Basement Domain Map of the Conterminous United States and Alaska

Data Series 898

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

Cover: Isoclinally folded Paleoproterozoic tonalite orthogneiss from newly identified Wallace domain basement, northern Idaho.

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Abbreviations Used in This Report

b.y.	billion years
m.y.	million years
sedex	sedimentary exhalative
PGE	platinum-group elements
REE	rare-earth elements
USGS	U.S. Geological Survey
VMS	volcanogenic massive sulfide

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Abstract

The basement-domain map is a compilation of basement domains in the conterminous United States and Alaska designed to be used at 1:5,000,000-scale, particularly as a base layer for national-scale mineral resource assessments. Seventy-seven basement domains are represented as eighty-three polygons on the map. The domains are based on interpretations of basement composition, origin, and architecture and developed from a variety of sources. Analysis of previously published basement, lithotectonic, and terrane maps as well as models of planetary development were used to formulate the concept of basement and the methodology of defining domains that spanned the ages of Archean to present but formed through different processes. The preliminary compilations for the study areas utilized these maps, national-scale gravity and aeromagnetic data, published and limited new age and isotopic data, limited new field investigations, and conventional geologic maps. Citation of the relevant source data for compilations and the source and types of original interpretation, as derived from different types of data, are provided in supporting descriptive text and tables.

The tectonic settings for crustal types represented in the basement domains are subdivided into constituent geologic environments and the types of primary metals endowments and deposits in them are documented. The compositions, architecture, and original metals endowments are potentially important to assessments of primary mineral deposits and to the residence and recycling of metals in the crust of the United States portion of the North American continent. The databases can be configured to demonstrate the construction of the United States through time, to identify specific types of crust, or to identify domains potentially containing metal endowments of specific genetic types or endowed with specific metals. The databases can also be configured to illustrate other purposes chosen by users.

Introduction

The U.S. Geological Survey (USGS) conducts mineral resource assessments at a variety of scales including the national scale. Such studies help ensure adequate mineral supplies and effective stewardship of resources in the future, a critical conclusion of the National Mineral Resource Assessment of 1995 (U.S. Geological Survey National Mineral Resource Assessment Team, see Schruben, 2002). A challenge in assessing mineral resources at the national scale is in employing systematic and uniform approaches based on methodologies and datasets appropriate to that broad scale. For example, national-scale assessments can be frustrated by traditional geologic maps that portray surface geology and widespread cover sequences, that are commonly at more detailed scales, and that are not integrated across political boundaries. Geologic map data are generally inappropriate for identifying broad national-scale mineral endowments and mineralizing processes because they depict the surface geology that commonly conceals the mineralized (or source) rocks and fundamental geologic structures. Research into crustal metal endowments, mineral belts, and mining districts as a means of discriminating mineral resource trends is needed to improve the accuracy and validity of mineral resource models and assessments.

In considering regional crustal processes in relation to ore deposits, Titley (2001), using models of metallogenic provinces (Petrascheck, 1965), explored the concept that basement (defined as

> "…The crust of the Earth below sedimentary deposits, extending downward to the Mohorovičić discontinuity. In many places the rocks of the complex are igneous and metamorphic and of Precambrian age, but in some places they are Paleozoic, Mesozoic, or even Cenozoic." (American Geological Institute, 2008, p. 57))

composition and architecture are fundamental and critical elements of metallogenesis on a lithospheric scale. Previous USGS mineral resource evaluations do not adequately consider this concept, that basement characteristics (including age and formation processes) influenced the nature or distribution of mineral deposits. Maps of basement domains based on their origin and composition (as opposed to maps limited to the cratonal portions or tectonic maps) of the entire United States remain unavailable. In the context of regional to national resource assessments, this lack of consistent information makes it difficult to incorporate data about the basement.

This study presents an interpretation of the inherent composition, origin, and architecture of the largely unexposed basement underlying the United States in order to produce a national-scale map of basement domains. The map reflects a new approach for investigating mineral deposit systems in the context of whether they formed (1) as part of the primary tectonic setting of basement domains, (2) by processes that thickened the original crust to form continental crust, or (3) in special cases, during multiple reactivations of crust and structures by younger, superposed orogenic events. Although many of the domains portrayed in this map continue into Canada and Mexico, maps showing post-Laurentian basement domains of all ages are not available for those areas. The main goal of this study is to identify domains that compose the United States portion of North American basement for the purpose of evaluating original metal endowments in basement domains at a national scale. The suggested scale for use of the map is 1:5,000,000 to match other national datasets used in national assessments by the Mineral Resources Program.

Origin and Growth of Crust Types

Continental crust (defined as "That type of the Earth's *crust* which underlies the continents and the continental shelves: it is equivalent to the *sial*,…" (American Geological Institute, 2008, p. 139)) forms where preexisting mafic crust and overlying supracrustal rocks are modified and thickened during intracrustal tectonic events that produce deposition, deformation, metamorphism, partial melting, underplating, and magmatism (Rudnick and Gao, 2003; Hawkesworth and others, 2010). Continental crust contains basement domains of widely differing origins and evolutionary histories. The most widely recognized basement domains are shield and platform blocks (cratons that have been stable and undisturbed for about 1 billion years (b.y.)) that formed as ancient (generally during Archean and Paleoproterozoic time, possibly extending into the early Mesoproterozoic) orogenic belts. Other basement domains include younger (Mesoproterozoic to the present) blocks that formed in extensional or collisional orogenic belts. In both cases, reworked juvenile igneous crust evolved to continental crust and ultimately to basement (Cawood and others, 2013). The basement domain map presented herein portrays the U.S. basement inclusive of both buried and exposed subaerial continental crust and submerged continental crust on continental shelves (fig. 1).

In general, maps and studies of U.S. basement are restricted to and portray only exposed or inferred Precambrian continental basement (for example, Condie, 1982; Hoffman, 1988; Sims, 1990; Boerboom and others, 2005; Sims and others, 2005; Holm and others, 2007; Whitmeyer and Karlstrom, 2007). It is also common in some contexts to consider crystalline rocks beneath younger cover successions as "basement." The important difference between the basement map presented in this study and most maps of U.S. basement is the concept that relatively young basement domains also formed from original juvenile components. Thus, although commonly more limited in definition, the term "basement" as used herein is not restricted to Precambrian cratons. The concept of metamorphic rocks as basement does not match the definition of basement given previously. By using criteria widely applied to identification either of terranes or of cratons (but not usually combined), the term basement as used herein encompasses the fundamental crustal elements of all ages that compose basement in the conterminous United States and Alaska. Combinations of geochemical, geophysical, geological, and age characteristics (table 1) identify domains as discrete entities. Data table 1 illustrates the variety of tectonic settings and processes that formed and transformed juvenile rocks into continental basement.

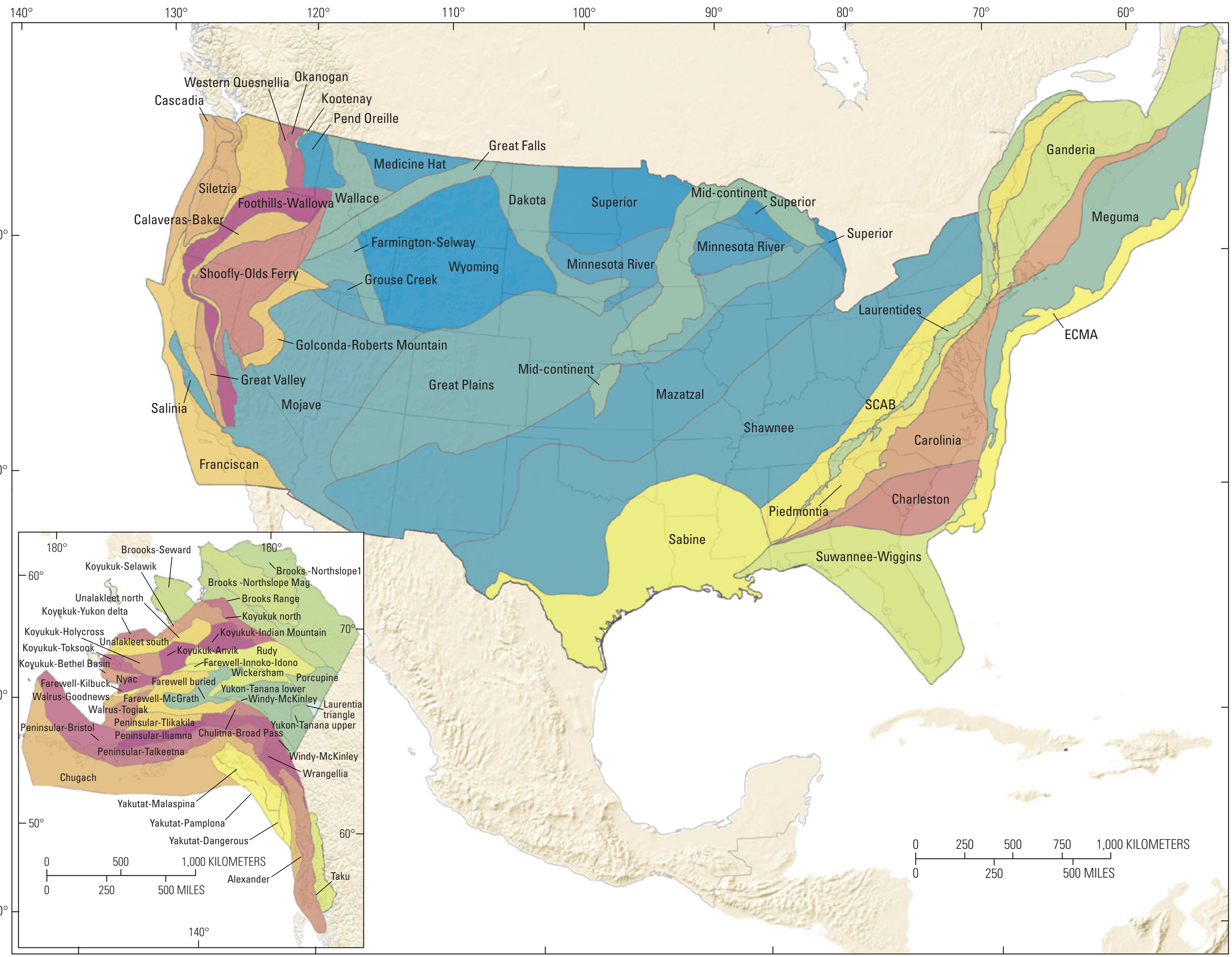

Figure 1. Basement domains of conterminous United States and Alaska.

Table 1. Basement domains of the United States including Alaska (see fig. 1 for basement domain map).

Domain_Name	Alternate_Name	Crust_Type	Crust_Formation_Age	Accretion_Type	Accretion_Age	References_	Notes
Minnesota River	--	Sialic protocontinent	3600–3000 Ma	--	--	Sims and others, 1987; Hoffman, 1988; Bickford and others, 2006; Schmitz and others, 2006	Cratonized ~2500 Ma.
Superior	--	Sialic protocontinent	2750–2600 Ma	Collisional	2.7–2.5 Ga	Gibbs and others, 1984; Sims and others, 1987; Hoffman, 1988; Bickford and others, 2006; Schmitz and others, 2006; van Schmus and others, 2007	S-vergent collision with Minnesota River terrane, Great Lakes tectonic zone; Cratonized ~2500 Ma.
Dakota	Trans-Hudson	Intracratonic mobile belt	1848–1750 Ma	--	--	Dutch and Nielson, 1990; Ross and others, 1991; Sims and others, 1991; Dahl and others, 1999, 2006; Schneider and others, 2007; McCormick, 2010	Orogenic events 1.78–1.74 G; post-tectonic magmatism and cratonization at 1.715 Ga; 50–60 m.y. younger than Trans-Hudson orogenic events in Canada.
Mojave	Mojavia	Lateral-extensional orogen	1840 Ma	--	--	Wooden and DeWitt, 1991; Barth and others, 2000; Duebendorfer and others, 2006; Bickford and Hill, 2007; Whitmeyer and Karlstrom, 2007; Mueller and others, 2011; Nelson and others, 2011	Older crustal component >2.0; crustal growth ages 1.84, 1.78–1.76 Ga; includes Elves Chasm gneiss.
Great Plains	Yavapai	Lateral-extensional orogen	1800–1720 Ma	--	1.71–1.68 Ga	Sims and others, 1987; Carlson, 2007; Whitmeyer and Karlstrom, 2007	--
Mazatzal	--	Lateral-extensional orogen	1720–1650 Ma	--	1.65–1.62 Ga	Sims and others, 1987; Van Schmus and others, 2007; Whitmeyer and Karlstrom, 2007; Jones and others, 2013	--
Mid-continent	Keweenawan	Intracontinental rift	1100–1000 Ma	--	--	Van Schmus and Hinze, 1985; Sims and others, 1987; Van Schmus and others, 2007	--
Wyoming	--	Sialic protocontinent	3500–3200 Ma	--	--	Graff and others, 1982; Tosdal and others, 2000; Mueller and others, 2004; Mueller and Frost, 2006; Foster and others, 2006; Grauch and others, 2003; Rodriguez and Williams, 2008	Includes 3.5–3.2 Ga Montana metasedimentary province; 3.0–2.5 Ga Beartooth-Bighorn magmatic zone, 2.9 Ga Southern accreted terranes; cratonized 3.0–2.8 Ga.

Table 1. Basement domains of the United States including Alaska (see fig. 1 for basement domain map).—Continued

Domain_Name	Alternate_Name	Crust_Type	Crust_Formation_Age	Accretion_Type	Accretion_Age	References_	Notes
Pend Oreille	--	Sialic protocontinent	2670–2650 Ma	--	--	Whitehouse and others, 1992; Doughty and others, 1998; Doughty and Chamberlain, 2008; Lewis and others, 2011; Brown and others, 2012	--
Medicine Hat	--	Sialic protocontinent	3300–2600 Ma	--	--	Ross and others, 1991; Boerner and others, 1998; Buhlmann and others, 2000; Lemieux and others, 2000	--
Grouse Creek	--	Sialic protocontinent	2700–2600 Ma	--	--	Cameron, 2010; Strickland and others, 2011	2.57 Ga Albion-Grouse Cr; 2.674 Ga, 2.608 Ga Boulder-Pioneer.
Farmington-Selway	--	Intracratonic mobile belt	1670 Ma	--	--	Leeman and others, 1985; Wolf and others, 2005; Foster and others, 2006; Mueller and others, 2011; Nelson and others, 2011; Strickland and others, 2011	Possibly 2 extensional episodes, 2.45 Ga and 1.67 Ga.
Wallace	--	Intracratonic mobile belt	1870 Ma	--	--	Armstrong and others, 1977; Armstrong, 1988; Mueller and others, 1995; Foster and Fanning, 1997; Foster and others, 2006; Doughty and Chamberlain, 2007; Lewis and others, 2011	1.87 Ga orthogneiss; 1.79 Ga anorthosite.
Great Falls	--	Intracratonic mobile belt	1870–1790 Ma	--	--	O'Neill and Lopez, 1985; Lemieux and others, 2000; Kellogg and others, 2003; Mueller and others, 2002, 2005; Vogl and others, 2004	Orogenic events superposed 1.77–1.71 Ga.
Kootenay	--	Passive margin	780–500 Ma	Collisional	Jurassic	Colpron and Price, 1995	Basement age Neoproterozoic to Early Paleozoic.
Western Quesnellia	--	Oceanic arc	385–175 Ma	Collisional	170 Ma	Cheney and others, 1994; Roback and Walker, 1995; Dostal and others, 2001; Unterschutz and others, 2002	Continent-marginal island arc.
Okanogan	--	Oceanic arc	320–250 Ma	Collisional	Mesozoic	Brown and others, 2012	Continent-marginal island arc, Carboniferous-Permian.

Table 1. Basement domains of the United States including Alaska (see fig. 1 for basement domain map).—Continued

Domain_Name	Alternate_Name	Crust_Type	Crust_Formation_Age	Accretion_Type	Accretion_Age	References_	Notes
Shawnee	Granite-rhyolite, Llano	Lateral-extensional orogen	1550–1350 Ma	in situ cratonization	1.45–1.35	Van Schmus and others, 1996; McLelland and others, 1993; Mosher, 1998; Patchett and Ruiz, 1989	New name for Granite/rhyolite (not in literature).
SCAB	Southern and central Appalachian basement	Extensional accretionary orogen	1400–1100 Ma	Collisional	1.1 Ga	Fischer and others, 2010; Loewy and others, 2003; Tohver and others, 2004	Amazonia origin, Mesoproterozoic; AL-NY lineament is boundary?
Laurentides	Blue Ridge-Taconide	Passive margin	1250–750 Ma	Collisional	Late Ordovician-Early Silurian	Williams, 1978; Stanley and Ratcliffe, 1985; Barr and others, 1998; Hibbard and others, 2006, 2010	Peri-Gondwana origin, converted to extensional accretionary orogen.
Carolinia	Carolina and (or) Raleigh	Oceanic arc	670 Ma	Collisional	Devonian	Hibbard and others, 2006, 2007	Peri-Gondwana origin.
Charleston	Brunswick	Oceanic arc	1000–542 Ma	Collisional	--	Horton and others, 1989; Hatcher and others, 2010	Peri-Gondwana origin, Neoproterozoic.
Piedmontia	Peri-Laurentia	Extensional accretionary orogen	1000–416 Ma	Collisional	Devonian and younger	Drake, 1989; Horton and others, 1989; Horton and others, 2010; Tull and others, 2014	Laurentian origin, Neoproterozoic-Silurian (or younger).
Ganderia	--	Passive margin	630–488 Ma	Collisional	455–423 Ma	van Staal and others, 2009	Neoproterozoic-Silurian (or younger); Converted to extensional accretionary orogen.
Meguma	--	Passive margin	542–472 Ma	Transpressional	Famennian	Hadley, 1970; van Staal, 2007; van Staal and others, 2009	Peri-Gondwana origin, Cambrian-Early Ordovician; converted to rift basin.
ECMA	East Coast Magnetic Anomaly	Large igneous province	228–176 Ma	Magmatic	--	Eldholm and others, 2000	Late Triassic-Early Jurassic; crustal boundary based on geophysical feature.
Suwannee-Wiggins	Peri-Gondwana	Passive margin	530–511 Ma	Collisional	325–300 Ma	Dallmeyer, 1989; Thomas, 1991, 2010; Horton and others, 1991; Heatherington and others, 2010; Shaulis and others, 2012	Converted to extensional accretionary orogen (forearc basin).
Sabine	--	Continental arc	360–299 Ma	Collisional	325–309 Ma	Viele and Thomas, 1989; Keppie and Ramos, 1999; Poole and others, 2005	Late Paleozoic Gondwana microcontinent origin; includes Sabine volcanic arc and Yucatan platform.

Table 1. Basement domains of the United States including Alaska (see fig. 1 for basement domain map).—Continued

Domain_Name	Alternate_Name	Crust_Type	Crust_Formation_Age	Accretion_Type	Accretion_Age	References_	Notes
Salinia	Salinian block	Lateral-extensional orogen	1700 Ma	Strike-slip	30–0 Ma	Mattinson and James, 1985; Barth and others, 2003; Barbeau and others, 2005	Fragment of Mohave domain?
Golconda-Roberts Mountain	--	Accretionary wedge	380–350 Ma	Collisional	350 Ma	Dickinson, 2006; Wright and Wyld, 2006; Holm-Denoma and others, 2011	--
Shoofly-Olds Ferry	--	Oceanic arc	365–187 Ma	Collisional	135 Ma	Edelman and others, 1989; Snow and Scherer, 2006; Northrup and others, 2011	--
Calaveras-Baker	--	Accretionary wedge	315–215 Ma	Collisional	135 Ma	Hacker, 1993; Vallier, 1995; Dickinson, 2008; Dorsey and Lamaskin, 2008	--
Foothills-Wallowa	--	Oceanic arc	280–165 Ma	Collisional	135 Ma	Vallier, 1995; Dickinson, 2008; Dorsey and Lamaskin, 2008; Ernst and others, 2008	Basement to arc as old as 300 Ma in Klamath Mtns (Saleeby, 1982).
Great Valley	--	Oceanic basin	175–165 Ma	Magmatic?	165 Ma	Cady, 1975; Shervais and others, 2005	--
Franciscan	Franciscan equivalents	Accretionary wedge	165–50 Ma	Underthrusting	165–50 Ma	Saleeby, 1982; Ernst, 2011; Snow and others, 2010; Wakabayashi and others, 2007	In NW CA, accreted rocks as young as 15 Ma (McLaughlin and others, 1982).
Siletzia	--	Oceanic basin	60–50 Ma	Collisional	50 Ma	Babcock and others, 1992; Parsons and others, 1999	Converted to continental arc. Some authors (Schmandt and Humphreys, 2011) suggest accretion at 55 Ma.
Cascadia	--	Accretionary wedge	50–0 Ma	Underthrusting	50–0 Ma	Tréhu and others, 1994, 2012; Stewart and Brandon, 2004	Some authors (Brandon and others, 1998) suggest onset of accretion at 35 Ma.
Farewell-Innoko-Idono	--	Continental arc	2600–2100 Ma	Collisional	135–115 Ma	Miller and others, 1991; Bradley and others, 2014	Farewell platform, Baltica origin.
Farewell-Kilbuck	--	Continental arc	2600–2100 Ma	Collisional	135–115 Ma	Box and others, 1990; Moll-Stalcup and others, 1996	Farewell platform, continent-marginal arc.
Laurentia triangle	--	Continental arc	2450–1850 Ma	Collisional	1.85 Ga	Villeneuve and Theriault, 1991; Gehrels and others, 1999; Pilkington and Saltus, 2007	Laurentian origin.
Brooks-Northslope1	--	Passive margin	2000 Ma	--	--	Moore and others, 1994, 1997; Fuis and others, 2008	Brookian crust, Baltica origin.
Brooks-Northslope Mag	--	Passive margin	2000 Ma	--	--	Moore and others, 1994; Saltus and others, 2006	Brookian crust, Baltica origin.

Table 1. Basement domains of the United States including Alaska (see fig. 1 for basement domain map).—Continued

Domain_Name	Alternate_Name	Crust_Type	Crust_Formation_Age	Accretion_Type	Accretion_Age	References_	Notes
Brooks Range	--	Passive margin	2000 Ma	--	--	Moore and others, 1994; Fuis and others, 2008 Till and others, 2008	Brookian crust, Baltica origin.
Ruby	--	Passive margin	2000 Ma	--	--	Arth and others, 1989a; Roeske and others, 1995, 2006	Laurentian and Baltica origins.
Brooks-Seward	--	Passive margin	2000 Ma	--	--	Akinin and others, 2009; Amato and others, 2009; Till and others, 2011	Brookian crust, Baltica origin.
Farewell-McGrath	--	Passive margin	2000 Ma	--	--	McClelland and others, 1999; Bradley and others, 2003	Farewell platform, Baltica origin.
Porcupine	--	Passive margin	2000–1000 Ma	--	1–2 Ga	Dover, 1994; Till and others, 2006; Saltus and Hudson, 2007	Laurentian origin, setting, ages poorly constrained.
Farewell buried	--	Back-arc basin	1000 Ma	--	--	McClelland and others, 1999; Bradley and others, 2003	Farewell platform, Baltica origin.
Yukon-Tanana upper	--	Passive margin	700–350 Ma	Collisional/StrSlip	215 Ma	Dusel-Bacon and Williams, 2009; Piercey and Colpron, 2009	Continental rise, Laurentian origin.
Yukon-Tanana lower	--	Passive margin	700–350 Ma	Collisional/StrSlip	215 Ma	Hansen and Dusel-Bacon, 1998; Dusel-Bacon and Williams, 2009; Piercey and Colpron, 2009	Continental rise.
Wickersham	--	Passive margin	700–350 Ma	Collisional/StrSlip	215 Ma	Moore and Nokleberg, 1988; Bradley and others, 2007; Dusel-Bacon and Williams, 2009	Continental rise, Laurentian origin.
Alexander	--	Oceanic arc	600 Ma	Collisional/StrSlip	140 Ma	Samson and others, 1989, 1991; Gehrels and Berg, 1994	Peninsula arc.
Taku	--	Passive margin	380 Ma	Collisional	140 Ma	Rubin and Saleeby, 1991; Gehrels and Berg, 1994	Continental rise.
Chulitna-Broad Pass	--	Oceanic arc	380 Ma	Collisional/StrSlip	80 Ma	Clautice and Newberry, 2006; Gilman and others, 2009; Hampton and others, 2009	Peninsula arc.
Peninsular-Iliamna	--	Oceanic arc	310 Ma	Collisional	80 Ma	Reed and Lanphere, 1973; Detterman and others, 1996; Bacon and others, 2012	Peninsula arc.
Wrangellia	--	Oceanic arc	310 Ma	Collisional	80 Ma	Aleinikoff and others, 1988; Glen and others, 2007; Greene and others, 2010	Peninsula arc.

Table 1. Basement domains of the United States including Alaska (see fig. 1 for basement domain map).—Continued

Domain_Name	Alternate_Name	Crust_Type	Crust_Formation_Age	Accretion_Type	Accretion_Age	References_	Notes
Walrus-Goodnews	--	Accretionary wedge	280–135 Ma	Collisional	135–115 Ma	Box and others, 1993; Decker and others, 1994	Forearc fragment, Walrus arc.
Windy-McKinley	--	Passive margin	275 Ma	Collisional/StrSlip	100 Ma	Nokleberg and others, 1994; Nokleberg and others, 2007; Hampton and others, 2009	Continental rise, Farewell platform.
Walrus-Togiak	--	Oceanic arc	225–135 Ma	Collisional	135–115 Ma	Box and others, 1993; Decker and others, 1994; Miller and others, 2007	Walrus arc.
Peninsular-Bristol	--	Oceanic arc	215–185 Ma	Collisional	80 Ma	Marlow and Cooper, 1980; Cooper and Marlow, 1983	Peninsula arc.
Peninsular-Talkeetna	--	Oceanic arc	215–185 Ma	Collisional	80 Ma	Detterman and others, 1996; Hacker and others, 2008, 2011; Farris, 2009	Peninsula arc.
Peninsular-Tlikakila	--	Accretionary wedge	180 Ma	Underthrusting	80 Ma	Wallace and others, 1989; Amato and others, 2007	Forearc fragment, Pennin-sula arc.
Koyukuk-Bethel Basin	--	Oceanic arc	175–125 Ma	Collisional	135–115 Ma	Hoare, 1961; Patton and Box, 1989; DGGS Staff and others, 1995	Koyukuk arc, setting poorly constrained.
Koyukuk-Toksook	--	Oceanic arc	175–125 Ma	Collisional	135–115 Ma	Box and Patton, 1989; Patton and Box, 1989	Koyukuk arc.
Koyukuk-Holycross	--	Oceanic arc	175–125 Ma	Collisional	135–115 Ma	Hoare, 1961; Box and Patton, 1989; Patton and Box, 1989	Koyukuk arc.
Koyukuk-Yukon delta	--	Oceanic arc	175–125 Ma	Collisional	135–115 Ma	Hoare and Condon, 1962; Box and Patton, 1989; Patton and Box, 1989	Koyukuk arc.
Unalakleet south	--	Back-arc basin	175–125 Ma	Collisional	135–115 Ma	Patton and Box, 1989; Patton and Moll-Stalcup, 1996; Patton and others, 2009	Related to Koyukuk arc.
Koyukuk-Anvik	--	Oceanic arc	175–125 Ma	Collisional	135–115 Ma	Box and Patton, 1989; Moll-Stalcup and Arth, 1989; Patton and Box, 1989; Patton and others, 2009	Koyukuk arc.
Unalakleet north	--	Back-arc basin	175–125 Ma	Collisional	135–115 Ma	Patton and Box, 1989; Patton and Moll-Stalcup, 1996; Patton and others, 2009	Back-arc basin? Koyukuk arc.
Koyukuk-Indian Mountain	--	Oceanic arc	175–125 Ma	Collisional	135–115 Ma	Arth and others, 1989b; Box and Patton, 1989; Patton and Box, 1989; Patton and others, 2009	Koyukuk arc.

Table 1. Basement domains of the United States including Alaska (see fig. 1 for basement domain map).—Continued

Domain_Name	Alternate_Name	Crust_Type	Crust_Formation_Age	Accretion_Type	Accretion_Age	References_	Notes
Koyukuk-Selawik	--	Oceanic arc	175–125 Ma	Collisional	135–115 Ma	Arth and others, 1989b; Box and Patton, 1989; Patton and Box, 1989; Patton and others, 2009	Koyukuk arc.
Koyukuk north	--	Oceanic arc	175–125 Ma	Collisional	135–115 Ma	Box and Patton, 1989; Patton and Box, 1989; Patton and others, 2009	Koyukuk arc.
Nyac	--	Oceanic arc	170–110 Ma	Collisional	135–110 Ma	Box and others, 1993; Decker and others, 1994; Wenz, 2005	Walrus arc.
Chugach	--	Accretionary wedge	75–0 Ma	Underthrusting	75–0 Ma	Plafker and others, 1994; Amato and Pavlis, 2010; von Huene and others, 2012	Forearc fragment, Peninsula arc.
Yakutat-Pamplona	--	Large igneous province	55 Ma	Collisional/StrSlip	50–0 Ma	Plafker and others, 1994; Worthington and others, 2012	Oceanic plateau, Yakutat block.
Yakutat-Dangerous	--	Large igneous province	55 Ma	Collisional/StrSlip	50–0 Ma	Plafker and others, 1994; Worthington and others, 2012	Oceanic plateau, Yakutat block.
Yakutat-Malaspina	--	Large igneous province	55 Ma	Collisional/StrSlip	50–0 Ma	Plafker and others, 1994; Worthington and others, 2012	Oceanic plateau, Yakutat block.

Origin of Crust Types

The compositions, original tectonic settings, and basement-forming processes associated with the large Archean and early Proterozoic basement core of the United States (central and southwestern parts of Laurentia) differ in many respects from those prevalent in the later Proterozoic and the Phanerozoic. Cratonization occurred by a variety of "premodern" tectonic processes (that is, ancient tectonic processes may have operated at different geographic or time scales than do more modern processes). Some premodern processes may have been unique to that time period owing to secular evolution of the planet (Pollack, 1986; Dewey, 2007; Petit, 2010; Rollinson, 2010; Van Kranendonk, 2010; Nagel and others, 2012).

By Mesoproterozoic to Neoproterozoic time, prevailing tectonic processes had begun to transition into those consistent with modern (Mesoproterozoic to the present) processes. Late Mesoproterozoic and younger crustal domains in the United States and Alaska were modified and thickened into continental crust but were not cratonized, as were the older domains. Interpreting original tectonic setting is commonly difficult because orogenic activity may have dismembered or incompletely preserved the original associations (that is, accretionary prisms are identified as part of volcanic arc settings but also in some cases as domain fragments). The basement domain map presented here does not portray orogenic events that overprinted basement domains (and their structural, metamorphic, or igneous manifestations), although a tectonic map that portrays those events could be developed as a derivative of this basement domain map.

Mechanisms of Continental Growth

Modern continents grow—add crust to a continental margin—through three basic accretion processes. A common mechanism is accretion of both exotic and native crustal fragments along consumptive plate boundaries (Condie, 2005; Kearey and others, 2009). The exotic fragments may consist of more primitive crustal fragments, such as seamount, island arc chain, oceanic plateau, and backarc or oceanic basin. Other fragments may be native continental blocks transported and reattached. A second mechanism accretes crust as a consequence of failed rifting and extensional orogenesis within continents. A third, less commonly discussed, extensional process that also results in continental growth involves prolonged slab-rollback (or slab-retreat) processes associated with lateral growth (for example, extensional accretionary orogens, Collins, 2002a,b). In modern examples, this type of continental growth involves complex, short-lived (≈10 million years (m.y.)), and laterally extensive tectonic switching in the continent-fringing backarc region. It is a consequence of transient slab rollback (relative to the overriding plate) and resultant local rifting and basin inversion in the overriding plate (Betts and Giles, 2006; Gray and others, 2007). The backarc region may evolve into continental crust (Cawood and others, 2011) through as much as 250 m.y. (Collins, 2002b).

The secular evolution of the planet requires that tectonic processes changed during the more than 4 b.y. history of U.S. basement geology. The accretionary processes described in the previous paragraph are those operative in modern tectonism, but these processes had ancient tectonic analogues that also formed basement. In particular, Archean greenstone belt domains were formed by tectonic processes that are not presently operative (Adam and others, 2012). High heat production (radiogenic heat and residual heat from planet formation and amalgamation processes) during the Archean depleted incompatible elements of the mantle during formation of early oceanic crust (Rollinson, 2010; Van Kranendonk, 2010; Polat, 2012). Hybrid or protomodern tectonic processes may have been responsible for formation of other domains such as late Paleoproterozoic to Mesoproterozoic domains.

Relations among domains are complicated where basement that formed in one setting becomes a fundamental element reworked in a second crust-building event (for instance, passive marginal basin was converted to extensional accretionary orogen in the Piedmont domain of the Appalachian region (Barr and others, 1998; van Staal and others, 1998; Tull and others, 2014). A second complication involves native fragments that originally formed as part of proto–North America but translated or rifted and subsequently reattached; both the eastern and western Laurentian Phanerozoic margins grew by means of this style of tectonic amalgamation. Determining the geospatial origin of the affected fragments is correspondingly difficult (Wyld and Wright, 2001; Hibbard and others, 2006; Colpron and others, 2007; Lund and others, 2008). Another structural complication, difficult to portray on a two-dimensional map, is the obduction of one crustal domain over another.

Secular Evolution of Domains, Their Tectonic Origins, and Crust Types

Early Earth Domains

Much about early Earth crust-forming processes is controversial, but most agree that the operative tectonic processes differed in important ways from those involved in "modern" late Proterozoic and Phanerozoic basement formation (Armstrong, 1991; Hamilton 1998; Shervais, 2006; Hawkesworth and others, 2010; Rollinson, 2010; Van Kranendonk, 2010; Adam and others, 2012; Polat, 2012). The number and scale of early sialic protocontinental masses is also controversial because of their poor preservation and extremely limited exposure (Bleeker, 2003; Condie, 2007).

Sialic Protocontinent

The oldest rocks in the Archean sialic protocontinental domains are ultramafic (such as high-magnesium komatiite) and mafic volcanic rocks that reflect extraction of large volumes of magma from the mantle at oceanic ridges, as a consequence of high heat production in the mantle (Rollinson, 2010; Van Kranendonk, 2010; Polat, 2012). Closely associated supracrustal volcanogenic turbiditic sedimentary rocks were deposited in associated ocean basins. Other mafic to felsic volcanic rocks, plutonic rocks, and related volcanogenic sedimentary rocks may have formed in proto-oceanic arcs (Van Kranendonk, 2010; Polat, 2012). High temperature gradients prevailing in the Archean [?] crust resulted in greenstone- and eclogite-facies metamorphism and the partial melting of mafic to ultramafic crust; early-style subduction caused greenschist to amphibolite facies metamorphism (Polat, 2012). Both types of metamorphism promoted partial melting of metamorphosed basalt, producing voluminous felsic batholiths of the tonalite-trondhjemite-granite association (Jahn and others, 1981; Adam and others, 2012; Nagel and others, 2012). Metamorphosed volcanic and volcanogenic sedimentary belts were in-folded between domal-shaped tonalite-trondhjemite-granite-association batholiths, thereby preserving metamorphic rocks in large synformal hinges separated by the batholithic antiformal hinges and resulting in characteristic granite-greenstone belt complexes.

The presence of Paleoproterozoic lower crustal layers below Archean upper crust in some domains suggests that early-formed crust underwent thermal evolution and thickened to form cratons during Paleoproterozoic modification along the margins of Archean sialic protocontinents (Pollack, 1986; Gorman and others, 2002). Premodern cratonization generated roots or cratonal “keels” about twice as thick as those in younger continental crust, which caused Archean domains to resist younger deformation and structural reactivation and destruction by plate tectonic processes (that is, subduction) in later Proterozoic and Phanerozoic supercontinent cycles (Nance and others, 2014).

Lateral-Extensional Orogen

Broad Paleoproterozoic to early Mesoproterozoic orogenic belts (or orogens; see Sims and Peterman, 1986; Hoffman, 1988; Van Schmus and others, 1996; Whitmeyer and Karlstrom, 2007) abut the southern margins of the Archean domains (fig. 1). They are generally envisioned as having been amalgamated in processes similar to those active in modern accretionary collages (for example, Bowring and Karlstrom, 1990; Karlstrom and Humphreys, 1998; see references in Whitmeyer and Karlstrom, 2007). However, the products of magmatism and deformation, which would correspond to collisional tectonism along the margins of adjacent Archean sialic protocontinental domains, are extremely limited or absent (Bickford and Hill, 2007; Jones and others, 2009, 2013; see references in Whitmeyer and Karlstrom, 2007).

Rocks in the Paleoproterozoic and early Mesoproterozoic domains (fig. 1) contain much primitive basalt and bimodal volcanic rocks that are characterized by distinctive intraoceanic arc and backarc affinities and thick turbidite fan successions (Hill and Bickford, 2001; Whitmeyer and Karlstrom, 2007; DeWitt and others, 2010a); locally this suite contains primitive mafic and ultramafic complexes, dikes, and sheeted dike complexes (Dann, 1997). Isotopic and geochemical data indicate that these rocks formed as juvenile ensimatic crust in ocean and backarc basins (Aleinikoff and others, 1993; Hill and Bickford, 2001; Holm and others, 2005; Duebendorfer and others, 2006; DeWitt and others, 2010a). Temporally associated, large, calc-alkaline batholiths intruded these rocks (table 1) (Duebendorfer and others, 2001; Karlstrom and Williams, 2006). These primitive-basin Paleoproterozoic domains in Laurentia initiated synchronously with a period of widespread rifting of Archean sialic protocontinental domains (Bleeker, 2003).

Rock unit ages, deformational and metamorphic events (Van Schmus and others, 1993), and mantle derivation of magmas, as suggested by Nd and Pb isotope data (Wooden and DeWitt, 1991; Aleinikoff and others, 1993; Wooden and others, 2012), document the progressive crustal growth (accretion) outward from the Archean domains. These domains are underlain by extensional-style oceanic (hot and seismically low-velocity) upper mantle (Gorman and others, 2002). Temporally overlapping magmatism and deformation in each Proterozoic domain were ongoing for 100–150 m.y. These relations suggest domain formation involving prolonged outward growth accompanied by multiple, short-lived orogenic events that alternated between (1) rift and slab rollback forming transient ocean-crust-floored and backarc rift basins and (2) flat or shallow subduction or slab polarity flip that formed narrow transient orogenic belts. The lateral-extensional belts (orogens) manifest as narrow, short-lived fragments, oceanic arcs, accreting arc, and forearc interleaved with oceanic (and backarc) basin rocks in relations similar to those of assemblages in modern extensional accretionary orogens (see Collins, 2002b; Gray and others, 2002).

Other evidence pointing to this origin is that, although juvenile igneous rocks underlie large portions of the lateral-extensional domains, rocks in the domains also commonly contain evidence of older crust on the basis of isotopic inheritance signatures. This isotopic inheritance is explained by the presence of extended older crust (Archean or mixed Archean and earlier Paleoproterozoic), rafted blocks of older crust within intervening juvenile crust, or incorporation of detritus shed from the older (Archean or mixed) provenance onto the younger (Paleoproterozoic) oceanic crust (for example, Duebendorfer and others, 2006; Bickford and Hill, 2007; Egan and Meredith, 2007; Whitmeyer and Karlstrom, 2007; Nelson and others, 2011).

Evolution from juvenile crust to basement was accomplished by transient and intermittent deformation (Harris and others, 1987; Condie, 1992; Duebendorfer and others, 2001) and granulite facies metamorphism (Condie, 1992; Hill and Bickford, 2001; Duebendorfer and others, 2001; Whitmeyer and Karlstrom, 2007). The metamorphism was related in part to large-volume magmatism (Williams and Karlstrom, 1996; Dumond and others, 2007) that accompanied high heat flow in thinned (extended) crust.

Ferroan (A-type) granite and rhyolite are particularly abundant in these late Paleoproterozoic and especially Mesoproterozoic domains (Anderson, 1983; Anderson and Morrison, 1992; Shaw and others, 2005; Goodge and Vervoort, 2006; DeWitt and others, 2010b). These magmas were likely generated during crustal extension, when the rigid juvenile crust of these lateral-extensional orogens was sufficiently thinned to allow upwelling of asthenosphere, decompression melting or underplating, high heat flow, and partial melting of the crust (Jones and others, 2010; Dall'Agnol and others, 2012). The prevalence of these ferroan granitic magmas at this time probably reflects the transition in the Earth's ongoing structural evolution to modern plate tectonic processes (Dall'Agnol and others, 2012). Locally thick supracrustal quartzite successions of about the same age as the ferroan igneous events provide the timing of depositional basins and relatively short-lived crustal extension, possibly caused by slab rollback events (Jones and others, 2009). Such late-tectonic magmatic and supracrustal basin formation events may both contribute to basement formation (Gray and others, 2007).

Intracratonic Mobile Belt

Narrow Paleoproterozoic intracratonic mobile belt domains between Archean sialic protocontinent domains are composed of tholeiitic and komatiitic basalt, possible komatiite, volcanogenic turbidite deposits, island arc successions, and plutonic rocks (O'Neill and Lopez, 1985; Mueller and others, 2002; Egger and others, 2003; Burger, 2004; Corrigan and others, 2005; White and others, 2005; Foster and others, 2006; Mueller and Frost, 2006; Strickland and others, 2011; Gaschnig and others, 2013). Using modern collisional tectonic models, these domains were previously interpreted as (1) intracratonic deformation zones (Boerner and others, 1998; Buhlmann, and others, 2000; Lemieux and others, 2000), (2) active collision zones between Archean continents (Ross, 2002; Corrigan and others, 2005; Hajnal and others, 2005), or (3) crust (of unspecified origin) captured during collisions between Archean sialic protocontinents (Mueller and others, 2002, 2004, 2005; Harms and others, 2004). Isotopic data indicate that a large proportion of rocks in the intracratonic mobile belt domains originated as complex intracontinental rift basins floored by juvenile crust (Baird and others, 1996; Dahl and others, 1999, 2006). Supporting a rift origin are age and isotopic evidence (table 1; Ross and others, 1991; Doughty and others, 1998; Dahl and others, 1999, 2006; Lewis and others, 2011), which suggest that Archean sialic protocontinental domains separated by the mobile-belt rocks originated as part of a single crustal domain (the Wyoming and Superior domains, Dahl and others, 1999, 2006). The intracratonic mobile belts are all broadly synchronous (Harms and others, 2004) and possibly initiated by mantle-plume activity (as suggested for the Dakota domain; Schmitz and others, 2006) that caused breakup of Archean sialic protocontinental domains. Other dating studies (table 1, Farmington-Selway domain) have produced complex age data suggesting development scenarios that involved (1) supracrustal rocks with Archean provenance (Nelson and others, 2011) atop rocks that underwent Paleoproterozoic extension and magmatism or (2) incomplete rifting of older basement (Mueller and others, 2011). Within the juvenile rift-related rocks, restricted zones of island arc magmatic rocks and evidence of short-lived structural and metamorphic events parallel the domain axes (McCormick, 2010); these orogenic zones are interpreted as late or terminating phases of domain development (Mueller and others, 2005; Dahl and others, 2006; Schneider and others, 2007). Age data (table 1) suggest relatively rapid tectonic switching from rifting to slab failure and tectonic reversal whereby juvenile crust was consumed in transitory local, zone-parallel subduction zones. Seismic imaging has not revealed remnant, subducted slabs or extensive magmatic arcs related to collisional accretion (Buhlmann and others, 2000; Lemieux and others, 2000), thus corroborating ideas that these intracratonic mobile belt domains represent an extensive, early type of failed rift system in which short-lived incipient subduction systems formed restricted island arcs and collisions without major consumptive margins.

Intracontinental mobile belts are particularly associated with younger extensional reactivation and accompanying rapidly subsiding, deep sedimentary basins, especially the Mesoproterozoic Belt and Lemhi basins in the Wallace and Great Falls domains, the Paleozoic-Mesozoic Williston basin in the Dakota domain (Baird and others, 1996; McCormick, 2010), the Neoproterozoic Uinta Mountain basin in the Farmington-Selway domain (Dehler and others, 2005), and the Mesoproterozoic basin overlapping the boundary between the Yavapai and Mazatzal domains (fig. 1; Daniel and others, 2013). As is true for the lateral-extensional domains, Mesoproterozoic extension and deposition were followed by ferroan magmatism (Wallace domain; Evans and Zartman, 1990; Ferguson and others, 2007; Lewis and others, 2007) and orogeny including magmatism (Picuris orogeny; Daniel and others, 2013), both of which may have contributed to cratonization. Relative to adjacent Archean sialic protocontinental domains, the Paleoproterozoic intracratonic mobile-belt domains, which were reactivated by Mesoproterozoic extension, subsequently produced more voluminous Phanerozoic crustal magma (Foster and others, 2006) and contain more abundant overprinted mineral deposits (Klein and Sims, 2007).

Supercontinental Cycle Domains

During planetary evolution, tectonic settings transitioned from ancient earth types to the present settings. Modern, subduction-related tectonic processes became dominant by the middle part of the Mesoproterozoic, reflecting maturity of Earth crustal structure, heat flow, and convective recycling (Cawood and others, 2006; Dewey, 2007; Van Kranendonk, 2010). These processes operated in similar time scales and at similar geographic scales to those associated with modern plate tectonics (for example, extensive stable island-arc systems or marginal rift basins were established). Descriptions of these well-defined settings and discussions of the geologic processes responsible for their formation are widely available (for example, Condie, 2005; Kearey and others, 2009).

Recurrent processes involved supercontinent assembly and breakup. One result was repeated collisions between the older domains, whereby domains were added around the cratonal core. Nonnative domains were added as well as the translation and reattachment of some native domains (Fischer and others, 2010). Another result of the supercontinent cycles was an early stage of intracontinental rifting that added crust before ultimately forming a failed rift (midcontinent rift, table 1; Van Schmus and Hinze, 1985).

In supercontinent breakup, rift margins formed on both sides of Laurentia (the complex cratonic core of North America). Resultant passive margins promoted formation of large marginal-rift sedimentary basins on transitional crust (Hoffman, 1991). Along the eastern margin, repeated Phanerozoic arc-continent and continent-continent collisions added allochthonous and para-autochthonous domains, including exotic juvenile and older continental fragments (table 1). Along the western margin (shown on fig. 1 as defined by the 0.706 initial Sr isopleth; Armstrong and others, 1977; Armstrong, 1988; Carlson and others, 1991; Fleck and Gunn, 1991; Tosdal and others, 2000; Fleck and Criss, 2007; Benford and others, 2010), prolonged sediment deposition in passive-margin domains were punctuated by late Paleozoic contraction causing these domains to be thrust faulted over and accreted onto the edge of Laurentia. Subsequent development of a prolonged consumptive plate boundary resulted in orthogonal and tranpressional collisions, complicated by secondary margin-parallel translation that formed the accretionary collage of Alaska and western Cordillera of the conterminous United States. These domains originated in a variety of tectonic settings, including both allochthonous oceanic domains and those native to North America (mostly in the form of slivers of passive-margin domains, table 1).

Metals Endowments

The rocks associated with each original tectonic setting and geologic environment (table 1) are potentially enriched in specific groups of metals that originated as particular mineral deposit types (table 2). Such enrichments represent primary accumulations that formed synchronously with and as part of the same processes responsible for the development of the hosting basement (“constructional phase deposits” of Groves and Bierlein, 2007). Potential metal accumulations, depicted as potential original endowments in the context of geologic environments of particular tectonic settings (table 2), are expressed by the full array of grades from subeconomic to economic. Thus, although potentially buried or not sufficiently concentrated to constitute ore deposits, these original metal endowments may be deposits in their own right or may have been available for remobilization by younger magmatic and (or) hydrothermal systems to form mineral deposits by a broad variety of younger mineralizing processes.

The origins of some Archean-Paleoproterozoic (to possibly early Mesoproterozoic) host rocks and the mineral deposits or metal endowments contained therein are relatively unusual because of similarly unusual geotectonic processes that operated during early planetary evolution (De Wit and Thiart, 2005; Groves and Bierlein, 2007; Cawood and Hawkesworth, 2012). In addition, the formation of Archean to early Mesoproterozoic host rock is more closely related to formation of their original metal endowments than is true for many younger basement-domain types. These close relations among older basement-domain types and original metal endowments largely reflect the thick roots and resultant buoyancy of the domains, which render ancient continental crust relatively resistant to younger deformation and destruction. Consequently, there have been fewer opportunities to remobilize and concentrate original metal accumulations in the Archean and Paleoproterozoic domains (Groves and Bierlein, 2007).

Table 2. Primary metal endowments of geologic environments that may be present in each crust type interpreted for basement domains in the United States.

Crust_Type	Geologic_Environments	Primary_Metals_Deposits	References
Sialic protocontinent	Oceanic ridge	Magmatic Ni-Cu ± PGE	Cox and Singer, 1986; Arndt and others, 2005.
		Podiform Cr ± PGE	Singer and others, 1986; Cawthorn and others, 2005; Mosier and others, 2012.
		Stratiform Ni-Cu-Cr ± PGE	Schultz and others, 2010.
	Early oceanic arc	Cu-Zn-Pb ± Au-Ag volcanogenic massive sulfide (VMS)	Barrie and others, 1999; Mosier and others, 2009; Shanks and Thurston, 2012.
		Porphyry Cu-Mo	John and others, 2010; Taylor and others, 2012.
	Supracrustal basin	Banded Fe formation	Cox and Singer, 1986; Bekker and others, 2010.
	Mantle plume	Diamond-bearing kimberlite and lamproite	Hausel, 1998; Gurney and others, 2005; Wyman and others, 2008.
Lateral-extensional orogen	Spreading ridge	Stratiform Ni-Cu-Cr ± PGE	Cox and Singer, 1986; Schulte and others, 2012.
		Podiform Cr	Cox and Singer, 1986; Cawthorn and others, 2005; Mosier and others, 2012.
		Magmatic Ni-Cu ± PGE	Arndt and others, 2005; Schultz and others, 2010.
		Cu-Zn-Pb ± Au-Ag VMS	DeMatties, 1994; Franklin and others, 2005; Mosier and others, 2009; Shanks and Thurston, 2012.
	Intraoceanic arc	Cu-Zn-Pb ± Au-Ag VMS	Hannington and others, 2005; Mosier and others, 2009; Shanks and Thurston, 2012.
		Porphyry Cu-Mo	John and others, 2010; Taylor and others, 2012.
	Supracrustal basin	Banded Fe formation	Cox and Singer, 1986; Bekker and others, 2012.
	Late-stage A-type igneous activity	Magmatic Sn ± Nb-Ta-Zr-F and Zr, Y ± REE	Dall'Agnol and others, 2012.
Intracratonic mobile belt	Spreading ridge	Magmatic Ni-Cu ± PGE	Schultz and others, 2010.
		Podiform Cr	Singer and others, 1986; Cawthorn and others, 2005; Mosier and others, 2012.
		Zn-Pb-Cu-Ag VMS	Mosier and others, 2009; Shanks and Thurston, 2012.
	Intraoceanic arc	Cu-Zn-Pb ± Au-Ag VMS	Franklin and others, 2005; Hannington and others, 2005; Mosier and others, 2009; Shanks and Thurston, 2012.
		Porphyry Cu-Mo	John and others, 2010; Taylor and others, 2012.
	Late-stage A-type igneous activity	Magmatic Sn ± Nb-Ta-Zr-F and Zr, Y ± REE	Dall'Agnol and others, 2012.
Intracontinental rift	Layered mafic intrusion and ring complexes	Magmatic Ni-Cu ± PGE	Nicholson and others, 1992; Schultz and others, 2010.

Table 2. Primary metal endowments of geologic environments that may be present in each crust type interpreted for basement domains in the United States.—Continued

Crust_Type	Geologic_Environments	Primary_Metals_Deposits	References
		Fe-Ti ± V	Nicholson and others, 1992; Schultz and others, 2010.
		U-REE-Nb	Nicholson and others, 1992; Schultz and others, 2010.
	Mafic volcanic and supracrustal basin	Native Cu	Nicholson and others, 1992; Schultz and others, 2010.
		Cu ± Pb-Zn sedex	Leach and others, 2005; Goodfellow and Lydon, 2007.
		Zn-Pb-Cu-Ag VMS	Shanks and Thurston, 2012.
Passive margin	Marginal basin (miogeocline)	Zn-Pb-Ag ± Au and barite sedimentary exhalative (sedex)	Albers, 1983; Dawson and others, 1991; Goodfellow and others, 1993; Leach and others, 2005; Lund, 2008.
Continental arc	Magmatic arc	Porphyry Cu ± Mo (± Au-Ag)	Berger and others, 2008; John and others, 2010.
		Cu-Zn-Pb ± Au-Ag VMS	Hannington and others, 2005; Mosier and others, 2009; Shanks and Thurston, 2012.
	Forearc wedge	Podiform Cr	Singer and others, 1986; Cawthorn and others, 2005; Mosier and others, 2012.
Oceanic arc	Magmatic arc	Porphyry Cu-Au	Berger and others, 2008; John and others, 2010.
		Au-Cu epithermal	Groves and others, 1998; Simmons and others, 2005.
		Cu-Zn-Pb ± Au-Ag VMS	Hannington and others, 2005; Mosier and others, 2009; Shanks and Thurston, 2012.
Oceanic basin	Spreading ridge	Magmatic Ni-Cu ± PGE	Arndt and others, 2005; Galley and others, 2007; Schultz and others, 2010; Shanks and Thurston, 2012.
		Podiform Cr	Cawthorn and others, 2005; Mosier and others, 2012.
	Black smoker and brine pool	Cu-Zn and Au-base metal VMS	Galley and others, 2007; Schultz and others, 2010; Shanks and Thurston, 2012.
Accretionary wedge	Oceanic crust	Cu-Zn-Pb ± Au-Ag VMS	Alt and others, 1998; Shanks and Thurston, 2012.
		Podiform Cr	Cawthorn and others, 2005; Mosier and others, 2012.
	Trench	MVT (forearc)	Leach and others, 2005.
Back-arc basin	Spreading ridge	Cu-Zn-Pb ±Au-Ag-Ba VMS	Shanks and Thurston, 2012.
	Supracrustal basin	Cu ± Pb-Zn sedex	Leach and others, 2005; Goodfellow and Lydon, 2007.
Extensional accretionary orogen	Spreading ridge	Stratiform Ni-Cu-Cr ± PGE	Cox and Singer, 1986; Schulte and others, 2012.
		Podiform Cr	Cox and Singer, 1986; Cawthorn and others, 2005; Mosier and others, 2012.

Table 2. Primary metal endowments of geologic environments that may be present in each crust type interpreted for basement domains in the United States.—Continued

Crust_Type	Geologic_Environments	Primary_Metals_Deposits	References
		Magmatic Ni-Cu ± PGE	Arndt and others, 2005; Schultz and others, 2010.
		Cu-Zn-Pb ± Au-Ag VMS	DeMatties, 1994; Franklin and others, 2005; Mosier and others, 2009; Shanks and Thurston, 2012.
	Intraoceanic arc	Cu-Zn-Pb ± Au-Ag VMS	Hannington and others, 2005; Mosier and others, 2009; Shanks and Thurston, 2012.
		Porphyry Cu-Mo	John and others, 2010; Taylor and others, 2012.
	Supracrustal basin	Banded Fe formation	Cox and Singer, 1986; Bekker and others, 2012.
	Late-stage A-type igneous activity	Magmatic Sn ± Nb-Ta-Zr-F and Zr, Y ± REE	Dall'Agnol and others, 2012.
Large igneous province	Layered mafic intrusion	Magmatic Ni-Cu ± PGE	Nicholson and others, 1992; Schultz and others, 2010.
		Fe-Ti ± V	Nicholson and others, 1992; Schultz and others, 2010.
		U-REE-Nb	Nicholson and others, 1992; Schultz and others, 2010.
		Stratiform Ni-Cu-Cr ± PGE	Cox and Singer, 1986; Schulte and others, 2012.

Metal Endowments Characteristic of Archean and Proterozoic Domains

In Archean sialic protocontinental and Proterozoic lateral-extensional and intracratonic mobile-belt domains, mafic and ultramafic rocks, which originated as oceanic crust in greenstone complexes, host magmatic Ni-Cu-PGE (platinum group elements) sulfide deposits and enrichments (Schulz and others, 2010). Types of banded iron formation deposits are closely related to submarine volcanic rocks or to passive-margin sedimentary successions that reflect associations with greenstone complexes, to variable atmospheric conditions and, in part, to ancient changes in oceanic and atmospheric oxidation conditions (Cox and Singer, 1986; Bekker and others, 2010). Diamond deposits formed in deep roots beneath the cratons in Archean sialic protocontinental domains, where mantle plumes melted metasomatized mantle at the base of thickened subcontinental lithospheric mantle (Cox and Singer, 1986; Hausel, 1998; Piranjo, 2000; Gurney and others, 2005; Wyman and others, 2008).

Several other metal endowments or deposit types hosted in Archean-Paleoproterozoic greenstone belts have analogues in Phanerozoic rocks (table 2). However, variations among these similar types of modern and ancient mineral-deposit (endowment) types were probably the result of different conditions or processes that prevailed early in the Earth's evolution—such as higher ancient heat flow, variation in distribution of elements in the crust, redox conditions, and rates of tectonic processes. Volcanogenic massive sulfide deposits are associated with volcanic and volcanogenic rocks in the Archean-Paleoproterozoic greenstone complexes (Mosier and others, 2009; Shanks and Thurston, 2012). In the presence of rift-related hydrothermal activity, podiform Cr deposits formed within mafic volcanic rocks derived from ocean-spreading centers (Singer and others, 1986; Mosier and others, 2012). Stratiform Ni-Cu-Cr-PGE deposits formed in layered mafic-ultramafic intrusions (Cox and Singer, 1986; Schulte and others, 2012) associated with greenstone complexes. Mafic to felsic rocks of marine intraarc volcanic origin may contain early porphyry Cu-Mo deposits, although most Precambrian volcanic systems are eroded to levels well below the crustal levels at which this type of deposit forms (John and others, 2010; Taylor and others, 2012).

In Paleoproterozoic and early Mesoproterozoic domains, large genetically related Sn deposits formed in late-stage ferroan granitic magmatic systems, some of which also contain Nb, Ta, Y-REE (rare earth elements), Zr, and F resources (Dall'Agnol and others, 2012). Iron oxide–copper-gold (IOCG) deposits are spatially related to these granitic rocks, but the magmas may have been a crustal preparatory event that rendered the crust conducive to the formation of this deposit type. Most IOCG mineralizing systems were driven by much younger hydrothermal activity during which the metals were introduced (Groves and others, 2010).

Metal Endowments Characteristic of Phanerozoic Domains

Metal endowments characteristic of late Mesoproterozoic through Phanerozoic domains relate directly to modern plate tectonic processes and settings (table 2). However, because tectonic events after formation of these endowments affected most of these domains, many mineral deposits are related to superposed orogenic events. Most of these orogenic mineral deposits were ultimately derived from and superimposed on original metal accumulations that originated with the basement domain. Accordingly, establishing the basement-forming tectonic settings (basement constructional stages) can guide identification of original metal endowments and subsequent metal assemblages (Groves and Bierlein, 2007). In comparison to the Archean and Paleoproterozoic domains, metal accumulations of Phanerozoic domains, which formed at shallow crustal levels in their original tectonic settings, may be preserved because more limited erosion acted on these younger domains.

Intracontinental rift and continental rift-margin domains, which augmented Laurentia during protracted late Mesoproterozoic and Neoproterozoic to early Paleozoic events, generated large sedimentary basins and miogeoclines, respectively, built on transitional rifted crust. Both of these environments hosted notable sedimentary exhalative (sedex-type) mineral endowments and deposits (Albers, 1983; Dawson and others, 1991; Goodfellow and others, 1993; Leach and others, 2005; Goodfellow and Lydon, 2007; Lund, 2008). Volcanism associated with intracontinental rifting also produced volcanogenic massive sulfide (commonly called VMS) and native Cu deposits in basin settings (Nicholson and others, 1992; Shanks and Thurston, 2012). Layered mafic rocks and ring complexes associated with intracontinental rifting were enriched in magmatic Ni-Cu±PGE as well as Re-Ti and U-REE-Nb (Nicholson and others, 1992; Schulz and others, 2010).

Diverse oceanic-origin domains, which were accreted to Laurentia as part of the accretionary collages of the western Cordillera and Alaska as well as to the collisional orogenic belts associated with the Appalachian and Gulf regions (table 1), constitute a wide variety of geologic environments potentially enriched in metals (table 2). Oceanic crust found in accretionary wedge, backarc, and ocean basin domains are potential hosts for Cu-Zn-Pb±Au-Ag volcanogenic massive sulfide, podiform Cr, and Ni-Cu±PGE endowments (increased abundance to form deposits) (Ben-Avraham and Nur, 1983; Arndt and others, 2005; Cawthorn and others, 2005; Galley and others, 2007; Schulz and others, 2010; Mosier and others, 2012; Shanks and Thurston, 2012). Domains containing forearc trench fragments may also have genetic associations with Mississippi Valley–type (known as MVT) Pb-Zn deposits (Leach and others, 2005). Magmatic-arc domains, such as island arcs and Andean-type continental margin arcs, are conducive to the formation of porphyry (Berger and others, 2008; John and others, 2010) and volcanogenic massive-sulfide-style deposits or endowments (Alt and others, 1998; Shanks and Thurston, 2012). Relatively less deeply eroded, young magmatic-arc domains may also contain Au-Cu epithermal-type metal deposits or endowments (Simmons and others, 2005).

Discussion

Basement Concepts and Map Construction

Construction of the North American continent is conventionally viewed as a series of four general, temporally discrete assembly phases. In that context, the first two phases formed Archean cratons and Paleoproterozoic orogens (parts of Laurentia) and, subsequently, the last two formed orogenic belts that were added during supercontinent assembly and breakup and as the Cordilleran and Alaskan accretionary collages. These two sets of phases are each conceptualized differently and not portrayed on the same maps (see Hoffman, 1988, 1997; Silberling and others, 1992; Hibbard and others, 2006; Whitmeyer and Karlstrom, 2007; Sims and others, 2008). Whereas tectonic origins are generally of primary importance to basement maps of the midcontinent and southwestern U.S. cratonal regions (the Laurentian parts), the concept of basement or its origin is little considered for other parts of the conterminous United States. The orogenic belts added during supercontinent assembly and breakup (Grenville and Appalachian orogens), including multiple tectonic overprints and displacements, are commonly mapped according to lithotectonic units and zones of orogenic overprint (Hibbard and others, 2006) rather than as discrete terranes or basement types (that is, the distinction between Grenville deformation front and the Grenville-age basement of Fischer and others, 2010). The Cordilleran collage is most commonly treated using terrane concepts in which the tectonic setting of supracrustal rocks, but not necessarily of the basement, is highlighted (Silberling and others, 1992). The differences in geology and tectonic evolution among the broad regions of the United States are striking and important, and the differing approaches generally used to define their origins do not promote ready comparison of basement compositions or of potential metal endowments.

The basement domain map presented herein was constructed region by region (fig. 2) by using a unifying approach for the constituent elements of basement domains underlying the entire United States. Despite differences relative to the amounts of original data as compared with compilation of published interpretations used to synthesize each regional map (table 3), the map was constructed to characterize the original tectonic setting in which each domain developed and according to the general scheme described in this report. Thus, the basement of each identified domain (table 1) has a characteristic geochemical signature, structural fabric, paleotectonic and paleoclimatic history, and potential inherent metal endowment

Figure 2. Basement-domain study regions of the United States.

Table 3. Status of compilation for each study region of the United States (see fig. 2 for regions).

Study_Region_Name	Status	Source
Alaska	Domain interpretations revised based on published geochronologic, geologic, and geophysical data	Box, S., and Saltus, R.
Western Cordillera	Domain interpretations revised based on published geochronologic, geologic, and geophysical data	Box, S., and Blakely, R.
Northern Rocky Mountains	Preliminary domain interpretations based on new and ongoing geochronologic and geologic studies and on geophysical maps	Lund, K., and Anderson, E.
Central and Southwest	Boundaries from compilation. Revised interpretations of original tectonic setting	Lund, K.; See references, table 1
Southeastern Laurentia and Appalachians	Revised interpretations based on ongoing geochronologic and geologic studies and compilation	Holm-Denoma, C.
Gulf Coast	Compilation	Lund, K.; See references, table 1

(table 2). Synthesizing the characteristics by using these data resulted in a relatively finite number of original tectonic settings. Because basement of all ages was classified in terms of original tectonic setting, the settings and their characteristics are common across the various regions of the country despite different subsequent tectonic histories. This approach also highlights the changes in tectonic setting and mineral endowment produced during planetary evolution.

The relatively uniform approach to characterization of U.S. basement domains led to a reevaluation of tectonic settings and aspects of continental growth for some domains. The map of interpreted basement domains (fig. 1) depicts extension-dominant orogenesis (lateral-extensional orogen and intracontinental mobile belt) as a principal contributor to crust-forming processes and possibly the predominant process that formed basement in the Paleoproterozoic. More than a third of the area of the conterminous United States seems to have originated by this efficient process of intermittent and transient switching between (1) relative slab retreat (extensional accretion) causing basin formation and (2) relative convergence, which caused arc or forearc development and collision-related thickening (arc accretion). Thus, substantial continental growth was accomplished by generating magmatic and sedimentary additions in an overall extensional setting (Collins, 2002b; Giles and others, 2002; Gray and others, 2007). Interpretation of slab rollback models proposed to explain accretion of continental crust (Bickford and Hill, 2007; Jones, Connelly, and others, 2009; Jones, Barnes, and others, 2013) represents a departure from the generally accepted "assembly" scenario, which depends on collisional accretion as the predominant process of growth during the Paleoproterozoic (for example, Whitmeyer and Karlstrom, 2007).

Another benefit of the approach used to create the new basement domain map is that its development in a geographic information system framework allows conceptualization of broadly different derivative products. For instance, the database can be used to create time slices for the tectonic construction of the U.S. parts of North American basement (fig. 3), either for all regions together or with basement in the conterminous United States and Alaska being considered separately. Reconstructions of this sort can be tailored to the needs of the user—for example, to show age groupings of basement domains (fig. 1), selected crust types (fig. 4), or selected metal endowment types (fig. 5).

Role of Basement in Formation of Mineral Deposits

North American mineral deposits formed through many prolonged crust-building and orogenic cycles of continental amalgamation and breakup as well as of accretionary collages that reactivated structures, thickened crust, and recycled crustal materials. The tectonic settings and mechanisms of formation of orogenic and postorogenic mineral deposits are the subject of many decades of research (see for example, Hedenquist and others, 2005). What is less well defined is the source of the metals and, in the larger sense, which metals were derived from subducted slabs, the mantle, or innate endowments in continental basement (for example, Petrascheck, 1969).

Studies of regional mineral deposit distribution relative to the origin of enveloping terranes and cratonal fragments (that is, basement domains) have documented contrasting metal accumulations in crust of different origins (Albers, 1983; Tooker, 1983). Original tectonic setting is clearly important to metal accumulations in some supracrustal rock associations (Leach and others, 2005; Goodfellow and Lydon, 2007; Lund, 2008). Similarly, early Earth processes that produced unique chemical compositions of Archean-Paleoproterozoic crust and genetically related underlying metasomatized mantle are thought to be instrumental in the occurrence of specific types of younger metal deposits (Groves and Bierlein, 2007). Consequently, the composition and original metal endowments of individual basement domains and of different geologic settings within domains (table 2, fig. 5) may be important progenitors

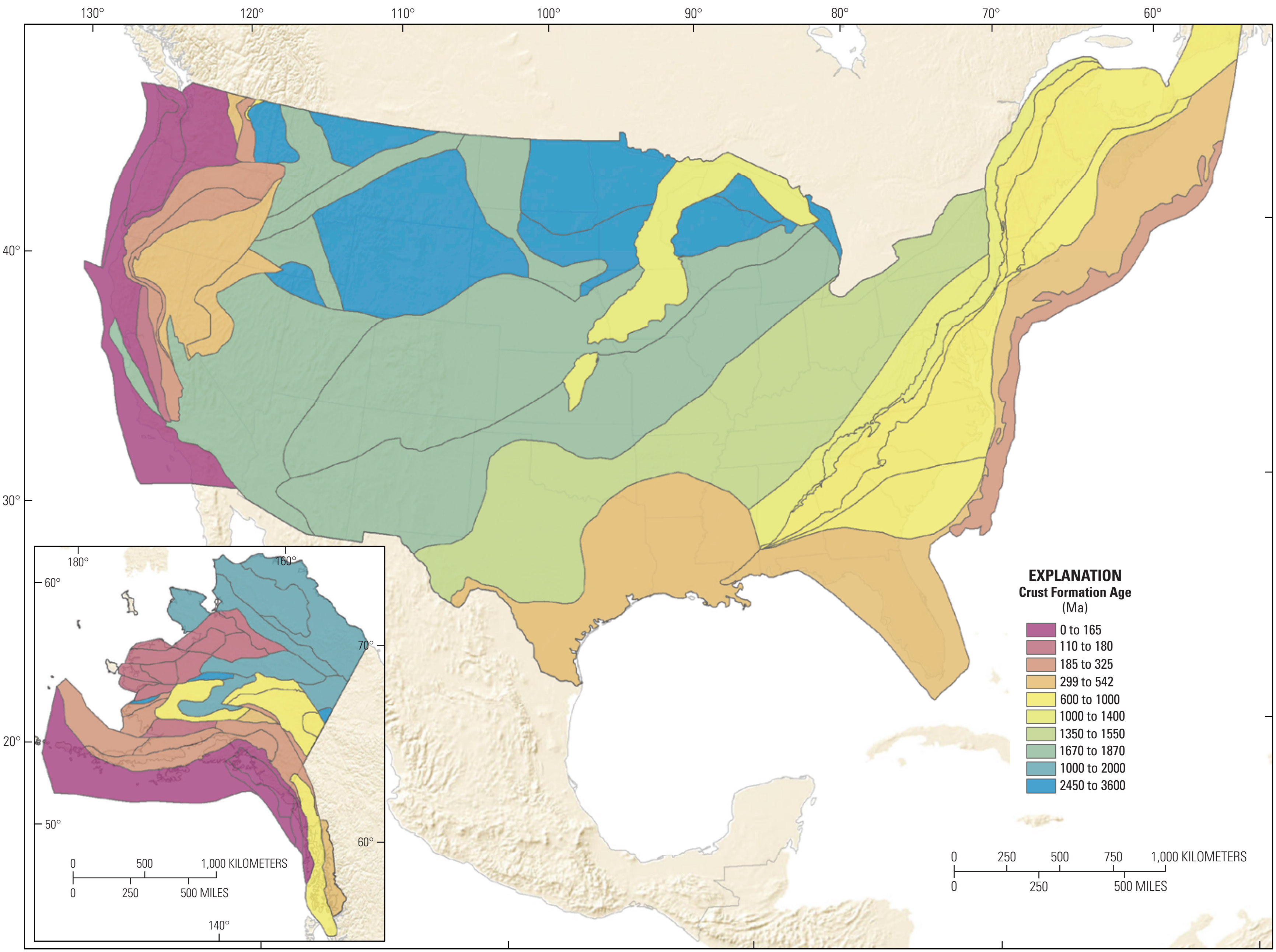

Figure 3. Time-slice reconstruction of United States basement domains according to the time when each domain was added to the continent, as determined by crust formation age or accretion age (see table 1).

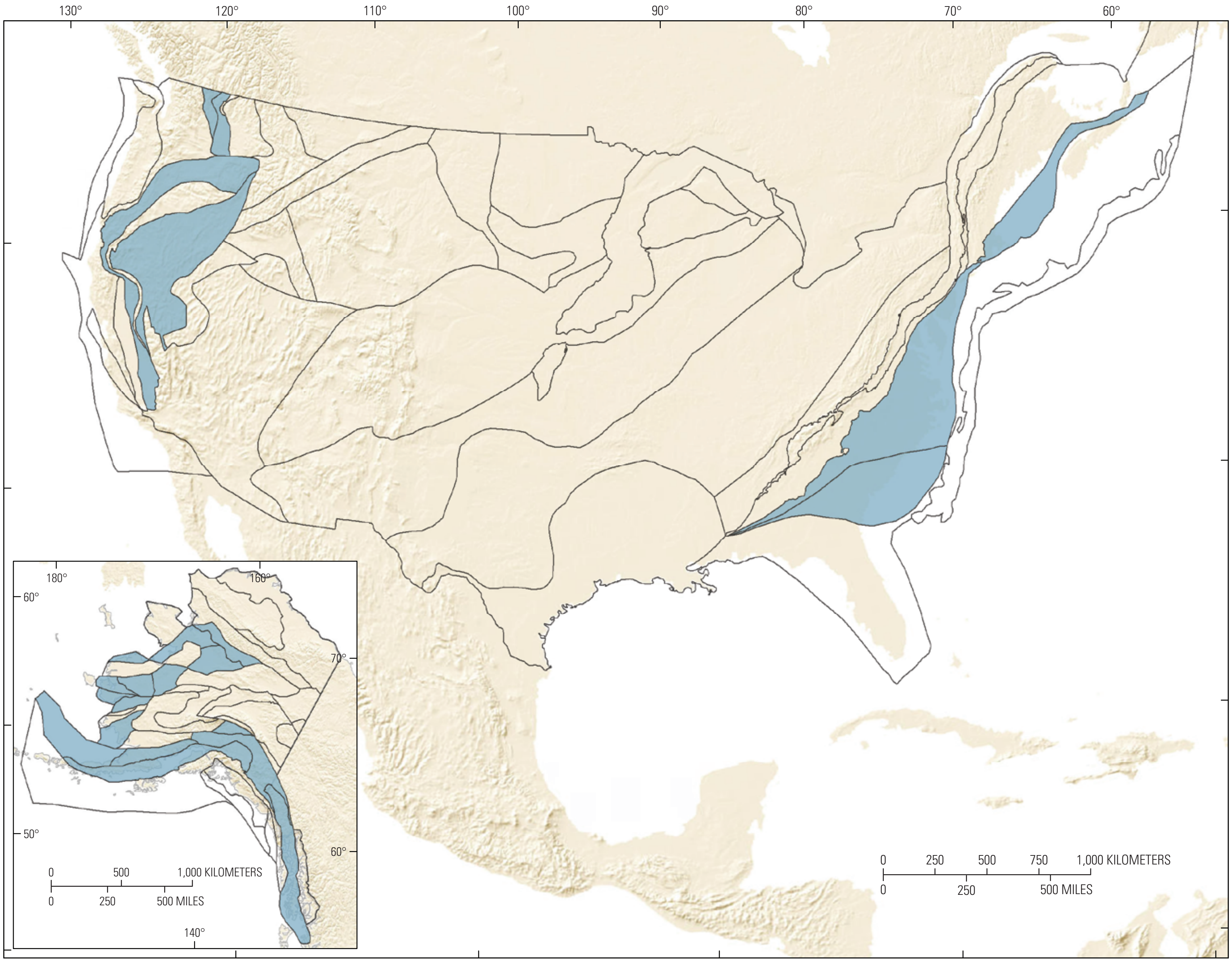

Figure 4. Sample map product of basement domains that formed as oceanic arc crust.

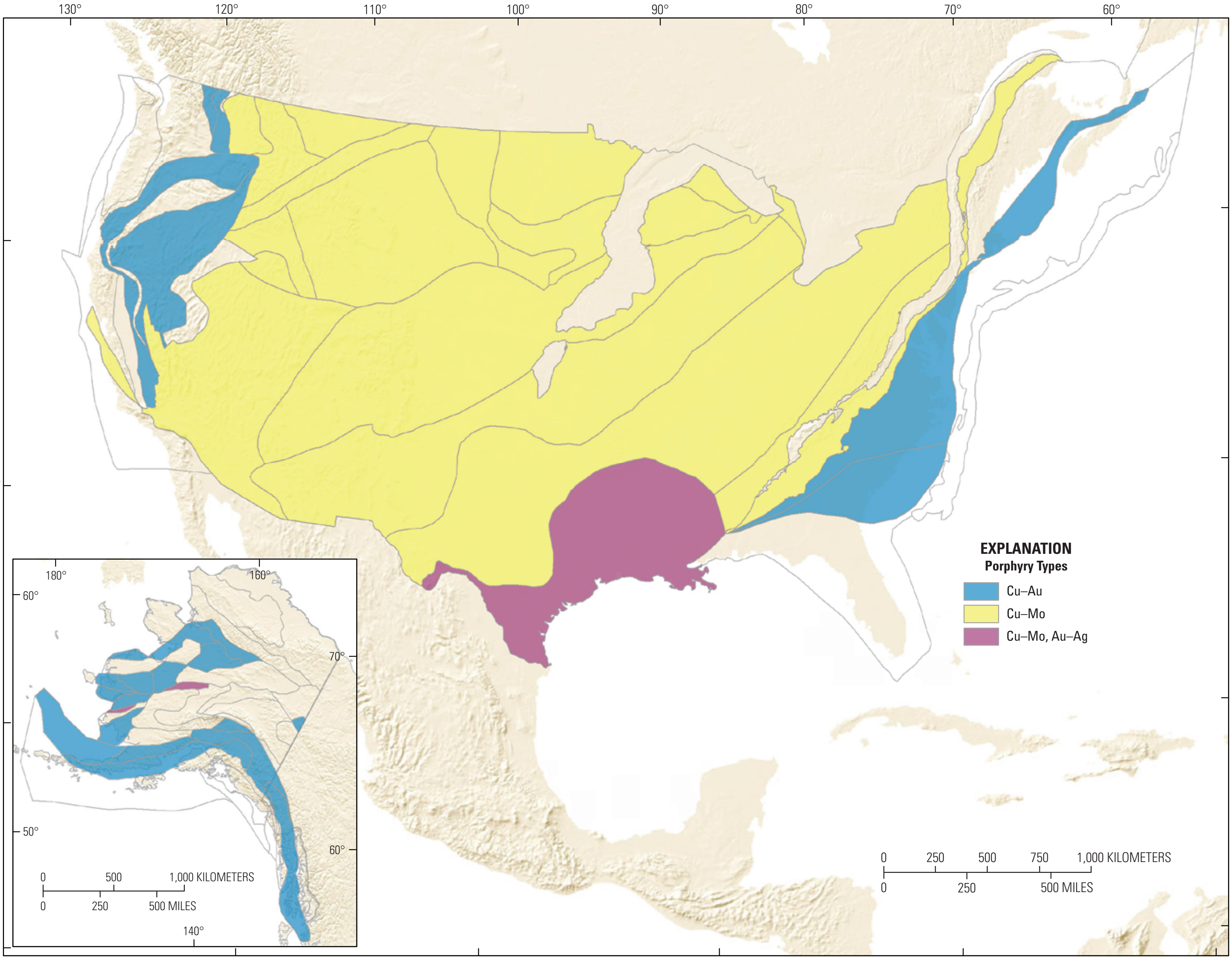

Figure 5. Sample map product of basement domains that potentially contain geologic environments conducive to formation of porphyry-type mineral deposits.

of mineral deposits by contributing metals from original basement endowments (Titley, 2001).

Each subsequent tectonic event that participated in continent growth—whether compressional or extensional—reactivated structural zones, localized sedimentary basins, and magmatism. Many of these structural zones became pathways that influenced and controlled mineralizing fluids. In addition, orogenic and postorogenic processes that act on or within the crust remobilize and recycle metals and contribute to mineral deposit formation (see discussion and references in Groves and others, 1998; Leahy and others, 2005; Groves and Bierlein, 2007).

Further, reactivation of deep-seated structural framework components inherited from earlier events may help to focus younger deformation and to provide structural pathways as suggested for the Colorado Mineral Belt, for example (Tweto and Sims, 1963; Karlstrom and Humphries, 1998). Similarly, the juvenile crust of the concealed Paleoproterozoic Great Falls tectonic zone may have contributed metals to the Cretaceous and Tertiary upper-crustal Cu-Mo deposits (Klein and Sims, 2007) of the Idaho-Montana porphyry belt (Armstrong and others, 1978; Rostad, 1978). The importance of structural reactivation of basement features in forming multistage mineral belts, such as the world-class Carlin-type gold deposits of the Great Basin is also well documented (Emsbo and others, 2006). Accordingly, orogenic overprinting and recycling have the potential to form complex and long-lived mineral belts that contain multiple ages and styles of mineral deposits.

The map presented herein provides one possible template for basement domains. It provides a dataset evaluating the types, distribution, and origins of metal endowments in basement domains and for how continent-scale structural events influenced the composition and location of younger mineral deposits. The map broadly identifies domain elements of the United States including Alaska so that (1) major regional structural zones within and between them can be identified and evaluated in terms of their role as conduits for mineralizing systems and (2) continent-scale magmatic and hydrothermal systems can be identified in terms of their origin in response to rift or collisional events and their capability to have introduced metals into the upper crust or remobilized metals in the upper crust. Future mineral resource assessments can utilize the framework data included as part of this map and, digitally layered with other national-scale geoscience datasets (figs. 6 and 7), these data can be used to evaluate continent-scale mineral resource potential and to define associations among certain types of mineral deposits in relation to the original tectonic setting of host basement domains. The map synthesizes an approach to defining the tectonic and paleogeographic evolution of metal-endowed regions of the United States. Better discrimination of basement character, origin, and relation to mineral deposits can be used to test and refine this approach.

Summary

The approach used to create this basement domain map employs the terrane concept, which recognizes that continents are composed of many crustal fragments of different ages and types. Further, the study synthesizes the variety of processes through which terrane fragments become continental crust and basement. The processes of continental-crust formation and evolution into basement domains have changed through the course of planetary development.

Two basic styles of continental growth (accretion) contributed to U.S. basement assembly. The most commonly recognized type of accretion was collision-related consumption of crust and juxtaposition of exotic and native fragments against (adjacent, onto, and under) the developing continental margin (typically seamounts, island arc chains, backarc basins, and tectonized fragments such as melange). These processes either resulted in or were preceded by collisions of continental masses, causing both orogenic thickening and attachment of allochthonous continental basement (for example, the Appalachian orogenic cycle). Translation and reattachment of native basement slices is a variant of the first type of accretion. Accretion caused by extension resulted from variable subduction rates (slab rollback) along noncollisional margins. Extensional accretionary orogenesis is typically nondestructive and generates growth of continental crust outward from the preexisting continental margin.

Synthesizing the original tectonic setting and original metals accumulation, in relation to basement evolution, highlights potential innate metal endowments in diverse basement domains. Cratons resist tectonic reactivation and deformation and, thus, their metals endowments tend to be preserved in the state prevailing during formation and cratonization. Associating the origin of basement domains and their original metal endowments may clarify relationships among various domains and spatially associated mineral deposits of various types and ages. The accuracy and validity of regional mineral resource assessments may be improved by considering basement origin, composition, history, and architecture.

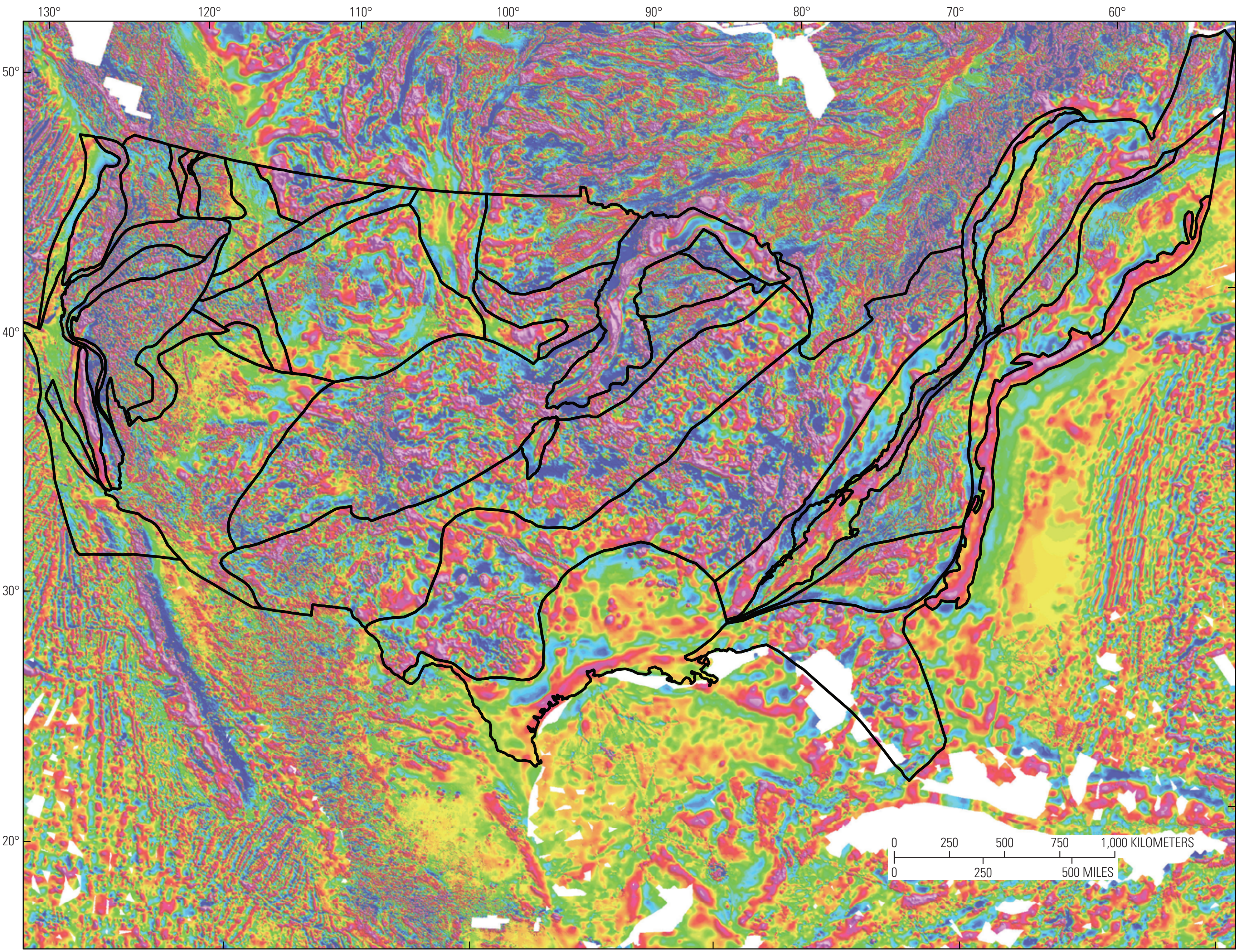

Figure 6. Basement domains overlaid on the North American magnetic map (NAMAG, 2002).

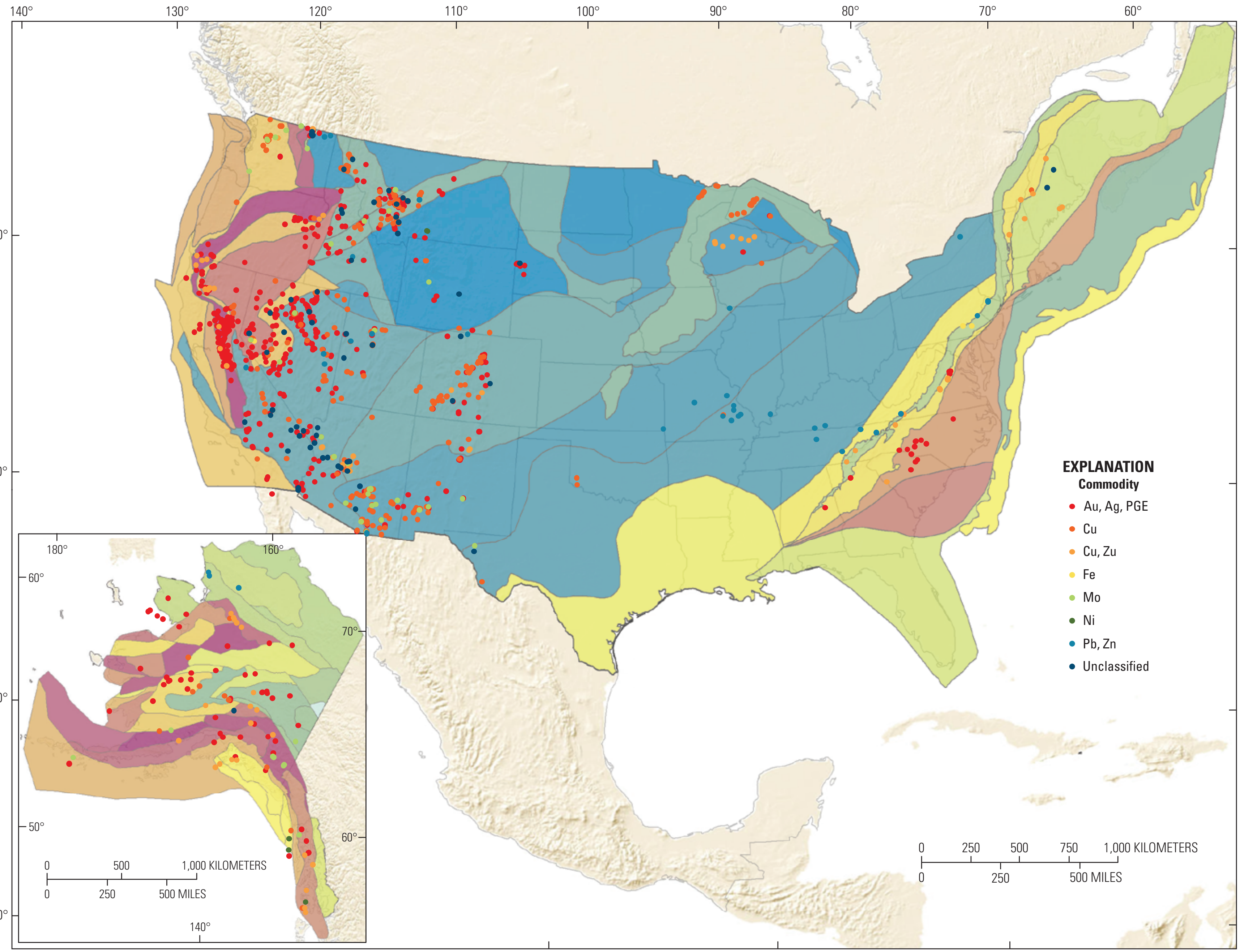

Figure 7. Basement domains layered with plot of principal metal deposits database revised from Long and others (1998) showing gold, silver, copper, platinum-group elements, nickel, lead, zinc and unclassified deposits of the conterminous United States and Alaska.

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