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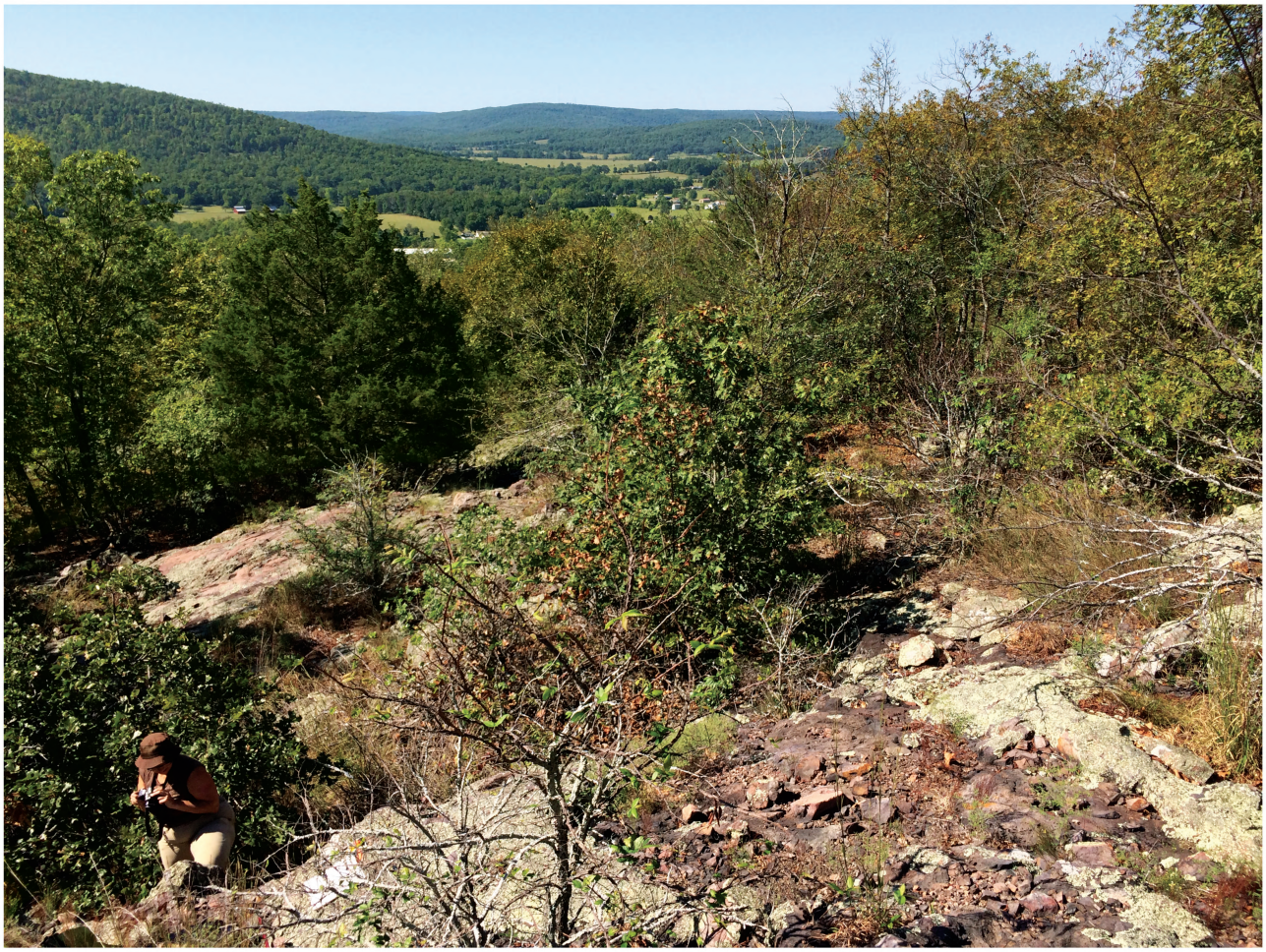
Compilation of New and Previously Published Geochemical and Modal Data for Mesoproterozoic Igneous Rocks of the St. Francois Mountains, Southeast Missouri



Data Series 1080

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photo looking southwest toward Shepherd Mountain along the south flank of Cedar Hill, Pilot Knob, Missouri. Photo by Warren C. Day, U.S. Geological Survey, 2017.

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RYAN K. ZINKE, Secretary

U.S. Geological Survey
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ScienceBase data release files that support this report are available at https://doi.org/10.5066/F79W0DSN

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Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

Ages are expressed in Ga for giga-annum (billion years or 109 years).

Acknowledgments

Data compilation undertaken for this study was carried out as part of the "Iron Oxide-Copper-Cobalt-Gold-Rare Earth Element Deposits of Southeast Missouri—From the Ore Deposit Scale to a Global Deposit Model Basement Tectonic Framework Project" funded by the U.S. Geological Survey Mineral Resources Program. Constructive reviews by A.B. Wilson and Matthew Granitto (U.S. Geological Survey) are much appreciated and helped clarify data presentation.

Compilation of New and Previously Published Geochemical and Modal Data for Mesoproterozoic Igneous Rocks in the St. Francois Mountains, Southeast Missouri

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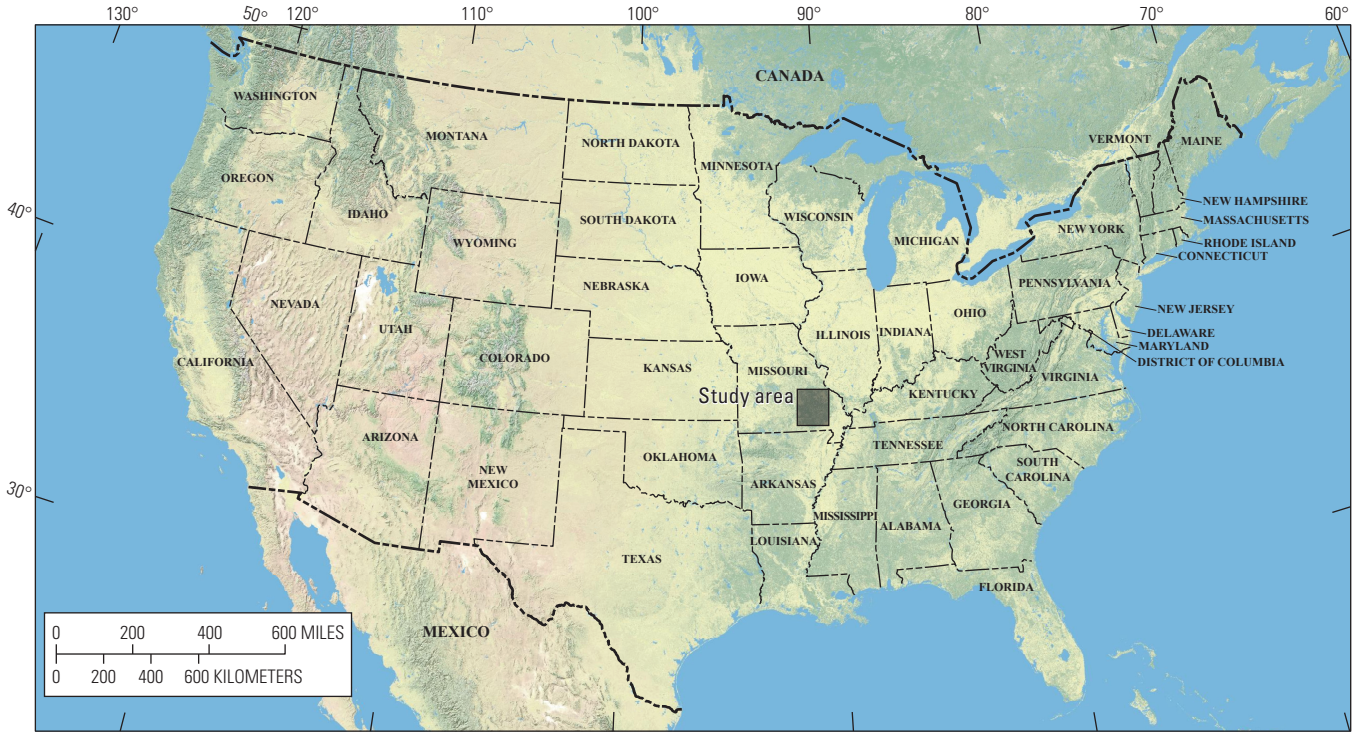
Introduction

The purpose of this report is to present recently acquired as well as previously published geochemical and modal petrographic data for igneous rocks in the St. Francois Mountains, southeast Missouri, as part of an ongoing effort to understand the regional geology and ore deposits of the Mesoproterozoic basement rocks of southeast Missouri, USA (fig. 1). The report includes geochemical data that is (1) newly acquired by the U.S. Geological Survey (USGS) and (2) compiled from numerous sources published during the last fifty-five years. These data are required for ongoing petrogenetic investigations of these rocks. Voluminous Mesoproterozoic igneous rocks in the St. Francois Mountains of southeast Missouri constitute the basement buried beneath Paleozoic sedimentary rock that is over 600 meters (m) thick in places (Tolman and Robertson, 1969). The Mesoproterozoic rocks of southeast Missouri represent a significant component of approximately broadly 1.4 billion-year-old (Ga) igneous rocks that crop out extensively in North America along the



Base from U. S. Geological Survey digital data, 2017
Albers Equal-Area Conic projection
Standard parallels 29°30′ N. and 45°30′ N.
Central meridian 96°00′ W.
North American Datum of 1983

Figure 1. Location map of the study area in the St. Francois Mountains, southeast Missouri.

southeast margin of Laurentia (Anderson and Bender 1989; Bickford and others, 2015; du Bray and others, 2018). Kisvarsanyi (1972) and Kisvarsanyi and Kisvarsanyi (1989) and subsequent researchers (see Day, Slack, and others, 2016 and references therein) suggested that iron oxide-copper deposits in the St. Francois Mountains are genetically associated with ca. 1.4 Ga magmatism in this region. The geochemical and modal data sets described herein were compiled to support investigations concerning the tectonic setting and petrologic processes responsible for the associated magmatism.

Previously Published and New Geochemical Data Produced by the U.S. Geological Survey

Two previous data releases included major oxide and trace element analyses obtained by the USGS (Day and Granitto, 2014; Day, Granitto, and others, 2016). These previously published USGS products include sample descriptions, sample locations, and major oxide and trace element abundances for samples collected by the USGS during the late 1980s through the early 2000s; these publications included additional data obtained for these samples through 2015 (Day and Granitto, 2014; Day, Granitto, and others, 2016).

Additional analyses obtained by the USGS for samples collected between 2015 and 2017 are included in this report, as well as in the data release that accompanies this report by Granitto and others (2018). The ScienceBase data release can be found at https://doi.org/10.5066/F79W0DSN.

Field notes pertinent to samples collected between 2015 and 2017, prefixed with MO15, MO16, and MO17 and where "_xxx" is the individual sample number, were compiled using Excel and can be accessed using software compatible with .xlsx files. The data being described here are presented both as a data release (available at https://doi.org/10.5066/F79W0DSN) and also accompany this report. The Excel file is "ds1080_appendix1_Field_Notes.xlsx," and its derivative ASCII tab-delimited text file is "ds1080_appendix1_Field_Notes.txt."

Data attributes in these files (table 1.1) include the field number (*Field_ID*), location (*Latitude*, *Longitude*) rock type (*Rock_Type*), description of the rock and (or) outcrop from which the sample was collected (*Rock_Description*), the alteration minerals observed in the field (*Alt_Minerals*), and their mode of occurrence (*Alt_Style*). The field notes files also includes information for samples for which corresponding geochemical analyses were not obtained; this descriptive information is included for completeness.

Geochemical Data Compiled From Published Literature

Several prior investigations report significant amounts of compositional data for Mesoproterozoic igneous rocks in the St. Francois Mountains that have been compiled during our investigations; these contribute significantly to the understanding of the geochemistry of the region. The publications that include the results of earlier data acquisition efforts are itemized as sources tabulated in the *Data_Src* field in the Microsoft Excel database file (see table 2.1) and in the data release for this report (https://doi.org/10.5066/F79W0DSN).

Original data source materials (subsequently referred to as sources), including published reports and theses, were used to add information to the database described herein. For an individual sample to be included in our compilation, at a minimum, sample identification, location information, and a major oxide analysis were required. Additional data were added as available. Data were compiled using Excel and can be accessed using software compatible with .xlsx files. The data being described here are presented both as a data release (available at https://doi.org/10.5066/F79W0DSN) and also accompany this report. The Excel file is "ds1080_appendix2_SE_MO_ChemData.xlsx," and its derivative ASCII tab-delimited text files are "ds1080_appendix2SE_MO_ChemData_FreshUnaltered.txt" and "ds1080_appendix2_SE_MO_ChemData_AlteredMineralized.txt."

The references cited in each data source product were examined and used to identify additional sources of data. Accordingly, data for 618 unaltered samples and 549 altered samples were identified and included here (appendix 2) and in the accompanying data release (https://doi.org/10.5066/F79W0DSN). This compilation process has likely resulted in identification and incorporation of the majority of compositional data available for Mesoproterozoic igneous rocks in the St Francois Mountains, Missouri.

Compiling analytical methods and associated estimates of precision and accuracy associated with previously published data is beyond the scope of this effort. Analytical protocols, precision, and accuracy were highly variable among the previous publication sources. Fortunately, most sources document these parameters, and this type of documentation can be retrieved by referring to the source reference publication in which the data were originally released.

Background documentation for some samples and (or) analytical data presented in this report may be incomplete, misleading, or incorrect, any of which could result in the inclusion of inappropriate information in the database. All efforts have been made to exclude inappropriate samples and (or) misleading data; the amount of inappropriate data inadvertently included in the database is probably small and is unlikely to significantly affect data interpretation.

Identification of Geochemically Altered Samples

In order to understand the origin of the Mesoproterozoic terrane and subsequent overprinting by mineralizing systems, it is critical to discern the relative intensity and type of alteration superimposed on the primary igneous rocks. Altered samples were identified using standard geochemical criteria. Specifically, for the purposes of this compilation, altered samples are those with any of the following characteristics: SiO_2 abundances greater than or equal to 78 weight percent (*SiO2_pct*), Al_2O_3 abundances greater than 23 weight percent or lower than 9 weight percent (*Al2O3_pct*), Na_2O abundances greater than 6.5 weight percent or less than 0.5 weight percent (*Na2O_pct*), K_2O abundances greater than 8 weight percent (*K2O_pct*), CO_2 concentrations greater than 0.35 weight percent (*CO2_pct*), Na_2O/K_2O greater than 5 (*Na2O_pct* and *K2O_pct*), K_2O/Na_2O greater than 1.5 (*Na2O_pct* and *K2O_pct*), total volatile concentrations greater than 3 weight percent (*LOI_pct*), or samples that explicitly exhibit secondary alteration or mineralization. Some additional samples were identified as altered because of their geochemical systematics: abundances for some oxides stray significantly from the abundance arrays defined by unaltered samples. In addition, sample oxide abundances that total greater than 103 or less than 97 weight percent (*Total_I_pct*) probably reflect inaccurate analyses. Samples with any of these characteristics probably do not accurately preserve primary igneous rock compositions; consequently, the associated data were removed from the fresh/unaltered rock compilation and added to the companion compilation of compositions for altered rocks. Data for unaltered, fresh samples are presented (in the Excel file "ds1080_appendix2_SE_MO_ChemData.xlsx") in the worksheet tab titled "FreshUnaltered," whereas those for altered samples can be accessed via the workbook tab labeled "AlteredMineralized". Samples in the "AlteredMineralized" dataset are sorted into subsets that share similar alteration characteristics (indicated by the column *Subset*).

Geochemical Data Processing

Starting with original information extracted from all sources, the geochemical data were processed to enhance their usability. Specifically, all censored values (greater than, less than, not detected, and so forth) were replaced by blank cells. Also, because different sources report iron concentrations determined by different analytical protocols, iron-abundance data required standardization. For some samples, abundances of both ferric and ferrous iron were reported in the source, whereas other sources report only total iron abundances as either Fe_2O_3 or FeO. In most samples, reported ferrous and ferric iron abundances are unlikely to represent magmatic values because of oxidation during late- to post-magmatic processes. Therefore, to facilitate meaningful comparison of oxide abundances, all iron abundances were converted to ferrous iron (reported in the *FeO_pct* columns in each worksheet) and each major oxide analysis was recalculated to 100 percent on a volatile-free basis.

Modal Data

Modal data, the relative proportions of minerals in particular rock samples, have been determined for many of the least altered Mesoproterozoic igneous rocks in the St. Francois Mountains for which geochemical data are also available. These data were acquired by microscopic examination of (1) rock slabs stained to enhance identification of particular mineral species and (or) (2) thin sections: both types of examination involve point counting and recording the mineral present at each of a large number of pre-determined grid points. These data are a standard form of igneous rock characterization and were included in many of the publications from which geochemical data for these rocks were compiled. All modal data contained in the source publications and generated for selected USGS samples collected between 2015 and 2017 are included in the data compilation for the unaltered/fresh rocks Fresh/Unaltered tab in "ds1080_appendix2_SE_MO_ChemData.xlsx," columns BT-CH (see appendix 2, and the accompanying data release at https://doi.org/10.5066/F79W0DSN).

Data Fields

Geochemical and modal data are presented in columns or sets of related columns (see appendix 2 of this report, and the accompanying data release at https://doi.org/10.5066/F79W0DSN). Geochemical data in some worksheet cells may appear to be more precise than displayed values, but the implied precision is a misleading artifact of computational processes (for instance, recalculation to 100-percent volatile free) used to create data-cell contents. Blank cells in the Excel files indicate null values or that no data are available. Some blank cells reflect abundances that were reported as "less than the detection limit," these values were replaced by blank cells to enable statistical analysis of the uncensored data.

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Appendix 1. Field Notes for Igneous Rocks of the St. Francois Mountains, Southeast Missouri Collected Between 2015 and 2017 (ds1080_appendix1_MO15_17_Field_Notes)

ds1080_appendix1_MO15_17_Field_Notes.xlxs..... LINK
ScienceBase data release files available at https://doi.org/10.5066/F79W0DSN.

Table 1. Definition and characterization of data fields for field notes for igneous rocks of the St. Francois Mountains, southeast Missouri collected between 2015 and 2017 (ds1080_appendix1_MO15_17_Field_Notes.xlxs and .txt).

[All censored values (greater than, less than, not detected, and so forth) were replaced by blank cells]

Field name	Field description
Field_ID	Field sample number
Latitude	Latitude for sample site
Longitude	Longitude for sample site
Rock_Type	Rock type name for sample collected
Rock_Description	Description of rock and outcrop from which sample was taken
Alt_Minerals	Alteration mineral assemblage noted in the field
Alt_Style	Style or the mode of occurrence of the alteration mineral assemblage

Appendix 2. Geochemical and Modal Data for Igneous Rocks in the St. Francois Mountains, Southeast Missouri (ds1080_appendix2_SE_MO_ChemData.xlsx)

ds1080_appendix2_SE_MO_ChemData.xlsx ..... LINK
ScienceBase data release files available at https://doi.org/10.5066/F79W0DSN.

Table 2.1. Definition and characterization of data fields for geochemical and modal data for igneous rocks in the St. Francois Mountains, southeast Missouri (ds1080_appendix2_SE_MO_ChemData.xlsx).

[All censored values (greater than, less than, not detected, and so forth) were replaced by blank cells; <, less than; > greater than; REE, rare earth elements; %, percent]

Field name	Field description
Field_Number	Field-assigned sample identifier; Field_Number entries link data for individual rows, for U.S. Geological Survey (USGS) samples, to samples in the National Geochemical Database (U.S. Geological Survey, 2013)
Subset	Stratigraphic or alteration characteristic for subset grouping
Strat_Name	Formal or informal stratigraphic nomenclature for igneous rock unit represented by sample, in agreement with lexicon of the USGS National Geologic Map Database (https://ngmdb.usgs.gov/Geolex/search)
Lithology	Composition of intrusive rock samples according to the classification scheme of Streckeisen (1976) or composition of extrusive and hypabyssal intrusive rock samples according to the classification scheme of Le Maitre (2002)
Lith_Code	Code "M" where entries for intrusive rocks indicate compositions supported by modal data, and code "C" where entries for intrusive rocks reflect compositional estimates
Ign_Form	Form (pluton, plug, dike, sill, lava, ash-flow tuff and so forth) of the igneous rock represented by each sample
Longitude	In decimal degrees, relative to the North American Datum of 1927. At 40 degrees latitude, locations with five significant figures to the right of the decimal (0.00001) are accurate to 0.9 meters (m); those with four significant figures to the right of the decimal (0.0001) are accurate to 8.5 m; those with three significant figures to the right of the decimal (0.001) are accurate to 85.4 m; those with two significant figures to the right of the decimal (0.01) are accurate to 854 m; those with one significant figure to the right of the decimal (0.1) are accurate to 8,540 m. Longitude is reported as a negative value (western hemisphere)
Latitude	In decimal degrees, relative to the North American Datum of 1927. At 40 degrees latitude, locations with five significant figures to the right of the decimal (0.00001) are accurate to 1.1 m; those with four significant figures to the right of the decimal (0.0001) are accurate to 11.1 m; those with three significant figures to the right of the decimal (0.001) are accurate to 111 m; those with two significant figures to the right of the decimal (0.01) are accurate to 1,110 m; those with one significant figure to the right of the decimal (0.1) are accurate to 11,103 m. Latitude is reported as a positive value (northern hemisphere)
SiO2_pct	Silicon, as silicon dioxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
TiO2_pct	Titanium, as titanium dioxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
Al2O3_pct	Aluminum, as aluminum trioxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
FeO_pct	Total iron, as ferrous oxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
MnO_pct	Manganese, as manganese oxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
MgO_pct	Magnesium, as magnesium oxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
CaO_pct	Calcium, as calcium oxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis

Table 2.1. Definition and characterization of data fields for geochemical and modal data for igneous rocks in the St. Francois Mountains, southeast Missouri (ds1080_appendix2_SE_MO_ChemData.xlsx).—Continued

[All censored values (greater than, less than, not detected, and so forth) were replaced by blank cells; <, less than; > greater than; REE, rare earth elements; %, percent]

Field name	Field description
Na2O_pct	Sodium, as sodium oxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
K2O_pct	Potassium, as potassium oxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
P2O5_pct	Phosphorus, as phosphorus pentoxide, in weight percent; based on major oxide data recalculated to 100 percent on a volatile-free basis
LOI_pct	Volatile content lost on ignition, in weight percent
H2Ob_pct	Structurally bound or essential water, in weight percent
H2Om_pct	Nonessential moisture, in weight percent
CO2_pct	Carbon dioxide, in weight percent
Cl_pct	Chlorine, in weight percent
F_pct	Fluorine, in weight percent
S_pct	Sulfur, in weight percent
Total_I_pct	Initial, pre-recalculation sum of oxide abundances, in weight percent
Volatile_pct	Total volatile content, in weight percent; calculated as the sum of moisture, bound water, carbon dioxide, chorine, fluorine, and sulfur or as the content lost on ignition
Ba_ppm	Barium, in parts per million
Be_ppm	Beryllium, in parts per million
Cs_ppm	Cesium, in parts per million
Rb_ppm	Rubidium, in parts per million
Sr_ppm	Strontium, in parts per million
Y_ppm	Yttrium, in parts per million
Zr_ppm	Zirconium, in parts per million
Hf_ppm	Hafnium, in parts per million
Nb_ppm	Niobium, in parts per million
Th_ppm	Thorium, in parts per million
U_ppm	Uranium, in parts per million
Ga_ppm	Gallium, in parts per million
La_ppm	Lanthanum, in parts per million
Ce_ppm	Cerium, in parts per million
Pr_ppm	Praseodymium, in parts per million
Nd_ppm	Neodymium, in parts per million
Sm_ppm	Samarium, in parts per million
Eu_ppm	Europium, in parts per million
Gd_ppm	Gadolinium, in parts per million
Tb_ppm	Terbium, in parts per million
Dy_ppm	Dysprosium, in parts per million
Ho_ppm	Holmium, in parts per million
Er_ppm	Erbium, in parts per million
Tm_ppm	Thulium, in parts per million
Yb_ppm	Ytterbium, in parts per million
Lu_ppm	Lutetium, in parts per million

Table 2.1. Definition and characterization of data fields for geochemical and modal data for igneous rocks in the St. Francois Mountains, southeast Missouri (ds1080_appendix2_SE_MO_ChemData.xlsx).—Continued

[All censored values (greater than, less than, not detected, and so forth) were replaced by blank cells; <, less than; > greater than; REE, rare earth elements; %, percent]

Field name	Field description
Ag_ppm	Silver, in parts per million
Au_ppm	Gold, in parts per million
Co_ppm	Cobalt, in parts per million
Cr_ppm	Chromium, in parts per million
Ni_ppm	Nickel, in parts per million
Sc_ppm	Scandium, in parts per million
V_ppm	Vanadium, in parts per million
Cu_ppm	Copper, in parts per million
Mo_ppm	Molybdenum, in parts per million
Pb_ppm	Lead, in parts per million
Zn_ppm	Zinc, in parts per million
Sn_ppm	Tin, in parts per million
W_ppm	Tungsten, in parts per million
Ta_ppm	Tantalum, in parts per million
As_ppm	Arsenic, in parts per million
Sb_ppm	Antimony, in parts per million
B_ppm	Boron, in parts per million
Abd_Pl	Modal abundance of plagioclase relative to the whole rock, in volume percent; Major, >10 volume percent, Minor, <10 volume percent
Abd_AlkFld	Modal abundance of alkali feldspar relative to the whole rock, in volume percent; Major, >10 volume percent
Abd_Qtz	Modal abundance of quartz relative to the whole rock, in volume percent; Major, >10 volume percent
Abd_Hbl	Modal abundance of hornblende relative to the whole rock, in volume percent; TR, trace (<0.5 volume percent)
Abd_Ol	Modal abundance of olivine relative to the whole rock, in volume percent; TR, trace (<0.5 volume percent)
Abd_Opx	Modal abundance of orthopyroxene relative to the whole rock, in volume percent
Abd_Cpx	Modal abundance of clinopyroxene relative to the whole rock, in volume percent
Abd_Bt	Modal abundance of biotite relative to the whole rock, in volume percent; TR, trace (<0.5 volume percent) amounts
Abd_Mu	Modal abundance of muscovite relative to the whole rock, in volume percent; TR, trace (<0.5 volume percent) amounts
Abd_Opq	Modal abundance of opaque iron-titanium oxide minerals relative to the whole rock, in volume percent; TR, trace (<0.5 volume percent)
Abd_Tot_mafics	Modal total mafic mineral content relative to the whole rock, in volume percent
Abd_Acc	Modal total accessory mineral content relative to the whole rock, in volume percent; TR, trace (<0.5 volume percent) amounts
Abd_Alt	Modal total alteration mineral content relative to the whole rock, in volume percent; TR, trace (<0.5 volume percent) amounts
Groundmass	Modal abundance of groundmass relative to the whole rock, in volume percent

Table 2.1. Definition and characterization of data fields for geochemical and modal data for igneous rocks in the St. Francois Mountains, southeast Missouri (ds1080_appendix2_SE_MO_ChemData.xlsx).—Continued

[All censored values (greater than, less than, not detected, and so forth) were replaced by blank cells; <, less than; > greater than; REE, rare earth elements; %, percent]

Field name	Field description
Data_Src	Source of data—For a few samples, data were culled from two or more sources; for example, major oxide data may have been compiled from one source, trace element data from another, and petrographic data from a third. *Data_Src* entries are compiled below: Anderson (1962) Bickford and others (1981) Brown (1983) Cullers and others (1981) Day and Granitto (2014) Day and others (2017) Granitto and others (2018) Harrison and others (2002) Kisvarsanyi (1972) Lowell and others (2010) McDowell and Harrison (2000) Menuge and others (2002) Orndorff and others (1999) Pippin (1996) Sylvester (1984) U.S. Geological Survey, 2013 Walker and others (2002) Weary and Orndorff (2012) Weary and Weems (2004)

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