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Overview with Methods and Procedures of the U.S. Geological Survey Mineral-Resource Assessment of the Sagebrush Focal Areas of Idaho, Montana, Nevada, Oregon, Utah, and Wyoming

Chapter A of
Mineral Resources of the Sagebrush Focal Areas of Idaho, Montana, Nevada, Oregon, Utah, and Wyoming

Scientific Investigations Report 2016–5089–A

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

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

Foreword

Scientific Investigations Report 2016–5089 and accompanying data releases are the products of the U.S. Geological Survey (USGS) Sagebrush Mineral-Resource Assessment (SaMiRA). The assessment was done at the request of the Bureau of Land Management (BLM) to evaluate the mineral-resource potential of some 10 million acres of Federal and adjacent lands in Idaho, Montana, Nevada, Oregon, Utah, and Wyoming. The need for this assessment arose from the decision by the Secretary of the Interior to pursue the protection of large tracts of contiguous habitat for the greater sage-grouse (*Centrocercus urophasianus*) in the Western United States. One component of the Department of Interior plan to protect the habitat areas includes withdrawing selected lands from future exploration and development of mineral and energy resources, including copper, gold, silver, rare earth elements, and other commodities used in the U.S. economy. The assessment evaluates the potential for locatable minerals such as gold, copper, and lithium and describes the nature and occurrence of leaseable and salable minerals for seven Sagebrush Focal Areas and additional lands in Nevada ("Nevada additions") delineated by BLM. Supporting data are available in a series of USGS data releases describing mineral occurrences (the USGS Mineral Deposit Database or "USMIN"), oil and gas production and well status, previous mineral-resource assessments that covered parts of the areas studied, and a compilation of mineral-use cases based on data provided by BLM, as well as results of the locatable mineral-resource assessment in a geographic information system. The present assessment of mineral-resource potential will contribute to a better understanding of the economic and environmental trade-offs that would result from closing the designated 10 million acres of Federal lands to mineral entry.

The initial request for USGS involvement in this resource assessment occurred in October 2015, with a need to provide a report to BLM by mid-July 2016 to inform the National Environmental Policy Act (NEPA) process and environmental impact statement (EIS) preparation. Such a short timeframe required mobilizing a large number of USGS Mineral Resources Program staff to focus on the SaMiRA project, which began in November 2015 with a series of programwide teleconferences to get the project rolling. All of the 61 staff members enlisted to work on the project, including three emeritus scientists who are experts in assessment and in the geology of the areas under consideration, put aside other research and dedicated themselves to this new effort. The first step was to assemble the many types of data needed, including geology, geophysics, geochemistry, location of known deposits, production history, current exploration results, and information from State geological surveys and industry.

By the end of January 2016, the assessment teams were working hard to evaluate the myriad data needed for the assessments. State geological surveys were invited to participate in the process, and meetings were held over a period of several weeks in February and March in Butte, Montana; Denver, Colorado; Menlo Park, California; Moscow, Idaho; and Reno, Nevada, to conduct the assessment workshops and present the results to the State geological surveys for their feedback. The immense task of report writing and figure preparation began during and following the assessment meetings, always mindful of the looming July deadline. The support of the USGS Science Publishing Network is gratefully acknowledged in getting these reports finished in time to meet the BLM's EIS and NEPA deadlines.

We are, as individuals and as an organization, proud of these reports and the dedication and hard work of all the scientists and specialists who worked to produce them. We hope these volumes serve to inform the decisions regarding the future of these Federal lands in the West, the protection of greater sage-grouse and their habitat, and the economies of the Western States. Although we sought information and advice from numerous outside contributors, the results of this study are solely those of the USGS.

Larry Meinert, Program Coordinator, Mineral Resources Program, USGS

Preface

Landscape-scale conservation efforts by the Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (FWS), the U.S. Forest Service (USFS), State agencies, private landowners, and other partners are striving to conserve the breeding sagebrush habitat for the greater sage-grouse (*Centrocercus urophasianus*) across 11 Western States. In September 2015, the FWS decided that the greater sage-grouse did not warrant protection under the Endangered Species Act. Concurrent with this decision, the BLM and USFS finalized land-use plans for the Federal lands containing sagebrush habitat, consisting of more than 165 million acres, of which 10 million acres (15,625 square miles) of BLM and National Forest System lands have been proposed for withdrawal from mineral entry across Idaho, Montana, Nevada, Oregon, Utah, and Wyoming. An additional 394,289 acres (616 square miles) in Nevada (termed the "Nevada additions") were also evaluated by the U.S. Geological Survey (USGS), at the request of the BLM, that were proposed by the State of Nevada for consideration. The land-use plans outline management practices aimed at conserving viable sagebrush habitats that support the greater sage-grouse across large areas termed Sagebrush Focal Areas (SFAs). The SFAs contain lands that have been proposed for withdrawal ("withdrawal areas") from location and entry under the U.S. mining laws, subject to valid existing rights.

The USGS Sagebrush Mineral-Resource Assessment (SaMiRA) project was initiated in November 2015 and supported by the BLM to (1) assess locatable mineral-resource potential and (2) to describe leasable and salable mineral resources for the seven SFAs and Nevada additions. Because of the limited duration of the SaMiRA project, the effort focused on publically available geoscience data. Additionally, the State geological surveys of Idaho, Montana, Nevada, Oregon, Utah, and Wyoming provided valuable mineral resource and geologic data, as well as scientific expertise. Information was solicited directly by the USGS from the mineral industry, as well as through BLM's public comment process, regarding any information the mineral industry wished to make public and have considered in the assessment. However, the conclusions presented herein are solely those of the USGS.

Acknowledgments

Matthew Granitto, Douglas Yager, and Stephen Smith. The geophysical data were compiled and processed by Eric Anderson and David Ponce; Barnaby Rockwell provided data and guidance on interpretation of remote sensing data. A number of USGS energy experts contributed data and analysis for uranium, geothermal energy, oil and gas, and coal (see below). Donald Bleiwas, Beth Sangine, and the staff of the USGS National Minerals Information Center (NMIC) contributed commodity information and expertise.

Before writing began, the individual area preliminary assessment tracts were reviewed by an "Assessment Oversight Committee" (AOC) comprised of USGS project leads and scientists of the project to evaluate completeness and consistency from area to area. AOC leads include Thomas Frost, Jane Hammarstrom, and Michael Zientek. Panelists include Donald Bleiwas, Warren Day, Jeffrey Mauk, Mark Mihalasky, Gilpin Robinson, and Bradley Van Gosen.

The following provides an outline of the SaMiRA project structure and lists the names of contributors.

SaMiRA Project Coordination
Warren C. Day, co-lead
Thomas P. Frost, co-lead

North-Central Montana SFA Team
B. Carter Hearn, Jr. (Emeritus)
Jeffrey L. Mauk, lead
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Gilpin R. (Rob) Robinson
Michael L. Zientek, co-lead

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Susan Hall
Jane M. Hammarstrom
David A. John
Mark J. Mihalasky
Gilpin R. (Rob) Robinson
Lisa L. Stillings
Bradley S. Van Gosen
Michael L. Zientek

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Conversion Factors

[U.S. customary units to International System of Units]

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
barrel (bbl; petroleum, 1 barrel=42 gal)	0.1590	cubic meter (m^3)
Mass		
ounce, troy (oz)	31.103	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)
ton, long (2,240 lb)	1.016	metric ton (t)

[International System of Units to U.S. customary units]

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
Area		
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
Volume		
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)

Multiply	By	To obtain
cubic meter (m³)	35.31	cubic foot (ft³)
cubic meter (m³)	1.308	cubic yard (yd³)
cubic kilometer (km³)	0.2399	cubic mile (mi³)
cubic meter (m³)	0.0008107	acre-foot (acre-ft)
Mass		
gram (g)	0.032	ounce, troy (oz)
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t)	1.102	ton, short [2,000 lb]
metric ton (t)	0.9842	ton, long [2,240 lb]
Density		
kilogram per cubic meter (kg/m³)	0.06242	pound per cubic foot (lb/ft³)
gram per cubic centimeter (g/cm³)	62.4220	pound per cubic foot (lb/ft³)

Supplemental Information

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C = (°F − 32) / 1.8.

Datum

Vertical coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

Ad	andradite (iron-rich garnet)
AMIS	Automated Minerals Information System
AOC	Assessment Oversight Committee
API	American Petroleum Institute
AR	"as received"
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTM	American Society for Testing and Materials
AU	assessment unit (oil and gas)
BCF, BCFG	billion cubic feet (of gas)
BHT	bottom-hole temperature
BLM	Bureau of Land Management
BRW	Bear River Watershed (Sagebrush Focal Area)
Bt	billion metric tons
BV	"best value"
CAGR	compound annual growth rate
CAI	color alteration index
CFR	Code of Federal Regulations
CIGS	copper-indium-gallium selenide
CSA	Canadian Standards Association
CSM	clay-sulfate-mica
CSAMT	controlled-source audiofrequency magnetotellurics
DLA	Defense Logistics Agency
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EGS	enhanced geothermal system
EIS	Environmental Impact Statement
ETM+	Landsat 7 Enhanced Thematic Mapper Plus
FLPMA	Federal Land Policy and Management Act of 1976
f.o.b.	free on board
FWS	U.S. Fish and Wildlife Service
g/t	gram per metric ton
Ga	giga-annum or billions of years ago

GFTZ	Great Falls Tectonic Zone
GHC	Geo-Heat Center
GIS	geographic information system
HSSR	Hydrogeochemical and Stream Sediment Reconnaissance
IDW	inverse distance weighted
LEDs	light-emitting diodes
LLD	lower limit(s) of determination
m.y.	millions of years
Ma	mega-annum or millions of years ago
MAS	Minerals Availability System
MCF	thousand cubic feet of gas
MILS	Mineral Industry Location System
MMBO	million barrels of oil
MMBNGL	million barrels of natural gas liquids
MOP	muriate of potash
Moz	million troy ounces
MRDS	Mineral Resources Data System
Mt	million metric tons
MTU	metric ton unit
MVT	Mississippi-Valley-type
MW	megawatt
MWe	megawatt electricity
NASGLP	North American Soils Geochemical Landscape Project
NBMG	Nevada Bureau of Mines and Geology
NDS	National Defense Stockpile
NEPA	National Environmental Policy Act of 1989
NGDB	National Geochemical Database
NGL	natural gas liquids
NGS	National Geochemical Survey
NMIC	USGS National Minerals Information Center
NOAA	National Oceanic and Atmospheric Administration
NOGA	USGS National Oil and Gas Assessment
NURE	National Uranium Resource Evaluation
NWR	National Wildlife Refuge
opt	troy ounce per metric ton

oz	troy ounce
PGE	platinum-group element
PGM	platinum-group metal
PLSS	Public Land Survey System
ppm	parts per million
REE	rare earth element
REOE	rare earth oxide equivalent(s)
RMOTC	Rocky Mountain Oilfield Testing Center
ROD	Record of Decision
RTP	reduction-to-the-pole
SaMiRA	Sagebrush Mineral-Resource Assessment
SEDAR	Canadian System for Electronic Document Analysis and Retrieval
SEDEX	sedimentary exhalative
SFA	Sagebrush Focal Area
SG	specific gravity
SI	structural index
SOP	sulfate of potash
SWIR	shortwave-infrared (region of the electromagnetic spectrum)
t	metric ton
TCM	Tax Court Memorandum
Th/K	thorium/potassium ratio
TMI	total magnetic intensity
TOMS	Topographically Occurring Mine Symbols
TPS	total petroleum system
UMOS	Utah Mineral Occurrence System
USBM	former U.S. Bureau of Mines
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USMIN	USGS Mineral Deposit Database
VMS	volcanogenic massive sulfide
wt.%	weight percent
WYO	Southwestern and South-Central Wyoming (Sagebrush Focal Area)

Chemical Symbols and Formulas Used

Ag	silver	Gd	gadolinium
Al	aluminum	Ge	germanium
Al_2O_3	aluminum oxide	H	hydrogen
Ar	Argon	H_2S	hydrogen sulfide
As	arsenic	Hf	hafnium
Au	gold	Hg	mercury
B	boron	Ho	holmium
Ba	barium	In	indium
$BaSO_4$	barium sulfate	Ir	iridium
Be	beryllium	K	potassium
Bi	bismuth	K_2O	potassium oxide
Br	bromine	La	lanthanum
C	carbon	Li	lithium
C_{org}	organic carbon	Lu	lutetium
CO	carbon monoxide	Mg	magnesium
CO_2	carbon dioxide	MgO	magnesium oxide
Ca	calcium	Mn	manganese
CaO	calcium oxide	Mo	molybdenum
Cd	cadmium	N	nitrogen
Ce	cerium	NH_3	ammonia
CH_4	methane	Na	sodium
Cl	chlorine	NaCl	sodium chloride
Co	cobalt	Na_2O	sodium oxide
Cr	chromium	Nb	niobium
Cs	cesium	Nd	neodymium
Cu	copper	Ni	nickel
Dy	dysprosium	O	oxygen
Er	erbium	Os	osmium
Eu	europium	P	phosphorous
F	fluorine	P_4	elemental (white) phosphorus
Fe	iron	PO_4	phosphate
Fe_2O_3	ferric iron oxide	P_2O_5	phosphorous pentoxide
Ga	gallium	Pb	lead
GaAs	gallium arsenide	Pd	palladium
GaN	gallium nitride	Pr	praseodymium

Pt	platinum	Te	tellurium
Rb	rubidium	Th	thorium
Re	rhenium	Ti	titanium
Rh	rhodium	TiO_2	titanium dioxide
Ru	ruthenium	Tm	thulium
S	sulfur	Tl	thallium
Sb	antimony	U	uranium
Sc	scandium	U_3O_8	triuranium octaoxide (yellowcake)
Se	selenium	V	vanadium
Si	silicon	V_2O_5	vanadium pentoxide
SiO_2	silicon dioxide (silica)	W	tungsten
Sm	samarium	WO_3	tungsten trioxide
Sn	tin	Y	yttrium
Sr	strontium	Yb	ytterbium
Ta	tantalum	Zn	zinc
Tb	terbium	Zr	zirconium

Mineral Formulas Used

adularia	$KAlSi_3O_8$
alunite	$KAl_3(SO_4)_2(OH)_6$
andradite (garnet)	$Ca_3Fe^{3+}_2(SiO_4)_3$
ankerite	$Ca(Fe,Mg,Mn)(CO_3)_2$
argentite	Ag_2S
arsenopyrite	$FeAsS$
barite	$BaSO_4$
bornite	Cu_5FeS_4
cassiterite	SnO_2
chalcocite	Cu_2S
chalcopyrite	$CuFeS_2$
cinnabar	HgS
clinoptililite (zeolite)	$(Ca, Na,K_6[Al_6Si_3O_{72}] \cdot \sim 20H_2O$
coffinite	$U[SiO_4,(OH)_4]$

corderoite	$Hg_3S_2Cl_2$
dolomite	$CaMg(CO_3)_2$
erionite (zeolite)	$(Ca,Na,K)_{10}[Al_{10}Si_{26}O_{72}]\cdot{\sim}30H_2O$
fluorite	CaF_2
galena	PbS
hectorite (smectite clay)	$Na_3(Mg,Li)_3Si_4O_{10}(F,OH)_2$
hematite	Fe_2O_3
ilmenite	$FeTiO_3$
kaolinite	$Al_2Si_2O_5(OH)_4$
leucite	$K(AlSi_2O_6)$
magnetite	Fe_3O_4
molybdenite	MoS_2
molybdite	MoO_3
monazite	$(Ce,La,Th,Nd)PO_4$
montmorillonite	$(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$
nepheline	$Na_3KAl_4Si_4O_{16}$
opal	$SiO_2{\cdot}nH_2O$
phillipsite (zeolite)	$(Ca,Na,K)_{4-7}[Al_{4-7}Si_{2-9}O_{32}]\cdot12H_2O$
powellite	$CaMoO_4$
pyrite	FeS_2
quartz	SiO_2
rutile	TiO_2
scheelite	$CaWO_4$
siderite	$FeCO_3$
sillimanite	Al_2SiO_5
sylvite	KCl
sylvinite	$KCl+NaCl$
sphalerite	$(Zn,Fe)S$
staurolite	$Fe_2Al_9Si_4O_{23}(OH)$
stilpnomelane	$(K,Ca,Na)(Fe^{2+},Mg,Fe^{3+})_8(Si,Al)_{12}(O,OH)_{27}{\cdot}nH_2O$
tetrahedrite	$(Cu,Fe,Ag,Zn)_{12}Sb_4S_{13}$
uraninite	UO_2
xenotime	YPO_4
zircon	$ZrSiO_4$

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Section A. Overview of the U.S. Geological Survey Sagebrush Mineral-Resource Assessment (SaMiRA) Project

By Warren C. Day, Jane M. Hammarstrom, Michael L. Zientek, and Thomas P. Frost

Abstract

This report, chapter A of Scientific Investigations Report 2016–5089, provides a project overview and a consolidated resource for the methods, procedures, and voluminous fundamental reference information used throughout the Sagebrush Mineral-Resource Assessment (SaMiRA) project. Mineral occurrence and deposit information is a key component of assessments for non-energy minerals. Data were used from several major databases. The new U.S. Geological Survey (USGS) Mineral Deposit Database project (USMIN) (Fernette, section B) provides a modern compilation that captures all information publically available through historical records, Federal and State databases, company reports, and from the Bureau of Land Management's (BLM) public comments on the proposed withdrawal action of greater sage-grouse (*Centrocercus urophasianus*) habitat received by the USGS on April 4, 2016. USMIN provides updated location and mineral information on mine sites, mining districts, areas of active exploration, and production data. The USGS Mineral Resource Data System (MRDS) legacy database (Schweitzer, section B) contains mineral-resource information used in the SaMiRA project. The Automated Minerals Information System (AMIS) database operated by the USGS (see Sangine, section B) contains proprietary mineral data that, when aggregated to assure that the individual operators were not identified, provided a list of active facilities in the project area.

Geochemical data for approximately 26,300 stream sediment and soil samples, 3,700 heavy concentrate fractions, and 6,890 rock samples were compiled from USGS geochemical databases for the SaMiRA project. After statistical evaluation, selected elements indicative of a wide variety of mineral-deposit types were used to identify areas with mineral potential (Smith and others, section C). Geophysical methods are powerful tools to map geologic materials that have differing physical properties in areas

that are both exposed on the land surface and concealed beneath thick sequences of overburden. Such information helps define mineral-potential tracts like those used in the SaMiRA project. Anderson and Ponce (section D) review the magnetic susceptibility, density, and radioactivity data sources and analytical methods used. Rockwell (section E) describes remote-sensing data used for the project.

The BLM's Legacy Rehost System, or LR2000, database provides a compendium of information on mineral-use authorizations for oil, gas, and geothermal leasing, rights-of-ways, coal and other mineral development, land and mineral titles, mining claims, withdrawals, classifications, and more on Federal lands or on Federal mineral estates. The LR2000 data used in the SaMiRA reports as described by Dicken and San Juan (section F) are as of March 6, 2016. To expedite the locatable mineral-resource assessments and consolidate the LR2000 data for the leasable and salable minerals, Dicken and San Juan built a geographic information system (GIS) database that relates the attributes to allow for statistical analysis of claim- and lease-density information for numerous commodities.

The primary focus of the SaMiRA project was to provide qualitative mineral-resource assessments for the significant locatable mineral commodities. Mineral-deposit models provide powerful tools to integrate various geologic, geochemical, geophysical, and mineral-deposit data to develop the locatable mineral assessment tracts. Parks and others (section G) compiled data on previous mineral assessments that overlap the SaMiRA project area. Hammarstrom and Zientek (section H) review the principal mineral-deposit types and mineral systems applicable to the vast landscape of the SaMiRA project area. They provide an overview of the assessment methods and procedures for creating the tracts for locatable mineral resources, evaluating the potential and level of certainty for the tracts, and the assessment guidelines used. The geospatial data for all of the locatable mineral resources assessed for the SaMiRA project are presented in San Juan and others (2016).

The BLM requested present and potential future market-demand analyses for the locatable minerals. Bleiwas (section I) provides a general description of domestic production and a qualitative assessment of inferred future market demands for the important locatable minerals identified to have a moderate or high potential for occurrence within the proposed withdrawal areas.

The SaMiRA project was tasked with describing the nature and occurrence of the leasable and salable minerals relevant for each Sagebrush Focal Area (SFA). Leasable minerals include energy-resource commodities and fertilizer minerals such as potash. The evaluation of energy minerals was based on previous USGS assessments and the information from the BLM's LR2000 database. Glen and others (section J) provide a review of the source information, an overview of previous USGS geothermal-assessment reports, discussion of the identified geothermal systems, and context for the geothermal-energy setting for the major geothermal provinces

of the project area. Coal is a vital energy resource for the Nation; Haacke (section J) provides a brief overview on how coal resource information was incorporated into each of the assessment reports. Oil and gas development plays an important part in land-use planning for the BLM. Drake and others (section J) review the Total Petroleum System (TPS) methodology used in USGS oil and gas assessments. A TPS is a naturally occurring hydrocarbon-fluid system that presumes that migration pathways exist now or existed in the past and that they connect the provenance with the accumulations. Such concepts led to the assessments that were used in the individual SFA reports.

The extensive appendixes that accompany this report are a major resource used throughout the SaMiRA project. They provide a comprehensive listing of the individual locatable, leasable, and salable minerals; mineral-potential classification system used; a general glossary of terms; a consolidation of the applicable mineral-deposit models; and market-demand commodity profiles for the locatable mineral commodities that have moderate to high potential of occurrence.

Introduction

In September 2015, the Bureau of Land Management (BLM) and U.S. Forest Service (USFS) finalized land-use plans for regions containing sagebrush habitat for more than 165 million acres of public and National Forest System lands across in Idaho, Montana, Nevada, Oregon, Utah, and Wyoming. The intent of the plans is to provide guidance on land-management practices to conserve viable sagebrush ecosystems that support the greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse). The plans, released as Records of Decision (RODs) for the Great Basin greater sage-grouse sub-regions (Bureau of Land Management, 2015a) and for the Rocky Mountain region (Bureau of Land Management, 2015b), identified Sagebrush Focal Areas (SFAs), which are landscape-scale unconsolidated and contiguous tracts of land that contain high breeding population densities of sage-grouse and high quality sagebrush ecosystems (see Bureau of Land Management, 2015c). Notification of the extent of the SFAs was initially given in September 2015 in the Federal Register (U.S. Department of the Interior, 2015a), with subsequent corrections to the legal land descriptions in October 2015 (U.S. Department of the Interior, 2015b).

The BLM and USFS RODs of September 2015 recommended withdrawal from location and entry under U.S. mining laws. To inform the decision on whether to withdraw the SFAs from mineral entry, the BLM requires a mineral-resource assessment be completed to identify mineral resources within the proposed area of withdrawal. Mineral-potential reports are required to satisfy the requirements of 43 CFR 2310.3-2, "Development and processing of casefile for submission to the Secretary." The analysis needs to provide information on the general geology, known mineral deposits, past and present mineral production, mining claims, and

mineral leases, as well as an evaluation of future mineral potential and a review of mineral economics.

The USGS initiated the Sagebrush Mineral-Resource Assessment (SaMiRA) project in November 2015. There are seven SFAs discussed herein—(1) North-Central Idaho, (2) North-Central Montana, (3) Southeastern Oregon and North-Central Nevada, (4) Southern Idaho and Northern Nevada, (5) Sheldon-Hart Mountain National Wildlife Refuge Complex of Oregon, (6) Bear River Watershed of Utah, and (7) Southwestern and South-Central Wyoming. In February 2016, the BLM requested assessments of two additional areas in Nevada, termed the "Nevada additions," which lie to the south of the Southern Idaho and Northern Nevada SFA and the Southeastern Oregon and North-Central Nevada SFA (fig. A1). The Nevada additions were proposed by the Governor of Nevada in January 2016 (http://gov.nv.gov/uploadedFiles/ govnvgov/Content/News_and_Media/Press/2016_Images_ and_Files/Final Transmittal Letter 1.15.16 Signed-reduced-combined.pdf).

The data used throughout this report are based on publicly available sources. Very limited new field data and no new geochemical or geophysical data were collected because of the limited time available to provide preliminary information to the BLM by July 15, 2016. Because the proposed withdrawal only affects locatable minerals, these reports focus on the potential for and provide market analysis only on those mineral commodities that are classified as "locatable" minerals under the General Mining Act of 1872 (30 U.S.C. 22–42) that are important to the regional, national, and international economies (see appendix 1). The present and potential future market-demand analysis is focused on current use and U.S. domestic production to provide a qualitative assessment of inferred future market demands for the relevant locatable minerals. These reports also review the current situation, but not future potential, for leasable minerals (such as, oil, gas, coal, geothermal energy minerals, and phosphate deposits) and salable minerals (such as, sand and gravel resources). The USGS relied on the BLM's LR2000 database for information on mining claims, mineral leases, mineral-material sales contracts, and surface-management (43 CFR 3809) authorizations.

This report summarizes the approach taken to provide mineral-resource information to the BLM, with discussions on the sources of data incorporated, mineral-resource assessment methods, the mineral-deposit models employed, and an analysis of the market demand.

Lands Involved

The U.S. Department of the Interior (DOI) (2015a, b) defined the initial legal boundaries of the proposed lands for withdrawal from mineral entry within the SFAs. There are three important terms used in these reports that reference the lands under consideration by the BLM for conservation actions (fig. A1)—(1) Sagebrush Focal Areas (SFAs), (2) the

part of the SFAs that are under consideration and proposed for withdrawal from mineral entry ("withdrawal areas"), and (3) Public Land Survey System (PLSS) boundaries, which are the boundaries of the townships that contain proposed withdrawal areas.

The SFAs are broad landscape-scale regions considered to have high breeding-population densities of sage-grouse and existing high-quality sagebrush habitat within the Western Association of Fish and Wildlife Agencies sage-grouse management zones. Only some parts of the SFAs are proposed for withdrawal from locatable mineral entry. Within the SFAs, some lands, such as BLM wilderness study areas, have already been excluded from mineral entry. There are also inholdings of State and private lands within the SFAs. Examples include the two sections set aside in every PLSS township to support State schools, mineral patents, and homesteads. With these exclusions, the proposed withdrawal areas have irregular and patchy shapes. To ensure complete coverage of the withdrawal areas, USGS used a study area that is made up of all the townships that include areas proposed for withdrawal. The townships include those first described by BLM (Bureau of Land Management, 2015c), as formally proposed by DOI (U.S. Department of the Interior, 2015a, b), plus amendments proposed by the State of Nevada on January 15, 2016 (http://gov.nv.gov/uploadedFiles/govnvgov/Content/ News_and_Media/Press/2016_Images_and_Files/Final Transmittal Letter 1.15.16 Signed-reduced-combined.pdf), and further amended by BLM through correspondence (Anthony Titolo, BLM, written commun., April 22, 2016). The adjacent PLSS township boundaries were dissolved to define the study area and then modified to exclude Native American lands, which are sovereign and exempt from withdrawal, that are inside the study area (fig. A1). Inclusion of lands in the USGS mineral assessment that are not part of the formally proposed withdrawal areas has no implications regarding land value, management alternatives, or recommendation for disposition. They were included only to assure continuity in evaluation of the regional geologic information to inform the assessment of the proposed withdrawal areas.

A 25-kilometer (km) buffer zone beyond the outermost PLSS boundary was defined within which the USGS compiled the geologic, geochemical, geophysical, and mine and mineral-deposit data, to assure completeness, although the analysis does not include the buffer areas. This assured that the USGS effort captured the pertinent data adjacent to the PLSS townships and consequently, all data relevant to the proposed withdrawal areas.

Project Overview

The BLM uses legal definitions that group minerals into three categories—(1) locatable minerals (General Mining Act of 1872, 30 U.S.C. 22–42), including most metallic commodities and many high-unit value industrial commodities), (2) leasable minerals (Mineral Leasing Act of

Figure A1.   Map of the Sagebrush Focal Areas (SFAs) studied for the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States. USGS, U.S. Geological Survey; NWR, National Wildlife Refuge.

1920, 30 U.S.C. 181 et seq.), including energy and fertilizer minerals), and (3) salable minerals (Mineral Materials Act of 1947, 30 U.S.C. 601 et seq.), which includes common varieties of sand, stone, gravel, pumice, pumicite, cinders, and clay. A listing of the mineral commodities and their classification is given in appendix 1.

For this study, the USGS integrated publically available regional-scale geoscience data to discuss the mineral potential (current condition and future potential) for locatable minerals in the seven SFAs and the Nevada additions and provide a summary of the current condition for the most important leasable and salable minerals. The mineral-assessment reports follow the general guidelines outlined in BLM Manual Sections 3031 (Bureau of Land Management, 1985) and 3060 (Bureau of Land Management, 1994) using the best data from the published literature and USGS and BLM databases. The BLM requested that the USGS mineral-resource assessments use the overall method summarized by Goudarzi (1984), which prescribes a qualitative approach to evaluating mineral-resource potential (none, low, moderate, or high) with levels of certainty dependent on the available evidence for the occurrence of a given mineral-deposit type (for example, least certain with insufficient evidence to most certain with abundant direct and indirect evidence). Appendix 2 provides a description of the criteria for determining the levels of mineral potential and certainty as requested by BLM. The geospatial data that outline the assessment tracts, potential for occurrence, and levels of certainty for the mineral deposit types that often contain the locatable minerals using the BLM guidelines discussed above are given in San Juan and others (2016).

Who Did the Work?

The assessment work was done by a multidisciplinary team of USGS geologists, economic geologists, geophysicists, geochemists, mineral commodity specialists, and GIS experts. These geoscientists reached out to the State geological surveys (or equivalent) for Idaho, Montana, Nevada, Oregon, Utah, and Wyoming to gather the most recent geologic and mineral information available. The State geological surveys provided invaluable data and expertise that informed the USGS effort.

Reports for this study include other chapters of Scientific Investigations Report 2016–5089 by Mauk and others (in press) for the North-Central Montana SFA assessment study and Lund and others (in press) for the North-Central Idaho SFA. Vikre and others (in press) combined three SFAs that occur along the northern Nevada border (Sheldon-Hart Mountain National Wildlife Refuge, Southeast Oregon and North-Central Nevada, and Southern Idaho and Northern Nevada SFAs) and the Nevada additions into one report. Vikre and others (in press) provides a coherent summary over a large region, yet presents mineral-potential results for the individual SFAs and Nevada additions. Similarly, the discussion of the geologic overview and potential mineral-deposit types for the Bear River Watershed, Utah, and the Southwestern and South-Central Wyoming SFAs was combined by Wilson and others (in press).

Data Sources

The USGS mineral-resource assessments for the locatable mineral commodities are based on integration of the available digital geospatial information that address the favorability criteria defined by the specific mineral-deposit models applicable to the SFA under consideration. The mineral-deposit models (see appendix 3) are extremely powerful tools that simplify the complex ore-forming processes into criteria that can be used to estimate the favorability of landscape-scale tracts such as the SFAs. The models are syntheses of key features of the mineral deposits that include succinct geologic descriptions, associated mineral commodities, key features of the geologic environment of formation, ore controls, and economic factors for each deposit type. Mineral-deposit models provide rigorous constructs that specify the geologic, geochemical, and geophysical features that lead to formation of a given mineral-deposit type. Mineral-deposit models can be highly detailed (for example, Hayes and others, 2015), the full application of which demands detailed datasets such as isotope geochemical studies, detailed geologic mapping, alteration mineralogical studies, multispectral remote-sensing studies, and high-precision geophysical data. Such detailed models are extremely powerful at the ore-deposit to district-scales and can lead to discovery of individual mineral deposits. In contrast, the generalized ore-deposit models compiled by and used for the SaMiRA study (appendix 3), which rely on large, regional-scale geoscience datasets to delineate tracts of the locatable mineral commodities, result in landscape-scale qualitative mineral-resource assessments that meet the requirements of the regulations followed by the BLM. The following is a brief description of the major datasets that were combined with the mineral-deposit models that underpin delineation of the resource-potential tracts for the locatable minerals.

Geologic Map Data

Geologic maps provide a fundamental building block for mineral-resource assessments. The USGS relied on publically available geologic maps published at a variety of scales to conduct the resource analyses. Digital geologic map compilations for this project built on the approach taken by Ludington and others (2005), Stoeser and others (2005), and Zientek and others (2005) for geologic maps of the Western United States and included the maps from the California (Saucedo and others, 2000), Idaho (Bond and others, 1978; Lewis and others, 2012), Montana (Vuke and others, 2007), Nevada (Crafford, 2007), Oregon (Walker and others, 2002), Utah (Hintze and others, 2000), and Wyoming (Green and Drouillard, 1994) at their original scales. The digital geologic map compilations do not resolve map-unit discontinuities along the borders between the States nor the inherent differences in mapping styles and scales between the source maps. However, their compilation provided a useful first-order dataset where more detailed published digital geologic maps were not available.

Several more-detailed geologic maps were used to refine the assessment-tract boundaries and identify key lithologic information to help delineate the assessment tracts for locatable mineral-resource potential. For Idaho, the 1:100,000-scale maps of Link and others (1995), Evans and Green (2003), Kuntz and others (2007), Skipp and others (2009), and Othberg and others (2012) were incorporated in the assessments along with the 1:250,000-scale maps of Worl and others (1991), Fisher and others (1992), Wilson and Skipp (1994), and Worl and Johnson (1995).

The digital geologic-map data used for Montana were a series of 1:100,000-scale, 30'×60' quadrangle maps developed by the Montana Bureau of Mines and Geology (http://www. mbmg.mtech.edu/gis/gis-datalinks.asp). The maps used include the Dodson (Bergantino, 2001), Fort Peck Lake East (Wilde and Bergantino, 2004a), Fort Peck Lake West (Wilde and Bergantino, 2004b), Glasgow (Bergantino, 1999a), Jordan (Wilde and Vuke, 2004a), Malta (Bergantino, 1999b), Winnett (Porter and Wilde, 1993), Sand Springs (Wilde and Vuke, 2004b), and Zortman (Porter and Wilde, 2001) quadrangles.

The digital geospatial information incorporated for assessments of the SFAs in Nevada included sources from several map scales. The 1:250,000-scale Crafford (2007) map formed the basic reference for the statewide data. This was augmented by data on intrusive rocks from du Bray and Crafford (2007). Reheis (1999) provided constraints on the extent of Pleistocene-aged lake deposits. In addition to the Oregon geologic map of Miller and others (2002), we incorporated data from the Oregon Department of Geology and Mineral Industries released in the GIS data compilation of Smith and Roe (2015).

For Utah, the Hinze and others (2000) State-scale geologic map was used. The primary source of digital geologic information used for the assessment of the Bear River Watershed was the 1:100,000-scale map of Dover (1995) for the Logan 30'×60' quadrangle.

The digital geologic map information used for the mineral-resource assessments for Wyoming included the digital geologic-map compilation of Green and Drouillard (1994), which was based on the 1:500,000-scale mapping of Love and Christiansen (1985). More detailed geologic data were captured from the 1:100,000-scale mapping of M'Gonigle and Dover (2004), Sutherland and Hausel (2006), Johnson and Sutherland (2009), Jones and Scott (2010), and Sutherland and Luhr (2011).

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Section B. Mineral-Resource Information

By Gregory L. Fernette, Peter N. Schweitzer, and Elizabeth S. Sangine

This discussion on mineral-resource information used in the SaMiRA project consists of three sections. The first section describes the U.S. Geological Survey (USGS) Mineral Deposit Database (USMIN) data compilation developed for the Bureau of Land Management. The second section describes the USGS Mineral Resources Data System (MRDS). The third section describes the data contributed by the USGS National Minerals Information Center (NMIC).

USMIN Project Mineral-Resource Data for the USGS SaMiRA Project

By Gregory L. Fernette

Introduction

Mineral-occurrence, mining, and mineral-exploration information is one of the foundations for developing mineral-resource assessments such as the U.S. Geological Survey (USGS) Sagebrush Mineral-Resource Assessment (SaMiRA) project done for the Bureau of Land Management (BLM). The BLM mineral-resource assessment guidelines outlined in BLM Manual Sections 3031 (Bureau of Land Management, 1985) and 3060 (Bureau of Land Management, 1994) require that mineral-assessment reports contain information on current and past mining, exploration activity, and known mineral occurrences. The USGS has an ongoing project, the USGS Mineral Deposit Database (USMIN), whose objective is to develop a new geospatial database of the mineral resources of the United States. Personnel working on this project were temporarily retasked to work exclusively on the SaMiRA Project.

This report describes the type, source, and nature of the mineral-resource data compiled for the assessment by the USMIN project, which was used along with other data throughout the USGS SaMiRA project. The data compiled for the SaMiRA assessment differs somewhat in structure from that being compiled for USMIN. The mineral-resource data for SaMiRA were compiled as a series of GIS data "themes" designed to meet the requirements of BLM assessments. Previously compiled USMIN GIS data showing mine- and prospect-related features from USGS

topographic maps were also made available to the SaMiRA project.

A core part of the USGS Mineral Resources Program's mission is to inventory the mineral resources of the United States. Consequently, the USGS has a long history of publishing maps and reports on domestic mineral resources. The first USGS digital mineral-resource database began to be built in late 1960s and was released in 1972 as the Computerized Resources Information Bank (CRIB) (Calkins and others, 1973). The name was changed in the early 1980s to the Mineral Resource Data System (MRDS). The MRDS database was used to manage descriptive data about mines, prospects, and mineral occurrences (Arndt, 1990). Much of the data in MRDS were entered during the 1970s and 1980s, when USGS conducted numerous mineral-resource assessments for the U.S. Forest Service (USFS) and the BLM.

The U.S. Bureau of Mines (USBM) concurrently developed two digital databases—the Minerals Availability System (MAS) and the Mineral Industry Location System (MILS) (Berg and Carrillo, 1980; Babitzke and others, 1982). The primary purpose of the MAS/MILS databases was to support the minerals-supply analysis function of the USBM (Davidoff, 1980). After closure of the USBM in 1996, the MAS/MILS databases were transferred to the USGS (McFaul and others, 2000).

The MAS/MILS and MRDS databases were merged into a single Oracle database, which was available on the USGS Mineral Resources Data Web site (http://mrdata.usgs.gov). The database now has a total of about 303,000 records, of which some 270,000 are for sites in the United States (U.S. Geological Survey, 2016). Work thereafter concentrated on improving the Oracle database interface with little updating of data. In 2012, the USMIN project began with the objective of providing an up-to-date, comprehensive, site-specific, geospatial database of the mines, mineral regions, and mineral occurrences of the United States. The following year an interagency agreement covering the USMIN project was implemented with the BLM Solid Minerals Program, whereby BLM provided additional funding for the project.

The reasons for the development of the new USMIN database include the following:

- Advances in Geographic Information Systems (GIS) software and data delivery mechanisms via the Internet allow for the use and analysis of large landscape-scale datasets of which mineral resources are a part.

- New technology for data capture, such as "heads up" digitizing from georeferenced raster images of paper

maps, allows the rapid capture of accurate locations and other digital data.

- New sources of data, such as digital air photos and high-resolution satellite imagery, allow for the rapid and efficient capture of spatial data.

- New laws that require permitting of mine sites at both the State and Federal level provide new sources of timely data on the nature and location of mine sites, which can be incorporated into a national database.

An underlying concept of USMIN is to transition USGS mineral-resource information from the traditional "point with attributes" style of database into the geospatial realm where the data also include the spatial elements of mineral resources, such as the footprints of the mineral deposits and the spatial extent of mine features and mineral regions.

The USMIN database has three feature groups—(1) mineral occurrences, (2) mineral regions, and (3) mine features. Each feature group contains spatial data in the form of points and polygons, but all features are tied to point locations. Feature locations are captured primarily by "heads up" digitizing from georeferenced maps and (or) imagery. Point locations are captured for all features and, where available, the polygons that outline the footprint of a given feature. In USMIN, a mineral occurrence is considered "a concentration of a mineral (usually, but not necessarily, considered in terms of some commodity, such as copper, barite, or gold) that is considered valuable by someone somewhere, or that is of scientific or technical interest" (Cox and Singer, 1986). Mineral occurrences are classified as deposits, prospects, or showings. A mineral deposit is a mineral occurrence that has a defined size and grade as shown by past production and (or) a resource estimate. A mineral prospect is a mineral occurrence where there is sufficient data to describe at least two dimensions of the occurrence and its commodity. A mineral showing is a site where a potentially valuable mineral is present. Mineral regions are geographic features, such as mining districts, mineral belts, and mineral provinces that are associated with mineral-resource data. Mine features are those features created as part of the process of mining mineral deposits, such as mine shafts, adits, open pits, and waste piles. As noted above, the structure of the data compiled for SaMiRA, where the data was organized into "themes," differs from that in USMIN and includes a data theme for Active Exploration Sites. This data is not a part of USMIN but was added to the SaMiRA data specifically to meet the requirements of BLM assessment reports.

Data Compilation

Work on the USMIN project started in 2012 with an emphasis on augmenting and complementing existing USGS data and laying the foundation for the eventual geospatial database. An early focus of the project was on compiling data on active mineral exploration sites and active mines

in the United States, as most of the data in MRDS had not been updated since the 1980s. For the SaMiRA project, the data compilation effort focused on those lands proposed for withdrawal including a 25-kilometer (km) buffer that enclosed the Public Land Survey System (PLSS) township boundaries that include the proposed withdrawal areas in the seven Sagebrush Focal Areas (SFA) and two additions in Nevada (fig. B1).

The data were compiled from all publicly available sources including USGS publications, data from other Federal agencies, State geological surveys, other State agencies, geological societies, and mineral-industry data. A considerable amount of additional data came from sources such as industry Web sites, press releases, presentations, annual reports, and technical reports filed with regulatory agencies. An important example is the technical reports prepared in accordance with Canadian National Instrument 43-101, referred to as "NI 43-101 Reports." Completed preliminary maps of active mines and exploration sites were sent to the State geological surveys of Montana, Wyoming, Idaho, Utah, Nevada and Oregon for review and comment. Data were also sent to BLM and U.S. Forest Service geologists in the affected regions. Maps of active mine and exploration sites were also displayed at the annual meeting of the American Exploration and Mining Association (AEMA) in December 2015. Industry and government agency personnel at the meeting were invited to review the maps and the site listings and identify missing sites. In April 2016, BLM provided the USGS with copies of public comments received on the proposed land withdrawals. Comments specific to mineral resources were reviewed to insure that any specific mineral occurrences, mines, and (or) exploration sites mentioned were in the data being used by the assessment teams.

Data Files and Sources

USMIN project data used in the SaMiRA project are presented as six data themes, described below. One of these themes for prospect- and mine-related sites, is a subset of a larger database that was published separately (Fernette and others, 2016b). The data described here are being published as a USGS data release (Fernette and others, 2016a).

Prospect- and Mine-Related Features

Locations of historical or past mining sites were compiled by capturing prospect- and mine-related symbols from USGS 7.5- and 15-minute topographic maps. In the SaMiRA region, mine symbols are shown on USGS topographic maps published between 1935 to 2006. Early in the USMIN project, it was decided to capture these data as a first step in developing a GIS of mines in the United States. The process and rationale were based on the Abandoned Mine Lands programs of the Nevada Division of Minerals (Hess, 2001) and the California Department of Conservation's Abandoned Mine Lands Unit (California Department of Conservation, 2013).
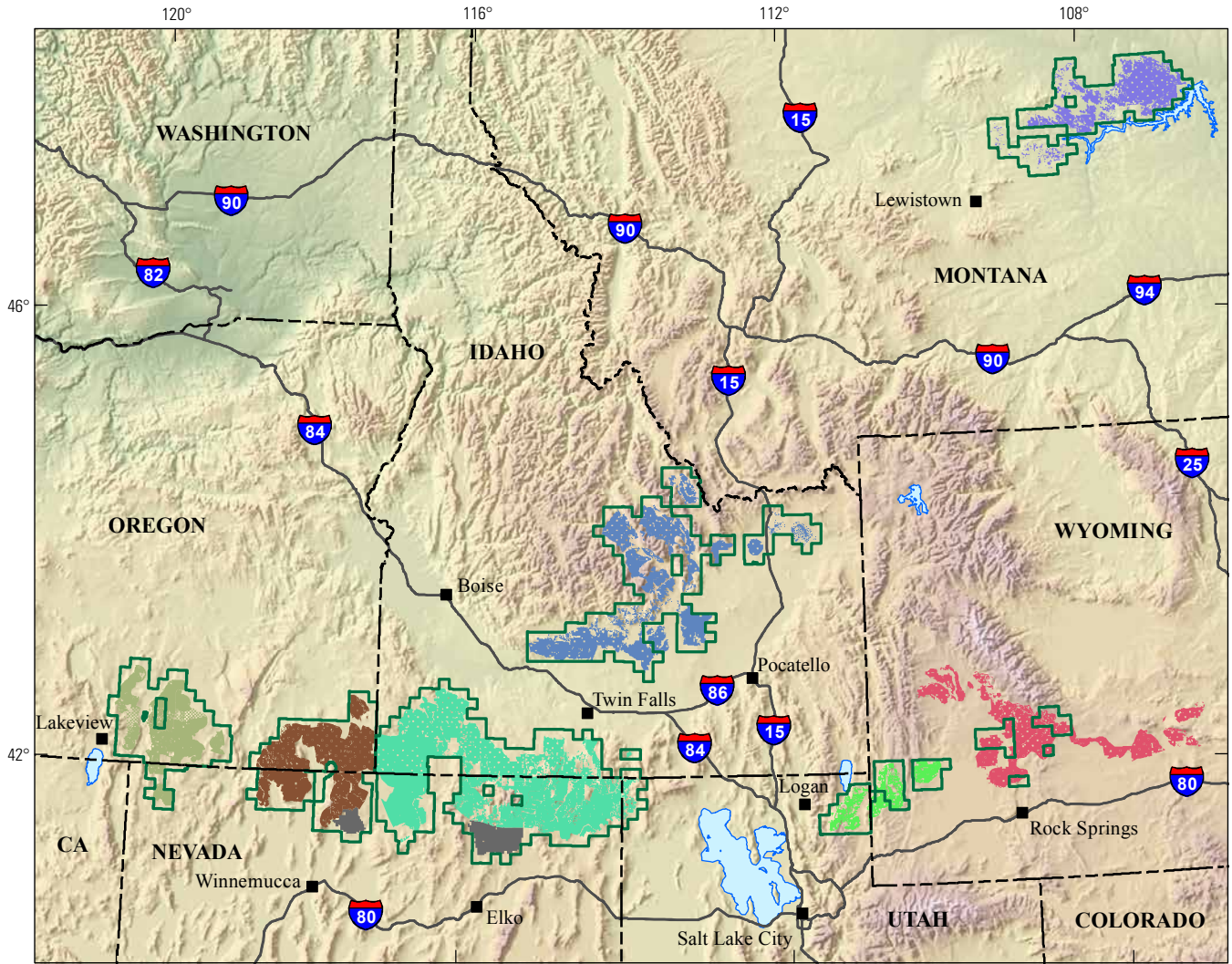
Base modified from U.S. Geological Survey DEM digital data.
Boundary data from BLM (2016). Roads and political data from Esri (2013).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 114° W, latitude of origin, 37.5° N.
North American Datum of 1983.
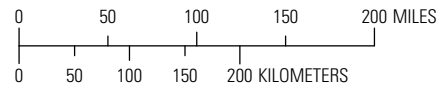
EXPLANATION

USGS study area boundary
Bear River Watershed SFA
North-Central Montana SFA
North-Central Idaho SFA
Southeast Oregon and North-Central Nevada SFA
Sheldon-Hart Mountain NWR Complex SFA
Southern Idaho and Northern Nevada SFA
Southwestern and South-Central Wyoming SFA
Proposed Nevada additions

Figure B1.   Map of the Sagebrush Focal Areas (SFAs) studied for the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States. USGS, U.S. Geological Survey; NWR, National Wildlife Refuge.

The historical mine site data were captured by digitizing from georeferenced raster images of historic topographic maps of the United States obtained from the USGS Historical Topographic Map Collection (see http://ngmdb.usgs.gov/maps/TopoView/). Mine sites were digitized and attributed with the source map name and date and the feature type. Locational accuracy for data derived from 7.5-minute quadrangle (1:24,000-scale) topographic maps is estimated to be about 100 feet. The most common features captured were mineshafts, adits, open pit mines, and prospect pits. In the mineral-resource assessment process, these data can be used to highlight areas of past mining activity, which is one of the requirements of the BLM mineral-assessment reports.

Mining Districts

Mining districts are historical administrative areas organized by miners under the mining laws of the United States. They typically comprise an area covering a group of mines that often exploit the same or similar commodity such as gold or silver. Considerable mineral-resource information, including production data, is tied to mining districts, and they have been the focus of many USGS studies (Hill, 1912; Koschmann and Bergendahl, 1968).

Mining districts were being compiled as a part of the Mineral Regions USMIN feature group, and data in progress was extracted for the SaMiRA Project. Most district locations were obtained from compilations by the State geological surveys of Nevada (Tingley, 1998), Utah (Doelling and Tooker, 1983; Utah Geological Survey, 2012), Idaho (Ross, 1941; Gustafson, 1987), Montana (Chavez, 1994), and Wyoming (Gregory and others, 2010; Harris and others, 1985). For Oregon, district locations were compiled primarily from Bradley (1982) and Gilluly and others (1933).

Mining district locations are areas represented as polygons. In the GIS data, all districts also have a point location, which is typically the centroid of the polygon. Mining-district data attributes are shown in table B1. The distribution of mining districts in the SaMiRA region is shown on figure B2.

All commodities associated with mineral occurrences located within a district are recorded whether they have been mined or not, contingent on the available data. Commodity groups for districts include metallic minerals (excluding uranium), industrial minerals, gemstones, and uranium. The USGS mineral-deposit models for mineral deposits present in a district were extracted from the Mineral Occurrence data theme. Geoenvironmental deposit models were derived from the equivalency relationship in du Bray (1995).

Mining districts can be used as a part of the mineral-resource assessment process, as they highlight areas of past mining activity, groupings of mineral occurrences, and provide a focus for the discussion of other data such as production.

Mineral Occurrences

The locations of mineral occurrences were compiled from a variety of sources. Early in the USMIN project a review of the literature with the objective of identifying existing mineral-resource databases that could be incorporated into USMIN eliminated the need for a completely new data compilation. The State geological surveys of Oregon, Idaho, and Utah have published mineral occurrence databases that include the SaMiRA assessment areas. For the SaMiRA project, data were compiled on a state-by-state basis with USGS, USBM, and other data being added to State data. A large number of mineral occurrences were found through the USMIN compilation of active exploration projects.

Table B1. District data theme attribute fields used for the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States.

Field name	Description
Name	Primary name of the district.
Other name	Other names for the district.
State	State in which the district is located.
Commodity(s)	Commodities present in mineral deposits in the district.
Commodity group	Group to which the commodities belong: metallic minerals, nonmetallic and industrial minerals, gemstones, and uranium.
Deposit model number(s)	ID numbers for the USGS deposit models of mineral deposits present in the district.
Deposit model name(s)	Names of the USGS deposit models of mineral deposits present in the district.
Geoenvironmental model(s)	Names of the USGS geoenvironmental deposit models for mineral deposits present in the district.
Remarks	Additional data or comments on the data.
References	Source of the location and other data for the district.
Associated polygon	Whether or not there is a shape associated with the point (yes/no).
Polygon definition	Description of the nature of the polygon.
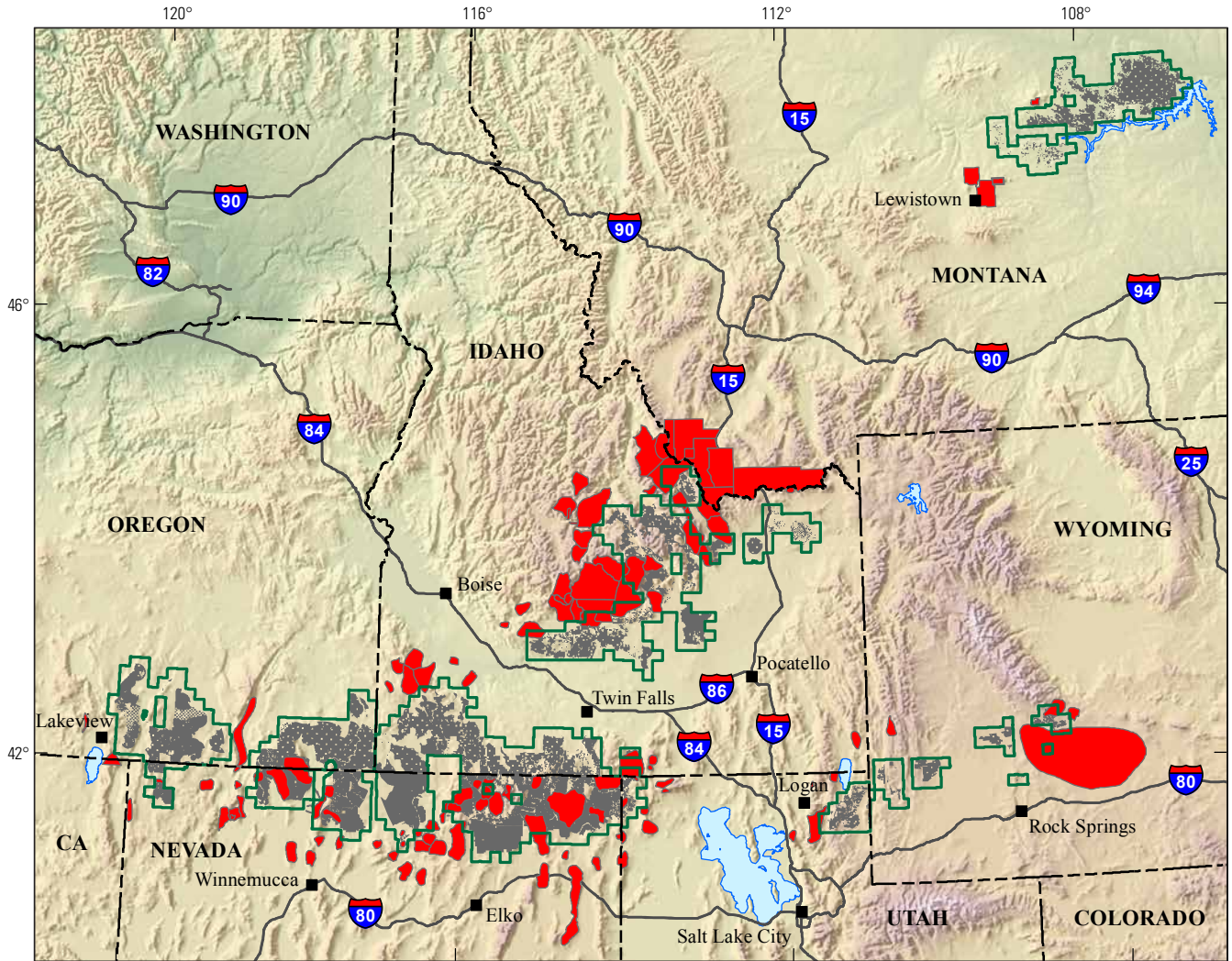
Figure B2.   Map of the mining districts in and near Sagebrush Focal Areas (SFAs) for the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States. USGS, U.S. Geological Survey; BLM, Bureau of Land Management.

For the State of Nevada, the primary sources of data were commodity reports produced by the Nevada Bureau of Mines and Geology (NBMG); for example, Stager and Tingley (1988), Papke and Castor (2003), Davis and others (2006), and the county reports on Elko, Humboldt and Washoe Counties (Willden, 1964; Bonham, 1969; Lapointe and others, 1991). Active mines and exploration sites were compiled from annual reports by the Nevada Division of Minerals and the NBMG and through a search of company activities in mining publications on the Web. Locations of material sites and gravel pits were obtained from the Nevada Department of Transportation. Active mine and exploration sites were identified from permits of the Nevada Department of Environmental Protection, the BLM, and USFS. Significant data were also collected from publications of the Geological Society of Nevada. Data from these sources were captured and then reconciled into single data layers.

For Oregon, data were extracted from the Oregon Department of Geology and Mineral Industries Mineral Information Layer MILO-2 (Oregon Department of Geology and Mineral Industries, 2010). This was augmented with data from other sources, including BLM Plans of Operations, company data, and USGS and USBM reports.

For Utah, the Utah Mineral Occurrence System (Utah Geological Survey, 2015) was the primary data source. This was augmented by data from the Utah Geological Association, company data, and USGS and USBM reports.

The primary sources of mineral occurrence data in Idaho were the Idaho Geological Survey's Database of Mines and Prospects and the Database of Select Aggregate Material Sources (Idaho Geological Survey, 2015; Tate and others, 2015). These data were augmented by reports of the USGS and USBM.

For Wyoming, the primary data sources were Wilson and others (2001), Wilson (2014), and Wyoming Geological Survey maps and publications (Harris and others, 1985; Hausel, 1986, 1989; Harris, 2004; Gregory and others, 2010). These data were augmented by company data collected by the USMIN project.

For Montana, the primary data sources were MRDS (U.S. Geological Survey, 2016) and the Montana Abandoned and Inactive Mines Database (Montana Bureau of Mines and Geology, 2006). Additional data were added from other USGS databases, including Klein (2004), and Spanski (2001, 2004), as well as from company data.

Attributes assigned to mineral occurrences in the GIS data were limited to those judged most critical for assessment purposes (table B2). The key geological attributes were commodity and mineral-deposit model. The mineral-deposit model ascribed to each occurrence was derived from the source data inasmuch as no mineral deposit classification was done by USMIN project personnel. Geoenvironmental models were assigned by using the equivalency relation in du Bray (1995).

A primary objective of the compilation of mineral occurrences was to develop accurate locations, commodity data, deposit models, source references, and where available production and resource (grade-tonnage) data. Industry data were one of the most important sources for accurate locations, deposit outlines (or footprints), and resource data. Whenever a deposit footprint was available, it was captured as a polygon that is associated with the point location. The meaning of the deposit footprint is variable. In some deposits that were at the resource estimation stage at the time of the data compilation, there were often maps showing the extent of the estimated resource. In other cases, a grade limit or grade-thickness map might be available. Older reports tended to show the limit of mineralization.

Table B2. Mineral-occurrence data theme attribute fields used for the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States.

Field name	Description
Name	Primary name of the occurrence.
Other name	Other names for the occurrence.
State	State in which the occurrence is located.
Feature type	Classification of occurrence as deposit, prospect, or showing.
Exploration project	Name of exploration project associated with the mineral occurrence.
Commodity(s)	Commodities present in mineral occurrence.
Commodity group	Group to which the commodities belong: metallic minerals, nonmetallic and industrial minerals, stone, sand and gravel, gemstones, and uranium.
Deposit model number(s)	ID numbers for the USGS deposit models of mineral deposits present in the district.
Deposit model name(s)	Names of the USGS deposit models of mineral deposits present in the district.
Deposit model source	Source of the deposit model(s).
Geoenvironmental model(s)	Names of the USGS geoenvironmental deposit models for mineral deposits present in the district.
Remarks	Additional data or comments on the data.
References	Reference for the primary source of the location and other data for the occurrence.
Associated polygon	Whether or not there is a shape associated with the point (yes/no).
Polygon definition	Description of the nature of the polygon.

Mine Sites

A discussion of current and past mining activity is a required part of the BLM mineral-assessment reports. Data on mines, both active and closed, in the assessment areas were compiled from a number of sources to form the Mines data theme. The USGS National Mineral Information Center (NMIC) publishes data on active mines and mineral processing plants in the United States (U.S. Geological Survey, 2005) and provided the 2011 version of these data to the SaMiRA project. These data include only mines that voluntarily report data to NMIC. In the USMIN project these data are augmented by data collected from other sources such as the Mine Safety and Health Administration (MSHA) and other Federal and State agencies so that as complete an inventory of mines as possible could be compiled. Amongst valuable sources of data on active mines in the SaMiRA region are State agency data for mine permits and BLM and USFS Plans of Operations.

In the State of Nevada, locations of active mines are published annually by the Nevada Division of Minerals and the Nevada Bureau of Mines and Geology (NBMG) in their Major Mines of Nevada Special Publication series. This series provides location and production data for most mines in Nevada. Additional sources of data were the NBMG maps of mines and energy resources (for example, Hess and Davis, 2010). The Nevada Department of Environmental Protection provides the locations of mining permits on its Web site (http://ndep.nv.gov). The Nevada Department of Transportation Material Site Atlas contains the locations of gravel and borrow pits (Nevada Department of Transportation, 2013).

For Utah, a GIS database of mine permit locations was obtained from the Utah Division of Oil Gas and Mining (Utah Division of Oil Gas and Mining, 2016). Mine locations are also published by the Utah Geological Survey (Bon and Heuscher, 2008; Bon and Wakefield, 2008).

Mine locations and current status of mine sites in Oregon were obtained from permit data from the Oregon Department of Geology and Mineral Industries (Oregon Department of Geology and Mineral Industries, 2015).

Data on active mines in Wyoming were provided by the Land Quality Division of the Wyoming Department of Environmental Quality (Wyoming Department of Environmental Quality, 2015). Additional information was obtained from the Annual Reports of the Wyoming State Inspector of Mines (Wyoming Department of Workforce Services, 2013, 2014).

Locations of open-cut mines in Montana were obtained from the Montana Department of Environmental Quality, Open Cut Mining Program (Montana Department of Environmental Quality, 2015). Further data were obtained from the annual presentations of the Montana Bureau of Mines and Geology (for example, McCullogh, 2014) and BLM Plans of Operations.

In Idaho, locations of active mines were obtained from the annual mineral industry reports of the Idaho Geological Survey (for example, Gillerman, 2014), the Idaho Geologic Survey aggregate site database (Tate and others, 2015), and from BLM and USFS field office personnel.

The attributes for the mines data theme are listed in table B3. The data-capture process for mines emphasized accurate locations and status data that were as timely as possible. Permit data were checked using digital air photos, and locations were corrected to the actual site of the mining activity. Where applicable, notes on the current level of activity, as visible on air photos, were made.

Table B3. Mines data theme attribute fields used for the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States.

Field name	Description
Name	Primary name of the mine.
Other name	Other names for the mine.
State	State in which the mine is located.
Operator	Name of the operator of the mine based on the source data.
Commodity(s)	Commodities being mined.
Commodity group	Group to which the commodities belong: metallic minerals, nonmetallic and industrial minerals, gemstones, stone, sand and gravel, uranium, and coal.
Current status	Activity status of the mine—active, inactive (closed), unknown.
Status date	Year of the status data.
Remarks	Additional data or comments on the data.
References	Source(s) of the location and other data for the mine.

Active Exploration Sites

BLM mineral-resource assessment guidelines require a discussion of current and past exploration activity in the assessment areas. The collection of information on the location and nature of active mineral-exploration projects in the United States was one of the principal components of the USMIN data compilation effort before the SaMiRA project. Previously collected and newly compiled data for exploration projects within the SaMiRA areas were compiled into the Exploration Sites data theme. Exploration projects were classed as "active" if data on exploration activity within the past 10 years could be found. Key sources for the SaMiRA project area were the annual exploration reports and other reports of the NBMG, Idaho Geological Survey, Utah Geological Survey, Wyoming Geological Survey, Oregon Department of Mineral Industries, and Montana Bureau of Mines and Geology. Other data were collected from mining trade publications, such as the Canadian and American Mines Handbook, the Northern Miner, and Mining News.

Additional important sources of information were the individual mining company Web sites and technical reports filed in the Canadian System for Electronic Document Analysis and Retrieval (SEDAR) on-line database (http://www.sedar.com/). An extensive review of the Web sites of mining and exploration companies had been started in 2013, and this data was used in the SaMiRA project. Where Web sites contained information on exploration projects, the data were captured by printing to a .pdf file. For Canadian companies, National Instrument 43-101 technical reports (NI 43-101 Reports) were searched for using the SEDAR on-line database and company Web sites. These reports are a significant source of data on project history, mine production, the resources of mineral deposits, and typically also contain a description of the property history. Exploration sites were located as points and, where available, polygons showing the aerial extent of the project or property. "Properties" can be blocks of mining claims or exploration target areas. The sites were attributed with data on ownership, exploration status, and commodity (table B4).

Mineral Production Data

BLM mineral-assessment reports are required to present data on current and past mine production within the assessment areas. Production data for mines within the buffer zone surrounding the SFAs were compiled from a variety of sources. Reported production data were then converted to standard units and formatted for presentation in the production data theme. This data theme contains a summary of available production data, including ore tonnage, value, and (or) amounts of commodities produced.

For Nevada, the annual Major Mines of Nevada reports published by the Nevada Division of Minerals and NBMG contain production data and locations for major mines. Production data for past-producing mines were compiled from other NBMG reports and company reports. Important sources of information included Couch and Carpenter (1943), Lapointe and others (1991), Bailey and Phoenix (1944), and Stager and Tingley (1988). Production data for past producing mines in Idaho was found in Staff Reports of the Idaho Geological Survey and in the Idaho Mines and Prospects Database (Idaho Geological Survey, 2015). The data in the Mines and Prospect database are presented as ranges. For the Production data theme, the minimum values in each range were used. Significant additional mine production data for Idaho were found in Spanski (2004).

Table B4.   Exploration data theme attribute fields used for the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States.

Field name	Description
Name	Primary name of the exploration site.
Other name	Other names for the exploration site.
State	State in which the exploration site is located.
Operator	Name of the operator of the exploration site based on the source data.
Commodity(s)	Commodities present at exploration site.
Commodity group	Group to which the commodities belong: metallic minerals, nonmetallic and industrial minerals, stone, sand and gravel, gemstones, and uranium.
Current status	Activity status of the exploration site: active, development, drilling, early, resource, no data, uncertain.
Status date	Year of the status data.
Remarks	Additional data or comments on the data.
References	Source of the location and other data for the exploration site.
Associated polygon	Whether or not there is a shape associated with the point (yes/no).
Polygon definition	Description of the nature of the polygon.

The principal sources of mine production data in Wyoming were Gregory and others (2010), Hausel (1986), and the Wyoming Mines Inspector annual reports (Wyoming Department of Workforce Services, Office of Mine Inspector, 2014).

NI 43-101 reports are also valuable sources of data for both currently active and formerly active mines. For active mines, the Web sites and annual reports of the operators were consulted.

Mineral-Resource Data

The BLM mineral-assessment reports are also required to contain information on the resources contained in known mineral deposits in the assessment area. Data on the resources (tonnage and grade) of mineral deposits located in the 25-km buffer zone around the SFAs were compiled to develop the Resource data theme. This data theme includes summaries of the tonnage and grade of mineral deposits for which data were available. For many deposits, these data were discovered during the compilation of data on active exploration projects. Projects at the resource stage frequently present resource data in NI 43-101 reports, which were the major source of recent resource estimates. Other sources of data included USGS and USBM reports, such as Wilderness Study reports and USGS mineral-resource assessment data (for example, Spanski, 2004). For the Resource data theme, all categories of resources such as "reserves" and "resources" were combined into a total tonnage and average grade for each deposit.

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Mineral Resources Data System (MRDS)

By Peter N. Schweitzer

Several sources of mineral deposit information were used for the U.S. Geological Survey (USGS) Sagebrush Mineral-Resource Assessment (SaMiRA) reports. One such data source for mine and mineral-district information is available through the Mineral Resources Data System (MRDS) (U.S. Geological Survey, 2016). MRDS contains global mineral-resource occurrence data, most thoroughly within the United States. The database contains the records previously provided in the Mineral Resource Data System (MRDS) of the USGS and the Mineral Availability System/Mineral Industry Locator System (MAS/MILS) of the U.S. Bureau of Mines.

MRDS is a large and complex relational database developed over several decades by hundreds of researchers and collaborators. The content of MRDS records was drawn from reports previously published or made available to USGS researchers, some of which are no longer available.

The information contained in MRDS reflects the limitations of the material used as sources, and its recency is that of the date of the source reports. Mining operations are continually evolving and global mineral economies represent a dynamic flow of information. Consequently, MRDS does not reflect up-to-date changes to the operating status of mines, ownership, land status, production figures, and estimates of reserves and resources or the nature, size, and extent of workings. However, the geological characteristics of the mineral resource are likely to remain correct and are very useful for understanding the deposit type and mineral commodities present for the major and many of the smaller mines, occurrences, and prospects.

Mineral-Resource Data from the USGS National Mineral Information Center

By Elizabeth S. Sangine

The Automated Minerals Information System (AMIS) database operated by the U.S. Geological Survey (USGS) National Minerals Information Center (NMIC) is a large and complex database developed over several decades based on surveys conducted annually on mineral commodities. More than 140 surveys are conducted annually on mineral commodities from domestic producers. More than 18,000 domestic producer and consumer establishments voluntarily complete about 40,000 survey forms annually. In developing lists of companies to canvass for each of the commodities, NMIC specialists monitor the published literature, review company reports, review commodity-specific reports prepared by industry, and gather information from conferences, field trips, and industry and Government contacts.

The NMIC AMIS database has comprehensive mineral-commodity data from the 1980s to the present. Mining operations are continually evolving, and AMIS houses both historical and current production figures and estimates of production. The USGS canvass forms contain a proprietary data banner that describes the treatment of the company data collected. The proprietary information is considered sensitive and usually contains commercially valuable business data, such as production figures and consumption projections. Before specific statistics can be published, a determination must be made as to whether the publication would result in the disclosure of proprietary data. In order to publish production data, the policy is that there must be three or more companies contributing to an aggregated statistic; however, if the minerals statistic under consideration does have three or more companies but one company contributes more than 75 percent of the total, or two companies contribute more than 90 percent, then the figure cannot be published because the preponderance of the data released is considered proprietary.

For the Sagebrush Mineral-Resource Assessment (SaMiRA) project, NMIC staff queried the AMIS database for active facilities using States and counties with assessment areas contained within. A listing of the facility names and physical locations, latitudes and longitudes, was then provided for mapping against the specific proposed withdrawal areas. Specific production figures were not provided for these facilities, as that would violate business proprietary rules.

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Section C. Geochemical Data

By Steven M. Smith, Karen D. Kelley, Helen W. Folger, Douglas B. Yager, Matthew Granitto, and Stuart A. Giles

Introduction

The geochemical datasets used for the assessments of the Bureau of Land Management (BLM) Sagebrush Focal Areas (SFA) were compiled from U.S. Geological Survey (USGS) geochemical databases and include soil and stream-sediment (primarily, but not exclusively, <80 and <100 mesh) samples (hereafter referred to as SedsSoils), concentrate fractions from sediment and soil samples (hereafter referred to as concentrates), and rock samples. The samples were collected and analyzed over a period of 50 years from the mid-1960s through 2013. After statistical evaluation, selected elements (silver, gold, and others) indicative of a wide variety of mineral-deposit types were plotted, either as point plots (rock, concentrates, and SedsSoils) or interpolated grids (SedsSoils only). A summary of the data sources, methods for statistical evaluation and determination of threshold values, replacement of lower limits of determination (LLD) required for gridding, and GIS methods are provided below.

Databases Used to Build the SaMiRA Datasets

Multiple USGS databases were evaluated for inclusion in the Sagebrush Mineral-Resource Assessment (SaMiRA) geochemical datasets. These are listed below with brief descriptions.

NURE-HSSR (collected 1976–1980)

The National Uranium Resource Evaluation (NURE) program included a Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) task that collected and analyzed more than 300,000 sediment and soil samples from Alaska and the conterminous United States between 1976 and 1980. These data were compiled, reformatted, and released online by Smith (1997) and are available from the USGS Mineral Resources On-Line Spatial Data Web site (http://mrdata.usgs.gov/nure/sediment). The NURE-HSSR samples in the SaMiRA area were collected or analyzed under the auspices of three U.S. Department of Energy National Laboratories—Oak Ridge Gaseous Diffusion Plant (OR), Los Alamos National Laboratory (LA), and Savannah River National Laboratory (SR). Because multiple analytical methods in different laboratories were used, the NURE-HSSR database contains analytical bias between areas covered by each laboratory.

The NURE-HSSR program was terminated before collection and analyses of samples from the entire United States were completed.

NGS (2008 release)

The National Geochemical Survey (NGS) was a USGS project tasked with creating complete geochemical coverage of the United States at a scale of one sample per 289 square kilometers (km^2). The project (1) reanalyzed selected NURE-HSSR samples, (2) assembled other similar reanalyzed NURE-HSSR sample datasets, and (3) collected and analyzed additional samples where the NURE program was incomplete. This database was published (U.S. Geological Survey, 2004), and the data (as of the 2008 release) are available from the USGS Mineral Resources On-Line Spatial Data Web site (http://mrdata.usgs.gov/geochem).

NGS-NURE

Analytical bias displayed by many elements, due to the use of multiple analytical methods and labs, was characteristic of the original NURE-HSSR data. The NGS project described above was designed to reanalyze approximately 13 percent of the available NURE-HSSR samples using a 40-element inductively coupled plasma atomic emission spectrometry (ICP-AES) (Briggs, 2002) or ICP-MS (Briggs and Meier, 2002) method. The availability of new analyses by consistent methodology creates the possibility to mathematically level the NURE-HSSR data and remove most of the analytical bias. A review of overlapping analyses revealed that leveling was possible for 29 elements (Al, As, Au, Be, Ca, Ce, Co, Cu, Eu, Fe, K, La, Li, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sc, Sm, Ti, U, V, Y, Yb, and Zn; chemical symbols are defined in the front matter of this report). A revised NGS-NURE database was created by combining the NGS and the leveled NURE-HSSR datasets. This process and database is described by Smith and others (2015) and the database is currently being prepared for release on the USGS Mineral Resources On-Line Spatial Data Web site (http://mrdata.usgs.gov/).

NGDB (mid-1960s through 2007)

The National Geochemical Database (NGDB) is a compilation of geochemical records from samples collected for various USGS projects and analyzed by USGS laboratories from the mid-1960s until the present, although currently only data

through 2007 have been released. Because samples in the NGDB were originally collected and analyzed for multiple purposes, there is a large variety of geologic materials (for example, rocks, sediments, soils, concentrates), sampling densities, requested analytical procedures, and number of elements analyzed. Many of these samples came from mineral-resource assessment studies of 1°×2° quadrangles or BLM Wilderness Study Areas. The NGDB also contains reanalyzed NURE-HSSR samples from the NGS and other USGS projects. The NGDB rock, soil, sediment, and concentrate data (through 2007) are available from the USGS Mineral Resources On-Line Spatial Data Web site (http://mrdata.usgs.gov/ngdb).

NASGLP Soils (2013 data release)

The North American Soils Geochemical Landscape Project (NASGLP) collected and analyzed topsoil and C-horizon soil from the conterminous United States at a density of one sample per 1,600 km². These samples were collected in conjunction with similar projects in Canada and Mexico. The use of randomly selected sites within a grid that covered the entire conterminous United States makes this an ideal dataset to use for the determination of elemental baseline or regional background concentrations for U.S. soils. These data were published (Smith and others, 2013) and are available from the USGS Mineral Resources On-Line Spatial Data Web site (http://mrdata.usgs.gov/ds-801).

Compilation and Evaluation of Data for the SaMiRA Dataset

Data for concentrates, rocks, sediment, and soils were extracted exclusively from the NGDB (U.S. Geological Survey, 2016a–d). The combined dataset for SedsSoils was derived from all of the available USGS databases described above. However, most records for SedsSoils within the SaMiRA areas were pulled from the NGS-NURE database. Additional records were added from the NGDB and the NASGLP databases (A-horizon soils only because they were more likely to be consistent with the variety of other soil samples from other databases). Many samples were represented by duplicate records in the NGDB and NGS-NURE databases. Considerable effort was made to remove duplication and preserve the best information for each of the overlapping records. Every record in the SedsSoils database is identified by its data source:

1. *NASGLP A-Horizon Soils*—A-horizon soil records with chemistry and sample description information derived from the NASGLP database.

2. *NGDB SedsSoils-with NGDB BV chemistry*—Sample records pulled exclusively from the NGDB database with "best value" (BV) chemistry (Granitto and others, 2013) as described below.

3. *NGSNURE-Leveled NURE plus NURE*—Records for samples collected during the NURE program, analyzed only by NURE laboratories. The sample descriptive information comes from the NURE-HSSR database (Smith, 1997), and the chemistry for 29 leveled elements was obtained from the NGS-NURE database of Smith and others (2015). Additional chemistry for Ag, B, Ba, Cd, Cr, Cs, Dy, Hf, Nb, Rb, Sb, Se, Sn, Sr, Th, W, and Zr was added directly from the original NURE-HSSR database.

4. *NGS-NURE-with NGS chemistry*—Sample records from the NGS database that were not found in the NGDB. Most of these were NURE-HSSR samples reanalyzed by USGS projects using non-USGS commercial or university laboratories. The sample descriptive information and the chemistry were combined from the NGS-NURE and NGS databases.

5. *NGSNURE-with NGDB BV chemistry*—Sample records from the NGS database that were duplicated in the NGDB. The sample descriptive information was obtained from the NGS-NURE database and the more complete "best value" chemistry (Granitto and others, 2013) was added from the NGDB.

When compilation of the datasets was complete, records were examined to remove samples that were not appropriate for the purpose of assessing the mineral potential of the BLM SFAs. Examples of samples removed include (1) those that were collected at depths greater than 1 meter below the surface (primarily drill cores), (2) those identified as mill products (for example, tailings, slag), and (3) those with no relevant chemical data. Surface samples collected at mine sites were not removed.

The NGDB contains many records with poor coordinate precision or accuracy. In the past, it was common to report sample coordinates that were less precise than the nearest second of latitude or longitude. Although the actual accuracy of a coordinate location is dependent on the care given by the submitter and cannot be assessed without other information, it is possible to assess the apparent coordinate precision, defined as the precision level to which a coordinate was reported (for example, nearest second, minute, degree, and fraction thereof). The apparent reported coordinate precision was determined for every latitude and longitude value. Because it is possible that a few coordinates in a batch (job) of samples actually did plot on what appears to be a less precise coordinate, each sample job was assessed based on the best apparent coordinate precision of samples within the batch. If coordinates in a job were not provided to the nearest 15 seconds or better (±760 feet or ± 0.14 miles), samples were removed. After jobs with imprecise coordinates were removed, individual samples with poor apparent precision were assessed and, where it was evident that precision within a job was not maintained, those samples were also removed.

The duplication of samples at single sites was also assessed (after removal of samples with poor coordinate precision). Some additional jobs or batches of samples were removed when it became evident that the submitter had used only a

single coordinate instead of accurate coordinates for a study. For example, samples were removed for a couple of soil surveys, known to have been collected on a traverse or grid, when all samples had the same single-site coordinates. Several rock samples with similar problems were also removed. However, within the existing database, a large number of rocks plotting at single sites more likely represent multiple sample collections from a single locality.

Finally, the analytical values were examined, and a few samples were checked against the original laboratory paperwork to correct or remove bad values that had been mistakenly entered. Another common issue was the use of two or more analytical methods on a sample or batch of samples, resulting in multiple values for the same element. This situation occurred most commonly when more than one multielement analytical package was used (typically with the second one containing some of the same elements but with better LLDs). To ensure that the most appropriate single value for each element was preserved in the database, we used the "best value" (BV) method as described by Granitto and others (2013). Because of the multitude of analytical methods used on these samples, there was also a large variation of LLDs for many elements—sometimes greatly exceeding the average crustal abundance of that element. For example, the median value for tellurium (Te) in the A-horizon soils throughout the conterminous United States (Smith and others, 2013) is 0.03 milligrams per kilogram (mg/kg) or parts per million (ppm), but the LLDs for Te in the SedsSoils database were <0.02, <0.05, <0.1, <0.2, <0.5, <50, and <2,000 ppm, whereas the maximum detected value is 1.6 ppm Te. It was determined that, in the case of Te, the values of <50 and <2,000 ppm were not useful for a mineral-resource assessment, and so these two LLD values were removed from the data. In summary, two rules were applied when determining which of multiple LLDs were not useful for the assessment:

1. For elements that were less than 40 percent censored ("censored" indicates values that are less than the LLD, for example, <0.5 ppm, which is the LLD in this case), high LLDs were removed when they exceeded 2 times the crustal abundance or median topsoil value in the United States, as determined by Smith and others (2013).

2. For elements that were 40 percent or more censored, two additional conservative criteria were applied—(1) the LLD of the method or methods with the majority of detected values was kept, even if it exceeded two times the estimated crustal abundance of the element in that media; and (2) high LLDs were not removed if they significantly changed the median and upper quartile statistics of the population.

Because heavy-mineral concentrates have undergone a concentration factor of 1,000 to 10,000 times the original source material (method for obtaining heavy-mineral concentrates is described in later section), even seemingly high LLDs can be meaningful. No LLD values were removed from the concentrate database.

The resulting database for the SaMiRA project is summarized in table C1 and distinguished based on sample media type within each of the four SFAs. Analyses from a total of 26,343 SedsSoils, 6,890 rock samples, and 3,717 concentrates were used in this evaluation. Data within the Public Land Survey System (PLSS) areas were included, as well as within a 25-kilometer (km) buffer zone around each SFA in order to incorporate geochemical trends that could fall near the edge of the SFAs. The distribution of samples is shown in figure C1.

Analytical Methods

The SaMiRA database contains reported values obtained by analytical methods provided by multiple laboratories. In general, samples were collected and analyzed from the mid-1960s to the mid-2000s, and there were significant developments in analytical methods during that timeframe. Table C2 lists the analytical methods used. The method codes are included as a column in the sediment, soil, rock, and concentrate databases.

Table C1. Number of samples listed by sample media type for Sagebrush Focal Areas (SFA) studied in the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States.

[SedsSoils, soil and stream-sediment samples]

SFA	SedsSoils	Concentrates	Rocks
Nevada border[1]	13,103	1,458	2,552
North-Central Idaho	8,624	1,905	3,765
Wyoming/Utah[2]	2,293	354	496
Montana	2,323	0	77
Total	26,343	3,717	6,890

[1]Includes Sheldon-Hart Mountain National Wildlife Refuge, Southeast Oregon and North-Central Nevada, and Southern Idaho and Northern Nevada SFAs.

[2]Includes Bear River Watershed of Utah and Southwestern and South-Central Wyoming.
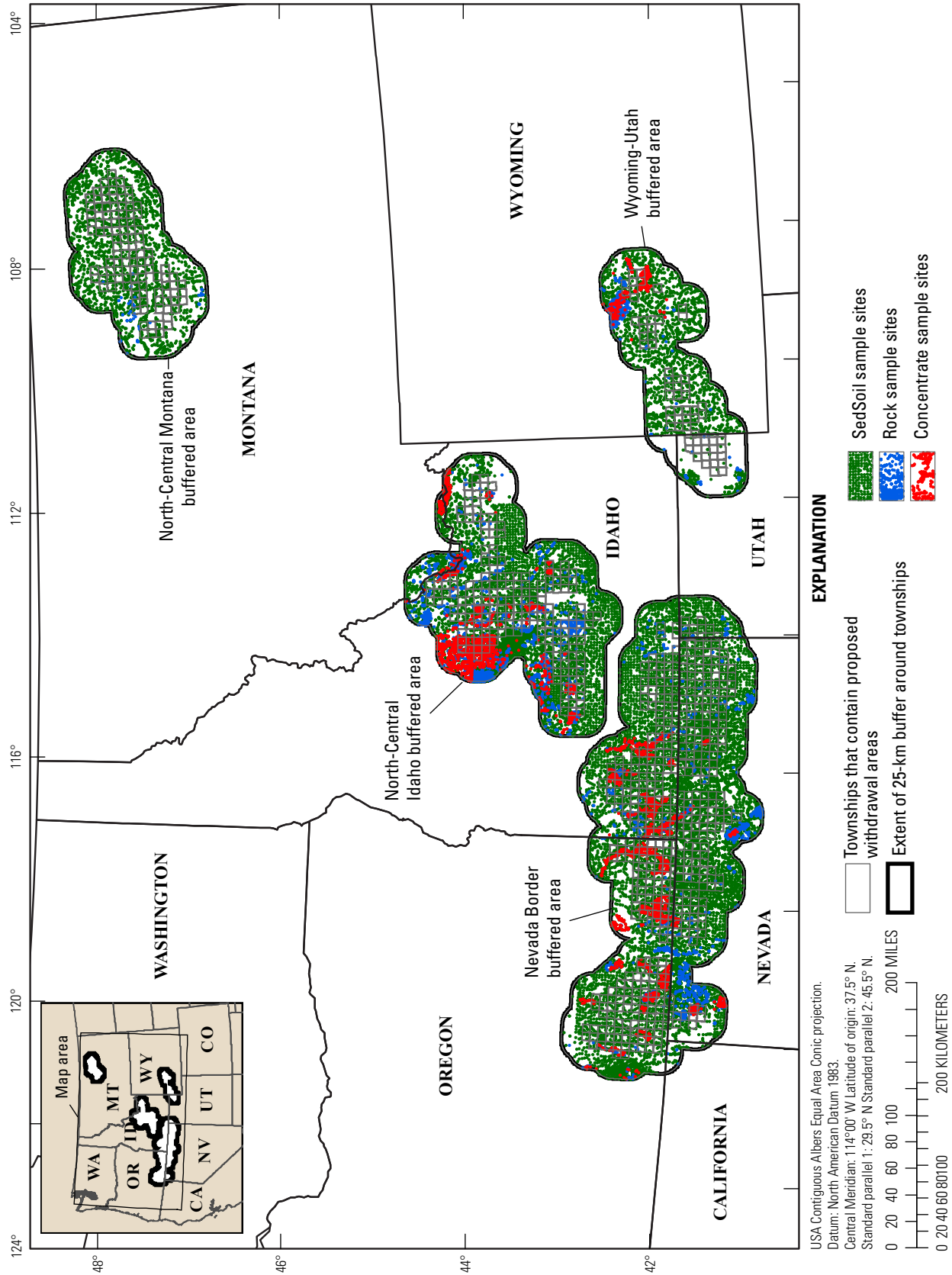
Figure C1.   Map showing the distribution of all geochemistry sample sites for the Sagebrush Focal Areas (SFA) studied in the Sagebrush Mineral-Resource Assessment (SaMiRA) project, Western United States. See figure A1 for SFA boundaries and names. SedSoil, soil and stream-sediment.

Table C2.   Analytical methods used for the Sagebrush Mineral-Resource Assessment (SaMiRA) project soil and stream-sediment samples (SedsSoils), concentrate samples, and rock samples.

[NURE, National Uranium Resource Evaluation; DIBK, diisobuytl ketone, an extraction solvent sometimes written as di iso butyl; MIBK, methyl isobutyl ketone, an organic solvent; Aliquat 336, trioctylmethylammonium chloride; HF, hydrofluoric acid; other chemical symbols are defined in the front matter of this report]

Analytical method code	Analytical method description	Reference
AA_CV	Mercury by cold-vapor atomic absorption spectrometry after multi-acid digestion and solution.	Brown and others, 2002
AA_CV_WO	Mercury by cold-vapor atomic absorption spectrometry after wet oxidation from multi-acid digestion and solution.	Huffman and others, 1972
AA_F_Fuse	Major and minor elements by flame atomic absorption spectrometry after $LiBO_2/Li_2B_4O_7$ fusion digestion.	Shapiro, 1975
AA_F_HBr	Gold and tellurium by flame atomic absorption spectrometry after $HBr-Br_2$ digestion and selective organic extraction with Aliquat 336-MIBK.	O'Leary and Meier, 1996
AA_F_HF	Major and minor elements by flame atomic absorption spectrometry after multi-acid digestion with HF.	Doughten and Grossman, 1993; Aruscavage and Crock, 1987
AA_FE	Sodium and potassium by flame emission spectrometry (flame photometry) after $HF-HClO_4$ dissolution or $LiBO_2$ fusion.	Fries and others, 1996; Jackson and others, 1987
AA_GF_HBr	Gold and tellurium by graphite furnace atomic absorption spectrometry after $HBr-Br_2$ digestion and selective organic extraction with Aliquat 336-MIBK.	O'Leary and Meier, 1996
AA_GF_HF	Arsenic, gold, bismuth, indium, antimony, tellurium and thallium by graphite furnace atomic absorption spectrometry after multi-acid digestion with HF and selective organic extraction with Aliquat 336-MIBK.	Doughten and Grossman, 1993
AA_GF_ST	Thallium by graphite furnace atomic absorption spectrometry after Na_2O_2 sinter, $HCl-HNO_3$ dissolution, and selective organic extraction with DIBK.	Modified from Doughten and Grossman, 1993
AA_HG_Acid	Selenium by flow injection or continuous flow hydride generation-atomic absorption spectrometry after digestion with $HNO_3-HCl-H_2SO_4-KMnO_4$.	Modified from Doughten and Grossman, 1993
AA_HG_HF	Arsenic, antimony, selenium and tellurium by flow injection or continuous flow hydride generation-atomic absorption spectrometry after multi-acid digestion with HF.	Hageman and others, 2002
AA_HG_ST	Arsenic and antimony by flow injection or continuous flow hydride generation-atomic absorption spectrometry after Na_2O_2 sinter digestion.	Modified from Hageman and Welsch, 1996
AA_TR	Mercury by thermal release and atomic absorption spectrometry after heating (Vaughn-McCarthy method).	Ward and others, 1969
AES_Fuse	Major and minor elements by inductively coupled plasma-atomic emission spectrometry after $Li_2B_4O_7$ fusion digestion.	Doughten and Grossman, 1993
AES_HF	Major and minor elements by inductively coupled plasma-atomic emission spectrometry after digestion with $HF-HCl-HNO_3-HClO_4$.	Briggs, 2002
AES_HF_REE	Rare earth elements by ion exchange and inductively coupled plasma-atomic emission quantitative spectrometry after $HF-HCl-HNO_3-HClO_4$ digestion.	Lichte and others, 1987
AES_IE	Molybdenum, niobium and tungsten by inductively coupled plasma-atomic emission quantitative spectrometry after $HF-HCl-HNO_3-HClO_4$ digestion and ion exchange separation.	Doughten and Aruscavage, 1996
CB_IRC	Carbon and sulfur by infrared detection after combustion.	Brown and Curry, 2002a; Brown and Curry, 2002b
CB_TC	Total carbon and organic carbon by thermal conductivity detection after combustion.	Jackson and others, 1987
CB_TT	Sulfur by iodometric titration after combustion.	O'Leary, 1990
CM_Acid	Arsenic by colorimetry after Na_2O_2 sinter digestion.	Brown and others, 1975
CM_Fuse	Major and minor elements by colorimetric spectrophotometry after fusion digestion.	Shapiro, 1975
CM_HF	Vanadium and tungsten by colorimetric spectrophotometry after multi-acid digestion with HF.	Wilson and others, 1987
CM_HSF	Fluorine by colorimetric spectrophotometry after H_2SiF_6 digestion and chemical separation.	Shapiro, 1975
CM_ST	Chloride by colorimetric spectrophotometry after Na_2CO_3 and ZnO sinter digestion.	Jackson and others, 1987
CP	Organic carbon, carbonate carbon and totals by computation.	Jackson and others, 1987
DN	Uranium and thorium by delayed neutron activation counting.	Knight and McKown, 2002

Table C2.—Continued

Analytical method code	Analytical method description	Reference
EDX	Minor elements by energy-dispersive X-ray fluorescence spectrometry.	Siems, 2002
ES_Q	Major and minor elements by quantitative emission spectrography.	Golightly and others, 1987
ES_SQ	Major and minor elements by semi-quantitative emission spectrography.	Skeen and Crandell, 1989; Adrian and others, 1996
FA_DC	Gold by direct current plasma-atomic emission spectroscopy or atomic absorption spectrophotometry after PbO fire assay chemical separation.	Modified from Wilson and others, 1987
FA_MS	Platinum-group elements by inductively coupled plasma-mass spectrometry after NiS fire assay chemical separation.	Meier and others, 1996
FL_HF	Uranium by fluorimetry after multi-acid digestion with HF.	O'Leary and Meier, 1986
GRC	Uranium by gamma counting.	Grimaldi and others, 1954
ISE_Fuse	Fluoride by ion specific electrode after fusion digestion.	O'Leary and Hopkins, 1990; Pribble, 1996
ISE_HF	Chloride by ion specific electrode after fusion digestion or multi-acid digestion with HF.	Aruscavage, 1996
MS_HF	Major and minor elements by inductively coupled plasma-mass spectrometry after HF-HCl-HNO$_3$-HClO$_4$ digestion.	Briggs and Meier, 2002
MS_ST_REE	Rare earth elements by inductively coupled plasma-mass spectrometry after Na$_2$O$_2$ sinter digestion.	Meier and Slowik, 2002
NA_LC	Major and minor elements by long count instrumental neutron activation analysis.	Budahn and Wandless, 2002b
NA_REE	Rare earth elements by long count instrumental neutron activation analysis.	Wandless, 1987
NA_SC	Major and minor elements by short count instrumental neutron activation analysis.	Budahn and Wandless, 2002a
NURE-LA2	Minor elements by energy-dispersive X-ray fluorescence spectrometry, from NURE program, Los Alamos National Laboratory.	Grimes, 1984
NURE-LA3	Minor elements by energy-dispersive X-ray fluorescence spectrometry, from NURE program, Los Alamos National Laboratory.	Grimes, 1984
NURE-LA5	Major and minor elements by long count instrumental neutron activation analysis, from NURE program, Los Alamos National Laboratory.	Grimes, 1984
NURE-Level	Major and minor elements in NURE sediment and soil samples, leveled for the conterminous United States to eliminate laboratory and analytical method bias, multiple analytical methods used per element.	Smith and others, 2015
NURE-OR7	Major and minor elements by inductively coupled plasma-atomic emission spectrometry after digestion with HF-HCl-HNO$_3$-HClO$_4$, from NURE program, Oak Ridge Gaseous Diffusion Plant.	Grimes, 1984
NURE-OR8	Arsenic and selenium by flow injection or continuous flow hydride generation-atomic absorption spectrometry after multi-acid digestion with HF, from NURE program, Oak Ridge Gaseous Diffusion Plant.	Grimes, 1984
NURE-ORSN	Tin by flame atomic absorption spectrometry after multi-acid digestion with HF, from NURE program, Oak Ridge Gaseous Diffusion Plant.	Grimes, 1984
NURE-SR2	Major and minor elements by long count instrumental neutron activation analysis, from NURE program, Savannah River Laboratory.	Grimes, 1984
NURE-SR3AA	Major and minor elements by flame atomic absorption spectrometry after digestion with HF-HNO$_3$-HClO$_4$, HNO$_3$-HClO$_4$, or K$_2$S$_2$O$_7$ fusion, from NURE program, Savannah River Laboratory.	Grimes, 1984
NURE-SR3CA	Phosphorus, niobium and tungsten by colorimetry after HF-HNO$_3$-HClO$_4$ digestion (P) or K$_2$S$_2$O$_7$ fusion (Nb-W), from NURE program, Savannah River Laboratory.	Grimes, 1984
NURE-SR3XX	Arsenic and selenium by flow injection or continuous flow hydride generation-atomic absorption spectrometry after multi-acid digestion with HF (?), from NURE program, Savannah River Laboratory.	Grimes, 1984
WDX_Fuse	Major and minor elements by wavelength-dispersive X-ray fluorescence spectrometry after LiBO$_2$ fusion digestion.	Taggart and Siems, 2002

Statistical Summaries

Elements of most interest for the mineral assessment include Ag, As, Au, Be, Bi, Ce, Co, Cr, Cu, Dy, Ga, Ge, Hg, La, Li, Mn, Mo, Nb, Ni, Pb, Re, platinum-group elements (Ir, Os, Pd, Pt, Rh, and Ru), Sb, Sn, Te, Th, Tl, U, V, W, Y, Yb, and Zn, many of which are pathfinder elements for a variety of deposit types known to occur within or near one or more of the SFAs. Summary statistics were calculated for these elements in each of the three media types (SedsSoils, concentrates, and rocks). Distribution diagrams (histograms and boxplots) were constructed (for example, fig. C2) based only on the samples with values greater than the LLD, that is, uncensored values). This interval was selected to identify and evaluate the range of values that can reflect enrichment in these particular pathfinder elements. For the SedsSoils and rock databases, we also calculated minimum, maximum, and median values (for uncensored data). The four upper threshold values (determined by methods described below) are shown on each boxplot/histogram diagram, and are consistent with those used to create the point plots and grid maps.

Determination of Threshold Values for SedsSoils and Rocks

The purpose of geochemistry in mineral-resource assessments is to determine concentrations of elements that are relatively high compared to a threshold value (and thus, could potentially record proximity to mineral deposits containing those elements). Methods for determination of threshold values for a given dataset are varied, and it is critical to use one that is best suited for the goal of assessing mineral potential. Calculation of percentile values is a common method, and doing so will always produce element classes that are "anomalous" (for example, >90th percentile) with respect to the dataset as a whole; however, the absolute concentrations of an element in samples represented by these >90th percentile classes may not always be high (and thus, potentially not reflective of mineral deposits). Such false anomalies are not always meaningful for mineral-resource assessments. Hence, we chose a method that is consistent across all of the SFAs and would not elevate any element to anomalous status without justification. To do this, we used estimates of natural element abundance (described below) as the basis for classifying element concentrations. For SedsSoils, we primarily used the median value for A-horizon soils determined from samples collected throughout the entire conterminous United States (Smith and others, 2013). For rocks, we primarily used the crustal abundance estimates, also known as the Clarke Index, compiled by Fortescue (1992). For a few elements, it was necessary to obtain abundance values from other sources. Table C3 lists the abundance values (expressed in parts per million unless mentioned otherwise) used for SedsSoils and rocks.

Number of samples	10,051
Minimum	1
Maximum	907
Median	26
No. censored	26
No. uncensored	10,051
Total analysed	10,077
Percentage of censored values (of total analyzed)	0.3
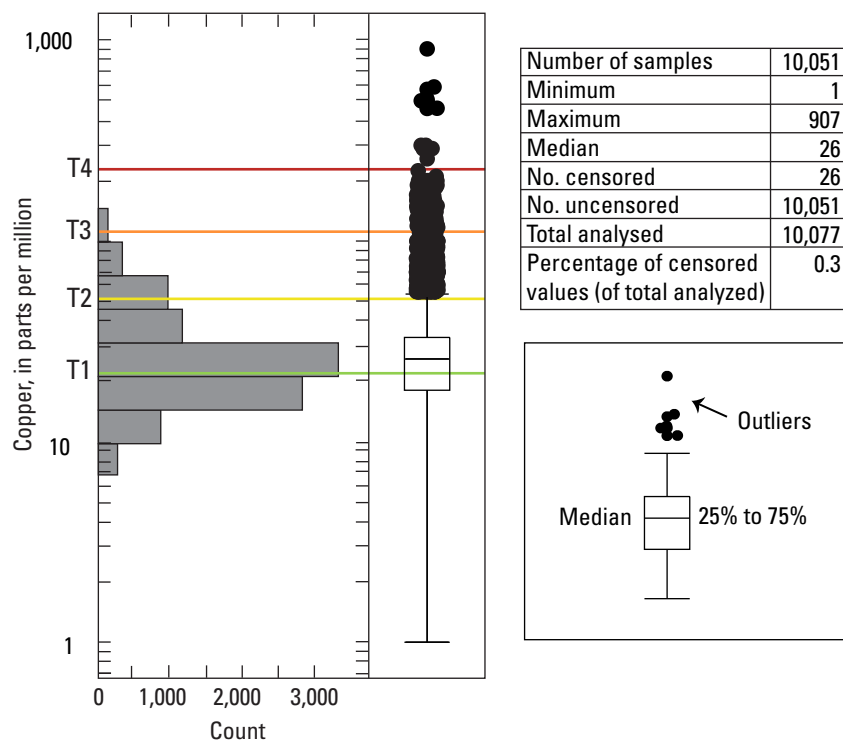
Figure C2. Example diagram showing copper concentrations in parts per million (ppm) in stream-sediment and soil samples (SedsSoils) from the Sheldon-Hart Mountain National Wildlife Refuge, Southern Idaho and Northern Nevada, and Southeastern Oregon and North-Central Nevada Sagebrush Focal Areas (see section A, fig. A1). The histograms and boxplot diagrams and median are based on uncensored (above lower limits of determination, LLD) data only, but the percentage of censored data is shown in statistics table in the diagram (N, number). T1, T2, T3, and T4 are the threshold values (see text for description). T1 = 2–3× background (green line), T2 = 4–7× background (yellow line), T3 = 8–15× background (orange line), and T4 = >16× background (red line). %, percent.

Table C3. Abundance values for stream-sediment and soil samples (SedsSoils) and rocks used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[All values in parts per million (ppm) unless otherwise noted; wt.%, elements reported in weight percent; chemical symbols are defined in the front matter of this report]

Sediments and Soils[1]				Rocks[2]			
Element	Abundance	Element	Abundance	Element	Abundance	Element	Abundance
Ag[3]	0.27	Sc	6.1	Ag	0.08	Mo	1.2
Al wt.%	4.71	Se	0.2	Al wt.%	8.36	Na wt.%	2.27
As	5.2	Sm[3]	3.96	As	1.8	Nb	20
Au[4]	0.004	Sn	1.3	Au	0.004	Nd	39.6
B[5]	26	Sr	122	B	9	Ni[6]	75
Ba	512	Ta[3]	0.68	Ba	390	P wt.%	0.112
Be	1.3	Te[3]	0.03	Be	2	Pb	13
Bi	0.16	Th	7.7	Bi[6]	0.17	Pd	0.015
Ca wt.%	0.74	Ti wt.%	0.24	Br	2.5	Pr	9.1
Cd	0.2	Tl	0.4	Ca wt.%	4.66	Pt	0.0005
Ce	51.7	U	2	Cd	0.16	Rb	78
Co	7.8	V	54	Ce	66.4	Re	0.0007
Cr	31	W	0.8	Cl	126	Rh	0.0002
Cs[3]	3.71	Y	14.5	Co	29	Ru	0.001
Cu	14.8	Yb[3]	1.99	Cr	122	S wt.%	0.034
Dy[3]	3.42	Zn	59	Cs	2.6	Sb	0.2
Eu[3]	0.77	Zr[5]	180	Cu	68	Sc	25
Fe wt.%	1.99			Dy	5	Se[7]	0.15
Ga	11.2			Er	3.46	Sm	7.02
Hf[3]	5.55			Eu	2.14	Sn	2.1
Hg	0.02			F wt.%	0.0544	Sr	384
K wt.%	1.5			Fe wt.%	6.22	Ta	1.7
La	25.7			Ga	19	Tb	1.18
Li	20			Gd	6.14	Te	0.004
Lu[3]	0.3			Ge	1.5	Th	8.1
Mg wt.%	0.46			Hf	2.8	Ti wt.%	0.632
Mn wt.%	0.05			Hg	0.086	Tl	0.72
Mo	0.78			Ho	1.26	Tm	0.5
Na wt.%	0.69			In	0.24	U	2.3
Nb	8.6			Ir	0.000002	V	136
Nd[3]	20.8			K wt.%	1.84	W	1.2
Ni	13.8			La	34.6	Y	31
P wt.%	0.055			Li	18	Yb	3.1
Pb	17.8			Lu	0.54	Zn	76
Rb	65.8			Mg wt.%	2.764	Zr	162
Sb	0.57			Mn wt.%	0.106		

[1]Sediment and soil abundance values from A-horizon median values of Smith and others (2013) unless otherwise noted.

[2]Rock crustal abundance values from Fortescue (1992) Clarke Index unless otherwise noted.

[3]Salminen and others (2005) topsoil median.

[4]Fortescue (1992) Clarke index.

[5]Shacklette and Boerngen (1984).

[6]Taylor (1964).

[7]Gao and others (1998).

To map abundances in terms of classified ranges, the following scheme was used: background range was determined to be between 0.5× and 1.5× the abundance value; 2× background is the range from 1.5× to 2.5× abundance; 3× background is the range from 2.5× to 3.5× abundance, and so on. Classification ranges or multiples of background for each element were grouped in a pseudo-logarithmic scale of <background, background, 2–3× background, 4–7× background, 8–15× background, and >16× background. The thresholds (T1, T2, T3, and T4) between the upper four classification ranges were then assigned the values of 1.5×, 3.5×, 7.5×, and 15.5× abundance, respectively. These thresholds are indicated by colored lines on histograms and boxplots (fig. C2).

Determination of Threshold Values for Concentrates

Many USGS mineral-resource assessment projects used concentrate samples that were derived from samples of stream sediment, soil, and less commonly, rock. These concentrates were processed by a variety of methods to concentrate the heavy-mineral fraction. These techniques commonly enhanced the concentration of selected minerals from 1,000 to more than 10,000 times their concentration in the original material and permitted the determination of elements in some samples that could not otherwise be detected.

Almost all concentrates were initially processed by panning the sample with a gold pan to remove clay, organic material, and the majority of lighter density minerals (primarily quartz and feldspar). A sample prepared to this point is known as a panned concentrate. Some of these panned concentrate samples were not processed further before geochemical analysis. Alternately, a panned concentrate might have had magnetite removed with a hand magnet before submittal. A larger proportion of panned concentrate samples were taken to the laboratory and processed by a heavy liquid, usually bromoform, which concentrated minerals with specific gravities of greater than about 2.8. This was usually followed by an electromagnetic separation (Frantz Isodynamic Separator) to create three magnetic splits of the heavy-mineral sample—(1) strongly magnetic minerals (C1 fraction), primarily magnetite and ilmenite; (2) weakly magnetic minerals (C2 fraction), including most of the iron and manganese oxides and ferromagnesian silicates; and (3) very weakly to nonmagnetic minerals (C3 fraction), primarily consisting of zircon, apatite, and titanite but also including many ore-related oxide and sulfide minerals. The C3 fraction, commonly referred to as a nonmagnetic heavy-mineral concentrate, was commonly analyzed. The C1 and C2 fractions were occasionally analyzed.

Unfortunately, much of this concentrate processing information was not stored in the USGS geochemical databases. These older databases have now been combined into the NGDB, and a large, but still incomplete, effort has been made to distinguish various types of concentrates in the data. Therefore, the SaMiRA concentrate database contains a mixture of all of these types of concentrates. Thus, the data cannot be treated as a consistent sample medium but must be interpreted as a secondary source of information in areas that contain enhanced concentrations of elements of interest.

Unlike sediments, soils, or rocks, there are no relevant databases or crustal abundance estimates for concentrates that can be used to create classes of values by element. Using the SaMiRA concentrate data alone, we classified the data based on percentiles for the entire population (including values below lower detection limits) for each element. The chosen percentile classes for plotting concentrate data were as follows: not detected; <25th percentile; 25–50th percentile; 50–75th percentile; 75–90th percentile; 90–97.5th percentile; and >97.5th percentile. These seven classes allowed us to use the same colored dot symbols that we used for the Sediment/Soil and Rock geochemistry layers. Some highly censored elements, like Ag only had three classes—not detected, 90–97.5th percentile, and >97.5th percentile. Four elements (As, Au, Cd, and Sb) were so extremely censored that we had to modify these classes slightly to Not Detected, 97.5–99th percentile, and >99th percentile. Two elements (Ti and Zr) had so many "greater than" values that we could not distinguish the upper end of the spectrum and had to make the last class as >75th percentile.

Interpolated Geochemistry Grids

Before gridding, samples with elemental concentrations below the LLD were replaced with an arbitrary value of ½ the lowest measured concentration. For some samples the LLDs were too high to be meaningful and those samples values were replaced with null values.

Geochemical data were gridded using an inverse distance weighted (IDW) algorithm and Geosoft Montaj™ software. The data were projected to the Albers equal-area conic with the datum of NAD 83 and a central meridian of −114° before gridding. The parameters used for IDW are (1) grid cell size: 1 km; (2) weighting power: 2; (3) weighting slope: 1; (4) search radius: 4 km; (5) blanking distance: 4 km; (6) cells to extend beyond data: 0; (7) log option: linear; and (8) log minimum: 1. The grids were converted from Geosoft file (.grd) formats to Arc View Binary Grid (.flt) formats before being imported into an ArcGIS version 10.3.1 geodatabase. A typical sample would be located in the center of a 1-km^2 cell, and the gridding algorithm searched 4 km around this unit cell for neighboring samples (fig. C3). The value of neighboring samples influenced the values in the surrounding cells according to the distances from each unit cells. When more than one sample was located within a single cell, the algorithm took the average of the values for the unit cell value.

In ArcGIS, the grids were classified into six intervals based on elemental abundance concentrations of soils (tables C3 and C4). These intervals were ranked and colored in order of increasing concentration from blue to red. A buffer area extending 25 km outside of the study area was included to capture any trends that could exist near the PLSS boundaries.
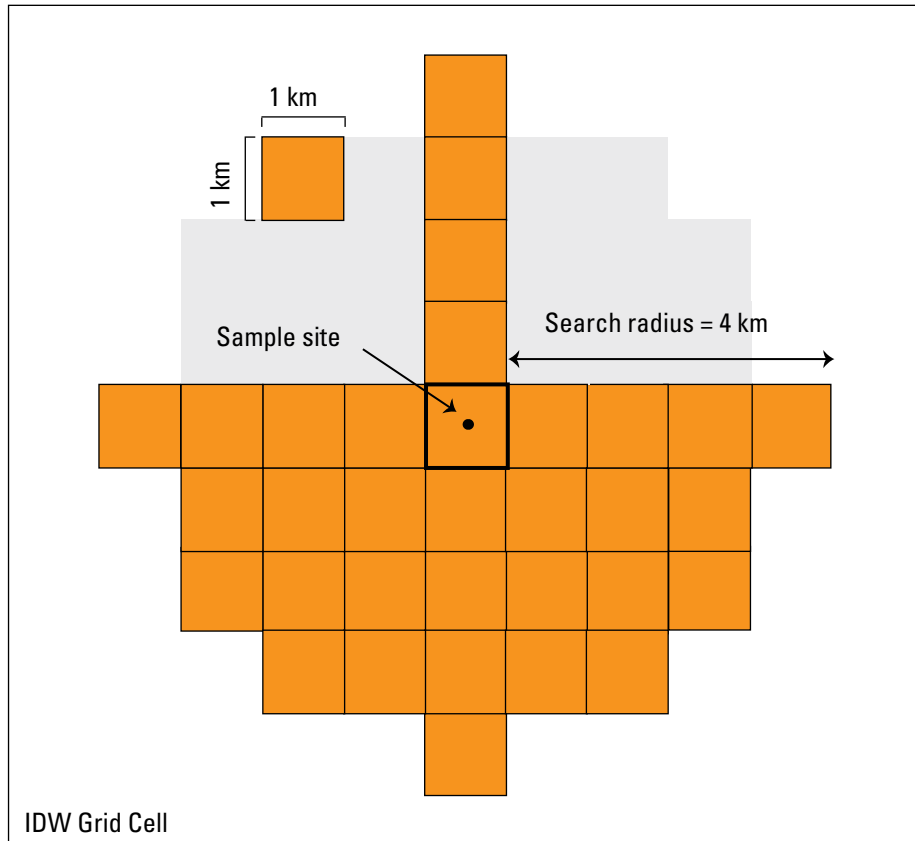
Figure C3.   Diagram showing dimensions of inverse distance weighted (IDW) grid cell used for geochemical data in the Sagebrush Mineral-Resource Assessment (SaMiRA) project. km, kilometer.

The IDW grids, when combined with dot plots, yield a stable backdrop for comparing the different focal areas and for assessing areas that appear anomalous.

Geographic Information Systems and Symbolized Layers

To calculate spatially accurate sample locations and grids, all sample-site coordinates must be in a single geographic coordinate system. Sample sites with coordinates that were not already in the World Geodetic System of 1984 (WGS84) were selected by existing projection and exported into a working geographic information system (GIS) (Esri ArcGIS 10.3.1) as feature classes. The data in a particular projection were loaded into an ArcGIS map document with a WGS84 coordinate system and then had WGS84 coordinates calculated and appended to the data using the Xtools Pro for ArcGIS 11.1 extension. The new WGS84 coordinates were then extracted from the various sub-datasets and merged back into the Microsoft Access data tables. When all WGS84 coordinates were added, and the data collection, selection, and geochemistry preparation were complete, the data were assembled into final Access database tables for conversion into the project GIS.

After the geochemistry geodatabases were constructed and the feature classes, tables, and prediction grids were generated, the elements for each sample media type were classified (binned into ranges) and symbolized according to class divisions determined for each element. See previous discussions on determination of threshold values for details on class divisions.

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Section D. Geophysical Data and Methods Used in Mineral-Resource Assessments within the Sagebrush Focal Areas

By Eric D. Anderson and David A. Ponce

Introduction

Geophysical investigations help assess the mineral-resource potential of the Sagebrush Focal Areas (SFAs) in parts of Idaho, Montana, Nevada, Oregon, Utah, and Wyoming. Magnetic, gravimetric, and radiometric methods help map variation in the physical and geochemical properties of rocks both at and near the Earth's surface. Thus, publically available datasets have been described, processed, and interpreted to help provide a better understanding of the mineral-resource potential of the SFAs. Magnetic and gravity data transforms, including reduction-to-the-pole, total horizontal gradient, first vertical derivative, tilt derivative, and analytic signal were applied to facilitate interpretation. Similarly, radiometric data were ratioed to help further discriminate the radiogenic variations/compositions of surface material.

Magnetic data sources include existing compilations, both at the national- and State-scale, as well as individual survey datasets. The data provide information on the lateral distribution of magnetic material within the Earth's crust, and in all SFAs these data were most effective for mapping plutonic rocks that could be associated with mineral systems. Magnetic data were also used to provide depth estimates to magnetic sources and showed that in Montana magnetic sources are likely too deep to be of interest for mineral extraction.

Gravity data from national-scale compilations are relatively coarse over the SFAs, thereby making them less useful for mapping lateral changes in rock types. These data are more effective for understanding basin thickness within the Basin and Range Province. Gravity inversions provide an estimate of the thickness of low-density basin fill, thereby helping to map depth to bedrock that could host mineral resources beneath basin fill.

Radiometric data provide information on the distribution of potassium, thorium, and uranium at the Earth's surface. Changes in the relative abundances of these elements can reflect rock types or hydrothermal alteration that could be associated with mineral deposits. In the SFAs, the radiometric data complemented geologic maps and helped differentiate subtle changes in rock compositions. Geophysical investigations of the Sagebrush Mineral-Resource Assessment (SaMiRA) focal areas are part of an interagency effort by the U.S. Geological Survey (USGS) and Bureau of Land Management (BLM) to help characterize the mineral resources of parts of Idaho, Montana, Nevada, Oregon, Utah, and Wyoming. The seven Sagebrush Focal Areas (SFAs) are Bear River Watershed, North-Central Idaho, North-Central Montana, Southeastern Oregon and North-Central Nevada, Sheldon-Hart Mountain National Wildlife Refuge Complex, Southern Idaho and Northern Nevada, and Southwestern and South-Central Wyoming. For the purpose of geophysical data interpretation, the seven SFAs have been grouped into four areas based on proximity to each other. The areas and contained SFAs include (1) Area A: Sheldon-Hart Mountain National Wildlife Refuge Complex, Southeastern Oregon and North-Central Nevada, and Southern Idaho and Northern Nevada; (2) Area B: North-Central Idaho; (3) Area C: Bear River Watershed and Southwestern and South-Central Wyoming; and (4) Area D: North-Central Montana. This report section describes the geophysical methods, datasets, and analyses used to aid in the mineral-resource assessment of the SFAs.

Geophysical methods map geologic materials that have differing physical and (or) geochemical properties. In this study, the geophysical methods used magnetic, gravity, and radiometric data, which reflect variations in magnetization, density, and radioactivity, respectively. The geophysical methods are most effective where the rock properties vary considerably. Physical property variation can occur along and across geologic structures, across rock type contacts, or within a mineral deposit. For example, (1) structures that juxtapose differing rock types can show changes in physical properties; (2) structures can provide pathways for reactive hydrothermal fluids that can alter the physical properties of rocks; (3) the distribution of igneous rocks, both intrusive and extrusive, can lead to abrupt physical property changes; (4) sedimentary-rock layers within basins can have differing physical properties as a function of lithology; (5) the physical properties of a sedimentary-rock cover as a whole can differ from the underlying basement; (6) metamorphic rocks can have different physical properties; (7) hydrothermal fluids within, and surrounding, a mineral deposit can alter the host rock physical properties; and (8) mineral deposits themselves can have physical properties that contrast with the surrounding host rocks. Geophysical methods take advantage of these changes in the rock properties and can help identify the structures, host rocks, and hydrothermal systems that may be associated with ore deposit formation.

Qualitative interpretation of magnetic and gravity anomalies helps produce a geology map based on anomaly patterns. The resultant maps can assist with identifying near-surface favorable lithology or structures that host mineral deposits. Digital enhancements of these data can further facilitate interpretations. Enhancements include mathematical filters, or transforms, which can highlight areas of contrasting physical properties at both shallow and deep crustal levels. A gradient, or derivative, filter is commonly employed to emphasize changes in the dataset that may represent a geologic contact between bodies of contrasting physical properties. Filters can highlight anomalies of certain frequencies, or wavelengths, within the data that may represent a particular lithology or source depth. High-pass filters enhance the higher frequency, or short-wavelength, component of the dataset that generally corresponds to shallow sources. In contrast, a low-pass filter will highlight the lower frequency, or long-wavelength, component of the dataset that may correspond to deeper sources.

Quantitative interpretation of magnetic and gravity anomalies, such as forward and inverse mathematical models, seeks to better understand the distribution of physical properties at depth. Depth to magnetic and gravity sources can be estimated to help develop a three-dimensional framework for subsurface geology. Such interpretations help to assess for mineral resources that are under cover.

Geophysical Methods

Magnetic and Gravity

Magnetic and gravity methods, commonly referred to as potential-field methods, have been used for geologic mapping and mineral-resource assessments (Grant, 1985; Hinze, 1985; Blakely, 1995; Clark, 1997; 1999; Nabighian and others, 2005a, b). They can provide a nearly continuous set of observations over large areas. Magnetic and gravity data are collected and processed in such a way that they reflect lateral changes in subsurface magnetization and density, respectively. Because the known spectrum of rock types can have several orders of magnitude variation in magnetic properties and can vary in density by about a factor of two, magnetic and gravity data provide powerful subsurface mapping tools. Gravity data are typically more difficult to process because effects not related to geology have to be removed. Such effects include the tidal attraction of the Moon and Sun, instrument drift, changes in gravity with elevation, changes in gravity with latitude, the Earth's curvature, and the surrounding topographic terrain. Magnetic data are simply

corrected for diurnal variations in the Earth's magnetic field, magnetic effects of the aircraft (if applicable), and a regional geomagnetic model of the Earth.

Magnetic data provide information on the distribution of magnetic minerals, mainly magnetite, within the crust. These data can be used to map areas of magnetite variability within a hydrothermal system or more commonly to map magnetic patterns and trends that may reflect differing rock types and structures proximal to mineral deposits. Magnetic anomalies are caused by two different kinds of magnetism—induced and remanent. The induced component is mostly determined by magnetic susceptibility of the rock and is proportional to the magnetic field in which it is measured. The remanent component depends on the thermal, mechanical, and magnetic history of the rock and is independent of the field in which it is measured. In general, but not exclusively, the induced component is predominant, especially for Cenozoic volcanic rocks. Magnetic anomalies measured on rocks that carry significant remanent magnetization not aligned with the inducing field can be difficult to interpret.

Gravity data provide information on variations in subsurface rock density. In general, igneous and metamorphic rocks have higher densities than sedimentary rocks. For igneous rocks, increasing density tends to be negatively correlated with silica content. Thus, felsic rocks have low densities, intermediate rocks have moderate densities, and mafic and ultramafic rocks have highest densities. For sedimentary rocks, evaporites generally have low densities, siliciclastics have moderate densities, carbonates have high densities, and iron formations tend to be most dense. Gravity anomalies are centered over the source body and, similar to magnetic anomalies, will broaden with increasing distance from the source body.

Radiometric

The radiometric method measures gamma radiation intensities from the radioactive decay of potassium (K), thorium (Th), and uranium (U) within the upper few centimeters of the Earth's surface (Dickson and Scott, 1997). Intensities can then be converted into elemental concentrations. These elements are the three most abundant radioactive elements present in various proportions in all rocks and soils. A measured intensity value from airborne data is an average element concentration over a surface area, the areal extent of which is determined by the altitude of the aircraft. Radiometric data are calibrated and corrected for instrument spikes, cosmic background, and height-related scattering. Airborne radiometric data are interpreted in terms of surface chemistry and presented as individual element maps or the ratio of two elements that aid the recognition of lithologic units. Linear features within the data may indicate

the presence of faults, or structures, which can be favorable for mineral-deposit types. In general, felsic igneous rocks have higher radioelement concentrations than mafic rocks; whereas the radioelement concentration in sedimentary rocks reflects the parent source rocks (Dickson and Scott, 1997).

Geophysical Data

The magnetic, gravity, and radiometric data assembled for the mineral-resource assessments within the SFAs are derived from publically available databases. For each compiled dataset, several basic data-processing steps were conducted. Each dataset was projected into a common map projection (Albers equal-area conic with central meridian of −114.0° longitude). The final processed datasets were subset to remove all data outside of regions that encompass a 25-kilometer (km) buffer surrounding the SFAs.

The U.S. Department of Energy as part of the National Uranium Resource Evaluation (NURE) program systematically collected airborne radiometric and magnetic data across the United States. The primary goal for the program was to identify uranium resources, and thus the airborne surveys were optimized for radiometric data collection. The airborne NURE datasets provide the most comprehensive radiometric and magnetic data coverage over the SFAs (Duval, 1999; Hill and others, 2009) and are the framework for the magnetic and radiometric compilations described below.

Aeromagnetic Data

Aeromagnetic data available as individual surveys and existing compilations were used to help understand the geologic setting and associated mineral deposits within the SFAs. The existing compilation that covers the United States, Canada, and Mexico has relatively low resolution of 1,000-meter (m) grid cells (Bankey and others, 2002), whereas the individual State compilations have higher resolution of 500-m grid cells (for example, Montana: McCafferty and others, 1998; Nevada: Kucks and others, 2006; Oregon: Roberts and others, 2008; and Wyoming: Kucks and Hill, 2000). The individual aeromagnetic survey datasets, available from the USGS Mineral Resources On-Line Spatial Data Web site (http://mrdata.usgs.gov/), exist in two forms—(1) digital, where original flight-line data are digitally preserved or (2) digitized, where analog contour maps have been digitized (no flight-line data are available). The individual surveys were designed for many purposes; as such their coverage varies considerably in both areal extent and anomaly resolution (fig. D1). In the focal areas, the flight-line spacing ranges from less than about 800 m to about 8,000 m. The flight-line height ranges from about 120 m above ground to 3,960 m barometric elevation. Thus, most of the focal areas have low spatial and anomaly resolution. Because of low resolution, shallow magnetic sources of limited areal extent may not be well resolved in some parts of the aeromagnetic maps. Thus, these datasets are not adequate to map individual mineral deposits that have limited areal extent; instead these data are more useful for imaging the regional geologic framework within which the mineral resources occur.

The national-scale magnetic compilation data covering the study area were obtained from the magnetic anomaly map of North America (Bankey and others, 2002). In this compilation, all survey data were reduced using industry standard techniques (Luyendyk, 1997). The data were corrected for the Earth's magnetic field and diurnal variations, upward or downward continued to a common datum of 305 m above the topography, and merged to produce a uniform anomaly map with grid spacing of 1,000 m. The resultant total magnetic intensity anomaly data (fig. D2) were the initial dataset from which subsequent data transforms, described below, were derived (table D1).

In addition, the individual surveys that encompass the focal areas were used to generate relatively high-resolution compilations with grid cell spacing of 500 m for the SFAs. The surveys within and surrounding the SFAs were assessed for quality, and the best available datasets were used to generate new, higher resolution compilations (table D2). The survey specifications varied considerably with flight-line spacing between 800 and 8,000 m and a range in flight-line altitude from 120 m above ground to 3,960 m barometric elevation. The NURE data were collected at low altitudes along relatively widely spaced flight lines. Such a survey geometry can cause problems when gridding flight-line data over magnetic sources. Artifacts can be introduced into the data in the form of lineations perpendicular to flight lines. To reduce these artifacts, the NURE flight-line data were continued to 305 m height before gridding. Where necessary, data gaps between individual surveys were filled using the existing State compilations (table D3). All survey data were corrected for the Earth's magnetic field and diurnal variations, upward or downward continued to a constant elevation of 305 m above the ground, gridded using a minimum curvature algorithm, and merged to produce a uniform map with a grid spacing of 500 m. These data have a grid resolution four times higher than that of the national scale. The new compilations, although initially composed of surveys acquired with different specifications, allow seamless interpretation of magnetic anomalies across survey boundaries within the SFAs and provide the initial dataset from which subsequent data transforms described below were derived (table D1).

Political boundaries from Esri (2013).
Shaded relief from Esri (2008).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 114° W., latitude of origin, 37.5° N.
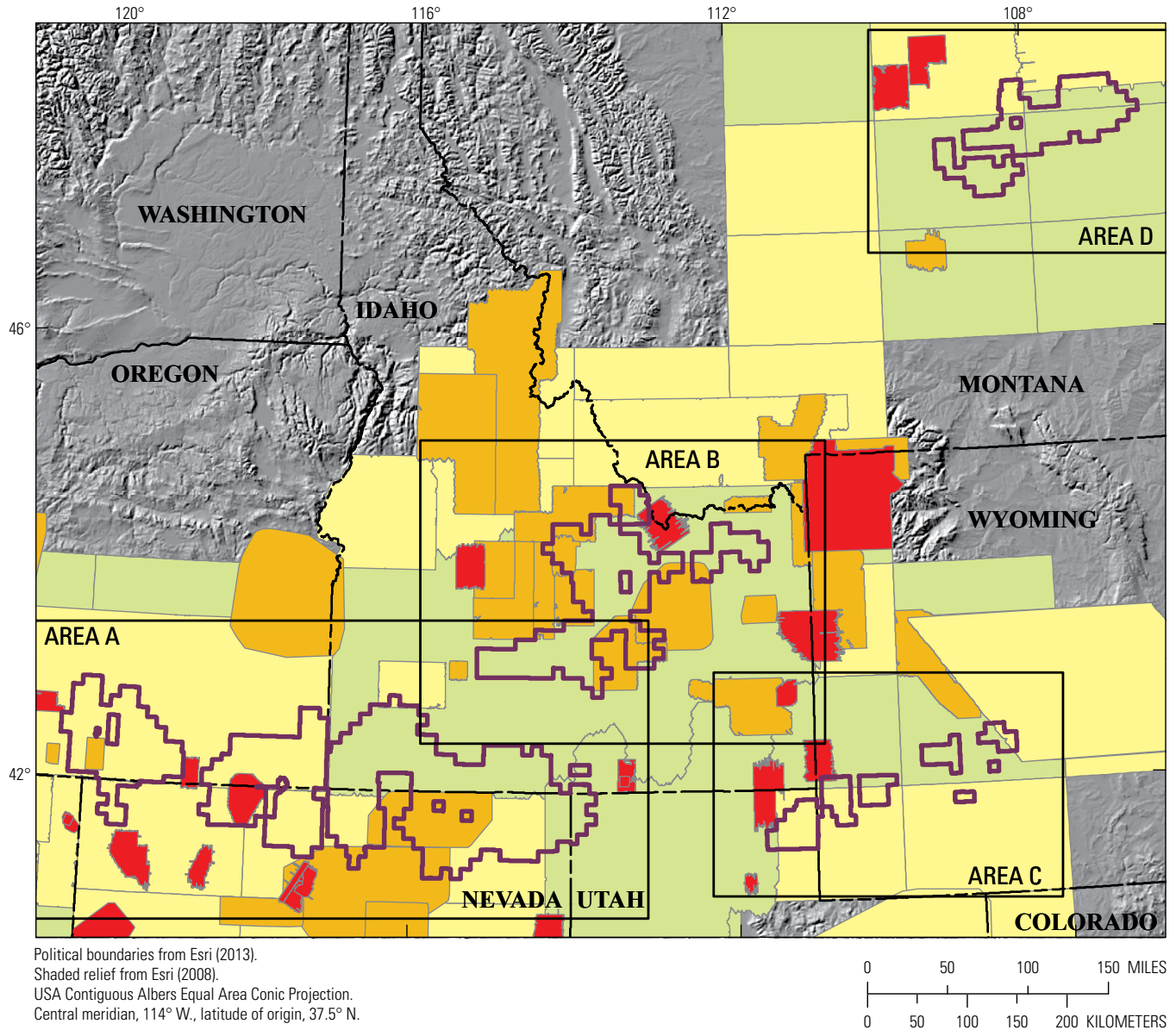
EXPLANATION

USGS study area boundary

Flight-line spacing (meters)

less than 800
800 to 1,600
1,600 to 4,800
4,800 to 8,000
greater than 8,000

Figure D1.   Map showing airborne magnetic surveys that intersect a rectangular region encompassing a 25-kilometer buffer surrounding Sagebrush Focal Areas (SFAs), Western United States. Data available through the U.S. Geological Survey (USGS) Mineral Resource Program on-line spatial data Web site (http://mrdata.usgs.gov/).
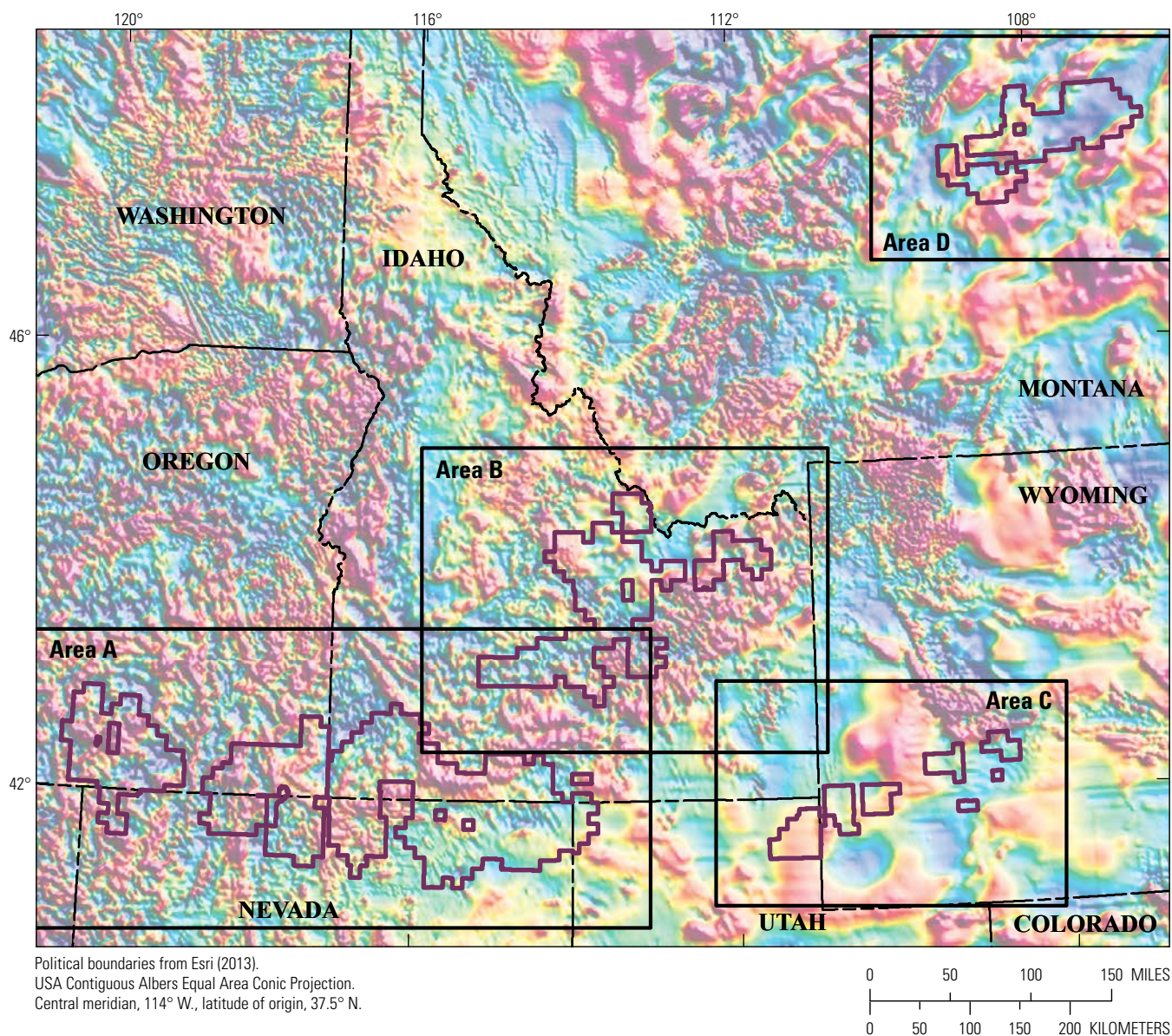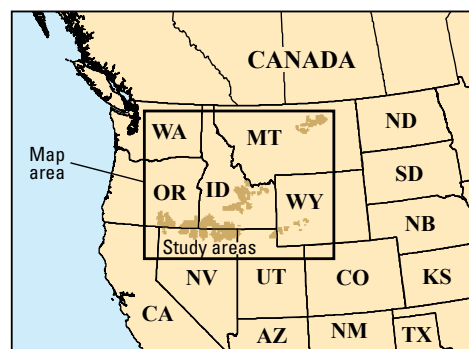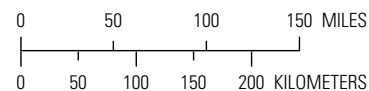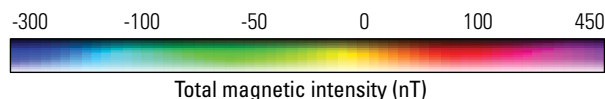
Figure D2.   Map showing total magnetic intensity (TMI) in the Western United States (Bankey and others, 2002). These data were subset to the four rectangular regions (black boxes) surrounding Sagebrush Focal Areas (SFAs; see section A, fig. A1) and provided the basis for subsequent data transforms (table D1). USGS, U.S. Geological Survey. nT, nanotesla.

Table D1.   List of filtered or transformed geophysical datasets generated for the Sagebrush Focal Areas (SFAs; see section A, fig. A1) as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

Dataset	Description
Magnetic compilations:	
TMI	Total magnetic intensity anomaly map.
RTP	Reduced-to-pole transform of total magnetic intensity anomaly map.
RTP-HGD	Total horizontal gradient of the reduced-to-pole anomaly map.
RTP-1VD	First vertical derivative of the reduced-to-pole anomaly map.
RTP-TDR	Tilt derivative (or tilt angle) of the reduced-to-pole anomaly map; Also, vector file of –45, 0, 45 degree contours for tilt-depth estimates.
RTP-TDR-HGD	Horizontal gradient of the tilt derivative of the reduced-to-pole anomaly map.
RTP-AS	Analytic signal of the reduced-to-pole anomaly map.
Gravity compilation:	
CBA	Complete Bouguer anomaly map.
ISO	Isostatic anomaly map.
ISO-HGD	Total horizontal gradient of the isostatic anomaly map.
ISO-1VD	First vertical derivative of the isostatic anomaly map.
ISO-TDR	Tilt derivative (or tilt angle) of the isostatic anomaly map; Also, vector file of -45, 0, 45 degree contours for tilt-depth estimates.
ISO-TDR-HGD	Horizontal gradient of the tilt derivative of the isostatic anomaly map.
Radiometric compilation:	
K	Potassium map.
TH	Thorium map.
U	Uranium map.
U:TH	Uranium to thorium (ratio) map.
TH:U	Thorium to potassium (ratio) map.
U:K	Uranium to potassium (ratio) map.
U^2:K	Uranium squared to thorium (ratio) map.
K-TH-U	Ternary image where red=potassium, green=thorium, blue=uranium.

Table D2.   Aeromagnetic surveys used to generate new, higher resolution compilations for the Sagebrush Focal Areas (SFAs) as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[NURE, National Uranium Resource Evaluation; Focal areas: A, Sheldon-Hart Mountain National Wildlife Refuge Complex, Southeastern Oregon and North-Central Nevada, and Southern Idaho and Northern Nevada; B, North-Central Idaho; and C, Bear River Watershed and Southwestern and South-Central Wyoming]

Survey name	Type	Focal area(s)	Year flown	Line spacing (m)	Survey height (m)	URL
Modoc North-central	Digitized	A	1957	3,200	2,100[1]	http://mrdata.usgs.gov/magnetic/show-survey.php?id=CA03c
Modoc South-central	Digitized	A	1957	3,200	2,450[1]	http://mrdata.usgs.gov/magnetic/show-survey.php?id=CA03d
Modoc East	Digitized	A	1957	3,200	2,900[1]	http://mrdata.usgs.gov/magnetic/show-survey.php?id=CA03e
Idaho Regional '69	Digitized	A, B	1969	8,000	3,650[1]	http://mrdata.usgs.gov/magnetic/show-survey.php?id=0667
Susanville	NURE	A	1965	8,000	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-295
Boise	NURE	A	1976	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-227
Jordan Valley	NURE	A	1973	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-250

Table D2.   Aeromagnetic surveys used to generate new, higher resolution compilations for the Sagebrush Focal Areas (SFAs) as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project.—Continued

Survey name	Type	Focal area(s)	Year flown	Line spacing (m)	Survey height (m)	URL
Brigham City	NURE	A, C	1962	8,000	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-270
Toole	NURE	A	1970	8,000	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-296
Challis	NURE	B	1963	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-210
Elk City	NURE	B	1982	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-186
Dubois	NURE	B	1976	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-194
Dillon	NURE	B	1962	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-171
Ashton	NURE	B	1972	8,000	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-207
Bozeman	NURE	B	1972	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-178
Driggs	NURE	B	1972	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-229
Preston	NURE	B, C	1978	8,000	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-252
Pocatello	NURE	C	1976	8,000	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-243
Ogden	NURE	C	1978	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-283
Rock Springs	NURE	C	1962	4,800	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-287
Lander	NURE	C	1978	8,000	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=NURE-260
Wind River	Digitized	C	1969	1,600	3,950[1]	http://mrdata.usgs.gov/magnetic/show-survey.php?id=0669
Wind River Basin	Digital	C	1974	3,200	120	http://mrdata.usgs.gov/magnetic/show-survey.php?id=6001
Bonneville	Digitized	C	1969	8,000	3,650[1]	http://mrdata.usgs.gov/magnetic/show-survey.php?id=0664
Idaho Thrust Belt	Digitized	C	1963	1,600	2,750[1]	http://mrdata.usgs.gov/magnetic/show-survey.php?id=0523
Mt. Naomi	Digital	C	1981	800	305	http://mrdata.usgs.gov/magnetic/show-survey.php?id=3188

[1]Barometric survey.

Table D3.   Specifications for State-compilation of magnetic data over the Sagebrush Focal Areas (SFAs) as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

State	Grid interval, in meters	Datum, in meters	Reference
California	1,000	305	Roberts and Jachens, 1999
Idaho	1,000	305	McCafferty and others, 1999
Montana	500	305	McCafferty and others, 1998
Nevada	500	305	Kucks and others, 2006
Oregon	500	305	Roberts and others, 2008
Utah	1,000	3,810[1]	Bankey and others, 1998
Wyoming	500	305	Kucks and Hill, 2000

[1]Barometric altitude.

Gravity Data

Gravity stations were compiled from the Pan-American Center for Earth and Environmental Studies (PACES) U.S. Gravity Database accessed January 5, 2016, at http://irpsrvgis08.utep.edu/viewers/Flex/GravityMagnetic/GravityMagnetic_CyberShare/ (Hildenbrand and others, 2002; Aldouri and Keller, 2011). The gravity-station spacing is irregular and coarse, having approximately 0.1 stations per square kilometer. Gravity-station data were processed using standard data reduction techniques (Hinze and others, 2005) and include the following corrections: (1) an Earth-tide correction, which corrects for tidal effects of the Moon and Sun; (2) an instrument-drift correction, which compensates for drift in the instrument's spring; (3) a latitude correction, which accounts for variation in the Earth's gravity with latitude; (4) free-air correction, which accounts for the variation in gravity due to elevation relative to sea level; (5) a Bouguer correction, which corrects for the attraction of material between the station and sea level; (6) a curvature correction, which corrects the Bouguer correction for the effect of the Earth's curvature; and (7) a terrain correction, which removes the effect of topography to a radial distance of 167 km from the station. Gravity-station data were gridded using a minimum curvature algorithm at an interval of 500 m to produce complete Bouguer anomaly datasets over the four areas (fig. D3). The Bouguer anomaly data were the initial starting point from which the gravity data transforms described below were derived (table D1). For each area, an isostatic correction was applied to remove the long-wavelength variations in the gravity field related to the compensation of topographic loads. For this reduction, the digital elevation model (Lukas and others, 2015) was resampled to 500 m. A 2.67-gram per cubic centimeter (g/cm^3) Bouguer density and a 0.35-g/cm^3 Moho density contrast were assumed.

Radiometric Data

Radiometric data over the SFAs were derived from previously released map compilations across the United States (Duval and others, 2005). The original data were acquired as part of the National Uranium Resource Evaluation (NURE) program in the 1970s. The NURE flight-line spacing over the SFAs varied from 3,200 m to 8,000 m and had a nominal terrain clearance of 120 m. The flight-line data were previously processed to produce internally consistent data (Duval, 1999; Duval and Riggle, 1999). Data corrections included compensation for aircraft and cosmic radiation background, altitude variations, Compton scattering, and airborne bismuth-214. The data were subsequently converted from counts per second to concentration values. The compiled radiometric data provide a uniform suite of maps showing potassium, thorium, and uranium concentrations within the upper few centimeters of surface material at a grid spacing of 2,000 m. These data can be combined in single display by producing a ternary image where potassium, thorium, and uranium concentrations are displayed as red, green, and blue, respectively (fig. D4). The concentration maps form the basis for additional data transforms (table D1) described below.

Political boundaries from Esri (2013).
Shaded relief from Esri (2008).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 114° W., latitude of origin, 37.5° N.

EXPLANATION

USGS study area boundaries

-250   -200   -175   -150   -130   -75

Complete Bouguer anomaly (mGal)
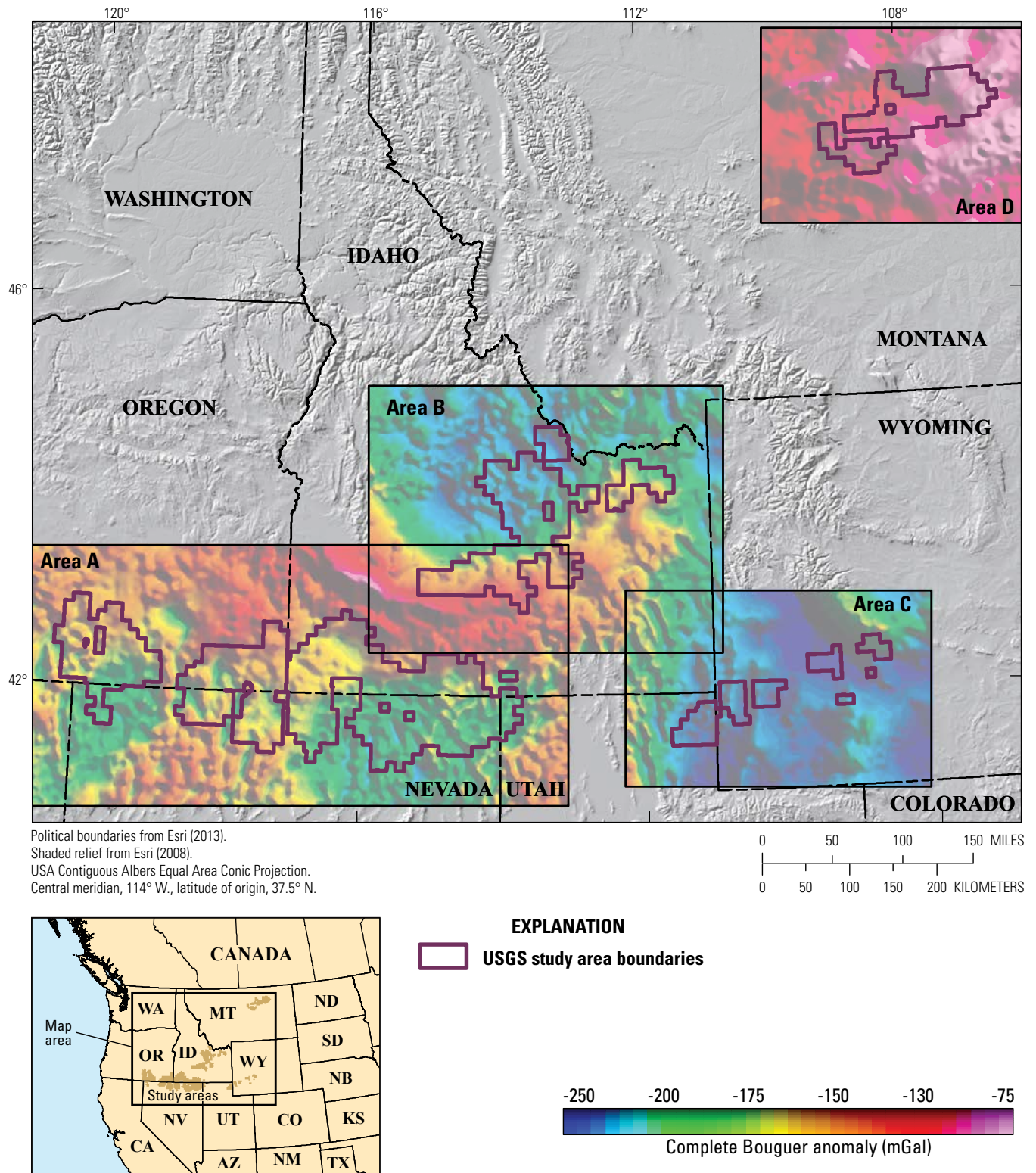
Figure D3.   Complete Bouguer gravity anomaly map for four rectangular regions surrounding Sagebrush Focal Areas (SFAs; see section A, fig. A1) in the Western United States, which was created as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project. USGS, U.S. Geological Survey. mGal, milligal.

Political boundaries from Esri (2013).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 114° W., latitude of origin, 37.5° N.
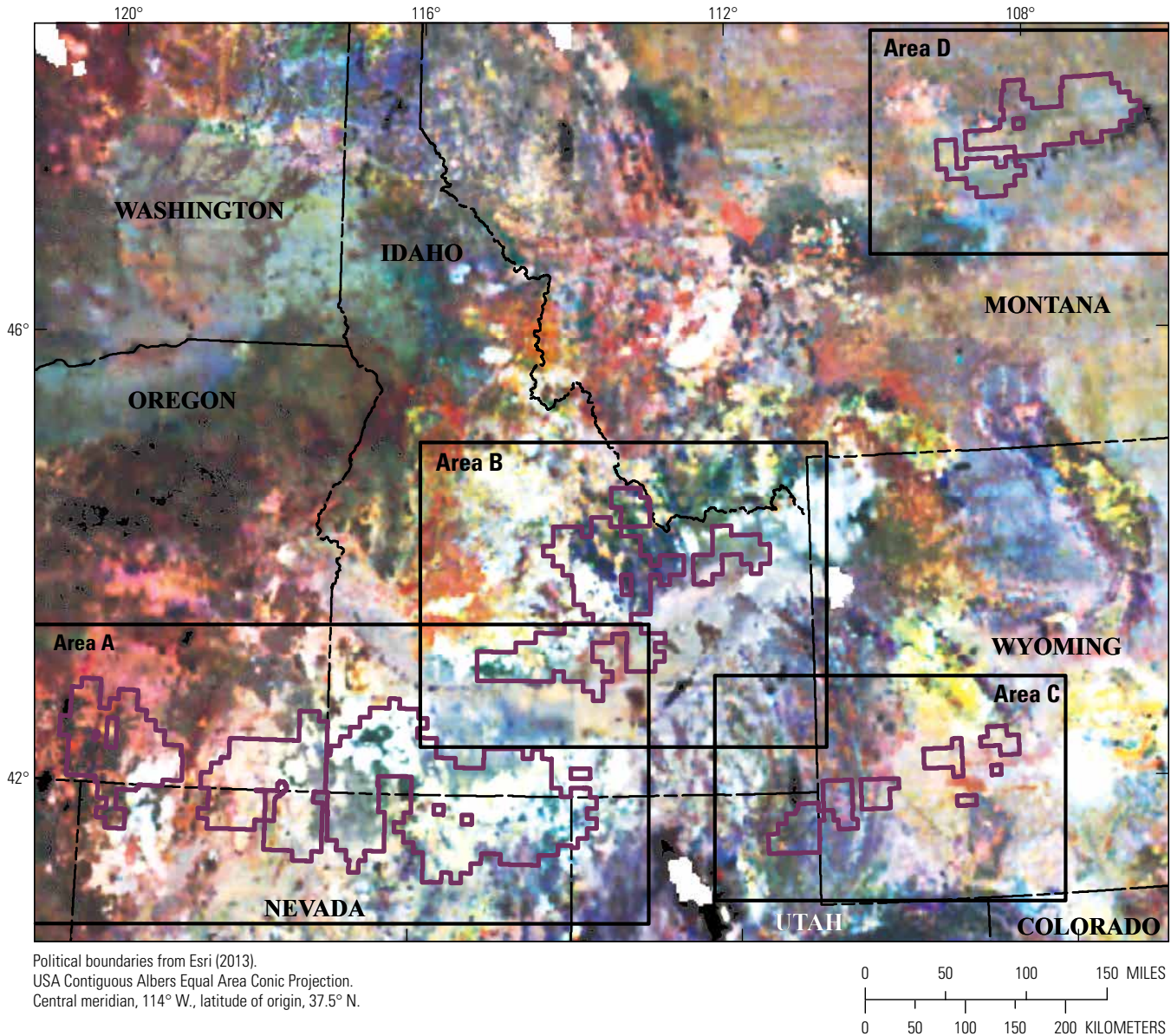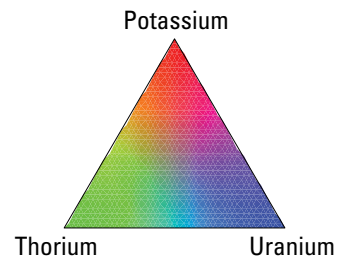
Figure D4. Ternary radiometric map of the Western United States (Duval and others, 2005). These data were subset to four rectangular regions (black boxes) surrounding the Sagebrush Focal Areas (SFAs; see section A, fig. A1) and provided the basis for subsequent data transforms (table D1) used as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project. USGS, U.S. Geological Survey.

Derivative Geophysical Products

Reduction-to-the-Pole (RTP) of Magnetic Data

The reduction-to-pole (RTP) transform better aligns magnetic anomalies with causative sources (Baranov and Naudy, 1964; Blakely, 1995). The transform removes the effect of the direction of the Earth's magnetic field and the direction of magnetization by transforming the data to their expression at a vertical field and magnetization as if measured at the north magnetic pole. This transformation approximately centers magnetic anomalies over their sources and will produce a symmetrical anomaly over a symmetrical source. Remanent magnetization is assumed to be either negligible or in the same direction as the Earth's magnetic field. The total magnetic-intensity anomaly data were transformed to RTP data using parameters described in table D4.

Total Horizontal Gradient of Magnetic and Gravity Data

The total horizontal gradient of potential-field data maps the edges of anomaly sources (Cordell and Grauch, 1985; Grauch and Cordell, 1987). The transform, which assumes a vertical contact and vertical magnetization for the case of magnetic sources, produces maxima coincident with the contact. If a body is dipping or the source is narrow, the total horizontal gradient response will be displaced; however, displacement is only normally significant in high-resolution data (Grauch and Cordell, 1987). To help map geologic contacts and structures, the total horizontal gradient method was applied to the RTP, isostatic anomaly, and tilt derivatives (see below) of the RTP and isostatic anomaly data (table D1).

First Vertical Derivative of Magnetic and Gravity Data

The first vertical derivative (for example, Evjen, 1936; Blakely, 1995) amplifies short-wavelength anomalies and typically highlights steep gradients along edges of shallow sources. Thus, local features are sharpened at the expense of broad or regional features that can often mask shallow anomalies. Although horizontal gradients mentioned above enhance edges of causative features, vertical derivatives narrow the width of the anomaly and help to better constrain the location of the causative feature. Because first vertical derivative maps reflect shallow sources, they are also useful for correlating geophysical anomalies with exposed surface geology. In addition, the first vertical derivative of gravity anomalies is equivalent to a pseudomagnetic transformation and thus can be used to compare gravity anomalies with observed magnetic anomalies (for example, Simpson and others, 1986).

Tilt Derivative of Magnetic and Gravity Data

The tilt derivative and its total horizontal gradient are useful tools for enhancing causative sources and can be less sensitive to noise than other higher order derivatives (Miller and Singh, 1994; Verduzco and others, 2004). The tilt derivative is defined as the arctangent of the ratio of the first vertical derivative of the potential field to the horizontal gradient of the field. The ratio of the derivatives helps to overcome the large dynamic range in the size of the gradients, whereas the arctangent places the ratio in the range of $-90°$ and $90°$. The result is a map sensitive to both shallow and deep sources, where positive values occur over the source, zero values occur along the edge of vertical contacts, and negative values occur outside the source region. The total horizontal gradient method can be applied to the tilt derivative to indicate the anomaly edge in shallow basement targets (Verduzco and others, 2004). The tilt-depth method provides a rapid way to estimate source depths (Salem and others, 2007; Fairhead and

Table D4.   Reduction-to-the-pole (RTP) parameters used to transform magnetic-intensity anomaly data as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[Focal areas: A, Sheldon-Hart Mountain National Wildlife Refuge Complex, Southeastern Oregon and North-Central Nevada, and Southern Idaho and Northern Nevada; B, North-Central Idaho; C, Bear River Watershed and Southwestern and South-Central Wyoming; and D, North-Central Montana; nT, nanotesla]

Focal area	Longitude	Latitude	Field strength, in nT	Inclination	Declination
A	-117.011	42.1205	53,190	66.3	15.3
B	-113.39	43.7846	54,683	68.4	14.6
C	-110.17	42.0032	54,264	67.6	12.9
D	-107.952	47.73	57,207	72.6	13.0

others, 2011). This method estimates the depth to a vertical contact by calculating half the distance between the -45° and 45° tilt angle.

Analytic Signal of Magnetic and Gravity Data

The analytic signal can be computed from the horizontal and vertical gradients of potential-field data in both two and three dimensions (Nabighian, 1972; Roest and others, 1992). The result depends on the geometry of the source body, not its magnetization, such that all bodies with the same geometry have the same analytic signal. The analytic signal can be used to determine location and estimate the depth of causative bodies (Nabighian, 1972; Roest and others, 1992). Because the analytic signal is independent of the direction of magnetization, it can also be used to estimate the magnetization of source bodies (for example, Blakely, 1995). The analytic signal peaks are symmetrical and occur directly over the edges of wide bodies and directly over the centers of narrow bodies. Thus, the analytic signal maps can be used to map source contacts and geometries.

Radioelement Element and Ratio Maps of Radiometric Data

Radiometric data map major variations in the radioelement concentrations in soil and exposed rock. Minor variations in radioelement concentration within rock units can be due to lithological changes, weathering, or mineralizing events (Dickson and Scott, 1997). These minor variations can be enhanced using ratios of the radiometric data. Ratio maps have the added advantage of being able to discriminate areas where relative concentrations of elements have increased or decreased possibly as a result of hydrothermal alteration within an ore system. For example, potassium enrichment associated with formation of potassium-rich bearing minerals formed during hydrothermal event(s) can be imaged using the potassium/thorium ratio. Potassium and thorium generally covary with changing silica content in unaltered rocks. Because thorium is relatively immobile during hydrothermal alteration, the potassium/thorium ratio map may better show potassically altered rocks than potassium concentrations alone (Dickson and Scott, 1997; Shives and others, 2000).

Depth Estimates

Magnetic Methods

Euler deconvolution is a semiautomated way to estimate source position and depths (Reid and others, 1990; Phillips, 2002). The calculated depths are dependent on the source geometry. For this reason, a structural index (SI) term is used as a measure of the rate of change of a field with distance. The SI changes with source geometry such that geologic contacts, vertical dikes, vertical pipes, and spheres (or point sources) have a SI of 0, 1, 2, and 3,

respectively. A SI that is too low gives depths that are too shallow, whereas one that is too high gives estimates that are too deep. A data window size is chosen such that it incorporates substantial variation of the magnetic field, but is small enough to minimize significant contributions from multiple sources.

The Euler deconvolution method was used in the North-Central Montana SFA to better understand the source depth of the northeast-trending RTP magnetic anomalies (fig. D5). The anomalies have been previously interpreted as reflecting Paleoproterozoic oceanic-arc rocks that accreted to the Archean Wyoming craton margin (Sims and others, 2004). Near the North-Central Montana SFA, Precambrian rocks are exposed as roof pendants in the Tertiary plutonic rocks within the Little Rocky Mountains. Recently digitized high-resolution aeromagnetic data (Anderson and others, 2016) indicate that the Tertiary plutonic rocks also appear to contribute to the northeast-trending anomalies.

The depth estimates presented here are for source geometries that represent the contact of plutonic bodies. Structural indices of 0.0, 0.5, and 1.0 were chosen and estimates were generated for window sizes that ranged from 2,500 to 8,500 m. The solutions were subset to a 1,000-m buffer along the maximum total horizontal gradient associated with the northeast-trending magnetic anomalies. The results were compared to a structure contour map to top of Precambrian crystalline rock based on geology and drill-hole information that indicates the top of Precambrian rocks deepens from about 1,500 m east of the Little Rocky Mountains to more than 2,500 m just east of the eastern extent of the North-Central Montana SFA (Bergantino and Clark, 1985).

The preferred results were calculated from the RTP data using an SI of 0.5 and a window size of 8,500 m (fig. D5). The results show good clustering of solutions along the total horizontal gradients of the RTP data. The northeast-trending anomalies appear to have sources typically greater than 2,000 m depth. This agrees generally with the reported depths to the top of Precambrian basement, which range from 1,500 to 2,500 m depth (Bergantino and Clark, 1985). Shallow sources occur over the Little Rocky Mountains that likely reflect the outcropping Tertiary plutonic rocks. Two areas within the north-central Montana Sagebrush Focal Area indicate relatively shallow magnetic sources—(1) approximately 50 km southeast of the Little Rocky Mountains are clusters of shallow solutions ranging from 500 to 2,000 m, and (2) approximately 35 km east-southeast of Malta, Montana, is another cluster of depth solutions that range mostly from 500 to 2,000 m. Both areas may represent Mesozoic to Cenozoic igneous rocks.

Gravity Methods

Previously, an iterative gravity inversion method was used to determine the thickness of Cenozoic basin deposits in Nevada and Utah (Jachens and Moring, 1990; Saltus and Jachens, 1995). The depth-to-basement method separates the gravity field into two components—(1) the field caused by pre-Cenozoic basement rocks and (2) the field caused by overlying younger basin deposits. An initial basement gravity field is determined by using just those gravity measurements located

Political boundaries from Esri (2013).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 108° W., latitude of origin, 36.5° N.

EXPLANATION
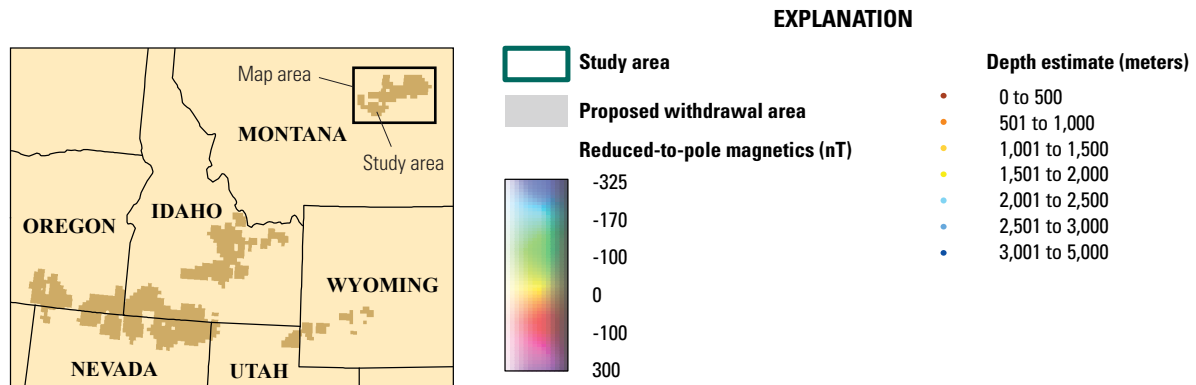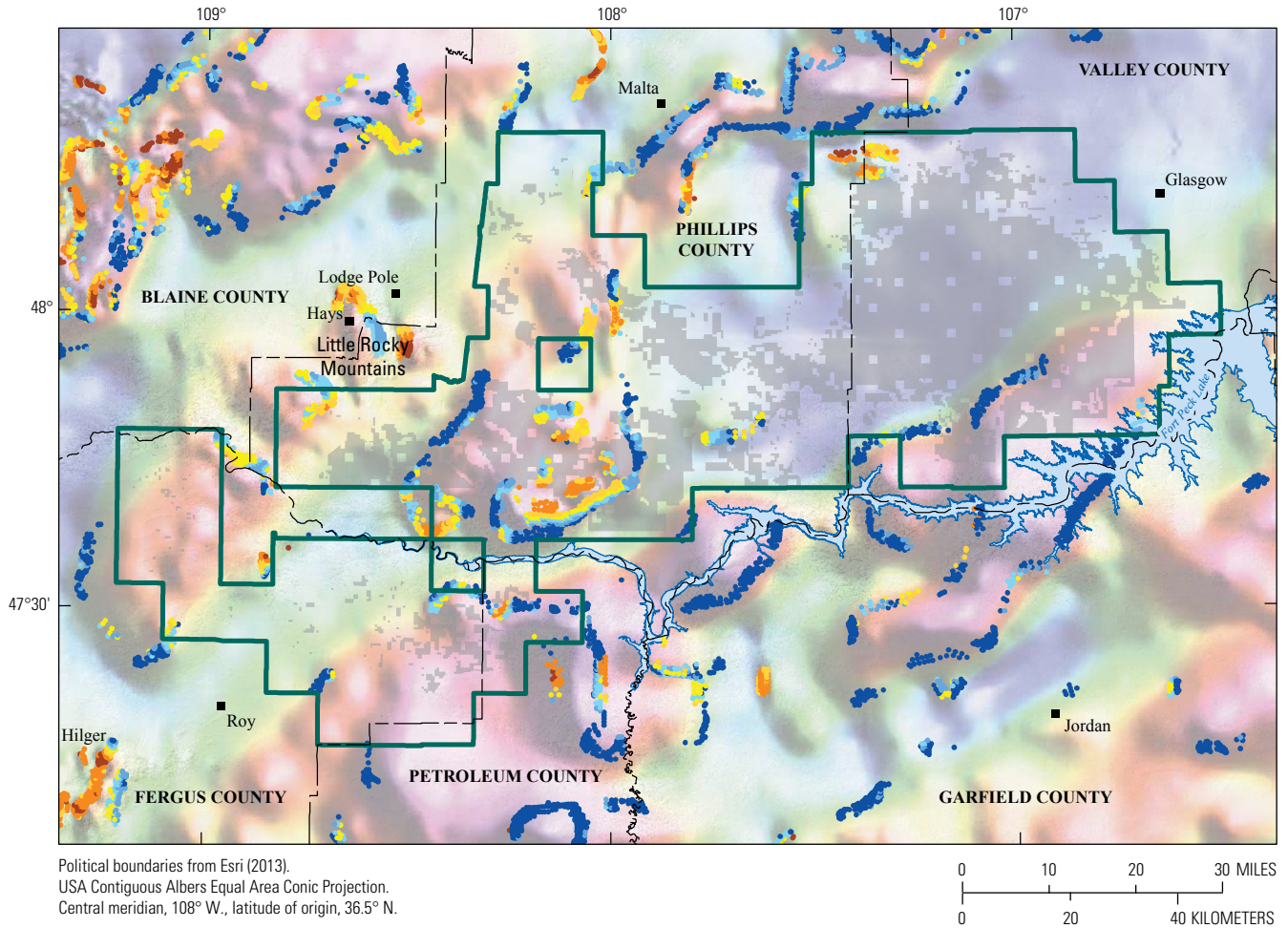
Figure D5. Map of Euler depth estimates overlain on a reduced-to-pole (RTP) magnetic-anomaly map of the North-Central Montana Sagebrush Focal Area (SFA; see section A, fig. A1). Map was generated as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project. nT, nanotesla.

on pre-Cenozoic basement outcrops. The initial basement gravity field is only approximate, because measurements located on basement are influenced by the gravity effect of low-density deposits in nearby basins, especially for those measurements near the edge of the basins. The difference between the isostatic gravity and basement gravity fields provides the first estimate of the basin gravity field, which is inverted to provide the first estimate of the basin depth and shape. The gravitational effects of the basins are subtracted from each measurement located on basement, and a new and improved basement gravity field is determined. This process is repeated until successive iterations converge. Inversion of the final basin gravity field constrained with a density-depth function (table D5) and geology yields an estimate of the depth to pre-Cenozoic basement. The density of basement rocks is allowed to vary horizontally, whereas the density of basin-filling deposits increases with depth according to the density-depth relations shown in table D5. The density-depth function is based on density information from rock samples, geophysical well logs, and borehole gravity data. A density-depth profile representative for the state of Nevada (Jachens and Moring, 1990) was used for sedimentary and volcanic deposits.

A number of limitations are inherent in the gravity data themselves, as well as in the inversion process. Uncertainties are related to the distribution of gravity data, especially for measurements on basement outcrops, the assumed density-depth function, accuracy or scale of the geologic mapping, simplifying assumptions regarding concealed geology, and the distribution of basement outcrops. The depth-to-basement process itself is regional in scope, and caution should be exercised when using these results at a scale greater than about 1:250,000. A more detailed discussion of the limitations and accuracy of the method are provided by Jachens and Moring (1990).

In the North-Central Idaho SFA, three-dimensional (3-D) gravity inversions were used to map areas in the Pahsimeroi and Lemhi Valleys where the thickness of Cenozoic basins exceeds 1,000 m, a depth that is nonpermissive for economic extraction of hard rock mineral resources. The gravity inversion

method assumed a two-layer model with 0.3-g/cm^3 density contrast (Liberty and others, 2006) that consisted of low-density basins underlain and surrounded by higher density material representing pre-Cenozoic bedrock. Three datasets were used to constrain the inversion—isostatic anomaly, topography, and mapped geology. The isostatic anomaly map (described above) characterized the observed anomalous gravity field. The topography was defined by a digital elevation model (DEM) generated as part of the USGS 3D Elevation Program (Lukas and others, 2015). Mapped surface lithologies were used to define lateral extent of basin and bedrock materials (Lewis and others, 2012). The basin thickness was initially set at 1,000 m below topography. The inversion process iteratively adjusted the basin thickness until the predicted gravity field adequately matched that of the observed gravity field. The inversions over the Pahsimeroi and Lemhi Valleys were run separately. The Pahsimeroi Valley inversion was first run and parameters were adjusted until areas within the basin agreed well with seismic-reflection data (Liberty and others, 2006). The inversions over the Lemhi Valley were then run using similar parameters and areas of overlap were inspected for consistency. The results were then contoured and the 1,000 m-depth contour helped define tract boundaries by indicating depths too deep for mineral resource extraction (fig. D6).

Pluton Mapping

Isostatic gravity, aeromagnetic, and the horizontal gradient of gravity and magnetic anomalies were used to infer the lateral extent of known and unknown granitoid plutons in Nevada (Grauch and others, 1988; Grauch, 1996). Although aeromagnetic data (Hildenbrand and Kucks, 1988) and their correlation to mapped granitic rocks (Stewart and Carlson, 1978) was primarily used, isostatic- and basement-gravity maps of Nevada (Jachens and Moring, 1990; Saltus and Jachens, 1995) were also used to supplement the aeromagnetic interpretations. Because mineral-resource deposits are often spatially or temporally associated with granitic plutons, their inferred horizontal extent plays a major role in mineral-resource assessments.

In the North-Central Idaho SFA, plutons were also mapped using transformed RTP data. The upward continuation transformation calculates the magnetic field at an elevation higher than that at which it was originally measured. This transform attenuates near-surface effects and accentuates the anomalies from deeper magnetic sources (Blakely, 1995). A common technique to enhance near-surface sources, such as shallow plutons, is to upward continue magnetic data a short distance to generate a regional field and then subtract this regional field from the original dataset. The resulting map is a high-frequency-passed magnetic field associated with shallow sources. Using a 1,000-m upward-continuation distance and the RTP field, the resultant anomalies helped map near-surface plutons in North-central Idaho SFA (fig. D7).

Table D5. Density-depth functions used to constrain final basin gravity fields as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[g/cm^3, gram per cubic centimeter]

Depth range, in kilometers	Sedimentary density contrast, in g/cm^3	Volcanic density contrast, in g/cm^3
0–0.2	-0.65	-0.45
0.2–0.6	-0.55	-0.40
0.6–1.2	-0.35	-0.35
>1.2	-0.25	-0.25

Political boundaries from Esri (2013).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 114° W., latitude of origin, 37.5° N.

EXPLANATION

▭ **USGS study area boundaries**

• **Gravity station**

Basin thickness (meters)

— 500
— 1,000
— 1,500
— 2,000
— 2,500

Isostatic anomaly, in milligals
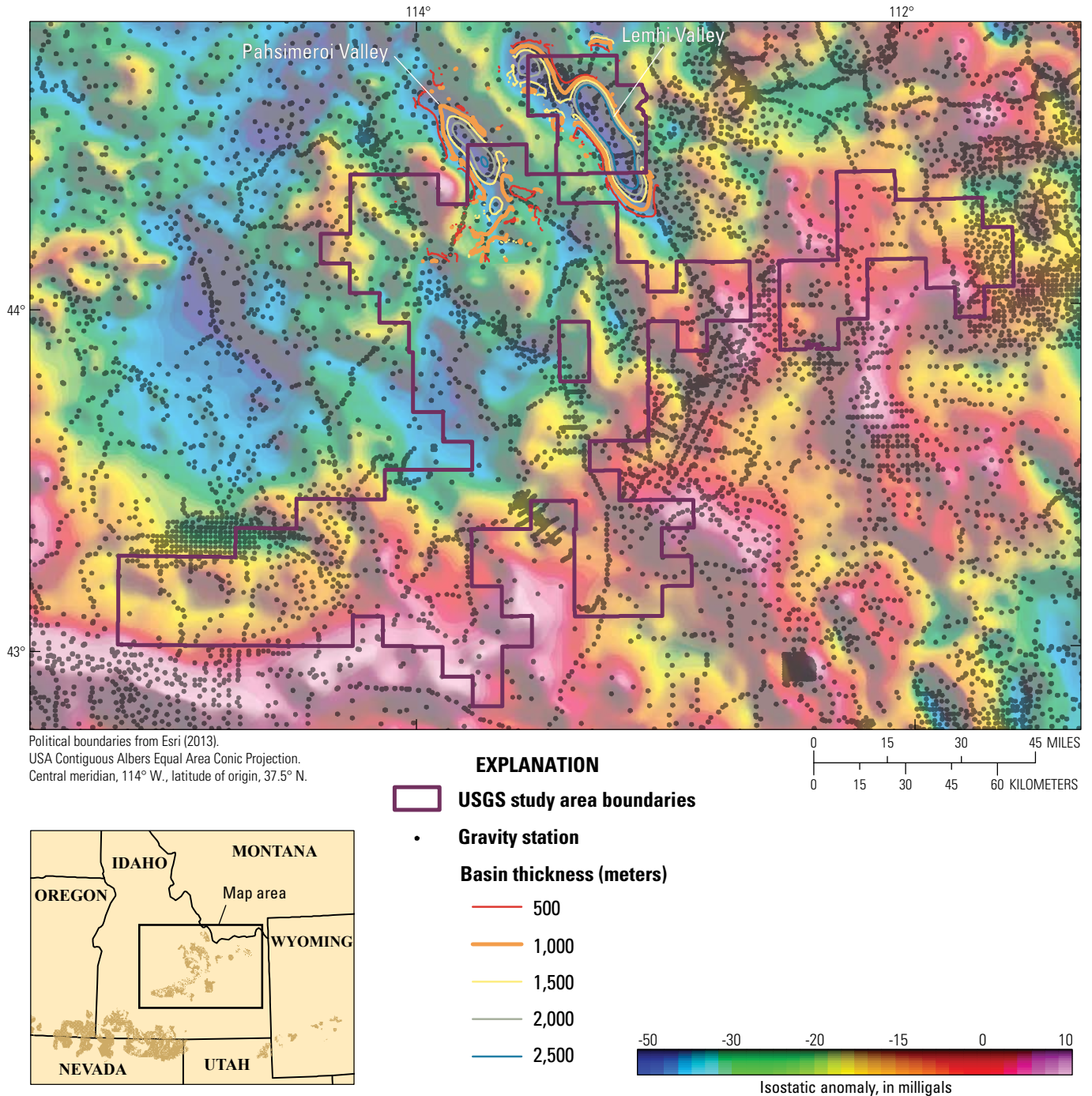
Figure D6. Isostatic-anomaly map and basin-thickness estimates derived from gravity inversions over the North-Central Idaho Sagebrush Focal Area (SFA; see section A, fig. A1). Map was generated as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project. USGS, U.S. Geological Survey.

Political boundaries from Esri (2013).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 114° W., latitude of origin, 37.5° N.

EXPLANATION

☐ **USGS study area boundary**

Residual magnetic anomaly (nT)
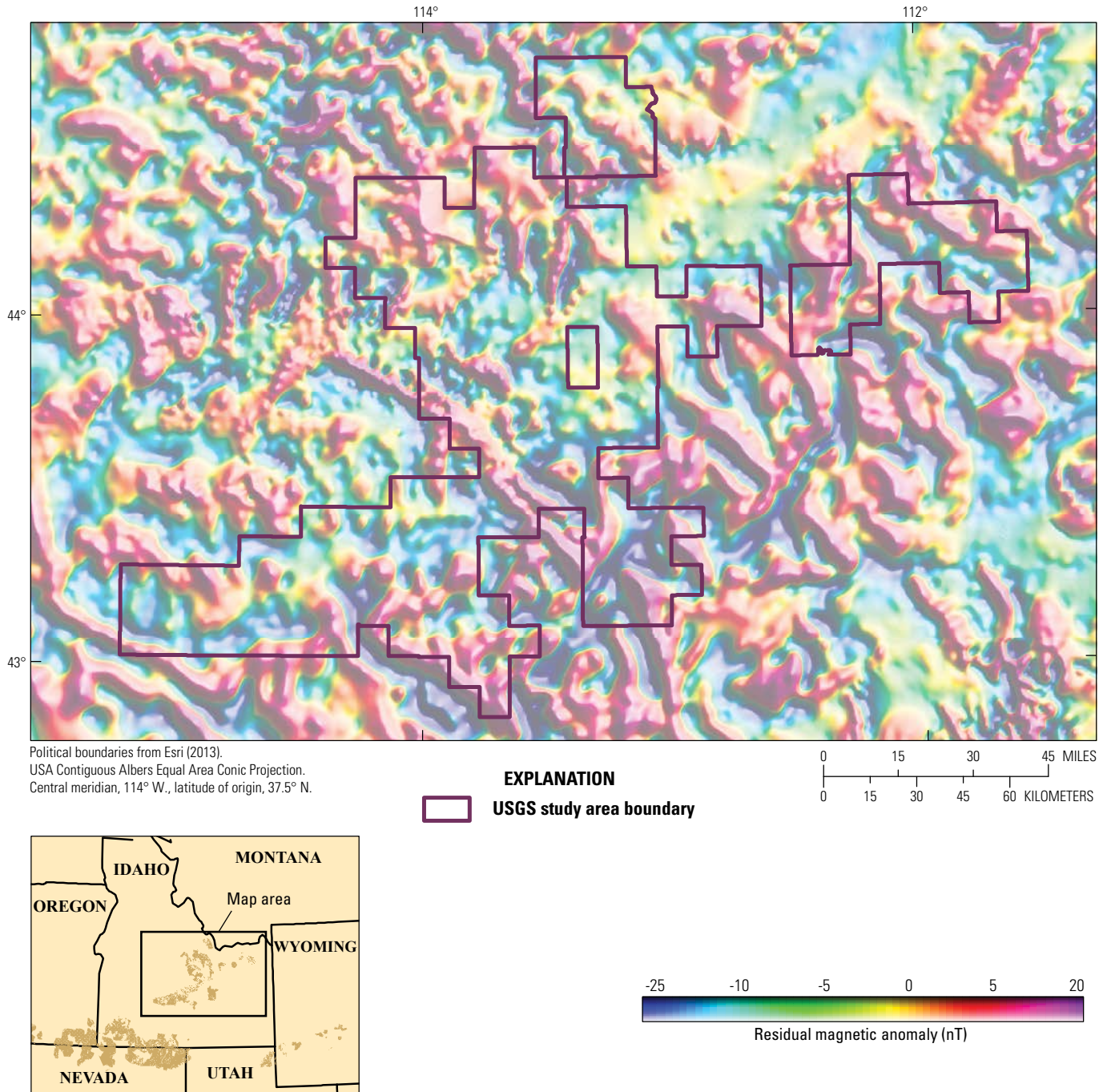
Figure D7.   Map of residual magnetic anomalies used to help map plutons in North-Central Idaho Sagebrush Focal Area (SFA). Map was generated as part of the Sagebrush Mineral-Resource Assessment (SaMiRA) project. USGS, U.S. Geological Survey.

Diatreme Mapping

In 1981, Anaconda Minerals Company collected high-resolution aeromagnetic data over the Missouri Breaks diatremes in Montana. The survey was flown along north-south flight lines spaced 200 m at a nominal terrain clearance of 130 m. The analog contour maps of these data were digitized (Anderson and others, 2016) and digitally enhanced. The RTP anomaly map shows discrete magnetic highs over mapped diatremes. The analytic signal also images these rocks and suggests the location of additional diatremes in the shallow subsurface.

Large-Scale Fractures in Nevada and Idaho

On the basis of gravity and aeromagnetic data, Ponce and Glen (2002) interpreted large-scale fractures across northern Nevada and extending into Idaho that are probably related to the inception of the Yellowstone Hotspot. These features are particularly evident in aeromagnetic data as linear positive anomalies, but some are also prominently expressed in gravity data. These geophysical lineaments represent major crustal discontinuities within the Earth that are interpreted to have formed as a result of mid-Miocene rift-related magmatism.

These large-scale features may have served as conduits for ore-forming hydrothermal solutions and are both spatially and temporally associated with mid-Miocene epithermal gold-silver deposits (Ponce and Glen, 2002). The statistical proximity of these arcuate features to mid-Miocene and younger epithermal gold-silver deposits suggests that they may serve as a guide to future epithermal mineral-resource potential in Nevada, Oregon, and Idaho.

General Discussion

Gravity and magnetic anomalies can be used to infer the subsurface structure of known or unknown geologic features, where a physical-property contrast occurs across the geologic boundaries. Typically, gravity anomalies reflect lateral (horizontal) density variations in the middle to upper crust. Thus, isostatic-gravity anomalies can be used to infer the subsurface structure of known or unknown geologic features. In general, gravity anomalies reflect carbonate rocks, calderas, deep sedimentary basins, plutons, and linear geologic features such as faults. Many of these features play an important role in assessing the mineral-resource potential across the SFAs.

Magnetic anomalies typically reflect lateral changes in rock magnetic properties and can be analyzed to gain insights into the three-dimensional nature of the causative source. In general, short-wavelength, high-amplitude magnetic anomalies are caused by moderately to strongly magnetic volcanic rocks, whereas broad circular long-wavelength magnetic anomalies reflect magnetic granitoid intrusions or other mafic basement rocks. Many of these features play an important role in ore formation, and their distribution is important to the understanding of the mineral-resource potential of the area.

The diverse physical properties of rock units that underlie this region are well suited to geophysical investigations. The contrast in magnetic properties between pre-Cenozoic rocks, volcanic rocks, and alluvium produces a distinctive pattern of anomalies that can be used to determine the sources of the anomalies and their subsurface extent.

Radiometric data map the surficial variation in potassium, thorium, and uranium concentrations. These data map lateral changes in geologic material and complement geologic maps. Ore deposits can have preferential host or source rocks, which may be imaged by the data. In addition, the hydrothermal systems associated with ore deposits can alter the concentrations of potassium, thorium, and uranium, thereby making them an effective dataset for mineral-resource assessment. However, because of the relatively low spatial resolution of the data over the SFAs, these data are most useful for lithologic mapping. The contrast in radioactivity between Paleozoic sedimentary rocks, volcanic rocks, and plutonic rocks made these data effective for understanding their surficial distribution throughout the SFAs.

Most Paleozoic rocks are relatively nonmagnetic within the study area, whereas intrusive rocks are, in general, moderately magnetic and are associated with magnetic highs. Tertiary volcanic rocks are strongly magnetic with variable magnetic properties, and they play significant roles in assessing the mineral-resource potential and extensional history of the area. Thick accumulations of these volcanic rocks are present throughout the study area. Alluvial deposits within the study area are essentially nonmagnetic and most basins have subdued magnetic anomalies with the exception of those basins that may contain volcanic centers, buried volcanic rocks, or buried granitic rocks.

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Section E. Remote Sensing

By Barnaby W. Rockwell

The occurrence and mineralogy of exposed, hydrothermally altered rocks related to locatable mineral-resource potential in the U.S. Geological Survey (USGS) Sagebrush Mineral-Resource Assessment (SaMiRA) project study areas were assessed using digital geospatial data derived from spectral analysis of satellite remote sensing data. Maps of alteration types and key mineral groups derived from automated analysis of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data were the most important source of surface mineralogical information (Rockwell, 2012). Maps of mineral groups derived from automated analysis of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data were used to verify occurrences of anomalous mineral concentrations observed using the ASTER-derived maps, especially in areas with abundant dry vegetation that can complicate remote sensing-based mineral mapping, such as the northern Great Basin (Rockwell, 2013). In northern Nevada, maps of quartz and carbonate abundance derived from analysis of ASTER thermal infrared data were used to identify jasperoids associated with Carlin-type gold deposits and hydrothermal quartz in areas of potential epithermal gold-silver mineralization (Rockwell and Hofstra, 2008). The mineral maps used for the mineral-resource assessment are available through an online viewer and associated data services (Rockwell and others, 2015).

The maps of surficial mineralogy were not used as the sole criteria for defining permissive tracts in the mineral-resource assessment but locally were used to refine the boundaries of tracts for epithermal gold-silver and intrusion-related deposits for which hydrothermal alteration is an important characteristic of the deposit type. The areas defined by mapped occurrences of the "sericite and (or) smectite" mineral group from the ASTER-derived data exhibited high correlation with known bentonite claims, mines, and exposures of thin, light-colored, bentonite-bearing beds interpreted using aerial imagery within widespread shales of the Bearpaw Formation in the North-Central Montana Sagebrush Focal Area. As a result, the ASTER-derived data were used as an important criterion for the delineation of permissive tracts for bentonite in that study area. Strong hematitic alteration associated with sediment-hosted "roll front" uranium deposits, such as that mapped using both the ASTER and ETM+ data in sandstones on Red Rim, 21 kilometers southwest of Rawlins, Wyoming, is another example of an alteration-related mineralogical signature used as an assessment criterion for a specific deposit type. Integration of various data types, including data of known mineral deposits, claims, permissive lithologic map units, airborne geophysics, regional geochemistry, and remote sensing typically yields higher confidence levels when defining permissive tracts, and the mineral maps derived from remote sensing play a key role in that process for certain deposit types.

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Section F. BLM Legacy Rehost System (LR2000)

By Connie L. Dicken and Carma San Juan

The Bureau of Land Management's (BLM) Legacy Rehost System, or LR2000, contains legal descriptions of BLM lands. LR2000 provides reports on BLM land- and mineral-use authorizations for oil, gas, and geothermal leasing, rights-of-ways, coal and other mineral development, land and mineral title, mining claims, withdrawals, classifications, and more on Federal lands or on Federal mineral estates (Bureau of Land Management, 2016).

The LR2000 database was queried for relevant data for the seven focal areas in the Western United States included in the Sagebrush Mineral-Resource Assessment (SaMiRA) project. The BLM compiled tabular queries and reports to generate data spreadsheets that were processed and delivered to U.S. Geological Survey (USGS) as spatial information; BLM reported an expected accuracy of 90 percent for the data provided (John Varner, BLM, written commun., 2016).

Spatial data were compiled by BLM and delivered to USGS on March 6, 2016, using the data extracted from LR2000 for the study area. The data included polygon feature classes and nonspatial tables in an Esri file geodatabase format to be used in a geographic information system (GIS). The database contained seven feature classes—coal, geothermal, mineral materials, mining claims, non-energy solid minerals, oil and gas, and notices and plans. Each feature class was comprised of a polygon file of Public Land Survey System (PLSS) sections and a nonspatial related table. The PLSS is used to describe and subdivide land in the United States. The PLSS is typically divided into 6-mile-square townships and those townships are then subdivided into 36 one-mile-square sections (U.S. Geological Survey, 2016).

To work with the data in a more simplified way, the related tables were merged with the spatial sections and processed so that the data could be easily queried. The processing required the creation of frequency tables for each feature class and removing duplicate entries. After the frequency tables were complete, those tables were joined with corresponding feature class based on a unique attribute. This process allowed the nonspatial tables to be connected with polygon sections in a one-to-one relation. The next step was to combine sections that contained the same unique case number, which was done by dissolving polygon section boundaries. This allowed users to visualize the data in a GIS, as well as define queries to show spatial distribution of the data. Status and number of mining claims, mineral leases, mineral-material sales sites, and surface-management (43 CFR 3809) authorizations were provided as summary tables for each

focal area based on the processed LR2000 data. The processed LR2000 data for the SaMiRA project are available in a data release (Dicken and San Juan, 2016).

Each of the seven feature classes was used for the mineral-resource assessment. The following descriptions were provided by BLM for each dataset.

Coal

Nonrenewable energy.—The Mineral Leasing Act of 1920, as amended, and the Mineral Leasing Act for Acquired Lands of 1947, as amended, gives the BLM responsibility for coal leasing on approximately 570 million acres where the coal mineral estate is owned by the Federal Government. The surface estate of these lands could be controlled by BLM, the U.S. Forest Service, private landowners, State landowners, or other Federal agencies. Not all public lands are available for coal exploration or leasing. The purpose of the coal-screening part of the land-use planning process (43 CFR 3420.1-4) is to identify those Federal lands that are acceptable for further consideration for coal leasing and development.

Geothermal

Renewable energy.—Geothermal energy is the use of steam and hot water generated by heat from the Earth to perform work. Geothermal resources include (1) all products of geothermal processes, including indigenous steam, hot water, and hot brines; (2) steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations, heat or other associated energy found in geothermal formations, and any byproducts.

Mineral Materials Disposal

43 CFR 3600.—This law applies to disposal of sand, gravel, and other mineral and vegetative materials that are not subject to mineral leasing or location under the mining laws. Mineral materials means, but is not limited to, petrified wood and common varieties of sand, stone, gravel, pumice, pumicite, cinders, and clay. Mineral materials are some of our

most basic natural resources, such as sand, gravel, dirt, and rock, used in every day building and other construction uses. These materials generally are bulky and have a low unit price.

Mining Claims

A mining claim on Federal land gives exclusive rights to develop the minerals under the claim beginning on the date the mining claim was located. Within a mining claim, the surface lands remain open to the public for other multiple uses. A mining claim is located in order to acquire the right to develop the mineral values in a specified area. Locating a mining claim requires a discovery of a valuable mineral.

Non-Energy Solid Minerals

The BLM leases certain solid minerals, such as phosphate, sodium, potassium, sulfur, gilsonite, or a hardrock mineral, on public and other Federal lands. The BLM can also lease these minerals on certain private lands, provided the mineral rights are owned by the Federal Government. Prospecting permits are issued under 43 CFR 3505 in areas where it is not known a mineral deposit exists. A prospecting permit provides the exclusive right to prospect and explore for leasable mineral deposits.

Oil and Gas Leasing

Leasable minerals include energy resources of coal, phosphate, oil, oil shale, and gas on the public domain as designated by the Mineral Leasing Act of 1920, as amended. An oil and gas lease grants the lessee the right to explore and drill for, extract, remove, and dispose of oil and gas deposits, except helium, that may be found in the leased lands.

Notices and Plans (Surface Management)

Surface-management notices and plans refers to all surface disturbing activity conducted under the General Mining Act of 1872 (30 U.S.C. 22–42), as amended, and the Federal Land Policy and Federal Land Policy and Management Act of 1976 (FLPMA; Pub. L. 94–579; 90 Stat. 2743), as well other laws. Notices and plans facilitate the administration of exploration, mining, and milling activities on the public lands, or interests in such lands, in order to prevent unnecessary or undue degradation of the lands.

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Section G. Previous Mineral-Resource Assessment Data Compilation

By Heather L. Parks, Michael L. Zientek, M. Christopher Jenkins, Cassandra K. Hennings, John C. Wallis, and Duc M. Nguyen

For the Sagebrush Mineral-Resource Assessment (SaMiRA) project, mineral-potential maps from previous mineral-resource assessments that covered the project area were compiled into raster or vector geographic information system (GIS) databases. Georeferenced tract-map images from Bureau of Land Management (BLM) and U.S. Forest Service (USFS) wilderness study summary reports were used, along with multiple other mineral-potential reports that were done under the U.S. Geological Survey (USGS) Conterminous United States Mineral Assessment Program (CUSMAP) program and for USGS assessments of U.S. National Forests. In the previous studies, assessment results were described using different schemes. The BLM used "qualitative categorical," and others used the USGS "three-part form" (Singer and Menzie, 2010). For this compilation, we captured the information as presented but also standardized nomenclature when we could in Parks and others (2016).

We reviewed BLM and USFS wilderness study summary reports along with BLM Surface Management Agency GIS data to help locate the reports that covered the SaMiRA project areas. The USFS wilderness studies were summarized in USGS Professional Paper 1300 (Marsh and others, 1984). The BLM wilderness studies were summarized in unpublished reports for Montana and Wyoming and published reports for Idaho, Oregon, and Nevada (Diggles, 1991; U.S. Geological Survey Central Mineral Resources and U.S. Bureau of Mines Western Field Operations Center, 1989; Conrad, 1990). We did not locate a summary report for Utah but consulted the BLM Surface Management Agency's Special Public Purpose Withdrawal Areas GIS data to double check that there were no assessments covering the SaMiRA Utah areas (DOI–BLM, National Operations Center—Division of Information Resource Management, 2016). Fifty-nine mineral potential reports covering the SaMiRA project areas were located, and 134 mineral potential maps shown in these reports were either extracted from report .pdf files or scanned and then georeferenced using ArcGIS. The georeferenced images were imported into four ArcGIS raster mosaic datasets, one for each of the four report areas—*MT.gdb*, *NC_IDAHO.gdb*, *NV_ID_OR.gdb*, and *WY.gdb*. The *MT.gdb* raster mosaic dataset contained 7 georeferenced images, *NV_ID_OR.gdb* contained 66 georeferenced images, *NC_IDAHO.gdb* contained 60 georeferenced images, and the *WY.gdb* contained 1 georeferenced image.

When viewed in ArcMap, the raster mosaic dataset appears as a group of three layers under the mosaic dataset. The first item in the group is the "Boundary," which contains a single polygon representing the extent of all images in the dataset. The second item is the "Footprint," which contains a polygon representing the extent of each individual image in the dataset. The "Footprint" layer also contains the attribute-table data associated with each of the images. The third item is the "Image" layer and contains the images in the dataset. The images are overlapping and must be selected and locked or queried in order to be viewed one at a time. To select and lock an image, right-click on the "Footprint" layer in the table of contents window and hover over "Selection," then click "Lock To Selected Rasters." Another way to view a single image is to run a definition query on the image. This is done by right clicking on the raster mosaic in the table of contents and opening the layer properties box. Then click on the "Definition Query" tab and create a query for the desired image.

The images were clipped to the extent of the map and all explanatory text gathered from map explanations or report text was imported into the raster mosaic dataset database as attributes. The data compiled into the attribute tables contained the figure caption from the original map. In addition, the images were catalogued according to the legal definition of mineral resources—metallic, non-metallic, leasable non-fuel, leasable fuel, geothermal, paleontological, and salable. This allows users to view the image along with information about the images without the need for referring back to the source report.

Some previous mineral-resource assessments were available in vector GIS format. We searched for reports covering the SaMiRA project area and compiled the GIS vector data. The original data was both in ArcInfo coverage and shapefile format. The coverages were converted to shapefiles, and then these and the other shapefiles were imported into ArcGIS geodatabases. Table G1 lists the geodatabases and reports used in the compilation.

Table G1. Geodatabases containing mineral-resource assessment geographic information system (GIS) data that covered the Sagebrush Mineral-Resource Assessment (SaMiRA) study areas compiled from preexisting reports.

[USGS, U.S. Geological Survey]

Geodatabase name	Source report number and title	Reference
IdMt_USGS_OFR2007_1101_Asmt.gdb	USGS Open-File Report 07–1101: A compilation of spatial digital databases for Selected U.S. Geological Survey nonfuel mineral-resource assessments for parts of Idaho and Montana	Carlson and others, 2007
IdOr_USGSar2016_MJA_Asmt.gdb	USGS unpublished data, Oregon and Idaho	James Evans, USGS, written commun., 1999
Nv_USGSofr96-712_1996_Asmt.gdb	USGS Open-File Report 96–712: Metallic mineral resources in the U.S. Bureau of Land Management's Winnemucca District and Surprise Resource Area, northwest Nevada and northeast California	Peters and others, 1996
Nv_USGSofr2004-1245_2004_Asmt.gdb	USGS Open-File Report 04–1245: Spatial databases of the Humboldt Basin mineral-resource assessment, northern Nevada	Mihalasky and Moyer, 2004
NV_USGSar_Sheldon_2010_Asmt.gdb	USGS unpublished data, Oregon and Nevada	James Rytuba and others, written commun., 2009
US_USGSc1178_2000_and_PacNW_USGSofr682_1996_Asmt.gdb	USGS Circular 1178: 1998 Assessment of Undiscovered deposits of gold, silver, copper, lead, and zinc in the United States	U.S. Geological Survey National Mineral-Resource Assessment Team, 1998
	USGS Open-File Report 95–682: Assessment of undiscovered mineral resources in the Pacific Northwest—A contribution to the Interior Columbia Basin Ecosystem Management Project	Box and others, 1996

The original GIS data had varying data structures, and therefore, we reformatted the data so that all of the GIS files had a consistent attribute-table structure. We referred to the report text in some instances to fill in missing data into the attribute tables. We used two basic attribute-table structures—one for reports that had quantitative data and one for reports with qualitative data. We set up a general attribute table structure, which contained fields for information on the deposit type assessed, assessment rank, type of assessment, and tract name and identifier. For the attribute table of the quantitatively assessed reports that used the USGS three-part form of assessment, we added additional fields for the deposit model name and number, probabilistic assessment results data, and estimators.

These results were crucial in defining what deposit types needed to be assessed for this project. The deposit types assessed were compiled and distributed to all assessment teams as part of the evaluation of what expertise and data would be needed. This compilation helped to determine what deposit models needed to be developed (appendix 3). Assessment teams used the results to guide mineral-potential assessment. Assessment Oversight Committee (AOC) members used the compilation to assess the work done by the assessment teams.

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Section H. Mineral-Resource Assessment for Locatable Minerals

By Jane M. Hammarstrom and Michael L. Zientek

Introduction

The objective of this project is to provide a description of mineral potential of the Sagebrush Focal Areas (SFAs) evaluated in the Sagebrush Mineral-Resource Assessment (SaMiRA) project in narrative form and on maps that can be used by others to evaluate reasonably foreseeable development in the study area. For this study, the assessment of mineral potential is required only for locatable minerals. Leasable and salable minerals are discussed in the reports prepared for the focal areas, but their potential was not evaluated.

Bureau of Land Management (BLM) focal areas in Montana, Wyoming and Utah, central Idaho, and the Oregon-Nevada-Idaho area were assessed by four different teams, each of whom produced an assessment report for their region. Each team (1) identified the possible mineral-deposit types for locatable commodities that could be present within the focal areas identified by the BLM for possible withdrawal from future mineral activity, (2) outlined those areas that could contain different types of mineral deposits on the basis of geology and other publically available data, and (3) evaluated the level of mineral-resource potential and level of certainty associated with the outlined areas using BLM assessment categories. In this study, areas that have potential for one or more types of mineral deposits are called mineral-resource tracts.

A Geologically Based Assessment Approach

The potential for mineral resources is a prediction of the likelihood of the occurrence of these resources. The specific form of the assessment qualitatively classifies mineral potential into categories based on the level of potential and the level of certainty as specified in BLM Manual Sections 3031 and 3060. The level of potential is based on favorable geologic environment, inferred geological processes, mineral occurrences, and other evidential data such as geochemistry and geophysics. The level of certainty is based on the amount of direct and indirect evidence to support the interpretation of the level of potential. For this study, a geologically based assessment method used the interrelated concepts of mineral-deposit types and mineral systems to evaluate mineral-resource potential. Models based on these concepts provide a predictive capability largely based on analogy with well-characterized mineral deposits and research on geologic processes of ore formation.

In this study, we report mineral potential by deposit type, rather than commodity, to facilitate the evaluation of reasonably foreseeable development. We use our understanding of geologic processes to define favorable geologic environments and elevated mineral potential. This assessment addresses the potential for deposits that may occur within the upper 1 kilometer (km) of the Earth's surface. Exploration and development of deeper-seated deposits is technically feasible but extremely costly.

Mineral-Deposit Types and Models

A mineral deposit is a mineral concentration of sufficient size and quality that it might, under the most favorable of circumstances, be considered to have potential for economic development. Most mineral commodities occur in a variety of different types of mineral deposits. Gold, for example, occurs in surficial concentrations as placer deposits, in some volcanic environments as epithermal vein deposits, in metamorphic terrains as orogenic gold deposits, and as a coproduct in porphyry copper deposits that form in shallowly emplaced igneous intrusions.

Mineral deposits that share characteristics, in terms of how they form, their inherent value (tonnage and grade), the mining and beneficiation methods that can be used to develop them, and the remediation that must be done to minimize environmental impacts of mining are grouped into types. Mineral-deposit models are descriptive summaries of mineral-deposit types, used primarily for classifying occurrences into types but also for providing descriptive information on the favorable geologic setting.

Mineral-deposit models describe the essential attributes of each types of mineral deposit (Cox and others, 1986). The function of the model is to provide the geologist with information that they can interpret and use to discriminate (1) possible mineralized environments from barren environments and (2) types of known deposits from each other. Within the Bureau of Land Management (BLM), mineral-deposit models are used for resource assessment to classify land as to its potential for mineral and energy resources (Fisher and Juilland, 1986).

Descriptive mineral-deposit models such as the U.S. Geological Survey (USGS) models of Cox and Singer (1986) and the BLM models compiled by Fisher and Juilland (1986) list characteristics of the geologic environments in which the deposits are found and identifying characteristics of deposits. The deposit description includes information on host rocks, mineralogy, alteration, and geochemical and geophysical anomalies that are used by the assessment geologists to recognize the deposit type and to discriminate one deposit type from another. Mineral-deposit models compiled for the SFAs are included as appendix 3.

Mineral Systems

Individual mineral deposits can be small parts of much larger mineralizing systems. For example, porphyry copper deposits, associated skarns, polymetallic veins, and epithermal precious-metal veins can all be reflections of a hydrothermal system associated with plutonic rocks (fig. H1). Similarly, sediment-hosted copper deposits and Mississippi-Valley-type zinc-lead-silver deposits are associated with regional fluid flow involving basinal brines in areas that lack active magmatism.

Knowledge of processes that control where mineral deposits form at regional and local scales is used to describe favorable geologic environments and can be expressed by mineral systems models. These models differ from simply descriptive models of mineral-deposit types, because they explicitly integrate research on geologic process. Commonly, mineral system models use "source-transport-trap" as a way to summarize information (Magoon and Dow, 1994; Wyborn and others, 1994; Magoon and Schmoker, 2000), but any model that summarizes a process-based understanding could be used. Mineral system models were developed for exploration targeting and mineral potential mapping.

Mineral-system models use components and processes to organize ideas about how different mineral-deposit types form. For example, hydrothermal mineral deposits can be understood by

Figure H1.   Illustration of a schematic cross section of possible deposit types associated with a hydrothermal-plutonic rock associated system.

considering the source of the ore-forming fluid, its physical and chemical character, the mechanisms for dissolving and transporting ore-forming components, and the causes of precipitation from it (Skinner and Barton, 1973). Sites where appropriate combinations of structural, chemical, and physical conditions that force ore-mineral precipitation reactions are called ore traps (Reed, 1997). The deposition of ore minerals will not occur unless all the essential components are present and processes occur in the correct sequence and location (Magoon and Dow, 1994; Kreuzer and others, 2008; McCuaig and others, 2010).

Mineral systems models serve two functions in mineral-resource assessments. All components and processes that relate to mineral-deposit type can be systematically evaluated to identify areas where a mineral-forming system could be present. Another function of these models is to use the components and processes of the mineral-system model to define the assessment unit in areas where the existence of a mineral-forming system is known from the presence of deposits and prospects.

The types of mineral deposits that may occur within the focal areas are grouped in mineral systems associated with magmatic, hydrothermal, sedimentary, or surficial geologic processes (table H1). Within a given mineral system, a variety of different types of deposits can form. The occurrence of porphyry copper deposits for example, suggests that the hydrothermal-plutonic mineral system may have also formed skarns or replacement deposits or other deposit types where metals are transported in magmatic fluids interacting with meteoric water in a plutonic setting. The mineral-system concept provides a framework for considering what could occur in a given setting.

Table H1.   Relation between classes of mineral deposits, mineral systems, and mineral-deposit types with locatable commodities used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[Systems represent a subjective classification of deposit types adopted for SaMiRA to group deposit types that share some broad genetic characteristics or processes of formation. Note that some of the models listed in appendix 3 cover multiple deposit types, such as hectorite and specialty clay. In addition, some mineral-resource tracts were developed for multiple deposit types, such as both porphyry copper and copper skarn. SEDEX, sedimentary exhalative deposits]

General class	System	Deposit type
Magmatic	Magmatic–directly related to igneous processes	Diatreme-hosted diamond
		Basalt-hosted sunstone
Hydrothermal	Hydrothermal–plutonic rock associated	Porphyry copper
		Arc-related porphyry molybdenum (low-fluorine)
		Climax-type porphyry molybdenum
		Copper skarn
		Lead-zinc skarn
		Molybdenum-tungsten greisen
		Tungsten skarn
		Tungsten vein
		Polymetallic replacement
		Polymetallic vein
		Distal-disseminated silver-gold
		Carlin-type gold (silver, mercury, antimony)
	Hydrothermal–volcanic rock associated	Epithermal gold-silver (mercury)
		Jasperoid precious metal
		Epithermal gypsum
		Volcanogenic uranium (Aurora and Kings River types)
		Stanley district (Idaho)-type uranium
		Volcanic rock-hosted opal
		Specialty gemstone
		Hectorite (lithium-rich clay)
		Specialty clay
	Hydrothermal–exhalative-magmatic processes	Volcanogenic massive sulfide (Besshi-subtype)
	Hydrothermal–exhalative-sedimentary processes	SEDEX lead-zinc-silver
		Bedded barite
	Hydrothermal–metamorphic rock associated	Orogenic low-sulfide gold-quartz vein
Sedimentary	Sedimentary (formed during or after the conversion from sediment to sedimentary rock)	Bentonite
		Dolomite (high purity)
		Sediment-hosted stratabound copper
		Sandstone uranium (roll front) in intermontane basins
		Hydroallogenic volcanic-hosted uranium
		Zeolite
	Sedimentary (formed during deposition of the sediment)	Iron formations (Algoma and Superior subtypes)
		Lacustrine diatomite
Surficial	Surficial–mechanical (placer)	Heavy mineral placer
		Placer gold
		Paleoplacer gold

Map Scale and Resolution

We assume that the scale at which the data are needed is about 1:100,000 to 1:250,000. For a given scale, the minimum map unit is the size in map units below which a narrow feature can be reasonably represented by a line and an area by a point. USGS map standards state that the minimum polygon size on maps is about 1 square millimeter (mm^2) (GDS-FGDC, 2006). For 1:100,000-scale maps, 1 mm^2 corresponds to 0.01 square kilometer (km^2) (10,000 square meters, m^2). For 1:250,000-scale maps, 1 mm^2 corresponds to 0.063 km^2 (62,500 m^2). The acceptable error for USGS maps is about 1/50th of an inch (U.S. Geological Survey, 1999), which corresponds to 50 meters (m) for 1:100,000-scale maps and 100 m for 1:250,000-scale maps.

In 1987, Waldo Tobler, analytical cartographer (now emeritus from University of California-Santa Barbara) wrote, "The rule is: divide the denominator of the map scale by 1,000 to get the detectable size in meters. The resolution is one half of this amount" (Nagi, 2010). This rule is a useful guide to keep in mind when applying geographic information system (GIS) tools in assessment (table H2).

Table H2.   Guide to map scale, detectable size of a map feature, and resolution.

Map scale	Detectable size, in meters	Raster resolution, in meters
1:100,000	100	50
1:250,000	250	125

Assessment Process

The focal area assessment teams followed a number of steps or procedures to conduct the assessment of mineral potential. In general, the steps were:

1. Work with project managers to understand the scope of work and the anticipated end use of the assessment. This started with a project meeting in December 2015 and continued throughout the course of the assessment work.

2. Determine which mineral-deposit types and commodities need to be assessed and make sure appropriate models are available. This was done by using the expertise of USGS scientists who have worked in the study areas and by reviewing results of previous mineral-resource investigations and assessments in the study area.

3. Gather and compile data such as geology, mineral occurrences, mineral exploration, rock alteration inferred from satellite imagery, soil and stream-sediment geochemistry, and potential-field geophysics. Many of the datasets used for these assessments are described in other sections of this report.

4. Enhance existing datasets as needed from larger scale geologic maps and geological literature.

5. Construct preliminary maps showing areas with mineral potential

6. Conduct a workshop to revise the preliminary maps and assign levels of mineral potential and certainty. In most cases, representatives from State geological surveys were observers or participants at the workshops.

7. Present results of the assessment to an evaluation panel.

8. Prepare report for technical review.

Before each workshop, the assessment teams developed a list of possible mineral-deposit types and commodities to consider, classified known deposits and prospects in terms of deposit type, and identified mineral-deposit models needed to conduct the assessment. The assessment teams evaluated available data and developed preliminary mineral-resource tracts.

At the workshops, the teams refined the tracts and assigned a mineral potential and level of certainty to each tract. The tracts were compared to compilations that summarized the level of mineral activity as indicated by authorized and closed mining claims, surface-management notices and plans, and a compilation of active exploration areas from literature. The rationale for tract delineation and the classification potential and certainty were recorded and summarized in a tabular format (table H3).

Following each workshop, the mineral-potential tracts were refined, and any unresolved issues identified during the assessment workshops were addressed. Each focal area team prepared a presentation for an evaluation panel composed of five scientists who were not directly involved in the assessment of the focal area. The selection of mineral-deposit models, rationale for mineral-resource tracts, and classification of mineral potential for locatable commodities were evaluated by the panel and comments were communicated to the assessment team prior to final report preparation. The panel also evaluated the information presented for leasable and salable commodities. This evaluation process provided a check on consistency in applying the assessment criteria throughout the focal areas.

Mineral-Resource Tracts

According to BLM guidelines, when known geologic conditions in an area fit a model, they define a "favorable geologic environment." Mineral-resource specialists determine favorable geologic environments by integrating and assessing different lines of evidence (Bureau of Land Management, 1985):

A. Favorable rocks (lithostratigraphic suitability).

B. Favorable geologic structure (faults, folds, and other structural features).

Table H3.   Example data table for a mineral-resource tract used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[BLM, Bureau of Land Management; MRDS, Mineral Resources Data System; USMIN, U.S. Geological Survey Mineral Deposit Database project; PLSS, Public Land Survey System; ASTER, Advanced Spaceborne Thermal Emission and Reflection Radiometer]

Focal Area:	
Mineral-resource tract name:	
Tract identifier:	
State:	
County(ies):	
Mineral-Deposit Types:	
Commodities:	
Mineral potential (H, M, L) **Level of certainty (A, B, C, D)**	See appendix 2 for definitions.
Basis for tract	Fundamental basis for the tract (for example, Cretaceous arc segment, Triassic basin)
Previous assessment(s)	Yes or No? Overlapped by a permissive tract from a previous assessment ranked high?
Favorable rocks **(litho-stratigraphic suitability)**	Source map and scale Map units
Favorable geologic structures **(faults, folds, other)**	Fault bounded? Regional trend? Folds? Describe or state no data.
Evidence from mineral occurrences **(specify dataset: MRDS, USMIN, other)**	Deposits (production or mineral inventory within 500 meters of PLSS boundary) Related deposit type Prospects Occurrences of possible related commodity
Evidence of rock alteration **(maturation, hydrothermal alteration)**	Alteration mapped or described in literature Landsat alteration ASTER alteration
Geochemical evidence	Anomalies or other data
Geophysical evidence	Anomalies or other data
Evidence from other sources	For example, depth to basement, mineralogy, petrology, and so forth
Exploration history **(BLM data)**	Plans of operations for appropriate commodity Active notices for an appropriate commodity Closed plans of operations for appropriate commodity Active lode claims Active placer claims
USMIN data	Active exploration areas
Additional notes and references	

C. Evidence of rock alteration (maturation, hydrothermal alteration).

D. Geochemical evidence (anomalies).

E. Geophysical evidence (anomalies).

F. Evidence from mineral occurrences.

G. Evidence from other sources (depth to basement, mineralogy, and so forth).

Mineral-resource tracts were constructed by identifying the appropriate geological environments and the deposit types likely to occur in each focal area (see table H4 for an example). When data and time permit, computational techniques can be used to map mineral potential by combining digital files for the different types of evidence as listed above. For this study, a single computational approach was not possible, given the quality of the data and the diversity of deposit types and mineral systems

that were present. The areal extent of a particular mineral-resource tract varies by mineral system and by deposit type. Experts determined what data and approach was best suited to map areas with mineral potential. In the following sections, we give some examples of how mineral potential was mapped. Specific descriptions are included with each focal area report.

A mineral-resource tract for a hydrothermal mineral system associated with plutonic rocks, for example, could contain porphyry deposits, as well as associated deposit types such as skarn and replacement deposits in carbonate rocks, polymetallic veins, and distal disseminated deposits. In some cases, mineral-resource tracts for one deposit type are coincident with tracts for other deposit types. However, the mineral potential and uncertainty are assigned by deposit type. Shallow-level magmatic rocks formed at convergent tectonic-plate margins are indicative of the favorable environment for porphyry copper deposits. For some deposit types, criteria were established by defining very specific lithologies. Skarns, for example, typically form at the contact of limestone with a calcalkaline pluton. For polymetallic

Table H4.   Example of mineral-resource tract criteria used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project for Carlin-type gold deposits in the Southeastern Oregon and North-Central Nevada, Southern Idaho and Northern Nevada, and Sheldon-Hart Mountain National Wildlife Refuge Complex of Oregon Sagebrush Focal Areas (SFAs; see section A, fig. A1).

[km, kilometer]

Necessary criteria for a mineral-resource tract
1. Areas underlain by continental crust and subcontinental lithospheric mantle (for example, east of the initial strontium 0.706 crustal discontinuity).
2. Areas within the limits of the southward sweeping Eocene calcalkaline magmatic arc.
3. Cambrian to Permian marine calcareous or dolomitic sedimentary rocks deposited along the western margin of the United States in slope, shelf, foreland basin, and overlap settings, as well as rocks of the Havallah Basin. The largest deposits are in Ordovician, Silurian, and Devonian slope facies near the platform margin below the Roberts Mountains allochthon. Nevada border map units: PzMzs, Pzrm, Pzh. State of Nevada map units include Nolan, Basin, Slope, Shelf, Foreland, Overlap, and Golconda.
4. Aforementioned sedimentary host rocks are within 1 km of present surface. In other words less than 1 km of sedimentary, volcanic, or alluvial cover.

veins to form, structural controls such as faults are more important than host rock because the structures provide hydrothermal fluid transport pathways through a variety of rock types.

In addition to permissive geology for the deposit type, the tract is drawn to include any direct evidence of mineral occurrences, such as deposits that have a defined resource, active exploration projects for the deposit type, and (or) BLM permits, as well as indirect evidence, such as geochemical anomalies, mineral showings of a commodity that could be related to the deposit type, and (or) alteration (fig. H2). Mineral occurrences include mineral deposits, mineral prospects, and mineral showings. Table H5 lists the criteria used to assign mineral-occurrence data to one of these three categories. The essential distinction between a deposit and a prospect is that a deposit has a formal mineral inventory (table H6). The nature and density of mineral occurrences, the nature and density of alteration appropriate for the deposit type, and the level of exploration and mining activity indicated by BLM permits and claims were also considered in delineating the extent, potential, and level of certainty associated with each tract. A mineral-resource tract may or may not contain known deposits or prospects.

In some cases, a geologic structure such as a fault provided a tract boundary. Geophysical data (chapter C) provided guidance on areas where shallow buried plutons might exist or areas of thick basin cover (>1 km) are present. Although deposits can occur at greater depth, this assessment only considered the mineral potential within the upper 1 km of the surface.

A number of tools are available for processing data to facilitate making mineral-resource tracts. These include the application of buffer distances around known deposits or particular map units and using geospatial tools to examine the density of mineral occurrences. These tools, used in conjunction with the other available data, aid the delineation of the spatial extent of mineral-resource tracts, as described in the focal area reports. The mineral-resource tracts for locatable minerals for the SaMiRA project are provided in a data release of spatial data (San Juan and others, 2016). Mineral potential and level of certainty are included in the tract attributes.

Buffers

The geoprocessing buffer tool in ArcGIS can be used to simplify complex shapes, address cartographic uncertainty, approximate the size of a feature that is not mapped, and (or) determine an appropriate search radius for adjacent deposits. Buffering was used by most of the assessment teams. Most of the geologic-map databases used in the assessment combine geologic bedrock and surficial geologic units. If a favorable geologic unit is selected from the database, the polygon commonly has a complex shape because of intersecting surficial geologic units. Buffering can be used to fill in areas underlain by alluvium to make a polygon that more closely represents the bedrock extent of the permissive unit.

Buffering was also used to approximate the extent of hydrothermal alterations systems that are associated with hydrothermal deposit types. Hydrothermal mineral deposits are the most common mineral-deposit types, but direct evidence of the areal extent of hydrothermal alteration is almost never shown on regional-scale (1:100,000–1:250,000) geologic maps. For some hydrothermal mineral deposits, the sizes of areas underlain by mineralized or altered rock have been compiled and summary statistics can be calculated. For example, these data have been compiled for porphyry copper deposits (Singer and others, 2008), polymetallic veins (Bliss, 1994), and sediment-hosted gold deposits (Berger and others, 2014). Using the information compiled for these systems, a buffer radius was selected and applied to data points that provided direct evidence for the presence of a hydrothermal mineral occurrence (of a given type).

Depending on the scale of available geologic maps, deposit type, and the occurrence of unexposed mineral deposits, the presence of a mineral system may not always be readily inferred from a geologic map. In such cases, the mapped mineral occurrences can serve as the primary sampling method for delineating the extent of a mineral-resource tract. The approximate diameter of well-exposed pluton-related hydrothermal systems ranges from just a few hundred meters to tens of kilometers
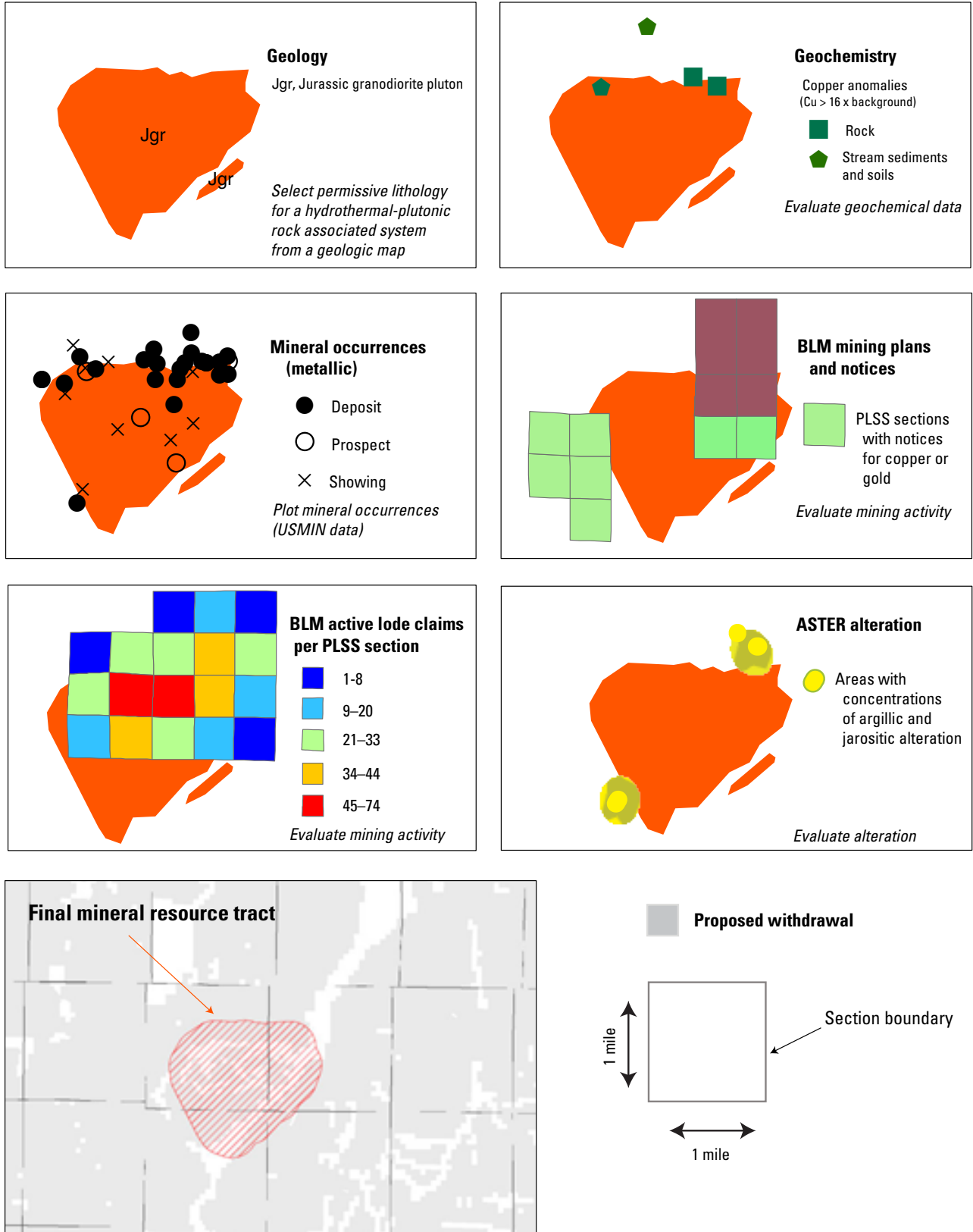
Figure H2.   Illustration showing an example of datasets used to develop a mineral-resource tract for porphyry copper and skarn deposits. The final tract outline encompasses the permissive map unit, the mineral occurrences, alteration, and areas of exploration interest based on Bureau of Land Management (BLM) records. PLSS, Public Land Survey System; ASTER, Advanced Spaceborne Thermal Emission and Reflection Radiometer; USMIN, U.S. Geological Survey Mineral Deposit Database.

Table H5. Relations among mineral occurrences, deposits, prospects, and showings used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

Name	Name	Criteria	Notes
Mineral occurrence	Mineral deposit	Has a formally defined (drill-indicated) mineral-resource estimate; does not need to be economic (include sites with resources, as well as reserves)	May be able to categorize by deposit type
	Mineral prospect	Significant exploration site; drilling; plan-of-operation	May be able to categorize by deposit type
	Mineral showing	Exploration target; minor occurrence	May only know commodities present

Table H6. Sources of information for classifying mineral occurrences as deposits or prospects used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[BLM, Bureau of Land Management; USFS, U.S. Forest Service; NI, National Instrument]

Sources of information on mineral inventory	Deposit	Prospect
	Formal mineral inventory (supported by drilling and sampling as appropriate for deposit type).	No formal mineral inventory; some geologic estimates of resources may be in older literature.
Companies listed on Canadian, Australian, London stock exchanges	Feasibility study completed and reserves reported. Resources reported (Annual reports; NI 43-101 reports).	Information may be on company Web pages; usually for junior companies; almost never for majors.
Companies listed on U.S. stock exchange	Reserves reported in company annual reports.	
USFS and BLM	Pending patent application. Plan of operation indicating extensive drilling and sampling.	Notice of intent.
Federal and (or) State regulatory agencies	Pending or approved mining permit Environmental impact studies or environmental analysis reports studies or reports.	
Mineral occurrences database	Past production, reserves, and measured and indicated resources. Inactive (closed) or abandoned mine.	Incompletely characterized mineral resources; may be some drilling.
Imagery	Mine pit and operations may be visible.	Surface disturbance and evidence of exploration such as trenches or drill pads.
Privately held companies	Information usually not reported.	Information usually not reported.

(Sillitoe, 2010). The maximum radius that would be appropriate to depict the uncertainty in the location of a hidden or unmapped part of a mineral system related to a sampling point (mineral occurrence) that encounters the system would be half that distance (probably less than 10 km). The footprint of porphyry copper systems, the archetype of pluton-related systems, for example, was documented by Berger and others (2008). The median radius for those systems is about 5 km, and the 90th percentile is about 2.6 km (table H7). These data represent minimum sizes, because parts of many porphyry systems are covered. Thus, about 3 km may serve as an appropriate buffer radius around a porphyry-type mineral occurrence as a tool for developing mineral-resource tracts for porphyry copper deposits.

The polygons created by buffering the mineral occurrence points formed the basis for many of the mineral-potential tracts in some reports. What buffer radius should be used to approximate the size of a hydrothermal system for a known mineral-occurrence point? Histograms of available data show that alteration areas are right skewed for a given deposit type (similar to tonnage values). Some assessors wanted to use a buffer radius that would approximate the maximum size of an alteration area; others argued that the buffer radius should be closer to the mean or median value. The recommended radius is based on the 90th percentile (table H7).

Users of the mineral-resource tracts should consult the tract descriptions in the SaMiRA reports for each SFA to understand the rationale for the buffer radius, the value that was used (maximum, mean, or other), and how it was applied (to data points corresponding to a mineral occurrence of a given deposit type).

Table H7. Summary statistics for the areal extent of mineralized rock and alterations systems associated with various deposit types and suggested buffer radius for tract delineation used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

Deposit	90th percentile	75th percentile (quartile)	50th percentile (median)	25th percentile (quartile)	10th percentile	Mean	Number	Buffer radius based on 90th percentile (assuming circle), in kilometers	Reference
			Deposit, ore body, or ore						
Volcanogenic massive sulfide	0.52	0.11	0.02	0.00	0.00	0.18	126	0.4	Mosier and others, 2009
Sediment-hosted gold	2.85	1.30	0.40	0.13	0.04	1.04	112	1.0	Berger and others, 2014
Porphyry copper	2.65	1.53	0.60	0.27	0.10	1.25	174	0.9	Singer and others, 2008
Sediment-hosted zinc-lead	15.70	4.70	1.00	0.40	0.24	38.96	129	2.2	Singer and others, 2009
Sediment-hosted stratabound copper	50.11	9.90	1.55	0.53	0.15	19.40	55	4.0	Taylor and others, 2013
Nickel-cobalt laterite	70.40	33.00	9.40	3.15	1.06	24.10	93	4.7	Berger and others, 2011
			Alteration or target area						
Volcanogenic massive sulfide	49.35	8.53	1.04	0.00	0.00	8.76	12	4.0	Mosier and others, 2009
Mixed base-and-precious metal veins	23.00	No data	2.90	No data	0.36	No data	49	2.7	Bliss, 1994
Sediment-hosted zinc-lead	17.28	9.33	3.20	0.43	0.14	5.63	17	2.3	Singer and others, 2009
Porphyry copper	21.00	12.00	5.10	2.00	0.85	8.92	184	2.6	Singer and others, 2008

Using Near Distance and Density Mapping to Map Areas with Mineral Potential

Other geoprocessing tools were used to examine the distance relations between one site and another as a guide to delineating mineral-resource tracts. In applying these tools, the spatial relation of, for example, metallic-mineral sites relative to each other can be determined using a proximity tool to compute the distance that one would have to search from a given site to reach other sites. The results of generating a "near distance table" provide a guide to the distance beyond which it would be highly unlikely that another site would be found

Mineral occurrences tend to be spatially clustered. Statistics that summarize the nearest distance between spatially clustered points were used in the development of some mineral-potential tracts when the distribution of mineral occurrences could not be related to features on geologic maps. In the absence of other information, the maximum near distance between clustered points for a given type of mineral occurrence was used as the buffer distance to establish the farthest search area for that deposit type. In some cases, this was used to define the lowest ranked mineral tracts in this study (low levels of potential and confidence).

To define areas of higher confidence, density of mineral-occurrence points was calculated using the kernel-density tool in ArcGIS. This tool calculates a magnitude-per-area from the point features to illustrate the spatial density of sites. Tobler's first law of geography (http://support.esri.com/other-resources/gis-dictionary/term/Tobler's%20First%20Law%20of%20Geography) was used when generating kernel-density maps for SaMiRA (table H8). ArcGIS usually asks for cell size of output raster, and the information in table H2 was used to determine an appropriate value. The 90th-percentile value near distance was used as the search radius when performing this calculation. This value was chosen because a search distance of this radius

Table H8. Examples of near distance calculations that were considered for kernel-density mapping used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[MRDS, U.S. Geological Survey Mineral Resource Database; USMIN, U.S. Geological Survey Mineral Deposit Database project]

Data	Number of points	Near-distance, 90th percentile, in meters	Near-distance, 95th percentile, in meters
Missouri River Breaks diatremes	86	3,923	11,220
Leucite Hills diatremes	25	7,123	7,643
Bedded barite in MRDS and USMIN in Sagebrush Focal Areas in Nevada		2,700	3,300
Carlin-type gold deposits in Nevada		4,200	12,000

should find most (90 percent) of the mineral occurrences used in the calculations. The resulting density maps were classified into groups and used to map level of certainty. This approach was used for assessing diamond potential associated with diatremes and related intrusions in Montana (Missouri River Breaks field) and Wyoming (Leucite Hills).

Geostatistical Analysis

Geostatistical models were used to model where bentonite should crop out in the assessment for bentonite in the Montana focal area. The models were also used to create surfaces that represent the bentonite layers or the interval containing the bentonite layers. Those modeled surfaces were then intersected with a digital elevation model to create a map showing where bentonite layers should crop out.

Mineral-Resource Potential and Certainty

The assessment methodology used in this report follows the BLM assessment guidelines and relies on subjective assessment. For locatable minerals, areas are assigned high, moderate, low, or no mineral-resource potential according to the degree of likelihood that geologic processes operated in an area in such a way as to permit accumulation of resources (appendix 2). If no useful data are available, the designation ND (not determined) is used. In addition to the level of mineral-resource potential, a level of certainty is applied to document the quality and quantity of data available to support the assigned level of potential (appendix 2). These levels range from A (least certain) to D (most certain), depending on the evidence to support the possible existence of mineral resources on the mineral-resource tract. Known deposits, for example, provide direct evidence of mineral resources, whereas a geochemical anomaly or a mineral showing might represent indirect evidence of mineral resources.

The definitions of these levels of resource potential were developed by Goudarzi (1984) and adopted by BLM (1985). The range of possible mineral-potential classifications for a given mineral-resource tract is illustrated in figure H3. The assessment of mineral potential and level of certainty assigned to mineral-resource

tracts depends on consideration of BLM evidence factors. For example, a mineral-resource tract assigned an H/D classification has a high potential for mineral resources and a high level of certainty. By definition, mineral-resource tracts have at least a low potential because the tract is based on some geologic evidence that indicates that the area is permissive for the occurrence of the deposit type. Additional types of evidence are necessary to warrant a designation of moderate or high mineral potential.

A practical way to interpret the different subjective levels might be that most mining companies would be willing to risk exploration dollars in an area with high potential, whereas areas with moderate potential might be attractive to some optimistic investors but not to more conservative ones (Ludington, 2006). The level of certainty of the assigned resource potential reflects the amount and quality of useful data available at the time of the assessment. As new or more detailed information becomes available, the resource potential and level of certainty in an area can change. The designation of an area as having high potential does not necessarily imply that deposits that might be discovered there could be developed and operated successfully. When information is available about resource quality that might bear on the economic viability of deposits, it is presented separately from the potential designation.

SaMiRA Assessment Guidelines

The guidelines adopted for assigning mineral potential and level of certainty for locatable minerals in SaMiRA are summarized in figure H3. Specific rationales for each permissive tract are cited in the focal area reports. The tract example shown in figure H2 would be classified as H/D because of the abundant direct evidence illustrated by the occurrence of deposits with production, prospects, and exploration activity, and the indirect evidence from geochemistry and alteration. Examples of datasets that provided direct and indirect evidence to support the interpretation of the level of potential and certainty are listed in table H9. Direct evidence indicates that the mineral occurrence can be assigned to a deposit type or that mineralized rock is present. These guidelines, in combination with the subject matter expertise of the assessment teams, determined the final designation of each mineral-resource tract.

Table H9.   Direct and indirect evidence indicators for assigning mineral potential used in the Sagebrush Mineral-Resource Assessment (SaMiRA) project.

[ASTER, Advanced Spaceborne Thermal Emission and Reflection Radiometer]

Criteria	Mineral occurence databases		Geochemistry of soils, stream sediments, and rocks	ASTER anomalies	Regional-scale geophysics	43 CFR 3809 permits	Mining claims
	Current or historical deposit with identified resources, past production, or active exploration	Prospect or showing					
Direct evidence of a particular deposit type	X						
Direct evidence that mineralized rock is present	X	X	X			Maybe	
Indirect only				X	X	X	X

H/A High potential with insufficient evidence	**H/B** High potential with indirect evidence Contains 2 or more of the following: Attractive exploration targets. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**H/C** High potential with direct evidence Contains 2 or more of the following: Minor past production. Attractive exploration targets. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**H/D** High potential with abundant direct and indirect evidence Contains 2 or more of the following: Current production/significant inventor. Significant past production. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.

⟵ Permissive host rocks +/- previous assessment ⟶

M/A Moderate potential with insufficient evidence	**M/B** Moderate potential with indirect evidence Contains 1 or more of the following: Attractive exploration targets. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**M/C** Moderate potential with direct evidence Contains 1 or more of the following: Minor past production. Attractive exploration targets. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**M/D** Moderate potential with abundant direct and indirect evidence Contains 1 or more of the following: Current production/significant inventory. Significant past production. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.

⟵ Permissive host rocks +/- previous assessment ⟶

L/A Low potential with insufficient evidence	**L/B** Low potential with indirect evidence No active exploration. No claims. No other applicable data.	**L/C** Low potential with direct evidence Historic mining. Historic claims. No active notices or mine plans. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**L/D** Low potential with abundant direct and indirect evidence Few active claims. Historic mining. No USMIN active exploration. No active notices or mine plans. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.

⟵ Permissive host rocks +/- previous assessment ⟶

			N/D No potential Reserved for a specific type of resource in a well-defined area. For example, it is appropriate to say that there is no oil potential in an area where the only rocks present are unfractured Precambrian granite, but the term "low" is appropriate if there is a slight possibility for the presence of resources.

Level of resource potential (vertical axis): H, M, L, N

Level of certainty (horizontal axis): A, B, C, D

Figure H3. Matrix of possible mineral potential and certainty designations and criteria used for the mineral-resource assessment for locatable minerals in the Sagebrush Mineral-Resource Assessment (SaMiRA) project. Levels of resource potential: N, none; L, low; M, moderate; H, high. Levels of certainty: A, insufficient evidence; B, indirect evidence; C, direct evidence; D, abundant evidence. USMIN, U.S. Geological Survey Mineral Deposit Database.

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Section I. Locatable Mineral Market-Demand Analysis Commodity Profiles

By Donald I. Bleiwas

The present and potential future market-demand analyses were developed to provide a general description of domestic production and a qualitative assessment of inferred future market demands for the important locatable minerals identified to have a moderate and high potential for occurrence within the proposed withdrawal areas in the Bureau of land Management (BLM) Sagebrush Focal Areas (SFAs; see section A, fig. A1). A table of strategic and critical materials is provided in appendix 4. A complete listing of the market-demand commodity profiles are provided in appendix 5.

Individual mineral-commodity profiles contained in the market-demand analysis section were developed by U.S. Geological Survey (USGS) minerals and materials specialists in the National Minerals Information Center (NMIC). The NMIC's primary mission is to collect, monitor, and analyze data on domestic and foreign nonfuel mining and mineral-processing industries and markets for more than 90 mineral commodities essential to the U.S. economy and national security.

The sources of information used for developing the mineral-commodity profiles include academia, Federal, State and local agencies, industry contacts, international and domestic organizations, publications, questionnaires and surveys, and site visits.

Each mineral-commodity profile contains descriptive and statistical information that address domestic and global production, domestic consumption, historical and recent prices, major uses, recycling, stocks, shipments, the strategic and critical nature of the commodity, and trade. In some cases, recent mine production in or proximal to the proposed withdrawal area is discussed in each commodity profile.

Section J. Energy Mineral Resources

By Jonathan M.G. Glen, Jacob DeAngelo, Colin F. Williams, Jon E. Haacke, Ronald M. Drake II, Gregory L. Gunther, Stuart A. Giles, and Aimee E. Graeber

This section on energy mineral resources data compiled for the Sagebrush Mineral-Resource Assessment (SaMiRA) project consists of three subsections. The first section describes geothermal energy resources. The second section provides an overview of methods used for reporting coal resources. The third section describes the methods used in reporting oil and gas data.

Geothermal Energy Resources

By Jonathan M.G. Glen, Jacob DeAngelo, and Colin F. Williams

Introduction

Geothermal energy constitutes one of the Nation's largest sources of renewable electric power. Its potential is an important consideration given that current projections indicate the United States will need to increase its electrical power generating capacity by approximately 25 percent over the next 25 years (Energy Information Administration, 2015). Although the installed capacity of geothermal (approximately 3,000 megawatts-electric or MWe) falls short of meeting the Nation's entire power needs, it constitutes a potentially significant part of the estimated available resources based on recent assessments. With potential advances in exploration and development technologies, these resources could provide a substantial source of baseload electric power. Owing to government mandates and incentives for renewable energy, it is expected that the demand for geothermal energy will continue to grow, and, given the concentration of geothermal resources in the Western United States, a substantial part of this growth could occur on public lands. This section, which provides a review of the geothermal resource potential of the proposed Sagebrush Focal Areas, is based on the results of the USGS 2008 assessment of the Nation's moderate- and high-temperature geothermal resources (Williams and others, 2008b) that includes a provisional assessment of Enhanced Geothermal Systems (EGS), as well as earlier USGS and State-level inventories and assessments.

Overview of USGS Geothermal-Resource Assessments and Definitions

Comprehensive efforts to assess the geothermal resources of the United States began after passage of the Geothermal Energy Research, Development, and Demonstration Act of 1974, which assigned responsibility for the evaluation and assessment of geothermal resources to the USGS through the U.S. Department of the Interior. The USGS produced three national geothermal-resource assessments in the following 8 years, USGS Circular 726, Assessment of Geothermal Resources of the United States-1975 (White and Williams, 1975), USGS Circular 790, Assessment of Geothermal Resources of the United States–1978 (Muffler, 1979), and USGS Circular 892, Assessment of Low-temperature Geothermal Resources of the United States–1982 (Reed, 1983). After the passage of the Energy Policy Act of 2005, the USGS produced an updated assessment of the moderate-temperature (90 to 150 degrees Celsius, °C) and high-temperature (>150 °C) geothermal resources of the United States (Williams and others, 2008a, b). In the 2008 assessment, the USGS provided estimates of the geothermal electrical power generation potential from identified and undiscovered resources and included a provisional estimate of the power-production potential of Enhanced Geothermal Systems (EGS) techniques, which involve the creation of producing geothermal reservoirs in low-permeability rock units.

All four of these national geothermal assessments consider both identified and undiscovered resources and use the following definitions established for the USGS by Muffler and Cataldi (1978). The geothermal-resource base is all of the thermal energy in the Earth's crust beneath a specific area, measured from the local mean annual temperature. The geothermal resource is that part of the resource base at depths shallow enough to be tapped by drilling in the foreseeable future that can be recovered as useful heat economically and legally at some reasonable future time. Similarly, the geothermal reserve is the identified part of the resource that can be recovered economically and legally at the present time using existing technology.

Conventional Geothermal Resources

In the context of this report, geothermal resources are divided into two categories—conventional and unconventional. Conventional resources are those associated with geothermal systems defined by Muffler (1979) as "any regionally localized

geological setting where naturally occurring parts of the Earth's thermal energy are transported close enough to the Earth's surface by circulating steam or hot water to be readily harnessed for use." These geothermal (or alternatively, hydrothermal) systems involve the natural vertical movement of water through either free or forced convection (for example, Duffield and Sass, 2003). All of the geothermal systems developed for commercial electric power generation in the United States fall in this category. Within this framework, identified hydrothermal systems are divided into three temperature classes—low temperature (<90 °C), moderate temperature (90 to 150 °C), and high temperature (>150 °C). High-temperature systems include both liquid- and vapor-dominated resources. Moderate-temperature systems are principally liquid dominated, and all low-temperature systems are liquid dominated. All three temperature classes are suitable for direct-use applications, but in general only moderate- and high-temperature systems are economically viable for electric power generation. The heat source of a hydrothermal system can be characterized as either magmatic or amagmatic. Magmatic geothermal reservoirs, which derive their heat from shallow-crustal magma bodies, are typically larger and higher in temperature than amagmatic systems that owe their heat to deep circulating fluids within the background geothermal gradient of the upper crust (Coolbaugh and others, 2006).

Unconventional Geothermal Resources

In addition to conventional hydrothermal resources, there are several geothermal-resource types that have the technical potential either for electric power generation, reductions in demand for other nonrenewable sources of energy, or direct-use applications but have not yet been adopted commercially. These resources include deep high-temperature sedimentary basins; especially geothermal resources colocated with oil and gas accumulations or zones of geopressured fluids, and EGS. Enhanced geothermal systems are the part of a geothermal resource for which a measureable increase in production over its natural state is or can be attained through mechanical, thermal, and (or) chemical stimulation of the reservoir rock (Williams and others, 2011).

This section, dealing with the geothermal-resource potential of Sagebrush Focal Areas, is primarily based on results from the 2008 assessment that addresses moderate-temperature (90 to 150 °C) and high-temperature (greater than 150 °C) conventional and EGS systems capable of electric power generation. In addition, low-temperature systems that may offer important direct-use applications are briefly discussed. Also considered are sedimentary-basin resources that may hold substantial future potential when technologies have improved to allow commercial exploitation of those resources for electric power generation and other applications, such as in Utah and Wyoming.

2008 USGS National Resource Assessment

The USGS 2008 national resource assessment (Williams and others, 2008b) assessed the electric power generation potential of geothermal resources in the United States. These resources are concentrated in 13 States that include all 6 of the States (Idaho, Montana, Nevada, Oregon, Utah, and Wyoming) spanned by the Sagebrush Focal Areas (SFAs). The assessment considered conventional moderate-temperature (90 to 150 °C) and high-temperature (greater than 150 °C) geothermal systems located on private or accessible public lands and included a provisional estimate of the power-generation potential from the application of unconventional, EGS technology.

The assessment of conventional resources addresses those that can be accessed and exploited in the foreseeable future with existing methods and technology (Williams and others, 2011). In contrast, the provisional EGS assessment addresses EGS resources that are within depths accessible with existing technology but that will require methods and technology presently being developed, which have not yet been established as commercially viable (Department of Energy, 2008), for stimulation of the reservoir.

Identified Geothermal Systems

The majority of identified moderate- and high-temperature geothermal systems across the Western United States occur within the Great Basin Province and Snake River Plain (fig. J1). These are resources that are known and characterized by in-situ measurements through drilling or other lines of evidence such as geochemical, geophysical, and geological surveys. There are numerous low- and moderate- to high-temperature identified geothermal systems that occur within and around the proposed withdrawal areas (figs. J1–J4). Although there are currently no installed geothermal power plants located with the proposed withdrawal areas, there are four producing sites that lie within 100 kilometers (km) of the withdrawal boundaries in Oregon, Idaho, and Nevada, as well as sites under development (according to the National Renewable Energy Laboratory; http://www.nrel.gov/gis/geothermal.html) in those States and Utah (figs. J3 and J4; see individual SFA reports for further information).

Undiscovered Geothermal Resources

Undiscovered geothermal resources were assessed for the Western States that contain identified moderate- and high-temperature geothermal systems in the 2008 assessment. The assessment was based in part on a series of Geographic Information Systems (GIS) weights-of-evidence and logistic regression analyses through which geothermal potential was modeled using a weighted combination of evidence layers derived from mappable geologic and tectonic
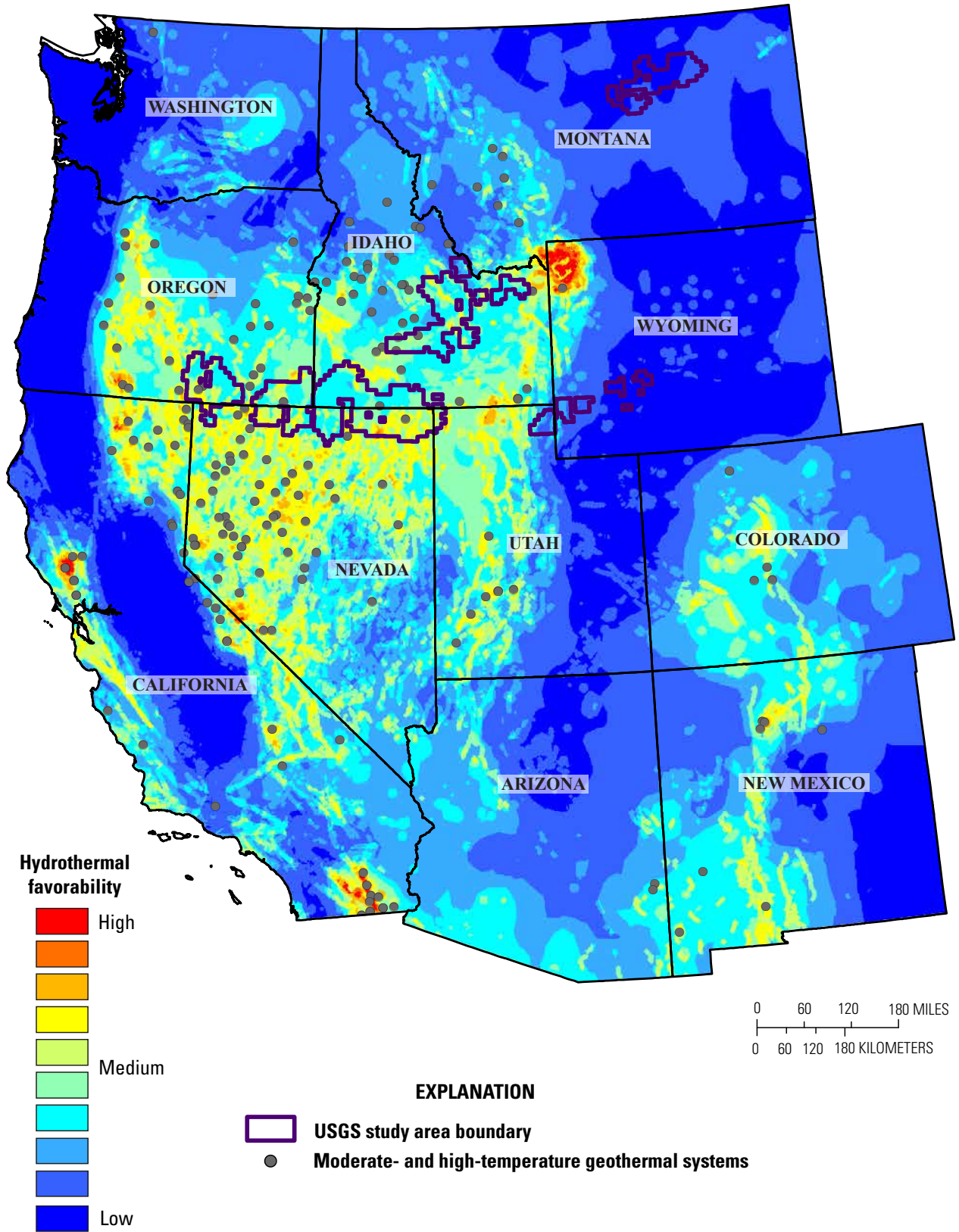
Figure J1. Geothermal-favorability map showing the relative favorability of occurrence for conventional moderate- to high-temperature geothermal resources across the western contiguous United States (after Williams and others, 2008b). Warmer colors equate with higher favorability. Identified geothermal systems are represented by black dots. USGS, U.S. Geological Survey.

EXPLANATION

USGS study area boundary

Temperature at 6-km depth (C°)

■ (red)	greater than 250
■ (orange)	225.1 to 250
■ (yellow)	200.1 to 225
■ (light green)	175.1 to 200
■ (green)	150.1 to 175
■ (cyan)	125.1 to 150
■ (blue)	100.1 to 125
■ (dark blue)	less than 100
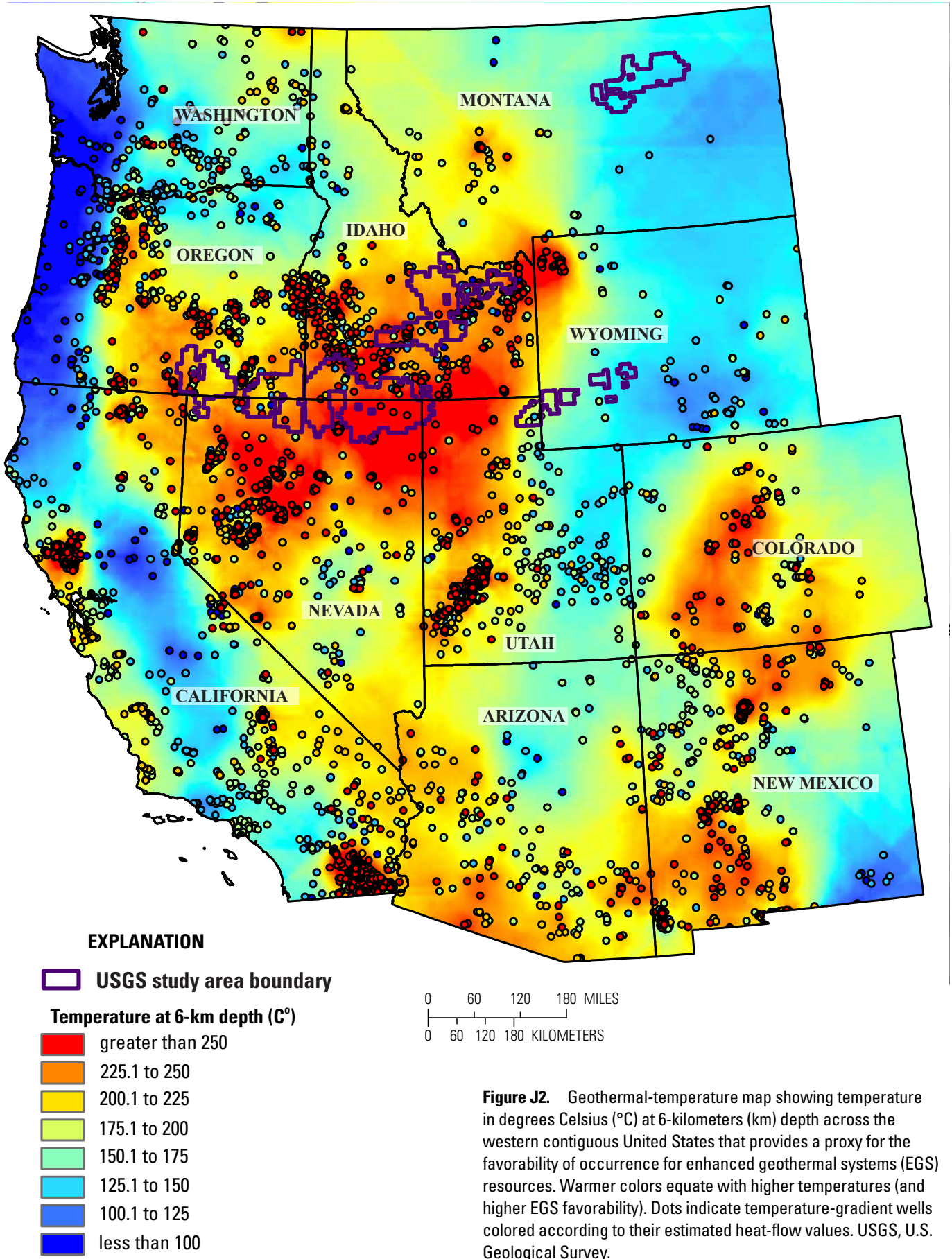
Figure J2.   Geothermal-temperature map showing temperature in degrees Celsius (°C) at 6-kilometers (km) depth across the western contiguous United States that provides a proxy for the favorability of occurrence for enhanced geothermal systems (EGS) resources. Warmer colors equate with higher temperatures (and higher EGS favorability). Dots indicate temperature-gradient wells colored according to their estimated heat-flow values. USGS, U.S. Geological Survey.

Figure J3. Geothermal-favorability map for the region of Sagebrush Focal Areas (SFAs; see section A, fig. A1), Western United States, showing logistic regression results for geothermal favorability (after Williams and others, 2008b) spanning the areas proposed for withdrawal. Warmer colors equate with higher favorability. USGS, U.S. Geological Survey; SaMiRA, Sagebrush Mineral-Resource Assessment.

Political boundaries from Esri (2013).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 114° W., latitude of origin, 37.5° N.

EXPLANATION

Temperature at 6-km depth (°C)

- greater than 250
- 225.1 to 250
- 200.1 to 225
- 175.1 to 200
- 150.1 to 175
- 125.1 to 150
- 100.1 to 125
- less than 100

▲ Geothermal developing sites
   (September 2, 2014)

⬡ Geothermal operating sites
   (October 26, 2015)

● Moderate- and high-temperature
   geothermal systems

☐ USGS SaMiRA project report areas

☐ USGS study area boundary

Figure J4. Geothermal-temperature map for the region of Sagebrush Focal Areas (SFAs; see section A, fig. A1), Western United States, showing temperature in degrees Celsius (°C) at 6-kilometers (km) depth, which provides a proxy for enhanced geothermal systems (EGS) favorability spanning the areas proposed for withdrawal. Warmer colors equate with higher temperatures (and higher EGS favorability). USGS, U.S. Geological Survey; SaMiRA, Sagebrush Mineral-Resource Assessment.

features available in digital databases (Coolbaugh and others, 2005; Williams and DeAngelo, 2008; Williams and others, 2009). The spatial variations in probability for the presence of a geothermal system were determined by mapping the presence or absence of various indicators comprising evidence layers that were weighted for their influence on the feature of interest.

Based on the 2008 assessment, the mean estimated power production potential from undiscovered geothermal resources is more than three times that from identified geothermal systems (more than 30,000 MWe versus approximately 9,000 MWe, respectively). These results indicate that additional exploration for undiscovered systems could substantially augment the potential exploitable resources. A plot of relative geothermal-resource favorability of both identified and undiscovered systems is given in figures J1 and J3. As indicated by the geothermal-favorability maps, regions with significant geothermal potential but few identified geothermal systems include parts of the proposed SFAs. The favorability scale in these maps is set relative to the average favorability for the occurrence of moderate- and high-temperature geothermal systems in the Western United States, which has significantly greater geothermal resource potential than east of the Rocky Mountains. Consequently, low values of favorability should be evaluated in this context and not considered an absolute measure of resource absence.

Enhanced Geothermal Systems (EGS) Resources

Enhanced Geothermal Systems involve efforts to engineer geothermal reservoirs where they did not previously exist by stimulating the host rock to generate permeable pathways for the circulation of hot water or steam necessary for electrical power generation. Although this has yet to be demonstrated on a commercial basis in the United States, EGS are the focus of substantial research and development worldwide due to their vast resource potential. For the 2008 provisional estimates of EGS potential (Williams and others, 2008b), the dominant factor determining the favorability of occurrence for EGS resources is the presence of elevated temperatures at viable drilling depths (Williams and DeAngelo, 2011). As a simple proxy for the detailed assessment analyses EGS potential is represented in figures J2 and J3, as well as subsequently in the regional sections, by the estimated temperature at a depth of 6 km. The provisional estimate of EGS resources indicates that the EGS electric power production potential is significantly larger than from conventional geothermal resources (~500,000 megawatts, MW, versus ~30,000 MW) and represents approximately half of the current installed electric power generating capacity in the United States (Williams and others, 2008b). In comparison to the geothermal-favorability map (fig. J1), the high crustal heat flow favorable for EGS development (fig. J2) is much more uniformly distributed across the Western United States.

Geothermal Provinces

The Western United States is a region characterized by active tectonics and magmatism that has resulted in an elevated conductive thermal gradient capable of driving hydrothermal convection of water along permeable pathways in the crust. Hydrothermal systems driven by magmatic sources are typically concentrated along the western margin of the actively extending tectonic zones within the Great Basin and along the Snake River Plain, whereas those that result from amagmatic sources tend to be associated with basin and range settings. Extensive geothermal resources relevant to the present study occur principally in the northern Great Basin, Snake River Plain, and their surroundings (including the basin and range north of the plain, Oregon-Idaho Graben, and the High Lava Plains).

Great Basin Province

The Great Basin Province is a broad, highly extended basin and range province characterized by significantly elevated heat flow relative to the rest of the continental craton (Sass and others, 2005). It represents one of the largest geothermal provinces in the world and hosts more than 20 operating power plants that support roughly 550 MW of installed capacity. Estimates based on the 2008 National assessment (Williams and others, 2008b) suggest that the province has the potential of producing ~30,000 MW. Most of the geothermal systems within the Great Basin Province are believed to be primarily fault-controlled and not related to magmatic heat sources residing in the upper crust. Furthermore, many of these systems have little or no surface manifestation (Faulds and Hinz, 2015; Coolbaugh and others, 2006). Given the presence of such "blind" systems, assessments may underestimate the region's full geothermal potential. The high geothermal potential of the province is attributed to significant crustal thinning from high extensional strain rates (Blewitt and others, 2005; Faulds and others, 2012) that have led to elevated geothermal gradients.

Snake River Plain

The Snake River Plain is a major physiographic feature of the Western United States that forms a continuous arcuate topographic depression extending from the Oregon-Idaho border, across southern Idaho, to northwest Wyoming. The western plain represents a rift graben that developed ~11–12 million years ago (Ma) with the eruption of silicic volcanic rocks, and it is filled with thick sequences (several kilometers) of late Cenozoic lacustrine sediments. In contrast, the eastern plain forms a topographic depression thought to represent an expression of a mantle plume that heats the base of the continental crust in response to the northeast migration of the Yellowstone hotspot from the south-central Snake River Plain to its present location at Yellowstone as the North American Plate passed over the

plume. The eastern plain is filled with a thick sequence of basalts that blanket a series of caldera complexes and associated silicic volcanic rocks that were all emplaced during passage of the hotspot.

The Snake River Plain and its surroundings represent one of the highest heat flow provinces in North America. The thermal anomaly associated with the plain originates from a thinned lithosphere, voluminous silicic volcanism, and extensive intrusions emplaced into the middle and lower crust. Very high heat-flow values are expected for the youngest part of the plain that have experienced recent (in the past 2,000 years) basaltic volcanism (Brott and others, 1978, 1981). Although the Snake River Plain and surroundings likely represents an important geothermal resource area (Fleischmann, 2006; Shervais and others, 2016; Welhan, 2016), much of the eastern plain's expected high heat flow is masked by shallow groundwater flow (Brott and others, 1981). This leads to relatively low heat-flow values observed along the axis of the plain (with the exception of a few deep boreholes that penetrate below the base of the aquifer). Although the most recent volcanism occurs in the eastern Snake River Plain, relatively young (~200,000 years ago) basaltic volcanism has also occurred in the west. Elevated heat-flow values mark the margins of the western Snake River Plain, where it is believed that the heat-flow pattern is influenced by crustal-scale thermal refraction imposed by the thick sequence of sediments infilling the western graben.

Methods Used for Reporting the Coal Resources

By Jon E. Haacke

Coal is a major energy source in the United States. Although its contribution has diminished significantly in recent years, as of 2014 some 39 percent of U.S. electricity generation came from coal (U.S. Energy Information Administration, 2015). More than half of U.S. coal production comes from the Western States. Because so much is on lands with Federal mineral ownership, coal resources in the Western United States have been extensively evaluated by the U.S. Geological Survey (USGS).

The USGS divides the United States into coal regions that are known to contain coal and (or) lignite (East, 2013). The regions are further subdivided into coal fields, which are those areas that are or have been actively mined or that have significant potential to be mined.

Coal assessments by the USGS can be unofficially divided into four levels of detail:

1. *Presence of coal*.—At the simplest level is a geologic study to identify those areas that have any coal deposits.

2. *Estimation*.—An estimate of coal resources based on general knowledge of the geology.

3. *Zonal*.—A more detailed study of coal resources to add up all the coal at a given thickness and at some maximum depth, such as coal greater than 30-inches thick and at a depth no greater than 1,000 feet.

4. *Resources and Reserves*.—The most detailed approach involves bed-by-bed correlation, calculation of available coal resources, and evaluation of the economically minable reserves.

For the coal assessment of the Sagebrush Focal Areas (SFAs; see section A, fig. A1), the first step was to determine those areas that were within any of the coal regions. For those focal areas in known coal areas, publications of the USGS and other sources were referenced.

The majority of the SFAs are not within regions of known coal occurrences (fig. J5). In the late 1990s, the National Coal Resource Assessment (Fort Union Coal Assessment Team, 1999) studied much of the Western United States; however, none of the focal areas were assessed. For those focal areas within coal-bearing regions, there is low economic potential. None of the focal areas are within the higher (zonal or resource and reserves) assessment levels. The only area with estimated coal resources is a small part of the Bear River Watershed SFA.

Methods Used for Reporting the Oil and Gas Resources

By Ronald M. Drake II, Gregory L. Gunther, Stuart A. Giles, and Aimee E. Graeber

Introduction

The U.S. Geological Survey (USGS) was tasked with providing a summary of published oil and gas assessments that overlie the land tracts for the Sagebrush Focal Areas (SFAs; see section A, fig. A1). The USGS oil and gas assessments were conducted at a basin scale using the Total Petroleum System (TPS) concept. As defined by Magoon and Schmoker (2000), the TPS approach considers the source rock, reservoir rock, seal rock, and overburden rock and processes of generation, migration, accumulation, and trap formation for discovered and undiscovered accumulations. A TPS is a naturally occurring hydrocarbon-fluid system that presumes that migration pathways exist now or in the past, and they connect the provenance with the accumulations. Therefore, the goal of the previous assessments was to map this natural fluid system, or TPS, in three-dimensional space through time to locate, define, and evaluate those areas for undiscovered hydrocarbons (Magoon and Schmoker, 2000).
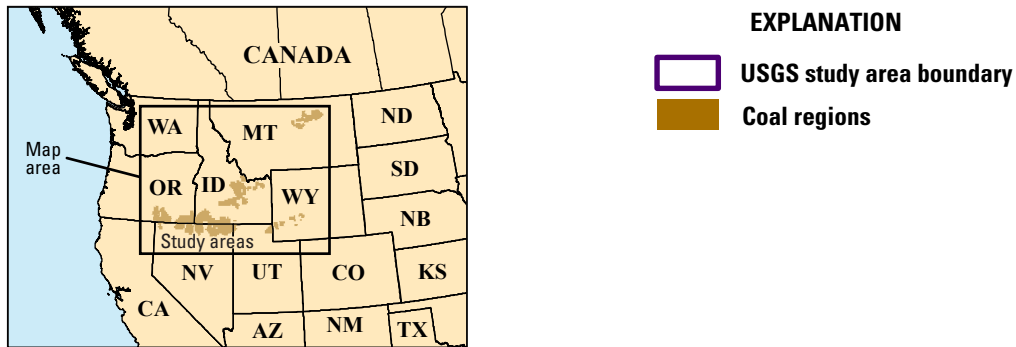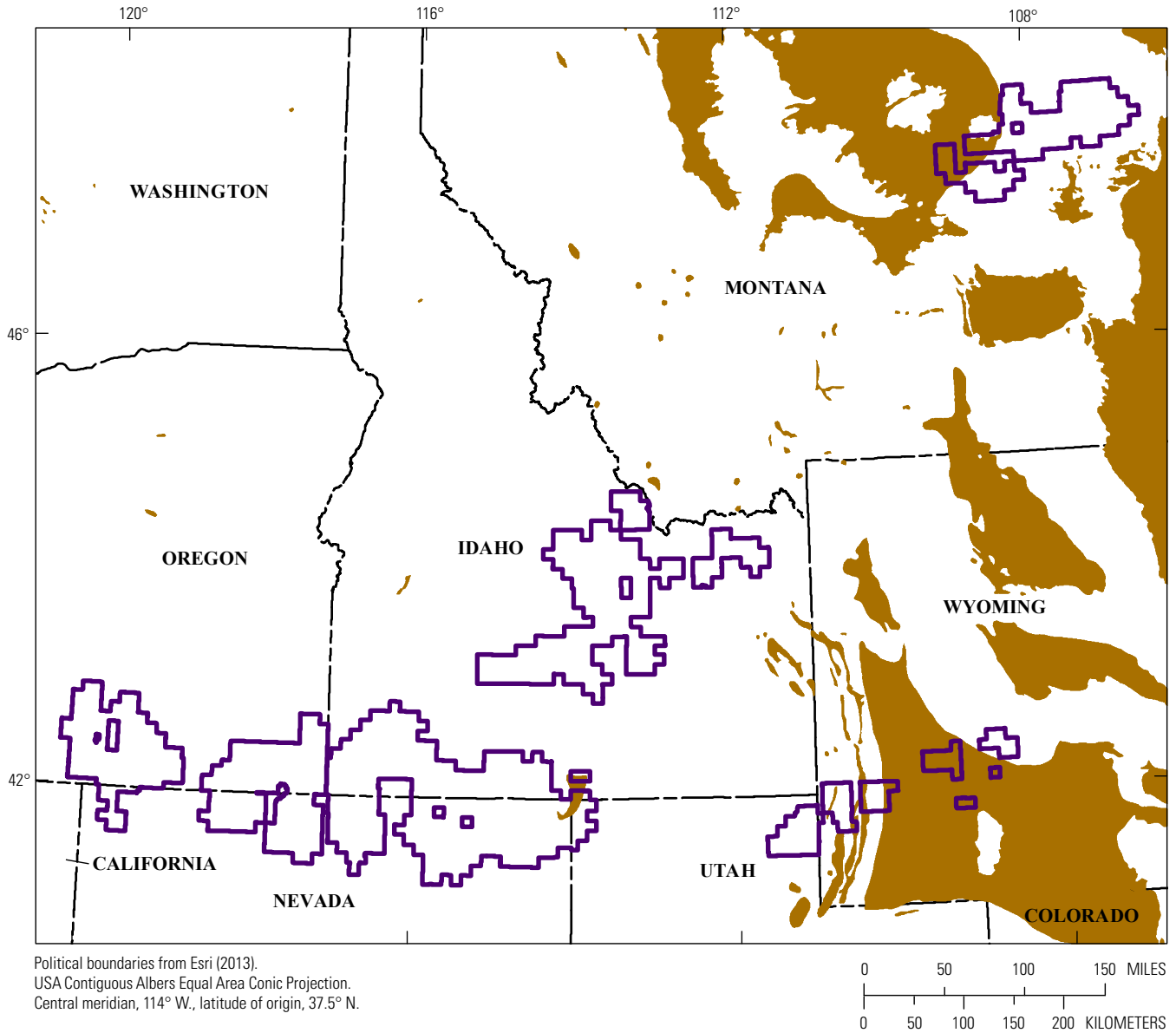
Figure J5.   Map of known coal occurrences for the region of the Sagebrush Focal Areas (SFAs; see section A, fig. A1), Western United States. Coal regions from East (2013). USGS, U.S. Geological Survey.

Base modified from U.S. Geological Survey DEM data (2016).
Political boundaries and roads from Esri (2013).
Withdrawal area boundaries from BLM (2016).
USA Contiguous Albers Equal Area Conic Projection.
Central meridian, 114° W., latitude of origin, 37.5° N.
North American Datum of 1983.
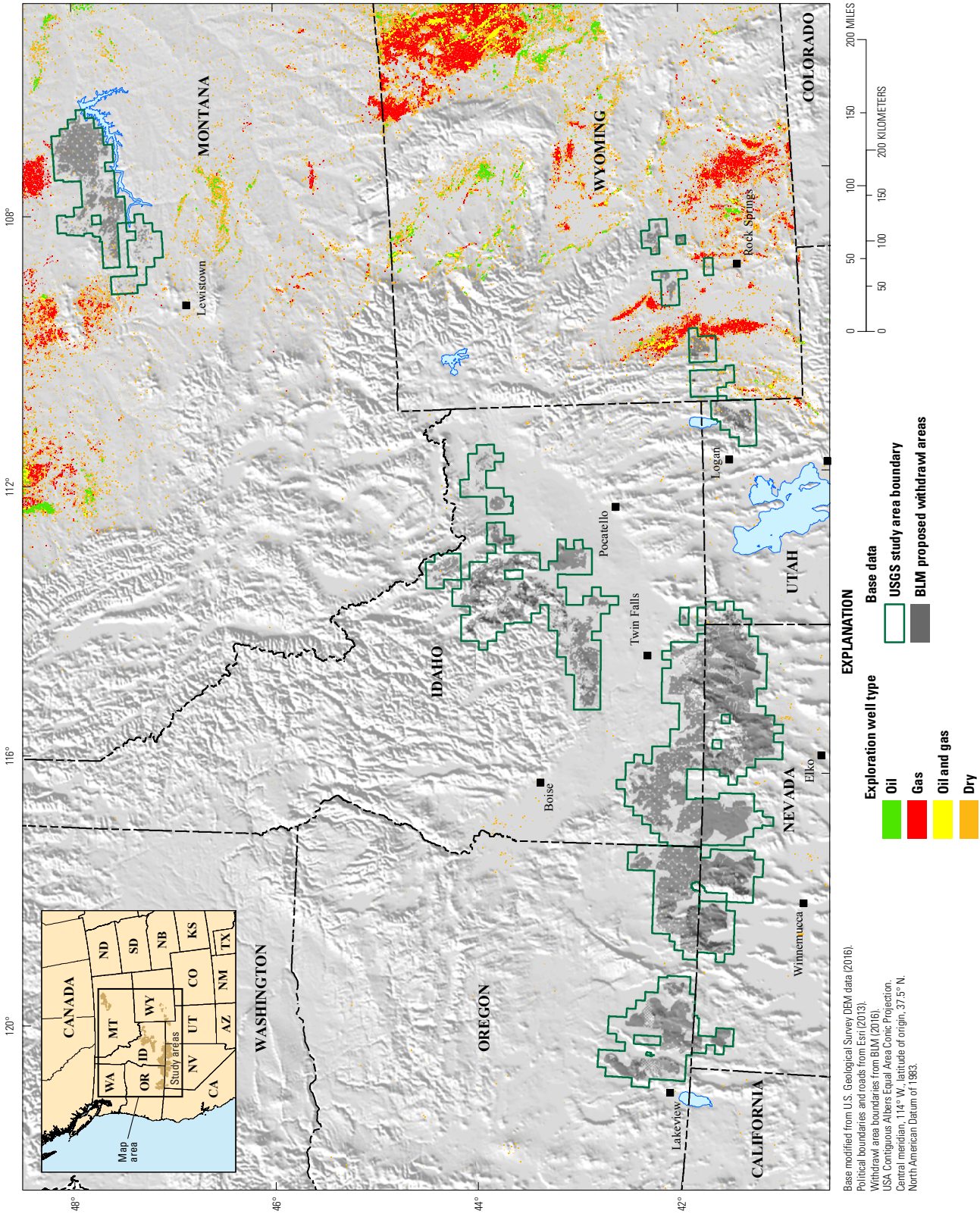
Figure J6.   Map showing the ¼ section-level cell summary oil and gas exploration and well-type information from the propriety IHS Energy Group (2016) database and from Gunther and others (2016b) used for the Sagebrush Mineral-Resource Assessment (SaMiRA) project. USGS, U.S. Geological Survey; BLM, Bureau of Land Management.

Methodology

A geographic information system (GIS) dataset was created that combined the Sagebrush Mineral-Resource Assessment (SaMiRA) township areas (as defined by the BLM) and USGS oil and gas assessment boundaries. A query was run within the GIS for intersecting assessment units within the Public Land Survey System (PLSS) townships containing SFAs. The resulting table related each PLSS Township with any correlating USGS oil and gas assessment unit or play. If an assessment was done in 1995, then the terminology used was "Play," and, after 1995, the terminology became "Assessment Unit" (AU). In many cases, more than one play or assessment unit (AU) was present within a PLSS Township. The table created lists each PLSS Township and the associated play or AU, the name of the AU or play, the publication title, and a URL link to the published USGS geologic assessment report. The published USGS assessment reports include many details regarding the source rocks, reservoir rocks, type of trap, reservoir properties, and resource potential. In some cases, many AUs or plays overlie a township. A table of oil and gas plays and AUs for each SFA is given in the corresponding SaMiRA report chapter as an appendix.

Using the list of AUs and plays that overlap the SFA townships, we were able to report the assessed potential oil and gas resources for those AUs and plays. The assessed resources are for areas larger than the SFA's PLSS township boundary. The assessment units and plays are usually basin size in scale.

Map figures provided in each individual SFA report incorporate borehole data from the IHS Energy Group (2016) and from Gunther and others (2016a, b) for well type and oil and gas production data. Although these data are proprietary, we were able to summarize the data by showing the majority type of wells at the ¼ section scale (fig. J6). These maps have been added to the reports for each SFA if there was production within a PLSS township containing a given proposed withdrawal area.

Nearly all oil and gas production occurred outside of the proposed withdrawal areas. For example, only one inactive well in Sweetwater County, Wyoming, produced a minor amount of oil and gas within the proposed withdrawal areas (IHS Energy Group, 2016). Although there are many assessed potential oil and gas resources near the proposed withdrawal areas, there has not been any significant hydrocarbon production within them.

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Glossary

B

base metal   A metal inferior in value to gold and silver, a term generally applied to the commercial metals such as copper and lead (Bureau of Land Management, 2000).

base metals   Those metals usually considered to be of lesser value and of greater chemical reactivity compared to the noble or precious) metals, most commonly copper, lead, zinc, and tin (NRC, 1999).

beneficiation   Improvement of the grade of ores by milling, flotation, sintering, gravity concentration, or other processes. Also termed "concentration" (National Research Council, 1999). The dressing or processing of ores to (1) regulate the size of a desired product, (2) remove unwanted constituents, and (3) improve the quality, purity, or assay grade of a desired product. Beneficiation includes concentration or other preparation of ore for smelting by drying, flotation, or magnetic separation (Bureau of Land Management, 2000).

bentonite   A rock consisting of clay minerals formed from the decomposing of volcanic ash. Commonly bentonite can readily absorb or adsorb water and swell accordingly (Bureau of Land Management, 2000).

BLM   Bureau of Land Management.

C

casual use   Mining activities that only negligibly disturb Federal lands and resources. Casual use generally includes the collecting of geochemical, rock, soil, or mineral specimens using hand tools, hand panning, and nonmotorized sluicing. It also generally includes use of metal detectors, gold spears, and other battery-operated devices for sensing the presence of minerals, and hand and battery-operated drywashers. Operators may use motorized vehicles for casual-use activities if the use conforms to the regulations governing such use, off-road vehicle use designations in BLM land-use plans, and temporary closures. Casual use does not include use of mechanized earth-moving equipment, truck-mounted drilling equipment, suction dredges, motorized vehicles in areas designated as closed to off-road vehicles, chemicals, or explosives. It also does not include occupancy or operations where the cumulative effects of the activities result in more than negligible disturbance. Under casual use, operators do not have to notify BLM, and operations do not need to be approved. But operations are subject to monitoring by BLM to ensure that Federal lands do not undergo unnecessary or undue degradation. Casual use operations must be reclaimed (Bureau of Land Management, 2000).

claim   See **mining claim** (Bureau of Land Management, 2000).

common variety minerals   Mineral materials that do not have a special quality, quantity, character, or location that makes them of unique commercial value. On public lands such minerals are considered salable and are disposed of by sales or by special permits to local governments (National Research Council, 1999). Stone, gravel, pumice, pumicite, and cinders that, though possibly having value for trade, manufacture, the sciences, or the mechanical or ornamental arts, do not have a distinct, special value for such use beyond normal uses. On Federal lands such minerals are considered salable and are disposed of by sales or by special permits to local governments. (National Research Council, 1999). See **salable minerals, mineral materials**, and **uncommon variety minerals**.

critical minerals   Minerals essential to the national defense, the procurement of which in war, although difficult, is less serious than those of strategic minerals because they can be either domestically produced or obtained in more adequate amounts or are less essential, and for which some degree of conservation and distribution control is needed (Bureau of Land Management, 2000). See **strategic minerals**.

D

development (mineral)   The preparation of a proven deposit for mining (Bureau of Land Management, 2000).

discovery   As used in this report, initial recognition and demonstration of the presence of valuable mineral within a claim (National Research Council, 1999). The knowledge of the presence of valuable minerals within or close enough to a location to justify a reasonable belief in their existence. Discovery is an extremely important to public-lands mining because the General Mining Act of 1872 (30 U.S.C. 22–42) provides that mining claims can be located only after a discovery is made. Discovery was first legally defined in a landmark Department of the Interior 1894 land decision—Castle versus Womble. The definition, now known as the "Prudent Person Test, 'described a discovery as'... where minerals have been found and the evidence is of such a character that a person of ordinary prudence would be justified in the further expenditure of his labor and means, with a reasonable prospect of success in developing a valuable mine . . ." (Bureau of Land Management, 2000).

E

entry   An application to acquire title to public lands (Bureau of Land Management, 2000).

environmental assessment (EA)   A concise public document for which a Federal agency is responsible that does the following: (1) briefly gives enough evidence and analysis for determining whether to prepare an environmental impact statement (EIS) or a finding of no significant impact (FONSI), (2) aids an agency's compliance with the National Environmental Act when no EIS is needed, and (or) (3) facilitates preparing an EIS when one is needed (Bureau of Land Management, 2000).

environmental impact statement (EIS)   A document required by the National Environmental Policy Act (NEPA) for certain actions "significantly affecting the quality of the human environment."

evaporite   Sedimentary rock formed by the evaporation of a saline solution. Examples include rock salt, gypsum, and chemically precipitated limestone (Bureau of Land Management, 2000).

exploration   The work of investigating a mineral deposit to determine by geological surveys, geophysical surveys, geochemical surveys, boreholes, pits, and underground workings if it is feasible to mine. Exploration is undertaken to gain knowledge of the size, shape, position, characteristics, and value of the deposit. For 43 CFR 3809 regulations, exploration means creating surface disturbance that is greater than casual use and that includes sampling, drilling, or developing surface or underground workings to evaluate the type, extent, quantity, or quality of mineral values present. Exploration does not include activities where material is extracted for commercial use or sale (Bureau of Land Management, 2000).

F

Federal Land Policy and Management Act (FLPMA)   The act that (1) set out for the Bureau of Land Management standards for managing the public lands, including land-use planning, sales, withdrawals, acquisitions, and exchanges; (2) authorized the setting up of local advisory councils representing major citizens groups interested in land-use planning and management; (3) established criteria for review of proposed wilderness areas; and (4) provided guidelines for other aspects of public land management such as grazing (Bureau of Land Management, 2000).

ferrous metals   Metals commonly occurring in alloys with iron, such as chromium, nickel, manganese, vanadium, molybdenum, cobalt, silicon, tantalum, and columbium (niobium) (National Resource Council, 1999).

FWS   U.S. Fish and Wildlife Service.

G

General Mining Act of 1872 (30 U.S.C. 22–42)   The Federal act of May 10, 1872, that, with its amendments, formed the framework for the mining of locatable minerals on the public lands. This law declared that "valuable" mineral deposits rather than simply "mineral deposits" were to be free and open to exploration and purchase, limited individual claims to 20 acres, required $100 worth of assessment work yearly, and allowed milling or processing claims of 5 acres or less to be entered on nonmineral lands (Bureau of Land Management, 2000).

geophysical exploration   The use of geophysical instruments and methods to determine subsurface conditions by analyzing such properties as specific gravity, electrical conductivity, or magnetic susceptibility (Bureau of Land Management, 2000).

H

hardrock   Locatable minerals that are neither leasable minerals (oil, gas, coal, oil shale, phosphate, sodium, potassium, sulfur, asphalt, or gilsonite) nor salable mineral materials (for example, common variety sand and gravel). Hardrock minerals include, but are not limited to, copper, lead, zinc, magnesium, nickel, tungsten, gold, silver, bentonite, barite, feldspar, fluorspar, and uranium. (Bureau of Land Management, 2000b) Usually refers to rock types or mining environments where the rocks are hard and strong and where blasting is needed to break them for effective mining. As used in this report, the term hardrock minerals are defined synonymous with "locatable minerals."

heavy metal   Any of the metals that react readily with dithizone, including zinc, copper, cobalt, lead, bismuth, gold, cadmium, iron, manganese, nickel, tantalum, tellurium, platinum, and silver (Bureau of Land Management, 2000).

I

industrial minerals   Rock and minerals that are not produced as sources of metals and are not mineral fuels. Examples include salt, gravels, building materials, talc, and sands (Bureau of Land Management, 2000).

L

leasable minerals   A legal term that identifies a mineral or mineral commodity that is leasable by the Federal Government under the Mineral Leasing Act of 1920 and similar legislation. Leasable minerals include oil, gas, sodium, potash, phosphate,

coal, and all minerals on acquired lands (NRC, 1999) (examples are given in appendix 1). Minerals whose extraction from Federal land requires a lease and the payment of royalties. Leasable minerals include coal, oil and gas, oil shale and tar sands, potash, phosphate, sodium, and geothermal steam (Bureau of Land Management, 2000).

locatable minerals   A legal term that identifies minerals acquired through the General Mining Act of 1872 (30 U.S.C. 22–42), as amended (examples are given in appendix 1). Locatable minerals are distinguished from federally owned minerals that are disposed of by leasing (see **leasable minerals**). In some situations, the term "hardrock minerals" is applied to locatable minerals (National Research Council, 1999). Minerals that may be acquired under the General Mining Act of 1872, as amended (Bureau of Land Management, 2000).

location   The act of taking or appropriating a parcel of mineral land, including the posting of notices, the recording thereof when required, and marking the boundaries so they can be readily traced; also the claim acquired by an act of location. See **mining claim** (Bureau of Land Management, 2000).

lode claim   A public lands mining claim that contains valuable minerals occurring in a vein or lode (Bureau of Land Management, 2000).

lode   A mineral deposit in solid rock (Bureau of Land Management, 2000).

M

millsite   A site located on nonmineral land and used for erecting a mill or reduction works, or for other uses reasonably incident to support of a mine. Millsites are limited to 5 acres and may be located either by metes and bounds or by legal subdivision. See **location** and **mining claim** (Bureau of Land Management, 2000).

mine   An opening or excavation in the earth for extracting minerals (Bureau of Land Management, 2000).

mineral activity   Mining and mineral exploration (Bureau of Land Management, 2000).

mineral assessment   The determination of mineral potential, including the process for making that determination. Assessment usually does not include calculations of value or quantity, although these data may be part of an assessment where they are already known (Bureau of Land Management, 1985).

mineral claimant   A person, association, corporation, or government that claims minerals rights or title in the public lands (Bureau of Land Management, 2000).

mineral entry   The filing of a claim on public land to obtain the right to any minerals it may contain (Bureau of Land Management, 2000).

mineral materials   Materials such as common varieties of sand, stone, gravel, pumice, pumicite, and clay, that are not obtainable under the mining or leasing laws but that can be acquired under the Mineral Materials Act of 1947, as amended. See **common variety minerals** (Bureau of Land Management, 2000).

mineral occurrence   A concentration of mineral that is considered to be valuable or that is of technical or scientific interest (National Research Council, 1999).

mineral prospect   A mineral property whose value has not been proved by exploration (Bureau of Land Management, 2000).

mineral resource   "A concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a mineral resource is currently or potentially feasible (after USGS Circular 831, p.1)" (Bureau of Land Management, 1985).

mineral rights   Ownership of all minerals, including all rights needed for access, exploration, development, mining, ore dressing, and transportation (Bureau of Land Management, 2000).

mineral   Several other common meanings, but the following are used in this report: Any natural resource extracted from the earth for human use; for example, ores, salts, coal, or petroleum (National Research Council, 1999). Any solid or fluid inorganic substance that can be extracted from the earth for profit (Bureau of Land Management, 2000).

mineral species   Term used in this report to distinguish specific mineralogical species from the unmodified term "mineral" as defined above (National Research Council, 1999).

mineralization   The processes taking place in the Earth's crust resulting in the formation of valuable minerals or ore bodies (Bureau of Land Management, 2000).

mineralogy   The study of minerals—their formation, occurrence, properties, composition, and classification (Bureau of Land Management, 2000).

mining claim   A parcel of land that a miner takes and holds for mining purposes, having acquired the right of possession by complying with the **General Mining Act of 1872** and local laws and rules. A single mining claim may contain as many adjoining locations as the locator may make or buy. There are four categories of mining claims: lode, placer, millsite, and tunnel site. For 43 CFR 3809 regulations, mining claim means any unpatented mining claim, millsite, or tunnel site

located under the mining laws. The term also applies to mining claims and millsites that were located in the California Desert Conservation Area and patented after the enactment of the Federal Land Policy and Management Act of 1976 (Bureau of Land Management, 2000). See **location**, **lode claim**, **placer claim**, **millsite**, and **tunnel site claim**.

mining district   An area, usually designated by name, with described or understood boundaries, where minerals are found and mined under rules prescribed by the miners, consistent with the **General Mining Act of 1872** (Bureau of Land Management, 2000).

mining laws   The Lode Law of July 26, 1866, as amended (14 Stat. 251); the Placer Law of July 9, 1870, as amended (16 Stat. 217); and the General Mining Act of May 10, 1872, as amended (17 Stat. 91); as well as all laws supplementing and amending those laws, including the Building Stone Act of August 4, 1892, as amended (27 Stat. 348); the Saline Placer Act of January 31, 1901 (31 Stat. 745); the Surface Resources Act of 1955 (30 U.S.C. 611-614); and the Federal Land Policy and Management Act of 1976 (43 U.S.C. 1701 et seq.) (Bureau of Land Management, 2000).

mining location   A mining claim on the public lands (Bureau of Land Management, 2000).

N

National Environmental Policy Act (NEPA)   The Federal law, going into effect on January 1, 1970, that established a national policy for the environment and requires Federal agencies (1) to become aware of the environmental ramifications of their proposed actions, (2) to fully disclose to the public proposed Federal actions and provide a mechanism for public input to Federal decision-making, and (3) to prepare environmental impact statements for every major action that would significantly affect the quality of the human environment (Bureau of Land Management, 2000).

notice level operation   A mining or exploration operation on BLM land involving more than casual use but requiring that the operator submit only a notice rather than a plan of operations. It is limited to an area of disturbance of 5 or fewer acres (National Research Council, 1999).

O

open-pit mining   A surface mining method in which overlying rock and soil are removed to expose an ore body, which is then drilled, blasted, and hauled from the pit (Bureau of Land Management, 2000).

operations   All functions, work, facilities, and activities on public lands in connection with prospecting, exploration, discovery, and

assessment work, development, extraction, and processing of mineral deposits locatable under the mining laws; reclamation of disturbed areas; and all other reasonably incident uses, whether on a mining claim or not, including the building of roads, transmission lines, pipelines, and other means of access across public lands for support facilities.

operator   Any person who manages, directs, or conducts mining operations at a project area, including a parent entity or an affiliate who materially participates in such management, direction, or conduct. An operator on a particular mining claim may also be the mining claimant (Bureau of Land Management, 2000).

ore   The naturally occurring material from which a mineral or minerals of economic value can be extracted profitably or to satisfy social or political objectives (National Research Council, 1999).

ore body   A mineralized mass whose characteristics have been determined and deemed commercially viable. The term ore body is used once the economic limits of the mineralized mass and its grade have been examined (Bureau of Land Management, 2000).

ore reserves   The part of a mineral deposit that can be profitably mined. Use of this term implies detailed knowledge of all the geological, engineering, economic, and environmental parameters that might affect the profitability of an operation. For a new mining project or for the mining of new zones in an existing mine, a formal feasibility study is conducted to evaluate all the project's parameters (Bureau of Land Management, 2000).

ore deposit   A mineral deposit of high enough quality to be mined at a profit (Bureau of Land Management, 2000).

P

patent   The instrument by which the Federal Government conveys title to public lands (Bureau of Land Management, 2000).

placer claim   A mining claim located on gravel or ground whose mineral contents are extracted by the use of water (Bureau of Land Management, 2000).

placer deposit   A mass of gravel, sand, or similar material resulting from the crumbling and erosion of solid rocks containing particles of gold or other valuable minerals that have been derived from rocks or veins (Bureau of Land Management, 2000).

placer mining   A method of mining in which the overburden is removed to expose gold-bearing gravel deposits beneath. The gravel is then sluiced to separate the gold (Bureau of Land Management, 2000).

placer   An alluvial deposit of sand and gravel containing valuable minerals such as gold (Bureau of Land Management, 2000).

plans of operations   Plans for mining exploration or development on BLM land involving more than 5 acres or a plan for mining where the operator with preexisting, valid claims intends to mine in an area of critical environmental concern or a wilderness area. Also a plan required for mining or exploration on U.S. Forest Service lands whenever the U.S. Forest Service determines that the operation will result in "significant" disturbance of the land surface (National Research Council, 1999).

precious metal   A general term for gold, silver, or any of the metals of the platinum group (Bureau of Land Management, 2000). Any of several relatively scarce and valuable metals, such as gold, silver, and the platinum-group metals (National Research Council, 1999).

priority habitat management area (PHMA)   BLM-administered lands as having the highest habitat value for maintaining sustainable sage-grouse populations. These areas are larger than the SFAs.

project area   The area of land on which an operator conducts mining operations, including the area needed for building or maintaining of roads, transmission lines, pipelines, or other means of access (Bureau of Land Management, 2000).

public lands   Any land and interest in land owned by the United States and administered by the Secretary of the Interior through the Bureau of Land Management, without regard to how the United States acquired ownership, except for (1) land located on the Outer Continental Shelf and (2) land held for the benefit of Indians, Aleuts, and Eskimos (Bureau of Land Management, 2000).

Public Lands Survey System (PLSS) boundary or "study area"   The aggregate of all townships shown at various times since October 2015 on BLM Web sites, the Records of Decision (Bureau of Land Management, 2015a, b), or in written communication from BLM (Anthony Titolo, April 20, 2016) as those that include the "**withdrawal areas**."

R

rare earth metals   A group of widely distributed metals consisting of the elements scandium, yttrium, and 15 elements of atomic numbers 57 to 71, inclusive. These metals have the same arrangement of the two external shells of electrons in their atoms and resemble one another closely in chemical and physical properties, being thus most difficult to separate from each other. It is for this property, rather than their actual rarity in nature, that they are so described (Bureau of Land Management, 2000).

record of decision (ROD)   A document signed by a responsible official recording a decision that was preceded by the preparing of an environmental impact statement (Bureau of Land Management, 2000).

reserve   "That portion of a mineral resource from which a mineral commodity can be economically and legally extracted at the time of determination (after USGS Circular 831, p. 2)" (Bureau of Land Management, 1985).

resource management plan (RMP)   A BLM planning document, prepared in accordance with Section 202 of the Federal Land Policy and Management Act that presents systematic guidelines for making resource management decisions for a resource area. An RMP is based on an analysis of an areas' resources, their existing management, and their capability for alternative uses. RMPs are issue oriented and developed by an interdisciplinary team with public participation (Bureau of Land Management, 2000).

S

sagebrush focal area or "SFA"   FWS has identified as important landscape blocks with high breeding-population densities of greater sage-grouse (*Centrocercus urophasianus*), existing high quality sagebrush habitat, and a preponderance of Federal ownership or protected area that serves to anchor the conservation value of the landscape. "The BLM and USFS plans will focus the highest protections in the SFAs." (http://www.blm.gov/wo/st/en/prog/more/sagegrouse/documents_and_resources.html)

salable minerals   A legal term that defines mineral commodities that are sold by contract from the Federal Government. These are generally construction materials and aggregates. (National Research Council, 1999). See appendix 1.

segregation   Any act such as a withdrawal or exchange that suspends the operation of the public land laws. See **withdrawal** (Bureau of Land Management, 2000).

SFA   Sagebrush Focal Area

strategic minerals   Minerals essential to the national defense for the supply of which during war we are wholly or partly dependent on sources outside the continental limits of the United States, and for which strict measures are needed to control conservation and distribution. See **critical minerals** (Bureau of Land Management, 2000).

study area   See **Public Lands Survey System (PLSS) boundary**

T

trace metals   Metals that are present in small concentrations (Bureau of Land Management, 2000).

troy ounce   A unit of measure based on troy weight (12 ounces to a pound) and equal to 1.09714 avoirdupois ounces. (An avoirdupois ounce is the conventional U.S. weight measure in which 16 ounces equal 1 pound.)

tunnel site claim   A mining claim located to secure an area for a tunnel. A tunnel site claim may be located on land where a tunnel is run to develop a vein or lode, or for intersecting unknown veins or lodes. See **location** and **mining claim** (Bureau of Land Management, 2000).

U

uncommon variety minerals   On the Federal lands stone, gravel, pumice, pumicite, and cinder deposits that have distinct and special properties making them commercially valuable for use in a manufacturing, industrial, or processing operation. Such minerals are locatable under the General Mining Act of 1872, as amended. In determining a deposit's commercial value, the following factors may be considered: quality and quantity of the deposit, geographic location, accessibility to transportation, and proximity to market or point of use (National Research Council, 1999).

USFS   U.S. Forest Service.

USGS   U.S. Geological Survey.

wilderness area   A congressionally designated area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, that is protected and managed to preserve its natural conditions and that (1) generally appears to have been affected mainly by the forces of nature, with human imprints substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least 5,000 acres or is large enough to make practical its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historic value (Bureau of Land Management, 2000).

wilderness study area   On BLM-managed lands, a roadless area that has been inventoried (but not designated by Congress) and found to have wilderness characteristics as described in Section 603 of the Federal Land Policy and Management Act of 1976 (FLPMA; Pub. L. 94–579; 90 Stat. 2743) and section (c) of the Wilderness Act of 1964 (PUB. L. 88–577). BLM manages wilderness study areas to protect their wilderness characteristics until Congress decides whether to designate them as wilderness (Bureau of Land Management, 2000).

withdrawal areas, or "withdrawals"   Informal term used within these reports to identify those Federal lands within the Sagebrush Focal Areas (SFAs) that are proposed for closure to locatable mineral entry subject to valid existing rights. The proposed withdrawal areas are a subset of lands within the larger SFAs.

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Appendixes 1–5

Appendix 1. List of Locatable, Leasable, and Salable Minerals

[BLM, Bureau of Land Management]

Mineral commodity	BLM designation	Comment
		Primarily locatable minerals
Aluminum	Locatable	None
Antimony	Locatable	None
Barite	Locatable	None
Bentonite	Locatable	None
Beryllium	Locatable	None
Bismuth (byproduct)	Locatable	None
Building stone	Locatable or salable	Not all building stone is locatable. Much building stone requires a mineral material sale contract. The determination is made by a BLM Certified Examiner.
Calcium borates	Locatable	Calcium borates are locatable minerals. Sodium borates are leasable minerals.
Carbon	Locatable	Carbon is not usually a metal in the Mendeleev Periodic Chart of the Elements. It is included in this list as a metal because of its metallic properties, such as being a conductor of electricity, which is useful in certain green energy batteries. Carbon is also locatable as an industrial mineral, and as diamond.
Chromium	Locatable	None
Cobalt	Locatable	None
Decorative stone	Locatable or salable	Most decorative stone requires a mineral material sales contract. Only uncommon varieties of decorative stone may be acquired using mining claims.
Diamond	Locatable	None
Diatomite	Locatable	None
Fluorspar	Locatable	Also known as fluorite.
Gallium	Locatable	None
Garnet	Locatable	None
Gemstones	Locatable or salable	Most nonprecious and semiprecious gemstones require a mineral material sale contract. But most production comes from hobby collection on mining claims.
Geodes	Primarily salable	Geodes are seldom locatable. Only uncommon varieties of geodes are.
Gypsum	Locatable	None
Iron	Locatable	None
Lead	Locatable	None
Limestone	Locatable or salable	None
Lithium	Locatable	Lithium is locatable in solid mineral form, such as lepidolite and hectorite, and also in ionic form in subsurface brines.
Magnesium	Locatable	None
Mercury	Locatable	None
Mica	Locatable	None
Mineral Specimens	Rarely locatable	Mineral specimens are seldom locatable. Only uncommon varieties of geodes are considered locatable.
Niobium	Locatable	Also called columbium.
Perlite	Locatable	None
Platinum-group metals	Locatable	Platinum-group metals (PGMs) commonly occur together and include platinum, palladium, rhodium, ruthenium, osmium, and iridium.
Pozzolan	Locatable	Pozzolan is a naturally occurring additive to concrete. When pozzolan meets specifications, it increases the strength of the resulting structure. Pozzolan can generally replace portland cement in the concrete by about one-to-one. Doing so reduces the emission of carbon dioxide (CO_2) during the production of the portland cement. Not a specific mineral; can be from volcanic ash, pumice, or diatomaceous earth.
Pumice (greater than 2 inches diameter)	Locatable	By Act of Congress, to be locatable, pumice must have at least one dimension that is 2 inches or larger.

Mineral commodity	BLM designation	Comment
		Primarily locatable minerals—Continued
Rare Earth Elements	Locatable	Elements commonly referred to as rare earths include yttrium, scandium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium.
Silica and Silica Sand (high purity or uncommon variety)	Locatable	Silica must be high purity, suitable for an uncommon use. Silica sand must be an uncommon variety, such as proppant sand for hydrofracking.
Silver	Locatable	None
Sulfur	Locatable or leasable	None
Tantalum	Locatable	None
Tellurium	Locatable	None
Thorium	Locatable	None
Tin	Locatable	None
Titanium	Locatable	None
Travertine	Locatable	None
Tungsten	Locatable	None
Uranium	Locatable	None
Vanadium	Locatable	None
Vermiculite	Locatable	None
Zeolite	Locatable	None
Zinc	Locatable	None
Zirconium	Locatable	None
		Leasable minerals
Bituminous rock	Leasable	None
Coal	Leasable	None
Geothermal energy	Leasable	None
Native asphalt	Leasable	None
Oil and gas	Leasable	None
Phosphate	Leasable	None
Potash	Leasable	None
Solid and semisolid bitumen	Leasable	None
Sulfur	Leasable	None
Iodides	Leasable	None
Helium	Leasable	None
Magnesium evaporites	Leasable	Or "bitterns"
		Primarily salable minerals
Sand	Salable	None
Stone	Salable	None
Gravel	Salable	None
Pumice	Salable	None
Pumicite	Salable	None
Cinders	Salable	None
Clay (common)	Salable	None
Decorative stone	Salable	None
Building stone (common)	Locatable or salable	None
Gemstones	Locatable or salable	None
Limestone	Locatable or salable	None

Appendix 2. Mineral-Potential Classification System

The approach to classification of the qualitative mineral-resource potential for locatable minerals followed that prescribed in Bureau of Land Management (BLM) Manual Sections 3031 and 3060 defined originally by Goudarzi (1984).

Level of Potential

N. The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

L. The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.

H. The geologic environment, the inferred geologic processes, the reported mineral occurrences and (or) valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The "known mines and deposits" do not have to be within the area that is being classified but have to be within the same type of geologic environment.

ND. Minerals potential not determined due to lack of useful data. This does not require a level of certainty qualifier.

Level of Certainty

A. The available data are insufficient and (or) cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.

B. The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C. The available data provide direct but quantitatively minimal evidence to support or refute the possible existence of mineral resources.

D. The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

For the determination of "no potential" use N/D. This class shall be seldom used, and when used it should be for a specific commodity only. For example, if the available data show that the surface and subsurface types of rock in the respective area is batholithic (igneous intrusive), one can conclude, with reasonable certainty, that the area does not have potential for coal.

As used in this classification, potential refers to potential for the presence (occurrence) of a concentration of one or more energy and (or) mineral resources. It does not refer to or imply potential for development and (or) extraction of the mineral resource(s). It does not imply that the potential concentration is or may be economic, that is, could be extracted profitably.

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	A	B	C	D
H	**H/A** High potential with insufficient evidence	**H/B** High potential with indirect evidence Contains 2 or more of the following: Attractive exploration targets. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**H/C** High potential with direct evidence Contains 2 or more of the following: Minor past production. Attractive exploration targets. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**H/D** High potential with abundant direct and indirect evidence Contains 2 or more of the following: Current production/significant inventor. Significant past production. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.
		← Permissive host rocks +/- previous assessment →		
M	**M/A** Moderate potential with insufficient evidence	**M/B** Moderate potential with indirect evidence Contains 1 or more of the following: Attractive exploration targets. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**M/C** Moderate potential with direct evidence Contains 1 or more of the following: Minor past production. Attractive exploration targets. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**M/D** Moderate potential with abundant direct and indirect evidence Contains 1 or more of the following: Current production/significant inventory. Significant past production. Active or pending notices or mine plans. Numerous active claims. USMIN active exploration. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.
		← Permissive host rocks +/- previous assessment →		
L	**L/A** Low potential with insufficient evidence	**L/B** Low potential with indirect evidence No active exploration. No claims. No other applicable data.	**L/C** Low potential with direct evidence Historic mining. Historic claims. No active notices or mine plans. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.	**L/D** Low potential with abundant direct and indirect evidence Few active claims. Historic mining. No USMIN active exploration. No active notices or mine plans. Prospects, geochemical anomaly, geophysical anomaly, and (or) related deposit type.
		← Permissive host rocks +/- previous assessment →		
N				**N/D** No potential Reserved for a specific type of resource in a well-defined area. For example, it is appropriate to say that there is no oil potential in an area where the only rocks present are unfractured Precambrian granite, but the term "low" is appropriate if there is a slight possibility for the presence of resources.

Level of resource potential →

Level of certainty →

Appendix 3. Mineral-Deposit Models

Concise mineral-deposit models for the mineral-deposit types that were considered for the Sagebrush Mineral-Resource Assessment (SaMiRA) study are included in this appendix, grouped by the mineral systems adopted for this study. See section H for a discussion of mineral systems and mineral deposits. These mineral-deposit models are based on the references cited for each model. See the complete reference for additional information on the deposit type. The table that accompanies this appendix contains additional information about these deposit types such as an association of the deposit type with metallic or nonmetallic commodities and strategic or critical minerals (table 3-1). In addition, the most common mining methods associated with each deposit type are listed using Bureau of land management (BLM) mining method classifications (A. Merrill, written commun., May 2016). The last two columns of the table list median tonnages and references for the deposit types that have published tonnage models. The populations of deposits used to construct the cited tonnage models may or may not be appropriate for the study area; these are simply provided as a general guide to the order of magnitude of tonnages typically associated with the deposit type throughout the world. (Note that chemical symbols used in the tables below are defined in the front matter of this report.)

Table 3-1. Typical mining methods for mineral-deposit types assessed within the Sagebrush Mineral-Resource Assessment (SaMiRA) study areas.

[Deposit types are grouped by mineral system. X, typical mining method; -, unlikely mining method; median ore tonnage based on a population of well-characterized deposits of the type; see individual models for median tonnage source references]

Deposit types in the study area	Metallic/ nonmetallic	Contains strategic or critical materials	Industrial mineral mine	Casual use/ suction dredging (<5 acres)	Placer mining, small (<5 acres)	Placer mining, large (>5 acres)	Open pit mine, small (<5 acres)	Open pit mine, large (>5 acres)	Underground mine, small (<5 acres)	Underground mine, large (>5 acres)	Median ore tonnage, in million metric tons	Median tonnage source
Magmatic–directly related to igneous processes												
Diatreme-hosted diamond	Nonmetallic	No	-	-	-	-	X	X	-	X	26	Bliss (1992)
Basalt-hosted sunstone	Nonmetallic	No	-	-	-	-	X	X	-	-	No data	-
Hydrothermal–plutonic rock associated												
Porphyry copper	Metallic	No	-	-	-	-	-	X	-	Unlikely, if so, block cave	240	Singer and others (2008)
Arc-related porphyry molybdenum (low-fluorine)	Metallic	Yes, molybdenum	-	-	-	-	-	X	-	Unlikely, if so, block cave	94	Cox and Singer (1986)
Climax-type porphyry molybdenum	Metallic	Yes, molybdenum	-	-	-	-	-	X	-	X	200	Cox and Singer (1986)
Copper skarn	Metallic	No	-	-	-	-	X	X	X	X	0.56	Cox and Singer (1986)
Lead-zinc skarn	Metallic	No	-	-	-	-	-	X	-	X	1.4	Cox and Singer (1986)
Molybdenum-tungsten greisen	Metallic	Yes, molybdenum and tungsten	-	-	-	-	-	X	-	X	No data	Cox and Singer (1986)
Tungsten skarn	Metallic	Yes, tungsten	-	-	-	-	-	X	-	X	1.1	Cox and Singer (1986)
Tungsten vein	Metallic	Yes, tungsten	-	-	-	-	X	X	X	X	0.56	Cox and Singer (1986)
Polymetallic replacement	Metallic	No	-	-	-	-	-	X	-	X	1.8	Cox and Singer (1986)
Polymetallic vein	Metallic	Yes, tungsten	-	-	-	-	X	X	X	X	0.0076	Cox and Singer (1986)
Distal disseminated silver-gold	Metallic	No	-	-	-	-	-	X	-	X	7.4	Cox and Singer (1990)
Carlin-type gold-silver	Metallic	No	-	-	-	-	-	X	-	X	5.7	Berger and others (2008)
Hydrothermal–volcanic rock associated												
Epithermal gold-silver (mercury) [includes jasperoid precious metal and epithermal gypsum]	Metallic	Yes, mercury	-	-	-	-	-	X	-	X	Many deposit types in this category	-
Volcanogenic uranium	Metallic	No	-	-	-	-	X	X	X	X	0.34	Cox and Singer (1986)
Stanley district (Idaho)-type uranium	Metallic	No	-	-	-	-	X	-	X	-	No data	-
Volcanic opal and specialty gemstones	Nonmetallic	No	-	-	-	-	X	X	-	X	No data	-
Hectorite (lithium-rich clay) and specialty clays	Metallic	Yes	X	-	-	-	-	X	-	-	No data	-

Table 3-1.—Continued

Deposit types in the study area	Metallic/ nonmetallic	Contains strategic or critical materials	Industrial mineral mine	Casual use/ suction dredging	Placer mining, small (<5 acres)	Placer mining, large (>5 acres)	Open pit mine, small (<5 acres)	Open pit mine, large (>5 acres)	Underground mine, small (<5 acres)	Underground mine, large (>5 acres)	Median ore tonnage, in million metric tons	Median tonnage source
Hydrothermal–exhalative–magmatic processes												
Volcanogenic massive sulfide (Besshi–subtype)	Metallic	No	-	-	-	-	X	X	X	X	0.22	Cox and Singer (1986)
Hydrothermal–exhalative–sedimentary processes												
SEDEX lead-zinc-silver	Metallic	No	-	-	-	-	-	X	-	X	15	Cox and Singer (1986)
Bedded barite	Nonmetallic	No	-	-	-	-	X	X	-	X	1.24	Orris (1992)
Hydrothermal–metamorphic rock associated												
Orogenic low-sulfide gold-quartz veins (tonnage for Chugach–type)	Metallic	No	-	-	-	-	X	X	X	X	0.0032	Bliss (1992)
Sedimentary (formed during or after the conversion from sediment to sedimentary rock)												
Bentonite	Nonmetallic	No	-	-	-	-	X	X	-	-	No data	-
Dolomite (High purity)	Nonmetallic	No	X	-	-	-	X	X	-	-	No data	-
Sediment-hosted stratabound copper	Metallic	No	-	-	-	-	-	X	X	X	10	Zientek and others (2013)
Sandstone uranium (roll-front) in intermontane basins	Metallic	???	-	-	-	-	-	X	-	X	No data	-
Hydroallogenic volcanic-hosted uranium	Metallic	???	-	-	-	-	-	X	-	X	No data	-
Zeolites (closed system subtype)	Nonmetallic	No	-	-	-	-	X	X	-	-	No data	-
Zeolites (open system subtype)	Nonmetallic	No	-	-	-	-	X	X	-	-	No data	-
Sedimentary (formed during deposition of the sediment)												
Banded iron formations (Algoma and Superior subtypes)	Metallic	No	-	-	-	-	-	X	-	X	170	Cox and Singer (1986)
Lacustrine diatomite	Nonmetallic	No	X	-	-	-	X	X	-	-	No data	-
Surficial –mechanical (placer)												
Heavy mineral placer	Metallic	Yes	-	X	X	X	-	-	-	-	No data	-
Placer and paleoplacer gold	Metallic	No	-	X	X	X	-	-	-	-	1.1	Cox and Singer (1986)

Table 3-1.—Continued

Deposit types in the study area	Metallic/ nonmetallic	Contains strategic or critical materials	Industrial mineral mine	Casual use/ suction dredging (<5 acres)	Placer mining, small (<5 acres)	Placer mining, large (>5 acres)	Open pit mine, small (<5 acres)	Open pit mine, large (>5 acres)	Underground mine, small (<5 acres)	Underground mine, large (>5 acres)	Median ore tonnage, in million metric tons	Median tonnage source
Other (non-locatable) mineral-deposit types												
Dimension stone (sandstone and quartzite)	Nonmetallic	No	X	-	-	-	X	X	-	-	No data	-
Sand and gravel	Nonmetallic	No	X	-	-	-	X	X	-	-	No data	-
Volcanic ash (pumice and cinders)	Nonmetallic	No	X	-	-	-	X	X	-	-	No data	-
Perlite	Nonmetallic	No	X	-	-	-	X	X	-	-	No data	-

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Magmatic Systems

Deposit types in the study area
Diatreme-hosted diamond
Basalt-hosted sunstone

Diatreme-Hosted Diamond

[km, kilometer; t, metric ton; g/t, grams per metric ton; ppm, parts per million; Ma, mega-annum or millions of years ago]

Synonyms	Diamond-bearing kimberlite pipes, diamond pipes, group-1 kimberlites.
Commodities	Diamond.
Description	Diamonds in kimberlite diatremes and other alkaline mafic rocks. Kimberlites are volatile-rich, potassic ultrasbasic rocks with macrocrysts (and sometimes megacrysts and xenoliths) set in a fine-grained matrix.

Geological environment	
Rock types	Small hypabyssal intrusions that grade upwards into diatreme breccias near surface and pyroclastic rocks in the crater facies at surface. Kimberlites are volatile-rich, potassic ultrasbasic rocks that commonly exhibit a distinctive inequigranular texture resulting from the presence of macrocrysts (and sometimes megacrysts and xenoliths) set in a fine-grained matrix. The megacryst and macrocryst assemblage in kimberlites includes anhedral crystals of olivine, magnesian ilmenite, pyrope garnet, phlogopite, Ti-poor chromite, diopside, and enstatite. Some of these phases may be xenocrystic in origin. Matrix minerals include microphenocrysts of olivine and one or more of monticellite, perovskite, spinel, phlogopite, apatite, and primary carbonate and serpentine. Kimberlites crosscut all types of rocks.
Age range	Any age except Archean for host intrusions. Economic deposits occur in kimberlites from Proterozoic to Tertiary in age. The diamond ages vary from early Archean to as young as 990 Ma.
Depositional environment	Kimberlites rise quickly from the mantle and are emplaced as multistage, high-level diatremes, tuff-cones and rings, and hypabyssal dikes and sills.
Tectonic setting(s)	Ancient stable cratons, alkalic rock provinces, regions of crustal tension with deep-seated fractures, broad anticlines and synclines with deep-seated fractures, and regions of low geothermal gradient.
Associated deposit types	Diamonds can be concentrated, by weathering to produce residual concentrations, or within placer deposits. Lamproite-hosted diamond deposits form in a similar manner, but the magmas may be of different origin.

Deposit description	
Ore mineralogy	Diamond
Alteration	Serpentinization in many deposits; silicification or bleaching along contacts. Secondary calcite, quartz, and zeolites can occur on fractures. Diamonds can undergo graphitization or resorption.
Ore controls	Kimberlites typically occur in fields comprising as much as 100 individual intrusions, often grouped in clusters. Each field can exhibit considerable diversity with respect to the petrology, mineralogy, mantle xenolith and diamond content of individual kimberlites. Economically diamondiferous and barren kimberlites can occur in close proximity. Controls on the differences in diamond content between kimberlites are not completely understood. They may be due to depths of origin of the kimberlite magmas (above or below the diamond stability field); differences in the diamond content of the mantle sampled by the kimberlitic magma; degree of resorption of diamonds during transport; flow differentiation; batch mixing; or some combination of these factors.
Geochemical signatures	Elevated Ti, Cr, Ni, Mg, Ba and Nb in overlying residual soils. However, caution must be exercised as other alkaline rocks can give similar geochemical signatures.
Geophysical signature	Geophysical techniques are used to locate kimberlites but give no indication as to their diamond content. Ground and airborne magnetometer surveys are commonly used; kimberlites can show as either magnetic highs or lows. In equatorial regions, the anomalies are characterized by a magnetic dipolar signature in contrast to the "bulls-eye" pattern in higher latitudes. Some kimberlites, however, have no magnetic contrast with surrounding rocks. Some pipes can be detected using electrical methods (for example, electromagnetic and very low frequency, resistivity) in airborne or ground surveys. These techniques are particularly useful where the weathered, clay-rich, upper parts of pipes are preserved because they are conductive and may contrast sufficiently with the host rocks to be detected. Ground-based gravity surveys can be useful in detecting kimberlites that have no other geophysical signature and in delineating pipes. Deeply weathered kimberlites or those with a thick sequence of crater sediments generally give negative responses and where fresh kimberlite is found at surface, a positive gravity anomaly may be obtained.

Economic factors	
Grade and tonnage	The amount of diamond contained within diamond bearing pipes is extremely small, with commercially mineable concentrations ranging from .01 ppm to 0.80 ppm (0.04 to 4.0 carats per ton). The clarity, size, shape, color, and volume of diamonds within a pipe need to be carefully determined before the true economic potential of a diamond-bearing pipe can be determined.

| Importance | Major source of gem and industrial diamonds. On a worldwide basis only about 10 percent of known kimberlites are diamond-bearing and only one or two percent of kimberlites contain economic quantities of diamond. |

Other assessment and exploration guides

Indicator minerals are used extensively in the search for kimberlites and are one of the most important tools, other than bulk sampling, to assess the diamond content of a particular pipe. Chrome pyrope and eclogitic garnet, chrome diopside, picroilmenite, chromite and, to a lesser extent, olivine in surficial materials (tills, stream sediments, loam, etc.) indicate a kimberlitic source.

Mineral chemistry is used extensively to help determine whether the kimberlite source is diamondiferous or barren. Diamond-bearing kimberlites can contain high-Cr, low-Ca pyrope garnets (G10 garnets), sodium-enriched eclogitic garnets, high-Cr chromites with moderate to high Mg contents, and magnesian ilmenites.

Examples

| In/near focal areas | Kimberlites occur in north-central Montana; however, only one microdiamond has been reported. |
| Elsewhere | Koala, Panda, Sable, Fox and Misery (Northwest Territories, Canada); Kimberly, Premier and Venetia (South Africa) |

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Basalt-Hosted Sunstone

[t, metric ton; N/A, not applicable]

Synonyms	Gem labradorite feldspar.
Commodities	Sunstone.
Description	Gem-quality labradorite in weathered basalt flows that exhibit adventurescence, a light reflectance phenomenon caused by inclusions of copper (in Oregon) or hematite (other localities).
Geological environment	
Rock types	In Oregon, sunstone occurs locally in a weathered basalt flow that is part of a classic volcanic highland typified by shield volcanoes, cinder cones, large bodies of ashfall tuffs, regionally extensive basalt flows of varying thicknesses, and locally extensive red cinder beds.
Deposit description	
Ore mineralogy	Labradorite
Alteration	Groundmass of gem-bearing zones at the Ponderosa Mine is highly weathered to unconsolidated reddish-brown material.
Ore controls	Sunstone occurs as phenocrysts in a moderately to heavily weathered scoriaceous porphyritic basalt of calcalkaline affinity composed of labradorite feldspar and basaltic glass, with minor olivine and magnetite/ilmenite present as accessory phases. The vesicles are filled to varying amounts with nonspecific clay and feldspar alteration products.
Geochemical signatures	N/A
Geophysical signature	N/A
Economic factors	
Grade and tonnage	At the Ponderosa Mine in Oregon, 500,000 t of ore is estimated to contain 200 t of gem material.
Importance	The premier U.S. gem-quality feldspar is the red labradorite, known as sunstone, mined in Oregon. Large quantities of gem-quality labradorite from deposits in southeastern Oregon for many years. The common color of Oregon sunstone is straw-yellow, it also can be pink, peach, red, salmon red-orange, red-green, and blue-green. It also can be bicolored and tricolored in combinations of yellow, red, and green, and a small percentage is dichroic and trichroic. In 1988, the availability and quality of sunstone, other than the standard yellow Oregon variety, drastically increased with the discovery of the Ponderosa Mine. The vivid-red faceted stones and cabochons from this mine set a new world standard sunstone. The opening of the mine also increased the supply of peach, salmon red-orange, red-green, green, blue-green, and bicolored and tricolored in combinations of yellow, red, and green. For the first time ever, there was a continuous U.S. supply of the more desirable colors in sizes needed by the jewelry industry. The largest faceted high-quality red sunstone is more than 10 carats. The supply from this and other developed deposits will continue to be adequate for many years into the future.
Other assessment and exploration guides	
N/A	
Examples	
In/near focal areas	Ponderosa Mine, Oregon; Dust Devil Mine, Oregon; Sunstone Butte Mine, Oregon.
References	

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Hydrothermal—Plutonic Rock Associated System

Deposit types in the study area
Porphyry copper
Arc-related porphyry molybdenum (low-fluorine)
Copper skarn
Tungsten skarn
Lead-zinc skarn
Polymetallic replacement
Polymetallic vein
Tungsten vein
Molybdenum-tungsten greisen
Distal disseminated silver-gold
Carlin-type gold-silver

Porphyry Copper

[wt.%, weight percent; g/t, grams per metric ton; Mt, million metric tons; avg, average; km, kilometer]

Synonyms	Calkalkaline porphyry.
Commodities	Cu, Mo, Au, Ag.
Description	Porphyry copper deposits consist of disseminated copper minerals and copper minerals in veins and breccias that are relatively evenly distributed in large volumes of rock, forming high tonnage (>100 Mt), low to moderate grade (0.3–2.0 wt.% Cu) ores. Host rocks are altered and genetically related granitoid porphyry intrusions and adjacent wall rocks.
Geological environment	
Rock types	Tonalite to monzogranite or syenitic porphyry intruding granitic, volcanic, calcareous sedimentary, and other rocks.
Textures	Porphyry has closely spaced phenocrysts and microaplitic quartz-feldspar groundmass.
Age range	Mainly Mesozoic and Cenozoic, but may be any age.
Depositional environment	High-level intrusive complexes that commonly include stocks, dikes, and breccia pipes. Many deposits are focused in swarms of porphyry dikes that may radiate from larger intrusions or batholiths. The deposits form at shallow (mostly 6 km or less) depth by fluids exsolved from underlying crystallizing magmas emplaced at greater than 3–10-km depth in the upper crust and by external waters heated by those magmas.
Tectonic setting(s)	Localized in time and space within magmatic arcs along convergent plate margins where subduction of oceanic crust and arc-type magmatism generates hydrous, oxidized upper crustal granitoids genetically related to ores. Arc crust is relatively thick, and there is evidence for broadly coeval compressional or transpressional tectonism.
Associated deposit types	Skarns (Cu, Fe, Au, Zn), polymetallic replacement, polymetallic veins, distal-disseminated Au-Ag, epithermal veins.
Deposit description	
Ore mineralogy	Hypogene: Chalcopyrite+pyrite±molybdenite; chalcopyrite+magnetite±bornite± Au; assemblages may be superposed. Quartz+K-feldspar+biotite±anhydrite; quartz+sericite+clay minerals. Late veins of enargite, tetrahedrite, galena, sphalerite, and barite in some deposits. Supergene: brochantite, copper pitch, cuprite, native copper, tenorite, chrysocolla, neotocite, malachite, and atacamite.
Alteration	Major alteration types are (1) potassic, (2) sericitic, (3) advanced argillic, (4) intermediate argillic, (5) propylitic, (6) sodic-calcic and sodic, (7) greisen, and (8) skarn. Weathering can form an enriched oxide zone above sulfide ore.
Ore controls	Stockwork veins in porphyry, along porphyry contact, and in favorable country rocks such as carbonate rocks, mafic igneous rocks, and older granitic plutons.
Geochemical signatures	Cu+Mo±Au+Ag+W+B+Sr center, Pb, Zn, Au, As, Sb, Se, Te, Mn, Co, Ba, and Rb outer. Locally Hg and Sn form most distal anomalies. High S in all zones. Some deposits have weak U anomalies.
Geophysical signature	Ore zones can be associated with magnetite-rich rocks and are indicated by magnetic surveys. Intensely hydrothermally altered rocks, with quartz-pyrite-sericite (phyllic) alteration produce magnetic and resistivity lows. Pyritic haloes surrounding ore respond well to induced polarization (IP) surveys but in sulfide-poor systems the ore itself provides the only significant IP response.
	Remote sensing: In areas of good exposure with limited vegetation, airborne and spaceborne multispectral and hyperspectral imaging systems can be used to map alteration mineral associations and their spatial relations in porphyry copper systems. Hydrothermal minerals characteristic of sericitic, intermediate and advanced argillic, and propylitic alteration, iron oxides and hydroxides, and silica can be remotely mapped using their distinctive absorption features in the visible near-infrared through short-wave infrared and thermal-infrared wavelengths.
Economic factors	
Grade and tonnage	Cu grades vary from 0.03 to 2 wt.%; avg 0.44 wt.%. Mo grades vary from < 0.001 to 0.1 wt.%; avg 0.019 wt.%. Au varies from 0.001 to 6.6 g/t; avg 0.31 g/t. Ag varies from 0.08 to 65 g/t; avg 3.2 g/t. Tonnages range from 2 to 21,000 Mt.
Importance	Porphyry copper deposits supply about 60 percent of the world's copper.
Examples	
In/near focal area	Contact, Nevada.
Elsewhere	Bingham, Utah; Yerington and Ann Mason, Nevada; Butte, Montana.
References	

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Arc-Related Porphyry Molybdenum (low fluorine)

[wt.%, weight percent; Mt, million metric tons]

Synonyms	Low-fluorine stockwork molybdenum, fluorine-poor, granodiorite-type, calcalkaline-type, differentiated monzogranite class, Endako-type, subduction-related porphyry molybdenum, porphyry molybdenum.
Commodities	Mo, W.
Description	Stockwork of molybdenite-bearing quartz veinlets and fractures in intermediate to felsic intrusive rocks and associated country rocks. Deposits are low grade but large and amenable to bulk mining methods.

<p align="center">Geological environment</p>

Rock types	Diorite to granite (mostly 65–77 wt.% SiO_2, most commonly quartz monzonite and granodiorite. Generally, peraluminous I-type granitoids.
Textures	Ore is predominantly structurally controlled; mainly stockworks of crosscutting fractures and quartz veinlets, also veins, vein sets, and breccias
Age range	Mostly Late Jurassic through Tertiary in the western cordillera of North America.
Depositional environment	High-level to subvolcanic felsic intrusive centers; multiple stages of intrusion are common. Typically, deeper-seated settings than for porphyry copper deposits.
Tectonic setting(s)	Subduction-related magmatic arcs at convergent plate margins. Close association with calcalkalic continental magmatic arcs; deposits form almost exclusively within continental crust.
Associated deposit types	Mo-bearing skarns, Ag-Pb-Zn veins.

<p align="center">Deposit description</p>

Ore mineralogy	Molybdenite. Chalcopyrite, scheelite, and galena are generally subordinate.
Alteration	Core zone of potassic and silicic alteration characterized by hydrothermal K-feldspar, biotite, quartz, ±anhydrite. K-feldspar and biotite commonly occur as alteration selvages on mineralized quartz veinlets and fractures but may be pervasive in areas of intense fracturing and mineralization.
	Phyllic alteration typically surrounds and may be superimposed to various degrees on the potassic-silicic core; it consists mainly of quartz, sericite and carbonate. Phyllic alteration is commonly pervasive and may be extensive.
	Propylitic alteration (chlorite and epidote) may extend for hundreds of meters beyond the zones of potassic- silicic and phyllic alteration.
	Argillic alteration, where present, characterized by clay minerals (kaolinite) typically overprinted on the other types of alteration
Ore controls	Quartz veinlet and fracture stockwork zones superimposed on intermediate to felsic intrusive rocks and surrounding country rocks; multiple stages of mineralization common.
Geochemical signatures	Pathfinder elements: Mo, Se, Re, As, Pb, Zn. Stream-sediment anomalies: Mo, W, F, Cu, Pb, Zn, Ag. Heavy mineral concentrates: Mo, W, Pb.
Geophysical signature	Ring of magnetic high anomalies may be present around a deposit if magnetite- or pyrrhotite-bearing hornfels or skarn occurs. Radiometric surveys may show potassic alteration zones. Overall low total sulfide content (generally <5 volume percent) reduces the usefulness of many geophysical methods; in many aspects, signatures of barren intrusions resemble those of productive intrusions.

<p align="center">Economic factors</p>

Grade and tonnage	Deposits are low-grade (0.03–0.22 wt.% Mo), but large (commonly >50 Mt), which makes them amenable to bulk-mining open-pit methods. Typical size is 100 Mt at 0.1 to 0.2 wt.% Mo.
Importance	Porphyry Mo deposits associated with low-F felsic intrusive rocks are a major source of world molybdenum production. Essentially all Mo production in the United States and Canada comes from these and from porphyry Cu-Mo-Au deposits.

<p align="center">Other assessment and exploration guides</p>

Magmatic belts that formed above subduction zones along convergent plate boundaries, in regions that already have discovered deposits and prospects.

Known arc-related porphyry molybdenum deposits are found in mountain belts where known porphyry copper mineralization also is located. However, many mountain belts where porphyry copper deposits are found do not contain any, as of yet discovered, arc-related porphyry molybdenum deposits.

Potassic alteration grading outward or upward into phyllic alteration is a diagnostic feature.

<p align="center">Examples</p>

In/near focal areas	Thompson Creek, Idaho.
Elswhere	Cannivan Gulch, Montana; Endako, British Columbia.

<p align="center">References</p>

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Copper Skarn

[wt.%, weight percent; Mt, million metric tons]

Synonyms	Pyrometasomatic and contact metasomatic copper deposits.
Commodities	Cu, Au, Ag, Mo, W, magnetite.
Description	Cu-dominant mineralization (generally chalcopyrite) genetically associated with a skarn gangue (includes calcic and magnesian Cu skarns).

Geological environment

Rock types	Tonalite to monzogranite intruding carbonate rocks or calcareous clastic rocks.
Age range	Mainly Mesozoic, but may be any age.
Depositional environment	Miogeosynclinal sequences intruded by felsic plutons.
Tectonic setting(s)	Most common where Andean-type plutons intrude older continental-margin carbonate sequences. Can be associated with oceanic island arc plutonism. Commonly associated with porphyry copper deposits intrusive into carbonate rocks.
Associated deposit types	Porphyry Cu deposits, other skarns (Au, Fe, Zn-Pb), and replacement Pb-Zn-Ag deposits.

Deposit description

Ore mineralogy	Moderate to high sulfide content. Chalcopyrite ± pyrite ± magnetite in inner garnet-pyroxene zone. Bornite ± chalcopyrite ±sphalerite ± tennantite in outer wollastonite zone. Hematite, pyrrhotite, or magnetite may predominate (depending on oxidation state). Scheelite and traces of molybdenite, bismuthinite, galena, cosalite, arsenopyrite, enargite, tennantite, loellingite, cobaltite, and tetrahedrite may be present.
Alteration	Diopside+andradite center; wollastonite+tremolite outer zone; marble peripheral zone. Igneous rocks may be altered to epidote+pyroxene+garnet (endoskarn). Retrograde alteration to actinolite, chlorite, and clays may be present.
Ore controls	Irregular or tabular ore bodies tend to form in carbonate rocks and (or) calcareous volcanic rocks or tuffs near igneous contacts. Pendants within igneous stocks can be important. Cu mineralization is present as stockwork veining and disseminations in both endo and exoskarn; it commonly accompanies retrograde alteration.
Geochemical signatures	Rock analyses may show Cu-Au-Ag-rich inner zones grading outward through Au-Ag zones with high Au:Ag ratios to an outer Pb-Zn-Ag zone. Co-As-Sb-Bi-Mo-W geochemical anomalies are present in the more reduced Cu skarn deposits.
Geophysical signature	Magnetics: plutons, batholiths, and regional geology/structure can be imaged. Oxidized plutons generally produce mag highs, whereas reduced plutons produce mag lows. Highs/lows also depend on contrast with host rocks. More oxidized in island-arc versus continental arc. Thick sedimentary pile of host rocks may reduce magmas during assimilation, thereby reducing magnetic response. Magnetite may be produced (sodic-calcic, K-feldspar, propylitic zones) or destroyed (phyllic and argillic, advanced argillic zones) during hydrothermal alteration processes, but regional geophysical surveys are unlikely to see hydrothermal system because of low resolution. Gravity: regional geology/structure. Radiometrics: lithology and hydrothermal alteration potassium enrichment (Th/K).

Economic factors

Grade and tonnage	Average 1 to 2 wt.% copper. Worldwide, they generally range from 1 to 100 Mt, although some exceptional deposits exceed 300 Mt.
Importance	Historically, these deposits were a major source of copper, although porphyry deposits have become much more important. However, major Cu skarns are still worked throughout the world, including in China and the United States.

Other assessment and exploration guides

Limestone/carbonate rocks proximal to calcalkaline intrusive complexes.
Limestone converted to marble.
Porphyry copper deposits; many skarns are porphyry-copper related.
Endoskarn alteration in intrusions; hornfels around intrusions.
Close proximity to stock contacts with oxidized skarn mineralogy dominated by andraditic garnet.
Zoning from garnet near the pluton to pyroxene to vesuvianite or wollastonite at the marble contact.

Examples

In/near focal areas	Contact, Nevada; Empire Mine, Idaho.
Elsewhere	Carr Fork, Utah; Mason Valley, Copper Canyon, and Victoria, Nevada.

References

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Tungsten Skarn

[wt.%, weight percent; Mt, million metric tons]

Synonyms	Pyrometasomatic or contact metasomatic tungsten deposits.
Commodities	W, Mo, Cu, Sn, Zn.
Description	Scheelite-dominant mineralization genetically associated with a skarn gangue.

Geological environment	
Rock types	Pure and impure limestones, calcareous to carbonaceous pelites. Associated with tonalite, granodiorite, quartz monzonite and granite of both I- and S-types. W skarn-related granitoids, compared to Cu skarn- related plutonic rocks, tend to be more differentiated, more contaminated with sedimentary material, and have crystallized at a deeper structural level.
Age range	Mainly Mesozoic, but may be any age.
Depositional environment	Contacts and roof pendants of batholith and thermal aureoles of apical zones of stocks that intrude carbonate rocks.
Tectonic setting(s)	Continental margin, synorogenic plutonism intruding deeply buried sequences of eugeoclinal carbonate-shale sedimentary rocks. Can develop in tectonically thickened packages in back-arc thrust settings.
Associated deposit types	Other skarn types (Sn, Mo, Zn-Pb, W).

Deposit description	
Ore mineralogy	Scheelite ± molybdenite ± chalcopyrite ±pyrrhotite ± sphalerite ± arsenopyrite ± pyrite ± powellite. May contain trace wolframite, fluorite, cassiterite, galena, marcasite and bornite. Reduced types are characterized by pyrrhotite, magnetite, bismuthinite, native bismuth and high pyrrhotite:pyrite ratios. Variable amounts of quartz-vein stockwork (with local molybdenite) can cut both the exoskarn and endoskarn.
Alteration	Exoskarn alteration: Inner zone of diopside-hedenbergite±grossular-andradite±biotite±vesuvianite, with outer barren wollastonite-bearing zone. An innermost zone of massive quartz may be present. Late stage spessartine±almandine±biotite±amphibole±plagioclase±phlogopite±epidote±fluorite±sphene. Exoskarn envelope can be associated with extensive areas of biotite hornfels. Endoskarn alteration: Pyroxene±garnet±biotite±epidote±amphibole±muscovite±plagioclase±pyrite±pyrrhotite±trace tourmaline and scapolite; local greisen developed.
Ore controls	Carbonate rocks in extensive thermal aureoles of intrusions; gently inclined bedding and intrusive contacts; structural and (or) stratigraphic traps in sedimentary rocks and irregular parts of the pluton/country rock contacts.
Geochemical signatures	W, Cu, Mo, As, Bi, and B. Less commonly Zn, Pb, Sn, Be, and F.
Geophysical signature	Magnetic and induced polarization surveys can be used to outline the surface projection of ore bodies because magnetite, pyrrhotite, and other sulfide minerals are common in these deposits. Although skarns typically have a positive density contrast relative to adjacent intrusions and carbonate rocks, gravity surveys are not commonly used due to high cost and nonspecificity for ore. Remote-sensing techniques can effectively identify carbonate terranes and iron enrichment in skarns if skarn is exposed. In some cases, contacts between intrusions and sedimentary rocks can be mapped and carbonate rocks can be distinguished from noncarbonate rocks.

Economic factors	
Grade and tonnage	Grades range between 0.4 and 2 wt.% WO_3 (typically 0.7 wt.%). Deposits vary from 0.1 to >30 Mt.
Importance	Historically, skarn deposits have accounted for nearly 60 percent of the Western world's tungsten production.

Other assessment and exploration guides

Reduced W skarns form in carbonaceous rocks and (or) at greater depth.

Oxidized W skarns form in hematitic or noncarbonaceous rocks, and (or) at shallower depths.

Late retrograde alteration is an important factor in many W skarns because, during retrogression, the early low-grade mineralization is often scavenged and redeposited into economic high-grade ore zones.

Dolomitic rocks tend to inhibit the development of W skarns; consequently, magnesian W skarns are uncommon.

Examples	
In/near focal areas	None.
Elsewhere	Osgood Range, Nevada; Pine Creek, California.

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Lead-Zinc Skarn

[wt.%, weight percent; Hd, hedenbergite; Jo, johannsenite; Mt, million metric tons; m, meter; CSAMT, controlled-source audiofrequency magnetotellurics]

Synonyms	Pyrometasomatic or contact metasomatic Pb-Zn deposits.
Commodities	Pb, Zn, Ag, (Cu, Cd, W, Au).
Description	Galena and (or) sphalerite-dominant mineralization genetically associated with a skarn gangue.
Geological environment	
Rock types	Host rocks vary from high-level skarns in thick limestones, calcareous tuffs and sediment to deeper level skarns in marbles and calcsilicate-bearing migmatites. Associated intrusive rocks are granodiorite to leucogranite, diorite to syenite (mostly quartz monzonite). Pb-Zn skarns tend to be associated with small stocks, sills and dikes and less commonly with larger plutons. The composition of the intrusions responsible for many distal Pb-Zn skarns is uncertain.
Age range	Mainly Mesozoic.
Depositional environment	Commonly occur along igneous or stratigraphic contacts, as subvertical chimneys or veins along faults and fissures, and as subhorizontal blankets. Pb-Zn skarn deposits formed either at higher structural levels or distal to the intrusions tend to be larger and more Mn- rich compared to those formed at greater depths or more proximal.
Tectonic setting(s)	Plutonism. Pb-Zn skarns occur at a wide range of depths, being associated with subvolcanic aphanitic dikes and high-level breccia pipes, as well as deep-level batholiths.
Associated deposit types	Porphyry Cu deposits, other skarns (Au, Fe, Zn-Pb), and replacement Pb-Zn-Ag deposits
Deposit description	
Ore mineralogy	Sphalerite±galena±pyrrhotite±pyrite±magnetite±arsenopyrite±chalcopyrite±bornite. Other trace minerals reported include scheelite, bismuthinite, stannite, cassiterite, tetrahedrite, molybdenite, fluorite, and native gold. Proximal skarns tend to be richer in Cu and W, whereas distal skarns contain higher amounts of Pb, Ag, and Mn.
Alteration	Exoskarn alteration: Mn-rich hedenbergite ($Hd_{30–90}$, $Jo_{10–50}$), andraditic garnet ($Ad_{20–100}$, $Spess_{2–10}$) ±wollastonite±bustamite±rhodonite. Late-stage Mn-rich actinolite± epidote±ilvaite±chlorite±dannermorite±rhodochrosite±axinite. Endoskarn alteration: Highly variable in extent of development, and in many of the distal Pb-Zn skarns the nature of the endoskarn is unknown. However, Zn-rich skarns formed near stocks are often associated with abundant endoskarn that may equal or exceed the exoskarn. Endoskarn mineralogy is dominated by epidote±amphibole±chlorite±sericite with lesser rhodonite±garnet± vesuvianite±pyroxene±K-feldspar±biotite and rare topaz. Marginal phases may contain greisen and (or) tourmaline.
Ore controls	Carbonate rocks, particularly along structural and (or) lithologic contacts (shale-limestone contacts or pre-ore dikes). Deposits may occur considerable distances (100–1,000 m) from the source intrusions.
Geochemical signatures	Pb, Zn, Ag, Cu, Mn, As, Bi, W, F, Sn, Mo, Co, Sb, Cd, and Au
Geophysical signature	Generally good induced polarization response. Galena-rich ore bodies may be marked by gravity anomalies whereas pyrrhotite-rich mineralization may be detected by magnetic surveys. CSAMT may also be a useful exploration system.
Economic factors	
Grade and tonnage	Pb-Zn skarns tend to be small (<3 Mt) but can reach 45 Mt, grading as much as 15 wt.% Zn, 10 wt.% Pb and > 150 g/t Ag with substantial Cd. Cu grades are generally < 2 wt.%. Some deposits contain Au.
Importance	Important past and current producers exist in Mexico, China, United States (New Mexico and California), and Argentina.
Other assessment and exploration guides	

Thick limestones distal to small granitoid stocks.
Structural traps and lithological contacts.
Exoskarns with low garnet/pyroxene ratios.
Mn-rich pyroxenes.

Examples	
In/near study area	White Knob Mine and Champion Group, Idaho.
Elsewhere	Hanover-Fierro district, New Mexico.
References	

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Polymetallic Replacement

[wt.%, weight percent; Mt, million metric tons; SEDEX, sedimentary exhalative deposits]

Synonyms	Manto.
Commodities	Ag, Pb, Zn, Cu (byproduct Au, Sn, Bi).
Description	Hydrothermal, epigenetic, Ag, Pb, Zn, Cu minerals in massive lenses, pipes in limestone, dolomite, or other soluble rock near igneous. Most massive ore contains more than 50 percent sulfide minerals.

Geological environment

Rock types	Hosted by limestone and dolostone. The carbonates are typically within a thick sediment package with siliciclastic rocks that is cut by granite, quartz monzonite, and other intermediate to felsic hypabyssal, porphyritic lithologies. There may be volcanic rocks in the sequence, or more commonly above, which are related to the intrusive rocks.
Age range	Many are late Mesozoic to early Cenozoic; age is not important.
Depositional environment	Carbonate host rocks that commonly occur in broad sedimentary basins, such as epicratonic shelf. Replacement by solutions emanating from volcanic centers and epizonal plutons. Calderas may be favorable. Can be distal to skarns and intrusions.
Tectonic setting(s)	Intrusions emplaced into miogeoclinal to platformal, continental settings. Most deposits occur in mobile belts that have undergone moderate deformation and have been intruded by small plutons.
Associated deposit types	Base-metal skarns, porphyry Cu.

Deposit description

Ore mineralogy	Sphalerite, galena, pyrite, chalcopyrite, marcasite; arsenopyrite, pyrargyrite/proustite, enargite, tetrahedrite, geocronite, electrum, digenite, jamesonite, jordanite, bournonite, stephanite, polybasite, rhodochrosite, sylvanite, calaverite. Chimneys may be more Zn-rich, Pb-poor than manto deposits.
Alteration	Limestone wallrocks are commonly dolomitized and (or) silicified, whereas shale and igneous rocks are argillized and chloritized. Jasperoid occurs in some U.S. examples.
Ore controls	The irregular shapes of these deposits and their occurrence in carbonate hosts emphasize the importance of ground preparation in controlling fluid channels and depositional sites. Controls include faults, fault intersections, fractures, anticlinal culminations, bedding channelways (lithologic contrasts), karst features and pre-existing permeable zones. In several districts karst development associated with unconformities is believed to have led to development of open spaces subsequently filled by ore. Some deposits are spatially associated with dikes.
Geochemical signatures	Elevated Pb-Zn±Cu±Au±Ag±Mo±As±Bi±Sb. In some districts, ore proximal to igneous intrusions is Cu- and Au rich, and grades laterally (and sometimes vertically) into Pb-Zn-Ag ore. A distal, Mn-enriched zone is present in some districts. Elevated Ba and Ag in jasperoid.
Geophysical signature	Magnetics: Igneous intrusions at depth may be imaged. Felsic character suggests a low magnetic response. Also, intrusions commonly emplaced into miogeoclinal to platformal, continental settings so should consider potential for sedimentary rocks to reduce oxygen fugacity of magma. Gravity: Igneous intrusions at depth may be imaged. Radiometrics: Lithology and alteration patterns may be evident.

Economic factors

Grade and tonnage	Deposits are small (10,000 t) to very large (as much as 30–40 Mt). Individual deposits average about a million metric tons grading tens to hundreds of g/t Ag and approximately 5 to 20 wt.% combined Pb-Zn.
Importance	As sources of base metals, manto deposits are overshadowed on a world scale by the giant syngenetic classes such as SEDEX and volcanogenic massive sulfide deposits. However, because of their high precious metal contents, they provide exciting targets for small producers.

Other assessment and exploration guides

Concentration of Ag-Pb-Zn vein deposits in or near carbonates.

Structural controls include regional faults, folds, fractures, fissures, and caverns.

Mantos and chimneys are usually carbonate-hosted and remote from intrusions (relative to skarns).

Examples

In/near focal areas	Copper Mountain Mine, Idaho.
Elsewhere	Park City, Utah; Leadville, Colorado; Northern Mexico.

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Polymetallic Vein

[wt.%, weight percent; km, kilometer; t, metric ton; g/t, grams per metric ton; m, meter]

Synonyms	Felsic-intrusion-associated Ag-Pb-Zn veins, clastic metasediment-hosted silver-lead-zinc veins.
Commodities	Ag, Pb, Zn (Cu, Au, Mn).
Description	Quartz-carbonate veins with Au and Ag associated with base-metal sulfides related to hypabyssal intrusions in sedimentary and metamorphic terranes.
	Geological environment
Rock types	These deposits are principally hosted by sedimentary rocks (dolomite, limestone, sandstone, and shale) that have been intruded by intermediate- to felsic-composition igneous stocks, dikes, and sills. Many veins are associated with dikes following the same structures.
Age range	Proterozoic or younger. Most are Mesozoic and Cenozoic, but may be any age.
Depositional environment	Metasediment host: Veins are emplaced along faults and fractures in sedimentary basins dominated by clastic rocks that have been deformed, metamorphosed and intruded by igneous rocks. Veins postdate deformation and metamorphism. Igneous host: Veins typically occur in country rock marginal to an intrusive stock. Typically veins crosscut volcanic sequences and follow volcano- tectonic structures, such as caldera ring-faults or radial faults. In some cases the veins cut older intrusions.
Tectonic setting(s)	These veins occur in virtually all tectonic settings except oceanic, including continental margins, island arcs, continental volcanic and cratonic sequences.
Associated deposit types	Polymetallic replacement, porphyry, skarn, placer Au.
	Deposit description
Ore mineralogy	Galena, sphalerite, tetrahedrite-tennantite, sulfosalts including pyrargyrite, stephanite, bournonite and acanthite, native silver, chalcopyrite, pyrite, arsenopyrite, stibnite. Silver minerals often occur as inclusions in galena; native gold and electrum in some deposits. Au grades are normally low for the amount of sulfides present. Rhythmic compositional banding sometimes present in sphalerite. Some veins contain more chalcopyrite and gold at depth.
Alteration	Generally wide propylitic zones and narrow sericitic and argillic zones. Silicification of carbonate rocks to form jasperoid.
Ore controls	Regional faults, fault sets, and fractures are an important ore control; however, veins are typically associated with second order structures. In igneous rocks the faults may relate to volcanic centers. Significant deposits are restricted to competent lithologies. Dikes are often emplaced along the same faults and may be roughly contemporaneous with mineralization. Polymetallic veins are typically steeply dipping, narrow tabular or splayed veins and commonly occur as sets of parallel and offset veins. Individual veins vary from cm as much as more than 3-m wide and can be followed from a few hundred to more than 1,000 m in length and depth. Veins may widen to tens of meters in stockwork zones. Areas of high permeability: intrusive contacts, fault intersections, and breccia veins and pipes. Replacement ore bodies may form where structures intersect carbonate rocks
Geochemical signatures	Zn, Cu, Pb, As, Au, Ag, Mn, Ba, Cd. Anomalies zoned outward from Cu-Au to Zn-Pb-Ag to Mn at periphery.
Geophysical signature	Magnetics: Veins are unlikely to be evident, but plutons below may be imaged depending on tectonic setting in which they formed (continental margins, island arcs, continental volcanic and cratonic sequences). More oxidized magmas will result in plutons with stronger magnetic response. Gravity: Regional geology/structure can be imaged. Relatively large underlying plutons or batholiths can be imaged. Radiometrics: Lithology and alteration can be imaged.
	Economic factors
Grade and tonnage	Median size 7,600 t at 9 wt.% Pb, 2.1 wt.% Zn, 820 g/t Ag, and 13 g/t Au. Polymetallic veins of two types appear to exist—a base-metal polymetallic vein worked primarily for a base metal or metals and silver and a gold-silver polymetallic vein with copper, lead, and zinc production

| **Importance** | Ubiquitous in many setting. These veins were a significant source of Ag, Pb, and Zn until the 1960s. They have declined in importance as industry focused more on syngenetic massive sulfide deposits. Larger polymetallic vein deposits are still attractive because of their high grades and relatively easy beneficiation. They are potential sources of cadmium and germanium. |

Other assessment and exploration guides

Presence of vein deposits.

Presence of base or precious metals in rock or stream-sediment samples.

Presence of faults, breccias, shear zones, fault intersections, or intrusive contacts. Strong structural control on veins and common occurrence of deposits in clusters can be used to locate new veins.

Presence of Mesozoic or Tertiary plutons or hypabyssal igneous bodies.

Near-surface fractures and breccias within thermal aureole of clusters of small intrusions.

Some polymetallic veins are found surrounding intrusions with porphyry deposits or prospects.

Examples

| **In/near focal areas** | Valley View Mine, Idaho. |
| **Elsewhere** | Wallapi district, Arizona; Marysville district, Montana. |

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Tungsten Vein

[wt.%, weight percent; km, kilometer; t, metric ton; g/t, grams per metric ton; REE, rare earth elements]

Synonyms	Quartz-wolframite veins.
Commodities	W, Mo, Sn.
Synoptic statement	Magmatic hydrothermal veins associated with granitic rocks and pegmatites.
Description	Simple to complex fissure filling or replacement quartz veins, including discrete single veins, swarms or systems of veins, or vein stockworks, that contain mainly wolframite series minerals (huebnerite-ferberite).
Geological environment	
Rock types	Granitic plutonic rocks, especially late-stage, highly evolved, specialized biotite and (or) muscovite (S-type or A-type) ilmenite series granites and leucogranites.
Age range	Paleozoic to late Tertiary.
Depositional environment	Tensional fractures in epizonal granitic plutons and their wallrocks.
Tectonic setting(s)	Belts of granitic plutons derived from remelting of continental crust. Country rocks are metamorphosed to greenschist facies.
Associated deposit types	Sn skarn, W skarn, Sn replacement, complex Sn-Ag-sulfide veins, Climax-type Mo deposits, and Mo vein and greisen deposits.
Deposit description	
Ore mineralogy	In general, the most common minerals in tungsten vein deposits in addition to quartz are: wolframite series minerals (huebnerite-ferberite), molybdenite, bismuthinite, pyrite, pyrrhotite, arsenopyrite, bornite, chalcopyrite, scheelite, cassiterite, beryl, mica, and fluorite.
Alteration	Alteration directly associated with ore includes greisenization, albitization, and (or) tourmalinization. Deepest zones, pervasive albitization; higher pervasive to vein-selvage pink K-feldspar replacement with minor disseminated REE minerals; upper zones, vein selvages or zinnwaldite (greisen). Chloritization. Widespread tourmaline alteration at Isla de Pines deposit, Cuba.
Ore controls	Swarms of parallel veins cutting granitic rocks or sedimentary rocks near igneous contacts.
Geochemical signatures	W, Mo, Sn, Bi, As, Cu, Pb, Zn, Be, F. Soil and stream sediment may have elevated tin and tungsten contents (tens to hundreds of ppm) and may contain anomalous abundances of elements characteristic of specialized granites (F, Rb, Be, Nb, Ta, Mo, U, Th, Li, and REE). Other possible pathfinder elements are As, Bi, B, Cu, Pb, and Zn.
Geophysical signature	Magnetics: Plutons generated from remelting of continental crust. I-type granites can produce relatively high magnetic anomalies, whereas S-type granites are likely to be reduced, having low magnetic response. Regional geology/structure can be imaged. Gravity: Orogenic granites can have low gravity response. Radiometrics: Host rock lithology and alteration patterns can be imaged.
Economic factors	
Grade and tonnage	The most common tungsten vein deposits are quartz-wolframite veins. These range from less than 0.1 to about 10 million Mt of ore containing 0.4 to 1.6 wt.% WO_3; median size and grade is 680,000 Mt and 0.81 wt.% WO_3.
Importance	Relative to W skarn deposits, W vein systems typically have smaller tonnages and comparable grades.

Other assessment and exploration guides

Veins and greisen deposits are found within or near highly evolved, rare-metal enriched plutonic rocks, especially near contacts with surrounding country rock; settings in or adjacent to cupolas of subsurface granitic batholiths are particularly favorable.

Deposits may be endocontact or exocontact. Exocontact deposits usually are in pelitic and arenaceous sedimentary or metamorphic rocks and within the contact metamorphic aureole of a pluton. Most endocontact deposits, are in or near cupolas and ridges developed on the roof or along margins of granitoids.

Wolframite persists in soils and stream sediments; stolzite and tungstite may occur as weathering products.

Zoned alteration has been identified in some tungsten vein systems, upper parts of veins have well developed greisen zones; middle parts have quartz-rich greisen and silicification; and lower parts have K-feldspar-rich greisen. Higher tungsten grades are found in the upper and middle parts of veins.

Examples

In/near focal areas	Round Mountain, Nevada.
Elsewhere	Hamme district, North Carolina; Isla de Pines, Cuba.

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Molybdenum-Tungsten Greisen

[wt.%, weight percent; ppm, parts per million; km, kilometer; Mt, million metric tons;*, based on 10 well-described deposits, including 5 in Nevada]

Synonyms and subtypes	Molybdenite in greisens, quartz and quartz-muscovite veins, and sheeted veins and veinlets, often with wolframite (scheelite).
Commodities	Mo, W.
Description	Fine- to coarse-grained molybdenite, molybdenite and wolframite (scheelite) in greisenized granites, massive greisen bodies, quartz veins and veinlets in greisen and greisenized adjacent rocks in the endocontact zone (endogreisen) and exocontact zone (exogreisen) of granites and alaskites.

Geological environment

Rock types	Granites with 73–75 percent SiO_2, $K_2O>Na_2O$ (1.1–2.5), Al_2O_3 >12.5–13 percent, low CaO (<1.0), variations in F content, lack of contamination process, nonspecialized. Multiphase hypabyssal plutons (10–1,000 km^2) with intermineral and postmineral dikes.
Age range	Proterozoic (1,000–2,650 Ma), Hercynian (292–348 Ma), Cimmerian (140–210 Ma).
Depositional environment	Apical lobes of multiphase plutons and adjacent rocks.
Tectonic setting(s)	Extensional zones in continental rifts. Endocontact and exocontact zones of batholiths, stocks, and cupolas.

Deposit description

Ore mineralogy	Molybdenite, wolframite, scheelite, bismuthinite, cassiterite; quartz, muscovite, fluorite, topaz, K-feldspar, lepidolite, zinnwaldite.
Alteration	Greisenization, albitization, microclinization, silicification, and sericitization.
Ore controls	Lobes of granite plutons, system of fractures, chemistry of adjacent rocks.
Geochemical signatures	Primary anomalies of Mo, W, Sn, Bi, Ag, Li, Zn, and Pb. Secondary anomalies in soil, stream sediments and plants of Mo, W, Sn, Bi, Cu, Zn, and Ag. Elevated Re in molybdenite, >50 ppm.
Geophysical signature	Thick crust (>40 km), regional and local gravity anomalies with positive electric anomalies (halo of pyrite mineralization surrounds bodies); distinct U/Th as well as magnetic anomalies in close proximity to the greisen.
Associated deposit types	Porphyry Cu, Cu skarn, Pb-Zn skarn, Au skarn polymetallic veins, polymetallic replacement and replacement Mn deposits.

Economic factors

Grade and tonnage*	Each molybdenum-tungsten greisen deposit represents a different level of emplacement. Taken together, they define a composite greisen column, which may be represented by distinct grade and tonnage models. Proximal deposits have a mean tonnage of 0.43 Mt and a mean grade of 0.17 wt.% Mo. Distal deposits have a mean tonnage of 40 Mt and a mean grade of 0.081 wt.% Mo.
Importance	Greisen deposits are one of the most important sources of rare metals, and contain a large part of the world's mineable reserves of tungsten, tin, beryllium, and molybdenum, and significant resources of tantalum, niobium, and rare earth elements (REE).

Assessment and Exploration Guides

Molybdenum-tungsten greisen is a distinct type of mineral deposit, apparently confined to granitic plutons in extensional rift zones in Proterozoic, Hercynian and Cimmerian continental plates, and primarily found in areas with thick crust in Asia.

General prospecting guides include extensional zones where crustal thickness is more than 40–45 km. Regional negative gravity anomalies, that may represent felsic plutons are also indicative. General analysis of geologic (petrologic and petrochemical) data, combined with the results of regional geophysical surveys, can lead to the delineation of potential targets.

Experience in exploration for this type of deposit in different countries shows that subsequent fieldwork must include geochemical surveys (rock, soil, or stream sediments), detailed gravimetric measurements, and aeromagnetic surveys. These methods usually detect the ore-bearing granites, particularly hidden plutons or their cupolas. Local negative gravity and positive magnetic anomalies may outline unexposed plutons, the specific characteristics of roof morphology (lobes), and variations in the thickness of granites (roots). Zonal dispersion of lead, zinc and copper from one side and molybdenum, tungsten, tin and bismuth from the other indicates the polarity, or symmetry of the metallized system. Separation of tungsten and molybdenum within a district, with tungsten dominant, might be the sign of an unexposed, compound mineral deposit

Although molybdenum-tungsten greisen deposits have many similarities with Climax-type deposits, they seem to form at greater depths, in a mostly plutonic environment.

Examples

In/near focal areas	Springs W deposit, Nevada.
Elsewhere	Mount Pleasant, Canada; Koktenkol, Akchatau, Bainazar, Kazakhstan; Yugodzir, Mongolia.

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Distal Disseminated Silver-Gold

[g/t, grams per metric ton; Mt, million metric tons;*, based on 10 well-described deposits, including 5 in Nevada]

Synonyms and subtypes	Sediment-hosted Ag-Au, disseminated Ag.
Commodities	Ag, Au, (Sb).
Description	Disseminated Ag and Au mainly in sedimentary rocks distal to porphyry Cu, skarns, and polymetallic veins. The deposits are somewhat similar to sediment-hosted Au deposits, but have significantly higher Ag grades and base-metal contents.

Geological environment

Rock types	Carbonate and elastic sedimentary rocks associated with felsic hypabyssal or subvolcanic intrusions.
Age range	Mesozoic-Tertiary in Western United States; may be any age.
Depositional environment	Shelf and basinal sedimentary rocks are folded and faulted and intruded by I-type granitic rocks.
Tectonic setting(s)	Continental margins.

Deposit description

Ore mineralogy	Native Au, native Ag, electrum, argentite, Ag sulfosalts, tetrahedrite, stibnite, galena, sphalerite, chalcopyrite, pyrite, marcasite, and arsenopyrite; at Cove deposit in Nevada, stannite and canfieldite.
Alteration	Silicification and decalcification of carbonate rocks; sericite-clay in elastic rocks. Differs from deposit to deposit in Nevada.
Ore controls	Deposits commonly occur in skarn and polymetallic vein and replacement districts outboard of all other types of mineralization. Fracture permeability is the most important ore control. Primary rock permeability may be important locally.
Geochemical signatures	Ag±Au±Pb±Mn±Zn±Cu± Sb±As±Hg±Te; Mn. Ag:Au ratios are highly variable. (For Nevada deposits: Candelaria, 400:1; Taylor, 143:1; Hilltop, <2:1).
Geophysical signature	None.
Associated deposit types	Porphyry Cu, Cu skarn, Pb-Zn skarn, Au skarn polymetallic veins, polymetallic replacement and replacement Mn deposits.

Economic factors

Grade and tonnage*	Tonnages range from <1 to 81 Mt; Au grades range from 0 to 4.8 g/t; Ag grades range from 2 to 142 g/t.
Importance	Deposits are a significant source of silver; the Cove deposit in Nevada is the fourth largest silver producer in the history of Nevada.

Other assessment and exploration guides

Structural setting: Shear zones, axial plane fractures in folded rocks.
Ore deposit geometry: Irregular bodies, locally conformable to bedding.
Weathering: Leaching and redeposition of Ag as cerargyrite forms bonanza deposits (White Pine district, Nevada; Vekol, Arizona).
Gangue minerals: Quartz, rhodochrosite, Ag-rich manganocalcite.
Depth: Typically form at higher crustal levels than porphyry copper deposits.

Examples

In/near focal areas	Vipont, Nevada.
Elsewhere	Taylor, Candelaria, Star Pointer, Cove deposits, White Pine district, Nevada; Tecoma, Utah; Vekol, Tombstone, and Hardshell, Arizona.

References

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Carlin-Type Gold (Silver, Mercury, Antimony)

[%, percent; wt.%, weight percent; g/t, grams per metric ton; Mt, million metric tons; °C, degrees Celsius; m, meter; ASTER, Advanced Spaceborne Thermal Emission Radiometer]

Synonyms and subtypes	Sediment-hosted gold, Micro-disseminated gold, Micron gold.
Commodities	Au. Byproducts: Ag, Hg, Sb.
Description	Epigenetic, replacement, disseminated, auriferous pyrite deposits at intersections of high angle faults and permeable reactive sedimentary rocks.
Geological environment	
Rock types	Most deposits are hosted in Paleozoic, marine, carbonaceous, pyritic, and calcareous and (or) dolomitic sedimentary rocks deposited on the slope near the carbonate platform margin. Some deposits are hosted in marginal basin, shelf, foreland basin, and overlap sequences. Others occur in dolomitize limestones, contact metamorphic aureoles of Mesozoic intrusions, and Jurassic lamprophyre dikes.
Age range	Mostly Eocene.
Depositional environment	Epizone, subvolcanic, a few 100 to 5,000 m below the paleosurface. Temperature 100–240 °C, 0–9 wt.% NaCl, pH < 5, CO_2 < 4 mole%, CH_4 <0.4 mole%, H_2S 10^{-1}-10^{-2} molar. Gold-bearing disseminated pyrite precipitates where H_2S-bearing hydrothermal fluids react with iron-bearing minerals or external fluids in sedimentary rocks.
Tectonic setting(s)	Underlain by attenuated continental crust and subcontinental lithospheric mantle (east of Sr_i 0.706 line). Mineral belts occur along reactivated basement faults produced during Neoproterozoic rifting and formation of the continental margin. Typically in carbonate rocks below a less permeable cap of shaley siliciclastic rocks, such as the Roberts Mountains allochthon. Districts are restricted to a region affected by a southward sweeping Eocene subduction-related magmatism. Eocene felsic dikes are frequently present.
Deposit description	
Ore mineralogy	Most of the gold and trace elements reside in micron-sized disseminated pyrite that often forms rims on diagenetic pyrite. Common open-space filling minerals include drusy quartz, calcite, barite, stibnite, orpiment, and realgar. Rare minerals include native gold, cinnabar, lorandite, getchellite, and galkhaite. Micron-sized native gold occurs in jasperoid and in supergene goethite pseudomorphs of pyrite.
Alteration	Ore pyrite was produced by sulfidation of iron-bearing minerals, silicification to form jasperoid, dissolution of carbonate minerals, argillization of silicate minerals, and mobilization of preexisting organic carbon. Ammonium phyllosilicates are present locally.
Ore controls	Intersections of faults and permeable reactive strata, sedimentary breccias, karsted unconformities, dolomitized limestones, calcsilicate hornfels, lamprophyre dikes, and hydrothermal dissolution collapse breccias.
Geochemical signatures	Common pathfinder elements in rock, soil, and stream sediment: Au, As, Sb, Tl, Hg. Au/Ag generally more than three and often much higher. Base metals and Ag generally are not anomalous.
Geophysical signature	Aeromagnetics: Map the distribution of plutons and dikes. Radiometrics: Detect shaley cap rocks (K high) and Valmy quartzites (K, Th, U low). Gravity: Map regional structures associated with deposits and underlying intrusive rocks. Remote sensing: ASTER data permit recognition of carbonate host rocks, quartzites, argillaceous cap rocks, jasperoid, ferric iron (oxidized pyrite), and clay minerals. Electrical methods: Delineating low-resistivity zones associated with organic carbon, clay, or sulfide-rich zones at shallow levels. Magnetotelluric methods can detect crustal scale features. Seismic methods: Detect the thickness of alluvial or volcanic cover.
Economic factors	
Grade and tonnage	Au grade 0.7–34 g/t (range). Tonnage 0.3–700 Mt (range) .

Importance	The wide range of tonnage-grade characteristics make the deposits amenable to both open-pit and underground mining.

Other assesment and exploration guides

Subcontinental lithospheric mantle may have been hydrated and enriched in Au by Mesozoic subduction- and rift-related magmatism.

Metalliferous black shales may be a potential source for Au and trace elements in the deposits.

Sedimentary facies and sequence stratigraphy.

Regional and local structural features. For example, extensional step-over faults within strike-slip fault zones and dilatant fracture systems on margins of Mesozoic plutons.

In areas with low ground water tables, supergene oxidation of pyrite allows Au recovery by low-cost cyanide heap leach methods.

Information on depth of post-mineralization cover and depth of erosion.

Exploration and drilling history.

Examples

In/near focal areas	Doby George, Nevada.
Nevada gold trends	Independence, Getchell, Carlin, Battle Mountain-Eureka, Alligator Ridge, Long Canyon.

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Hydrothermal—Volcanic Rock Associated System

Deposit types in the study area
Epithermal gold-silver (mercury)
Volcanogenic uranium
Stanley district (Idaho)-type uranium
Volcanic opal and specialty gemstones
Hectorite (lithium-rich clay) and specialty clays

Epithermal Gold-Silver (Mercury)

[g/t, grams per metric ton; Mt, million metric tons;*, based on 90 well-described deposits; CSMAT, controlled-source audio magnetotelluric surveys]

Synonyms and subtypes	Quartz-alunite (high-sulfidation), quartz-adularia (low sulfidation), hot spring deposits. Quartz-adularia subtypes include layered vein and polymetallic variants. Alkaline igneous rock-related epithermal gold deposits. Bonanza ores (>1 troy ounce gold per ton (34.3 g/t).
Commodities	Au, Ag. Byproducts: Pb, Zn, Cu, and (or) Hg (quartz-adularia); Cu (quartz-alunite), gypsum.
Description	Epithermal gold-silver deposits are shallowly formed vein, stockwork, disseminated, and replacement deposits that are mined primarily for their gold and silver contents. Hot-spring-type mercury deposits are commonly the near-surface expression of hot-spring type gold-silver deposits that occur at deeper levels below mercury-enriched sinter. Epithermal gypsum forms where carbonate host rocks are altered by sulfur-bearing hydrothermal fluids.
Geological environment	
Rock types	Most commonly hosted by alkaline to calcalkaline volcanic rocks and hypabyssal intrusions that range in composition from mafic to felsic, but generally fall into suites of andesite-dacite±rhyolite compositions or bimodal basalt-rhyolite compositions. Rocks of the andesite-dacite±rhyolite suite mostly have calcalkaline compositions, whereas some bimodal basalt-rhyolite suites have tholeiitic compositions, notably rocks associated with quartz-adularia deposits of the northern Nevada rift that are related to extension and hot spot or mantle plume magmatism in a back arc setting. Hosts for some deposits are silica-undersaturated, highly alkali-rich ($Na_2O + K_2O$) rocks ranging from felsic phonolites to ultramafic lamprophyres. Other igneous, sedimentary, and metamorphic rock types also can host deposits.
Age range	Mostly of Cenozoic age, which reflects preferential preservation of these shallowly formed deposits in tectonically active regions. Deposits as old as 1.9 billion years are preserved within some cratons.
Depositional environment	Quartz-alunite deposits: Lava domes and flows, diatremes, tuff rings, maars, and intrusive breccias associated with diatremes; uplands and basins with pyroclastic and volcaniclastic rocks.
	Quartz-adularia, layered vein, and hot springs deposits: Lava domes and flows; uplands and basins with pyroclastic and volcaniclastic rocks; dikes.
	Quartz-adularia, polymetallic deposits: Lava domes and flows, diatremes, tuff rings, maars, and intrusive breccias associated with diatremes; uplands and basins with pyroclastic and volcaniclastic rocks.
Tectonic setting(s)	Form from subaerial hydrothermal systems in volcanic arcs at convergent plate margins in continental and oceanic settings, in continental-margin back arcs, in rifts, and in intraplate environments.
Deposit description	
Ore mineralogy	Quartz-alunite: Gold, electrum, Au-Ag tellurides, Ag-bearing tennantite-tetrahedrite, enargite, luzonite, chalcopyrite, numerous Au-Ag-Cu-As-Sb-Bi-Sn-Te-Se-S minerals.
	Quartz-adularia, layered veins: Electrum, Ag sulfides, selenides and sulfosalts; low Ag/Au; generally no other metals recovered.
	Quartz-adularia, polymetallic: Electrum, Ag sulfides and sulfosalts; Ag-bearing tetrahedrite-tennantite; high Ag/Au; chalcopyrite, galena, sphalerite.
	Alkaline igneous rock-related epithermal gold deposits: native Au, numerous telluride minerals, auriferous pyrite.
	Hot springs deposits: cinnabar, metacinnabar, tiemannite, HgSeS minerals, sulfur.
Alteration	Quartz-alunite: Zoned. Inner residual (vuggy) quartz grading progressively outward to quartz-alunite; kaolinite (dickite) or pyrophyllite; illite; montmorillonite; distal chlorite-calcite ± epidote. All + pyrite.
	Quartz-adularia: Zoned: inner quartz/chalcedony ± adularia, carbonate, grading progressively outward to sericite/illite ± adularia; mixed layer clay ± chlorite; distal chlorite-calcite ± epidote. All + pyrite.
	Epithermal deposits may be overlain by zones of steam-heated opal, kaolinite, alunite, and (or) montmorillonite. Silica sinter overlies some quartz-adularia deposits. Gypsum replacement bodies occur in some systems.
	Hot-spring Hg deposits: Volcanic host rocks and associated clastic sedimentary rocks are altered to an assemblage of adularia, quartz, and sericite at depth, and in the near surface, to an advanced argillic alteration assemblage of kaolinite, alunite, and cristobalite that commonly contains elemental sulfur. Some of these deposits are hosted in hot-spring sinter that was deposited at the surface and that consists of banded silica phases and beds of hydrothermal eruption breccia.
Ore controls	Breccias (magmatic, tectonic, hydrothermal, diatreme); faults, fractures, voids; fault intersections.
Geochemical signatures	Au, Ag, As, Sb, Hg ±Tl, F, Mo, Se, Te, and W are generally enriched in and near epithermal deposits; combinations of Ba, Cu, Zn, Pb, Sn, and Bi may or may not be present. Hot-spring Hg deposits: Hg, Li, B, As, Sb, Au, Ag, Th, and W.

Geophysical signature	Aeromagnetics: Hydrothermal fluids can destroy magnetite; therefore, pervasively altered volcanic rock appears as areas of subdued magnetic anomalies (magnetic quiet zones) relative to high-amplitude, short-wavelength anomalies of surrounding unaltered volcanic rock.
	Radiometrics: Central zone of K metasomatism in quartz-adularia deposits characterized by enriched K/Th values, which may be particularly pronounced in alkaline igneous rock-related epithermal gold deposits.
	Gravity: Useful in mapping and characterizing regional structures associated with deposits, such as concealed basins, calderas, and underlying intrusive rocks. High-resolution gravity measurements may directly characterize hydrothermal alteration, which may reduce porosity, thereby increasing density.
	Remote sensing: Host rocks are commonly enriched in hydrothermal minerals that have diagnostic absorption features in the visible (VIS), near-infrared (NIR), shortwave-infrared (SWIR), and thermal infrared (TIR) regions of the electromagnetic spectrum. ASTER data permit mineralogical differentiation of various alteration types (argillic, phyllic, alunitic), carbonate minerals, and high concentrations of quartz.
	Electrical methods: Hydrothermal alteration associated with gold mineralization commonly involves the replacement of host rocks by clay and sulfide minerals, which can decrease electrical resistivity by several orders of magnitude, and silicification or quartz veining, which increases resistivity. Methods focused on shallow parts of the crust are useful in delineating low-resistivity zones associated with clay or sulfide-rich alteration or highly resistive zones dominated by quartz veins or silicification. CSAMT now widely used.

<div align="center">Economic factors</div>

	Quartz-alunite	Quartz-adularia
Grade and tonnage*	Au grade 3.8 g/t (avg), 0.45–17 g/t (range)	9.9 g/t (avg), 0.26–68 g/t (range)
	Ag grade 53 g/t (avg), 2.4–600 g/t (range)	164 g/t (avg), 1.6–1,100 g/t (range)
	Tonnage 170 Mt (avg), 1.2–1,700 Mt (range)	142 Mt (avg), 0.1–2,300 Mt (range)
Importance	These deposits are attractive because of their relatively rich gold and silver grades, their wide range of tonnage-grade characteristics, including bonanza grades, which are amenable to both underground and bulk tonnage mining, and in some cases, recovery of byproducts.	

<div align="center">Other assessment and exploration guides</div>

Known epithermal deposits and prospects.

Volcanic and volcaniclastic rocks coeval with similar rocks known to host deposits.

Hydrothermal alteration known to accompany epithermal deposits.

Regional and local structural features (for example, extensional stepover zones within strike-slip fault zones).

Some hot-spring Hg deposits occur in hot-spring sinter that consists of layered or bedded silica phases and hydrothermal eruption breccia.

Shallow hydrothermal features, such as sinters, stratiform alteration zones, and hydrothermal eruption breccias.

Information on depth of post-mineralization cover and depth of erosion.

Exploration and drilling history.

<div align="center">Examples</div>

In/near focal areas	Buckskin Mountain, Nevada (quartz-adularia, layered vein).
	Zortman-Landusky, Montana (alkaline igneous rock-related).
	Clear Creek gypsum mine, Idaho.
Elsewhere	Quartz-alunite: Goldfield, Nevada; Summitville, Colorado.
	Quartz-adularia, layered veins: Midas, Round Mountain, and Sleeper, Nevada.
	Quartz-adularia, polymetallic: Comstock Lode and Tonopah, Nevada.
	Alkaline igneous rock-related: Cripple Creek, Colorado; Golden Sunlight, Montana; Ladolam and Porgera, Papua New Guinea.

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Volcanogenic Uranium

[wt.%, weight percent; ft, feet; mi², square miles]

Synonyms	
Commodities	Uranium (sometimes associated mineable fluorite, molybdenum, mercury).
Description	Uranium minerals associated with felsic volcanic in caldera systems.

Geological environment

Rock types	Felsic volcanic rocks and associated volcanoclastic sediments and tuffs. Uranium enrichment increases with differentiation to more felsic composition, and deposits are most common in rocks with aluminous and alkaline affinities and high fluorine content (Cuney and Kyser, 2009).
Age range	Proterozoic through Tertiary
Depositional environment	Felsic volcanic centers: Both fracture zones and volcanoclastic sediments, tuffs and permeable lava flows associated that make up felsic volcanic complexes.
Tectonic setting(s)	Diverse tectonic settings, including rifts, hot spots (McDermitt caldera, Nevada), back arcs, and subduction zones where the stress field has shifted from compressional to extensional.
Associated deposit types	Mercury, fluorite, and molybdenum.

Deposit description

Ore mineralogy	Uraninite, pitchblende and coffinite with brannerite and uranothorite in more alkaline volcanic rocks. Associated fluorite and molybdenite in most volcanogenic uranium deposits; rare earth elements, thorium and zirconium in peralkaline volcanic systems. Polymetallic deposits (with copper, lead, silver, and zinc) in Europe and Asia are the result of a multistage hydrothermal history.
Alteration	Pre-ore alteration: alkali metasomatism with quartz, sericite, pyrite and carbonate mineral veining. Ore-stage alteration: uranium minerals associated with argillic alteration and fluorite. Post-ore alteration: redistribution of uranium and late-stage carbonate minerals, sulfates and additional argillic alteration.
Ore controls	Ore hosted in two settings: (1) vein and stockwork deposits filling fractures and faults and stratabound deposits hosted in permeable eruption breccia and (2) flow breccia and volcanoclastic rocks with associated fractures or feeder zones. Ore control may be reduction, with reducing phases including reduced sulfur species, ferrous iron and carbonaceous matter, or, in volcanoclastic sediments, hydrogen sulfide. Alternatively ore may have formed during boiling of ore-forming fluids with loss of CO_2 and fluoride destabilizing soluble uranium complexes (Cunningham and others, 1998) or by decreasing oxygen fugacity in parts of the volcanic complex.
Geochemical signatures	Elevated uranium, fluoride, and molybdenum in rock, water, soil, and stream sediments. Concealed deposits may be identified by elevated radon in soil gas samples and uranium and indicator elements (U, F, Mo) in groundwater.
Geophysical signature	Radiometric signatures that detect uranium enrichment in both deposits and elevated uranium in host rocks.

Economic factors

Grade and tonnage	Vein and stockwork deposits extend for tens to several hundreds of meters along strike and tens to hundreds of meters in dip. Stratabound deposits can extend for hundreds of meters laterally and range from less than one to tens of meters in thickness. These deposits have low to moderate grades of 0.05 to 0.23 wt.% U_3O_8. Known deposits range from relatively small deposits of a few thousand pounds. U_3O_8 to the Stretsovskoye district, which contains over 250 million pounds U_3O_8. Within the U.S., known deposits in Idaho, Nevada, Oregon and Utah produced an estimated 2 million pounds U_3O_8 during mining from the 1950s to 1970s.
Importance	Worldwide volcanogenic uranium deposits contain about 1.2 billion pounds of U_3O_8, which is about 6 percent of the world's known global resources (International Atomic Energy Agency, 2009). Within the U.S. potential resources within volcanic rocks are estimated to be 232 million pounds of U_3O_8 (Department of Energy, 1980).

Other assessment and exploration guides

Areas favorable to these deposits typically have basement rocks that are enriched in uranium. Crustal thinning accompanied by partial melting and hydrothermal fluid interaction with this enriched crust is thought to contribute uranium to the felsic volcanic rocks that host the deposits.

Multiple overprinting volcanic episodes may help concentrate uranium in later stage melts and hydrothermal fluids.

The identification of regions with progressive concentration of uranium by successive magmatic episodes may help identify favorable terrain.

Examples

In/near focal areas	McDermitt Caldera District (Aurora, Bretz, Moonlight deposits), Nevada–Oregon.

Elsewhere	Streltsovskoye, Russia.

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Stanley District (Idaho)-Type Uranium

[Mt, million metric tons]

Synonyms	Unconformity sandstone-conglomerate-hosted uranium; vein-hosted uranium.
Commodities	Uranium.
Description	In the Stanley district, the uranium deposits occur in two geologic settings: (1) as disseminated uranium minerals within fluvial-channel arkosic sandstones and conglomerates that rest on the eroded surface of the Cretaceous Idaho batholith and immediately beneath the Eocene Challis Volcanic Group and (2) as thin pockets of uranium minerals in silicified fractures that cut through the granitoid rocks of the batholith (Kern, 1959; Johnson and others, 1995a, 1995b; Van Gosen and others, 2006).

Geological environment

Rock types	Arkosic sandstones and conglomerates and thin siliceous veins in granitic rocks.
Age range	Uranium deposition is likely to be Eocene, perhaps younger.
Depositional environment	Microscopic textures in the uranium minerals suggest that the uranium mineralization in the strata-bound deposits is genetically linked to the widespread hydrothermal alteration in the area that was associated with igneous intrusions related to the eruption of the Eocene Challis Volcanic Group (Van Gosen and others, 2006).
Tectonic setting(s)	Mid-cratonic setting in volcanic terranes.

Deposit description

Ore mineralogy	Uraninite; meta-autunite; uranophane; a calcium uranium phosphate mineral (autunite? phosphuranylite?); kasolite, a member of the phosphuranylite-renardite series; beta-uranophane; clarkeite; schoepite; and vandendriesscheite (see Choate, 1962, p. 31; Van Gosen and others, 2006).
Alteration	Microscopic alteration of minerals in the U-mineralized intervals.
Ore controls	Uranium mineralization is confined to fluvial-channel arkosic sandstones and conglomerates that rest upon the eroded surface of the Cretaceous Idaho batholith and immediately beneath the Eocene Challis Volcanic Group and (2) as thin pockets of uranium minerals in silicified fractures that cut through the granitoid rocks of the Idaho batholith. Organic matter and sulfide minerals in the sedimentary hot rocks provided reductant materials for the precipitation of the uranium minerals.
Geochemical signature	U, As, Ca, P.
Geophysical signature	Radioactivity is the principal geophysical signature; radiometric surveys can locate radioactive concentrations. Electromagnetic surveys may be useful in detecting conductive sulfides in paleo-channels. Ground-penetrating radar may be useful in delineating the geometry of shallow paleo-channels.

Economic factors

Grade and tonnage	The average grade (about 0.18 weight percent U_3O_8) of the uranium deposits mined in the Stanley district was comparable to other U.S. producers during the late 1950s and early 1960s, but the district's output (no more than 8,000 metric tons of uranium ore per year) and its mines were relatively small.
Importance	Small production of uranium ore came from mines in the Stanley district from 1957 to 1962, making it the first commercial uranium district in Idaho. This district comprised at least 27 uranium mines and prospect claim groups, scattered across an area of about 10 square miles.

Other assessment and exploration guides

Identify Tertiary sandstones and conglomerates that rest of the surface of granitoid plutonic rocks of the Idaho Batholith and occur immediately below volcanic and volcaniclastic rocks of the Eocene Challis Volcanics.

Survey the appropriate sedimentary units and stratigraphic horizons for radioactivity using airborne radiometric surveys, followed up by on-the-ground radiometric surveys (scintillometer or Geiger counter).

Economic deposits of this type typically are exploited only if they lie at or within a few tens of meters of the surface due to their modest uranium concentrations and tonnage.

Examples

In/near focal areas	Central Idaho where Challis Volcanics lie in contact with the Idaho batholith.

Elsewhere   The uranium deposits of the Marysvale volcanic field in west-central Utah comprise another uranium district with geologic characteristics generally similar to those of the Stanley district. Uranium in the Marysvale volcanic field occurs in a variety of geologic settings, including hydrothermal vein deposits and sedimentary-trap deposits in basin-fill sediments (Steven and others, 1981).

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Volcanic Opal and Specialty Gemstones

Synonyms	Hydrothermal opal, precious opal in volcanic sequences.
Commodities	Gem opal (common opal, chalcedony, jasper, agate), geodes, petrified wood, picture rock.
Description	Opal (hydrated silica) in seams of volcanic ash or lahars sandwiched between successive lava flows. It occurs mainly as open space fillings and impregnations. Common opal, opalized wood, and "fire opal" are widespread within Triassic or younger volcanic sequences, but precious opal is rare. Where opal occurs in massive volcanic rocks, it occurs also as open-space fillings; however, the opal-bearing areas are much smaller. Regardless of volcanic host rock, the precious opal occurrences are discrete, whereas common opal occurs over large areas.

Geological environment

Rock types	Rhyolite, basalt, andesite and trachyte lavas, lahars and other volcaniclastic rocks. Associated rocks are perlite, bentonite, scoria, volcanic ash and diatomite; volcanic rocks may be intercalated with lacustrine sedimentary rocks.
Age range	Tertiary or younger, commonly Miocene.
Depositional environment	Volcanic sequences formed in subaerial or shallow marine environments where porous, pyroclastic or lacustrine rocks are interbedded with lava flows.
Tectonic setting(s)	Volcanic arcs, rifts, collapsed calderas, hot-spot related volcanism, and others.

Deposit description

Ore mineralogy	Precious opal; "fire opal," chalcedony, agate, common opal.
Alteration	Opal-bearing cavities may have zeolite and celadonite coatings, but so do the barren cavities. There is no known alteration that is specific to precious opal.
Ore controls	Open spaces and other permeable zones open to the silica-bearing solutions. Spencer deposit, Idaho: precious opal occurs as one or more thin layers within common opal partially filling gas cavities within a rhyolite-obsidian flow. Virgin Valley, Nevada: opal occurs primarily as replacement of wood, as replacement of conifer cones, as nodules filling void spaces in clay. Opal Butte, Oregon: opals are found in rhyolite geodes (thunder eggs) in a perlite that has altered to a pastel-colored clay.
Geochemical signatures	Mn oxide fracture coating proximal to some deposits. Indicators of epithermal deposits. Opal at Virgin Valley, Nevada is uraniferous.

Economic factors

Grade and tonnage	Grade and tonnage for volcanic-hosted opal deposits are not well documented, because the opal extraction is done by small-scale operations.
Importance	Volcanic rock-hosted opal deposits are numerous, but most of today's high-quality opal production comes from Australian sedimentary-hosted deposits.

Other assessment and exploration guides

Boulder tracing is commonly used in opal exploration.
Unmetamorphosed or weakly metamorphosed (zeolite facies) terrains (gem opal deteriorates and becomes brittle if subject to moderate temperatures).
Tertiary or younger volcanic rocks.
Areas containing known occurrences of precious or common opal, opalized wood and possibly chalcedony.
Opal occurrences hosted by volcaniclastic rocks are commonly confined to the same lithologic unit over a large area.
Presence of warm springs in an appropriate setting.

Examples

In/near focal areas	Virgin Valley, Nevada.
Elsewhere	Blue Fire Opal Mine, Idaho.

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Hectorite (Lithium-Rich Clay) and Specialty Clay

[ppm, parts per million; wt.%, weight percent; kt, thousand metric tons]

Synonyms	Lithium (Li) smectite, high-Li clay.
Commodities	Hectorite, Li, bentonite, specialty clays for drilling fluid additives and organoclays.
Description	Li- and Mg-rich smectite clay; "greasy" when wet, color ranges from bright white to pink pastel to dark-green and brown. Found in playa and caldera sediments.
Geological environment	
Rock types	Volcanic ash, preexisting smectites, lacustrine sediments in high Mg evaporative lakes.
Textures	Inherited from parent lacustrine sediments, may be thin or thickly bedded and laterally extensive. Hydrous with "greasy" fresh surface; dries to a blocky texture. Weathered surfaces may develop a "popcorn" texture.
Age range	Miocene-Holocene.
Depositional environment	Hydrologically closed basin containing evaporative lakes with discharge of geothermal waters. Geothermal waters provide the Li, previously leached from ash and alkaline volcanic rocks.
Tectonic setting(s)	Basin-and-Range or other rift settings characterized by rhyolitic volcanism, crustal extension, hydrothermal activity, and high rates of sedimentation.
Associated deposit types	Uranium, mercury, zeolites, bentonite, borate, gypsum, diatomite, dolomite, magnesite.
Deposit description	
Ore mineralogy	Hectorite, saponite, stevensite, bentonite.
Alteration	Clays may expand with moisture, leading to "popcorn weathering"; lithium may be lost through leaching or cation exchange; burial and diagenesis may convert smectite minerals to illite or chlorite.
Ore Controls	Extent of lacustrine sediments, geothermal source of Li.
Geochemical signatures	Li >300 ppm; ±F, U, Be, B enrichment; high Mg, low Al content.
Geophysical signature	Seismic surveys may delineate extent and thickness of lacustrine sediments, and basin depth.
Economic factors	
Grade and tonnage	Hectorite from Hector, California, contains approx. 0.7 wt.% Li. The Kings Valley deposit (McDermitt caldera, Nevada) contains a measured resource of 50,700 kt grading at >0.312 wt.% Li, and 1,370 kt grading at >0.529 wt.% Li.
Importance	Specialty clays for use as drilling fluid additives, organoclays, cosmetics, paints, medications.
Examples	
In/near focal areas	Kings Canyon mine, McDermit Caldera, Nevada-Oregon border.
Elsewhere	Hector Mine, Hector, California. Lyles Hectorite Mine, Yavapai County, Arizona.

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Hydrothermal—Exhalative-Magmatic Processes System

Deposit types in study area
Volcanogenic massive sulfide

Volcanogenic Massive Sulfide (Besshi-subtype VMS)

[wt.%, weight percent; km, kilometer; t, metric ton; g/t, grams per metric ton; VMS, volcanogenic massive sulfide]

Synonyms	Mafic-siliciclastic VMS, volcanogenic sulfide, volcanic massive sulfide.
Commodities	Cu, Pb, Zn, Ag (Au, Co, Sn, Mo, Cd).
Description	Stratabound concentrations of sulfide minerals precipitated from hydrothermal fluids in extensional seafloor environments. Thin sheets of massive to well layered base-metal sulfide minerals in interlayered, terrigenous clastic rocks and calcalkaline basaltic to andesitic tuffs and flows.
Geological environment
Rock types	Mainly shales, greywackes, sandstones, local dolomitic shales, basaltic sills and flows. Clastic sedimentary rocks and marine volcanic rocks; basaltic tuffs and flows, shale and siltstone, commonly calcareous; less commonly chert and Fe formations. Possibly ultramafics and metagabbro in sequence.
Age range	Mainly Paleozoic and Mesozoic.
Depositional environment	Besshi subtype: Terrigenous clastic rocks associated with marine volcanic rocks and sometimes carbonate rocks; these may overlie platformal carbonate or clastic rocks.
Tectonic setting(s)	Oceanic extensional environments, such as back-arc basins, oceanic ridges close to continental margins, or rift basins in the early stages of continental separation rift separation.
Associated deposit types	Cu, Zn veins.

Deposit description

Ore mineralogy	Pyrite, pyrrhotite, chalcopyrite, sphalerite, cobaltite, magnetite, galena, bornite, tetrahedrite, cubanite, stannite, molybdenite, arsenopyrite, marcasite.
Alteration	Difficult to recognize because of metamorphism. Chloritization of adjacent rocks is noted in some deposits. Similar to gangue mineralogy—quartz, chlorite, calcite, siderite, ankerite, pyrite, sericite, and graphite.
Ore controls	Difficult to recognize; early (syndepositional) faults and mafic volcanic centers. Deposits are thin, but laterally extensive and tend to cluster in en echelon pattern.
Geochemical signatures	Cu, Zn, Ag, Co/Ni>1; Mn halos, Mg enrichment, Cu, Pb, Zn, Ag, As, Au, Bi, Cd, Hg, In, Sb, Sn, and Tl.
Geophysical signature	Magnetics: Regional geology/structure. Gravity: Regional geology/structure. Radiometrics: Lithology.

Economic factors

Grade and tonnage	The type-locality Besshi deposits average 0.22 Mt, containing 1.5 wt.% Cu, 2–9 g/t Ag, and 0.4–2 wt.% Zn.
Importance	Minor global significance.

Other assessment and exploration guides

Mafic volcanic rocks (tholeiitic, less commonly alkalic) associated with clastic rocks.

Mn-rich garnets in metamorphosed exhalative horizons.

Presence of a submarine volcanosedimentary sequence having an age that falls within a time period containing numerous VMS deposits with large aggregate tonnages and base metal contents.

Evidence of an extensional geodynamic setting and synvolcanic faulting as reflected in distinctive compositions of volcanic and synvolcanic intrusive rocks.

Presence of coarse volcanic breccias or felsic domes indicating proximity to a volcanic center.

Occurrence of exhalites, especially those containing barite and (or) high concentrations of Cu, Zn, or Pb.

Favorable marine volcanosedimentary units including felsic or mafic lavas or tuffs, coarse breccias, and rhyolite domes that host mineralization within the same belt.

VMS-type prospects or occurrences including stratabound sulfides and discordant veins.

Evidence of VMS-type alteration zones represented by abundant chlorite or white mica, or their metamorphosed equivalents; abundant tourmaline and (or) gahnite.

Synvolcanic structures such as growth faults, calderas, and fault intersections, which may have focused fluid flow and localized sulfide mineralization.

Local fine-grained, highly carbonaceous or graphitic sedimentary rocks that record breaks in volcanism and in most cases indicate coeval anoxic or sulfidic bottom waters that prevented seafloor weathering and oxidation of sulfides.

Large synvolcanic sills and (or) dikes, which typically occur in the stratigraphic footwall of the deposits, having served as sources of heat to drive the hydrothermal systems.

Abundant chlorite or white mica and their metamorphosed equivalents (including Al-rich minerals), as evidence of VMS-type alteration.

Examples

In/near focal areas	Rio Tinto, Nevada.

Elsewhere	Windy Craggy, British Columbia; Besshi, Japan.

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Hydrothermal—Exhalative-Sedimentary Processes System

Deposit types in the study area
SEDEX (sedimentary exhalative deposits) lead-zinc-silver
Bedded barite

Sedimentary-Exhalative (SEDEX) Lead-Zinc-Silver

[wt.%, weight percent; Mt, million metric tons; g/t, grams per metric ton; m, meter; km, kilometer; °C, degree Celsius; SEDEX sedimentary exhalative; MVT, Mississippi-Valley-type]

Synonyms	Shale-hosted Zn-Pb-Ag, sediment-hosted massive sulfide Zn-Pb-Ag, SEDEX Zn-Pb.
Commodities	Zn, Pb, Ag (minor Cu, barite).
Synoptic statement	Hydrothermal deposit formed by the exhalation of metalliferous sedimentary brines into seawater.
Description	Beds and laminations of sphalerite, galena, pyrite, pyrrhotite and rare chalcopyrite, with or without barite, in euxinic clastic marine sedimentary strata. Deposits are typically tabular to lensoidal in shape and range from centimeters to tens of meters thick. Multiple horizons may occur over stratigraphic intervals of 1,000 m or more.

Geological environment

Rock types	Carbonaceous black shale, siltstone, cherty argillite and chert. Thin interbeds of turbiditic sandstone, granule to pebble conglomerate, pelagic limestone and dolostone, although volumetrically minor, are common. Evaporites, calcareous siltstone and mudstone are common in shelf settings. Small volumes of volcanic rocks, typically tuff and submarine mafic flows, may be present within the host succession. Slump breccia, fan conglomerates and similar deposits occur near synsedimentary growth faults. Rapid facies and thickness changes are found near the margins of second and third order basins. In some basins high-level mafic sills with minor dikes are important.
Textures	Sulfide and barite laminae are usually very finely crystalline where deformation is minor. In intensely folded deposits, coarser grained, recrystallized zones are common. Sulfide laminae are typically monomineralic.
Age range	Middle Proterozoic, Early Cambrian, early Silurian and Middle to Late Devonian to Mississippian. The middle Proterozoic and Devonian-Mississippian events are recognized worldwide.
Depositional environment	Large evaporative shallow-water epeiric carbonate platforms.
Tectonic setting(s)	Intracratonic or epicratonic sedimentary basin.
Associated deposit types	Mississippi-Valley type (MVT), bedded barite, iron formation, phosphate.

Deposit description

Ore mineralogy	Sphalerite, galena, pyrite, pyrrhotite ± chalcopyrite. Barite may or may not be a major component of the ore zone. Trace marcasite, arsenopyrite, bismuthinite, molybdenite, enargite, millerite, freibergite, cobaltite, cassiterite, valleriite and melnikovite have been reported from these deposits.
Alteration	Alteration varies from well-developed to nonexistent. In some deposits a stockwork and disseminated feeder zone lies beneath, or adjacent to, the stratiform mineralization. Alteration minerals, if present, include silica, tourmaline, carbonate, albite, chlorite and dolomite. They formed in a relatively low temperature environment. Celsian, Ba-muscovite and ammonium clay minerals have also been reported but are probably not common.
Ore controls	Favorable sedimentary sequences, major structural breaks, basins.
Geochemical signatures	Typically zoned with Pb found closest to the vent grading outward and upward into more Zn-rich facies. Cu is usually found either within the feeder zone of close to the exhalative vent. Barite, exhalative chert and hematite-chert iron formation, if present, are usually found as a distal facies. Phosphate may occur in temporal association with Pb and Zn. Sedimentary rocks such as pelagic limestone interbedded with the ore zone may be enriched in Mn. NH_3 Zn, Pb, and Mn anomalies at some deposits. The host stratigraphic succession may also be enriched in Ba on a basinwide scale. Dispersion halos and zoning of Fe, Ba, and Si at distances of tens and even hundreds of km from deposits. If phosphate occurs as apatite, may have enrichments of U and rare earth elements.
Geophysical signature	Magnetics: Regional geology/structure. Basin geometry. Gravity: Regional geology/structure. Radiometrics: Lithology, weak radioactivity in some deposits. Presence of graphite-rich zones in the host sedimentary rocks can complicate the interpretation of electromagnetic conductors.

Economic factors

Grade and tonnage	SEDEX deposits range from 0.01 to 746 Mt, with a median size of 10 Mt. Median ore grades are: 2.26 wt.% Pb, 5.55 wt.% Zn, 0.6 wt.% Cu, and 45 g/t Ag.

Importance	SEDEX deposits produce a significant proportion of the world's Zn and Pb. Their large tonnage potential and associated Ag values make them an attractive exploration target.

Other assessment and exploration guides

All SEDEX deposits occur in intracratonic or epicratonic sedimentary basins.

Depth to crystalline basement greater than 3 km (to achieve required fluid temperatures 100 °C).

Organic-rich black shale or siltstone with greater than 1 wt.% C_{org}.

Brine salinity source: Saline brine (>17 percent TDS) is necessary to form a SEDEX deposit. Basin-scale processes are required to produce the volume of brine necessary to form a deposit. Thus, direct geologic evidence for saline brine generation (such as evaporite minerals, breccias indicating salt dissolution or escape, or regional dolomitized platforms sequences) is required.

Basinwide organic-rich metalliferous black shales and PO_4, Fe, and Mn deposits may identify prospective sedimentary intervals in basins.

Areas within a few to tens of kilometers of large basin-bounding faults that control second-order features within sedimentary basins are highly favorable.

Synsedimentary faulting as indicated by abrupt and truncated facies boundaries in platform-to-slope transition, thick debris flows, intraformational breccias, changes in isopach thicknesses, and synsedimentary slump structures are highly useful indicators of favorable stratigraphic horizons for ore.

Extensive dolomitization of platform carbonate rocks and alkali-altered platform and rift-phase clastic sedimentary rocks are strong indicators of productive SEDEX basins.

On a local scale, faults that were fluid conduits may be identified by wallrock alteration with Fe- and Mn-rich carbonate rocks or silicification, and perhaps tourmalinization.

MVT-style mineralization and higher temperature dolomite along platform margins may be a strong indicator of the fluid-flow systems that form SEDEX deposits.

Examples	
In/near focal areas	Triumph, Idaho.
Elsewhere	Red Dog, Alaska; Sullivan, British Columbia.

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Bedded Barite

[wt.%, weight percent; Mt, million metric tons; SEDEX, sedimentary exhalative deposits; PGE, platinum-group elements; REE, rare earth elements]

Synonyms	Sediment-hosted, stratiform barite.
Commodities	Ba.
Description	Sedimentary-hosted, stratiform or lens-shaped barite bodies that may reach over ten meters in thickness and several kilometers in strike length. Some Ba-rich rocks are lateral distal equivalents of shale-hosted Pb-Zn (SEDEX) deposits.
Geological environment	
Rock types	Carbonaceous and siliceous shales, siltstones, cherts, argillites, turbidites, sandstones, dolomites and limestones. Chert is abundant in continental margin types. Clastics deposit in turbidity currents common in cratonic rift types.
Age range	Deposits are hosted by rocks of Archean to Mesozoic ages but are most common in rocks of the Phanerozoic, especially mid to late Paleozoic in age.
Depositional environment	Sedimentary depositional environment is mainly half-grabens and basins of second or third order. Although Zn-Pb-barite (SEDEX) deposits may require euxinic environment to stabilize sulfides, more oxidized depositional environment may be the key for deposition of high-grade (nearly sulfide-free) barite deposits.
Tectonic setting(s)	Continental margin types deposited in ocean basins between subduction zone and passive continental margin. (Nevada type). Cratonic rift types are deposited in intracratonic rifts with strong local relief (German type).
Associated deposit types	Shale-hosted Zn-Pb deposits, Irish-type massive sulfide deposits, sedimentary manganese deposits, and vein barite deposits. In oxygen starved basins, barite deposits may be stratigraphically associated with black shales enriched in phosphates, vanadium, REE and uranium mineralization, and possibly shale-hosted Ni-Mo-PGE deposits.
Deposit description	
Ore mineralogy	Barite.
Alteration	None in most cases. Secondary barite veining. Weak to moderate sericitization reported in, or near, some deposits in Nevada.
Ore controls	Syndepositional faults are extremely important for SEDEX deposits that are commonly proximal to the vents but may not be essential for all sediment-hosted stratabound barite deposits.
Geochemical signatures	Ba enrichment on the scale of the basin and other indicators of shale-hosted Zn-Pb deposits, such as high values of Zn, Pb, Mn, Cu, and Sr, in rock and stream sediment samples. Strongly anomalous Ba values in stream sediments and heavy mineral concentrates are only found in close proximity to barite mineralization because barite abrades rapidly during stream sediment transportation. The difference between $^{87}Sr/^{86}Sr$ ratios of barite and coeval seawater may be used to distinguish between cratonic rift (potentially SEDEX-related) barite occurrences and those of peripheral foreland basins.
Geophysical signature	Deposit may correspond to a gravity high.
Economic factors	
Grade and tonnage	Deposits range from less than 1 to more than 25 Mt grading 30 wt.% to over 95 wt.% barite with a median size of 1.24 Mt containing 87.7 wt.% $BaSO_4$ (Orris, 1992).
Importance	Main source of industrial barite, which is used in drilling fluids in the oil and gas industry.
Other assessment and exploration guides	

Appropriate tectonic and depositional setting.
Some barite deposits display breccias and slump structures.
In metamorphosed areas, barite may be remobilized forming veinlets and (or) recrystallized.
Proximity to known occurrences of barite, shale-hosted SEDEX, or Irish-type massive sulfide occurrences.
Exhalative chert, hematite-chert iron formations, and regional Mn marker beds.
Vegetation "kill zones" coincide with some barite occurrences.

Examples	
In/near focal areas	Snake Mountains, Nevada.

Elsewhere	Argenta, Rossi, Greystone, Big Ledge Mines, Nevada.

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Hydrothermal—Metamorphic Rock Associated System

Deposit types in the study area
Orogenic low-sulfide gold-quartz veins

Orogenic Low Sulfide Gold-Quartz Veins

[km, kilometer; t, metric tons; g/t, grams per metric ton; °C, degree Celsius]

Synonyms	Turbidite-hosted gold, low-sulfide gold quartz veins, mesothermal gold, greenstone gold, Slate Belt gold, Mother Lode type, Homestake type.
Commodities	Au.
Description	Structurally controlled lode gold in massive persistent quartz veins mainly in regionally metamorphosed volcanic rocks, volcanic sedimentary rocks, and banded iron formation.
Geological environment	
Rock types	A wide range of potential rock types within deformed and metamorphosed host terranes; greenstone belts; turbidites, banded iron formation. Mainly greenschist metamorphic grade rocks, less commonly amphibolite facies, rare granulite facies.
Age range	Archean to present.
Depositional environment	Adjacent to major, regionally extensive, deep crustal fault zones with deposit locations controlled by secondary faults. Gold is deposited from near-neutral pH, low-moderate salinity, and high CO_2 hydrothermal fluids within, or in proximity to, zones of brittle and (or) ductile deformation; transported in solution along permeable large-scale fault zones; temperatures of deposition are ± 350 ºC, at depths ranging from 4 to 12 km.
Tectonic setting(s)	Archaean granite-greenstone terrain. Terrains of turbiditic metasedimentary rocks. Continental margin accretionary (oceanic-continental) and collisional continent-continent) orogens.
Associated deposit types	Placer and paleoplacer gold deposits.
Deposit description	
Ore mineralogy	Gold, electrum, arsenopyrite, pyrite, pyrrhotite (minor chalcopyrite, sphalerite, galena, and telluride minerals). Au/Ag ratios >1. Mineralogy of deposits is limited, in descending order, to quartz, carbonates, alkali feldspar (usually albite), sericite, pyrite, and minor amounts of tourmaline, arsenopyrite, scheelite, molybdenite. No significant base metals.
Alteration	Intense carbonate alteration is always present (ankerite, dolomite, calcite, magnesite). A progression from calcite to Fe-carbonate can often be observed toward the deposit. Chlorite is an important alteration product when the wall rock is mafic. Fe-sulfide (commonly as pyrite) is ubiquitous. Silicification (an increase in modal quartz). Alteration is most obvious when it occurs within low-grade rocks.
Ore controls	Commonly near major regional faults/shear zones but located in secondary faults and (or) near hinge zones of folds. Ore bodies typically strike parallel to subparallel to the host structures. Major regional structures often along terrane or block boundaries serve as fluid pathways.
Geochemical signatures	Common pathfinder elements: Ag, As, Au, B, Bi, Hg, Sb, Te, and W. Local, low-level enrichment of Cu, Pb, and Zn may occur in some deposits.
Geophysical signature	Faults indicated by linear magnetic anomalies. Areas of alteration indicated by negative magnetic anomalies due to destruction of magnetite as a result of carbonate alteration. Airborne and ground magnetic and gravity surveys to map bedrock geology including deformation zones. Airborne and ground electromagnetic surveys to outline deformation zones, especially those that contain graphitic gouge and S-rich zones. Linear resistivity survey lows may locate fault structures; resistivity highs may be associated with massive quartz veins. Radiometric surveys may aid in defining areas of potassium alteration. Seismic-reflection surveys to locate linear fault zones.
Economic factors	
Grade and tonnage	World-class deposits range from about 100 to 5,000 t. Typical grades 4 to 20 g/t Au.

Importance	These deposits are a major source of global gold production.

<div align="center">Other assessment and exploration guides</div>

Placer gold or elevated gold in stream sediment samples is an excellent regional and property-scale guide to gold-quartz veins.

Ore shoots can have many forms that are related to the wide variety of second and third-order structures that can develop in (or be used by) strike-slip fault systems.

Broad "deformation envelopes" adjacent to regional listric faults where associated with carbonate alteration.

Alteration and structural analysis can be used to delineate prospective ground. Economic gold concentration in a deformation zone is often located in places where increased extension has occurred, such as in pull-apart basins.

Mineralization is often contemporaneous with spatially associated granitic intrusions but not genetically related to them.

Within carbonate alteration zones, gold is typically only in areas containing quartz, with or without sulfides.

Serpentinite bodies, if present, can be used to delineate favorable regional structures. Largest concentrations of free gold are commonly at, or near, the intersection of quartz veins with serpentinized and carbonate-altered ultramafic rocks.

<div align="center">Examples</div>

In/near focal areas	South Pass, Wyoming; Buffalo Hump, Elk City, Yellow Pine, and Boise Basin in central Idaho.
Elsewhere	Grass Valley, California; Timmins District, Ontario; Val d'Or District, Quebec; Homestake, South Dakota.

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Sedimentary System (formed during or after the conversion from sediment to sedimentary rock)

Deposit types in the study area
Bentonite
Dolomite (high purity)
Sediment-hosted stratabound copper
Sandstone uranium (rollfront) in intermontane basins
Hydroallogenic volcanic-hosted uranium
Zeolites (closed system subtype)
Zeolites (open system subtype)

Bentonite

[Mt, million metric tons; m, meter; km, kilometer]

Synonyms	Sodium (Na) bentonite, calcium (Ca) bentonite, swelling bentonite, nonswelling bentonite, hydrothermal bentonite, Wyoming bentonite, southern bentonite, montmorillonite.
Commodities	Na bentonite, Ca bentonite, hydrothermal bentonite.
Description	Any material composed of smectite clay minerals, whose properties are dictated by the dominant smectite clay mineral.

Geological environment

Rock types	Parent materials are felsic to intermediate volcanic rock, ash, and tuff.
Textures	Inherited from parent volcanic tuff or ash, clay deposits can be thinly bedded and laterally extensive, or they can be lens-shaped and massively bedded bodies with thickness 1–6 m.
Age range	Almost all commercial deposits are either Cretaceous or Tertiary
Depositional environment	Felsic to intermediate volcanism producing volcanic ash and (or) feldspar-rich rocks which are subsequently altered to clay by reaction with alkaline, marine-, or hydrothermal waters.
Tectonic setting(s)	Stable marine or fluvial-lacustrine basins. Hydrothermal bentonites form near conduits for thermal fluids.
Associated deposit types	Diatomite, other clay minerals, limestone, dolomite, zeolites.

Deposit description

Ore mineralogy	Na- and Ca-bentonite, montmorillonite, and other smectite clays.
Alteration	Leaching of Mg and Fe from bentonite may lead to formation of kaolinite, burial and diagenesis may convert smectite minerals to illite or chlorite. Abundance decreases with depth of burial; smectites become rare when buried >4 km.
Ore controls	For sedimentary bentonites: proximity of volcanism to alkaline marine basin; for hydrothermal bentonites: faults and fractures for fluid migration and reactive host rocks.
Geochemical signatures	Formed from alteration of volcanic ash and tuffs; often found containing feldspar, biotite, quartz, pyroxene, and zircon that were phenocryts in the original volcanic material. Na bentonite contains exchangeable Na ions and may increase 15–20 times in volume when wetted with water. Ca bentonite contains exchangeable Ca ions and may increase as much as five times in volume in the presence of water.
Geophysical signature	Seismic surveys may delineate extent and thickness of bentonite beds and basin depth.

Economic factors

Grade and tonnage	Almost 90 percent of Na bentonite comes from Wyoming and Montana; 45 percent of Ca bentonite comes from Mississippi and Alabama.
Importance	Na bentonite (swelling): used in drilling mud, foundry sand bond, iron-ore pelletizing, bleaching liquids, filler, sealant, nondrip paint, putty adhesives, liquid fertilizer suspensions, and animal feed. Ca bentonite (nonswelling): used as foundry sand bond, filler, catalyst, absorbent (kitty litter and oil and grease absorbents), water treatment filters, ceramic glazes, and used as "Fuller's earth" for cleaning agent and decolorizing oils. Hydrothermal bentonite: decolorizing oils, filler, filtration, pesticide carrier.

Examples

In/near focal areas	Ivanhoe Creek, Ca bentonite, Elko County, Nevada. Glasgow and Malta areas, Na bentonite, Montana. Ben-Jel bentonite mine, 22 km west of Grand View, Owyhee County, Idaho, 4.6 m thick bentonite bed overlying siliceous volcanic tuff. Liddy Hot Springs bentonite occurrence, 3-m clay beds.

| **Elsewhere** | Clay Spur Na Bentonite Bed, Cretaceous Mowry Shale near Black Hills in Wyoming and South Dakota. |
| | Sandy Ridge, a Ca bentonite at the base of the Late Cretaceous Ripley Formation, southeastern Lowndes County, Alabama. |

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Dolomite (high-purity)

[km, kilometer; t, metric ton; wt.%, weight percent]

Synonyms	Dolostone, dolomitite, dolospar.
Commodities	Dolomite (aggregate, filler). Sometimes dolomite may be a byproduct of quarrying limestone.
Description	A bedded or massive carbonate sedimentary rock that occurs as tabular bodies concordant with stratigraphy and beds as much as tens of meters thick and zones controlled by faults and permeable zones. Dolomite contains more than 90 percent of the mineral dolomite and is usually a finely crystalline and slightly porous rock. Calcite is the most common other mineral.

Geological environment

Rock types	Dolomites are often found within thicker sedimentary sequences with associated limestones, dolomitic limestones, argillites, sandstones, and evaporates. In island arcs, dolomites often have a volcanic component, such as tuffaceous rocks, sills, submarine lavas, palagonite breccias, and sometimes cherty layers and interbeds.
Age range	Dolomite can be any age, but the ages of dolomitization for secondary deposits often are not well defined. Large-scale regional dolomitization in western Canada has been linked to fluid circulation taking place during Devonian-Mississippian and Late Cretaceous-Tertiary periods. Generally these deposits are believed to be concurrent with large-scale tectonic activity.
Depositional environment	Dolomite is most common as a secondary replacement of marine sedimentary rocks that were a slightly magnesian calcium carbonate that was frequently aragonite originally and later recrystallized into calcite. Circulating ground water (sea water, hypersaline brine, pore water) containing magnesium reacted with the calcium carbonate to produce dolomitic limestones and dolomites. Dolomite may also form as a primary sediment, but this is not very common.
Tectonic setting(s)	Dolomite is more common in Holocene and ancient continental shelf and subsiding marginal marine environments; however, economically attractive deposits also occur in island arc environments.
Associated deposit types	Mississippi Valley Type Pb, Zn, barite, fluorspar deposits, limestone, accumulations of oil and natural gas, and hydrogen sulfide.

Deposit description

Ore mineralogy	Dolomite (may occur with quartz, brucite, calcite, chert, kaolinite, illite, sometimes bitumen).
Alteration	Dolomite is typically an alteration product. It may be accompanied by a variety of sulfides (pyrite, sphalerite, galena), Fe-Mn-Mg-Ca carbonates, chlorite, barite, gypsum or anhydrite, and fluorspar. High-temperature/low-pressure metamorphism may result in converting dolomite into a mixture of periclase (MgO) and calcite. Periclase in nature easily alters into brucite $Mg(OH)_2$.
Ore controls	Ore control reflects the mode and intensity of dolomitization. In some deposits a primary control is the chemical composition of the carbonate rock; in some others it is the upper and lower limits of the original limestone bed. For some deposits, the locations where fluid pathways along faults and permeable zones intersect reactive carbonate rocks are the control on the location of the replacement zones.
Geochemical signatures	High magnesium in carbonate rock.
Geophysical signature	Although karst features in dolomite are rather uncommon, resistivity and gravity could be used to outline karst-affected areas.

Economic factors

Grade and tonnage	Commercial dolomite must be very high-purity carbonate rock and almost stoichiometric in composition (30.4 wt.% CaO and 21.9 wt.% MgO). Industry specifications are set for the calcined product—that is, a dolomitic lime. Depending on the end use, the limits for impurities are usually between 0.1 and 4.5 wt.% Fe_2O_3, SiO_2 between 0.5 and 1.0 wt.%, and Al_2O_3 between 0.3 and 0.8 wt.%.

Importance	Very important as a source of magnesium to improve fluidity of molten product, such as in the production of mineral wool, float glass, and slag in metallurgical process. As agriculture soil conditioner; the magnesium content improves the neutralizing power and helps to retain the soil nutrients better than pure limestone. In many other end uses dolomite can be substituted by some other industrial minerals.

Other assessment and exploration guides

Sometimes yellow or brown color of outcrops; sandy talus.

Because of lower solubility of dolomite relative to calcite, dolomite does not fizz with diluted hydrochloric acid.

Ore control reflects the mode and intensity of dolomitization. In some deposits a primary control is the chemical composition of the carbonate rock, in some others it is the upper and lower limits of the original limestone bed. For some deposits, the locations where fluid pathways along faults and permeable zones intersect reactive carbonate rocks are the control on the location of the replacement zones.

Mining of high purity dolomite requires more exploration and quality control, and is more costly than mining dolomite for aggregate use.

Examples

In/near focal areas	None.
Elsewhere	Mill Creek, Oklahoma; northeastern Illinois.

References

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Sediment-Hosted Stratabound Copper

[Mt, million metric tons; wt.%, weight percent; g/t, grams per metric ton; Ma, mega-annum or millions of years ago]

Synonyms	Sediment-hosted stratiform Cu, Cu sandstone, sandstone Cu; sandstone Cu deposits are one of three subtypes: (1) reduced facies-type, (2) sandstone Cu-type, and (3) red bed-type.
Commodities	Cu, Ag, or Co.
Description	Bodies of disseminated, cementing, and veinlet-hosted copper (Cu) minerals that are peneconformable with their sedimentary or metasedimentary host rocks. Deposits are characterized by strong zoning of the ore minerals laterally along and across the bedding, from pyrite, to chalcopyrite, to bornite, to chalcocite, and to hematite.
Geological environment	
Rock types	Typically well-sorted feldspathic to arkosic sandstones. Where conglomeratic, they typically have only mud intraclasts and are not polymictic. These rocks were probably reservoir rocks for petroleum before copper minerals were deposited; petroleum was probably sour gas, for most cases.
Age range	Limited to sedimentary or metasedimentary formations younger than 2,300 Ma, when free oxygen first appeared in Earth's atmosphere and the earliest red beds formed.
Depositional environment	Sandstone-type host rocks were deposited in subtidal nearshore, beach, eolian, and fluvial environments. Various depositional environments that are among deltaic topset beds. Host rocks at Spar Lake are the lower quartzite beds of the upper member of the Revett Formation of the Belt Supergroup, which were deposited in a prograding beach and bar nearshore environment, and middle quartzite host rocks were deposited by laterally shifting subtidal channels.
Tectonic setting(s)	SSC deposits formed in sedimentary basins that now vary from virtually undeformed to intensely folded, thrust-faulted, and the host rocks metamorphosed. Host sedimentary-rock sequences were deposited within 20 to 30 degrees of the paleo-equator, associated with hot, dry climates that produced thick packages of red beds and commonly also produced evaporites.
Associated deposit types	Volcanic red bed Cu, tabular sandstone-hosted U-V.
Deposit description	
Ore mineralogy	Chalcocite and bornite zones are typically the ore zones. Mineral zonation both laterally and vertically from pyrite to chalcopyrite to bornite to chalcocite to hematite is characteristic. Less common ore minerals include digenite, djurleite, covellite, sulfur-rich bornite±carrollite, Co-rich pyrite, and native silver. Chalcocite, bornite, and digenite are commonly argentiferous.
Alteration	Alteration gangue minerals are zonally arranged, with their zone boundaries parallel to the zonation of sulfide minerals. Authigenic hematite lining and filling pores is present in chalcocite zones of most deposits. Authigenic K-feldspar may occur as overgrowths on detrital K-feldspar grains and as cements and replacements. Authigenic chlorite. Fe- and Mn-rich calcite cement. Na-rich alteration accompanies mobilization and transport (sodium sulfate minerals, albite, or analcime, and at higher metamorphic grade, sodic amphibole riebeckite).
Ore controls	Traps to create gas reservoirs include anticlines, fault traps, and combination traps produced by pre-ore folding and faulting. Faults at high angles to host beds are common, and some fed cupriferous oxidizing ore fluids to the gas reservoirs.
Geochemical signatures	Cu, Ag, and Co. Ag is useful in the sandstone Cu mineralizing system of the Revett Formation, because anomalies with Cu and Ag are distinct from anomalies associated with other types of deposits. Other potential pathfinder elements include Pb, Zn, As, Hg, Mn, and Ba.
Geophysical signature	Gravity, magnetic, and electromagnetic surveys to map basement topography, bedrock geology, and basin and subbasin margins. Seismic reflection or refraction surveys can identify basin and subbasin margins, anticlines, stratigraphic traps, and combination. Radiometrics can be used to image lithology and alteration. Induced polarization (IP) may be effective in direct sensing of deposits. Remote sensing of colors using Landsat imagery or remote sensing of ferric oxides using Landsat imagery can be used to map pre-ore bleaching of red beds.
Economic factors	
Grade and tonnage	Tonnages range from about 2 to 90 Mt, although the largest is 1,311 Mt; median size 10 Mt; Grades range from about 0.5 to 2.6 wt.% Cu, median 1.2 wt.% Cu; Ag grades 5 to 100 g/t.

Importance	Sediment-hosted stratabound copper deposits account for approximately 20 percent of the world's past production and known resources of copper. Although such deposits are common throughout the world, economically significant deposits are rare.

Other assessment and exploration guides

Evidence of essential ore system components:

Source rocks for copper, typically oxidized (hematite-stable) siliciclastic sediment or mafic subaerial volcanic rocks.

Hematite-stable (oxidized) subsurface sedimentary brines capable of dissolving and transporting copper in solution.

Brines moving generally in the direction of dewatering of a sedimentary basin. Evidence of brine can include bedded evaporite or casts, molds of halite, gypsum, and other evaporite minerals nearby.

Rock seals confining beds, stratigraphic pinchouts, and (or) anticlinal traps (focus fluid flow of the copper-bearing brines to rocks that contain organic material that will cause sulfide mineral precipitation).

Organic-rich sedimentary rocks that serve as source rocks for natural gas, oil, and H_2S, that cause the precipitation of copper from an oxidized subsurface sedimentary brine.

In terrains that have known sandstone Cu deposits, anticlines, areas with known stratigraphic traps, and those with known combination traps are more favorable than other parts of broadly permissive areas.

Areas of natural-gas production within basins that have known sandstone Cu deposits.

Host rocks overlie or are enclosed within thick (greater than 300 meters and commonly greater than 1 kilometer) sequences of red beds. The association with red beds is an important distinction from other Cu deposits found in sedimentary rocks.

Examples

In/near focal areas	Griggs mine, Wyoming.
Elsewhere	Spar Lake, Belt-Purcell Basin, Montana; Udokan, Transbaikalian Russia; Chu Sarysu Basin, Kazakhstan; Chuxiong Basin, China.

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Sandstone Uranium (Roll Front) in Intermontane Basins

[wt.%, weight percent; km, kilometer; t, metric ton; g/t, grams per metric ton]

Synonyms	Roll front U.
Commodities	U.
Description	Microcrystalline uranium oxides and silicates deposited from groundwater in localized reduced environments within fine- to medium-grained sandstone beds; some uranium oxides also deposited during redistribution by ground water at interface between oxidized and reduced ground.
Geological environment	
Rock types	Host rocks are feldspathic or tuffaceous sandstone. Pyroclastic material is felsic in composition. Mudstone or shale commonly above and (or) below sandstones hosting diagenetic ores that have channeled and focused uraniferous groundwater.
Age range	Jurassic to Oligocene sandstones in the Wyoming basin province, with most mineralization in the Paleocene Fort Union, Oligocene Wasatch, Wind River, and Battle Spring Formations.
Depositional environment	Intracratonic basins, fluvial channels, braided stream deposits. Contemporaneous felsic volcanism or eroding felsic plutons are sources of U.
Tectonic setting(s)	Stable platform or foreland-interior basin; adjacent major uplifts provide favorable topographic conditions.
Associated deposit types	Tabular remnant or "lag" deposits.
Deposit description	
Ore mineralogy	At the roll-front, uraninite, coffinite, uranyl sulfate, uranium vanadates, arsenic with pyrite, ferroselite, marcasite, and molybdenite
Alteration	The alteration zone on the oxidized side of the roll front is characterized by bleached sand containing limonite, hematite, magnetite, and nontronite. Adjacent-to-ore siderite, ferroselite, and goethite with vanadium and arsenic enrichment. At the roll-front interface, carbonate-cemented sand with iron oxides, siderite, ferroselite, and goethite.
Ore controls	Permeable sandstone sequences with low dips and adequate recharge to facilitate the movement of uranium rich groundwater into the sequence; felsic plutons or felsic tuffaceous sediments adjacent to or above host rock are favorable source for U. Groundwater flow as controlled by paleohighs (Casper arch southwest of Powder River Basin and the Granite Mountains adjacent to the Shirley, Wind River, and Great Divide Basins in Wyoming) Regional redox interface marks locus of ore deposition and has been attributed to amorphous organic material, petroleum, and natural gas within host sediments. Coalified logs and other vegetal remains behind the oxidized roll fronts yield remnant or lag deposits of uranium.
Geochemical signatures	U, V, Mo, Se, locally Cu, and Ag. Anomalous radioactivity from daughter products of U. Typical zoning across a roll front is Se/V–U–Mo/As.
Geophysical signature	Magnetics: Regional geology/structure. Gravity: Regional geology/structure. Radiometrics: Lithology that may focus grounwater flow (stream channels)
Economic factors	
Grade and tonnage	Sandstone-hosted deposits of all types in the United States range in size from 1 to 40 million pounds of U_3O_8 and grade from 0.07 to 0.9 wt.% U_3O_8. Roll-front deposits fall on the small size of this range and are characterized by their poddy nature along extensive roll-front systems. Within the Great Divide Basin, Sheep Mountain contains 16 million pounds of U_3O_8 (average grade 0.131 wt.% U_3O_8).
Importance	The majority of the ~ 4–5 million pounds of uranium currently being produced in the Untied States is from roll-front deposits in Wyoming. The Sheep Mountain deposit has produced uranium and is under development by Energy Fuels Resources, Inc.
Other assessment and exploration guides	

Anomalous radon and helium over mineralization.

Areas where oxygenated waters migrating through an aquifer with traces of dissolved uranium encounter a reducing zone and precipitate uranium along with other metals

Examples	
In/near focal areas	Great Divide Basin, Wyoming.
Elsewhere	Gas Hills, Wyoming.
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Hydroallogenic Volcanic-Hosted Uranium

[wt.%, weight percent; ft., feet; mi², square mile; lb, pound; NURE, National Uranium Resource Evaluation]

Synonyms	Epigenetic, supergene.
Commodities	Uranium.
Description	Hydroallogenic deposits form when uranium-enriched fluids are released from volcanic source rocks, transported by aqueous solutions, and concentrated in the same or nearby rocks.
Geological environment	
Rock types	Highly variably lithologies, with porosity and permeability the determining parameters. At Mountain City, deposits are hosted within Tertiary arkosic sandstone and conglomerate with intercalated clay, shale, and tuffaceous and volcanoclastic rocks. Mineralization is also noted in shear zones and joints within these sedimentary rocks and underlying granites. Deposits are associated with rhyolitic to andesitic welded to unwelded air-fall and ash-flow tuff, agglomerate, and granite.
Age range	Tertiary.
Depositional environment	At Mountain City: Tertiary conglomerate, sandstone and volcanoclastic rocks that collected in paleochannels or lows. Shear zones and joints within volcanic rocks, granite, and granitic grus. Within these rocks, charcoal, carbonaceous debris, and clay; trace pyrite is an important reductant.
Tectonic setting(s)	Volcanic settings favorable for groundwater circulation by faults and fractures.
Associated deposit types	Volcanogenic uranium deposits.
Deposit description	
Ore mineralogy	Most commonly uraniferous silica (chert/opal), uranosilicates, and (or) epigenetic uranium minerals (autunite, torbernite, soddyite, and carnotite). At Mountain City uranyl phosphates: Autunite (hydrated calcium uranyl phosphate $Ca(UO_2)_2(PO_4)_2 \cdot 10\text{-}12\ H_2O$), torbernite (hydrated copper uranyl phosphate $Cu(UO_2)_2(PO_4)_2 \cdot 12\ H_2O$), and meta-torbernite ($Cu(UO_2)_2(PO_4)_2 \cdot 8\ H_2O$).
Alteration	Host rocks usually silicified with widespread zeolitization and calcification. At Mountain City, diagenesis by groundwater alters feldspars to kaolinite and sericite; mafic rock constituents to iron oxide and chlorite; and tuffaceous material to montmorillonite and devitrifies the groundmass and quartz grains. This alteration presumably leaches uranium from source rocks.
Ore controls	Uranium minerals occur in (1) aureoles around the contact of the host rock with intrusive or effusive body from which mineralizing fluids originate, (2) tabular or lenticular units that follow bedding and permeable zones within sedimentary host rocks, (3) permeable Tertiary sediments deposited in paleochannels or lows developed on a Tertiary weathering surface, and (4) shear zones, fault breccias, and joints within volcanic rocks, granite, and grus.
Geochemical signatures	Few geochemical signatures of this deposit type are described nationwide. At Mountain City, elevated uranium and molybdenum in rock, surface water and groundwater, and soil and stream sediments samples.
Geophysical signature	Ground radiometric signatures detect uranium enrichment in discrete deposits.
Economic factors	
Grade and tonnage	These occurrences are highly variable in size and concentration. Deposits contain trace to 1–2 wt.% U_3O_8, and individual deposits have historically produced a few thousand pounds of U_3O_8. In the Mountain City area, cumulative production was 18,617 lb U_3O_8, as follows: Rim Rock Mine, 4,240 lb U_3O_8 (average grade 0.28 wt.% U_3O_8); Race Track Mine 9,866 lb U_3O_8 (average grade 0.24 wt.% U_3O_8); South Fork and Pixley Claims 4,511 lb U_3O_8 (average grade 0.12 wt.% U_3O_8). Deposits were mined from workings that are several hundred feet long; mineralization is described as a few to tens of feet thick.

| **Importance** | Past production, relatively high uranium grades and widespread distribution of these deposits is noteworthy. |
| | For the hydroallogenic class of deposits, nationwide in all resource categories (probable, possible and speculative) NURE estimated 157 million pounds U_3O_8 in the $30/lb U_3O_8 cost category and 716 million lb U_3O_8 in the $100/lb cost category (1980s prices). Most of this potential resource was identified in the Basin and Range resource region where, NURE estimated 148 million lb U_3O_8 in the $30/lb U_3O_8 cost category and 653 million pounds U_3O_8 in the $100/lb cost category. Note that the higher cost category is cumulative. |

Other assessment and exploration guides

Potential sources for leachable uranium including tuffaceous material and possibly granitic rocks.

Permeable sediments deposited on a paleo-topographic surface that allows transport of uranium-rich groundwater into host rocks.

Reductants within host rocks including charcoal, carbonaceous debris, clay, and pyrite.

Examples

| **In/near focal areas** | Nine deposits identified in the Mountain City region, Wells quadrangle, Nevada and Idaho. |
| **Elsewhere** | Truckee Formation (Tertiary) in Nevada. |

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Zeolites (Closed-Basin Subtype)

[cm, centimeter; m, meter; wt.%, percent]

Synonyms	Closed-system zeolites.
Commodities	Analcime, chabazite, clinoptilolite, erionite, mordenite, phillipsite.
	Byproducts: bentonite, fluorite, pumicite, potassium feldspar.
Description	Microcrystalline zeolite-bearing vitric tuff that consists chiefly of analcime, chabazite, clinoptilolite, mordenite, phillipsite, and sometimes erionite. Deposit may consist of one or several stacked zeolite layers separated by subeconomic or barren beds.

Geological environment

Rock types	Rhyolitic to dacitic, vitric tuff. Associated to rocks include bedded evaporites (trona, halite, borates), mudstone, diatomite, oil shale.
Age range	Late Paleozoic to Holocene, but most deposits are Cenozoic.
Depositional environment	Lacustrine basins that received silicic, vitric material either directly by airfall or by reworking. The saline lake water commonly was of the sodium carbonate-bicarbonate variety and had a pH of 9 or greater. These lakes are common in arid and semi-arid regions where annual evaporation exceeds rainfall.
Tectonic setting(s)	Closed hydrographic basins in either block-faulted terrains (such as the Basin and Range Province) or trough valleys associated with rifting. Lakes are commonly in block-faulted terranes or rift valleys.
Associated deposit types	Continental-basin bedded evaporites; finely crystalline, disseminated fluorite in lacustrine rocks.

Deposit description

Ore mineralogy	Analcime, chabazite, clinoptilolite, erionite, mordenite, phillipsite.
Alteration	In certain highly alkaline and saline lacustrine deposits, siliceous and alkali zeolites have been replaced during late diagenesis by analcime or potassium feldspar in the central part of the basin.
Ore controls	Grain size and permeability of the host silicic, alkali-rich, vitric tuff. Salinity, pH, and ratios of alkali and alkaline-earth ions in the pore water are important.
Geochemical signatures	B, Li in lacustrine environment of sodium carbonate-bicarbonate type.
	In most cases, zeolites can be detected and positively identified only by direct analytical techniques, such as x-ray diffraction. Lithogeochemistry may be a useful tool.
Geophysical signature	Possible use of color-composite imagery from airborne multispectral scanner data to distinguish zeolitic tuffs.
	Magnetics: Regional geology/structure. Gravity: Regional geology/structure. Radiometrics: Lithology.

Other assessment and exploration guides

Regional depositional environment of silicic, vitric tuffs in an alkaline, saline-lake deposit.

Alteration of tuff to zeolite require high alkalinity and lake brines rich the HCO_3 ion.

Host rock of vitric tuff of rhyolitic or dacitic composition; lateral zonation of zeolites and associated silicate minerals.

Ashfalls of glassy tuffs into alkaline-saline playas or rift lakes are ideal settings for high-grade deposits.

Unmetamorphosed or very low metamorphic-grade environments.

Molds of saline minerals, chemical delta of calcite or aragonite, associated dolomitic mudstone, occurrence of bedded or nodular chert.

Zeolites are finely crystalline and resemble bedded diatomite, feldspar, or bentonite in outcrop. Combination of x-ray diffraction and ammonia cation exchange capacity (CEC) are essential in the early screening of zeolite prospects.

Concentric zonation and lateral gradation in a basinward direction of unaltered volcanic glass to alkali-rich, silicic zeolites to analcime and then to potassium feldspar in the central part of the depositional basin.

Economic factors

Grade and tonnage	Thickness of the zeolitic tuffs commonly ranges from 10 cm to 10 m. Areal extent is commonly tens to hundreds of square kilometers. The cutoff grade varies greatly. For example, a 10 to 20 cm thick ore bed at Bowie contains 60 to 80 wt.% chabazite. Obviously, this zone would not have been economic if the main ore mineral was clinoptilolite. Most of the commercial clinoptilolite deposits contain between 50 wt.% and 90 wt.% zeolite.
Importance	This deposit type contains the largest variety of zeolite species, accounts for most of the present zeolite production in the United States, and is an important source for chabazite, erionite, and phillipsite in the United States.

Examples

In /near focal areas	McDermitt caldera, Nevada; Bear River zeolite deposit, southeast Idaho.

Elsewhere   Miocene-Pliocene Big Sandy Formation, Mohave County, Arizona; Bowie deposit, Arizona.

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Zeolites (Open-Basin Subtype)

[cm, centimeter; m, meter; wt.%, percent]

Synonyms	Open-system zeolites.
Commodities	Chabazite, clinoptilolite, mordenite, phillipsite (bentonite, pumicite).
Description	Microcrystalline zeolites crystallized in relatively thick, generally nonmarine tephra sequences that commonly show a more or less vertical zonation of zeolites and associated silicate minerals and that reflects the chemical modification of meteoric water as it flowed through the vitric sequence. The zeolites crystallized in the postdepositional environment over periods ranging from thousands to millions of years.

Geological environment	
Rock types	Tuffs having a broad compositional range, including rhyolite to dacite, trachyte or phonolite, and basalt to basanite. The silicic tuffs commonly were deposited as nonwelded ash flows. Associated with rhyolite to basalt flows; fluviatile mudstone, sandstone, and conglomerate; diatomite.
Age range	Mesozoic to Holocene, but most are Cenozoic.
Depositional environment	Most deposits are nonmarine (fluviatile and lacustrine), but some are shallow marine.
Tectonic setting(s)	Variety of nonmarine and shallow marine basins in volcanic terrains. Some thick tuffaceous deposits were air-laid onto the land surface and not into water.
Associated deposit types	The zonation of the open-system type of zeolite deposit is similar to the upper zones of burial diagenesis (burial metamorphism) that affected thick sequences of silicic, vitric tuffs. Associated deposits include pumicite and bentonite.

Deposit description	
Ore mineralogy	Chabazite, clinoptililite, mordenite, phillipsite.
Alteration	In silicic tuff sequences, the alkali-rich siliceous zeolites (clinoptilolite and mordenite) in the upper part of the deposit are replaced at depth by analcime, potassium feldspar, and (or) albite.
Ore controls	Grain size and permeability of host tuff; flow of meteoric water downward in an open hydrologic system; hydrolysis and solution of vitric material by the subsurface water in the upper part of the system raised the pH, activity of SiO_2, and content of dissolved solids to values where zeolites crystallized; resulted in a vertical or near-vertical zonation of zeolites and other authigenic minerals; composition of the vitric material may have dictated which zeolite species precipitated; clinoptilolite and mordenite are common in silicic tuffs, but chabazite and phillipsite are common in mafic or trachytic tuffs.
Geochemical signatures	None recognized. In most cases, zeolites can be detected and positively identified only by direct analytical techniques, such as x-ray diffraction. Lithogeochemistry may be a useful tool.
Geophysical signature	Possible use of color-composite imagery from airborne multispectral scanner data to distinguish zeolitic alteration.

Other assessment and exploration guides
Regional depositional environment containing thick sequence of vitric tuffs of Cenozoic age.
Very low grade or unmetamorphosed volcaniclastic sequences typically containing large proportions of ignimbrites.
Vertical zonation of zeolites and associated authigenic silicate minerals in thick (hundreds to thousands of meters) tuffaceous sequences, especially siliceous tuffs of Neogene age that were air-laid on land. The vertical zonation commonly is (from top to bottom) unaltered vitric material±smectite to clinoptilolite±mordenite±opal-(cristobilite-tridymite) to analcime±potassium feldspar±quartz and then to albite±quartz. This zonation may cut across bedding.
Thickness of the zeolitic tuffs commonly ranges from hundreds to thousands of meters. Areal extent is commonly hundreds to thousands of square kilometers.
Zeolitic tuffs commonly resist weathering and may be ledge formers.

Economic factors	
Grade and tonnage	The value of zeolite deposits varies depending on the end product use and zeolite species present. Properties, such as cation exchange capacity for radionuclides, heavy metals or NH^{+4}, are more meaningful than grade. This is because these properties are commonly different for the same zeolite species originating from two distinct deposits. The zeolite content of better deposits currently mined is estimated to have zeolite content above 60 wt.%, but may reach over 80 wt.%. Deposits supplying materials to control the odor to local farms may have zeolite content well below 50 wt.%, but must be close to the market.
	The Si/Al ratio and exchangeable cation ratios of the zeolites affect certain uses. Cation exchange capacity and adsorption capacity for various gases are important. Color (due to iron staining) and the abundance of nonzeolitic minerals may limit use.

Importance	Important sources of natural clinoptilolite and mordenite. Bentonite, attapulgite, and other materials known for their high absorbency may be cost effective alternatives to zeolites for specific ion exchange applications.

Examples

In /near focal areas	Miocene Paintbrush Group tuffs, tuffaceous beds of Calico Hills, and Crater Flat Group tuffs at Yucca Mountain, Nye County, Nevada (clinoptilolite and mordenite).
Elsewhere	Oligocene-Miocene John Day Formation, Oregon (clinoptilolite).
	Death Valley Junction, California (clinoptilolite).

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Sedimentary System (formed during deposition of the sediment)

Deposit types in the study area
Banded iron (Algoma type)
Lacustrine diatomite

Banded Iron Formation (Algoma type)

[wt.%, weight percent; Mt, million metric tons; nT, nanotesla; Ga, giga-annum or billions of years; REE, rare earth elements]

Synonyms	Volcanogenic iron formation, banded iron formation (BIF), taconite, itabirite.
Commodities	Fe (Mn).
Description	Oxide and carbonate lithofacies that contain 20 to 40 wt.% Fe as alternating layers and beds of micro- to macro-banded chert or quartz, magnetite, hematite, pyrite, pyrrhotite, iron carbonates, iron silicates, and manganese oxide and carbonate minerals. The deposits are interbedded with volcanic rocks, greywacke, and turbidite and pelitic sedimentary rocks; the sequences are commonly metamorphosed.

Geological environment

Rock types	Mafic to felsic submarine volcanic rocks and deep-water clastic and volcaniclastic sedimentary rocks. Pillowed greenstones, intermediate to felsic tuffs and agglomerates, poorly sorted clastic sedimentary rocks. Also, greywacke, black shale, argillite, and chert interlayered with pyroclastic and other volcaniclastic beds or their metamorphic equivalents. Algoma-type iron formations and associated stratiform sedimentary rocks commonly show a prolific development of different facies types within a single stratigraphic sequence.
Age range	Most widely distributed and achieve the greatest thickness in Archean terranes (2.9 to 2.5 Ga).
Depositional environment	Volcano-sedimentary basins (greenstone belts of Precambrian shields) generally with rapid turbidite sedimentation and thick volcanic accumulations.
Tectonic setting(s)	Volcanic arcs and at spreading ridges. Tectonically active Precambrian shields, most commonly preserved in Precambrian shields.
Associated deposit types	Kuroko massive sulfides, Homestake Au deposits.

Deposit description

Ore mineralogy	Magnetite, hematite; some deposits consist of siderite interbedded with pyrite and pyrrhotite.
Alteration	No syngenetic alteration, but commonly metamorphosed to varying degrees and weathered.
Ore controls	Iron-rich stratigraphic horizons with little clastic sedimentation, often near volcanic centers. Some Algoma-type iron-formations contain ore deposits due to metamorphic enhancement of grain size or structural thickening of the mineralized horizon.
Geochemical signatures	Elevated values for Fe and Mn; at times elevated values for Ni, Au, Ag, Cu, Zn Pb, Sn, W, REE, and other minor elements.
Geophysical signature	Gravity and magnetic methods can be used to delineate greenstone belts within granite-greenstone terranes at provincial to regional scales. Magnetic low and gravity high anomalies are usually associated with relatively nonmagnetic, dense greenstone terranes, whereas magnetic high and gravity low anomalies are usually associated with magnetic, low-density granitic. Gravity and magnetic methods can also be used for deposit-scale iron-formation studies. Most iron-formation is associated with positive, high-amplitude gravity anomalies because it contains elevated abundances of high-density iron minerals, including magnetite and hematite. The magnetic signature of an iron formation is usually one to two orders of magnitude greater than that of its host rock.
	Remote-sensing imaging spectroscopy can also be used in regional exploration because iron ore minerals and their alteration products have distinct spectral signatures.
	The magnetic character of an iron formation is dependent on magnetic mineral content, alteration, structural attitude, and remanent magnetization. Iron formation with low magnetite content, or deposits in which magnetite has been oxidized to nonmagnetic hematite, produce low-amplitude anomalies of tens to hundreds of nT. Flat-lying deposits with normal magnetic polarization typically produce positive anomalies of about several thousand nT. Steeply dipping or folded iron-formation dominated by remanent magnetic polarization can produce anomalies with extremely high positive amplitudes of as much as tens of thousands of nT.
	Electrical and electromagnetic methods are generally not applied to iron-formation exploration because the ore is resistive owing to high silica (chert) content. However, electrical techniques could be used to locate conductive sulfide facies or to delineate graphitic shale horizons associated with ore deposits.

Economic factors

Grade and tonnage	Ore bodies range in size from about 1,000 to less than 100 Mt with grades ranging from 15 to 45 wt.% Fe, averaging 25 wt.% Fe. Precambrian deposits usually contain less than 2 wt.% Mn.

Importance	Algoma-type iron-formations are widely distributed and may provide a convenient local source of iron ore. No deposits of this type are currently mined in the United States.

Other assessment and exploration guides

Discrete, well-defined magnetite and hematite lithofacies of iron formation are preferred with a minimum of other lithofacies and clastic sediment interbedded in the crude ore.

Iron formations are usually large regional geological features that are relatively easy to define.

Detailed stratigraphic information is an essential part of the database required for defining grade, physical and chemical quality, and beneficiation and concentration characteristics of the ore.

Basin analysis and sedimentation modeling enable definition of factors that controlled the development, location and distribution of different iron formation lithofacies.

Examples

In/near focal areas	Atlantic City-South Pass, Wyoming.
Elsewhere	Archean examples: Vermillion iron formation, Minnesota; Sherman Mine, Temagami, Ontario; Helen Mine, Wawa, Ontario; early Proterozoic example: Wadi Sawawin, Saudi Arabia.

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Lacustrine Diatomite

[wt.%, weight percent; ft, feet; mi^2, square mile; m.y., million years]

Synonyms	Diatomaceous earth, kieselguhr, bog deposits.
Commodities	Diatomaceous earth.
Description	A chalk-like, soft, earthy siliceous sedimentary rock composed of diatoms. Lacustrine diatomite deposits formed in fresh to brackish water, generally associated with volcanism, found worldwide both in paleosediments and in recent lake sediments. Large amount of silica necessary for thick accumulations of diatoms is from the weathering and decomposition of silica rich volcanic rocks where silica is transported to the lake through runoff, groundwater, and hot or cold springs.

Geological environment

Rock types	Diatomaceous lake sediments are typically hosted in volcanic rocks (craters, maars) and volcanic and sedimentary rocks (interbedded volcanic flows or tuffs).
Age range	Miocene to Recent. Occurrences noted as early as Late Eocene. Diatomite deposits in the Great Basin region formed in some Neogene basins in response to different regional and local processes over the past 16 to 17 m.y.
Depositional environment	Depositional conditions necessary for thick diatom accumulations: extensive, shallow basins for photosynthesis; abundant supply of soluble silica and nutrients; absence of toxic or growth-inhibiting constituents; sustained high rates of diatom reproduction; minimal clastic, chemical, and organic contamination; and a low energy environment for preservation of the delicate diatom structure.
Tectonic setting(s)	Typically found in volcanic terrain. Often associated with crustal extension, such as in the Basin and Range Province of the Western United States.
Associated deposit types	Trona, gypsum.

Deposit description

Ore mineralogy	Diatomaceous silica, opal-cristobalite.
Alteration	Diagenetic and postdiagenetic products can include various cements, chert phases, zeolites, and clay minerals, many of which form at the expense of the original sediment and diatoms, which undergo a structural transformation almost immediately after deposition, with a subsequent change to more stable silica phases.
Ore controls	The formation and localization of ore is controlled by the physical and chemical boundaries of the regional depositional environment.
Geochemical signatures	None?
Geophysical signature	Magnetics: regional geology/structure. Gravity: regional geology/structure. Radiometrics: lithology. Apparent resistivity and refraction seismic surveys have been used as exploration tools. Varying thermal characteristics of diatomaceous sediments have been noted using narrow pass-band infrared imagery.

Economic factors

Grade and tonnage	Deposits commonly extend over areas of 1 to 25 mi^2 and attain thicknesses of 10 to >200 ft. Deposits covering <1 mi^2 and <10 feet thick are generally uneconomic. Chemical analyses: 80.0–95.0 wt.% SiO_2, 1.0–6.0 wt.% Al_2O_3, 0.4–2.2 wt.% Fe_2O_3, 0.2–3.5 wt.% CaO, and minor to trace amounts of TiO_2, MgO, Na_2O, K_2O, and P_2O_5.
Importance	The United States is the world's largest producer of diatomite.

Other assessment and exploration guides

Tectonostratigraphic setting.
Basinal sediments.
Overburden typically <5:1.

Examples

In/near focal areas	Dickshooter deposit, Idaho.

Elsewhere	Juntura and Otis basins, Oregon.

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Surficial-Mechanical (Placer) Mineral System

Deposit types in the study area
Heavy mineral placer
Placer and paleoplacer gold

Heavy Mineral Placers

[wt.%, percent; Mt, million metric tons; REE, rare earth elements; PGE, platinum-group elements]

Synonyms	Placer deposits, placer heavy mineral deposits, black sand deposits, stream placers
Commodities	Ti-minerals (ilmenite, rutile), zircon, monazite, ± garnet, cassiterite, sillimanite, staurolite, xenotime, PGE
Description	Concentrations of water-deposited minerals with high specific gravities; formed by the physical-mechanical concentration of bedrock minerals freed by weathering, then deposited and reworked in fluvial environments.
Geological environment	
Rock types	Unconsolidated to weakly consolidated layers of fluvial sediments (alluvium).
Age range	Quaternary; principally modern, Holocene and Pleistocene alluvial sediments.
Depositional environment	Ancient and modern alluvial valleys fed by streams and rivers that drain terranes where abundant high-grade metamorphic rocks or igneous rocks crop out. Streams carry the sediments to valleys, where they are deposited and reworked by fluvial processes.
Tectonic setting(s)	Various.
Deposit description	
Ore mineralogy	Mainly gold, ilmenite, rutile, zircon, monazite; occasionally cassiterite, xenotime
Alteration	None
Ore controls	High-grade metamorphic or heavy mineral-rich igneous are source rocks. Fluvial processes in streams and rivers concentrate the heavy-minerals.
Geochemical signatures	Ti, Hf, REE, Th, U, Nb, and Ta in stream sediments can be pathfinder elements for gold (Au), ilmenite ($FeTiO_3$), rutile (TiO_2), zircon (($Zr,Hf,U)SiO_4$), monazite (($Ce,La,Y,Th)PO_4$), xenotime (YPO_4), platinum-group minerals, and euxenite (($Y,Ca,Ce,U,Th)(Ti,Nb,Ta)_2O_6$).
Geophysical signature	High-resolution magnetic, gravity, and seismic-reflection surveys can map paleotopography and outline paleochannels; electromagnetic surveys may be useful in detecting conductive material in paleochannels; ground-penetrating radar may be useful in delineating the geometry of shallow channels and deposits; and radiometric surveys can locate radioactive heavy-mineral concentrations.
Economic factors	
Grade and tonnage	Grade and tonnage in fluvial placers can vary considerably (see Robertson and Storch, 1955; Anderson, 1958; Storch and Holt, 1963; Staatz and others, 1979, 1980). The average heavy-mineral content of Idaho placers sampled by the U.S. Bureau of Mines ranged from 0.10 to 1.06 wt.% of the sediments, with an average of 0.5 wt.% (Staatz and others, 1980).
Importance	Heavy-minerals sands are a principal source of Zr and a primary source of Ti for the TiO_2 pigments industry. However, currently these elements are almost entirely produced from heavy-mineral sands deposited in coastal environments. Heavy mineral placers are significant sources of Au in some areas of the United States, such as Alaska, and also in some countries elsewhere (Yeend and others, 1989).
Other assessment and exploration guides	

Identify streams and rivers that drain terranes with outcropping (1) abundant high-grade metamorphic or igneous rocks or (2) ore bodies that host native gold, electrum, or platinum-group minerals

Restrict the assessment areas to unconsolidated or weakly consolidated Quaternary fluvial sediments as a first-level exploration and assessment guideline.

Detailed geologic mapping that distinguishes amongst Quaternary sedimentary units can benefit the search for deposits. For example, alluvium is the target host of heavy mineral sands, whereas landslide and colluvium generally lack the sorting necessary to form concentrations of heavy minerals.

Limited only to near-surface, unconsolidated or weakly consolidated alluvial sediments. Economic deposits of this type, regardless of their heavy-mineral content (grade), typically are exploited only if they lie at or within a few tens of meters of the surface.

Examples	
In/near focal area	Central Idaho valleys that are within or adjacent to the Idaho batholith (Staatz and others, 1980).

| **Elsewhere** | Stream deposits in the Piedmont region of North Carolina and South Carolina (Staatz and others, 1979). |

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Placer and Paleoplacer Gold

[g/t, grams per metric ton; Mt, million metric tons; PGE, platinum-group elements]

Synonyms	Holocene placer deposits; terrace placers; fluvial, alluvial, colluvial placers, buried-channel placers, paleoplacers.
Commodities	Au, platinum-group elements (PGEs), and Sn.
Description	Concentrations of valuable detrital (gold, PGE, cassiterite) formed by sedimentary processes where the high specific gravity of the minerals results in their concentration at or near the surface, usually in Holocene fluvial deposits or in buried valleys (typically with at least several meters of overlying barren material, usually till, clay or volcanic rocks), mainly as channel-lag and gravel-bar deposits.

Geological environment	
Rock types	Generally mature, well-sorted, fine to coarse-grained, quartz-rich sands and sandstones, and mature, well-rounded, clast-supported, quartz-rich gravels and conglomerates.
Age range	Mainly Tertiary and Quaternary. Older paleoplacers are rare due to poor long-term preservation of deposits in high-relief, subaerial environments.
Depositional environment	Surficial fluvial placer: large, high-order, stream channels and along bedrock in high-energy, steep-gradient, low-sinuosity, single-channel streams. Alluvial fan, fan-delta and delta deposit: relatively unconfined depositional settings dominated by massive or graded sands and gravel. Colluvial placers: develop from residual deposits associated with primary lode sources by sorting associated with downslope migration of heavy minerals. Paleoplacers: Incised paleochannels in mountainous areas such as high-gradient narrow bedrock-floored valleys (paleogulches); high-level, abandoned tributary valleys with intermediate gradients large, buried trunk valleys (on the order of 100 meters deep, a few hundred meters wide and >1 km long) with low channel gradients; channels buried in modern alluvial valleys with gradients similar to the modern streams.
Tectonic setting(s)	Stable intracratonic basin, platform, and intermontane plateau settings characterized by long periods of erosion and reworking of clastic sediments; accretionary orogenic belts, commonly in proximity to major faults that expose the bedrock sources to weathering and erosion.
Associated deposit types	The source mineral-deposit type will determine the type of placer deposit (lode gold deposit will erode to produce placer gold).

Deposit description	
Ore mineralogy	Native gold, gold nuggets, flakes, and grains, electrum, PGE minerals, cassiterite (gems).
Alteration	Fe and Mn oxide precipitates common; Ag-depleted rims of Au grains increase in thickness with age.
Ore controls	Fluvial settings: channel irregularities, bedrock depressions and below natural riffles created by fractures, joints, cleavage, faults, foliation or bedding planes that dip steeply and are oriented perpendicular or oblique to stream flow. Basal gravels over bedrock typically contain the highest placer concentrations. Fine-grained placer concentrations occur where channel gradients abruptly decrease or stream velocities lessen. Gold in alluvial fan placers is found in debris- flow sediments and in interstratified gravel, sand and silt. Colluvial placers are best developed on steeper slopes, generally over a weathered surface and near primary lode sources.
Geochemical signatures	Anomalous concentrations of Au, Ag, Hg, As, Cu, Fe, Mn, Ti, or Cr in stream sediments. Au fineness (relative Ag content) and trace element geochemistry (Hg, Cu) of Au particles can be used to relate placer and lode sources.
Geophysical signature	Magnetic, gravity, and seismic-reflection surveys to map paleotopography and outline paleochannels; induced-polarization/resistivity surveys to locate conductive disseminated mineralization; electromagnetic surveys may be useful in detecting conductive material in paleochannels; ground-penetrating radar may be useful in delineating the geometry of shallow channels and deposits; and radiometric surveys to locate radioactive heavy-mineral concentrations.

Economic factors	
Grade and tonnage	Deposits are typically high tonnage (0.1 to 100 Mt) but low grade (0.05-0.25 g/t Au, 50-200 g/t Sn). Placer concentrations are highly variable both within and between individual deposits.

Importance	Historically, placer gold deposits accounted for more than two-thirds of the world's gold. Shallow alluvial placers also account for a large part of world tin (mainly from Southeast Asia and Brazil) and diamond (Africa) production.

Other assessment and exploration guides

Quartz pebble conglomerates near lode gold sources.

Recognition of paleochannels in stratigraphy.

Panning and other methods of gravity sorting are used to identify concentrations of gold and other heavy minerals. Many placer gold paystreaks overlie clay beds or dense tills and in some camps these "false bottom" paystreaks are important.

Examples

In/near focal areas	Yankee Fork placers, Idaho; Homestake paleoplacer, Idaho.
Elsewhere	Klondike Au district, Yukon.

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Other (Non-Locatable) Deposit Types

Deposit types in the study area
Dimension stone (sandstone and quartzite)
Sand and gravel
Volcanic ash (pumice and cinders)
Perlite

Dimension Stone (Sandstone and Quartzite)

[m, meter; t, metric ton; wt.%, weight percent; SEDEX, sedimentary exhalative; VMS, volcanogenic massive sulfide]

Synonyms	High silica quartzite, quartz sandstone, silica rock silicastone. Bluestone, brownstone, freestone, arkose, greywacke, quartzite.
Commodities	Building stone.
Description	Uniform massive beds of sandstone with very few and well-spaced (more than 1 m) fractures and bedding planes. Sandstone must be suitable to be removed from a quarry face in square shaped blocks that are 10 t or larger with minimum waste. Metamorphic equivalent (quartzite) of uniform, massive beds of siliceous sediments, such as sandstone. These beds are commonly formed in sedimentary sequences. They have high silica contents with very limited impurities, usually less than 1 wt.%.
Geological environment	
Rock types	Siliceous sediments are found with a variety of clastic and carbonate rocks; quartzites are the metamorphic equivalents.
Age range	Precambrian to Tertiary.
Depositional environment	Shallow continental shelf, inland sea or large continental lacustrine basins with low energy environment and a steady supply of well sorted, detrital, sand size particles. The mineral composition is influenced by the regional climate over the source area; speed, type and intensity of weathering and speed of transport into the sedimentary basin.
Non-locatable tectonic setting(s)	Quartzites are found in orogenic belts of all ages.
Associated deposit types	Siliceous sediments—building stone; cherts—SEDEX and VMS deposits, marine diatomite.
Deposit description	
Ore mineralogy	Quartz; chert can also have other forms of amorphous and microcrystalline silica.
Alteration	Secondary Fe-Mn hydroxides and (or) calcium carbonate along fractures.
Ore controls	Source terrains that minimize impurities and depositional environments that includes long or repeated transportation with intensive wear of particles which includes separation from other silicates like feldspars for example. This may occur both by physical as well as chemical weathering.
Geochemical signatures	In general, more than 98 wt.% silica with traces of other elements. High silica contents and low aluminosilicate and carbonate contents.
Geophysical signature	Only applicable where there is significant contrast in physical rock properties of silica-rich rocks with surrounding rocks.
Economic factors	
Grade and tonnage	Each use has its very specific requirement for the particle size and shape, physical strength and permissible amounts of different impurities. Generally silica contents have to be 98 wt.% with significant impurities removable by processing.
	Even high-purity orthoquartzite usually contains minute titanium minerals, which are detrimental for silicon metal (even at 0.2% TiO_2). Also, even trace of Ca can, as well as iron oxide and alumina, make silica unacceptable for specific end use.
	Tonnage for 28 sandstone/quartzite silica deposits range from 0.3 to 42 Mt with grades of 87 to 97 wt.% SiO_2.
Importance	Used for building and construction and decorative stone.
Other assessment and exploration guides	

Large smooth bedrock exposures in cuts, on valley slopes and along shorelines lacking fragmented rock are good indicators. An air photo study can identify large outcrop areas and boulder fields.

Look for resistant ridges and outcrops and absence of impurities in hand sample visible to the naked eye.

Usually weather resistant, resulting in morphological highs.

Massive beds of thickness more than 1 m, may be layered or cross bedded, and uniform in appearance.

Deposits commonly extend over areas of at least several square kilometers. Usually the deposits are horizontal or tilted, and rarely folded.

Examples	
In/near focal areas	Idaho.
Elsewhere	Texas, Indiana, Wisconsin, Massachusetts, Georgia.

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Sand and Gravel

[km, kilometer; t, metric ton; kt, thousand metric tons; g/t, grams per metric ton; ASTM, American Society for Testing and Materials; CSA, Canadian Standards Association]

Synonyms	Aggregate, granular deposits, fluvial and glaciofluvial sediments, ice-contact deposits, outwash, alluvial sand and gravel, beach sand and gravel.
Commodities	All-purpose construction aggregate, special fill, railroad ballast.
Description	Surficial sediment of sand and gravel deposited as a stream channel and terrace deposits, alluvial fans, and glacial or marine deposits.

Geological environment

Rock types	Usually poorly to moderately well-sorted pebble, cobble and (or) boulder gravel with variable proportions of fine- to coarse-grained sand; deltaic deposits locally interbedded with glaciomarine or glaciolacustrine silts and clays; ice–proximal glaciofluvial deposits commonly interbedded with till or glaciogenic debris flow deposits; fluvial sands and gravels often overlain by floodplain silts and organic deposits.
Age range	Mainly Holocene and Pleistocene in glaciated areas; Holocene to Tertiary in unglaciated regions.
Depositional environment	Streams, alluvial fans, glaciated areas.
Tectonic setting(s)	Generally unimportant. Sand and gravel deposits occur in high energy stream sediments in all tectonic belts. In coastal areas, isostatic or tectonic uplift produces raised landforms that are readily mined.
Associated deposit types	Placer deposits of gold, platinum-group elements (PGE), gemstones and garnet.

Deposit description

Ore mineralogy	Composition of aggregate particles depends on the source areas. Provenance is also a major factor in determining the quality of the resulting aggregate product. Bedded and schistose rocks usually provide lower quality products, whereas massive igneous rocks and metamorphic rocks, such as gneisses and quartzites, produce better quality aggregate. In sedimentary source areas, limestones and cemented sandstones are better than shales, siltstones, or weak sandstone.
Alteration	Soft and weak rocks are a deleterious component of every type of construction aggregate. Prolonged weathering may weaken some otherwise competent rock types. This is particularly true for older Pleistocene and Tertiary deposits in glaciated areas, and for all deposits in nonglaciated areas. Percolating groundwater may result in coating of gravel particles with calcium carbonate, clay, or iron hydroxides. Such coatings may negatively affect the strength and durability of bonding with cement in concrete structures.
Ore controls	The composition of the bedrock in the source area has a major impact on aggregate quality. A variety of factors influence the usability of granular sediment for individual products, which frequently have distinct quality requirements. Quality of construction aggregate for particular end uses is controlled by a number of physical and chemical parameters specified in ASTM and CSA Standards. The main factors influencing suitability for different end uses are the relative proportions of competent rock types, components reactive with cement like chert, other amorphous silica varieties, volcanic glass, sulfides, and organics like peat. Other important criteria include the absence of clay and silt; clean clast surfaces; isometric shapes and granulometric composition. Sometimes in the absence of a quality aggregate, some granular deposits can be improved by more sophisticated processing. Use of a different type or higher proportion of cement in a concrete mix may be another solution.
Geochemical signatures	None.
Geophysical signature	Ground-penetrating radar can delineate the geometry, structure, and thickness of granular deposits provided they are not overlain by clay or clay-rich till. Shallow seismic and resistivity surveys can help outline the thickness and homogeneity of a granular deposit, particularly the presence of clay layers or till, and depth of the groundwater level.

Economic factors

Grade and tonnage	Grade is determined by ASTM or CSA specifications and can be highly variable, depending on location and intended use. Tonnage also can vary widely. For example, even a small deposit of a few hundred thousand tons may be an important source for local use in populated areas. Such a deposit, however, must contain aggregate that does not require complicated processing. Similar examples are borrow pits used in road construction and maintenance.

Importance	Sand and gravel are the main, basic construction materials for building cities and infrastructure. Building an average family home requires about 100 t of aggregate; for a school it takes approximately 15,000 t; for 1 km of 4-lane highway, between 40 and 60 kt of aggregate are needed.

<div align="center">Other assessment and exploration guides</div>

Geologic maps serve as a primary source of information for beginning the search for new sources of aggregate.

<div align="center">Examples</div>

In/near focal areas	All focal areas have sand and gravel (salable minerals).

<div align="center">References</div>

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Volcanic Ash (cinders and pumice)

[km, kilometer; t, metric ton; Mt, million metric tons; ASTM, American Society for Testing and Materials]

Synonyms	Volcanic scoria, volcanic ejecta, agglomerate, pyroclastics, lapilli, tuff.
Commodities	Lightweight aggregate, landscaping aggregate, anti-skid sand, stonewashing pumice, "lava (barbecue) rock," pozzolan, abrasive powders, absorbents, insulation fill, filler, filtration media.
Description	Unconsolidated pumice, cinder and other pyroclastic deposits are usually found near a volcanic vent or edifice. It is typically the vesicular pyroclastic material that is exploited because of its appearance or attractive strength to weight ratio. Pumice occurs in felsic pyroclastic flows, air-fall blankets, and flow domes; cinder usually forms basaltic pyroclastic tephra cones and blankets.
Geological environment	
Rock types	Ash, lapilli, and agglomerate pyroclastic deposits. Associated with lava flows, high-level dikes, ash flows, and flow domes. All these rock types can vary in composition from rhyolite to basalt.
Age range	Any age, although preserved deposits are commonly Tertiary to Holocene.
Depositional environment	Pumice in calderas, lava flow dome complexes and Plinian-type central eruptions. Blanket deposits are found in the vicinity of stratovolcanoes.
Tectonic setting(s)	Volcanic arcs and rift zone belts.
Associated deposit types	Perlite, open and closed system zeolites, and andesite dimension stone. Secondary deposits are produced by erosion of primary deposits and subsequent deposition in stream and riverbeds, for example, in Kansas and Oklahoma or along the Waikato and Wanganui Rivers in New Zealand.
Deposit description	
Ore	Pumice, cinder, volcanic ash, bombs, blocks.
Alteration	Clay minerals, alunite, zeolites, hematite, limonite.
Ore controls	Pumice, a product of highly viscous rhyolite magma, commonly forms an ashfall blanket surrounding the source vent. Its thickness depends on intensity and longevity of eruption. Large volumes of pumice and pumiceous rhyolite also accumulate in the upper parts of rhyolite and obsidian flow domes, as well in ash-flow tuffs in calderas. Volcanic cinder, because of low viscosity and higher density of the mafic magma, is more concentrated in proximity to the vent as cone-shaped deposits.
Geochemical signatures	For pumice, look for rhyolite compositions.
Geophysical signature	Ground-penetrating radar can delineate structure and thickness of a pyroclastic deposit. Shallow seismic surveys can help to outline the presence of lave flows or dikes in cinder cones, as well as the boundary between pumiceous rhyolite and nonporous rock facies.
Economic factors	
Grade and tonnage	Deposits range in size from 10,000 t to 10 Mt, although occasionally, deposits may reach 400 Mt. The average production from a single deposit in Western United States is approximately 35,000 t per year for cinder and 10,000 t per year for pumice. Use of a lightweight aggregate has several ASTM specifications for particle sizing and unit weight, so do some specific end uses, like stone washing.
Importance	Regionally important as a specialty aggregate, but represents only a small part of the overall aggregate market in North America (0.1 percent in the year 2000).
	Lightweight aggregate transportation costs ultimately determine the geographic extent of the market, as it can be substituted by expanded shales and similar products. Only specialty products, like "barbecue lava rock," stone-washing pumice, absorbents, landscaping cinder, and filter media can reach more distant markets. The demand for these specialty products is only a fraction of total production.
Other assessment and exploration guides	

Proximity to volcanic vents, particularly on the downwind side.
Areas with remnant volcanic edifices.
Remote sensing and air photo interpretation are useful to map the limits of cinder and pumice blanket areas.

Examples	
In/near focal areas	All focal areas except North-Central Montana.
References	

Hora, Z.D., 1999, Volcanic ash. Cinders and Pumice, *in* Simandl, G.J., Hora, Z.D., and Lefebure, D.V., eds., Selected British Columbia mineral deposit profiles, volume 3—Industrial Minerals: British Columbia Ministry of Energy and Mines, Open File 1999-10, accessed February 15, 2016, at http://www.empr.gov.bc.ca/Mining/Geoscience/MineralDepositProfiles/.

Perlite

[wt.%, weight percent; km, kilometer; t, metric ton; g/t, grams per metric ton; kg, kilogram; Mt, million metric tons; °C, degree Celsius; ASTM, American Society for Testing and Materials]

Synonyms	Onion skin rhyolitic glass, pitchstone, obsidian.
Commodities	Expanding perlite (pumice, foundry flux, synthetic zeolite feedstock).
Description	Hydrated volcanic glass, usually of rhyolite composition, formed through secondary alteration by the incorporation of water into the glass/silica structure. It is often distinguished by vitreous, pearly luster and concentric (onion skin) fractures. When heated, it will expand as much as 10 to 40 times its original volume.
Geological environment	
Rock types	Perlite is hosted by flow domes and lava flows of rhyolite composition. Most obsidian contains less than 1 wt.% of total water (water left after heating to 105 °C); the hydration of perlite increases the water content level to 2 to 5 wt.% but may reach as much as 10 wt.%.
Age range	Normally Tertiary through middle Quaternary, occasionally older.
Depositional environment	Rapidly cooled volcanic rocks of rhyolite composition occurring as the glassy parts of domes and flows, vitric tephra, chill margins of dikes and sills, and welded ash-flow tuffs.
Tectonic setting(s)	Orogenic rift belts and volcanic arcs.
Associated deposit types	Vitric tephra, ash-flow tuffs, pumiceous rhyolite and pumicite.
Deposit description	
Ore	Expandable hydrated siliceous volcanic glass. Most commercial perlites are "high silica rhyolites" with 75 to 77.5 wt.% SiO_2. In a few countries, obsidian and pitchstone are also expanded.
Alteration	Because volcanic glass is unstable, devitrification changes Tertiary age or older volcanic glass into a microcrystalline equivalent (there may be some rare exceptions of older volcanic glass being preserved). Alteration can introduce clay minerals and (or) chalcedony and can produce deposits of halloysite.
Ore controls	Perlite forms carapaces that partially or fully comprise extrusive domes and flows and tephra and tuff beds, where percolating meteoric water had access to hydrate the glassy volcanic material. Because felsic flows are viscous, most perlite deposits form close to the volcanic vent.
Geochemical signatures	Felsic volcanic rocks with more than 65 wt.% silica, preferably greater, as much as 75 wt.%; water contents of 2 to 10 wt.%.
Geophysical signature	Hydrated glass can be distinguished from nonhydrated obsidian by electrical properties.
Economic factors	
Grade and tonnage	Average perlite has an expanded density between 20 and 40 kg per cubic meter. Some deposits can contain as much as 15 percent nonperlite material. The quality of perlite products is controlled by performance standards developed by the Perlite Institute, as well as ASTM specifications. Deposits range in size from less than 5 Mt to more than 100 Mt. Annual production in North America is reported between 500,000 and 600,000 t annually. It comes from 10 production centers in the Western United States.
Importance	Important for horticulture and for construction products. Expanded perlite has a very limited number of substitutes; therefore, it may be shipped considerable distances. For example, Greece has exported perlite to the eastern seaboard of North America, whereas New Mexico supplies Canada and numerous Eastern U.S. locations. Perlite is usually mined from open pits (the Caliente deposit in Nevada is underground) and processed in expanding plants located in market areas. Raw perlite is shipped by truck or by rail and boat to more distant processing plants. The average capacity of an expanding plant is about 10,000 t per year. As a relatively large volume product, perlite products are sensitive to transportation costs.

Other assessment and exploration guides

A small portable blowtorch is the most effective field test. A potential perlite either expands or decrepitates; nonexpanding rock just glows red.

Detailed mapping must delineate rock type, perlite textures, and the abundance of contaminants, such as clay, felsite, phenocrysts, and obsidian.

A great variability of textures and zonation require careful deposit modeling.

For drilling the potential deposit, the core diameter must be large enough to ensure high and representative core recovery.

Examples

In/near focal areas	Caliente, Nevada.
Elsewhere	Grants, Socorro, New Mexico; Malad City, Idaho.

References

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Appendix 4. Strategic and Critical Materials

There is no global consensus on a definition for "strategic and critical" commodities. In general, it has been accepted as those materials that are considered vital to support societal requirements and Government policy. The Defense Logistics Agency, Strategic Materials, in the U.S. Department of Defense, is the leading U.S. agency for the analysis, planning, procurement, and management of materials critical to national security. Among the agency's many functions, is the acquiring, upgrading, rotating, and disposing of materials needed to support national defense as authorized under the Strategic and Critical Material Act (50 U.S.C. 98 et seq.)(Defense Logistics Agency, 2016). The stocks held by the agency include mineral-based commodities (alloys, compounds, metals, and minerals) that are not found or produced in sufficient quantity in the United States to meet the Nation's requirements and results in a dependence on foreign sources.

Table 4-1 lists most of the elements of the non-fuel mineral-based commodities held as stock by Defense Logistics Agency (DLA), as of September 30, 2015 (U.S. Geological Survey, 2016).

Table 4-2 lists proposed additions of non-fuel mineral commodities in fiscal year 2016 (Defense Logistics Agency, 2016).

None of the locatable mineral commodities containing the elements listed in tables 1 and 2 are currently produced in significant amount and (or) as the primary source of revenue from mines operating within the assessment area; however, they may be produced as minor byproducts. Individual market demand profiles include a discussion related to a mineral commodity's strategic and critical importance.

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Table 4-1. Elemental listing of materials stockpiled by the Defense Logistics Agency.

[Materials in the inventory may be in the form of mineral ores and concentrates but are more commonly held as advanced materials alloys, compounds, or metals (U.S. Geological Survey, 2016)]

Stockpiled material		
Beryllium	Manganese	Tantalum
Chromium	Mercury	Tin
Cobalt	Nickel	Titanium
Columbium	Platinum-group elements	Tungsten
Germanium	Silicon	Zinc
Lithium	Talc	

Table 4-2. Potential acquisitions of materials selected by the Defense Logistics Agency for fiscal year 2016.

[Materials may be in the form of alloys, metals, compounds, or advanced materials (Defense Logistics Agency, 2016)]

Potential acquisitions		
Boron carbide	Germanium metal	Triamino-trinitrobenzene
Carbon fibers	Lithium cobalt oxide	Tungsten-rhenium alloy
Cadmium Zinc Tellurium	Lithium-nickel-cobalt-aluminum oxide	Yttrium oxide
Dysprosium metal	Mesocarbon microbeads	
Ferro-niobium	Tantalum	

Appendix 5. Market-Demand Commodity Profiles

The following market-demand profiles for the locatable mineral commodities relevant to the Sagebrush Mineral-Resource Assessment (SaMiRA) project conducted by the U.S. Geological Survey (USGS) are listed in alphabetical order below by commodity:

Antimony

Alloys containing antimony are used in a variety of applications, including lead-acid storage batteries and solders for joining pipes that carry potable water. Antimony is converted to antimony trioxide, which is primarily used in the flame-retardant industry in applications such as children's clothing and aircraft seats (U.S. Geological Survey, 2013).

Publications of the USGS National Minerals Information Center reported that no marketable antimony was recovered from mines in the United States in 2014 and 2015. In 2013, one operation in Pershing County, Nevada, produced less than 1,000 metric tons (t) of unprocessed ore that is not within the assessment area. Information regarding the ore's antimony content was not available. The company experienced financial challenges during 2014, and the mine was place on care-and-maintenance status in early 2015. Although no or only negligible quantities of antimony have been recovered from domestic mines since 2000, the United States produced an average of 326 t per year of antimony contained in ore and concentrates from 1993 through 1999. Most of this antimony was recovered as a byproduct from silver-copper sulfide ore mined primarily in northern Idaho. There has also been some intermittent mining in central Idaho (Yellow Pine District) near Stibnite from 1925 to 1997. Midas Gold Corp. is considering the reactivation of the Yellow Pine property. Although, it is primarily a gold project, the deposit contains significant amounts of potentially recoverable antimony (Midas Gold Corp., 2016).

Primary antimony metal and oxides were produced from imported concentrates at a smelter in Montana. In 2014, approximately 4,230 t of secondary antimony was recovered, almost entirely as a component of lead alloys from recycled lead-acid batteries at secondary lead smelters.

The United States relies on foreign sources of raw and processed antimony to meet its commercial and strategic requirements. In 2014, the United States imported approximately 24,200 t of antimony contained in concentrates, raw metal, and other unwrought forms, and net import reliance, as a percentage of apparent consumption, was 84 percent. In 2014, China accounted for 76 percent of global antimony mine production and for 76 percent of antimony metal and oxide (metal content) imported to the United States. In 2014, world antimony mine production was estimated to be 158,000 t. Other major producers and their percentage share of world production in 2014 were Russia (approximately 6 percent); Australia (4 percent); and Bolivia, Tajikistan, and Turkey (3 percent each). From the year 2000 through 2014, the compound annual growth rate of world antimony production was 2 percent.

The U.S. Defense Logistics Agency does not hold a stockpile of antimony, although it is monitored for supply adequacy. Antimony sulfide is used by the U.S. Department of Defense (DOD) as a constituent in percussion primers for ammunition. Currently, there are few, if any, substitutes for antimony sulfide that meet DOD requirements, and sources of antimony sulfide are primarily limited to China. Antimony is not typically categorized as a critical metal (National Science and Technology Council, 2016).

The average annual antimony price since the year 2000 ranged from a low of about $1,430 per metric ton ($/t) in 2001 to a high of $14,300/t in 2011. In 2015, the nominal average price of antimony had dropped to approximately $7,200/t (Kelly and Matos, 2007; Llewellyn, 1993; Guberman, 2015, 2016).

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Barite

Barite is the mineralogical name for barium sulfate ($BaSO_4$), also known as barytes. In pure form, it has the highest specific gravity of any nonmetallic mineral, which makes it useful as a filler, extender, and weighting agent in a wide variety of applications including cement, paints, plastics, and rubber. However, its primary use is as a weighting agent in fluids used in the drilling of oil and natural gas wells. Globally, more than 80 percent of barite is used for this purpose (The Barytes Association, undated), and in the United States this use exceeds 97 percent.

For most applications, barite needs to be ground to a small uniform size before use. The American Petroleum Institute (API) sets specifications for barite used in drilling fluids. The most important characteristic of barite used in drilling mud is its specific gravity (SG), and until 2010, the API specification called for a minimum SG of 4.2. After concerns developed about dwindling reserves of 4.2-SG barite in the United States, the API issued a new edition of API Specification 13A, Specification for Drilling Fluids Materials, adding specifications for 4.1-SG barite (American Petroleum Institute, 2010). Since the adoption of the 4.1-SG specification, 4.1 and sub 4.1-SG barite gained widespread acceptance in the U.S. drilling industry. Barite's other advantageous properties include low abrasion, low oil absorption, chemical and physical inertness, nontoxicity, low solubility, and being relatively inexpensive in comparison to alternatives.

The United States was the world's fourth-ranked producer of barite, producing approximately 8 percent of total world production in 2014. The leading producers and their percentage share of world production were China (44 percent), India (19 percent), and Morocco (11 percent) (McRae, 2015a). The United States is the world's leading barite consumer, using an average of approximately 3 million metric tons (Mt) per year for the past 10 years. Nearly all U.S. production is used domestically. Domestic barite production peaked in the early 1980s, when more than 2 Mt was produced annually. A large decrease in domestic consumption, coupled with the availability of low-priced foreign imports contributed to a sudden decrease in domestic barite production in the mid-1980s (Bleiwas and Miller, 2015; Kelly and Matos, 2014). During this same time period, China surpassed the United States as the world's leading barite producer, and U.S. imports surpassed domestic production. Since 2000, the United States net import reliance, as a percentage of apparent consumption, has averaged approximately 80 percent. Barite is not considered a critical or strategic mineral under any of the widely accepted definitions.

Although numerous States have historically produced barite, barite mine production in Nevada has long led all other domestic production, the bulk of which has been concentrated in Elko (located within or near the boundaries of the assessment area) and Lander Counties. The Big Ledge Mine in Elko is within the Public

Land Survey System (PLSS) and has historically produced barite as the need arises. It was restarted in 2007 by Spirit Minerals, LP, and operated currently by National Oilwell Varco, LP. Nevada is thought to contain the leading share of U.S. barite resources. Since 2007, USGS estimated that U.S. barite reserves were approximately 15 Mt, most of which is located in ore deposits in Nevada (Miller, 2007; McRae, 2015a). It should be noted that the latest revision to the reserve estimate was made when 4.2-SG barite was the industry standard and before the widespread usage of 4.1 and sub 4.1-SG barite.

After peaking in the early 1980s, consumption trended downward through 2003, and U.S. barite consumption began resurgence in 2005 owing to advances in the application of horizontal drilling techniques and hydraulic fracturing in onshore shale and other tight formations. Concern was growing, however, within the barite industry about an imminent shortage of 4.2 SG barite.

As a consequence, exploration and development projects have been very active in northeastern Nevada in the past decade. Three oil services companies have either opened or begun development of new mines, two in Lander County and one in Elko County. A fourth company completed an expansion project of its mine in Elko County and the Bureau of Land Management announced in late 2015 that it was preparing an environmental impact statement for another expansion that would extend mine life by an additional 8 years (Bureau of Land Management, 2015). These same companies have also invested in processing capacity. In 2005, Nevada's grinding mill capacity was estimated to be 650,000 metric tons per year (Roskill Information Services, Ltd., 2006, p. 152). In 2015, grinding capacity was an estimated 1.7 Mt per year, more than double the amount of current annual mine production (Allen, 2015).

Numerous smaller projects have also received permits; primarily projects reprocessing tailings piles at abandoned mine operations. Because barite is often associated with gold deposits, gold exploration companies have been known to enter into agreements allowing other companies to explore for barite on their properties (McRae, 2015b). It is unknown if any of these projects have come to fruition.

Since 1990, the price of barite per metric ton ($/t), expressed in constant 1998 U.S. dollars was lowest in 2003 at about $40/t to high of about $96/t in 2012 (Kelly and Matos, 2014). The price of crude barite had increased significantly from the mid-2000s through 2014 in response to increased demand for domestic drilling by the oil and gas industry. In 2014, the average 1998 U.S. dollar unit value for crude barite was $93/t, free on board (f.o.b.), mine.

The number of operating drill rigs exploring for oil and gas traditionally has been a good barometer of barite consumption or industry stockpiling. The monthly average of drill rigs operating in December 2014 was 1,882, which by December 2015 had decreased to 714. Petroleum production in the United States is expected to decline through 2017, and many companies are expected to scale back investment in new projects (U.S. Energy Information Administration, 2016). The decrease in drilling

activity is estimated to have reduced domestic barite consumption by approximately 25 percent to 30 percent in 2015. Because of this decline, it is likely that many of the aforementioned barite exploration and development projects have been put on hold until oil prices stabilize. However, a return to growth in the U.S. onshore oil and gas industry will necessitate a return to development of barite resources.

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Bentonite Clay

Bentonite predominantly consists of smectite-group minerals (usually montmorillonite) with minor amounts of feldspar, biotite, and quartz. Bentonite is divided into two major types, nonswelling (calcium rich) and swelling (sodium rich). Nonswelling bentonite is used primarily as a binding agent for pelletization of iron ore and foundry sand, as well as for water treatment and filtering. The molecular structure of bentonite with sodium as the major exchangeable cation enables it to absorb several times its dry weight in fluid. The swelling behavior of the clay makes it useful as an important component in drilling muds required for drilling in oil and gas exploration and development, as an impermeable liner for isolating fluids from the environment, and for pet-waste absorbents (Flanagan, 2016; Industrial Minerals Association–North America, 2016; Virta, 2015).

In 2014, the USGS National Minerals Information Center (NMIC) reported that the United States produced a combined total of 25.9 million metric tons (Mt) of six types of clays. At 4.8 Mt, bentonite clay represented about 19 percent of the total clay sold or used by domestic producers in 2014. Swelling clays represented about 95 percent of that amount (Flanagan, 2016; Virta, 2015).

In 2013, Alabama was the leading domestic producer of nonswelling bentonite, followed by Mississippi and California (Virta, 2015). These States are not included in the assessment area.

In 2013, Wyoming led all States in the production of swelling bentonite with a 97 percent share, followed, in descending order of tonnage, by Utah, Texas, California, Oregon, Nevada, Montana, and Colorado (Virta, 2015). The States, which include the assessment area, are briefly discussed in the following paragraphs in descending order of estimated production.

Much of Wyoming's bentonite production originated in Big Horn County, which is outside of the SaMiRA project assessment area. Since 2005, bentonite production has been reported in Crook, Hot Springs, Johnson, Natrona, Washakie, and Weston Counties. None of these counties are included in the assessment area (U.S. Geological Survey, 2008e, 2015e).

Utah has produced bentonite since 2005 in Sanpete and Sevier Counties. The two counties are not included in the assessment area (U.S. Geological Survey, 2008d, 2015d).

Bentonite production in Oregon has been reported since 2005 in Malheur County, which is included in the assessment area, and in Crook County, which is not included in the assessment area (U.S. Geological Survey 2008c, 2015c)

Bentonite production in Montana has been reported in Carter County, Montana, since 2005, which is outside of the assessment area. New operations in Valley County are within the assessment area (U.S. Geological Survey 2008a, 2015a).

Bentonite production has been reported since 2005 in the Nevada counties of Esmeralda, Humboldt (possibly hectorite and

not bentonite), Nye, and Pershing. Humboldt County is in the assessment area, but the others are not (U.S. Geological Survey 2008b, 2015b).

It is possible that bentonite was mined within the assessment area and not identified for reasons which may include (1) clay production reported without identifying type(s), (2) incomplete and inconsistent reporting, and (3) intermittent low-tonnage production.

In 2014, the quantity of bentonite sold and used in the United States of 4.8 Mt was more than the 3.47 Mt that was sold and used in 1990. From 1990 to 2014, the compound annual growth rate in production was approximately 1.4 percent. The trend of increasing domestic production of bentonite from the mid-1990s was driven by its increased use as pet-waste absorbent and in domestic drilling for oil and gas exploration and development. Domestic production of bentonite has leveled off somewhat in recent years as demand for conventional drilling has decreased in response to weaker petroleum prices, increased use of proppants made from kaolin for horizontal drilling, and increases in the amount of imported bentonite (Flanagan, 2016; Kelly and Matos, 2007; Virta, 1993, 1994, 1996, 2004, 2015).

In 2014, approximately 22,000 metric tons (t) of bentonite was imported to the United States. This was a significant increase from 1990, when about 2,045 t were imported, but still only represents less than one-half of one percent of domestic usage. The principal sources of bentonite imports in 2013 were Mexico (43 percent), China (23 percent), Egypt (13 percent), and the United Kingdom (12 percent) (Virta, 2015 Kelly and Matos, 2007).

In 2014, the United States exported about 901,000 t of bentonite, or about 19 percent of estimated domestic sales. Canada was the primary recipient of U.S. bentonite exports (49 percent), followed by Japan (11 percent) and China (6 percent). For the years 1990 through 2014, exports reached a high of 1.43 Mt, but declined shortly thereafter in response to the global recession (Flanagan, 2016; Virta, 2015).

The United States is a net exporter of bentonite. The U.S. bentonite industry is able to meet domestic demand with relatively low imports while at the same time continuing to export comparatively high tonnages of the clay (Flanagan, 2016).

Apparent consumption of bentonite in the United States was approximately 2.78 Mt in 1990 and trended upward to about 3.48 Mt in 2013. Apparent consumption increased during the 24-year period as a function of growing demand for use in drilling muds and absorbents, which was met by an increase in domestic production and imports relative to the amount of bentonite exported (Kelly and Matos, 2007).

The U.S. Defense Logistics Agency does not hold a stockpile of bentonite, and the commodity is not considered of strategic or critical importance. The United States has large reserves and significant production. The United States does not rely on imports to meet its commercial and strategic requirements for the commodity.

From 1990 to 2014, the total world bentonite mine production increased from 9.6 Mt to an estimated 16.1 Mt, for an average compound annual growth rate of 2.2 percent. In 1990, the United States was the world leader in bentonite production with 3.47 Mt that represented a 36 percent share of world production. In 2014, the United States maintained its position as the world leader in bentonite production with 4.8 Mt, albeit with a lower percentage share of 30 percent. Other major producers of bentonite in 2014 and estimates of their respective share of global production were China (22 percent) and Greece and India (about 7 percent each). The increase in world bentonite production was driven primarily by demand in the oil and gas energy sector and the broad uses of the clay as an absorbent and binder in iron ore pelletizing and foundry sand to meet the needs of a growing global population (Flanagan, 2016; Kelly and Matos, 2007; Virta, 1992).

The average annual unit value per metric ton ($/t) of bentonite, expressed in constant 1998 U.S. dollars, ranged from a low of $17.10/t in 2008 during the global recession to a high of about $45.50/t in 2014. The increase in price over the past several years was primarily driven by higher demand for drilling mud. The price and level of demand for bentonite may be somewhat lessened over the next few years as if drilling for oil and gas continues to decrease (Flanagan, 2016; Kelly and Matos, 2007; Virta, 1992, 1993, 2004, 2015).

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Copper

Copper finds its major use in electrical applications distributed throughout all sectors of the global economy through use in the generation and distribution of electricity, signal transfer, and the circuitry of electronic devices. Other uses include plumbing tube, heat exchangers, building hardware, and roofing, and coinage.

Publications of the USGS National Minerals Information Center (NMIC) reported that in 2014 the United States remained the world's fourth-ranked mine producer of copper, behind Chile, China, and Peru, and accounted for approximately 7 percent of global production. Although from 1990 through 2014 U.S. copper mine production decreased at a compound annual rate of 1 percent, from 1990 through 1997, copper mine production rose by 22 percent to a record-high 1.94 million metric tons (Mt) before trending downward to 1.11 Mt in 2010. From 2011 through 2014, U.S. mine production trended upward, increasing by 22 percent from 1.11 Mt through 1.36 Mt (Brininstool, 2016).

Mine production during the next several years will likely remain close to the current level. The principal mining States for copper were, in descending order of production, Arizona, Utah, New Mexico, Nevada, and Montana, which altogether accounted for more than 99 percent of domestic production (Brininstool, 2016). No significant copper production has been reported within the assessment area since at least 1990. Nearly all of the copper in the United States is recovered from ore extracted from large open-pit mines that used conventional flotation to produce concentrate for smelting and refining or leaching and solvent extraction-electrowinning methods to recover refined copper.

The United States exports a significant amount of copper concentrate for offshore smelting and refining. In 2014, it was estimated that U.S. copper ore reserves contained approximately 35 Mt of copper. In addition to 1.05 Mt of domestic primary refined copper production in 2014, an additional 796 thousand metric tons of copper was recovered from scrap. There are also large producer, merchant, and consumer stocks of copper maintained in the United States. The U.S. Defense Logistics Agency does not hold a stockpile of copper, having liquidated its inventories in 1993. Historically, copper has been considered a strategic and critical material, with various price controls, export controls, Government stockpiling, and production incentives through the World Wars and the Vietnam War. The United States currently produces a significant amount of copper relative to its reduced consumption levels, and domestically imported supplies of copper are varied and generally from the Western Hemisphere. Therefore, copper is no longer categorized as a strategic and critical commodity despite its importance to the U.S. economy.

The United States relies on foreign sources of raw and processed copper to supplement its commercial and strategic requirements. In 2014, U.S. apparent consumption of refined copper was approximately 1.78 Mt. In 1990, net import reliance, as a percentage of apparent consumption, was 3 percent. By 2014, net import reliance had increased to 31 percent as a result of increased exports of concentrates for offshore treatment because of decreased domestic smelting and refining capacity (Brininstool, 2016).

From 1990 to 2014, the total world copper mine production more than doubled at an average compound annual growth rate of nearly 4 percent (Brininstool, 2016; Kelly and Matos, 2007). Since 2000, world refined copper production increased at average compound annual growth rate of approximately 2.6 percent, reaching about 21 Mt in 2014 with about 18 percent from secondary sources. The general trend of increased copper production reflects the growing global demand for use in consumer products, such as appliances and automobiles, and for building and upgrading infrastructure in China, India, and other developing economies. China has emerged as the leading driver for global demand, accounting for more than 40 percent of global consumption since 2011 and about 48 percent in 2014 (International Copper Study Group, 2016, p. 19). Barring global economic recession, the trend of increasing consumption may continue for the balance of the decade.

The average annual domestic producer price per pound of copper in nominal dollars over the past decade ranged from a low of $1.73 per pound in 2005 to a high of $4.06 in 2011 (Kelly and Matos, 2007). The price of the metal declined throughout 2015. In 2015, the average producer price was $2.56 per pound (M. Brininstool, USGS, written commun., January 21, 2016). In general, higher prices reflect periods of greater demand and a tightening of supply.

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Diatomite

Diatomite is a chalk-like, soft, friable, earthy, very fine-grained, siliceous sedimentary rock comprised of fossilized diatom remains. Diatomite is used for filter aids (55 percent), as a cement additive (21 percent), as a filler (14 percent), as an absorbent (9 percent), and in other applications (Crangle, 2013, 2016).

The USGS National Minerals Information Center (NMIC) reported that about 901,000 metric tons (t) of processed diatomite ore was sold and used by producers in the United States in 2014. The United States ranked first in global diatomite mine production. In 2014, diatomite was produced from mines in California, Nevada, Oregon, and Washington (Crangle, 2016). Diatomite production is ongoing or has occurred in the assessment area States since 2005 in the Nevada counties of Elko, Humboldt, and Washoe. Diatomite was previously mined in Lake County, Oregon, and a deposit was identified in Camas County, Idaho (Powers, 1947; Taylor, 1994).

In 2014, 901,000 t of diatomite was sold and used by producers, significantly more than the 631,000 t in 1990. The average annual growth rate was 1.5 percent over the period. In 2014, U.S. diatomite reserves were estimated to be 250 million metric tons (Mt). The apparent consumption of diatomite in the United States increased from 488,000 t in 1990 to 823,000 t in 2014 (Crangle, 2016; Kelly and Matos, 2007).

In 2014, the United States exported about 82,000 t of diatomite compared to 488,000 t exported in 1990. The decrease in exports reflects the increased domestic consumption, as well as increases in production among some competing foreign producers, such as China. Approximately 4,000 t of diatomite were imported for domestic consumption in 2014 compared to 1,000 t in 1990. Imports have not been a significant component of domestic consumption (Crangle, 2016; Kelly and Matos, 2007). For 2011–14, three countries accounted for 80 percent of U.S. diatomite imports—Mexico (30 percent), Canada (26 percent), and France (24 percent) (Crangle, 2016).

The United States is a net exporter of diatomite making its net import reliance as a percentage of apparent consumption zero for 2014, which has been the case since at least 1990 (Crangle, 2016; Davis, 1992).

The U.S. Defense Logistics Agency does not hold a stockpile of diatomite. Diatomite is not considered a strategic or critical commodity because of substantial U.S. production and substantial reserves and stocks held by producers and consumers (Crangle, 2016; Davis, 1992). In addition, substitutes exist for diatomite in most applications.

From 1990 to 2014, total world diatomite production increased from 1.68 Mt to 2.26 Mt for an average annual growth rate of about 1.2 percent. In 2014, the United States was the world leader in diatomite production with 901,000 t, which represented a 40 percent share. Other major diatomite producers in 2014 and their respective share of global production were China (19 percent), Peru (6 percent), and Argentina (4 percent). In 1994, China represented about 11 percent of world production (Taylor, 1994). Production in China for the years 1990–93 was not available.

According to reported by U.S. diatomite producers, the average unit value per metric ton ($/t) of diatomite ranged from a high of $283/t in 1993 to a low of about $170/t in 2009. In 2014, the average unit value of diatomite in nominal dollars was approximately $298/t (Kelly and Matos, 2007; Crangle, 2016).

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Dimension Stone—Quartzite

Dimension stone can be defined as a natural rock material quarried for the purpose of obtaining blocks or slabs that meet specifications as to size (width, length, and thickness) and shape. Color, grain texture and pattern, and surface finish of the stone are aesthetically desirable properties. Durability (essentially based on mineral composition, hardness, and past performance), strength, and the ability of the stone to take a polish are other important selection criteria. In addition to these desirable characteristics, a deposit will only have economic value if the rock is amenable to mining at a profit. Important criteria include the geometry of the deposit, orientation, and the site's access to infrastructure.

Although a variety of igneous, metamorphic, and sedimentary rocks are used as dimension stone, the principal rock types are granite, limestone, marble, sandstone (which includes quartzite), and slate. Other varieties of dimension stone that are normally considered to be special minor types include alabaster (massive gypsum), soapstone (massive talc), and various products fashioned from natural stone (Dolley, 2015).

The USGS National Minerals Information Center (NMIC) reported that approximately 2.47 million metric tons (Mt) of dimension stone valued at $470 million was sold or used by U.S. producers in 2014. Dimension stone was produced by 216 companies operating 293 quarries in 34 States. Leading producer States were, in descending order by tonnage, Texas, Indiana, Wisconsin, Massachusetts, and Georgia. These five States accounted for about 66 percent of the production and contributed about 63 percent of the value of domestic production. Approximately 42 percent by tonnage of dimension stone sold or used was limestone, followed by granite (21 percent), sandstone (which includes quartzite; 17 percent), miscellaneous stone (16 percent), marble (2 percent), and slate (2 percent). By value, the leading sales or uses were for limestone (38 percent), followed by granite (25 percent), miscellaneous stone (18 percent), sandstone (which includes quartzite; 11 percent), marble (4 percent), and slate (4 percent) (Dolley, 2016).

Quartzite, a metamorphosed sandstone, has been identified as a dimension and dressed stone that has been quarried in or proximal to the assessment area in Idaho. As there is a wide variety among the types and uses of dimension stone, a full discussion of types other than quartzite is beyond the scope necessary for the assessment area. The USGS does not publish statistical information specific to quartzite dimension stone. Statistical data related to quartzite production is aggregated with sandstone statistics. Quartzite represents a relatively small percentage of the stone included in the category, and in some cases, quartzite may be reported to the USGS as sandstone. Detailed information on production from individual sites is often considered confidential by companies and is therefore not published.

Rough stone represented 59 percent of the tonnage and 49 percent of the value of all the dimension stone sold or used by domestic producers, including exports. The leading uses and distribution of rough stone, by tonnage, were in building and construction (58 percent) and in irregular-shaped stone (27 percent). Dressed stone (usually cut to shape and sometimes smoothed) was primarily sold for facades and partially squared pieces (44 percent), curbing (20 percent), and flagging (11 percent), by tonnage (Dolley, 2016).

In 2014, approximately 63,700 metric tons (t) of dimension stone, most of which was slate, was produced in Idaho. It had a nominal value of $8.64 million. Quarries that have produced the majority of Idaho's quartzite decorative and dimension stone are located outside the cities of Clayton in Custer County and Oakley in Cassia County. Decorative quartzite and dimension-stone production from Idaho's famous "Oakley Stone," a micaceous quartzite quarried on Middle Mountain, was reported by the USGS in Cassia County, Idaho, in 2000–11. The Three Rivers Quarry near Clayton in Custer County reported production of 18,000 t of argillaceous quartzite, probably a fine-grained quartzite dimension stone used for flagstone, in 2002 (U.S. Geological Survey, 2004). Production was 23,000–27,000 t in 2006 and 32,000 t in 2007. Production data for prior and subsequent years were withheld to avoid disclosing company proprietary data (Dolley, 2007; U.S. Geological Survey, 2002a, b, 2003, 2005, 2008, 2009, 2010, 2012, 2014, and 2015).

Examples of the applications of quartzite produced by companies in Cassia County include flagstone, hearths and mantels, retaining walls, steps, table tops, tile, and veneer (Northern Stone Supply, Inc., 2016). It is likely that similar products are also produced by operations in Custer County.

On-site prices for the types of quartzite products vary significantly. Determining factors include the amount of finishing work, dimensions, and shape. It is likely that the bulk of sales of quartzite products shipped from Idaho are limited to regional markets because transportation is a major cost component.

The U.S. Defense Logistics Agency does not hold a stockpile of quartzite or any type of dimension stone. It is not considered a strategic or critical commodity because it is mostly for decorative purposes and numerous materials are readily available that can serve as a substitute for use in its applications.

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Gallium

Mined gallium is recovered globally as a byproduct of processing bauxite and zinc ores. Gallium is used in microelectronic components of a wide variety of products. The components include gallium arsenide (GaAs), gallium nitride (GaN), and copper-indium-gallium selenide (CIGS) direct band-gap semiconductors. GaAs and GaN are used in the manufacture of light-emitting diodes (LEDs), laser diodes, photo detectors, and solar cells. These devices are important for

the aerospace and telecommunications industries. They are also used in the production of highly specialized integrated circuits, semiconductors, and transistors to help regulate the flow of electricity and amplify power. These components are necessary for high-performance computers and smartphones (cellular telephones that have advanced personal computer-like functionality). Power transistors made with GaN operate at higher voltages and with a higher power density than those made with GaAs. The types and numbers of products that use advanced GaN based transistors are expected to increase in the future. CIGS was developed to make lightweight and durable thin-film photovoltaics that have a high absorption coefficient and applications in the manufacture of solar cells (Foley and Jaskula, 2013).

GaAs applications accounted for about 80 percent of the worldwide gallium market, whereas GaN and CIGS applications accounted for about 7 percent and 5 percent, respectively. Various other applications accounted for the remaining 8 percent (Jaskula, 2015).

Domestically, GaAs and GaN wafers used in integrated circuits and optoelectronic devices accounted for approximately 75 percent of gallium consumption. Uses in the United States include integrated circuits for defense applications, high-performance computers, and telecommunications equipment. Optoelectronic devices, which include laser diodes, LEDs, photodetectors, and solar cells, accounted for nearly all of the remaining gallium consumption (Jaskula, 2016).

Publications of the USGS National Minerals Information Center (NMIC) reported that in 2014, the United States did not recover gallium metal from domestic mining and has not done so since 1987. The Cordero primary gallium project, located within the assessment area, has been actively explored, but no production has been reported (Business Wire, 2005). The U.S. Geological Survey publishes detailed analyses and statistical data related to gallium derived from mining (gallium metal), GaAs wafers, and GaN wafers. GaAs and GaN wafers are manufactured products; the major focus of the following discussion is unwrought gallium metal, "waste," and "scrap," as it is more relevant to the methodology applied to the assessment area as it relates to mining (Jaskula, 2015, 2016).

Gallium is not recovered from old scrap in the United States; however, substantial quantities of domestic and imported new scrap generated in the manufacture of GaAs-based devices are reprocessed to recover high-purity gallium at one facility in Utah. The amounts and type of exported scrap are not available (Jaskula, 2016).

Approximately 53.9 metric tons (t) of unwrought gallium waste and scrap were imported and consumed in the United States in 2014. Imports have increased significantly since 1990, when only 9.9 t were imported. The rise reflects the increase in domestic waste-processing capacity and the Nation's demand for the production of electronic circuitry and other products that use the metal. The compound average annual growth rate in imports of nearly 7 percent over the time period reflects the increase in demand for technologically advanced products and growth in domestic manufacturing. For the years 2011–14, Germany was the leading import source with a 35 percent share. Other major

import sources and their percentage shares were China (26 percent), United Kingdom (22 percent), and Ukraine (9 percent) (Jaskula, 2016; Kelly and Matos, 2007). The United States does not have a vertically integrated gallium mining and processing industry and therefore relies completely on foreign imports to meet the Nation's commercial and strategic requirements. Since 2000, the net import reliance of the United States, as a percentage of apparent consumption has been estimated at 99 or 100 percent (Jaskula, 2016; Kramer, 2001).

Gallium is considered a strategic and critical mineral material because of total or nearly total U.S. import reliance and gallium's use in advanced commercial and military applications. GaAs- and GaN-based integrated circuits are used in many defense-related applications because of their unique properties, and no effective substitutes exist in these applications. The U.S. Defense Logistics Agency, however, does not hold a stockpile of gallium (Jaskula, 2016). From 1990 to 2014, the total amount of byproduct low-grade primary gallium recovered annually from global mines increased from approximately 37 to 438 t. The compound average annual increase of nearly 11 percent reflects the growth in global demand for use in a wide array of applications in advanced technologies. This rate of growth exceeds that of base metals and many other mineral commodities. In 2014, gallium recovered from mining was estimated to be 438 t, significantly below the estimated world capacity of 670 t, owing to large inventories of primary gallium. China is by far the leading primary gallium producer and possessed more than 80 percent of global production capacity. China's primary gallium production capacity expanded to approximately 550 t per year in 2014 from 140 t in 2010 on the expectations of increases in LED backlighting and general lighting demand. The other major primary gallium producing countries are Germany, Hungary, Japan, Kazakhstan, Republic of South Korea, Russia, and Ukraine (Jaskula, 2015, 2016; Kelly and Matos, 2007; Brian Jaskula, gallium commodity specialist, USGS, oral commun., March 15, 2016).

The average annual price per kilogram of gallium ($/kg), expressed in constant 1998 U.S. dollars for the purpose of comparison for the years 1990–15, was at a low of $203/kg ($295/kg in nominal dollars) in 2015 owing to China's continued overproduction and continued stock buildup of low-grade primary gallium. Prices attained a high of $626/kg in 1999, when gallium supply became tight because of high demand in the telecommunications industry (Jaskula, 2010, 2016; Kelly and Matos, 2007; Kramer, 2001).

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Gemstones

At least three gemstones are known to be produced in or proximal to the SaMiRA project assessment area—aventurine, precious opal, and sunstone.

Aventurine, also known as aventurine quartz, is a type of light- to dark-green quartz that exhibits a metallic iridescence or glittering (aventurescence), which is caused by light reflecting off of included fuchsite (green mica) flakes. Sometimes it occurs with red- or golden-brown color exhibiting metallic iridescence caused by included hematite flakes. It is cut into cabochons (unfaceted stones) and is carved into ornamental objects. Aventurine deposits are found in Austria, Brazil, India, Russia, Tanzania, and the United States (Schumann, 1998, p.122).

Opal is a mineraloid in the form of hydrated amorphous silicon dioxide and is generally classified as common opal or precious opal. It is valued as a precious opal for the intense rainbow of colors displayed as it diffracts and refracts light when it is shaped and polished to produce cabochons and, less commonly, cut and faceted. The value of precious opal can vary significantly and depends largely on the size of the gem, the intensity and range of colors it displays, and uniformity of the stone (Geology.org, 2016). A large part of the world's precious opal is mined in Australia, but it is also mined in significant quantities in Brazil, Ethiopia, Guatemala, Honduras, Indonesia, Japan, Mexico, Russia, and the United States. Common opal is usually milky in color, opaque, and may be used in jewelry and may have value to mineral collectors. It does not usually share the more-valued "rainbow" of colors and other characteristics of precious opal and is rarely considered a gemstone. Common opal has relatively low value and is mined in many countries (Schumann, 1998, p. 150–152).

Sunstone, also known as aventurine feldspar, is a type of clear, blue, green, orange-brown, red-brown, or yellow oligoclase feldspar that exhibits aventurescence caused by light reflecting off included copper, hematite, or goethite platelets or flakes. It typically is cut into cabochons and is sometimes faceted. Sunstone deposits are found in Canada, India, Madagascar, Norway, Russia, and the United States (Schumann, 1998, p. 166). Sunstone is the State gemstone of Oregon.

The USGS National Minerals Information Center (NMIC) reports on a wide range of statistical data related to the domestic and global production of gemstones with a focus on natural and synthetic gemstones, such as diamonds, emeralds, pearls, and rubies (Olson, 2014, 2016). The NMIC does not publish information on the carat weight of individual gemstone types produced by State, but does provide information on the estimated value of total gemstone production by State through a voluntary survey of mining companies. Statistics may underestimate actual production owing to the relatively low level of response to surveys and the amount of unreported production by individual collectors.

The total value of aventurine production in 2014 is withheld to avoid revealing company proprietary data. Commercial aventurine production and collection by hobbyists takes place in Utah. Production of aventurine in or proximal to the assessment area includes Northern Stone Supply's aventurine operation in Box Elder County, Utah.

The NMIC reported that in 2013 the total value of opal production in the United States was approximately $93,000 and represented less than 1 percent of the total estimated value of domestic natural gemstone production. Preliminary estimates suggest that the value of opal production in 2014 was about 5 percent lower (Olson, 2016). Commercial opal production and collection by hobbyists takes place in Arizona, California, Idaho, Louisiana, Nevada, and Oregon. Production of precious and common opal in or proximal to the assessment area includes the Spencer Mine in Clark County, Idaho, and several mines in the Virgin Valley area and in the Calico Mountains in Humboldt County, Nevada (Austin, 1995; U.S. Geological Survey, 2015; Olson, 2016).

The total value of 2013 sunstone production in the United States was approximately $576,000 and represented about 6 percent of the total estimated value of domestic natural gemstone production. Preliminary estimates suggest that the value of sunstone production was slightly less in 2014. Production of sunstone in or proximal to the assessment area includes several mines in Harney, Jackson, and Lake Counties, Oregon (Olson, 2016), including the Dust Devil Mining Company, which operates a fee digging sunstone mine near Plush, Oregon.

Aventurine, precious opal and sunstone are not considered to have strategic or critical importance to the United States. Their value is solely based on their actual or speculative desirability for personal adornment.

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Gold

Publications of the USGS National Minerals Information Center (NMIC) reported that in 2014, U.S. mines produced about 210 metric tons (t) of gold as a primary product and as coproduct or byproduct of other metals mining and processing; U.S. output ranked fourth in the world. Mines in Nevada and Alaska, the two leading producing States, accounted for about 72 percent and 15 percent, respectively, of domestic gold mine production in 2014. The remainder, in descending order of production, was from mines in Colorado, Utah, Washington, California, Montana, South Dakota, Arizona, and New Mexico, (George, 2016).

Within the assessment area, gold production was reported in Custer and Lemhi Counties, Idaho; in Fergus and Phillips Counties, Montana; and, most significantly, in Elko and Humboldt Counties, Nevada (Environmental Working Group, 2016; U.S. Geological Survey, 2015a, b). Gold production in these States is not within the specified proposed withdrawal areas, at the time of this analysis, but production in Elko and Humboldt Counties in Nevada, does fall within a 25-kilometer (km) zone outside the study area. In 2014, approximately 30 percent of all gold production in Nevada came from mines within the 25-km buffer zone in Elko and Humboldt Counties.

In 2014, the U.S. mine production of gold was about 210 t, significantly less than the estimated 294 t that was produced in 1990. Although gold production declined by an average compound annual rate of about 1.4 percent from 1990 through 2014, production rose to a record-high level of 366 t in 1998, owing to development of open-pit leach operations in the Carlin trend. The decline in domestic gold mine production since 1998 can be attributed to a combination of increasing costs, lower ore grades, decreased ore throughput at some mines, closure of some mines, and, reduced output from copper mines. During this period, an increased share of copper mine production was from leaching methods that preclude the recovery of gold. In 2014, it was estimated that U.S. gold ore reserves contained approximately 3,000 t of gold (George, 2016; Kelly and Matos, 2007).

In addition to domestically mined gold, an additional 140 t of the metal was recovered from the recycling of scrap in 2014; a substantial increase from 1990 when 44 t was recovered.

In 2014, the United States exported about 500 t of gold in refined bullion, doré, concentrates, and precipitates and imported approximately 308 t for domestic consumption. Four countries supplied 81 percent of U.S. imports—Mexico (41 percent), Canada (19 percent), Colombia (13 percent), and Peru (8 percent (George, 2016).

For 2014, U.S. consumption of gold was estimated to be 150 t, significantly lower than in 1990 when it was estimated to be 215 t. The United States has long been a net exporter of gold; however, large unreported investor stock changes preclude calculation of meaningful net import reliance (George, 2016; Kelly and Matos, 2007).

The U.S. Defense Logistics Agency does not hold a stockpile of gold. Gold is not considered a strategic or critical commodity. The United States has substantial production and stocks of gold held by industry and investors, the U.S. Treasury Department, and commodity exchanges. The U.S. Department of Defense operates a Government-wide secondary precious-metals recovery program (George, 2016). From 1990 to 2014, total world mine production of gold increased from 2,180 to 2,990 t at an average compound annual growth rate of about 1.5 percent. In 2014, China led the world in mined gold production with 450 t. This was a significant increase from 1990 when China produced an estimated 100 t. Other major gold producers in 2014, and their respective shares of global production, were Australia (9 percent); Russia (8 percent); the United States (7 percent); Canada, Peru, and South Africa (5 percent each); and Mexico (4 percent). The increase in world gold output from 1990 to 2014 has been driven by an overall increase in the demand for the metal in electronics and jewelry and as an investment vehicle, especially among some Asian countries, notably India (George, 2016; Kelly and Matos, 2007).

The average annual gold price per troy ounce, expressed in constant 1998 U.S. dollars, since 1990, ranged from a low of about $250 per troy ounce ($8,060,000/t) in 2001 to a high of $1,673 per troy ounce in 2012 ($38,200,000/t). In 2015, the average price of gold in nominal dollars was approximately $1,163 per troy ounce ($32,262,000/t) (Kelly and Matos, 2007; George, 2016).

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Gypsum

The USGS National Minerals Information Center (NMIC) reported that the United States produced gypsum from about 54 mines in 16 States in 2014. The United States was the world's third-ranked mine producer of crude gypsum with 11 million metric tons (Mt) accounting for nearly 5 percent of world production. Domestic reserves of crude gypsum were estimated to be 700 Mt. The United States and other countries also produce significant tonnages of synthetic gypsum, which is predominantly generated as a byproduct at coal-fired electrical power plants. In 2014, the United States sold approximately 15 Mt of synthetic gypsum, most of which was produced from flue-gas desulfurization (FGD) systems at coal-fired electric power plants. Some gypsum scrap that was generated by wallboard manufacturing, wallboard installation, and building demolition in the United State was recycled. The recycled gypsum was used primarily for agricultural purposes and feedstock for the manufacture of new wallboard.

In 2015, the leading crude gypsum-producing States were, in descending order of production, Oklahoma, Texas, Nevada, Kansas, Iowa, and Arkansas, which together accounted for 70 percent of total domestic output (Crangle, 2015a, b, 2016). Ongoing or previous gypsum mining activities in the States or counties within the assessment areas studied include Washoe County in northwestern Nevada, but

these locations were not within the proposed withdrawal area (State of Nevada, 2015, p. 15–24; Weissenborn, 1963).

A significant driver for gypsum production is the demand for its use as a component of wallboard and portland cement in the construction industry. From 1990 to 2014, total annual world mined gypsum production more than doubled from approximately 104 to 244 Mt for an average annual growth rate of about 3.5 percent. The effect of the global recession in 2008 was reflected by a decrease in world production in response to decreased demand for gypsum (Kelly and Matos, 2007). Increased use of wallboard in Asia, coupled with new gypsum-product manufacturing plants, spurred increased production and consumption in that region. As wallboard becomes more widely used in other regions, the trend of worldwide production of gypsum is expected to increase. In 2014, the United States apparent consumption of crude and synthetic gypsum was 25.7 Mt, about 15 percent higher than 1990. However, domestic production of crude gypsum decreased over the same period from 16 Mt to 11 Mt and synthetic gypsum production increased from 735,000 to 11 Mt. In 1990, 8.7 Mt of crude gypsum was imported and about 129,000 t was exported, but in 2014, imports of crude gypsum had decreased to 3.7 Mt and exports had decreased to 67,000 t. From 2011 through 2014, the leading import sources of crude gypsum and their percentage shares were Mexico (42 percent), Canada (35 percent), and Spain (22 percent) (Davis, 1992; Crangle, 2016). The U.S. net-import reliance as a percentage of apparent consumption was 14 percent in 2014.

The U.S. Defense Logistics Agency does not maintain an inventory of gypsum. Gypsum is not considered either of critical or strategic importance because of the numerous domestic sources, both crude and synthetic, and the significant number of foreign producers.

In 2014, approximately 80 countries produced mined gypsum for a total of about 244 Mt. China was the leading producer with an estimated 129 Mt and accounted for an approximately 53 percent share of world crude gypsum production. China is likely to maintain its position for the foreseeable future. The other leading producers were Iran and Turkey, each representing a 6 percent share of world production, followed by the United States accounting for nearly 5 percent (Crangle, 2016).

The average annual price per metric ton ($/t) of the total value of domestic sales of calcined and uncalcined gypsum in nominal dollars was about $12.00/t in 2014. Since 1990, average annual price per metric ton has ranged from a low of $9.70/t in 1992 to a high of $15.90/t in 2005 (Kelly and Matos, 2007). In 2014, the average nominal price for crude gypsum was approximately $9.00/t, free on board at the mine (Crangle, 2016).

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Iron Ore

The principal ore minerals of iron are hematite, magnetite, siderite, and goethite. An estimated 98 percent of the ore shipped in the world is consumed in the manufacture of iron and steel. The remaining 2 percent is used in the manufacture of cement, heavy-medium materials, pigments, ballast, agricultural products, or specialty chemicals, among other uses. As a result, demand for iron ore is tied directly to the production of raw steel, the availability and cost of high-quality ferrous scrap, and the percentage of steel produced using basic oxygen furnaces.

Publications of the USGS National Minerals Information Center (NMIC) reported that in 2014 the United States produced 55.9 million metric tons (Mt) of iron ore for use in steel production and ranked eighth in global iron-ore production. All of the ore is recovered from surface operations. Mines in Michigan and Minnesota shipped 98 percent of the usable iron ore in the United States (Tuck, 2016). Iron-ore production has not occurred in the assessment area within the past 10 years; however, production was reported in Utah County, Utah, in 1990 and in Fremont County, Wyoming, until about 1983 (Jeske and Gloyn, 1991; Starch and Glass, 1984).

In 2014, U.S. mine production of iron ore was slightly lower than the estimated 56.4 Mt that were produced in 1990. Except for a drop in production in the years surrounding the global recession, domestic iron-ore production has been relatively stable since 1990. In 2014, it was estimated that U.S. iron-ore reserves were approximately 11.5 billion metric tons (Bt) of crude ore, which is equivalent to a 3.5 Bt of iron (Tuck, 2016).

In 2014, the United States exported about 12.1 Mt of iron ore compared with 3.2 Mt in 1990. The increase in exports followed the increasing trade of iron and steel between Canada, Mexico, and the United States as domestic iron-ore producers expanded their iron and steel operations throughout North America. Approximately 5.1 Mt of iron ore were imported for domestic consumption in 2014 compared with 18.1 Mt in 1990. The decrease in iron-ore imports was a result of decreased domestic steel production. The countries importing the most U.S. iron ore during 2011–14, and their respective shares, were Canada (56 percent), Brazil (35 percent), Sweden (3 percent), and Argentina (2 percent) (Tuck, 2016).

Apparent consumption of iron ore in the United States has declined by 36 percent to 45.9 Mt in 2014 from 71.4 Mt in 1990. This trend resulted from decreasing imports and increasing exports of iron ore and reduced domestic steel production. The United States was a net exporter of iron ore in 2014 in contrast to 1990, when net import reliance as a percentage of apparent consumption was 21 percent.

The U.S. Defense Logistics Agency does not hold a stockpile of iron ore (Tuck, 2014, 2016). Iron ore is not considered a strategic or critical commodity because of substantial U.S. production, well-established domestic steel manufacturing, steel recycling, reliable import sources, and abundant stocks held by producers and consumers. The greatest risk to the domestic iron-ore industry lies in rising levels of steel imports, which increased by nearly one-third from 2013 to 2014. The sustained increase has directly affected the iron and steel industry causing iron-ore mines and iron-based steel production facilities to be idled, reducing the overall domestic capacity for raw steel production. Iron and steel is essential all aspects of the U.S. economy, because it is a critical component of all modern technology sectors, including agriculture, communications, defense, manufacturing, and transportation.

From 1990 to 2014, the total world iron-ore production increased from 982 Mt to 3.4 Bt, for an average compound annual growth rate of about 8.9 percent. During this period of time, U.S. production varied only slightly, while production in some other countries increased significantly. Iron-ore production rose nearly sixfold in Australia, nearly threefold in Brazil, and nearly fourteenfold in China from 1990 through 2014. Much of the increased production was to supply increased demand by China's steel industry for domestic construction goods, manufacture of consumer goods, and export. In 2014, China was the world leader in iron-ore production with 1,510 Mt, which represented a 44 percent share; however, unlike most of the reported global iron-ore production, which has an iron content averaging 62.5 percent iron content, China reports ore production as crude ore, which has an estimated iron content of 20 percent to 30 percent. Other major iron-ore producers in 2014, and estimates of their respective share of global production, were Australia (23 percent), Brazil (12 percent),

India (4 percent), and Russia (3 percent) (Kelly and Matos, 2007; Kuck, 1992; Tuck, 2016).

The average annual unit value of iron ore, expressed in constant 1998 U.S. dollars for the purpose of comparison, has varied since 1990 but reached a low of about $22/t in 2001 to a high of $74/t in 2010. The increase in iron-ore unit value beginning around 2004 was driven to a large extent by high demand from China. Prices began to weaken in 2014 as demand began to wane. In 2014, the average price of iron ore in nominal dollars was approximately $92.78/t (Kelly and Matos, 2007; Tuck, 2016).

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Lead

The major application for lead is in all types of lead-acid storage batteries. Other significant uses included ammunition, oxides in glass and ceramics, casting metal, and sheet lead. The remainder is consumed in solders, bearing metals, brass and bronze billets, covering for cable, caulking lead, and extruded products (Guberman, 2015, 2016).

Publications of the USGS National Minerals Information Center (NMIC) reported that in 2014 the United States produced about 379,000 metric tons (t) of lead in concentrates as a principal product, coproduct, or byproduct of mining. Lead is recovered from ore extracted from underground or open pit mines and concentrated using conventional flotation methods. In 2014, the United States ranked third in global mine production of lead. Mines in Alaska and Missouri accounted for most of the domestic mined lead production in 2014. The remaining production came from mines in Shoshone County, Idaho, and in Pend Oreille County, Washington (Gabby, 2007; Guberman, 2012, 2015). Lead production is ongoing or has occurred since 2005 in Jefferson County, Montana, and Shoshone County, Idaho (U.S. Geological Survey, 2015a, b, c). No mine production of lead was reported in the assessment areas or the 25-kilometer (km) buffers. In 2014, the U.S. mine production of lead in concentrates was about 379,000 t, significantly less than the 497,000 t produced in 1990. The compound annual growth rate has been about negative 1 percent in domestic lead mine production during the period, which can be attributed to a combination of shutdowns and curtailments at zinc and lead mines. Mine production of lead remained essentially unchanged from 2011 to 2013. In 2014, it was estimated that U.S. ore reserves contained approximately 5 million metric tons (Mt) of lead (Guberman, 2016; Kelly and Matos, 2007).

In 1990, approximately 404,000 t of primary refined lead was produced from domestic and imported concentrates by domestic refiners. In 2014, as a result of plant closures, the United States did not produce any primary refined lead. All domestically produced lead concentrates were exported and essentially no concentrates were imported. It is unlikely that lead concentrates will be smelted and refined in the United States before the end of the decade or perhaps the foreseeable future.

In 2014, in addition to domestically mined lead, 1.13 Mt of lead was recovered from the recycling of scrap, an increase from 1990 when about 922,000 t was recovered. Spent lead-acid batteries are the primary source of lead recovered from recycling (Guberman, 2016; Woodbury, 1992).

In 2014, the United States exported about 356,000 t of lead in concentrates plus 60,000 t of refined-lead (wrought and unwrought). Approximately 596,000 t of refined lead (wrought and unwrought) was imported for consumption in 2014 compared with 97,000 t in 1990. The increase reflects reduced domestic mine production and closures of U.S. primary lead smelters and refineries. For the years 2011–14, five countries accounted for 90 percent of refined-lead (wrought and unwrought) imports—Canada (57 percent), Mexico (20 percent), Peru (5 percent), and Australia and Kazakhstan (4 percent each) (Guberman, 2016).

Apparent consumption of lead in the United States has increased from 1,300 Mt in 1990 to 1,670 Mt in 2014, primarily owing to increased consumption for use in lead-acid batteries (Guberman, 2015; Woodbury, 1992).

The United States became increasingly reliant on imports of refined lead from 1990 through 2014, primarily owing to

the closures of all primary lead refineries. In 2014, net import reliance as a percentage of apparent consumption of refined lead was 32 percent, a substantial increase from 1990 when it was 3 percent (Guberman, 2015; Woodbury, 1992).

The U.S. Defense Logistics Agency does not hold a stockpile of lead. Lead is not considered a strategic or critical material because of substantial U.S. production of lead from recycling, reliable sources for imports, and sufficient stocks held by producers and consumers (Guberman, 2016). Although not held in the stockpile, the U.S. Department of Defense (DOD) has modeled for potential shortfalls of lead and looked into substitutes for specific applications that are vital to DOD. Refined lead is not considered to be difficult to obtain; however, there are some military applications, such as high-purity refined lead used in batteries for submarines, that use types of lead that have limited supply sources.

From 1990 through 2014, total world mine production of lead increased from 3.37 Mt to 4.87 Mt for an average compound annual growth rate of about 1.6 percent. In 2014, China was the leading world producer of mined lead with 2.4 Mt, accounting for 49 percent of world lead production. This was a significant increase from 1990 when China produced an estimated 315,000 t or about 9 percent of world mine production. Other major lead producers in 2014 were Australia (15 percent), United States (8 percent), Peru (6 percent), and Mexico (5 percent). The increase in world lead-mine production during that time period was driven primarily by increases in consumption in China and other developing nations (Guberman, 2015; Kelly and Matos, 2007; Woodbury, 1992).

The average annual lead price, expressed in constant 1998 U.S. dollars since the year 1990, ranged from a low of about $855 per metric ton in 2003 to a high of $2,150 per metric ton in 2007. The elevated price of the metal in 2007 was a result of increased global consumption, most notably in China, and a decline in global stocks. Prices decreased in subsequent years, partially owing to a global economic slowdown and more moderate increases in lead consumption in China. In 2014, the average annual price of lead expressed in constant 1998 U.S. dollars was approximately $1,610 per metric ton (Kelly and Matos, 2007; Guberman, 2016).

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Lithium

Although lithium markets vary by location, global end-use markets are estimated as follows: batteries, 35 percent; ceramics and glass, 32 percent; lubricating greases, 9 percent; air treatment and continuous-casting mold-flux powders, 5 percent each; polymer production, 4 percent; primary aluminum production, 1 percent; and other uses, 9 percent. Lithium consumption for batteries has increased significantly in recent years because rechargeable lithium batteries are used extensively in the growing market for portable electronic devices and increasingly are used in electric tools, electric vehicles, and grid-storage applications. Lithium minerals are used directly as ore concentrates in ceramics and glass applications worldwide (Jaskula, 2016).

The USGS National Minerals Information Center (NMIC) reported that in 2015 the United States continued to produce lithium from one lithium-brine operation located at Silver Peak in Esmeralda County, Nevada (Jaskula, 2016). In 2013, the mine produced approximately 870 metric tons (t) of lithium and represented about 3 percent of world production. Historical production statistics for the Silver Peak operation are withheld

to avoid disclosing company proprietary data in most years (Jaskula, 2015).

The United States was the world's leading producer until the late-1990s, when relatively low-cost lithium production recovered from subsurface lithium-rich brines in Chile underwent significant growth. In response to the lower market prices, hard-rock mining operations in North Carolina decreased production and eventually closed.

The recovery of lithium from scrap is an emerging industry, and only a relatively small quantity of lithium is recovered from the secondary sources such as batteries (Jaskula, 2015).

The estimated consumption of lithium in the Untied States from 1990 to 2014 ranged from a high of 2,800 metric tons (t) for the years 1997–2000 (when the two largest lithium-consuming sectors were ceramics and glass and primary aluminum production) to 1,100 t in 2002 (owing to the closure of several major aluminum smelters and a large cookware factory) and 2010 (owing to the economic downturn which began in 2008).

The United States relies on foreign sources of lithium carbonate, lithium hydroxide, and other lithium compounds to supplement its commercial and strategic requirements. In 2014, the United States imported approximately 2,120 t and exported about 1,420 t of lithium contained in a variety of different lithium compounds. In the 1990s until about 2001, the United States was a net exporter of lithium. With the closure of mines in the United States and increased imports for consumption, import reliance has increased. In 2014, net import reliance was estimated to be greater than 60 percent. From 2011 through 2014, the two leading import sources of lithium to the United States were Chile, with an average 58 percent share, and Argentina, with a 38 percent share of total imports. China supplied 3 percent of total U.S. imports over the same period (Jaskula, 2016).

The Defense Logistics Agency (DLA) Strategic Materials maintains the National Defense Stockpile (NDS) of strategic and critical materials to supply the military, industrial, and essential civilian needs of the United States for national defense. In an effort to modernize the NDS by acquiring new materials needed for defense applications, the DLA announced plans to acquire 150 kilograms (kg) of lithium cobalt oxide and 540 kg of lithium nickel cobalt aluminum oxide during fiscal year 2015. The materials are to be used for cathodes in lithium-ion batteries. By the end of 2015, the NDS had acquired stocks of 241 kg of lithium cobalt oxide and 690 kg of lithium nickel cobalt aluminum oxide, with plans to make additional purchases in the subsequent years (Defense Logistics Agency Strategic Materials, 2014, 2015; Jaskula, 2016).

From 1990 to 2014, total annual world lithium production, excluding U.S. production, increased from approximately 5,400 to 31,700 t for a compound average annual growth rate of more than 7.5 percent. The effect of the global recession is reflected by a short term, but significant decrease, in world production in 2009 (Kelly and Matos, 2007). A significant driver for increased world lithium production was the rise in demand for lithium compound use in rechargeable lithium-ion battery applications for electronic devices and electric and hybrid vehicles. Consumer demand in this sector is anticipated to continue to increase, barring technological

breakthroughs using different materials, economic downturns, and other factors. In 2014, Australia led the world in mined lithium production with a nearly 42 percent share, all of which was contained in lithium minerals. Other countries with significant lithium production included Chile, Argentina, and China, with 36, 10, and 7 percent shares of world production, respectively. Lithium in Argentina and Chile is recovered from brine deposits, and lithium from China is recovered from a combination of brine and mineral deposits. In 2014, world lithium reserves were estimated at 14 million metric tons; with about 3 percent located in the United States.

The average annual unit value per metric ton ($/t) of lithium content since 1990, expressed in constant 1998 U.S. dollars, has ranged from a low of $1,220/t in 2005 to a high of $5,040 in 1991 (Kelly and Matos, 2007). Prices are weighted toward lithium carbonate, because it is produced in the largest quantity and has the highest combined value among lithium compounds. The average unit value for lithium carbonate in 2014 was $3,110/t (Jaskula, 2016). In general, higher prices reflect periods of greater demand and a tightening of supply.

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Mercury

Publications of the USGS National Minerals Information Center (NMIC) reported that mercury has not been produced as a principal mineral commodity in the United States since 1992.

From 1990 to 1992, the United States produced a total of 684 t. About 70 percent of the production originated from the McDermitt Mine located in Humboldt County, Nevada, which closed in late-1990 (Reese, 1989, 1990, 1991). The balance of the domestic mercury-mine production during that period was as a byproduct of the pyrometallurgical treatment of sulfidic refractory gold concentrates in the Nevada counties of Elko, Eureka, Humboldt, Mineral, Nye, Washoe, and White Pine; Napa County, California; and Tooele County, Utah. In 2015, mercury continued to be recovered as a product of processing gold-silver ore at several mines in Nevada; however, production data were not reported. Mercury is also recovered by recycling batteries, compact and traditional fluorescent lamps, dental amalgam, medical devices, and thermostats, as well as mercury-contaminated soils (George, 2016). Owing to mercury's toxicity and concerns for the environment and human health, overall world mercury consumption has declined. Most of the metal's current end use is in chlor-alkali plants for the production of chlorine and sodium hydroxide (only two plants using mercury remained operating in the United States in 2015) and for the recovery of gold by artisanal miners, mostly in developing countries. The trend of decreasing global consumption is reflected in global mercury mine production statistics for the years 1990 to 2014, which has contracted from 4,100 metric tons (t) to 2,350 t for an average compound annual rate of decline of just more than 2 percent. It is likely that this trend will continue for the balance of the decade. In 2014, China produced an estimated 1,600 t of primary mercury and accounted for 68 percent of world production. Statistical data on mercury production in Mexico is incomplete, but based on the country's level of exports, it is likely they were the second leading producer with about a 21 percent share of world production (George, 2016). China is expected to continue to be the world's major producer for the foreseeable future.

At the end of 2014, an inventory of 4,436 t of mercury was held in storage at the Hawthorne Army Depot, Hawthorne, Nevada, and about 1,200 t of mercury was held by the U.S. Department of Energy, Oak Ridge, Tennessee. Sales of mercury from the National Defense Stockpile remained suspended. Beginning in January 1, 2013, the export of elemental mercury from the United States was banned, with some exceptions, under the Mercury Export Ban Act of 2008. Less than 1 t of mercury was exported in 2013, and no exports have been recorded in subsequent years. Imports for consumption to the United States declined substantially from 249 t in 2012 to 49 t in 2014 (George, 2015, 2016). Mercury is not considered a strategic and critical material, mainly because of its (1) limited remaining applications as determined by legislation, (2) substitution by other materials through advances in technology, and (3) large inventories.

The average free-market price in nominal dollars for mercury has remained unchanged at about $53,700 per metric ton ($/t) ($1,850 per flask) since 2011. Expressed in constant 1998 U.S. dollars, for the purpose of comparison, the price of mercury has increased nearly four-fold since 1990, when the price of mercury was $9,020/t. Two major factors contributed to the substantial increase in the price of mercury beginning in about 2009. Supply decreased from primary production, owing to the increase in regulation of the production and trade of mercury, and secondary production decreased, owing to reduced availability from recycling. Secondly, an increase in demand for mercury in the artisanal and small-scale mining industry resulted from a substantial increase in the price of gold.

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Molybdenum

Molybdenum is a refractory metallic element used principally as an alloying agent in cast iron, steel, and superalloys to enhance hardenability, strength, toughness, and wear-and-corrosion resistance. Other uses for molybdenum are in catalysts, chemicals, lubricants, and pigments (Polyak, 2015a, b).

The USGS National Minerals Information Center (NMIC) reported that in 2014, the United States produced 68,200 metric tons (t) of molybdenum in concentrates from 13 mines as either a primary product or byproduct of mining, ranking second in global mine production. In 2014, molybdenum was recovered from 5 mines in Arizona, 2 in Colorado, and 1 mine each in Montana, Nevada, and Utah. Molybdenum production is ongoing or has occurred within the States included in the assessment area since 2005 in Custer County, Idaho; Silver Bow County, Montana; White Pine County, Nevada; and Salt Lake County, Utah (Polyak, 2013, 2016). There are two molybdenum mines—Thompson Creek in Custer County and Ashdown Mine in Humboldt County, Nevada, that are within 25 kilometers (km) of the assessment area.

The Thompson Creek went on care and maintenance status in December 2014. There was no production in 2015. The Ashdown Mine has been closed since early 2012.

In 2014, U.S. mine production of molybdenum was about 68,200 t contained in concentrate, about 11 percent more than the estimated 61,600 t of molybdenum contained in concentrates that was produced in 1990. The average compound annual rate of growth was less than half of a percent. In 2014, estimated U.S. molybdenum ore reserves contained approximately 2.7 million metric tons (Mt) of molybdenum (Polyak, 2016).

Molybdenum is recycled as a component of catalysts, ferrous scrap, and superalloy scrap. The recycling of steel, which contains molybdenum as an alloying agent (the major use of molybdenum), is the most significant source of recovered molybdenum from secondary sources. Molybdenum is not separated and remains as a component of the reused steel. Currently, no processes for the separate recovery and refining of secondary molybdenum from its alloys are used. Data regarding the amount of molybdenum contained in the recycled steel are not available.

Approximately 25,300 t of molybdenum contained in concentrates (mostly as molybdenum trioxide) and other molybdenum-containing materials, such as ferromolybdenum, were imported for consumption to the United States in 2014, compared with 2,560 t in 1990. Total imported molybdenum ores and concentrates (roasted and unroasted) increased from about 433 t of contained molybdenum in 1990 to 15,770 t in 2014. For the years 2011–14, Mexico was the leading source of imported molybdenum ores and concentrates with a 31 percent share. Other major import sources during that time period and their share of imports were Canada (28 percent), Peru (23 percent), and Chile (17 percent) (Blossom, 1992, 1993; Polyak, 2015a, 2016).

The quantity of imported ferromolybdenum, also a component of molybdenum imports, increased from 1990 to 2014 from 871 to 5,110 t of contained molybdenum (Blossom, 1993; Polyak, 2015). The increases reflect higher production of specialty steels in the United States, mainly in full alloy steels for the construction and transport industry. For the years 2011–14, Chile was the leading source of ferromolybdenum with 83 percent, followed by Canada with 9 percent (Blossom, 1992, 1993; Polyak, 2015, 2016).

In 2014, the United States exported about 65,100 t of molybdenum contained in various products, most of which was contained in roasted concentrates (molybdenum trioxide), a significant increase from 1990 when the United States exported 43,400 t (Blossom, 1993; Polyak, 2016).

In the United States, molybdic oxide and ferromolybdenum are used principally in steels, with a significant volume of oxide being used in catalysts. Ammonium and sodium molybdate are used in pigments, catalysts, and other chemical uses. Molybdenum metal (mostly powder) products are used mainly in mill products and nonferrous alloys. Apparent consumption of molybdenum in the United States has increased from about 20,300 t in 1990 to an estimated 27,900 t in 2014 (Blossom, 1992, 1993; Polyak, 2016).

The U.S. Defense Logistics Agency does not hold a stockpile of molybdenum (Polyak, 2016). Molybdenum is not considered a strategic or critical commodity because of the Nation's substantial mine production and capacity of processing facilities and stocks held by consumers and producers. The United States has been a net exporter of molybdenum in various forms and compounds for several decades. For that reason, the United States is not reliant on imported molybdenum.

From 1990 to 2014, world production of molybdenum in concentrate increased from 112,000 to 281,000 t, for an average compound annual growth rate of about 4 percent. In 2014, China was the world leader in the production of molybdenum in concentrate with 103,000 t, which represented a 37 percent share. This was a significant increase from 1990, when the China produced an estimated 2,000 t of molybdenum in concentrate and represented a 2 percent share of world production. Other major producers of molybdenum in concentrate in 2014 were the United States (24 percent), Chile (17 percent), Peru (6 percent), and Mexico (5 percent) (Blossom, 1992, 1993; Polyak, 2016). Molybdenum consumption has continued to increase, owing to increases in China's industrial growth fueled by steel manufacturers producing higher-grade steel products for domestic consumption in China, as well as to increase steel exports. The principal areas of molybdenum growth are expected to be in the use of stainless and other steels containing molybdenum in aerospace and aircraft-engine components, chemical and petrochemical processing plants, motor-vehicle components, nuclear power plants, and in wind power generation components.

The average annual molybdenum price per metric ton ($/t) of molybdenum contained in technical-grade molybdic oxide, expressed in constant 1998 U.S. dollars for the purpose of comparison since the year 1990, ranged from a low of about $4,780/t ($2.16/per pound) in 2001 to a high of $58,500/t (26.53/per pound) in 2005. The sharp rise in the price of the metal in 2005 was a result of high demand by China and tight supply. Prices dropped in subsequent years in response to increased production followed by weakened demand for the metal in most major molybdenum-consuming nations during the global recession. In 2014, the average price of molybdenum contained in technical-grade molybdic oxide in nominal dollars was approximately $25,840/t ($11.72/per pound). Metal prices, in general, decreased during the 2014–15 period in response to decreasing demand and oversupply (Blossom, 1992, 1993; Kelly and Matos, 2007; Polyak, 2015a, 2016).

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Rare Earth Elements

The rare earth elements (REE) include the lanthanide elements with atomic numbers 57 through 71, plus scandium and yttrium. The lanthanides include, in order of atomic number, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium (International Union of Pure and Applied Chemistry, 2005).

The principal ores from which REE are extracted are characterized by the minerals bastnäsite, loparite, monazite, lateritic ion-adsorption clays, and xenotime. Bastnäsite, the leading ore mineral source of REE in the world, is enriched with cerium, lanthanum, neodymium, praseodymium, and other REE. Bastnäsite, a fluorocarbonate mineral, is produced in China and formerly in the United States. Loparite, which is an oxide mineral, is produced at one mine in Russia near Revda, Murmansk Oblast, and further processed into REE compounds in Solikamsk, Perm Oblast. Monazite is a phosphate mineral that contains REE and the radioactive element thorium. Although monazite has been and could be produced as a byproduct of many heavy-mineral operations, limited demand for thorium, and in some cases, environmental concerns associated with radioactivity, had led most producers outside of China to stop recovering monazite; however, recent efforts in India and elsewhere may be reversing this trend. REE mineral concentrates containing mostly supergene (enriched) monazite low in thorium are produced in Australia and then exported to Malaysia to be further processed into REE

compounds. Xenotime, a phosphate mineral rich in yttrium and certain other REE, has been produced from tin-bearing cassiterite deposits and is a potential byproduct from the production of heavy-mineral placer deposits. Like most REE minerals, xenotime may contain some level of thorium.

Lateritic deposits in southern China contain clays that have rare earth ions adsorbed into their mineral surfaces. These deposits make up the world's principal supply source of yttrium and the heavy REE (terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium).

Rare earth elements (individually and in combination with other REE) are used in a wide range of applications, including batteries, catalysts, ceramics, electronics, glass, lasers, medicine, permanent magnets, phosphors, polishes, and a host of metal alloys including aluminum-base, iron-base, magnesium-base, and super alloys. In 2014, the domestic consumption of rare earths by end use was as follows, in decreasing order: catalysts (60 percent), metallurgical applications and alloys (10 percent), ceramics and glass (10 percent), glass polishing (10 percent), and other (10 percent). The China Rare Earth Association reported that China's rare earth oxide equivalents (REOE) consumption in 2014 was 90,000 metric tons (t). The end use distribution in China was, in descending order, magnets (35 percent), polishing (18 percent), catalysts (15 percent), ferrosilicon (8 percent), hydrogen alloys (8 percent), aluminum alloys (6 percent), phosphors (2 percent), and magnesium alloys (0.2 percent). Rare earth demand in China was forecast to increase to 149,000 t by 2020.

In 2014, bastnäsite was mined by one company in the United States at Mountain Pass, California. The mine produced 5,400 t of REOE contained in mineral concentrates that were processed into downstream rare earth compounds. In October 2015, the mine shut down after nearly 4 years of continuous operation. The Mountain Pass mine was first developed in the 1950s and was idle from 2002 through 2011. Although the operation continued to process previously mined ore, no domestic mine production of REE was reported during those years. Domestic production in 2014 was significantly less than the estimated 22,700 t of REOE produced in 1990. Domestic production ceased in the early 1990s from the processing of monazite as a byproduct from heavy-mineral sands in Florida and North Carolina. No production of REE have been reported within the assessment area, although they may have been contained in heavy-mineral placers and not recovered. In 2014, it was estimated that U.S. reserves contained approximately 1.8 million metric tons of REOE (Bleiwas and others, 2013; Gambogi, 2016a, b; Hedrick, 1992, 1993, 1994; Kelly and Matos, 2007).

In addition to domestically mined material, a limited amount of REE was recovered from the recycling of batteries, permanent magnets, and fluorescent lamps (Gambogi, 2016a).

In 2014, the United States exported about 6,180 t of REOE contained in various rare earth compounds and metals. During the period 1990 to 2014, U.S. exports have varied between 5,360 t and 13,000 t, often fluctuating based on market conditions. Outside of China, the United States has been a

leading consumer of rare earths. The characteristics (elemental composition, type of compound, purity, and other qualities) of rare earth exports have changed over time because of the loss of downstream processing capabilities (Gambogi, 2016a).

In 2014, an estimated 11,600 t of REOE contained in various rare earth compounds and metals were imported to the United States. Increases in imports since 2012 reflect lower prices for rare earth compounds and metals. The leading import sources and their respective percentage shares for rare earth compounds and metals for the years 2011–14 were China (71 percent), Estonia (7 percent), and France and Japan (6 percent each) (Gambogi, 2016a).

Domestic consumption in 2014 was estimated at 17,000 t of REOE, significantly less than in 1990 when it was an estimated 28,700 t. Much of the decrease reflects reduced consumption by intermediate processors of rare earth compounds (Gambogi, 2016a; Kelly and Matos, 2007).

Net import reliance, as a percentage of apparent consumption in 2014, was estimated at 68 percent, an increase from 1990 when it was estimated at 20 percent. The significant change in import reliance from 1990 to 2014 reflects the reductions in domestic mining and processing of REE compounds (Gambogi, 2016a, b; Kelly and Matos, 2007).

Rare earths are important to numerous defense applications such as such as aircraft, communications, drive motors, electronics, lasers, optics, precision-guided missiles, radar, and smart bombs. The Defense Logistics Agency, Strategic Materials Division (DLA–SM) has conducted numerous assessments in regard to availability of REE for defense applications, and the Department of Defense has recommended that Congress authorize the acquisition of specific materials to mitigate the potential shortfalls. In the fiscal year 2014 National Defense Authorization Act, Congress authorized the acquisition of dysprosium and yttrium (Gambogi, 2016a; Grasso, 2013; Ucore Rare Metals, Inc., 2015).

From 1990 to 2014, the total world REOE mine production increased to 123,000 t from 52,900 t for an average compound annual growth rate of nearly 4 percent. The upward trend reflects technological advances that increased demand for REE used in materials such as batteries, catalysts, and magnets. In 2014, China produced 105,000 t of REOE and accounted for 85 percent of world production. This was a significant increase from 1990, when China produced an estimated 16,500 t and accounted for about 30 percent of world production. Other producers of mined REE in 2014, and estimates of their respective share of global production were Australia (7 percent), the United States (4 percent), and Russia and Thailand (about 2 percent each) (Hedrick, 1992, 1993, 1994; Gambogi, 2016a, b; Kelly and Matos, 2007). In general, the price per unit of the heavy REE is considerably higher than for light REE (lanthanum, cerium, praseodymium, neodymium, samarium, europium, and gadolinium). This price differential is driven by scarcity and higher processing costs.

Because of their importance for advanced technologies, the upward trend in demand for REE is likely to continue. The price of REE and their compounds vary considerably and are often negotiated by contract. Examples of published prices

at yearend 2014 ranged from a low of 4 to 5 U.S. dollars per kilogram ($/kg) for cerium oxide (99.5 percent minimum) to a high of $680–730/kg for europium oxide (99.9 percent minimum). In general, the prices for REE dropped significantly from prices published during the past several years as the available supply has exceeded growth in demand (Gambogi, 2016a, b).

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Silver

Traditional use categories for silver include coin and medal fabrication; industrial applications, including electrical and electronics components; jewelry and silverware; and photography (Virta, 2015).

Publications of the USGS National Minerals Information Center (NMIC) reported that in 2014 the United States mined about 1,180 metric tons (t) of silver as the principal product, coproduct, or byproduct from mines in 11 States. Combined, these mines accounted for approximately 4 percent of global silver mine production. In 2013, the principal mining States for silver were, in descending order of production, Alaska, Nevada, Idaho, and Utah. In Nevada, silver production is ongoing or has recently occurred in the gold producing counties of Elko, Esmeralda, Eureka, Humboldt, Pershing, Lander, Mineral, Nye, and White Pine (U.S. Geological Survey, 2015a). One silver producing company is within 25-kilometer (km) of the study area in Elko County, Nevada. In Idaho, silver production comes from two mines in Shoshone County. In Utah, silver is currently being produced in Salt Lake County, primarily from the Bingham Mine (U.S. Geological Survey, 2015b). In 2014, U.S. mine production of silver was about 1,180 t, which was significantly less than the 2,120 t that was produced in 1990. The overall decrease in silver domestic production can be attributed to a combination of increasing costs, lower ore grades, mine closures, and a decrease in the proportion of copper recovered through conventional flotation and smelting. Copper ores processed through leaching and solvent extraction-electrowinning do not yield any silver. Although the price of silver increased significantly from 1990 to its record-high level in 2011, silver mine production in the United States generally trended downward through several cycles from its near peak level in 1990 by an average compound annual rate of decline of about 1 percent. In addition to domestically mined silver, an additional 1,400 t of the silver was recovered from new and old scrap in 2014, a decrease of about 16 percent from the 1,675 t that was recovered in 1990. In 2014, it was estimated that U.S. ore reserves contained approximately 570,000 t of silver (George, 2016; Hilliard, 2000; Reese, 1992).

In 2014, the United States exported about 383 t of silver in concentrates and refined bullion and doré and imported approximately 4,960 t for domestic consumption. From 2011 through 2014, four countries accounted for 87 percent of U.S. imports. The country shares were Mexico (54 percent), Canada (26 percent), Poland (4 percent), and Peru (3 percent).

In 2014, the U.S. apparent consumption of silver was estimated to be 7,150 t, significantly higher than in 1990 when it was estimated at 4,355 t. A net decrease in consumption of silver in photographic applications was more than offset by increased consumption in other industrial uses, jewelry, and investment holdings. Net import reliance in 2014, as a percentage of apparent consumption, was estimated at 64 percent. Although the United States is a net importer of silver, changes in unreported investor stocks precluded calculations for reliable estimates of import reliance for the period 1990–97, but import reliance in 1998 was estimated at 14 percent.

The U.S. Defense Logistics Agency does not hold a stockpile of silver. Silver is not considered a strategic and critical commodity because of adequate supplies from substantial domestic production from primary and secondary sources; stocks held by industry, investors, traders, and the U.S. Treasury Department; and availability from multiple import sources (George, 2016; Hilliard, 2000; Reese, 1992).

In 2013, about 29 percent of global silver mine production was from primary silver ores, 38 percent was from lead and zinc ores, 20 percent from copper ores, 13 percent from gold ores, and less than 1 percent was from other types of mining operations (Virta, 2015). From 1990 through 2014, total world mine production of silver increased from 16,600 to 26,800 t for an average compound annual growth rate of nearly 2 percent. In 2014, Mexico was the leading mine producer of silver and accounted for 19 percent of global production. Other major silver producers were China (15 percent); Peru (14 percent); Australia and Chile (6 percent each); Bolivia, Poland, and Russia (5 percent each); and the United States (4 percent). China's silver production has increased more than thirtyfold from approximately 130 t in 1990 to 4,060 t in 2014. The increase in world silver production from 1990 to 2014 has been driven by an overall increase in consumption for electronics and jewelry and for demand as an investment vehicle.

Market sectors for silver consumption have changed since the early 1990s. For example, consumption in the photographic sector, which in 1990 used about 50 percent of total U.S. silver consumption, decreased to 8 percent in 2014 with the increase in use of digital photography (George, 2016; Reese, 1992).

The average annual silver price per troy ounce, ranged from a low of about $4.00 per troy ounce ($1,300/t) in 2001 to a high of nearly $36 per troy ounce in 2011 ($1,130,000/t). In 2014, the average price of silver was approximately $13.00 per troy ounce (Kelly and Matos, 2007; George, 2016).

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Specialty Clay—Hectorite

Hectorite is a bright white lithium-rich magnesium silicate mineral that belongs to the smectite clay group. Hectorite occurs in mineral deposits and can also be produced synthetically. The mineral's unique physical and chemical properties make it useful for applications such as increasing thermal stability and viscosity in ceramics and oil-based drilling mud and for adding color, spreadability, and viscosity in deodorants, facial cleansers, moisturizers, shampoos, and paints (Dell, 1996; Paint & Coatings Industry, 2004; Schlumberger, Ltd., 2016; Western Lithium USA Corp., 2016). Statistics on the distribution of domestic and global end-use markets are not available; however, in recent years hectorite clay products have been increasingly used in drilling muds by the oil and gas industry for directional drilling in unconventional reservoirs and deep drilling in high pressure-high temperature environments, owing to the mineral's inherent high temperature thermal stability (Lithium Americas Corp., 2016a, b).

Natural hectorite production data are not published to avoid revealing company proprietary information, but the United States continues to be world's largest natural hectorite producer, with surface mines in Hector, California, (the origin of the mineral's name) and the Kings Valley deposit in Humboldt County, Nevada. Some intermittent hectorite production also has been reported from the Disaster Peak Mine in Humboldt County, Nevada (Nevada Bureau of Mines and Geology, 2008, 2013). The United States does not rely on foreign sources of hectorite to supplement its commercial requirements. The Hector Mine is currently the world's leading producer of natural hectorite. The Kings Valley Mine came on-line at the end of 2014 and is within the Nevada assessment area. The company that operates the Kings Valley Mine has indicated that it may also become a source of lithium as the company continues toward a feasibility study and permitting of possible lithium extraction (Western Lithium USA Corp., 2014, 2015).

The Defense Logistics Agency (DLA) maintains the National Defense Stockpile (NDS) of strategic and critical materials to supply the military, industrial, and essential civilian needs of the United States for national defense. Hectorite is not considered a strategic or critical mineral.

The price of hectorite clay and hectorite-based products are not published in industry literature. Prices are usually negotiated between the seller and buyer. In 2015, Hectatone®, a hectorite-based specialty product for use in high pressure-high temperature drilling applications, was reported to sell in the range of $2,000–4,500 per short ton, free on board (f.o.b.) (IMFORMED Industrial Mineral Forums & Research, Ltd., 2015).

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Titanium Mineral Concentrates

Most titanium is not consumed in its metal form but is consumed as titanium dioxide (TiO_2), a white pigment used in paints, paper, and plastics because of its whiteness, brightness, and opacity. On a gross weight basis, 95 percent of domestic consumption of titanium mineral concentrates was used to produce TiO_2 pigment in 2014. The remaining 5 percent was used to produce metal and other miscellaneous products, including fluxes and welding-rod coatings. Because of the high strength-to-weight ratio of its alloys and their resistance to corrosion, titanium metal is an important strategic and critical material and is used widely for high-performance military and civilian aircraft in both engines and airframes (Bedinger, 2016).

Titanium minerals of economic importance include ilmenite, leucoxene, and rutile. Mining of titanium minerals is usually performed by surface-mining operations using dredging and dry-surface mining techniques for the recovery of heavy minerals, which include titanium mineral concentrates. Separation by gravity is used to isolate the heavy-mineral components. Further processing and separation of the heavy-mineral suite is accomplished using magnetic and electrostatic circuits, with ilmenite and rutile being the two principal mineral concentrates for titanium. Ilmenite is the most abundant titanium mineral and has a stoichiometric TiO_2 content of 53 percent, but intercalation and weathering causes the TiO_2 content to vary significantly. Rutile, a naturally occurring TiO_2 mineral with contained TiO_2 of about 95 percent, is less abundant. Ilmenite is often processed to produce a titanium concentrate, either as synthetic rutile or titaniferous slag. Although numerous technologies are used to produce synthetic rutile, nearly all are based on either selective leaching or thermal reduction of iron and other impurities in ilmenite (Bedinger, 2015; Gambogi, 2001; Kelly and Matos, 2007).

Because of heavy-mineral placer occurrences in or near the assessment area, rutile and ilmenite production derived from domestic mining operations is the major focus of this discussion. A search of U.S. Bureau of Mines, USGS, and other publications has not indicated any commercial production of ilmenite or other titanium ore minerals as a principal commodity within the assessment area since at least 1990. There are some Idaho placer deposits and abandoned historical dredge waste piles that contain ilmenite (Anderson, 1958; Storch and Holt, 1963), but there is no evidence that it was ever recovered as a salable product.

In 2014, U.S. mine production[1] of ore concentrates, from two mines in Virginia and one mine in Florida, was about 100,000 metric tons (t) of contained TiO_2, significantly less than the 300,000 t of contained TiO_2 produced in 2000.[2] For the years 2000–14, domestic mine production averaged about 200,000 t of contained TiO_2 and has trended downward since 2007, owing to a combination of shutdowns and production curtailments resulting from factors such as depletion of reserves and economic factors. In 2015, both mine operations in Virginia were scheduled to shut down, but there were also plans in place to mine heavy-mineral concentrates in Georgia and New Jersey. In 2014, it was estimated that U.S. reserves contained approximately 2 million metric tons (Mt) of TiO_2. No titanium concentrates were recycled in the United States, but titanium metal was recycled (Bedinger, 2016; Kelly and Matos, 2007).

Because domestic consumption has exceeded domestic production of titanium mineral concentrates, the United States has been import reliant for the entire period of consideration. In 2000, the United States was 79 percent net import reliant and in 2014 was 92 percent net import reliant. From 2011 to 2014, four countries represented 94 percent of U.S. imports of titanium mineral concentrates—South Africa (35 percent), Australia (31 percent), Canada (17 percent), and Mozambique (11 percent) (Gambogi, 2002; Bedinger, 2016).

From 2000 to 2014 the total world mine production of contained TiO_2 in ilmenite concentrates increased by 29 percent from an estimated 4.70 Mt to 6.04 Mt of contained TiO_2 concentrate for an average compound annual growth rate over the period of about 2 percent. The increase in production of concentrates was brought about to a large extent by increased demand by China (Gambogi, 2002; Kelly and Matos, 2007; Bedinger, 2016).

In 2014, China was the leading world mine producer of Ilmenite concentrates with 960,000 t of contained TiO_2, 16 percent of global production. This was a significant increase from 2000 when China produced about 150,000 t of contained TiO_2, less than 5 percent of global production. Australia was the world's leading producer in 2000—1.5 Mt of contained TiO_2, which was about 31 percent of world production. By 2014, Australia produced 910,000 t of contained TiO_2, 15 percent of global production (Bedinger, 2016; Gambogi, 2002).

Other major producers in 2014, and their respective share of global Ilmenite production, were South Africa (10 percent), Vietnam (9 percent), and Mozambique (8 percent). The market for titanium mineral concentrates is expected to continue to be driven by the production of TiO_2 pigment (Bedinger, 2016).

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[1]Domestic mine production was rounded to one significant digit to avoid disclosing company proprietary data.

[2]Domestic mine production for the years 1983–99 were not published to avoid the disclosure of company confidential data.

World production of TiO_2 contained in natural rutile concentrate increased from about 390,000 t in 2000 to 470,000 t in 2014, an average compound annual-growth rate over the period of about 1.3 percent. The increase in production of natural rutile concentrates resulted from the development of mines in Sierra Leone beginning in 2006. World production of TiO_2 in natural rutile concentrates was subordinate to that of ilmenite concentrate over the entire period. In 2014, Australia was the world leader in mined natural rutile production—about 190,000 t of contained TiO_2 with a 40 percent share. This was a decrease from 2000 when the country produced an estimated 195,000 t, 58 percent of world mine production. In 2014, Sierra Leone produced about 110,000 t of contained TiO_2, about 23 percent of TiO_2 in natural rutile concentrates (Bedinger, 2016; Gambogi, 2002, 2003; Kelly and Matos, 2007).

Other major natural rutile producers in 2014, and their respective production percentage share of global TiO_2 contained in rutile concentrates, were Ukraine (13 percent), South Africa (11 percent), and Kenya (5 percent) (Bedinger, 2016).

The price per metric ton ($/t) of ilmenite concentrate (54 percent of contained TiO_2 free on board (f.o.b.) Australian port), expressed in constant 2000 U.S. dollars for the purpose of comparison since the year 2000, ranged from a low of about $59/t ($73/t nominal) in 2009 to a high of $225 in 2012 ($300/t nominal). Prices were depressed in 2009 in response to weakened demand during the global recession but rebounded as world economic conditions improved and demand increased, with China's increased consumption being a major contributing factor. In 2014, the average price of ilmenite concentrate was approximately $113/t ($155/t nominal) (Gambogi, 2011; Bedinger, 2016; Kelly and Matos, 2007).

The price per metric ton ($/t) of natural rutile concentrate, 95 percent contained TiO_2, f.o.b, Australian ports, expressed in constant 2000 U.S. dollars for the purpose of comparison since the year 2000, ranged from a low of about $402/t ($430/t nominal) in 2003 to a high of $1,650 in 2012 ($2,200/t nominal). Prices increased significantly beginning in 2011 in response to increased demand. China's consumption was a major contributing factor. In 2014, the average price of rutile concentrate in dollars was approximately $691/t ($950/t nominal) (Bedinger, 2016; Gambogi, 2005; Kelly and Matos, 2007).

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Tungsten

The leading use of tungsten is in cemented carbides. Cemented carbides (also called hardmetals) are wear-resistant materials used by the construction, metalworking, mining, and oil and gas drilling industries. Tungsten metal contacts, electrodes, filaments, wires, and other products are used in electrical, electronic, heating, lighting, and welding applications. Tungsten is also used to make corrosion- and wear-resistant alloy parts and coatings; specialty steels for

pipes, tools, and valves; superalloys for turbine engine parts; and tungsten heavy alloys (also called "heavy-metal alloys") for armaments, heat sinks, and high-density applications, such as weights and counterweights. Tungsten, often in combination with less-dense materials, is used as a substitute for lead in ammunition, fishing weights, hunting shot, radiation shielding, wheel weights, and other high-density applications. Tungsten chemicals are used to make catalysts, corrosion-resistant coatings, dyes and pigments, fire-resistant compounds, lubricants, phosphors, and semiconductors (U.S. Geological Survey, 2013; Shedd, 2015a).

The USGS National Minerals Information Center (NMIC) reported that in 2014 the only tungsten concentrate production in the United States was from a mine north of Los Angeles, California. Historically, tungsten has been produced from, or was present at, numerous mines in the following counties that were within 25 kilometers (km) of the assessment area—Blaine, Butte, Camas, Custer, Elmore, and Lemhi Counties in Idaho; Beaverhead County in Montana; Elko, Humboldt, and Washoe Counties in Nevada; Box Elder and Summit Counties in Utah; and Fremont County in Wyoming. Annual tungsten production statistics for domestic mines have not been published by USGS since 1987. U.S. tungsten concentrate production contracted significantly in the early 1980s, when mines and beneficiation plants, most of which were located in California and Nevada, shut down in response to reduced consumption owing to a worldwide recession, a significant increase in low-priced exports of tungsten concentrates and intermediate products from China, and a precipitous drop in the price of tungsten concentrate (U.S. Geological Survey, 2013). In 2014, it was estimated that U.S. tungsten reserves were approximately 140,000 metric tons (t), most of which were located in California (Shedd, 2015b).

Apparent consumption of all forms of tungsten in the United States in 1990 was approximately 8,500 t and increased to 15,000 t by 2014. The increase was due in large part to the increase in U.S. industrial activity during that period.

The United States relies on foreign sources of tungsten concentrate and other tungsten-bearing materials, such as ammonium paratungstate and ferrotungsten, to supplement its commercial and strategic requirements. Shipments of tungsten materials from the National Defense Stockpile (NDS), which is administered by the U.S. Defense Logistics Agency Strategic Materials, and consumption of tungsten-bearing scrap also contribute to U.S. supply.

In 2014, the United States imported 12,800 t of tungsten contained in concentrates and other forms and exported 6,660 t. For 2011–14, China was the leading supplier, with a 40 percent share. Bolivia and Canada each represented an 8 percent share and Germany a 6 percent share. The balance of 38 percent was imported from more than 50 other countries. In 1990, U.S. net import reliance, as a percentage of apparent consumption, was estimated to be 81 percent. By 2014, import reliance had dropped to 43 percent mainly as a result of increased scrap consumption (Shedd, 2016).

In 2014, NDS held 11,600 t of tungsten in concentrate (Shedd, 2016). Government stockpiling is a means of reducing potential supply disruptions. Although the United States is a leading tungsten consumer, it has limited mine production and is highly reliant on imports for its tungsten needs. Tungsten's high concentration of world production in a single country (China) increases the risk of supply disruption. These factors, combined with tungsten's importance in a wide variety of commercial, industrial, and military uses and the limited options for substitution in most applications, are reasons why it has been identified as a strategic and (or) critical material by the U.S. Defense Logistics Agency Strategic Materials and other organizations.

From 1990 through 2014, world tungsten concentrate production expanded at a compound annual growth rate of approximately 2 percent, reaching 86,800 t of contained tungsten in 2014. China produced about 71,000 t (82 percent of world tungsten concentrate production) in 2014, a significant increase from 1990 when the country produced an estimated 32,000 t (62 percent of world production). China's increase can be explained in part by the country's investment in its domestic industries to produce goods for internal consumption and export. Other leading tungsten concentrate producers in 2014 were Vietnam (5 percent) and Canada and Russia (3 percent each) (Shedd, 2016).

Tungsten materials are not traded on the London Metal Exchange, Ltd., but are traded on some Chinese exchanges. Most tungsten sales are negotiated between producers and consumers or between traders and consumers. Prices published by trade journals, such as Metal Bulletin, Platts Metals Week, and CRU Ryan's Notes, are derived from information collected from consumers, producers, and traders. The average annual U.S. spot market price of tungsten concentrate per metric ton unit (MTU) of tungsten trioxide (WO_3) in nominal dollars over the past 15 years ranged from a low of approximately \$47/MTU in 1999 to a high of about \$358/MTU in 2012. A metric ton unit is equivalent to 10 kilograms (kg). For the purpose of comparison, the U.S. free-market price of ammonium paratungstate (the most important chemical precursor for most tungsten products), expressed in constant 1998 U.S. dollars per metric ton (\$/t) of tungsten, ranged from a low of \$6,920/t in 1999 to a high in 2012 of \$40,200/t. During this period, China's economy grew, its tungsten consumption increased, and its control over tungsten production and exports was strengthened. Prices trended downward beginning in 2013 and into 2015, as world tungsten-concentrate production was in oversupply, owing to an economic slowdown in China and weak economic conditions elsewhere (U.S. Geological Survey, 2015; Shedd, 2013, 2015b, 2016).

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Uranium (U_3O_8)

The primary use for uranium is as a fuel for generating electricity in nuclear power plants. Globally there are 439 operating reactors, 99 of which are in the United States (International Atomic Energy Agency, 2016). Other uses for uranium include nuclear medicine, nuclear weapons, and propulsion. Depleted uranium is used as ballast, high-density projectiles in weaponry, and as a material for shielding from radiation.

Mining uranium has been accomplished by conventional mining techniques and through in-situ mining, where aqueous fluids are pumped through a porous ore deposit. Historically, a significant amount of U.S. uranium-mine production was located in the Western United States but outside of the assessment area. Carnotite ore produced on the Colorado Plateau of western Colorado and eastern Utah was a major source of domestic supply. Exploration for uranium has occurred within many parts in or proximal to the assessment area; production has occurred in Custer County, Idaho; Lake and Malheur Counties, Oregon; and Converse, Freemont, and Sweetwater Counties, Wyoming (Petersen, 1969; University of Wyoming, 2010; Van Gosen and others, 2005).

The United States produced an estimated 2,200 metric tons (t) of U_3O_8 equivalents[3] in 2014, which represented about 4 percent of world production. Production has recently taken place from 2 underground mines in Mohave County, Arizona, and San Juan County, Utah; and 8 in-situ leach operations in Dawes County, Nebraska; Brooks, Duval, and Karnes Counties, Texas; and Campbell, Converse, Johnson, and Sweetwater Counties, Wyoming. Some byproduct uranium was recovered from

phosphate mining in the Western United States (St. George News, 2013; U.S. Energy Information Administration, 2015; Uranium Producers of America, 2014).

In 1993, the United States produced approximately 952 t of U_3O_8 equivalents from mills and in-situ mining, which was significantly less than the 2,200 t of U_3O_8 equivalents produced in 2014. The average compound annual rate of growth in production of about 4 percent over the 22-year time period can be attributed the development of relatively low-cost in-situ mining, the source for most of domestic uranium production. Many U.S. hard-rock mines have closed or suspended operation over the past two decades as a result of high costs, reserve depletion, and other factors. Uranium reserves in the United States are estimated at 163,000 t of U_3O_8 equivalents at prices of as much as \$220,460 per metric ton (\$100 per pound) of U_3O_8 equivalents (U.S. Energy Information Administration, 2015).

In 2014, the United States imported approximately 23,000 t of U_3O_8 equivalents to meet its commercial-civilian requirements. In 1990, the United States imported approximately 12,000 t of U_3O_8 equivalents, but by 1992, as some U.S. operations closed and few new mines were developed in response to decreasing prices, imports had increased to 21,000 t of U_3O_8 equivalents. Domestic production rebounded with the development of relatively low-cost in-situ mining. In 2014, Kazakhstan was the leading import source with a 23 percent share. Other major importers and their percentage share were Australia (21 percent), Canada (20 percent), Russia (14 percent), and Namibia (9 percent) (U.S. Energy Information Administration, 1995; U.S. Energy Information Administration, 2015; Organization of Economic Cooperation and Development, 2000). Data regarding the amount of exports of uranium-containing compounds from the United States are not available.

Uranium compounds are not part of the National Defense Stockpile managed by the Defense Logistics Agency within the U.S. Department of Defense. The National Nuclear Security Administration within the U.S. Department of Energy (DOE) controls an inventory of excess uranium from military use. DOE's inventories of uranium come from various sources, including governmental weapons programs, from its own former enrichment activities, and from inventories of natural uranium of Russian origin. Inventories of uranium are also held by domestic producers and consumers. According to the U.S. Energy Information Administration, at the end of 2014, commercial inventories were estimated to include 61,100 t of U_3O_8 equivalents. Data regarding U.S. supplier inventories of natural and enriched uranium hexafluoride (UF_6) were withheld (U.S. Energy Information Administration, 2015).

In 1990, approximately 56,000 t of U_3O_8 equivalents were produced from mines worldwide. Production continued to remain near this level through the 1990s into the early 2000s, as secondary-sourced materials were available from recycled nuclear warheads and other sources (Underhill and Müller-Kahle, 1993; World Nuclear Association, 2015). Total world mine production of U_3O_8 equivalents increased nearly every year since 2004, when 47,400 t of U_3O_8 equivalents were produced. In 2014, world production of U_3O_8 from mining was estimated at 66,300 t of U_3O_8 equivalents. The increase over the past 10 years has been driven

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[3]Units of production are often expressed in the literature as uranium (U) and triuranium octoxide (U_3O_8). All units expressed in source literature as U were adjusted to U_3O_8 equivalents by multiplying by 1.179 for the purpose of consistency.

by the decrease in secondary sources and demand for fueling nuclear power plants. In 2014, Kazakhstan was the world's leading in producer with 27,300 t of U_3O_8 equivalents, which represented a 41 percent share. This was a significant increase from that of 2007 when Kazakhstan produced about 7,800 t of U_3O_8 equivalents. Other major producers in 2014 and their respective share of global production were Canada (16 percent), Australia (9 percent), Niger (7 percent), Namibia (6 percent), Russia (5 percent), Uzbekistan (4 percent), United States (4 percent), and China (3 percent) (World Nuclear Association, 2015).

Uranium is not traded on an open market like most other mineral commodities. Buyers and sellers generally negotiate contracts privately. The average annual spot price per metric ton ($/t) of U_3O_8 equivalents, expressed in constant 1998 U.S. dollars since the year 1990, ranged from a low of about $855/t ($7 per pound, $/lb) in 1991 to a high of $2,150/t ($107/lb) in 2007 (Cameco, 2016). The elevated price of U_3O_8 equivalents in 2007 was a result of concerns related to potential interruptions of supply, anticipation of an increase in demand from China and India, and reduced availability of weapons-grade uranium for recycling. Prices dropped in subsequent years when the concerns did not materialize to the extent expected. In early 2016, the nominal price of U_3O_8 was approximately $75,000 per t ($34/lb) (Johnson, 2010; UXC, 2016; U.S. Energy Information Administration, 2015).

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Vanadium

Metallurgical use, primarily as an alloying agent for iron and steel, accounted for about 93 percent of domestic vanadium consumption in 2014. The vanadium industry is thus heavily dependent on the demand cycles from steel production. Other uses for vanadium are in chemical applications, specifically in catalysts. A growing use of vanadium is in rechargeable vanadium redox batteries, which may have significant potential for use in large power-grid applications and for electric vehicles (Polyak, 2016a, b).

The USGS National Minerals Information Center (NMIC) reported that in 2014 the United States did not produce any

vanadium as a byproduct or coproduct of mining uranium. The United States is a significant producer of vanadium pentoxide, ferrovanadium, and other vanadium products, although their production is almost exclusively from secondary and imported materials. From 1990 through 2014, mined vanadium production peaked at 3,730 metric tons (t) in 1999, most of which was produced as a coproduct from the mining of uraniferous sandstones on the Colorado Plateau. No vanadium was produced as a coproduct from 2000 through 2007 as a consequence of poor market conditions in the primary uranium industry and the Western U.S. phosphate industry. The uranium industry revived somewhat in 2008, and vanadium was once again produced as a coproduct from carnotite ores on the Colorado Plateau until 2014. In 2013, 591 t of vanadium was produced as a coproduct, but none was produced in 2014 or 2015. This vanadium production was outside the assessment area.

In the 1980s, Idaho followed Colorado as the second ranked producer of vanadium from mining. The ore was mined from vanadiferous phosphate ores in the Phosphoria Formation, which extends into the assessment area, although essentially all of the vanadium was produced from phosphate ores mined from outside the boundaries. The vanadium was extracted from ferrophosphorous slag, which was generated during the processing of phosphate ore to produce elemental phosphorous. Some minor amounts of vanadium may have been recovered from ores shipped from mines within the assessment area, but no production of vanadium has occurred from phosphate ores in Idaho since about 2000 (Judd and others, 1986; Kelly and Matos, 2007; Minarik and Gilleman, 1991; Ohl and Davis, 1991; Polyak, 2016a, b; U.S. Geological Survey, 2012).

Vanadium, contained in black shales in Eureka County, Nevada, also outside of the assessment area, have been investigated and evaluated for potential development (Mining-technology.com, 2016).

Statistical data on the amount of vanadium recovered from catalysts and specialty alloys in the United States through recycling are not available. Vanadium is recycled incidentally as a constituent of ferrous and nonferrous scrap (Goonan, 2011; Polyak, 2016a, b).

In 2014, the United States exported about 1,000 t of vanadium contained in various products, significantly less than that in 1990 when exports totaled 3,920 t, which were the highest for the period 1990 to 2014. The compound average rate of decline was estimated to be about 5.5 percent. A large part of the decrease can be attributed to the decline of domestic mine production (Kelly and Matos, 2007).

The United States does not import vanadium ores or concentrates produced directly from mining but does import significant tonnages of vanadium contained in ferrovanadium, vanadium pentoxide, and other materials, such as vanadium-bearing ash and slag, that require further processing. In 2014, the quantity of vanadium contained in imported materials was estimated to be 13,700 t, the highest for the period analyzed. The compound annual growth rate (CAGR) from 1990 to 2014 was estimated at 4.5 percent. The major sources for imported ferrovanadium for 2011–14 were Czech Republic (43 percent),

Canada (22 percent), Republic of Korea (18 percent), and Austria (14 percent). For vanadium pentoxide, the leading import sources were South Africa (40 percent), Russia (35 percent), and China (18 percent). For ash and other residues, the major import sources were Canada (80 percent) and Mexico (13 percent).

Apparent consumption of vanadium in the United States has increased from 4,080 t in 1990 to 12,400 t in 2014 for a CAGR of about 3.9 percent over the period (Kelly and Matos, 2007; Polyak, 2016a). U.S. import reliance for vanadium was estimated to be 100 percent in 2014, as a consequence of increased imports and no primary domestic production.

The U.S. Defense Logistics Agency did not maintain a stockpile of vanadium in 2015. In the early 1990s, approximately 651 t of vanadium contained in various materials was held in the stockpile.

Vanadium has been considered a strategic and critical material for its essential use in defense, energy, and construction applications, as well as its limited substitutability. Sharp increases in prices that occurred between 2003 and 2008 caused some steelmakers, particularly in China, to switch from vanadium to niobium. However, replacement of vanadium requires significant technical adjustments to steel production to ensure that product specifications and quality are not compromised. Therefore, substitution is normally not considered for short-term changes in market conditions.

In 2014, approximately 82,700 t of vanadium was mined globally. China was the world leader with a 54 percent share. In 2014, China's production was nearly 10 times than that of 1990 and reflected the country's accelerated industrialization over this time period. Other leading producers of mined vanadium in 2014, and their respective share of world production, were South Africa (25 percent) and Russia (18 percent).

The average annual price per metric ton ($/t) of contained vanadium, expressed in constant 1998 U.S. dollars for the purpose of comparison since the year 1990, ranged from a low of about $4,780/t in 2002 to a high of $53,500 /t in 2005 (Kelly and Matos, 2007). Industry analysts ascribed the low price in 2002 to an increase in global supply of material. The price rise in 2005 was primarily owing to strong demand in the steel and aerospace industries and the inability of producers to increase production of vanadium in a timely manner (Magyar, 2006). In 2015, the nominal price was $9,700/t of contained vanadium. Prices have declined since 2009 in response to reduced global demand for steels, triggered to a large extent by a slowdown of the economy in China (Polyak, 2016a).

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Zeolites

Zeolites are hydrated aluminosilicate minerals with loosely bound alkali and alkaline-earth metals within the crystalline structure that can be exchanged by water or other cations. Zeolite deposits in the United States occur predominantly in Arizona, California, Idaho, Nevada, New Mexico, Oregon, Texas, and Wyoming. Zeolite minerals present within these deposits are chabazite, clinoptilolite, erionite, mordenite, and phillipsite (Eyde and Holmes, 2006).

In 2014, the USGS National Minerals Information Center (NMIC) reported that the United States produced about 64,100 metric tons (t) of natural zeolite. Chabazite was mined in Arizona, and clinoptilolite was mined in California, Idaho, New Mexico, Oregon, and Texas. New Mexico was the leading natural zeolite-producing State, followed by Texas, Idaho, California, Oregon, and Arizona (Virta and Flanagan, 2015). Areas within or proximal to the assessment area where

natural zeolite production is ongoing or has occurred since 2005 include Franklin and Owyhee Counties, Idaho; Nye County, Nevada; Malheur County, Oregon; and Sweetwater County, Wyoming (Flanagan, 2016; Virta, 2002, 2006, 2010; Virta and Flanagan, 2015). Due to obligations to withhold company confidential data, no specific production amounts can be provided. Zeolite deposits in the United States are mined by surface methods.

Domestic uses for natural zeolites are, in decreasing order by tonnage, animal feed, odor control, water purification, other end uses, pet litter, wastewater treatment, gas absorbents (and air filtration), fertilizer carriers, oil absorbents, desiccants, catalysts, fungicide or pesticide carriers, aquaculture, and cement. Animal feed, odor control, water purification, pet litter, and wastewater treatment accounted for nearly 80 percent of the domestic sales tonnage (Virta and Flanagan, 2015). On a global basis, domestic mine production was about 2 percent of world production but sufficient for domestic consumption (Flanagan, 2016). Domestic reserves of zeolites are not quantified, but are considered adequate for the foreseeable future.

In 2014, approximately 64,100 t of natural zeolite was produced in the United States, compared to 1990 when production was 15,600 t. The compound annual growth rate of about 6 percent over the period can be attributed to a significant extent on the increased domestic consumption of zeolite in animal feed. Sales for cement, odor control, wastewater treatment, and water purification applications also increased in the past 10 years, although expansion of these markets has not been as great as with animal feed (Flanagan, 2016; Virta, 1993, 2002, 2006, 2010; Virta and Flanagan, 2015).

Nearly all imports and exports of zeolites are synthetic zeolite products. Comprehensive statistics distinguishing between the quantities of natural or synthetic zeolite products are not available because zeolite trade data are included under a category for miscellaneous mineral substances. In 2014, the United States exported an estimated 175 t of zeolites compared to an estimated 3,000 to 7,000 t in 2005. Imports have not been a significant component of domestic consumption. Zeolite imports were estimated to be only 25 t in 2014 and probably have not exceeded 500 t in any of the past 10 years (Virta, 2002, 2006, 2010; Virta and Flanagan, 2015; Flanagan, 2016). The United States was a net exporter of natural zeolites in 2014 (Flanagan, 2016) and has been so for at least the past 20 years.

The U.S. Defense Logistics Agency does not hold a stockpile of zeolites. Zeolites are not considered a strategic or critical commodity because domestic production is adequate to meet demand and substantial reserves exist (Flanagan, 2016).

In 2014, total world zeolite production was approximately 2.75 million metric tons. U.S. production represented about 2 percent of this amount. China dominates the world production of natural zeolite, with an estimated 73 percent, followed by the Republic of Korea, the world's second ranked producer, with 8 percent.

In 2014, the price per metric ton ($/t) of zeolite sold in bulk shipments typically ranged from $100/t to $230/t (Flanagan, 2016).

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Zinc

Zinc is used mostly for galvanizing steel, where it acts as a protective coating against corrosion. Zinc is also consumed for the production of zinc-based alloys for the die-casting industry, as a component of brass and bronze, and in chemical compounds, including zinc oxide used in tire manufacturing and zinc sulfate for fertilizers.

Publications of the USGS National Minerals Information Center (NMIC) reported that in 2014 the United States produced 832,000 metric tons (t) of zinc in concentrate and was the world's fourth-ranked mine producer of zinc behind China, Australia, and Peru, accounting for approximately 6 percent of global production (Tolcin, 2016). U.S. zinc-mine production has increased at a compound annual growth rate of about 2 percent in the past 25 years, mostly owing to increased production in Alaska beginning in the mid-to-late 1990s.

In 2014, zinc was produced in five States; Alaska was the leading zinc-producing State, followed by Tennessee, Missouri, Idaho, and Washington. No significant zinc production has been reported in or near the assessment area since at least 1990. Zinc was recovered from ore extracted from both open-pit and underground mines that used conventional flotation to produce concentrate for smelting and refining. In 2014, U.S. proven and probable ore reserves contained approximately 11 million metric tons (Mt) of zinc (Tolcin, 2016).

In 1990, approximately 263,000 t of zinc metal was produced from domestic and imported concentrates by domestic smelters (Jasinski, 1993). By 2014, as a result of plant closures and suspensions for various reasons, zinc production at primary smelters more than halved to approximately 110,000 metric tons (t). It is unlikely that new production capacity for processing zinc concentrates will be constructed in the United States before the end of the decade or perhaps the foreseeable future. An additional 70,000 t of zinc metal was recovered by secondary smelters from the recycling of scrap in 2014 (Tolcin, 2016).

The United States exports a significant amount of zinc-containing concentrates to foreign smelters and imported most of the zinc metal it consumed. In 2014, U.S. exports of zinc in concentrate were 644,000 t, whereas imports were less than 500 t, and imports of refined zinc were 805,000 t, whereas exports were 20,000 t. Zinc in concentrate was exported primarily to Canada (35 percent), the Republic of Korea (87 percent), and Spain (11 percent), and refined zinc was imported mostly from Canada (55 percent), Australia (14 percent), and Mexico (13 percent) (Jasinski, 1993; Jolly, 1993; Tolcin, 2016).

In 2014, U.S. apparent consumption of refined zinc was 965,000 t. From 1992 to 2008, annual apparent consumption exceeded 1 Mt, reaching a high of 1.43 Mt in 1999. Consumption declined in 2008 after the global economic recession began in late 2007 and fell to less than 1 Mt in 2009. Although the recession ended in 2009, consumption remained less than 1 Mt from 2010 to 2014, owing mostly to increased imports of galvanized steel from China (Kelly and Matos, 2007; Tolcin, 2016).

The U.S. Defense Logistics Agency holds a stockpile of about 7,000 t of zinc (Tolcin, 2016). As such, zinc continues to be considered a strategic or critical commodity, although domestically imported supplies of zinc are varied with a substantial amount sourced from North American Free Trade Agreement partners.

In the past 25 years, global zinc-mine production increased by a compound annual growth rate of 2.6 percent, from 7.15 Mt in 1990 to 13.3 Mt in 2014. During this period of time, China had the most substantial increase in zinc production and became the leading global producer—from producing 660,000 t of zinc in concentrate in 1990 (9 percent of the world's total) to producing 4.93 Mt in 2014 (37 percent of the world's total). Other major producers of mined zinc in 2014, and their share of global production, were Australia (12 percent), Peru (10 percent), United States (6 percent), India (5 percent), and Mexico (5 percent). The increase in world zinc production has been driven primarily by an upsurge in demand in China for galvanized steel and other materials used

in construction and consumer goods (Jasinski, 1993; Tolcin, 2015, 2016).

The average annual North American price for special high grade (SHG) zinc, expressed in constant 1998 U.S. dollars for the purpose of comparison since the year 1990, ranged from a low of about $772 per metric ton ($0.35 per pound in 2002) to a high of $2,830 per metric ton ($1.28 per pound) in 2006. Prices dropped shortly thereafter in response to weakened demand for the metal in most major zinc-consuming nations during the global recession, with China being an exception. Prices recovered somewhat in 2011 and 2012 but softened thereafter as demand for the metal lessened. In 2014, the average price of zinc in nominal dollars was approximately $2,359 per metric ton ($1.07 per pound) (Kelly and Matos, 2007; Tolcin, 2016).

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