported a limited variation in the composition of apatite in the Phosphoria Formation about an average that approaches our measurements. The composition of detritus can vary significantly from formation to formation, depending on such factors as source and degree of alteration. Initially,

we assumed that the detrital fraction was similar in composition to the average for worldwide shales (table 3). On the plots of major-element-oxide versus Al_2O_3 content (fig. 4), K_2O, TiO_2, and Fe_2O_3 all correlate well with Al_2O_3 (fig. 4). Least-square best-fit lines were drawn, yielding R values greater than 0.93. Assuming that Al_2O_3 is present solely in the detrital fraction, it follows that K_2O, TiO_2, and Fe_2O_3 also must be present solely in the detrital fraction. Their high degree of correlation and extrapolation to the origins of these plots confirm our assumptions that (1) the composition of the detrital fraction is constant throughout the stratigraphic column in Montpelier Canyon, (2) the compositional values approximate those of the average for worldwide shales (table 3), and (3) the detrital fraction has remained relatively nonreactive since deposition. Subsequent studies are underway to ascertain whether these assumptions hold true for the entire basin.

Although the other major-element oxides used to determine mineral abundances (CaO, P_2O_5, MgO) show no obvious correlation with Al_2O_3, some of each oxide can be present in detritus, as well as in other components. In fact, the plot of MgO versus inorganic-carbon content (fig. 5A) requires that some MgO is present in both dolomite and detritus: The curve extrapolates to 0.7 weight percent MgO. The average MgO content of worldwide shales is 2.6 weight percent (Wedepohl, 1969). Because the average proportion of detritus in these samples is 30 percent, the average detrital MgO content of worldwide shales is 0.78 weight percent (0.30 times 2.6 weight percent). The close agreement of this value with the expected value of 0.78 weight percent in Wedepohl's (1969) average for worldwide shales supports our use of his values to subtract out the detrital (shale) fraction (table 3) of the major-element oxides—CaO, MgO, P_2O_5—before calculating the abundances of the mineral components calcite, dolomite, and apatite (tables 4, 5).

Apatite

The major-element-oxide stoichiometry of apatite, as determined by Gulbrandsen (1966) and McClellan and Lehr (1980), was evaluated by plotting CaO versus P_2O_5 content (fig. 6). Minimums define a curve with a slope of 1.38 that intercepts the origin, in agreement with the CaO/P_2O_5 ratio reported by both Gulbrandsen (1966, 1970) and McClellan and Lehr (1969); the rest of the data plot above this curve. Clearly, CaO is present in other phases; however, because the extremums extrapolate to zero, we conclude that virtually all of the P_2O_5 is present in apatite, except for 0.16 weight percent P_2O_5 in detritus (Wedepohl, 1969). Therefore, we use the P_2O_5 content to calculate the apatite abundance. The actual P_2O_5 content in apatite and the complete equation used to calculate the apatite abundance are listed in table 4.

Calcite and Dolomite

MgO and CaO were plotted against inorganic carbon (fig. 5B), after subtracting out their detrital and apatite contributions. The apatite fraction of CaO was determined as described above. The detrital fractions of CaO and MgO were estimated from the average for worldwide shales (table 3). The adjusted CaO data plot along the curve for stoichiometric calcite, or between the calcite and dolomite curves; the first relation suggests that the calcite in the Phosphoria Formation is stoichiometric $CaCO_3$.

MgO data plot either on the curve representing the ratio of MgO to inorganic carbon in stoichiometric dolomite or below it (fig. 5B). MgO data that plot on this curve represent samples that contain only stoichiometric dolomite, and those that plot below this curve represent samples that contain both calcite and dolomite. MgO data plot along the x-axis, where there is only calcite. These plots support the assumption that MgO is present only in dolomite, except for 2.3 weight percent in detritus (table 3), and that stoichiometric dolomite (table 4) is present in at least a few samples.

Organic Matter

Organic-matter content was determined by multiplying the organic-carbon content by 1.7. This value, which is intermediate between the organic-matter content of the Monterey Formation of 1.5 weight percent (Isaacs, 1980) and modern marine organic-matter content of approximately 4 weight percent (Sverdrup and others, 1963), was obtained by comparing the measured LOI with an "LOI term" obtained by an iterative calculation (see subsection below entitled "Biogenic Silica").

Detritus

A residual fraction was calculated by subtracting the proportion of calcite, dolomite, apatite, and organic matter from 100 percent. Thus, this residual fraction equals the sum of the detrital fraction and biogenic-silica abundance. The residual fraction was then plotted against Al_2O_3 content; the plot shows a well-defined minimum that nearly extrapolates to the origin (fig. 7A). The slope of the curve is interpreted to represent the ratio of detritus to Al_2O_3. Extrapolation to 100 percent gives an Al_2O_3 content in detritus of 15.6 weight percent. This value compares well (table 3) with the averages of 16.7 weight percent for geosynclinal shales (Wedepohl, 1969), of 15.1 weight percent for Russian platform shales (Vinogradov and Ronov, 1956), and of 17.8 weight percent for the detrital fraction of the Monterey Formation (Isaacs, 1980). The scatter of the data points

above the curve represents a varying abundance of biogenic silica, which has no intrinsic relation to Al_2O_3.

Biogenic Silica

The abundance of biogenic/diagenetic silica can be calculated merely by assuming it to be the sole remaining major constituent, thus forcing the sum of all constituents to 100 percent. Because the abundance of calcite partly depends on the calculated abundance of dolomite and apatite, and the abundances of detritus and biogenic silica also depend on the calculated abundances of calcite, dolomite, apatite, and organic matter, the results would contain errors compounded by each successive calculation. An alternative method is to determine the SiO_2 content of the detrital fraction and then subtract it from the total silica content. This calculation can be done by simply plotting total silica against Al_2O_3 content; the minimums define a curve that is interpreted to be the SiO_2/Al_2O_3 ratio in detritus (Isaacs, 1983). The scatter of data points above this curve represents silica in excess of that in the detritus, that is, biogenic/diagenetic silica. In this study, however, only the samples analyzed by XRF spectroscopy have a total silica content, and they represent only half the samples. Therefore, we developed an equation for calculating total silica content from the ICP data.

We initially use only the XRF data to derive the equation for total silica content because this procedure allows us to compare our calculated total silica content with the measured total silica content. Part of the equation is an LOI term, which we also derive by using the XRF data and again compare with the measured LOI data. We then apply both equations to the ICP data.

Total silica content was calculated by subtracting four terms from 100 weight percent: (1) a term incorporating all the major-element oxides other than SiO_2, (2) a calculated LOI term, (3) a calculated fluorine term, and (4) a term for sulfur plus other significant minor elements (table 4). The major-element-oxide contents used in the first term are listed in table 1. The LOI term is composed of an aluminosilicate factor (8–9 weight percent H_2O in aluminosilicates), a carbonate factor (44 weight percent CO_2 in calcite and 47 weight percent CO_2 in dolomite), and an organic-matter factor (58.8 weight percent organic carbon). The equation is:

$$LOI = 0.55Al_2O_3 + 3.66 \text{Inorganic Carbon} + 1.7 \text{Organic Carbon}.$$

An iterative calculation designed to obtain the best-fit curve between the measured and calculated LOI gave a ratio of organic matter to organic carbon of 1.7 for these samples (fig. 7D), in comparison with a ratio of 1.5 for the

Monterey Formation (Isaacs, 1980). The H_2O content of detritus was determined as 8.6 weight percent.

Fluorine, for which we have no data, is present in apatite in significant amounts, 3.8 to 4.2 weight percent, as fluoride (Gulbrandsen, 1966). Assuming 4.2 weight percent F in apatite and reducing the number of oxygens to maintain charge balance, 2.47 percent of the apatite present was subtracted from 100 percent to account for fluorine.

After initially plotting calculated versus measured SiO_2 content, another 1 weight percent was subtracted for maximum agreement with the measured value. This procedure was justified by the known presence of sulfur, as sulfate in apatite (0.3–3.1 weight percent SO_3; Gulbrandsen, 1966), and of significant amounts of minor elements, such as Cr, Sr, V, and Zn (table 2).

Assuming that other nonoxide components are absent, the remainder should then be equal to the total silica content. The calculated total silica content was plotted against the SiO_2 content measured by XRF spectroscopy (fig. 7B), with $R=0.99$. The curve for minimums of calculated SiO_2 versus Al_2O_3 content, with a slope of 3.75, defines the SiO_2/Al_2O_3 ratio for the detrital fraction (fig. 7C). The ratio for detritus may be less than this value, by the abundance of biogenic silica actually present in samples that define the minimum, or it may be higher than this value as a result of precision errors compounded with each oxide analysis. However, the sharpness of the minimum leads us to believe that the SiO_2/Al_2O_3 ratio for detritus is close to 3.75.

The abundance of biogenic silica was determined from the plot of total silica versus Al_2O_3 content (fig. 7C). The amount by which the data points lie above the curve for silica in the detrital fraction represents the abundance of biogenic silica (see table 4 for actual equation used).

Discussion

All the calculated major mineral abundances are listed in table 5 and plotted in figure 8. By virtue of our normative-calculation procedure, 100 percent of the P_2O_5, Al_2O_3, CaO, and MgO are accounted for by this partitioning. The CO_3^{2-}, SiO_2, and sum of components, however, each offers a check on the calculations. To check the calcite, dolomite, and apatite calculation, CO_3^{2-}, calculated from the abundances of these mineral components (table 5), is plotted against measured carbonate, that is, inorganic carbon (table 1): The correlation is excellent (fig. 5C). The SiO_2 content was measured by XRF spectroscopy and estimated (fig. 7B) from the contents of other major-element oxides plus an LOI calculation (table 4). Both plots show strong correlations that approach a 1:1 relation in the midrange. The approach of the sum of all components to 100

percent (fig. 8) also supports our partitioning scheme: For all but one of the samples, this sum is within ±3 percent of 100 percent. These results offer strong support for our initial assumption of a constant composition for all components.

In other rock units, oxide ratios in the major components may differ from those for the Phosphoria Formation, but this general scheme should be the same.

CORRELATION-COEFFICIENT MATRIX

A correlation-coefficient matrix indicates the degree of linear relation between two variables. The R value indicates how well the individual data points behave around a calculated simple regression (line). If the data points cluster close to the linear regression, then the R value approaches 1.0; and if there is no correlation, then the R value approaches zero. Negative correlations indicate an inverse relation and can be just as informative as positive correlations; however, low positive correlations must be viewed critically. For example, we know from plots and calculations that CaO is associated with MgO, inorganic carbon, and P_2O_5, although the correlation coefficients between CaO and these major-element oxides is significant ($R>0.5$) only for CaO versus P_2O_5 (table 6). Therefore, we use the correlation-coefficient matrix as only an initial tool in evaluating the data.

Using a statistical program, a correlation-coefficient matrix was generated for all the data, that is, rock components and bulk minor-element analyses (table 6). Because the main purpose of this report is to explain our normative-calculation procedure, we mention only a few of the strongest correlations (table 6): detritus with Ba and Co, apatite with Sr, and organic matter with Cu and Cr. The rare-earth elements correlate very strongly with each other, as expected, because of their similar valence-electron configurations. Sc also correlates with the rare-earth elements. Mo, Ni, and Zn correlate strongly with each other but not with any of the calculated rock components. Eventually, we want to look similarly at data from four other places that traverse the Permian sea from east to west.

CONCLUSION

The abundances of the rock components were determined by assuming a constant composition throughout the stratigraphic column and assuming these components to be calcite, dolomite, apatite, organic matter, biogenic/diagenetic silica, and a single detrital fraction combining detrital quartz and aluminosilicates. Apatite abundance was calculated from P_2O_5 content, using 40.6 weight percent in

apatite and 0.16 weight percent in detritus. Dolomite abundance was calculated by multiplying the analyzed MgO content, less that proportion in the detrital fraction, by the proportion of MgO in stoichiometric dolomite (21.9 weight percent). CaO content was used to calculate calcite abundance (56 weight percent) after subtracting out its proportions in apatite, dolomite, and detritus. Organic-matter abundance was calculated by multiplying the organic-carbon content times 1.7, a factor derived from an iterative process. Biogenic/diagenetic-silica abundance was calculated by first calculating the total SiO_2 content and then subtracting out the proportion in the detrital fraction. The validity of these calculations was checked by comparing the inorganic-carbon content calculated from the abundances of dolomite, calcite, and apatite with the measured inorganic-carbon content, by comparing the calculated with measured SiO_2 content, and by the approach of the sum of the major rock components to 100 percent. This normative-calculation procedure can be applied in a general form to other fine-grained sedimentary rocks as well.

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FIGURES 3–8; TABLES 1–6
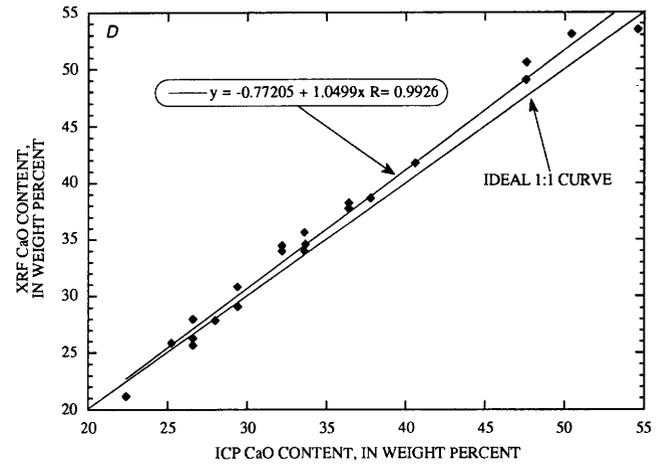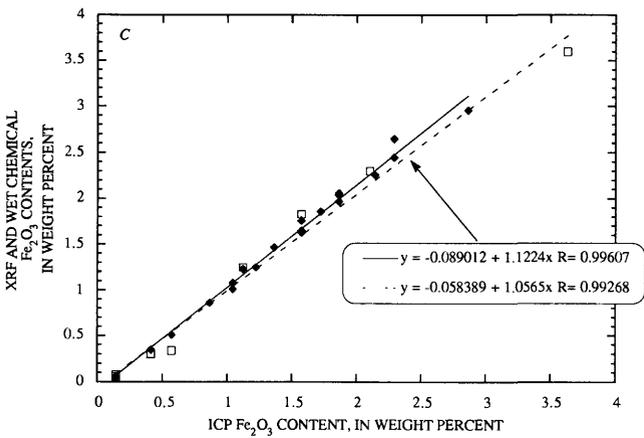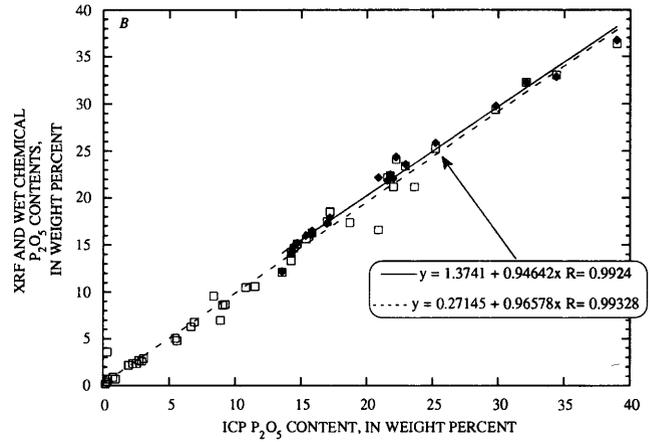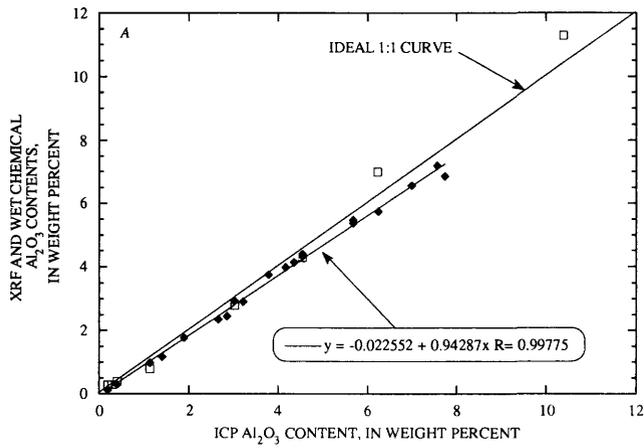
Figure 3. Comparison of measured Al_2O_3 (*A*), P_2O_5 (*B*), Fe_2O_3 (*C*), and CaO (*D*) contents by different analytical techniques: inductively coupled plasma (ICP) atomic-emission spectroscopy, X-ray-fluorescence (XRF) spectroscopy, and wet chemical analysis. *A*, XRF (diamonds) and wet chemical (squares) Al_2O_3 versus ICP Al_2O_3 content. *B*, XRF (diamonds) and wet chemical (squares) P_2O_5 versus ICP P_2O_5 content. *C*, XRF (diamonds) and wet chemical (squares) Fe_2O_3 versus ICP Fe_2O_3 content. *D*, XRF CaO versus ICP CaO content.
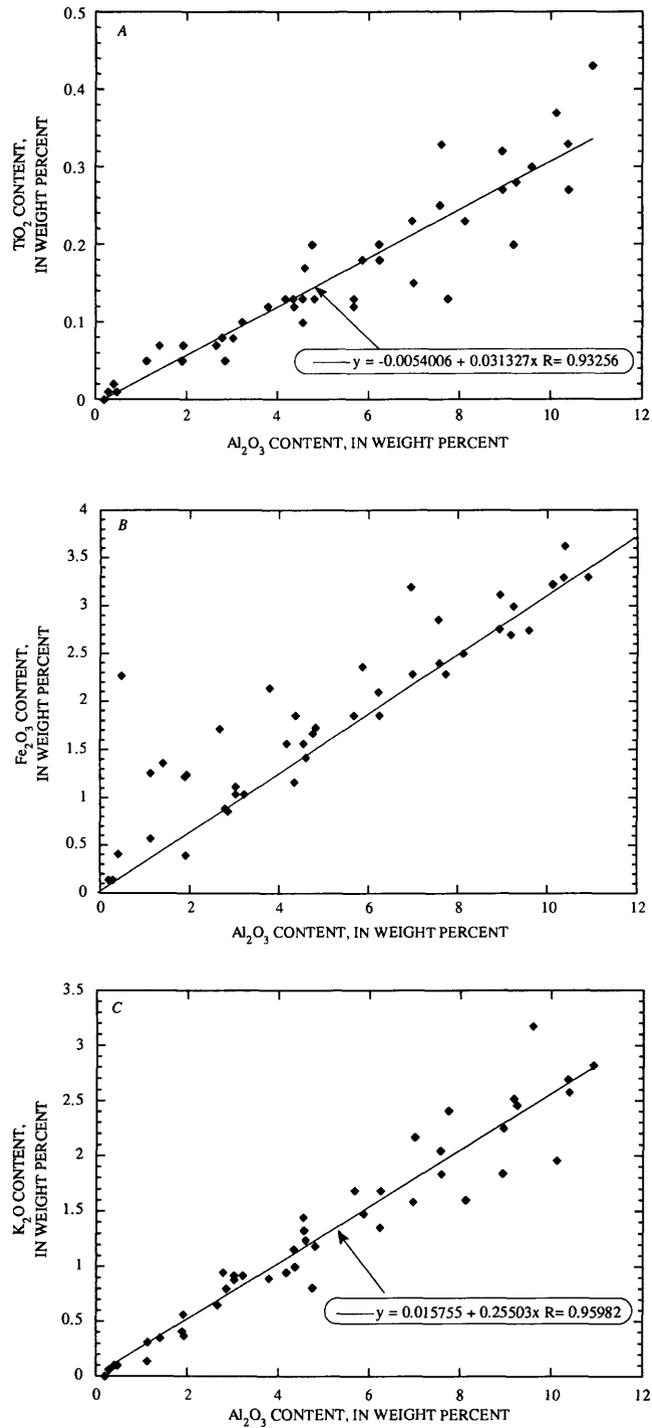
Figure 4. TiO$_2$ (A), Fe$_2$O$_3$ (B), and K$_2$O (C) versus Al$_2$O$_3$ content, as determined by inductively coupled plasma atomic-emission spectroscopy. Best-fit curve in figure 4B has been drawn visually. Samples with data points falling outside main trend contain iron in excess of that contributed by detritus; the presence of either iron oxide or pyrite in these samples was verified by optical microscope.
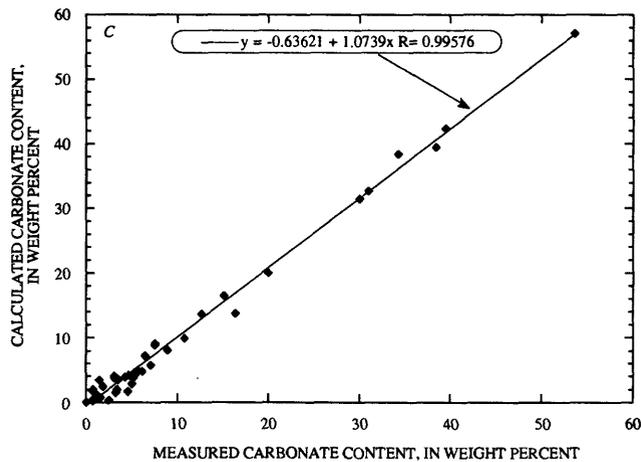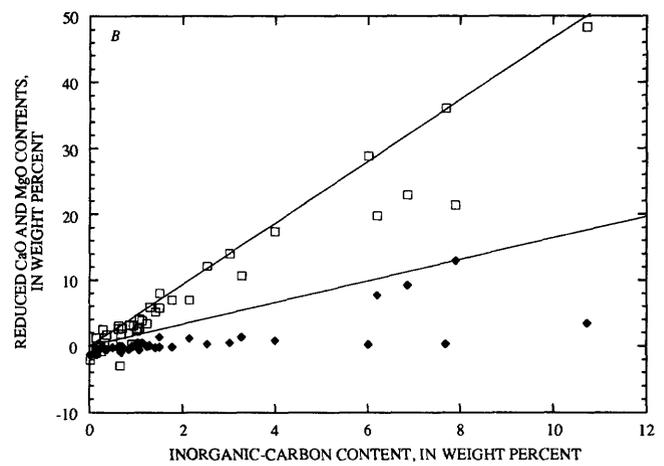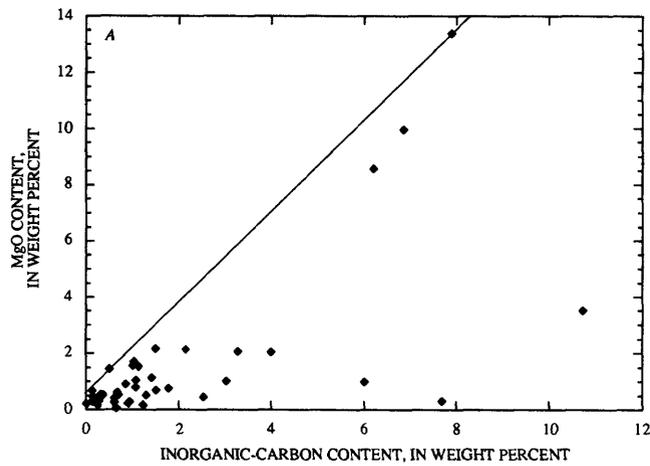
Figure 5. MgO (A, B) and CaO (B) versus inorganic-carbon content, and calculated versus measured carbonate content (C). A, MgO content, measured by inductively coupled plasma atomic-emission spectroscopy, versus inorganic-carbon content. Slope of curve represents ratio of MgO to inorganic carbon in stoichiometric dolomite; shifted up to include all data points, curve intercepts y-axis at approximately 0.7 weight percent MgO. B, CaO (squares) and MgO (diamonds) versus inorganic-carbon content. CaO content has been reduced by CaO contents in apatite and detritus; MgO content has been reduced by MgO content in detritus. Slopes of curves represent ratios of CaO and MgO to inorganic carbon in stoichiometric calcite and dolomite, respectively. C, Carbonate content, estimated from calculated abundances of dolomite, calcite, and apatite (see table 4), versus carbonate content measured by induction-furnace carbon analysis.
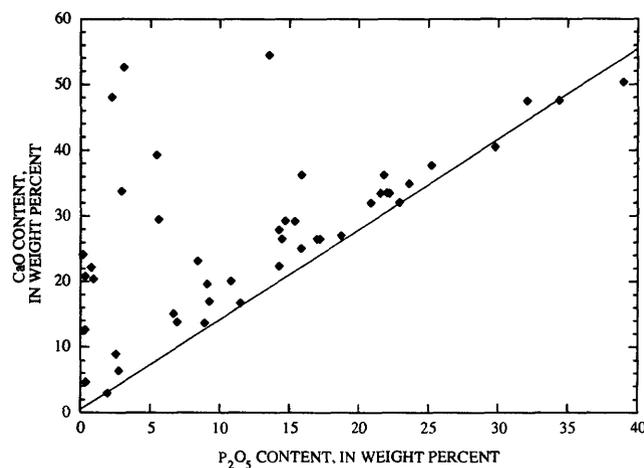
Figure 6. CaO versus P_2O_5 content in apatite, as determined by inductively coupled plasma atomic-emission spectroscopy. Minimums define a curve of slope 1.38 that is interpreted to represent a ratio of CaO to P_2O_5 in these samples.
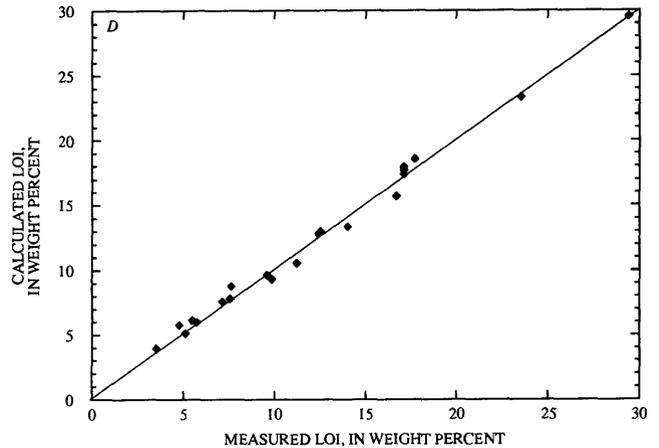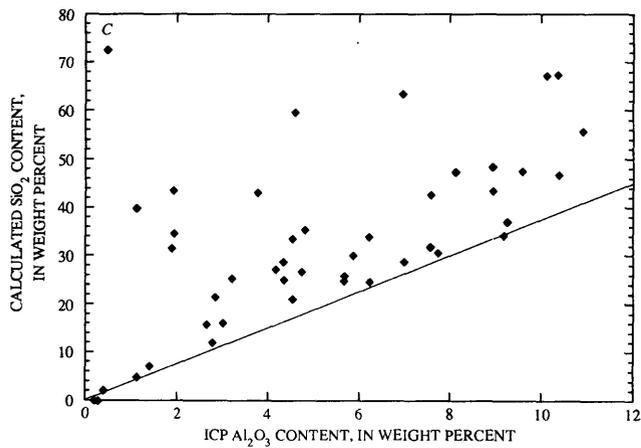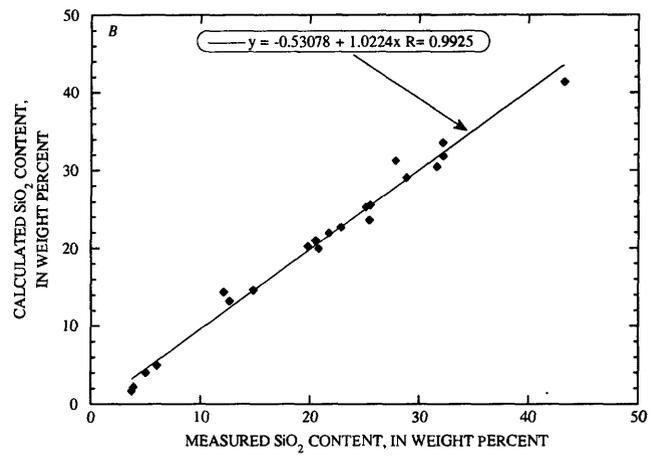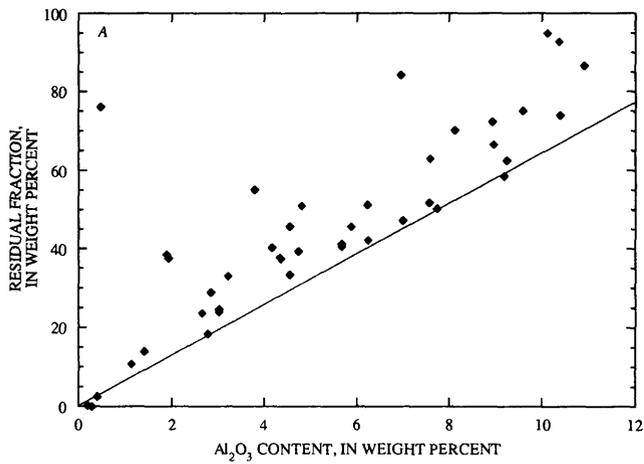
Figure 7. Residual fraction versus Al_2O_3 content (*A*), calculated versus measured SiO_2 content (*B*), calculated SiO_2 content versus Al_2O_3 content measured by inductively coupled plasma (ICP) atomic-emission spectroscopy (*C*), and calculated versus measured loss on ignition (LOI) (*D*). In figure 7*A*, minimums define a curve of slope 6.40 that is interpreted to represent the ratio of detritus to Al_2O_3; in figure 7*C*, minimums define a curve of slope 3.75 that is interpreted to represent the ratio of SiO_2 to Al_2O_3 to detritus.
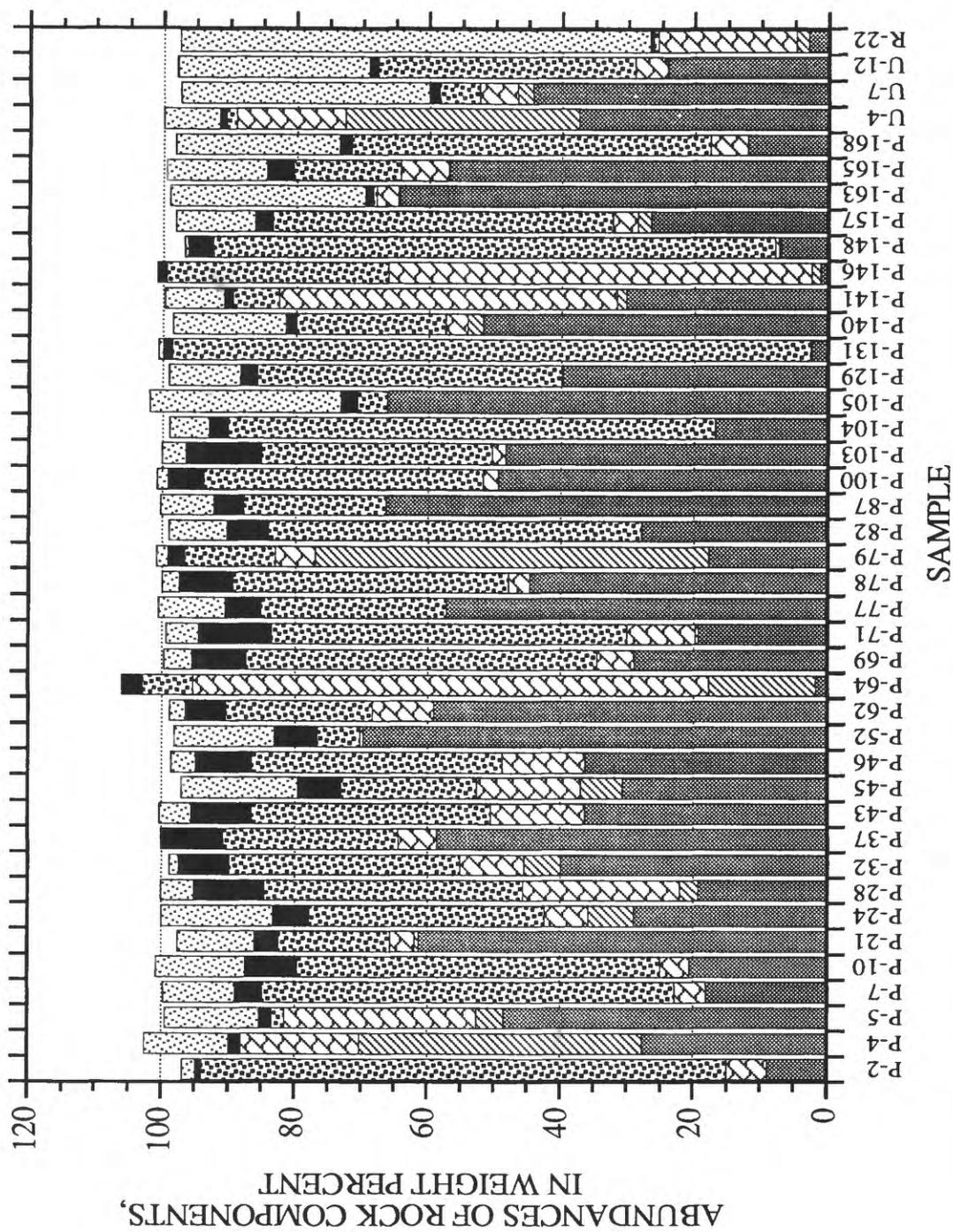
Figure 8. Bar graph showing calculated abundances of apatite, calcite, dolomite, organic matter, detritus, and biogenic/diagenetic silica in each sample analyzed. See table 4 for equations used in calculations.

Table 1. Major-element-oxide contents in samples of the Phosphoria Formation in Montpelier Canyon, Idaho

[All values in weight percent, as determined by inductively coupled plasma spectroscopy (I), X-ray-fluorescence spectroscopy (X), and wet chemical analysis (W). LOI, loss on ignition]

Sample	P-2	P-2-1	P-4	P-5	P-7	P-7-1	P-10	P-11	P-21	P-24	P-28	P-32
SiO2	5.00 (X)	- - -	- - -	- - -	20.80 (X)	- - -	20.50 (X)	- - -	- - -	27.80 (X)	12.10 (X)	25.10 (X)
Al2O3	1.40 (I) 1.18 (X)	4.59 (I)	4.33 (I)	7.58 (I)	2.84 (I) 2.46 (X)	1.12 (I)	3.21 (I) 2.91 (X)	1.91 (I)	9.58 (I)	4.54 (I) 4.34 (X)	3.02 (I) 2.93 (X)	6.24 (I) 5.75 (X)
Fe2O3	1.36 (I) 1.47 (X)	1.42 (I)	1.17 (I)	2.40 (I)	.86 (I) .86 (X)	1.26 (I)	1.04 (I) 1.01 (X)	.40 (I)	2.75 (I)	1.57 (I) 1.65 (X)	1.04 (I) 1.08 (X)	1.86 (I) 1.97 (X)
MgO	.18 (I) .38 (X)	10.60 (I)	9.98 (I)	2.06 (I)	.27 (I)	11.00 (I)	.33 (I) .51 (X)	1.92 (I)	1.57 (I)	2.16 (I) 2.38 (X)	1.04 (I) 1.18 (X)	2.16 (I) 2.25 (X)
CaO	47.59 (I) 50.60 (X)	20.85 (I)	24.20 (I)	20.43 (I)	37.77 (I) 38.70 (X)	39.45 (I)	33.58 (I) 35.70 (X)	48.13 (I)	13.92 (I)	26.57 (I) 28.00 (X)	36.37 (I) 37.80 (X)	27.98 (I) 27.90 (X)
Na2O	.66 (I) .63 (X)	.13 (I)	.07 (I)	.13 (I)	.23 (I) .31 (X)	.38 (I)	.19 (I) .29 (X)	.07 (I)	.26 (I)	.27 (I) .38 (X)	.22 (I) .25 (X)	.24 (I) .30 (X)
K2O	.35 (I) .34 (X)	1.24 (I)	1.16 (I)	1.84 (I)	.80 (I) .81 (X)	.14 (I)	.92 (I) .90 (X)	.57 (I)	3.18 (I)	1.33 (I) 1.47 (X)	.88 (I) .80 (X)	1.69 (I) 1.64 (X)
TiO2	.07 (I) .07 (X)	.17 (I)	.13 (I)	.33 (I)	.05 (I) .14 (X)	.05 (I)	.10 (I) .19 (X)	.05 (I)	.30 (I)	.13 (I) .25 (X)	.08 (I) .13 (X)	.18 (I) .28 (X)
P2O5	32.07 (I) 32.30 (X) 32.30 (W)	.30 (I) 3.60 (W)	.16 (I) .20 (W)	.89 (I) .70 (W)	25.20 (I) 25.90 (X) 25.30 (W)	5.43 (I) 5.10 (W)	22.19 (I) 24.40 (X) 24.10 (W)	2.20 (I) 2.40 (W)	6.87 (I) 6.80 (W)	14.43 (I) 14.90 (X) 14.70 (W)	15.81 (I) 16.10 (X) 16.30 (W)	14.20 (I) 14.10 (X) 13.30 (W)
MnO	.005 (I) .010 (X)	.017 (I)	.017 (I)	.023 (I)	.002 (I) .010 (X)	.018 (I)	.002 (I) .010 (X)	.021 (I)	.012 (I)	.007 (I) .010 (X)	.007 (I) .010 (X)	.014 (I) .01 (X)
LOI	5.73	- - -	- - -	- - -	7.55	- - -	11.20	- - -	- - -	14.00	23.50	17.70
C(inorganic)	1.23	- - -	8.85	3.99	.62	- - -	.29	- - -	1.00	1.50	3.01	2.15
C (organic)	.50	- - -	.89	1.06	2.47	- - -	4.66	- - -	2.20	3.24	6.31	4.46

| Sample	P-37	P-43	P-45	P-46	P-52	P-62	P-64	P-69	P-71	P-77	P-78	P-79
SiO2	- - -	25.50 (X)	- - -	22.80 (X)	- - -	- - -	- - -	19.80 (X)	12.60 (X)	- - -	28.80 (X)	- - -
Al2O3	9.17 (I)	5.67 (I) 5.48 (X)	4.80 (I)	5.67 (I) 5.38 (X)	10.90 (I)	9.24 (I)	.28 (I) .30 (W)	4.54 (I) 4.40 (X) 4.30 (W)	3.02 (I) 2.94 (X) 2.80 (W)	8.94 (I)	6.99 (I) 6.57 (X)	2.78 (I)
Fe2O3	2.70 (I)	1.86 (I) 2.04 (X)	1.73 (I)	1.86 (I) 2.05 (X)	3.30 (I)	3.00 (I)	.14 (I) .06 (W)	1.57 (I) 1.76 (X) 1.83 (W)	1.12 (I) 1.23 (X) 1.25 (W)	3.12 (I)	2.29 (I) 2.45 (X)	.89 (I)
MgO	.92 (I)	.71 (I) .82 (X)	2.09 (I)	.78 (I) .93 (X)	1.45 (I)	1.16 (I)	3.53 (I)	.43 (I) .56 (X)	.53 (I) .70 (X)	.31 (I)	.53 (I) .60 (X)	13.40 (I)
CaO	20.15 (I)	29.38 (I) 29.10 (X)	23.22 (I)	29.36 (I) 30.90 (X)	6.52 (I)	19.73 (I)	52.60 (I)	33.58 (I) 34.00 (X)	36.37 (I) 38.30 (X)	16.79 (I)	26.59 (I) 26.30 (X)	29.66 (I)
Na2O	.23 (I)	.32 (I) .34 (X)	.34 (I)	.24 (I) .31 (X)	.49 (I)	.20 (I)	.07 (I)	.42 (I) .46 (X)	.28 (I) .33 (X)	.93 (I)	.34 (I) .41 (X)	.28 (I)
K2O	2.52 (I)	1.69 (I) 1.48 (X)	1.19 (I)	1.69 (I) 1.45 (X)	2.82 (I)	2.46 (I)	.06 (I)	1.45 (I) 1.23 (X)	.92 (I) .84 (X)	2.25 (I)	2.17 (I) 1.84 (X)	.95 (I)
TiO2	.20 (I)	.13 (I) .30 (X)	.13 (I)	.12 (I) .28 (X)	.43 (I)	.28 (I)	.01 (I)	.10 (I) .24 (X)	.08 (I) .14 (X)	.27 (I)	.15 (I) .34 (X)	.08 (I)
P2O5	10.76 (I) 10.50 (W)	14.66 (I) 15.20 (X) 15.10 (W)	8.34 (I) 9.60 (W)	15.35 (I) 16.00 (X) 15.60 (W)	2.68 (I) 2.70 (W)	9.05 (I) 8.60 (W)	3.05 (I) 2.90 (W)	21.54 (I) 21.90 (X) 22.20 (W)	21.76 (I) 22.50 (X) 22.40 (W)	11.47 (I) 10.60 (W)	16.95 (I) 17.30 (X) 17.50 (W)	5.57 (I) 4.80 (W)
MnO	.009 (I)	.010 (I) .01 (X)	.018 (I)	.008 (I) .01 (X)	.018 (I)	.015 (I)	.008 (I)	.006 (I) .01 (X)	.004 (I) .01 (X)	.006 (I)	.011 (I) .01 (X)	.030 (I)
LOI	- - -	17.10	- - -	17.10	- - -	- - -	- - -	12.40	17.10	- - -	12.50	- - -
C(inorganic)	.85	1.51	3.27	1.78	.50	1.41	10.72	.62	1.29	.14	.37	7.89
C (organic)	5.47	5.38	3.84	5.00	3.84	3.57	1.81	4.79	6.50	3.15	4.72	1.49

Sample	P-82	P-87	P-100	P-103	P-104	P-105	P-129	P-131	P-140	P-141	P-146	P-148
SiO2	21.70 (X)	- - -	32.20 (X)	32.10 (X)	14.80 (X)	- - -	- - -	3.70 (X)	- - -	- - -	3.88 (X)	5.98 (X)
Al2O3	4.35 (I) 4.15 (X)	10.38 (I) 11.30 (W)	7.73 (I) 6.87 (X)	7.56 (I) 7.20 (X)	2.65 (I) 2.36 (X)	10.36 (I)	6.22 (I) 7.00 (W)	.40 (I) .30 (X) .40 (W)	8.11 (I)	4.74 (I)	.19 (I) .14 (X) .30 (W)	1.13 (I) .99 (X) .80 (W)
Fe2O3	1.86 (I) 2.06 (X)	3.63 (I) 3.6 (W)	2.29 (I) 2.65 (X)	2.86 (I) 2.96 (X)	1.72 (I) 1.86 (X)	3.30 (I)	2.10 (I) 2.3 (W)	.41 (I) .35 (X) .3 (W)	2.50 (I)	1.67 (I)	.14 (I) .06 (X) .08 (W)	.57 (I) .51 (X) .34 (W)
MgO	.33 (I) .48 (X)	.31 (I)	.48 (I) .60 (X)	.68 (I) .74 (X)	.18 (I) .34 (X)	.22 (I)	.55 (I)	.08 (I) .26 (X)	1.71 (I)	1.00 (I)	.33 (I) .48 (X)	.23 (I) .38 (X)
CaO	32.17 (I) 34.00 (X)	13.78 (I)	26.59 (I) 25.70 (X)	22.38 (I) 21.20 (X)	40.57 (I) 41.80 (X)	3.02 (I)	27.14 (I)	50.40 (I) 53.10 (X)	17.07 (I)	34.00 (I)	54.58 (I) 53.50 (X)	47.57 (I) 49.10 (X)
Na2O	.39 (I) .47 (X)	1.16 (I)	.42 (I) .44 (X)	.38 (I) .39 (X)	.47 (I) .47 (X)	1.31 (I)	.47 (I)	.13 (I) .18 (X)	.80 (I)	.92 (I)	.08 (I) 0 (X)	.20 (I) .21 (X)
K2O	1.00 (I) 1.26 (X)	2.58 (I)	2.41 (I) 1.83 (X)	2.05 (I) 1.69 (X)	.65 (I) .62 (X)	2.69 (I)	1.36 (I)	.10 (I) .08 (X)	1.60 (I)	.81 (I)	0 (I) .04 (X)	.31 (I) .26 (X)
TiO2	.12 (I) .22 (X)	.27 (I)	.13 (I) .36 (X)	.25 (I) .38 (X)	.07 (I) .15 (X)	.33 (I)	.20 (I)	.02 (I) 0 (X)	.23 (I)	.20 (I)	0 (I) 0 (X)	.05 (I) .03 (X)
P2O5	22.91 (I) 23.60 (X) 23.40 (W)	8.84 (I) 7.00 (W)	17.18 (I) 17.90 (X) 18.50 (W)	14.20 (I) 14.20 (X) 14.20 (W)	29.80 (I) 29.80 (X) 29.40 (W)	1.92 (I) 2.20 (W)	18.71 (I) 17.40 (W)	38.95 (I) 36.80 (X) 36.40 (W)	9.21 (I) 8.70 (W)	2.89 (I) 2.60 (W)	13.52 (I) 12.20 (X) 12.10 (W)	34.37 (I) 32.90 (X) 33.10 (W)
MnO	.004 (I) .01 (X)	.042 (I)	.012 (I) .01 (X)	.005 (I) .01 (X)	.007 (I) .01 (X)	.011 (I)	.015 (I)	.003 (I) .01 (X)	.028 (I)	.037 (I)	.032 (I) .01 (X)	.004 (I) .01 (X)
LOI	9.85	- - -	9.57	16.70	5.12	- - -	- - -	3.52	- - -	- - -	29.40	7.13
C(inorganic)	.24	.15	.15	.14	.25	.01	.32	.65	1.03	6.00	7.68	.91
C (organic)	3.63	2.57	3.13	6.63	1.72	1.51	1.49	.83	.95	.75	.82	2.19

Table 1. Major-element-oxide contents in samples of the Phosphoria Formation in Montpelier Canyon, Idaho—Continued

[All values in weight percent, as determined by inductively coupled plasma spectroscopy (I), X-ray-fluorescence spectroscopy (X), and wet chemical analysis (W). LOI, loss on ignition]

Sample	P-157	P-163	P-165	P-168	P-168a	U-4	U-7	U-12	R-22
SiO2	25.40 (X)	- - -	- - -	31.60 (X)	- - -	- - -	- - -	43.20 (X)	- - -
Al2O3	4.16 (I), 3.99 (X)	10.11 (I)	8.92 (I)	1.89 (I), 1.78 (X)	1.93 (I)	5.86 (I)	6.95 (I)	3.78 (I), 3.76 (X)	.47 (I)
Fe2O3	1.57 (I), 1.63 (X)	3.23 (I)	2.76 (I)	1.22 (I), 1.25 (X)	1.24 (I)	2.37 (I)	3.20 (I)	2.14 (I), 2.26 (X)	2.27 (I)
MgO	1.06 (I), 1.19 (X)	.62 (I)	.81 (I)	.30 (I), .42 (X)	.31 (I)	8.59 (I)	1.54 (I)	.53 (I), .63 (X)	.48 (I)
CaO	32.18 (I), 34.50 (X)	4.70 (I)	15.25 (I)	33.64 (I), 34.60 (X)	35.11 (I)	22.24 (I)	8.97 (I)	25.22 (I), 25.90 (X)	12.68 (I)
Na2O	.54 (I), .53 (X)	1.20 (I)	.74 (I)	.27 (I), .29 (X)	.28 (I)	.31 (I)	.78 (I)	.62 (I), .60 (X)	.05 (I)
K2O	.95 (I), .87 (X)	1.96 (I)	1.84 (I)	.41 (I), .37 (X)	.37 (I)	1.48 (I)	1.59 (I)	.90 (I), .87 (X)	.10 (I)
TiO2	.13 (I), .26 (X)	.37 (I)	.32 (I)	.05 (I), .10 (X)	.07 (I)	.18 (I)	.23 (I)	.12 (I), .16 (X)	.01 (I)
P2O5	20.85 (I), 22.20 (X), 16.60 (W)	.34 (I), .70 (W)	6.62 (I), 6.30 (W)	21.99 (I), 22.10 (X), 21.20 (W)	23.59 (I), 21.20 (W)	.71 (I), .90 (W)	2.52 (I), 2.40 (W)	15.81 (I), 16.50 (X), 16.30 (W)	.30 (I), .40 (W)
MnO	.013 (I), .01 (X)	.056 (I)	.016 (I)	.010 (I), .01 (X)	.010 (I)	.117 (I)	.046 (I)	.037 (I), .01 (X)	.039 (I)
LOI	7.62	- - -	- - -	5.48	- - -	- - -	- - -	4.77	- - -
C(inorganic)	1.07	.68	1.07	.94	- - -	6.19	1.13	.70	2.53
C (organic)	1.60	.65	2.41	1.03	- - -	.61	.98	.70	.30

Table 2. Minor-element contents in samples of the Phosphoria Formation in Montpelier Canyon, Idaho

[All values in parts per million. Elements below the limits of detection in more than half the samples are omitted]

Sample	P-2	P-2-1	P-4	P-5	P-7	P-7-1	P-10	P-11	P-21	P-24	P-28	P-32
Ag-----	0	0	0	2	9	0	10	4	8	13	7	5
As-----	30	10	0	20	20	0	20	0	50	30	20	40
Ba----	51	95	90	177	94	26	120	32	245	140	85	180
Cd-----	5	20	13	52	41	3	120	38	17	68	12	0
Ce-----	58	18	13	44	22	13	29	12	55	43	26	41
Co-----	3	4	3	7	2	3	2	2	6	3	4	6
Cr----	410	158	135	403	860	163	1,100	221	1,140	1,100	1,700	1,200
Cu----	22	28	14	46	77	29	110	23	82	140	160	87
La-----	180	14	10	30	76	47	110	29	129	160	120	120
Li-----	6	13	12	26	11	3	14	6	26	15	14	13
Mo----	10	8	3	13	47	3	29	8	25	77	37	20
Nd----	130	17	13	36	44	34	62	31	82	100	71	72
Ni-----	60	58	80	263	170	40	190	161	293	340	260	270
Pb----	9	8	8	12	11	0	13	4	11	12	5	7
Sc-----	5	4	4	6	5	2	6	0	11	9	9	11
Sr----	690	110	104	128	630	429	650	305	285	600	1,200	1,200
V-----	180	337	192	744	1,100	90	2,800	162	431	810	190	140
Y-----	310	14	10	27	120	56	170	32	172	270	190	160
Yb----	13	2	1	3	5	3	8	2	9	13	9	7
Zn----	400	460	590	1,670	1,100	146	1,400	1,250	1,630	2,000	1,200	1,300

Sample	P-37	P-43	P-45	P-46	P-52	P-62	P-64	P-69	P-71	P-77	P-78	P-79
Ag-----	6	5	3	7	8	6	0	9	7	5	9	4
As-----	30	30	20	20	20	30	0	30	30	30	40	20
Ba----	239	170	132	160	324	202	14	120	96	226	150	61
Cd-----	3	3	3	12	5	77	80	7	5	40	75	57
Ce-----	47	43	36	43	64	51	0	53	38	65	50	21
Co-----	5	5	5	4	9	7	2	4	3	3	7	3
Cr----	2,320	1,300	1,020	1,500	1,380	1,760	181	1,500	2,100	1,320	1,900	405
Cu----	114	100	57	110	68	93	21	140	190	86	140	25
La-----	128	150	96	150	78	128	12	240	220	123	170	66
Li-----	31	18	12	22	26	25	0	14	16	15	26	4
Mo----	20	24	16	52	41	84	8	25	33	7	29	9
Nd----	85	90	62	92	63	89	22	140	120	80	99	46
Ni-----	325	210	163	260	394	418	53	310	280	168	320	149
Pb----	9	6	5	9	12	9	0	8	6	11	9	5
Sc-----	11	9	6	10	12	13	0	10	10	10	11	4
Sr----	1,030	1,200	780	1,200	783	615	788	1,400	1,400	715	1,200	356
V-----	164	130	99	210	779	1,060	393	170	200	330	500	334
Y-----	160	180	109	220	93	146	17	360	320	136	240	86
Yb-----	8	8	5	10	6	7	1	15	14	7	11	4
Zn----	1,070	910	572	1,100	1,950	2,940	672	1,700	1,500	844	1,600	722

Sample	P-82	P-87	P-100	P-103	P-104	P-105	P-129	P-131	P-140	P-141	P-146	P-148
Ag-----	13	12	6	19	5	0	12	2	5	3	0	5
As-----	40	40	30	40	20	30	30	1	20	20	1	10
Ba----	110	198	180	220	97	291	197	51	212	124	28	120
Cd-----	94	36	24	130	50	59	48	23	10	42	97	60
Ce-----	61	66	52	67	75	71	53	17	65	30	0	10
Co-----	4	12	7	4	4	6	5	2	6	5	2	2
Cr----	1,600	1,090	1,500	3,900	980	478	1,000	430	543	235	270	930
Cu----	140	118	110	200	56	34	80	29	40	23	15	70
La-----	260	99	160	320	310	52	118	110	71	33	22	60
Li-----	16	11	25	41	8	10	18	2	18	8	0	6
Mo----	19	27	18	8	7	15	22	3	17	9	0	4
Nd----	180	73	110	170	230	46	70	60	49	33	8	31
Ni-----	210	403	160	170	55	145	114	17	125	65	13	36
Pb----	10	14	10	15	9	11	11	7	10	5	0	6
Sc-----	13	10	10	15	13	9	8	6	7	5	2	6
Sr----	1,400	595	1,300	1,100	1,700	137	639	1,100	374	259	540	1,200
V-----	550	374	190	590	320	389	535	560	258	178	340	860
Y-----	420	124	210	380	470	70	203	230	93	44	29	120
Yb----	21	6	9	16	18	5	10	11	5	3	1	5
Zn----	1,400	1,650	1,200	1,200	510	1,040	1,530	210	1,330	734	230	450

Table 2. Minor-element contents in samples of the Phosphoria Formation in Montpelier Canyon, Idaho—Continued

Sample	P-157	P-163	P-165	P-168	P-168a	U-4	U-7	U-12	R-22
Ag-----	0	0	3	0	0	0	0	0	0
As-----	10	10	10	1	0	0	0	1	0
Ba----	210	251	277	120	124	157	162	280	14
Cd-----	3	3	18	5	5	0	0	0	0
Ce-----	77	51	65	66	70	20	40	43	0
Co-----	4	9	6	3	3	5	6	4	4
Cr----	530	195	1,280	600	634	355	475	320	49
Cu----	36	21	68	32	32	13	46	37	44
La-----	270	32	148	340	382	21	52	87	8
Li-----	9	17	28	8	8	27	39	24	4
Mo----	7	3	8	3	3	14	4	3	0
Nd----	150	30	109	250	267	23	40	58	7
Ni-----	65	87	115	43	50	45	74	51	15
Pb----	8	14	11	6	8	5	4	0	0
Sc-----	9	9	10	8	6	6	7	5	0
Sr----	700	95	237	750	824	158	117	290	95
V-----	81	80	227	150	154	74	96	58	22
Y-----	480	29	249	630	642	26	68	130	9
Yb----	20	3	14	29	30	2	4	6	0
Zn----	270	129	370	220	212	38	604	320	35

Table 3. Shale compositions

[Major-element-oxide contents in weight percent; minor-element contents in parts per million. Dashes, no data. Data on worldwide shales and mainly geosynclinal shales from Wedepohl (1969), on Russian platform shales from Vinogradov and Ronov (1956), on detrital fraction of the Monterey Formation from Isaacs (1980), and on Cretaceous black shales from Brumsack (1986)]

	Detrital fraction of the Phosphoria Formation	Worldwide shales	Mainly geosyn-clinal shales	Russian platform shales	Detrital fraction of the Monterey Formation	Cretaceous black shales
Major-element oxides						
SiO_2	58.5	58.4	58.9	50.7	62.2	- - -
Al_2O_3	15.6	15.1	16.7	15.1	17.8	- - -
Fe_2O_3	4.81	6.75	6.9	6.7	3.6	- - -
MgO	2.34	2.5	2.6	3.3	2.0	- - -
CaO	3.90	3.09	2.2	7.2	1.4	- - -
Na_2O	- - -	1.29	1.6	.8	2.5	- - -
K_2O	3.98	3.20	3.6	3.5	3.6	- - -
TiO_2	.48	.77	.78	.78	5.3	- - -
P_2O_5	.16	.16	.16	.10	.5	- - -
MnO	- - -	.11	.09	.08	- - -	- - -
Minor elements						
Ag	- - -	0.07	- - -	- - -	- - -	- - -
As	- - -	13	- - -	- - -	- - -	- - -
Ba	- - -	580	- - -	- - -	- - -	- - -
Cd	- - -	.3	- - -	- - -	- - -	[1].13
Ce	- - -	59	[2]70	[3]98	- - -	- - -
Co	- - -	19	- - -	- - -	- - -	10.0
Cr	- - -	90	- - -	- - -	- - -	70.0
Cu	- - -	45	- - -	- - -	- - -	28.0
La	- - -	92	[2]32	[3]50	- - -	- - -
Li	- - -	66	- - -	- - -	- - -	- - -
Mo	- - -	2.6	- - -	- - -	- - -	- - -
Nd	- - -	24	[2]31	[3]44	- - -	- - -
Ni	- - -	68	- - -	- - -	- - -	40.0
Pb	- - -	20	- - -	- - -	- - -	[1]22.0
Sc	- - -	13	- - -	- - -	- - -	- - -
Sr	- - -	300	- - -	- - -	- - -	- - -
V	- - -	130	- - -	- - -	- - -	- - -
Y	- - -	26	[2]27	[3]49	- - -	- - -
Yb	- - -	2.6	[2]3.1	[3]4.2	- - -	- - -
Zn	- - -	95	- - -	- - -	- - -	[1]115.0

[1] Heinrichs and others (1980).
[2] Haskin and Haskin (1966).
[3] Balashov and others (1964).

Table 4. Formulas used in normative calculations

Mineral Component	Explanation	Formula
Apatite- - - - - - - - -	P_2O_5/apatite ratio is 0.406, assuming that the stoichiometry for carbonate fluorapatite is $Ca_5(PO_4)_{2.87}(CO_3)_{0.13}F_{1.13}$ and that all the P_2O_5 is in apatite, except 0.16 weight percent in detritus.	$$\frac{P_2O_5-0.01Al_2O_3}{0.406}$$
Dolomite- - - - - - -	Dolomite is calculated from MgO analyses assuming that 21.9 weight percent is in dolomite and 2.3 weight percent in detritus.	$$\frac{MgO-0.15Al_2O_3}{0.219}$$ If $MgO<0.15Al_2O_3$, then dolomite=0
Calcite- - - - - - - - -	Calcite is calculated from CaO analyses after initially subtracting out the CaO in apatite (55.5 weight percent), dolomite (30.4 weight percent), and detritus (3.9 weight percent). CaO is 56 weight percent of calcite.	$$\frac{CaO-0.25Al_2O_3-0.555Apatite-0.304Dolomite}{0.56}$$
Organic matter- - - -	Multiplication factor is adjusted from data of Isaacs (1980) after iterative calculation.	1.7Organic Carbon
Detritus- - - - - - - -	Detritus/Al_2O_3 ratio, 6.40, is determined from plot of residuals versus Al_2O_3 content. (The residual is that proportion of the rock which remains after the proportions of calcite, dolomite, apatite, and organic matter are subtracted.)	$6.40Al_2O_3$
Total silica- - - - - -	Total silica content from ICP data is calculated by subtracting from 100 major oxides and an LOI term; fluorine content is calculated from apatite abundances and adjusted for charge balance and 1, which represents sulfur and other significant minor elements. LOI term includes CO_2 in carbonates and organic matter and structural water in detritus.	100–(Sum of major oxides+LOI+0.0247Apatite+1) LOI=0.55Al_2O_3+3.66Inorganic Carbon+ 1.7Organic Carbon
Biogenic silica- - - -	Biogenic/diagenic silica is calculated by subtracting quartz and silica contents in detritus from total silica content calculated above. Quartz and silica contents in detritus are determined from slope (3.75) of well-defined minimum line when total silica is plotted against Al_2O_3 content.	Total Silica–3.75Al_2O_3

Table 5. Mineral abundances in samples of the Phosphoria Formation in Montpelier Canyon, Idaho

[All values in weight percent]

Sample	Dolomite	Calcite	Apatite	Organic matter	Detritus	Biogenic SiO$_2$
P-2	0	6.1	79.0	.9	9.0	2.0
P-2-1	45.3	10.0	.6	- - -	29.4	- - -
P-4	42.6	17.9	.3	1.5	27.7	12.6
P-5	4.2	28.8	2.0	1.8	48.5	14.3
P-7	0	4.7	62.0	4.2	18.1	10.8
P-7-1	49.4	29.9	13.3	- - -	7.1	- - -
P-10	0	4.4	54.6	7.9	20.6	13.3
P-11	7.5	75.7	5.4	- - -	12.2	- - -
P-21	.6	3.7	16.7	3.7	61.3	11.5
P-24	6.7	6.6	35.4	5.5	29.0	16.6
P-28	2.7	23.6	38.9	10.7	19.4	4.8
P-32	5.6	9.6	34.8	7.6	39.9	1.3
P-37	0	5.8	26.3	9.3	58.7	0
P-43	0	14.3	36.0	9.1	36.3	4.6
P-45	6.3	15.7	20.4	6.5	30.7	17.5
P-46	0	12.6	37.7	8.5	36.3	3.6
P-52	0	.5	6.3	6.5	69.8	15.0
P-62	0	9.2	22.1	6.1	59.1	2.4
P-64	15.9	77.7	7.5	3.1	1.8	0
P-69	0	5.5	52.9	8.1	29.0	4.2
P-71	.4	10.4	53.5	11.1	19.4	4.8
P-77	0	0	28.0	5.4	57.2	9.9
P-78	0	3.1	41.6	8.0	44.8	2.5
P-79	59.3	6.0	13.6	2.5	17.8	1.7
P-82	0	0	56.3	6.2	27.8	8.7
P-87	0	0	21.5	4.4	66.4	8.0
P-100	0	2.3	42.1	5.3	49.5	1.6
P-103	0	2.1	34.8	11.3	48.4	3.5
P-104	0	0	73.3	2.9	16.9	5.9
P-105	0	0	4.5	2.6	66.3	28.6
P-129	0	.2	45.9	2.5	39.8	10.7
P-131	.1	0	95.9	1.4	2.5	.6
P-140	2.3	3.4	22.5	1.6	51.9	16.9
P-141	1.3	50.9	7.0	1.3	30.4	8.9
P-146	1.4	63.6	33.3	1.4	1.2	0
P-148	.3	.4	84.6	3.7	7.3	0.5
P-157	2.0	3.7	51.2	2.7	26.6	11.8
P-163	0	3.3	.6	1.1	64.7	29.3
P-165	0	7.3	16.1	4.1	57.1	15.0
P-168	.1	5.5	54.1	1.8	12.1	24.6
P-168a	.1	4.3	58.1	- - -	12.3	27.4
U-4	35.2	16.4	1.6	1.0	37.5	8.2
U-7	2.3	5.7	6.0	1.7	44.5	37.3
U-12	0	4.9	38.8	1.2	24.2	28.9
R-22	1.9	20.7	.7	.5	3.0	70.8

Table 6. Correlation coefficients for rock components and minor elements

	Dolomite	Calcite	Apatite	Organic matter	Detritus	Biogenic silica	Ag	As	Ba	Cd	Ce	Co	Cr
Dolomite- - - -	1												
Calcite- - - - -	.17	1											
Apatite- - - - -	-.36	-.34	1										
Organic matter-	-.25	-.18	.18	1									
Detritus- - - -	-.18	-.4	-.51	.19	1								
Biogenic silica-	-.1	-.1	-.41	-.41	.03	1							
Ag- - - - - - -	-.24	-.36	.25	.66	.26	-.33	1						
As- - - - - - -	-.28	-.38	.12	.58	.49	-.38	.71	1					
Ba- - - - - - -	-.29	-.47	-.32	.13	.87	.1	.16	.31	1				
Cd- - - - - - -	-.02	.19	.13	.16	-.1	-.29	.48	.24	-.18	1			
Ce- - - - - - -	-.41	-.6	.08	.17	.62	-.04	.3	.52	.67	-.08	1		
Co- - - - - - -	-.19	-.25	-.48	.02	.8	.14	.12	.34	.62	-.23	.48	1	
Cr- - - - - - -	-.31	-.33	.21	.87	.33	-.4	.77	.64	.28	.29·	.38	.1	1
Cu- - - - - - -	-.35	-.31	.26	.89	.2	-.29	.83	.67	.11	.27	.26	.07	.88
La- - - - - - -	-.33	-.43	.56	.43	-.05	-.25	.43	.39	.06	.1	.63	-.13	.58
Li- - - - - - -	-.17	-.35	-.3	.36	.67	.03	.34	.29	.64	-.05	.4	.44	.56
Mo- - - - - - -	-.16	-.16	.04	.49	.25	-.23	.51	.44	.14	.15	.12	.16	.39
Nd- - - - - - -	-.31	-.41	.51	.32	-.03	-.21	.34	.34	.07	.06	.67	-.07	.47
Ni- - - - - - -	-.18	-.26	-.13	.66	.56	-.28	.61	.71	.37	.07	.33	.49	.58
Pb- - - - - - -	-.24	-.59	.05	.27	.64	-.18	.59	.59	.52	.23	.64	.43	.43
Sc- - - - - - -	-.38	-.6	.17	.6	.61	-.31	.6	.68	.58	.08	.76	.42	.76
Sr- - - - - - -	-.32	-.18	.68	.67	-.22	-.57	.46	.4	-.21	.13	.17	-.2	.6
V- - - - - - -	-.13	-.12	.24	.2	-.04	-.14	.41	.15	-.04	.64	-.1	-.18	.15
Y- - - - - - -	-.32	-.4	.63	.29	-.18	-.21	.31	.25	-.03	.04	.57	-.21	.41
Yb- - - - - - -	-.33	-.42	.58	.28	-.1	-.18	.32	.26	.05	.04	.61	-.16	.41
Zn- - - - - - -	-.21	-.2	-.06	.53	.47	-.29	.66	.7	.29	.31	.31	.36	.52

	Cu	La	Li	Mo	Nd	Ni	Pb	Sc	Sr	V	Y	Yb	Zn
Dolomite- - - -													
Calcite- - - - -													
Apatite- - - - -													
Organic matter-													
Detritus- - - -													
Biogenic silica-													
Ag- - - - - - -													
As- - - - - - -													
Ba- - - - - - -													
Cd- - - - - - -													
Ce- - - - - - -													
Co- - - - - - -													
Cr- - - - - - -													
Cu- - - - - - -	1												
La- - - - - - -	.52	1											
Li- - - - - - -	.41	.15	1										
Mo- - - - - - -	.51	.11	.22	1									
Nd- - - - - - -	.4	.97	.11	.08	1								
Ni- - - - - - -	.66	.17	.4	.76	.13	1							
Pb- - - - - - -	.38	.3	.38	.33	.29	.48	1						
Sc- - - - - - -	.64	.65	.57	.39	.63	.6	.65	1					
Sr- - - - - - -	.62	.64	-.06	.2	.59	.27	.06	.49	1				
V- - - - - - -	.22	-.03	0	.38	-.07	.24	.39	.03	.03	1			
Y- - - - - - -	.39	.97	.01	.06	.96	.05	.22	.53	.59	-.03	1		
Yb- - - - - - -	.39	.95	.06	.08	.95	.08	.27	.56	.53	-.02	.99	1	
Zn- - - - - - -	.61	.15	.36	.79	.12	.88	.49	.54	.23	.42	.04	.07	1

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Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geopnysical techniques, such as gravity, magnetic, seismic, or radioactivity, whicn reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000 and regional studies are at 1:250,000 scale or smaller.

Catalogs

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