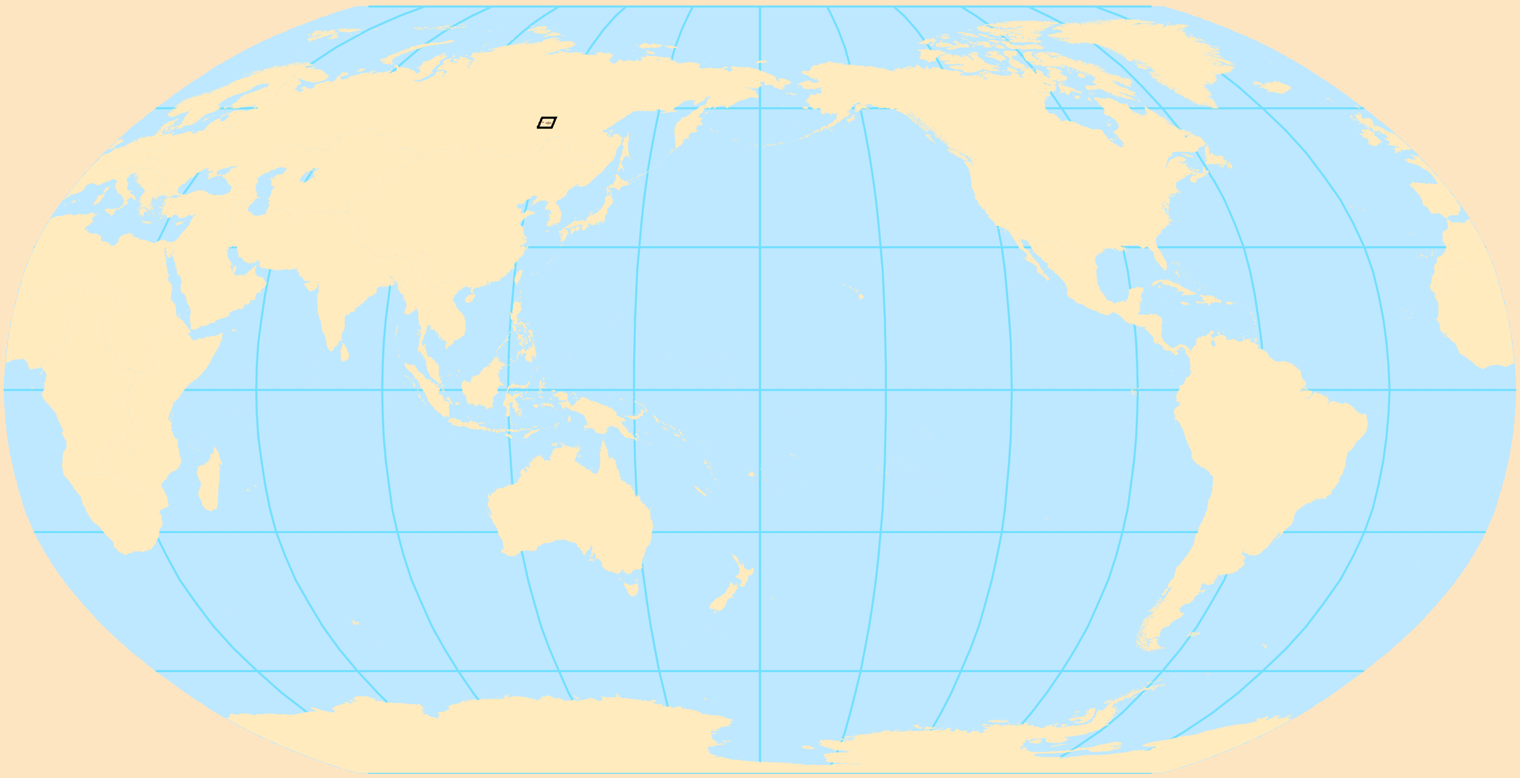
Global Mineral Resource Assessment

Assessment of Undiscovered Sandstone Copper Deposits of the Kodar-Udokan Area, Russia



Prepared in cooperation with the Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London; Mining and Economic Consulting Ltd., Almaty, Kazakhstan; and Zabaikalsky Division of the Russian Geological Society (RosGeo), Chita, Russia

Scientific Investigations Report 2010–5090–M

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Michael L. Zientek, Jane M. Hammarstrom, and Kathleen M. Johnson, editors

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SALLY JEWELL, Secretary

U.S. Geological Survey
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Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Mass	
ounce, troy (troy oz)	31.103	gram (g)
ounce, troy (troy oz)	0.0000311	megagram (Mg)
ton, short (2,000 lb)	0.9072	megagram (Mg)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
gram (g)	0.03215	ounce, troy (troy oz)
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram (Mg)	0.9842	ton, long (2,240 lb)
	Other conversions used in this report	
metric ton (t)	1	megagram (Mg)
troy ounce per short ton	34.2857	gram per metric ton (g/t)
percent	10,000	parts per million (ppm) or grams per metric ton (g/t)

Acronyms and Abbreviations Used

%	percent
Ag	silver
B	Russian mineral resource category that is analogous to measured mineral resources as defined by CRIRSCO.
C1	Russian mineral resource category that is analogous to indicated mineral resources as defined by CRIRSCO.
C2	Russian mineral resource category that is analogous to inferred mineral resources as defined by CRIRSCO.
COMECON	Sovet ekonomicheskoy vzaimopomoshchi [The Council for Mutual Economic Assistance]
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
commun.	communication
Cu	copper
Esri	a software development and services company providing geographic information system software and geodatabase management applications
g/t	grams per metric ton
Ga	giga-annum or billions of years before the present
GIS	geographic information system
GOE	great oxidation event
GOK	Gorno-Obogatitel'nyy Kombinat [Mining and Processing Combine]
km	kilometers
km^2	square kilometers
kt	thousand metric tons
LLC	limited liability company
Ltd.	limited
m	meters
Ma	mega-annum or millions of years before the present
Mt	million metric tons
P1	Russian mineral resource category that is analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS. These prognostic mineral resources estimates refer to extensions to inferred resources and are based on limited direct geological evidence.
P2	Russian mineral resource category used by Russian geologists that is analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS. These prognostic mineral resources estimates refer to exploration targets identified by geologic mapping, geophysical surveys, or geochemical data.
RosGeo	Russian Geological Society
Sm-Nd	samarium-neodymium
SRC USSR	State Reserves Committee, Union of Soviet Socialist Republics
SSIB	small-scale digital international boundaries
U/Pb	uranium/lead
USGS	United States Geological Survey
USSR	Union of Soviet Socialist Republics
VSEGEI	Vserossiyskiy Nauchno-Issledovatel'skiy Geologicheskiy Institut im. A.P. Karpinskogo [A.P. Karpinsky Russian Geological Research Institute]
US$	United States dollars

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Assessment of Undiscovered Sandstone Copper Deposits of the Kodar-Udokan Area, Russia

By Michael L. Zientek[1], Vladimir S. Chechetkin[2], Heather L. Parks[1], Stephen E. Box[1], Deborah A. Briggs[1], Pamela M. Cossette[1], Alla Dolgopolova[3], Timothy S. Hayes[4], Reimar Seltmann[3], Boris Syusyura[5], Cliff D. Taylor[6], and Niki E. Wintzer[1]

Abstract

Mineral resource assessments integrate and synthesize available information as a basis for estimating the location, quality, and quantity of undiscovered mineral resources. This probabilistic mineral resource assessment of undiscovered sandstone copper deposits within Paleoproterozoic metasedimentary rocks of the Kodar-Udokan area in Russia is a contribution to a global assessment led by the U.S. Geological Survey (USGS). The purposes of this study are to (1) delineate permissive areas (tracts) to indicate where undiscovered sandstone-hosted copper deposits may occur within 2 km of the surface, (2) provide a database of known sandstone copper deposits and significant prospects, (3) estimate numbers of undiscovered deposits within these permissive tracts at several levels of confidence, and (4) provide probabilistic estimates of amounts of copper (Cu) and mineralized rock that could be contained in undiscovered deposits within each tract. The workshop for the assessment, held in October 2009, used a three-part form of mineral resource assessment as described by Singer (1993) and Singer and Menzie (2010).

Permissive tracts were delineated by estimating the volume of rock that contains the stratigraphic section ranging from the Chitkanda to the Sakukan Formations of the Udokan Complex to a depth of 2 km and then projecting this rock volume to the surface. The six permissive tracts delineated in this assessment occur in several domains, referred to as troughs in Russian literature, which represent remnants of a much larger basin that likely covered the Kodar-Udokan region. Tracts range in size from about 100 km^2 to 800 km^2. The mapped distributions of rocks as shown on 1:200,000-scale geologic maps, supplemented in some areas by prospect mapping and drilling, were used to delineate the tracts.

In this study area, data are insufficient to constrain the original basin geometry or the structural or stratigraphic traps that would have localized copper mineralization. Some alteration is described, and the types of sandstone cements vary; however, no patterns are known that provide evidence for regional flow paths of metal-bearing brines that could localize deposits.

This probabilistic assessment indicates that a significant amount of undiscovered copper is associated with sediment-hosted stratabound copper deposits in the Kodar-Udokan Trough. In the assessment, a mean of 21 undiscovered deposits is estimated to occur within the Kodar-Udokan area. There are two known deposits in the area that contain drill-identified resources of 19.6 million metric tons of copper. Using Monte Carlo simulation, probabilistic estimates of the numbers of undiscovered sandstone copper deposits for these tracts were combined with tonnage and grade distributions of sandstone copper deposits to forecast an arithmetic mean of 20.6 million metric tons of undiscovered copper. Significant value can be expected from associated metals, particularly silver.

Introduction

The purpose of this assessment is to forecast undiscovered mineral resources that may be associated with sandstone-type copper deposits in the Kodar-Udokan area of Russia (fig. 1). The Paleoproterozoic metasedimentary rocks in this area host the Udokan sandstone-type copper deposit, one of the largest and oldest of that type found anywhere (Volodin and others, 1994; Hitzman and others, 2005, 2010). This study forecasts the potential for additional undiscovered copper resources associated with this deposit type in the Kodar-Udokan area.

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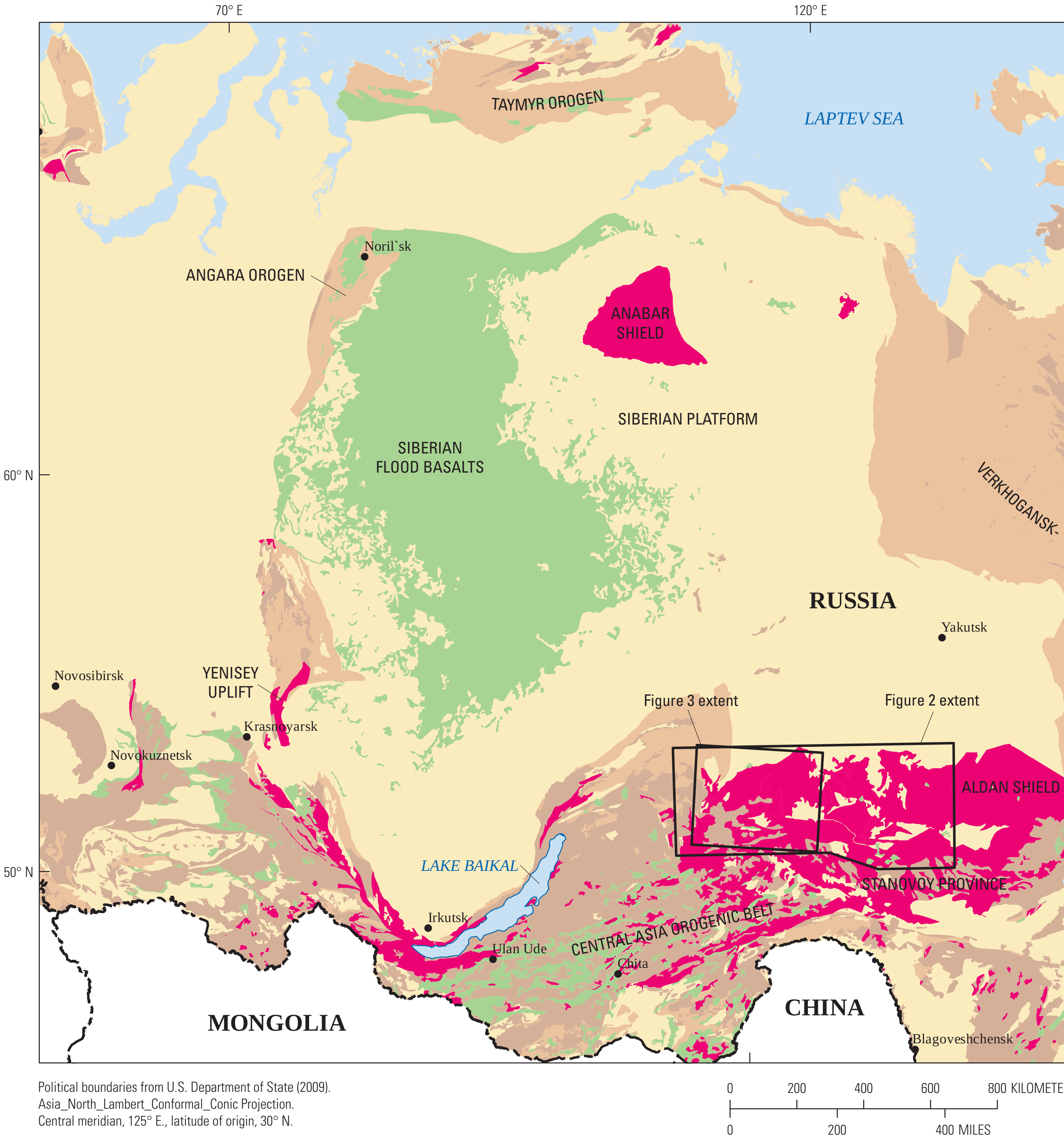


Political boundaries from U.S. Department of State (2009).
Asia_North_Lambert_Conformal_Conic Projection.
Central meridian, 125° E., latitude of origin, 30° N.

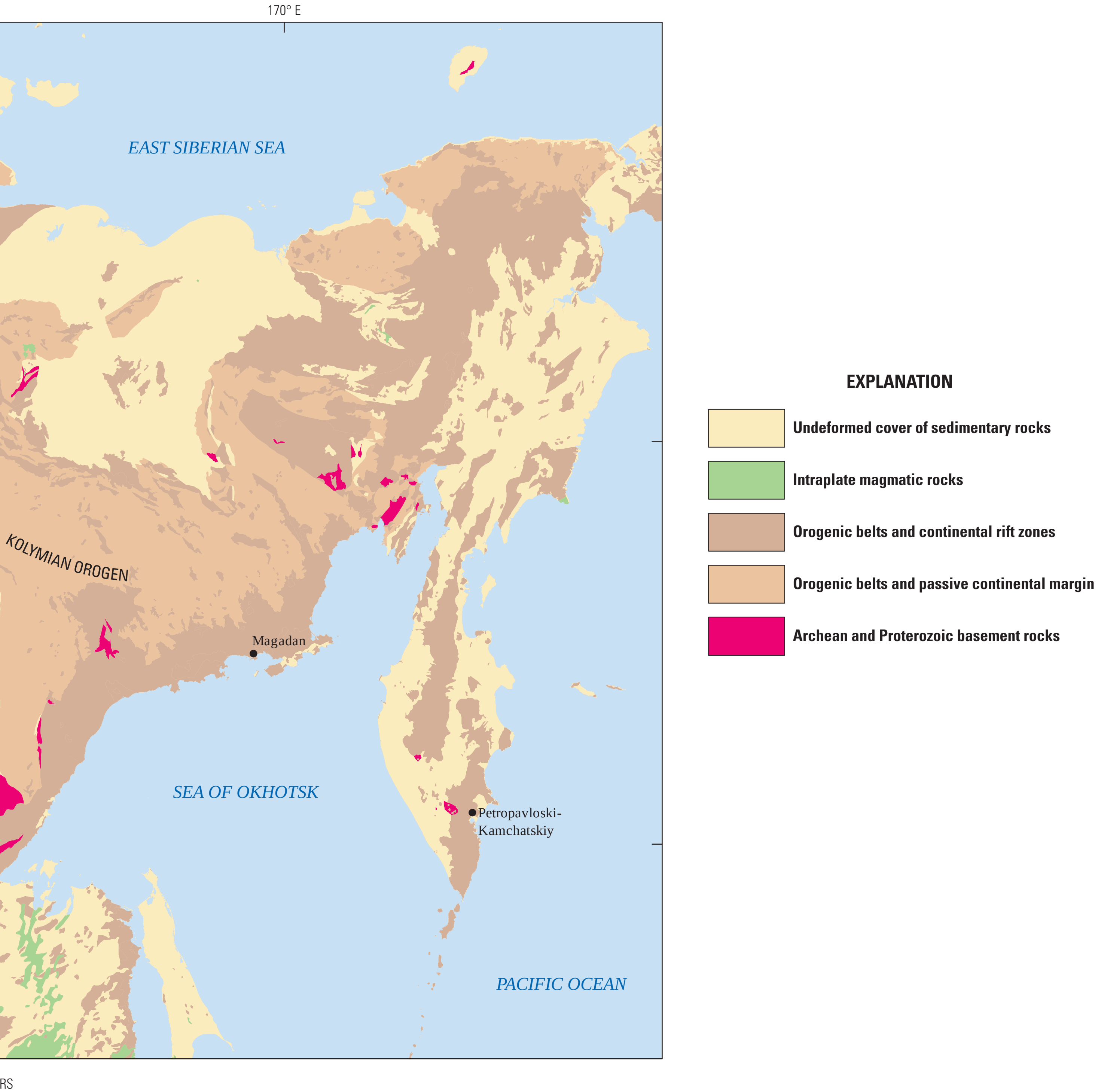


Figure 1. Simplified regional geologic map showing the location of the Archean and Proterozoic rocks in relation to major tectonic features in northeast Asia. The Proterozoic rocks that host stratabound sediment-hosted copper deposits and occurrences of the Kodar-Udokan area crop out on the southern margin of the Siberian Platform. Boxes show the locations of figures 2 and 3. Map simplified from Zonenshain and others (1988).

The study was led by the U.S. Geological Survey (USGS) as part of a cooperative international project to estimate the regional locations and probable quantity and quality of the world's undiscovered copper, platinum-group elements, and potash in selected deposit types to a depth of at least 1 kilometer (km). In the process, this research project is developing, testing, and applying a variety of methods to quantitatively assess undiscovered mineral resources (Briskey and others, 2001, 2007; Schulz and Briskey, 2003).

Regional assessment studies like this one compile and integrate existing datasets, including databases and maps of the location, size, and geologic type of known mineral deposits and occurrences; maps of regional geology, metallogeny, tectonics, geochemistry, and geophysics; and information about regional mineral exploration. The integrated information is used to delineate tracts of land permissive for particular types of undiscovered nonfuel mineral deposits and to make and constrain probabilistic estimates of the quantity and quality of the undiscovered resources.

This report includes a brief geologic overview of the Kodar-Udokan area and its known sandstone copper deposits, a description of the assessment process, a summary of results, and several appendixes. Appendixes A through F contain the following summary information for each tract: location, geologic feature assessed, rationale for tract delineation, tables and descriptions of known deposits and significant prospects, exploration history, model selection, rationale for estimates, assessment results, and references. Appendix G lists the name, grade, and tonnage of deposits used for the sandstone copper model. The accompanying digital files, appendix H, provide the outlines of the permissive tracts, assessment results, and data for deposits and prospects in a geographic information systems (GIS) format. Short biographies of the authors can be found in appendix I.

Assessment Methodology for Undiscovered Resources

Deposit models are the logical construct that underpins USGS mineral assessment methodology (Cox and Singer, 1986). Mineral deposits of a given type share genetic and physical factors that differentiate them from other styles of mineralization. These factors can be summarized in a model that identifies the geologic setting where such deposits form and describes the characteristics that can be used to distinguish and classify mineral deposits and occurrences by type.

This study specifically uses the quantitative mineral resource form of assessment described by Singer (1993) and Singer and Menzie (2010) to estimate the location and probable amounts of undiscovered resources for a given type of deposit. Undiscovered resources are mineralized materials whose location, grade, quality, and quantity are unknown or incompletely documented, either in partially characterized or completely unknown mineral deposits.

Location

Using the geologic environment summarized in descriptive deposit models, areas are delineated where favorable geology permits the existence of deposits of one or more types. Each delineated area, or permissive tract, represents the surface projection of a portion of the Earth's crust and overlying surficial materials that corresponds to a geologic environment described in a published deposit model; consequently, depth from surface is an essential part of a tract definition. In this study, undiscovered resources are assessed to a depth of 2 km below the Earth's surface.

Probable Amounts

The assessment is based on analogy: undiscovered resources are assumed to be similar to those that have already been discovered elsewhere. The amount of undiscovered resource is derived from (1) models for grades and tonnages of undiscovered deposits of the same type in geologically similar settings and (2) an estimate of the number of undiscovered deposits of each type that are predicted to exist in the delineated tracts. The grade and tonnage models are based on frequency distributions of tonnage and average grade of well-explored deposits (appendix G). The distribution of undiscovered deposits is estimated by expert panels of geologists at several probability percentiles. From these percentile values, a default probability distribution for the undiscovered deposits is chosen that is approximately in the middle of all possible choices (Root and others, 1992). Monte Carlo simulation is used to combine grade and tonnage models with the probability distribution of undiscovered deposits to obtain the estimated probability distributions of undiscovered metals in each tract (Root and others, 1996; Bawiec and Spanski, 2012; Duval, 2012). Results of the simulation are presented in summary tables and graphs. The quantitative mineral resource assessment then can be evaluated using economic filters and cash flow models for economic and policy analysis, and it can be applied to mineral supply, economic, environmental, and land-use planning. Such economic evaluations, however, are not part of this report.

Definitions of Deposits and Prospects

In this report, "mineral inventories" refer to the formal quantification of naturally occurring mineral materials, estimated by a variety of empirically or theoretically based procedures (Sinclair and Blackwell, 2002). "Mineral resources" are defined as concentrations or occurrences of material of economic interest in or on the Earth's crust in such form, quality, and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade, continuity, and other geological characteristics of a mineral resource are known, estimated, or interpreted from specific geological evidence, sampling, and knowledge (Committee for Mineral

Reserves International Reporting Standards, 2006). The term "mineral reserve" is restricted to the economically mineable part of a mineral resource.

The term "deposit" is restricted to those sites that (1) formed by the same genetic process (same deposit type), (2) may have economic potential, (3) have a mineral inventory defined using sampling density appropriate for the deposit type, and (4) are well explored (most of the mineralized rock at the site is included in the mineral inventory). Sites that lack a mineral inventory or are incompletely explored are referred to as "prospects" in this report.

Estimates of the mineral inventory for deposits and prospects in this report are based on the resource and reserve classification system used in the former Soviet Union and other countries that belonged to the Council for Mutual Economic Assistance (COMECON) (Diatchkov, 1994; Jakubiak and Smakowski, 1994; Henley and Young, 2006). COMECON was an economic organization under the leadership of the Soviet Union that comprised the countries of the Eastern Bloc along with a number of socialist states elsewhere in the world. Within this classification system, category B corresponds to a measured mineral resource that is estimated with a high degree of confidence. Category C corresponds to indicated and inferred mineral resources, as defined by the Committee for Mineral Reserves International Reporting Standards (2006), that are based on data from outcrops, trenches, pits, workings, and drill holes; however, the level of confidence is much less than for resources in Category B. Category P, prognostic resources, are inferred from indirect indications of mineralization (such as geochemical or geophysical anomalies), mineral occurrences, or isolated sampling. This resource category is equivalent to undiscovered resources in the classification of mineral resources used by the USGS (U.S. Bureau of Mines and U.S. Geological Survey, 1976). Resources within the P1 category may be adjacent to and extend beyond the limits of drill-indicated resources (Category C). Resources under the P2 category are estimated using geophysical and geochemical data (Diatchkov, 1994).

Sandstone Copper Ore-Forming Systems

The copper-silver mineralization within metasedimentary rocks of the Kodar-Udokan area is an example of the sediment-hosted stratabound copper deposit type (Cox and others, 2003; Kirkham, 1989; Hitzman and others, 2005, 2010). This style of mineralization results from the precipitation of copper sulfide minerals by oxidized fluids of moderate temperature and moderate to high salinity at oxidation-reduction interfaces in sedimentary rocks.

Sediment-hosted stratabound copper mineralization requires (1) sources of metals and sulfur, (2) a fluid capable of carrying metals in solution, (3) basin-scale fluid-flow systems that transport these metal-bearing fluids, and (4) a chemical and (or) physical trap in the basin that causes the precipitation of sulfide minerals from the solution (Hitzman and others, 2010). Synrift continental red bed sedimentary rocks and mafic volcanic rocks are thought to be the source of metals and sulfur for many of these deposits. Saline brines, derived from evaporite rocks in the basin, are fluids capable of leaching the metals from the red beds and volcanic rocks because of their high oxidation state and high chlorine concentrations. Basin-scale fluid-flow systems result from a combination of sedimentological and tectonic processes; gravitational fluid flow driven by the topographic configuration of the basin may be the most important process necessary for the formation of this type of sediment-hosted mineral deposit. Fluid flow processes at the basin scale can be documented by diagenetic alteration of the sedimentary rocks and by hydrocarbon accumulation. Mineralization is localized where oxidized, copper-bearing brines interact with reduced marine or lacustrine sedimentary rocks or with reservoirs filled with hydrocarbons (Hitzman and others, 2010). Mineralized zones range from sheet-like, having extensive horizontal dimensions, to tabular, having limited horizontal dimensions, depending on the nature of the reductant (Kirkham, 1989; Hitzman and others, 2010).

Two major subtypes of sediment-hosted copper deposits have been recognized: (1) reduced facies copper (also known as Kupferschiefer or Mansfeld types) and (2) sandstone copper (or Revett-type) (Cox and others, 2003). The host rocks of reduced-facies type deposits include marine or lacustrine rocks such as green, black, or gray shale, siltstone; thinly laminated tidal facies or reefoid carbonate rocks; and dolomitic shale that commonly contains organic carbon and finely disseminated pyrite. These host rocks overlie, or are interbedded with, red to brown or purple, hematite-bearing sandstone, siltstone, and (or) conglomerate. The reductant in reduced facies deposits is solid organic material trapped in shales or carbonate rocks.

The characteristic stratigraphic setting for sandstone copper deposits, such as those in the Kodar-Udokan area, is a thick sandstone sequence. Copper is not spatially associated with solid organic matter in these deposits; however, copper may have been precipitated by a mobile reductant, such as liquid hydrocarbons or natural gas (a transient gas reductant). In sandstone copper deposits, most of the ore contains disseminated sulfide minerals, including chalcocite and bornite, which replace sandstone cement or fill pore space. Disseminated sulfide minerals form clots that replace sand grains, follow bedforms, and form ore rods across stratification; minor amounts of ore are also present in veins (Lindsey and others, 1995; Cox and others, 2003).

Geologic Overview of the Kodar-Udokan Area

Tectonic Setting

Deformed and metamorphosed Paleoproterozoic metasedimentary rocks unconformably overlie Archean basement of the Chara-Olekma Terrane of the Aldan Shield (figs. 2 and 3). The Olekma Terrane is an Archean granite-greenstone terrane; rocks in the greenstone belts have been dated to approximately 3.0 Ga (fig. 3 and table 1; Glebovitsky and others, 2008). Various Archean terranes amalgamated to form the Aldan Shield; amalgamation was complete by about 2.6 Ga (Glebovitsky and others, 2008, 2009). Paleoproterozoic metasedimentary rocks that lie unconformably on this Archean basement occur in several domains, known as troughs in Russian literature (fig. 4), and represent remnants of a much larger basin that likely covered the region (Burmistrov, 1990). An upper concordia U/Pb intercept age of 2180±50 Ma based on analysis of a conventional multigrain zircon suite from tuffaceous sandstone in the Udokan Complex is interpreted to be the depositional age of the sediments (Berezhnaya and others, 1988; Pokrovskii and Grigor’yev, 1995). Sm-Nd model ages for the crust that was the source for the Paleoproterozoic sediments range from 2.6 to 2.3 Ga (Podkovyrov and others, 2006). These results suggest that the source areas for original sediments of the Udokan Complex had to include Paleoproterozoic rocks not currently exposed in the western Aldan Shield. The collision of the Aldan and Stanovoi Shields that produced the Peristanovoi belt/suture took place about 1.9 Ga (Pokrovskii and Grigor’yev, 1995; Sal’nikova and others, 2006; Glebovitsky and others, 2009); this orogenic event folded and deformed the Udokan metasedimentary rocks. Postorogenic felsic and mafic intrusions dated at 1.87 Ga cut the Udokan metasedimentary sequence (Podkovyrov and others, 2006; Popov and others, 2009). Udokan sedimentation was active at 2.18 Ga and probably ended early in the 1.9 Ga orogenic event (perhaps as early as 1.99 to 1.96 Ga).

Copper mineralization within the Udokan metasedimentary rocks has not been directly dated but is constrained in age to about 2.2 to 1.96 Ga (fig. 5). Sediment-hosted ore deposits are crosscut and metamorphosed by postorogenic 1.87 Ga gabbroic intrusions. The tectonic setting and architecture of the Paleoproterozoic basin filled by the Udokan metasedimentary rocks has been obscured by later deformation events and magmatic activity.

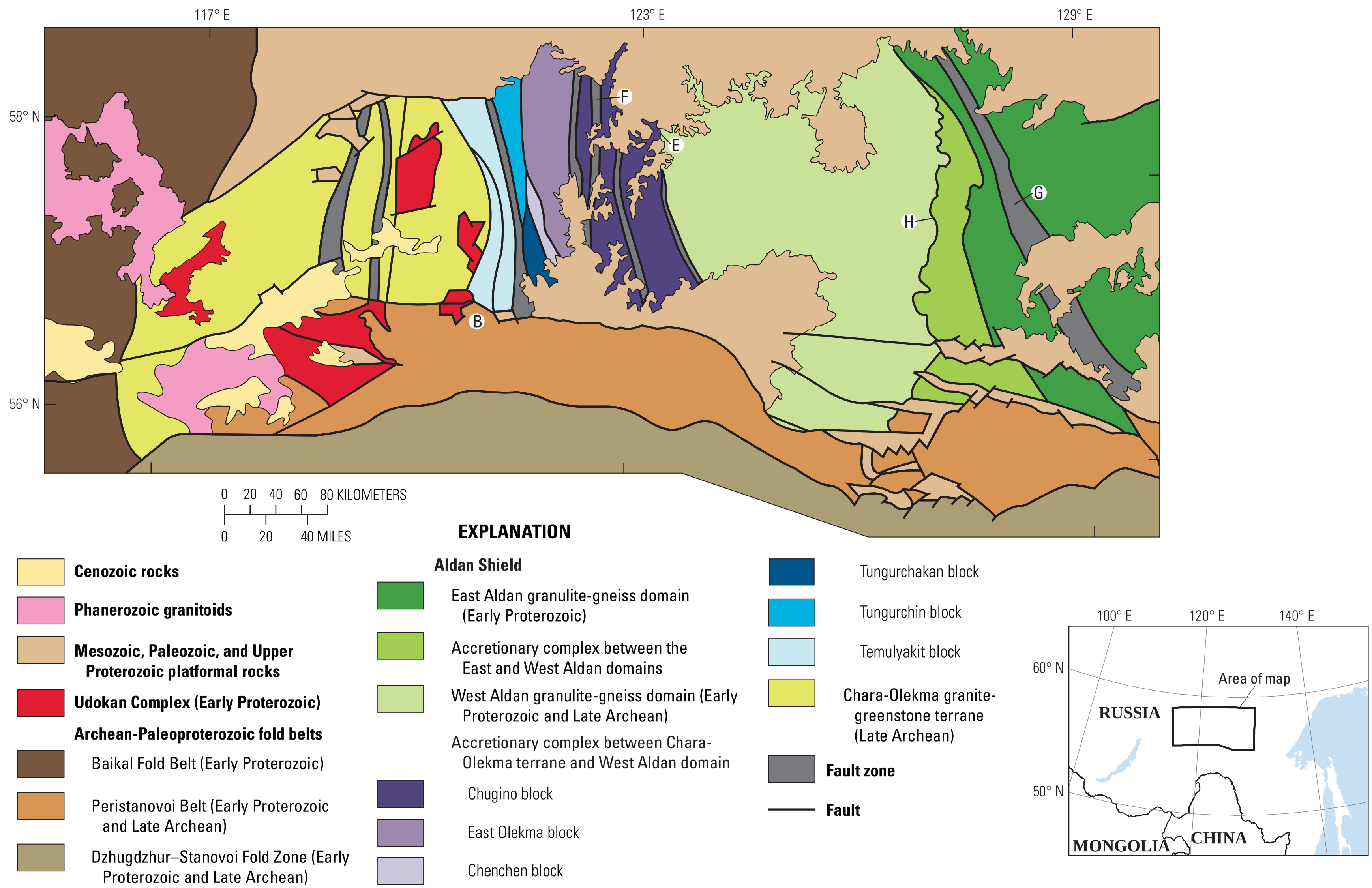


Figure 2. Regional geologic map showing Archean and Proterozoic terranes in southern Siberia, modified from Sal'nikova and others (2006) and Kotov and others (2006). Letters refer to localities described in table 1.

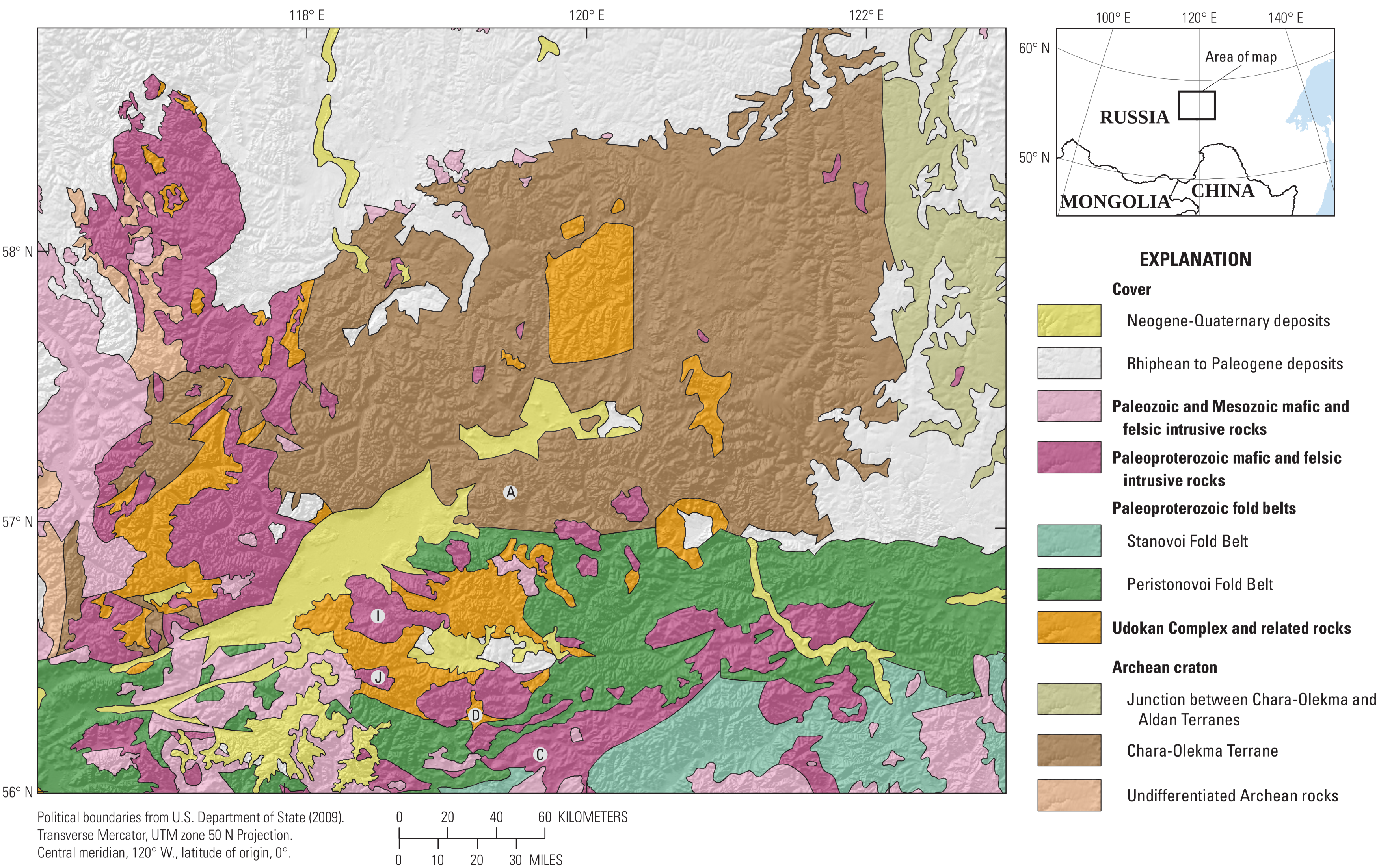


Figure 3. Simplified geologic map of the western Aldan shield showing the distribution of major Archean domains, Paleoproterozoic fold belts, Paleoproterozoic metasedimentary rocks, postorogenic magmatic rocks, and cover rocks in the Kodar-Udokan area, Russia (modified from All Russia Geological Research Institute, 2004). Letters refer to localities described in table 1.

Table 1. Geochronology of major Archean and Proterozoic geologic events in the Kodar-Udokan area, Russia.

[Ma, million years]

Event	Date (Ma)/ Method	Geologic feature	Reference	Location on figure
		Craton formation – the Olekma-Aldan Shield		
1	3006±9–2998±9/U-Th-Pb (SHRIMP)	Greenstone belts of the Olekma Terrane	Glebovitsky and others (2008)	A on fig. 3
	2960±70/U-Pb zircon			
Amalgamation of terranes that make up the granulite basement of the Dzhughzhur-Stanovoi Fold Region; granulite facies metamorphism in the Kurul'ta Block, Peristonovoi Belt				
2	2846±33	Granulite facies metamorphism	Glebovitsky and others (2009)	B on fig. 2
	2708±7/zircon	Granulite facies metamorphism of moderate pressure		
Amalgamation of terranes that make up the granulite basement of the Dzhughzhur-Stanovoi Fold Region; emplacement of Anorthosite-Charnockite-Enderbite in the Kurul'ta Block, Peristonovoi Belt				
2	2627±16	Enderbite intrusions of the Dzhelui Complex	Glebovitsky and others (2009)	
	2623±23–2611±38	Kalar Anorthosite-Charnockite Complex		C on fig. 3
	2614±7	Charnockite of the Altual Complex		
2	2675±15	Age of granites overlain by Kodar Group	Podkovyrov and others (2006)	
Exhumation and erosion of (i) the Archean Chara-Olekma terrane of the Aldan Shield and (ii) Paleoproterozoic continental crust that are the source area for terrigenous rocks of the Udokan Complex				
3	2611–2712	Sakukan Formation	Podkovyrov and others (2006)	
	2629	Aleksandrov/Butun Formation		
	2388–2598	Chitkanda Formation		
	2332–2733	Ayan Formation		
	2286–2452	Ikaby Formation		
		Deposition of Kodar-Udokan sediments		
3	2180±50/U-Pb zircon	Magmatic zircons from ash inter-layer in the Chinei Group	Pokrovskii and Grigor'yev (1995)	
		Arc-related magmatism and accretion along eastern margin of the Olekma-Aldan Shield		
4	2066±6	Alkaline granites of the Katugin Series intrudes the lower part of the Udokan Complex; emplaced under extension at the final stage of evolution of passive margin	Podkovyrov and others (2006)	D on fig. 3

Table 1. Geochronology of major Archean and Proterozoic geologic events in the Kodar-Udokan area, Russia.—Continued

[Ma, million years]

Event	Date (Ma)/ Method	Geologic feature	Reference	Location on figure
		Craton formation – the Olekma-Aldan Shield		
4	2055±18	Origination of volcanic arc along eastern margin of Olekma-Aldan Shield; onset of deposition of the volcanosedimentary sequences of the Balaganakh greenstone belt	Anisimova and others (2006)	E on fig. 2
	2006±3–2011±2	Fedorovka island arc magmatism		
	1993±1	Chuga and Fedorovka thrust faults formed by the collision of the Fedorovka island arc with the Olekma-Aldan Shield		
		Collision of the Olekma-Aldan and Uchur terranes indicated by age of movement on structure in central Aldan Shield		
5	1925±5–1966±4	Amga Fault zone	Sal’nikova and others (2006)	F on fig. 2
	1919±4–1953±5	Tykrandin Fault Zone		G on fig. 2
	1925±5–1950±2	Timpton Thrust		H on fig. 2
		Collision of the Aldan and Stanovoi microplates resulting in the Peristanovoi Belt/Suture		
5	1939±101	Metamorphism of the uppermost Naminga Formation	Pokrovskii and Grigor’yev (1995)	
5	1935±35	Formation of tectonic nappes; granulite facies metamorphism of elevated pressure in the Kurul’ta Block, Peristonovoi Belt/Suture	Glebovitsky and others (2009)	B on fig. 2
		Postorogenic magmatism		
6	1876±4	Granites of the Kodar Group (Kemen Massif) cut the upper part of the Udokan Complex (the Kemen Group)	Podkovyrov and others (2006)	I on fig. 3
6	1873±2	Granite of the Kodar Group emplaced into the Kurul’ta Block, Peristonovoi Belt	Glebovitsky and others (2009)	
6	1867±3	Crystallization age of the Chinei Massif which cuts terrigenous-carbonate rocks of the upper Chinei (Alexsandrov and Butun Formations) and the lower Kemen (Sakukan Formation) Subgroups of the Udokan Complex	Popov and others (2009)	J on fig. 3

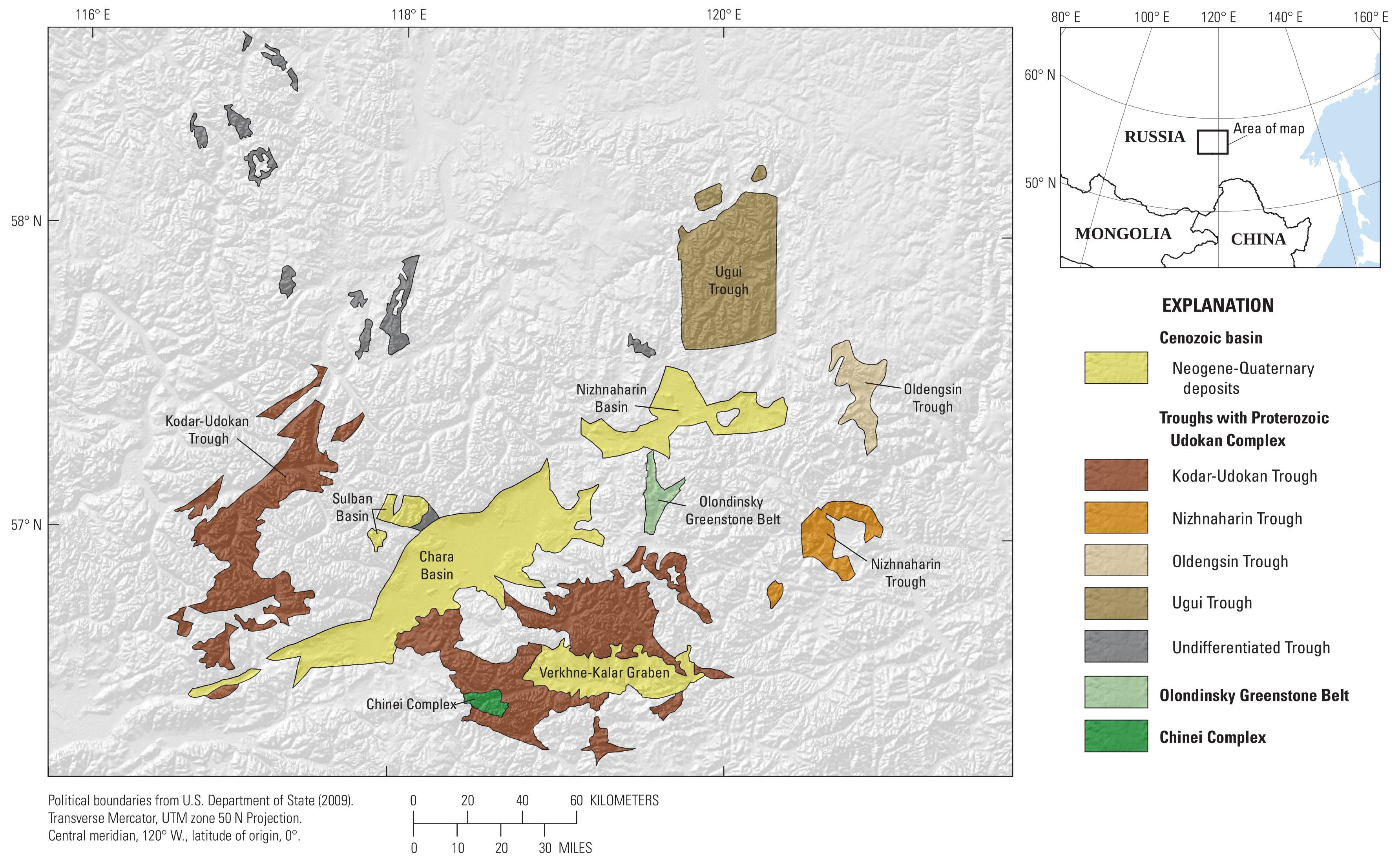


Figure 4. Index map of the Kodar-Udokan area showing the distribution of troughs of Paleoproterozoic metasedimentary rocks (modified from All Russia Geological Research Institute, 2004) in relation to Cenozoic tectonic basins.

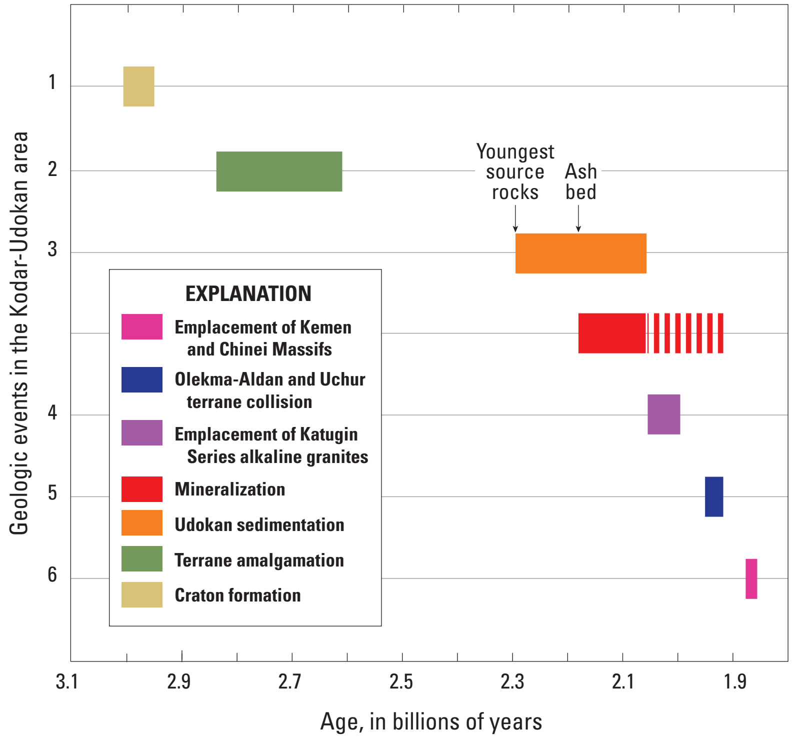


Figure 5. Chart displaying the ages of Archean and Proterozoic geologic events in the Kodar-Udokan area, Russia, and the proposed timing of sandstone copper mineralization. Events are also described in table 1. Mineralization does not have an event number because it is not listed in table 1.

Basin Stratigraphy

As much as 12,000 meters (m) of terrigenous clastic rocks are preserved in the synclinal feature that makes up the Kodar-Udokan Trough (fig. 6). These rocks, the Udokan Complex, comprise nine formations that make up three series or groups: the Kodar, Chinei, and Kemen (oldest to youngest). Each of these large groups, generally speaking, represents a gradual change from deep- to shallow-water depositional environments.

A study of clastic material in the Udokan Complex demonstrates that the detritus found in the Kodar and Chinei Groups could be derived from Archean rocks found nearby. However, detritus in the Kemen Group includes pebbles and rock fragments derived from granites, porphyries, sandstones, quartzitic sandstones, granophyres, and jasperoids. These rocks types, likely derived from a sedimentary-volcanic complex intruded by granites, are not characteristic of the Archean rocks in the Chara block or the Aldan Shield or the Paleoproterozoic formations of the Olekma-Vitim Mountains (Lavrovich, 1971).

The Kodar Group consists of the Ikaby and Ayan Formations (Bogdanov and others, 1966). The Ikaby Formation is characterized by dark gray mica schist, locally containing abundant pyrrhotite and pyrite. Thicknesses range from 700 to 2,400 m. The Ayan Formation is made up of thin, alternating dark gray to gray silty sandstone, siltstone, and shale. Many beds are carbonate-bearing. Ripple marks occur on bedding planes in the eastern part of the Kodar-Udokan Trough. Thicknesses vary from 100 to 1,100 m. Depositional settings range from deep marine in the Ikaby Formation to littoral in the overlying Ayan Formation.

The Chinei Group (Inyr, Chitkanda, Aleksandrov, and Butun Formations) conformably overlies the Kodar Group and consists predominantly of gray metamorphosed oligomictic and polymictic sandstone and siltstone, but it also includes carbonate rocks (Lavrovich, 1971). Depositional environments change upsection in the Chinei Group from littoral marine to lagoonal (locally with subaqueous deltas) and subcontinental settings (Bogdanov and others, 1966).

The Inyr Formation consists of fine-grained, gray arkosic to pure quartz sandstone with beds of black siltstone. Quartzose gravel beds occur locally at the base of this unit (Bogdanov and others, 1966). Thicknesses range from 250 to 800 m.

The Chitkanda Formation is divided into two subformations (Bogdanov and others, 1966). The lower unit consists of fine-grained arkosic sandstone (commonly with carbonate cement), siltstone, and shale. Stratification is horizontal to wavy; however, wavy cross- to finely cross-stratified rocks with ripple marks are also present. This lower unit is 350–1,300 m thick. The upper unit consists of light-colored arkosic sandstone interbedded with thin-bedded black shale.

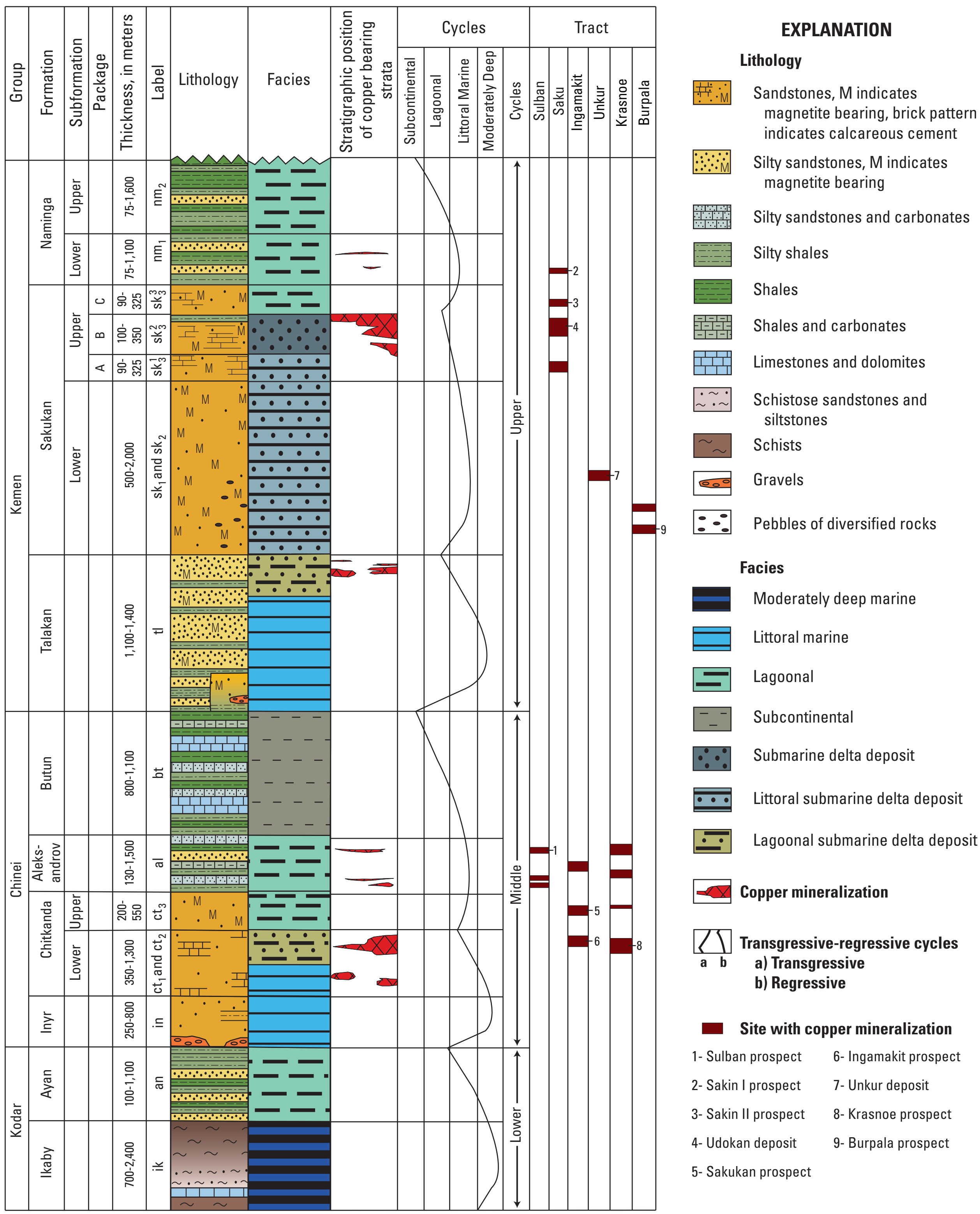


Figure 6. Stratigraphic column of the Kodar-Udokan sedimentary complex, Russia, showing the rocks included in the six defined permissive tracts and the stratigraphic position of mineralization in those assessed tracts (modified from Bogdanov and others, 1966).

Wavy stratification to wavy cross-stratification, locally enhanced by magnetite partings, is characteristic; ripple marks and mud cracks are also present. This upper unit is 200–550 m thick. The high sodium contents in sandstones of the Upper Chitkanda subformation suggest the presence of tuffaceous material (Podkovyrov and others, 2006).

An alternating sequence of thin siltstone, shale, silty sandstone, marl, and dolomite characterize the Aleksandrov Formation (Bogdanov and others, 1966). In the eastern part of the Kodar-Udokan Trough, the bedding planes show numerous ripple marks, mud cracks, and turbidite structures, whereas horizontal stratification is predominant in the south and west. This formation is 130–1,500 m thick.

The Butun Formation consists of alternating siltstone, shale, limestone, and dolomite (Bogdanov and others, 1966). In the northeastern part of the Kodar-Udokan Trough, the rocks are altered to lilac gray albitite that shows only a vestige of original stratification. Carbonate rocks become more abundant to the west.

The Kemen Group, which includes the Talakan, Sakukan, and Naminga Formations, lies conformably on the Chinei Group. Facies reflect an upward change from moderately deep-water littoral marine to deltaic and lagoonal settings (Bogdanov and others, 1966; Lavrovich, 1971).

The Talakan Formation is made up of fine-grained, mainly arkosic sandstone, siltstone, and shale, horizontally to wavy- and finely cross-stratified (Bogdanov and others, 1966). Cupriferous sandstone and siltstone units are also present. Thicknesses vary from 1,000 to 2,900 m.

The Sakukan Formation is divided into two subformations (Bogdanov and others, 1966). The Lower Sakukan consists of fine- to medium-grained, cross-stratified arkosic sandstone. Horizontal stratification is uncommon. Magnetite partings that enhance stratification are characteristic. Floating pebbles (dropstones) of intrusive, volcanic, and metamorphic rocks occur near the base (Burmistrov, 1990). The Lower Sakukan deposits formed by longshore and bottom shelf currents and to a lesser degree, by storm surges; these rocks may represent a marine molasse deposit (Burmistrov, 1990). Thicknesses range from 500 to 2,000 m.

The Upper Sakukan consists of fine-grained sandstone, more or less arkosic, accompanied by siltstone and shale (Bogdanov and others, 1966). A typical feature is the presence of calcite-cemented lenticular sandstone with shale fragments. The stratification varies from cross to wavy and horizontal, with ripple marks and mud cracks. The Upper Sakukan strata form fining-upward sequences typical of coastal-marine, subaqueous-delta, and terrestrial-delta environments (Burmistrov, 1990). This unit is 280 to 1,000 m thick.

The Naminga Formation consists of gray siltstone, shale, and silty sandstone (Bogdanov and others, 1966). Ripple marks and mudcracks are common on bedding surfaces (Volodin and others, 1994). These sedimentary rocks most likely accumulated in shallow-water bays, lagoons, and lakes (Burmistrov, 1990). Thicknesses range from 150 to 2,700 m.

In the Russian scientific literature, some scientists propose that the Kemen Group is Neoproterozoic rather than Paleoproterozoic. Some researchers believe they have found Riphean stromatolitic species and medusoid imprints in different metasedimentary units of the Udokan Complex (Gablina and Malinovksii, 2008). The morphology of a fossil, *Udokania problematica*, is comparable to those of some Neoproterozoic or lower Paleozoic organisms (Burmistrov, 1993). Based on this interpretation of fossil data, the spatial position of units in the Kodar-Udokan Trough is proposed to be a consequence of regional overthrusting, and the dropstones in the Lower Sakukan Subformation could be equivalent to those in other Neoprotereozoic glacial deposits (Burmistrov, 1993). This interpretation is not universally accepted and would not affect the outcome of the mineral resource assessment.

Assessment Data

Data used for the mineral resource assessment include 1:200,000-scale Russian geologic maps published between 1973 and 1976 and a 1:200,000-scale Russian metallogenic map published in 1984 (fig. 7). These maps were scanned and rectified for use in GIS. The assessment team also had access to a digital version of the 1:1,000,000-scale geologic maps of the Aldan and Bodaybo sheets (Konnikov and others, 1984; Lagzdina and others, 1978) and the 1:2,500,000-scale geologic map of Russia (Sergey Shokalsky, written commun., 2009).

Cupriferous sandstones of the Kodar-Udokan area are confined to specific stratigraphic units in the Chinei and Kemen Groups: the Sulban group of occurrences are found in the Aleksandrov Formation; the Krasnoe, Sakukan, and Pravo Ingamakit sites are hosted by the Chitkanda Formation; and the Burpala, Sakin II, Udokan, and Unkur occurrences are within the Sakukan Formation (fig. 6). Previously compiled mineral occurrence databases (such as Kirkham and others, 1994; Cox and others, 2003; Kirkham and Broughton, 2005) were not complete for this area. Mineral occurrences (points), mineralized layers (lines), and mineralized areas (polygons) were digitized from Russian geologic and mineral maps; however, for most mineral occurrence sites, only the location, general deposit type, and commodity are known.

Estimates of the mineral inventory for deposits and prospects are summarized in table 2. Only the Udokan and Unkur sites meet the criteria for deposits as defined in this report. All other sites are considered prospects. The geology of these deposits and prospects is summarized in appendixes A through F.

Aeromagnetic and gravity maps at 1:500,000 scale were provided by Russian colleagues; these were rectified for use in GIS. Gridded total magnetic field and reduced-to-pole aeromagnetic data (cell size = 2.5 km; scale approximately 1:2,500,000) were derived from National Oceanographic and Atmospheric Administration (1997).

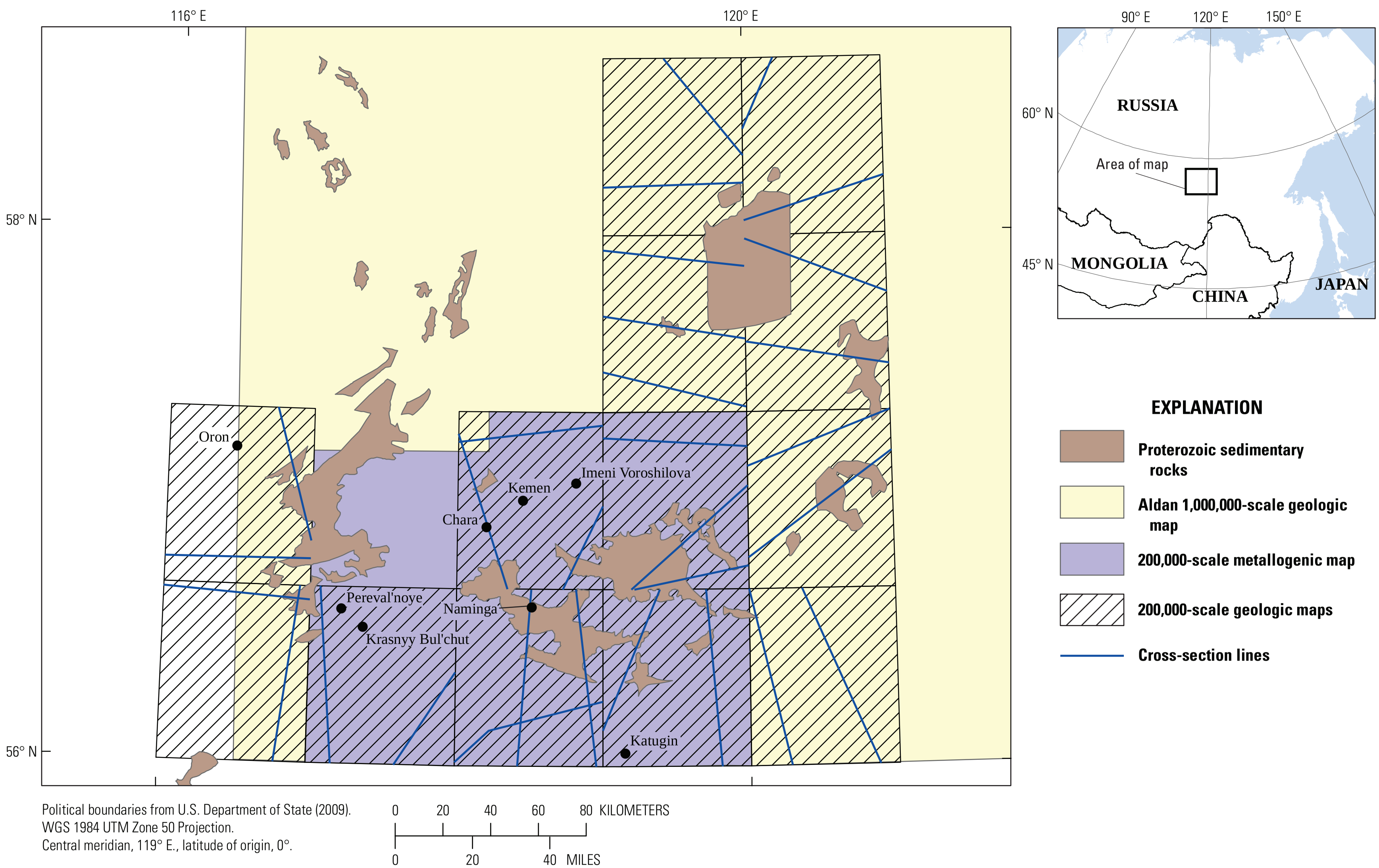


Figure 7. Map showing location and extent of geologic maps and cross sections used in the mineral resource assessment of the Kodar-Udokan area, Russia, superimposed on the general geology of the area.

Table 2. Sandstone copper deposits and prospects in the Kodar-Udokan area, Russia.

[Reserve and resource categories are explained in Diatchkov (1994), Jakubiak and Smakowski (1994), and Henley and Young (2006). Mt, million metric tons; %, percent; g/t, grams per metric ton; NA, no data. B, C1, C2, P1, and P2 are Russian mineral resource categories. B, C1, and C2 are analogous to measured, indicated, and inferred mineral resources as defined by CRIRSCO, respectively. P1 and P2 are analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS. P1 represents estimates associated with extensions to inferred resources and P2 refers to estimates for exploration targets]

Name	Host rock unit	Status	Resource category	Ore (Mt)	Cu grade (%)	Ag grade (g/t)
Burpala	Sakukan Formation	Prospect, with partial delineation of resources	C2	15.9	1.26	67.9
			P1	27.5	1.15	49.7
			C2+ P1	43.4	1.19	56.3
Krasnoe	Chitkanda Formation	Prospect	P1	33	1.50	NA
Pravo Ingamakit	Chitkanda Formation, Srednechitkan Member	Prospect, with partial delineation of resources	C2	54.3	0.88	23.9
			P1	69.1	0.88	23.9
			C2+ P1	123.4	0.88	23.9
Sakin - I	Naminga Formation and Upper Sakukan Subformation	Prospect	P1	56.4	0.81	10.9
Sakin - II	Sakukan Formation, upper subformation	Prospect	P1	41.1	0.98	3.1
			P2	24.7	0.98	3.9
			P1+ P2	65.8	0.98	3.9
Sulban group 1. Seregli-Kukugunda	Aleksandrov Formation	Prospect	P1	66.8	0.72	NA
Sulban group 2. Vershina Khadatkandy	Aleksandrov Formation	Prospect	P1	27.5	1.90	NA
Udokan	Sakukan Formation, upper subformation	Deposit	B+C1+C2	1,310.8	1.44	13
			C1 sub economic	770.6	0.38	4
			P1	217.2	1.20	10
Unkur	Sakukan Formation, lower subformation	Deposit, with potential for additional resources	C2	90.9	0.75	70.8
			P1	52.5	0.75	70.8
			C2+ P1	143.4	0.75	63.8

Exploration maps and cross sections for the Unkur, Sakin, Burpala, Sulban, and Krasnoe areas were supplied by Russian colleagues (fig. 8), who also provided a summary of copper reserve and resource data associated with sandstone-type copper deposits in the Kodar-Udokan area (table 2).

Exploration Activity in the Kodar-Udokan Area

The Udokan deposit was discovered by E.I. Burova and K.K. Denisov in 1949 (Volodin and others, 1994). Geology of the deposit was first described and a preliminary estimate of its size given in reports by the Forest Expedition of the Ministry of Geology and Preservation of Mineral Resources, USSR, which were based on exploration conducted by A.A. Semikhatov, G.A. Rusinov, and T.M. Mikhailova that ended in 1952. Subsequently, the deposit was explored in two phases by the Udokan Geological Exploration Expedition of the Chita Industrial Geological Department (table 3). After the first phase of work (1952 to 1966), commercial copper reserves were estimated according to the standards of the State Reserves Committee, USSR (SRC USSR). The second phase began in 1975 in connection with the Soviet government decision to construct the Baikal-Amur main rail line. The reserve estimate for the Udokan deposit was revised and subsequently confirmed by the SRC USSR. Exploration operations and surveys by different Russian technical institutes continued at Udokan and adjacent areas until about 2000 (Baikal Mining Company LLC, 2010). In 2008, the bid of Mikhailovsky GOK (incorporated into the Metalloinvest Group) won the rights to develop the Udokan deposit, and a mining license was acquired in 2009. Table 3 summarizes the dates of mapping, sampling, and drilling recorded on materials used for this assessment.

Delineation of the Permissive Tracts

As previously described, ore systems that result in sediment-hosted copper mineralization require (1) a source of metal and sulfur, (2) a fluid capable of carrying metals in solution, (3) basin-scale fluid-flow systems that transport these metal-bearing fluids, and (4) a chemical and (or) physical trap in the basin that causes precipitation of sulfide minerals from the solution. In the Kodar-Udokan area, only features related to the first and third criteria are known.

Even though all components for a sandstone copper ore system are not recognized in the Kodar-Udokan Trough, the presence of deposits and occurrences in the Paleoproterozoic metasedimentary strata of the region indicate that these rocks are permissive for the occurrence of undiscovered sediment-hosted copper deposits.

Potential sources of metal and sulfur and oxidized brines are not widely discussed in the literature on the Udokan-Kodar deposits. Mafic volcanic rocks, a potential source of copper, are not a component of the Paleoproterozoic basin of the Kodar-Udokan Trough. However, a small Archean greenstone belt (the Olondinsky) occurs to the north in the Olekma Terrane (fig. 4). The metasedimentary rocks are just young enough (relative to the global Great Oxygenation Event at about 2.45 to 2.32 Ga; Bekker and others, 2004) that subareal depositional environments in the upper sections of the Chinei and Kemen Groups could have formed red beds (fig. 9), which are also a potential source of copper. However, the mineralogy of originally hematite-bearing minerals within these strata has been modified by metamorphism (Gablina and Vasilovskaya, 1989); these rocks are now represented by magnetite-bearing sandstones (fig. 6). The original nature and extent of red bed deposits are therefore difficult to determine.

The sediment-hosted copper deposits and dozens of additional copper occurrences are found in coarse-grained, reservoir-facies siliciclastic rocks of the Chinei and Kemen Groups (fig. 6). Most cupriferous sandstones are associated with the Chitkanda, Aleksandrov, Talakan, and Sakukan Formations (Bogdanov and others, 1966). Within these formations, copper mineralization is most likely to occur in facies deposited in a subaqueous delta that developed in shallow lagoonal waters (Bogdanov and others, 1966).

Other criteria that could indicate favorable settings for sandstone copper deposits in the Kodar-Udokan Trough are absent or are not described. Evaporite deposits, a likely source of oxidized brines, have not been identified in these Paleoproterozoic metasedimentary rocks. However, saline brines may have formed during deposition of subareal sediments of the upper parts of the Chinei and Kemen Groups. Movement of brines in the basin can be documented by diagenetic alteration of the sediments, notably albitization and the conversion of red beds to gray beds. Studies in the literature describes silicification associated with mineralization (Gablina and Mikhaylova, 1994); variable amounts of sericite and calcite cements in the coarser clastic deposits and albitization near some copper deposits (Chechetkin and others, 2000); and albitization of parts of the Butun Formation (Bogdanov and others, 1966; Lesnyanskii, 1989; Gablina and Vasilovskaya, 1989). However, regional patterns of fluid movement in the sediments cannot be discerned from available information.

In some sedimentary basins, the structural and (or) stratigraphic traps that localized sediment-hosted copper deposits are known. For example, sandstone copper mineralization in the Paradox Basin, Colorado and Utah, is related to salt-cored anticlines (Hahn and Thorson, 2006), and maps clearly show the relation of copper mineralization to anticlines in the Chu-Sarysu Basin, Kazakhstan (Syusyura and others, 2010). Stratigraphic traps that localized mineralization in the Kupferschiefer in Germany are described by Schmidt and others (1986). Using available information, structural or stratigraphic traps in the Kodar-Udokan area could not be identified. The rocks are complexly deformed and folded, but the obvious fold structures appear to postdate the mineralizing event.

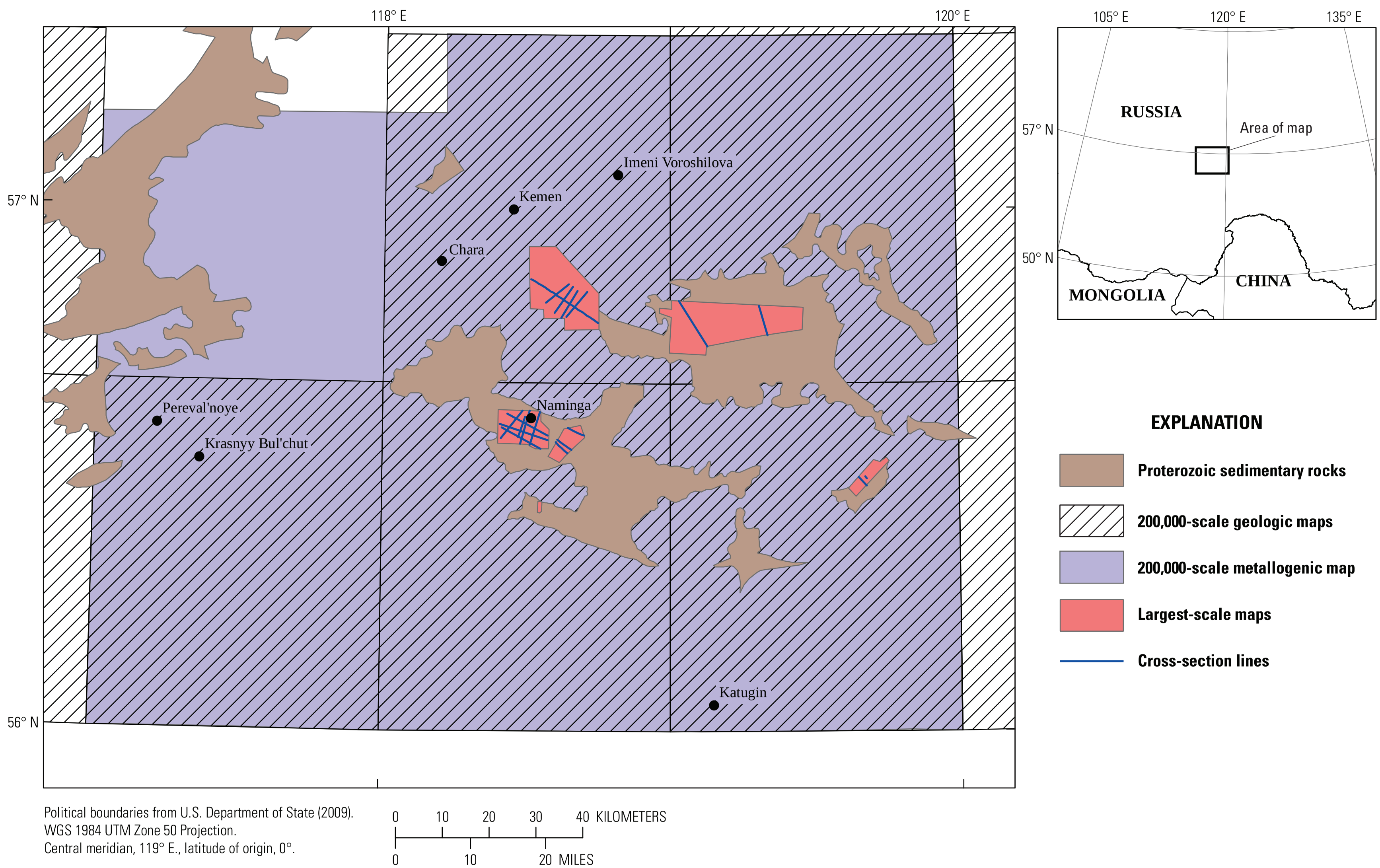


Figure 8. Map showing location and extent of detailed exploration geologic maps and cross sections used in the mineral resource assessment of the Kodar-Udokan area, Russia, superimposed on the general geology of the area.

Table 3. Summary of the times when exploration-related work was conducted in the Kodar-Udokan area, Russia.

Theme and scale	Permissive tract					
	150ssCu0001 Sulban	**150ssCu0002 Saku**	**150ssCu0003 Ingamakit**	**150ssCu0004 Unkur**	**150ssCu0005 Krasnoe**	**150ssCu0006 Burpala**
Geologic mapping						
1:10,000	1981–2001	1951–2001	1981–2001		1981–2001	
1:25,000	1957–1980	1957–2001	1957–2001	1981–2001	1981–2001	
1:50,000	1969–1970; 1975–1977	1961–1964; 1975–1989	1961–1964; 1967–1968; 1978–1989	1961–1962; 1975–1977; 1982–1989	1961–1962; 1967–1968; 1975–1989	1963–1964; 1967–1968; 1978–1989
1:200,000		1971–1984; 1999–2003	1999–2003	1971–1984	1971–1984; 1999–2003	1999–2003
Published geologic mapping						
Geologic—1:200,000	1973[2]	1973[1]; 1974[5]; 1975[6]	1973[2]; 1976[3]	1975[6]	1973[4]; 1975[6]; 1976[3]	1976[3]
Metallogenic—1:200,000	1984[7]	1984[7]	1984[7]	1984[7]	1984[7]	1984[7]
Geophysical and geochemical surveys						
Ground magnetic—1:10,000–1:50,000	1976–1990	1959–1990	1959–1990	1959–1990	1959–1990	
Geochemical—1:50,000	1963–1970; 1979–1980	1979–1990	1971–1990	1979–1990	1971–1990	1971–1990
Geochemical—1:100,000–1:200,000	1979–1990	1979–1990	1960–1963	1960–1963	1960–1963	1960–1963
Drilling and trenching						
Drilling—1:10,000–1:25,000		1973–1975; 1983–1985		1971–1972; 1975–?		
Trenches—1:10,000–1:25,000		1973–1975; 1983–1985		1971–?; 1978–?		

Geologic maps: [1]Bufeev and Shcherbakova (1973), [2]Enikeev (1973), [3]Fedorovskiy (1976), [4]Glukhovskiy (1973), [5]Kolesnikov and others (1974), [6]Shul'gina (1975); metallogenic map: [7]Feoktistov and Chechetkin (1984)

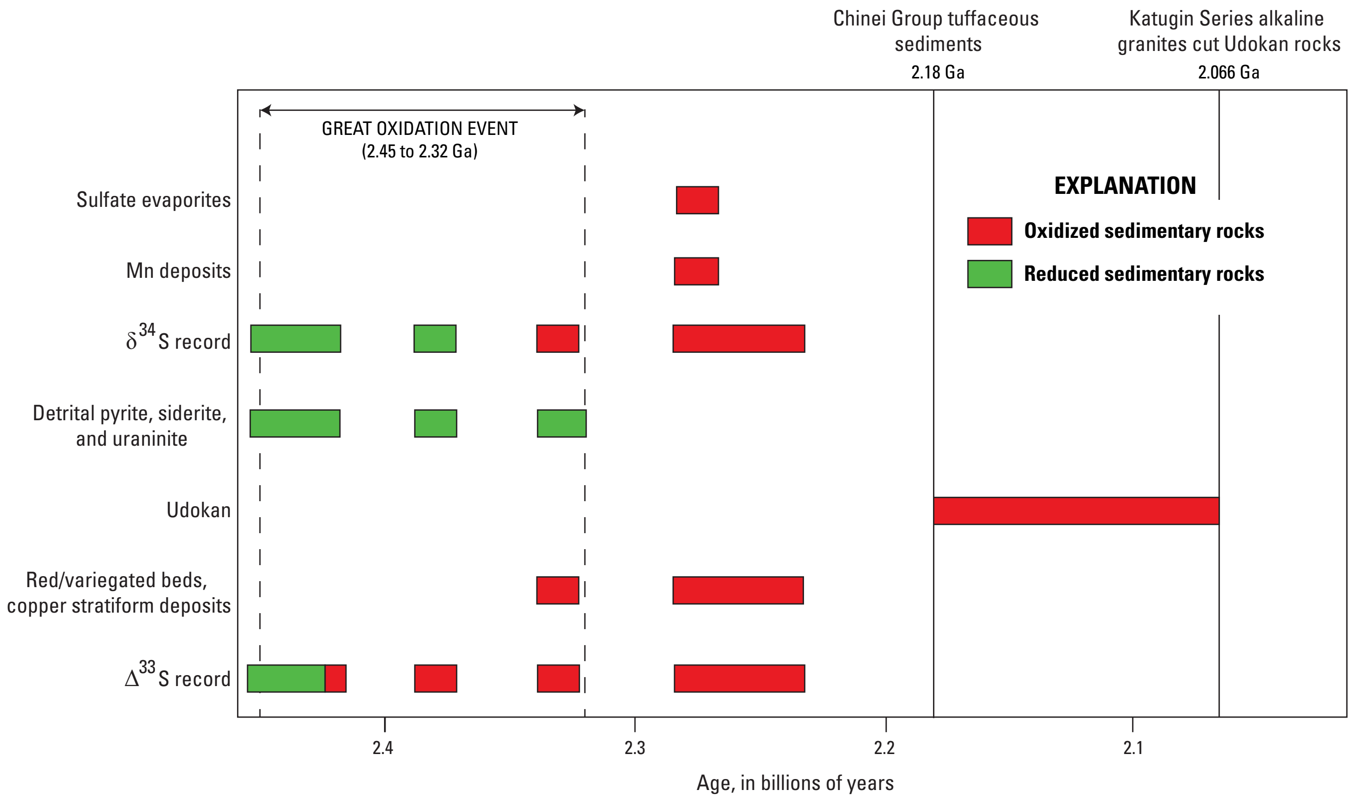


Figure 9. Time chart showing the transition from reduced to oxidized sedimentary rocks in response to changes in the oxygen levels of the Earth's atmosphere at the Great Oxidation Event, including the first appearance of red bed deposits (modified from Panel on Effects of Past Global Change on Life, National Research Council, 1995 and Bekker and others, 2004).

Therefore, the fundamental unit for delineation of permissive rocks in the Kodar-Udokan Trough is coarse-grained siliciclastic metasedimentary strata, which make up all or part of the Chitkanda, Aleksandrov, Talakan, and Sakukan Formations. Sediment-hosted stratabound copper mineralization has been described in siliciclastic rocks that form subaqueous deltaic complexes within these formations. Rocks deposited in deltaic environments form stacked distributary channels and sheet sands that have greater hydrologic conductivity than surrounding rocks, thus promoting the flow of potential metal-bearing brines. Clastic rocks deposited in subaqueous deltaic environments can be expected to have reduced mineral assemblages; however, the most likely reductant that would cause precipitation of copper in the sediments is hydrocarbons. Volodin and others (1994) briefly mention that organic carbon contents are higher in copper-rich ores than in surrounding rocks. Contents of organic carbon of the Upper Sakukan subformation in the Udokan deposit range from 0.02 to 0.12 weight percent in ordinary ores, 0.02 to 0.11 weight percent in weakly mineralized sandstones, and 0.01 to 0.05 weight percent in adjacent, nonmineralized rocks. The organic carbon content of bornite-chalcocite mineralization in the Udokan deposit ranges from 0.04 to 2.08 weight percent (Arkhangel'skaya and others, 2004)

Paleoproterozoic rocks that occur in the Ugui, Oldengsin, and Nizhnaharin Troughs were not assessed for undiscovered sandstone copper deposits (fig. 4). All three of these areas are characterized by thin stratigraphic sequences (approximately 1 to 1.5 km thick) and complex structures. The sections that are exposed represent the lower part of the Udokan Complex, from the Ikaby to the Chitkanda Formations. Copper occurrences in the Ugui Trough are similar to those found in the Chitkanda Formation in the Kodar-Udokan Trough; however, chalcopyrite is the only observed copper mineral (no bornite), and concentrations of silver are low. Rocks north of the Sygykta River (shown as undifferentiated trough on figs. 4 and 10) are also excluded from the assessment because they are too low in the stratigraphic section to contain coarse-grained siliciclastic sedimentary rocks.

The permissive tract is delineated by locating and estimating the volume of rock containing siliciclastic strata that lie stratigraphically above the Inyr Formation and projecting it to the surface (figs. 6, 10, and 11). Each tract is given a name and an identification code. Six tracts were delineated (from west to east): (1) Sulban (150ssCu0001); (2) Saku (150ssCu0002); (3) Ingamakit (150ssCu0003); (4) Unkur (150ssCu0004); (5) Krasnoe (150ssCu0005); and (6) Burpala (150ssCu0006). Specific information for each tract is given in appendixes A through F.

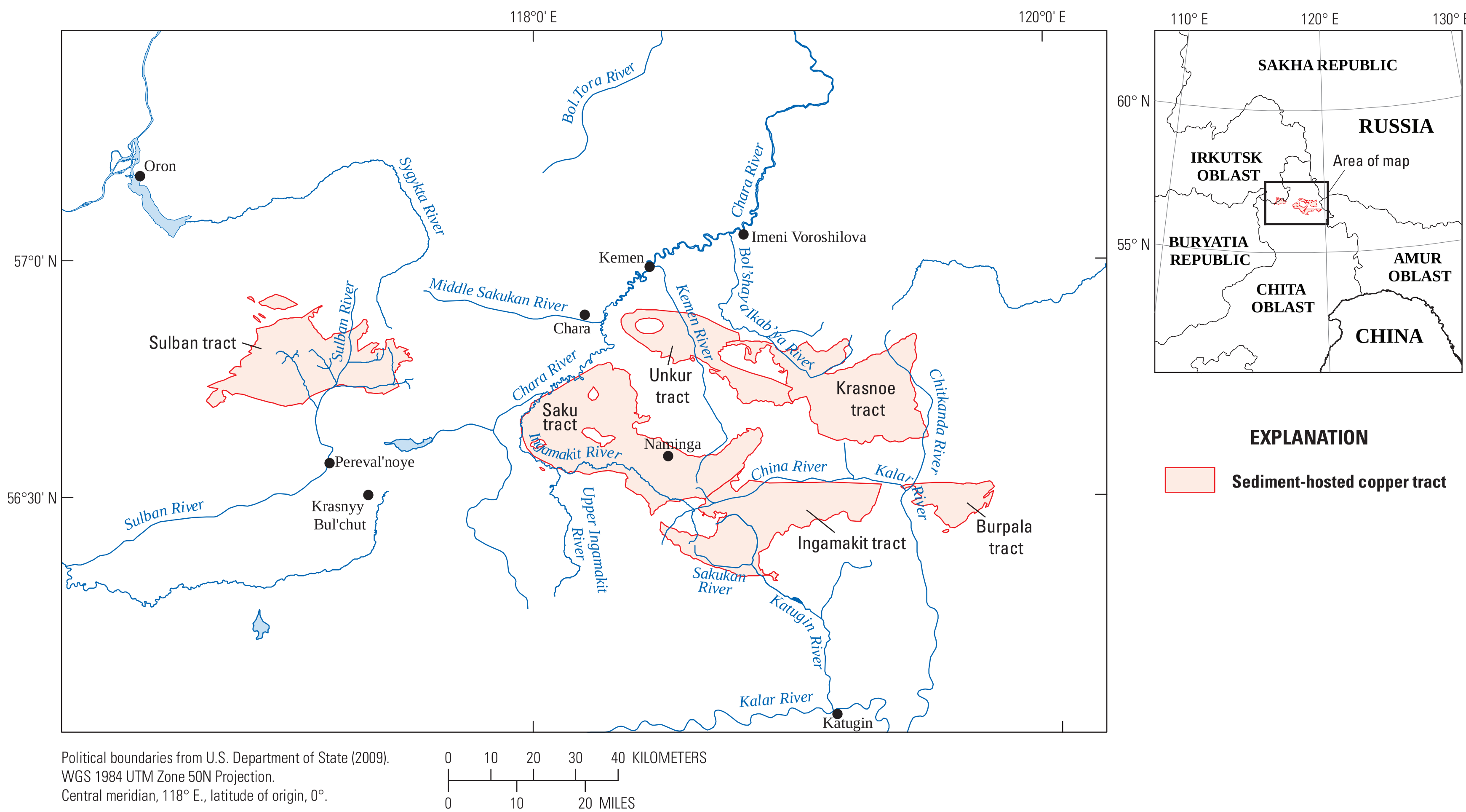


Figure 10. Index map showing the six sandstone copper permissive tracts delineated for the Kodar-Udokan assessment, Russia, in relation to major rivers.

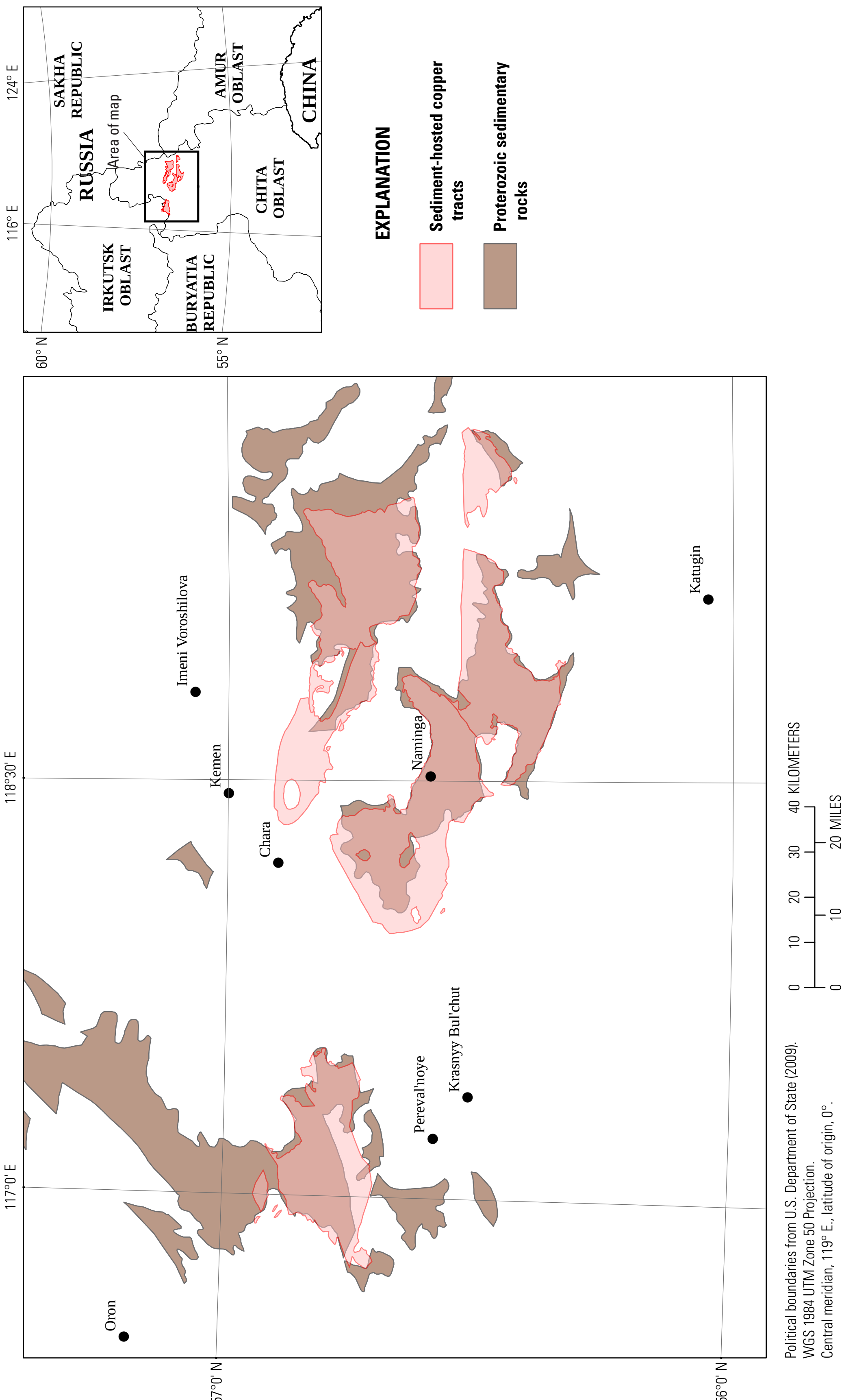


Figure 11. Index map showing the relation of Proterozoic sedimentary rocks to the six sandstone copper permissive tracts delineated for the Kodar-Udokan assessment, Russia. The tracts extend beyond the mapped distributed of Proterozoic sedimentary rocks where they have been projected under cover.

The widespread distribution of copper deposits and occurrences and the lack of detailed facies or alteration maps prevent the tracts being made more selective, areally or stratigraphically, within the Kodar-Udokan area. Generalized facies maps published by Bogdanov and others (1966) show that most of the Kodar-Udokan Trough is underlain by facies where sediment-hosted copper mineralization may exist.

Tract delineation is based on 1:200,000-scale geologic and mineral maps published beween 1973 and 1976 (Bufeev and Shcherbakova, 1973; Enikeev, 1973; Glukhovskiy, 1973; Kolesnikov and others, 1974; Shul'gina, 1975; Fedorovskiy, 1976) and a 1:200,000-scale metallogenic map (Feoktistov and Chechetkin, 1984). Polygons were digitized that comprise all Paleoproterozoic units above the Inyr Formation; rocks of the Chinei and Kemen Groups were distinguished to aid understanding of fold geometry. Axial traces of folds, faults having obvious offset at 1:200,000-scale, contours of Quaternary basin fill (Feoktistov and Chechetkin, 1984), and locations of cross sections were also digitized. The bedrock units from the 1:200,000-scale maps were projected under Quaternary cover using the cross sections, contours of basin-fill, and an image of a 1:500,000-scale aeromagnetic survey. Projections in the Unkur area were further constrained by an unpublished exploration map.

Sandstone Copper Tonnage and Grade Model

Mineralized rocks in the Kodar-Udokan metasedimentary succession display the same geologic characteristics as other sandstone copper deposits in the world. Therefore, grade and tonnage data for other sandstone copper deposits can be used to forecast undiscovered resources associated with sediment-hosted copper mineralization in the Kodar-Udokan Trough metasedimentary rocks. The deposit model used in this assessment is the sandstone copper model described by Zientek and others (2013) and in appendix G. The grade and tonnage model is based on 70 deposits; median and mean values, respectively, are (1) for ore tonnage, 10 and 77 million metric tons, and (2) for copper grade, 1.2 and 1.4 percent. Summary statistics are given in table 4.

Estimates of the Number of Undiscovered Deposits

Numbers of undiscovered deposits were estimated by an expert panel of geologists at an assessment workshop in October 2009 at Vancouver, Washington. Short biographies of the workshop participants, who are also the authors of this report, can be found in appendix I.

In the assessment workshop, the geology of the area and the deposit model were summarized and each tract was discussed in turn. After the discussion of a tract, the scientists were asked to estimate the number of undiscovered deposits at three to five probability percentiles (90th, 50th, 10th, 5th, and 1st). For example, an estimate at the 90th percentile is the greatest number of deposits for a given deposit type in a permissive tract being present that has a probability of 0.9 or more; that is, the probability of that many deposits or fewer being present is 0.9 or greater, and the probability of more deposits is less than 0.9. The estimators tried to estimate nonzero values for at least three of the percentiles (for example, 90th-50th-10th is X-X-X or 90th-50th-10th-5th-1st is 0-0-X-X-X).

General strategies have been suggested on how to arrive at undiscovered deposit estimates (such as those summarized by Singer and Menzie, 2010, p. 125–126 and p. 132 and following pages). Each geologist at the workshop recorded

Table 4. Summary statistics for sandstone copper deposits used as a grade and tonnage model for the Kodar-Udokan assessment (Zientek and others, 2013).

[Mt, million metric tons; %, percent; g/t, grams per metric ton; – no data]

Material	Number of deposits	Mean	Quantile 5th	Quantile 10th	Quantile 25th	Median	Quantile 75th	Quantile 90th	Quantile 95th
Ore (Mt)	70	77	1.1	1.9	4.5	10	39	91	310
Copper grade (%)	70	1.4	0.5	0.5	0.8	1.2	1.7	2.6	3.7
Silver grade (g/t)	18	38	8.0	11	13	32	64	73	93
Cobalt grade (%)	3	0.1	–	–	–	–	0.2	0.2	0.2
Contained copper metal (Mt)	70	1.0	0.016	0.018	0.054	0.12	0.41	1.0	5.5

their initial estimate on a ballot; after everyone had voted, the results were compiled and discussed. Initial estimates for each tract are tabulated in appendixes A through F and illustrated in figure 12. The results were discussed, usually with the persons giving the lowest and highest estimates providing their rationales for the estimates. This discussion almost always revealed information or insight not held by all of the panelists. The results were then adjusted and a single estimate was proposed for use with the tonnage and grade model in the Monte Carlo simulation process.

Plots of the undiscovered deposit estimates show that some USGS panelists typically had higher estimates than those made by experts outside the USGS (fig. 12). Analysis of the process reveals that panelists were using different strategies to estimate the number of deposits. Some of those who provided lower numbers were thinking about the extremes, in particular assessing the 90th percentile first, then considering the maximum number of deposits that could be present given the size of the deposits, the size of the tracts, and deposit density. Those who provided higher numbers were estimating the mean number of deposits based on the prognostic resource estimates previously made by Russian geologists. They then estimated the extremes to give a coefficient of variation indicating their uncertainty. In selecting a final value to use in the simulation, estimates made by panelists who had firsthand experience in the study area were weighted more than those made by people who did not. In addition, the estimates made by estimating the 90th percentile first were weighted more than those that estimated the mean number of deposits based on prognostic estimates. Deposit estimates used in the simulation process are given in table 5.

Preliminary assessment results were presented to a panel of mineral-resource assessment specialists and economic geologists in the USGS. In addition to hearing presentations, this Assessment Oversight Committee had access to all available data and could ask the assessment team technical questions. The committee provided a formal evaluation of the assessment, and their written comments were addressed in the preparation of this report.

Summary of Assessment Results

The estimated mineral inventory associated with known deposits and prospects within each tract is listed in table 6. There has been no mineral production in this area. More than 20 million metric tons of copper in the B and C resource categories have been delineated; however, more than 90 percent of this endowment is within the Udokan deposit. According to categories defined in Singer (1995), Udokan is a “giant” copper deposit (containing reserves and resources in excess of 2 million metric tons of contained copper). “Giant” deposits make up only 10 percent of the number of known copper deposits in the world, but collectively contain more than 80 percent of the metal discovered. The amount of copper delineated in the Burpala, Ingamakit, and Unkur tracts is classified as significant (each containing more than 50,000 metric tons copper; U.S. Geological Survey National Mineral Resource Assessment Team, 2000).

Summary statistics derived from 4,999 trials in the Monte Carlo simulation for undiscovered copper in each tract are summarized in table 7 and figure 13. Results are reported at selected quantile levels, together with the mean expected amount of metal, the probability of the mean, and the probability of no metal being present. The amount of metal reported for each quantile represents the least amount of metal expected. Mean estimates for each tract can be added to obtain the estimated total amount of copper in undiscovered deposits in the Kodar-Udokan area. The probability of occurrence associated with the mean typically is on the order of 20 to 40 percent.

This probabilistic assessment indicates that a significant amount of undiscovered copper is associated with sediment-hosted stratabound copper deposit in the Kodar-Udokan Trough (tables 7 and 8). The mean estimate of undiscovered copper in the study area, 20.6 million metric tons, is about the same as the known resources, 21.1 million metric tons. Significant value can be expected from associated metals, particularly silver. By comparison, the Chu-Sarysu Basin in Kazakhstan has identified copper resources of 27.6 million metric tons with a mean estimate of 25.1 million metric tons of undiscovered copper associated with an estimate of 26 undiscovered sandstone-type sediment-hosted stratabound copper deposits (Box and others, 2012).

Assumptions about dependencies among tracts need to be considered before percentile values are aggregated (Schuenemeyer and others, 2011). The percentile values can be added only if results for the tracts are totally dependent. Total dependency implies that the processes that control the distribution of deposits are related among tracts. If one tract has a large number of deposits, then all other tracts will have large numbers of deposits. However, the relation of ore-forming systems among the tracts that is needed to support this type of dependency is lacking. Conditions of total independence or partial correlation are thus a reasonable assumption for these tracts.

How much copper is present in undiscovered sandstone copper deposits in the Kodar-Udokan area? On the basis of the mean estimates from the Monte Carlo simulation, undiscovered deposits of this type in the assessed areas may contain a total of at least 20.6 million metric tons of copper. Resource estimates for undiscovered sandstone copper deposits are compared with identified and prognostic resource estimates in figure 13. Undiscovered resource estimates at the 50th percentile are comparable to the contained copper in P-category forecasts of undiscovered material represented by the prognostic resource estimate (fig. 14). For most tracts, more copper is estimated to be present than has been delineated by drilling and sampling (C category resources). Only for the Saku tract are fewer undiscovered resources predicted than those identified; this reflects discovery of the world-class Udokan deposit and the high degree of exploration near this deposit.

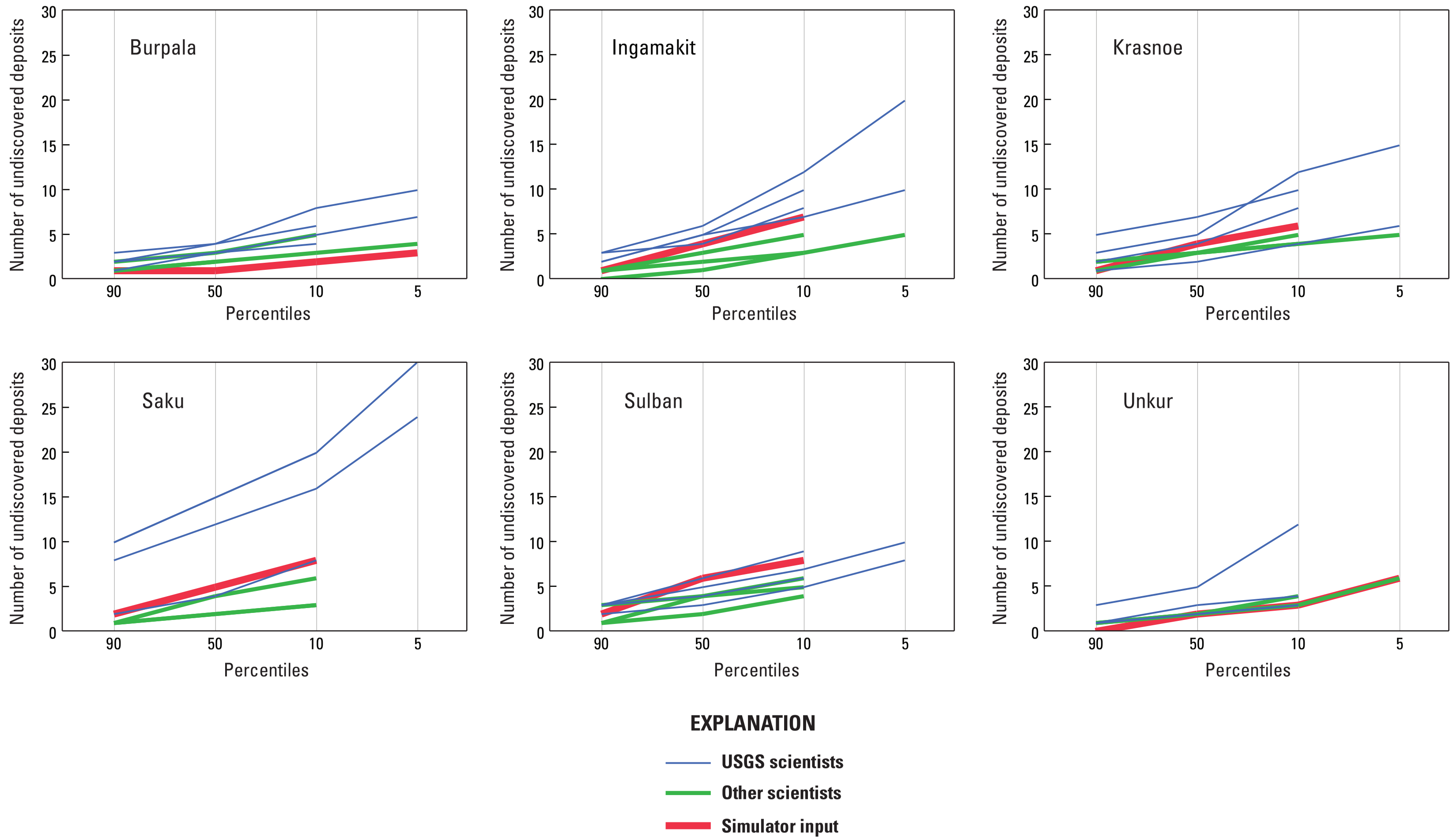


Figure 12. Parallel plots showing, for each of the six delineated tracts, the initial estimates of the number of undiscovered deposits made by scientific experts and the final estimates used for resource simulation for the six tracts assessed in the Kodar-Udokan area, Russia.

Table 5. Undiscovered deposit estimates for the Kodar-Udokan area, Russia.

[N_{XX}, Estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; Tract area, area of permissive tract in square kilometers; N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Coded ID	Tract name	Consensus undiscovered deposit estimate					Summary statistics					Tract area (km²)
		N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	*s*	C_v%	N_{known}	N_{total}	
150ssCu0001	Sulban	3	6	8	8	8	5.5	1.9	34	0	5.5	590
150ssCu0002	Saku	2	5	8	8	8	4.9	2.2	45	1	5.9	826
150ssCu0003	Ingamakit	1	4	7	7	7	3.9	2.2	55	0	3.9	553
150ssCu0004	Unkur	0	2	3	6	6	1.9	1.7	86	1	2.9	303
150ssCu0005	Krasnoe	1	4	6	6	6	3.6	1.8	49	0	3.6	603
150ssCu0006	Burpala	1	1	2	3	3	1.3	0.75	57	0	1.3	129

Table 6. Summary of previous mineral resource estimates for the Kodar-Udokan area, Russia.

[Reserve and resource categories are explained in Diatchkov (1994), Jakubiak and Smakowski (1994), and Henley and Young (2006). t, metric tons; –, no data. B, C1, C2, P1, and P2 are Russian mineral resource categories. B, C1, and C2 are analogous to measured, indicated, and inferred mineral resources as defined by CRIRSCO, respectively. P1 and P2 are analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS. P1 represents estimates associated with extensions to inferred resources and P2 refers to estimates for exploration targets]

Tract no.	Tract name	Known deposits	Significant prospects	Category of resources	Contained copper in B and C categories (t)	Contained copper in P category (t)	Contained copper in B+C+P categories (t)
4	Unkur	Unkur	–	C2>P1	682,000	393,800	–
6	Burpala	–	Burpala	C2<P1	201,100	315,900	517,000
5	Krasnoe	–	Krasnoye	P1	–	495,000	495,000
3	Ingamakit	–	Pravo Ingamakit	C2<P1	477,900	608,000	1,085,900
2	Saku	Udokan	–	B1+C1+C2> P1	19,730,000	2,600	19,732,600
2	Saku	–	Saku I; Saku II	P1 and P2	–	646,400	–
1	Sulban	–	Vershina Khadat-kandy; Seregli–Kukugunda	P1	–	1,003,460	1,003,460
Total					21,091,000	3,465,160	22,833,960

Table 7. Summary statistics for the quantitative mineral resource estimates of undiscovered sandstone copper mineralization in the Kodar-Udokan area, Russia.

Tract name	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Undiscovered resources of copper (metric tons)								
Burpala	0	16,000	180,000	2,100,000	7,400,000	1,300,000	0.14	0.07
Ingamakit	0	69,000	1,100,000	12,000,000	19,000,000	3,900,000	0.23	0.06
Krasnoe	0	58,000	970,000	11,000,000	19,000,000	3,600,000	0.21	0.07
Saku	52,000	190,000	1,500,000	15,000,000	21,000,000	4,700,000	0.24	0.04
Sulban	120,000	320,000	1,800,000	16,000,000	24,000,000	5,300,000	0.25	0.03
Unkur	0	0	290,000	3,700,000	11,000,000	1,800,000	0.15	0.19
Undiscovered resources of silver (metric tons)								
Burpala	0	0	0	2,000	5,200	1,200	0.13	0.69
Ingamakit	0	0	520	9,100	18,000	3,600	0.2	0.37
Krasnoe	0	0	430	8,300	16,000	3,200	0.2	0.4
Saku	0	0	790	12,000	19,000	4,100	0.23	0.29
Sulban	0	0	1,100	12,000	20,000	4,500	0.25	0.24
Unkur	0	0	0	3,200	7,900	1,600	0.15	0.63
Rock in undiscovered deposits (million metric tons)								
Burpala	0	1	14	180	790	110	0.14	0.07
Ingamakit	0	7	97	1,300	1,700	350	0.23	0.06
Krasnoe	0	5	85	1,200	1,600	310	0.21	0.07
Saku	4	15	130	1,400	1,900	420	0.24	0.04
Sulban	9	28	160	1,500	2,000	470	0.26	0.03
Unkur	0	0	24	330	1,200	160	0.17	0.19

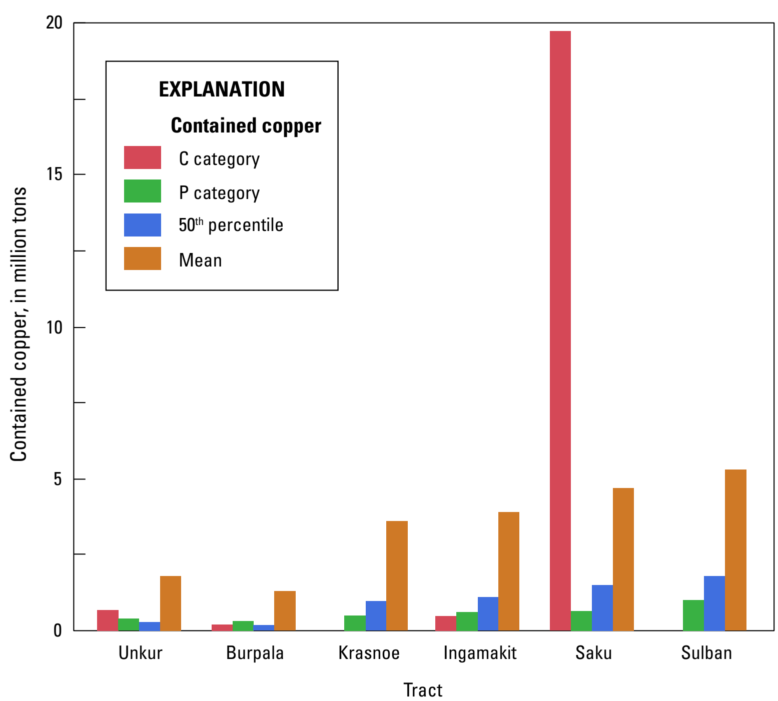


Figure 13. Histograms comparing discovered resources (C category), prognostic resource estimates (P category), and probabilistic undiscovered copper estimates for the Kodar-Udokan sandstone copper permissive tracts, Russia.

Table 8. An estimate of the in-situ value of a metric ton of rock for B and C category resources defined in Kodar-Udokan area, Russia.

[Metal prices as of March 11, 2011: copper, US$9,200/metric ton; silver, $1,100/kilogram. %, percent; g/t, grams per metric ton]

Deposits and occurrences	Resource category	Cu grade (%)	Ag grade (g/t)	Cu value (US$)	Ag value (US$)	Total value per ton (US$)
Burpala	C2	1.26	67.9	115.92	78.09	194.01
Pravo Ingamakit	C2	0.88	23.9	80.96	27.49	108.45
Udokan	B+C1+C2	1.44	13.0	132.48	14.95	147.43
Unkur	C2	0.75	70.8	69.00	81.42	150.42

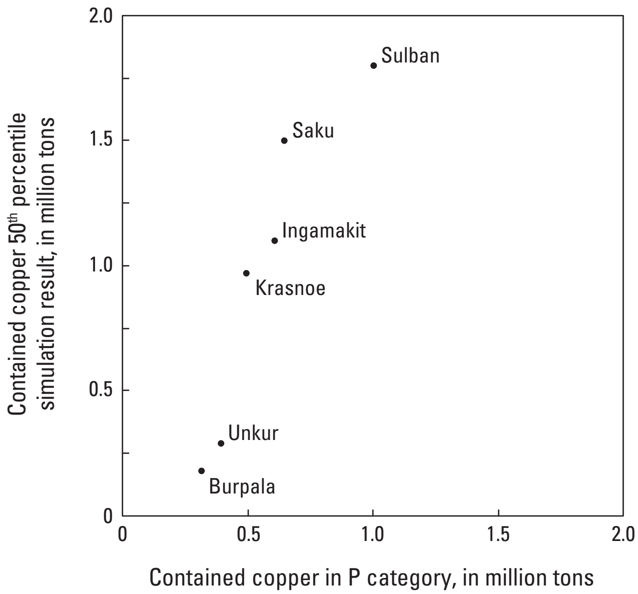


Figure 14. Bivariate plot comparing prognostic resource estimates (P category) with undiscovered copper estimated at the 95th and 90th percentiles for the Kodar-Udokan sandstone copper permissive tracts, Russia.

Forecasts of undiscovered resources for the Ingamakit, Krasnoe, Saku, and Sulban tracts are about the same order of magnitude. Among these, the Sulban tract appears to be less explored and, as a result, higher numbers of undiscovered deposits were forecast for this area. Resource estimates for the Burpala and Unkur tracts are much lower because they are about half the size of the other tracts.

Significant value can be expected from metals associated with the copper, particularly silver. Based on what is known about the concentration of silver in other sandstone-type copper deposits in the world, economically recoverable silver could increase the total value of a ton of rock by 10 to as much as 120 percent (table 8).

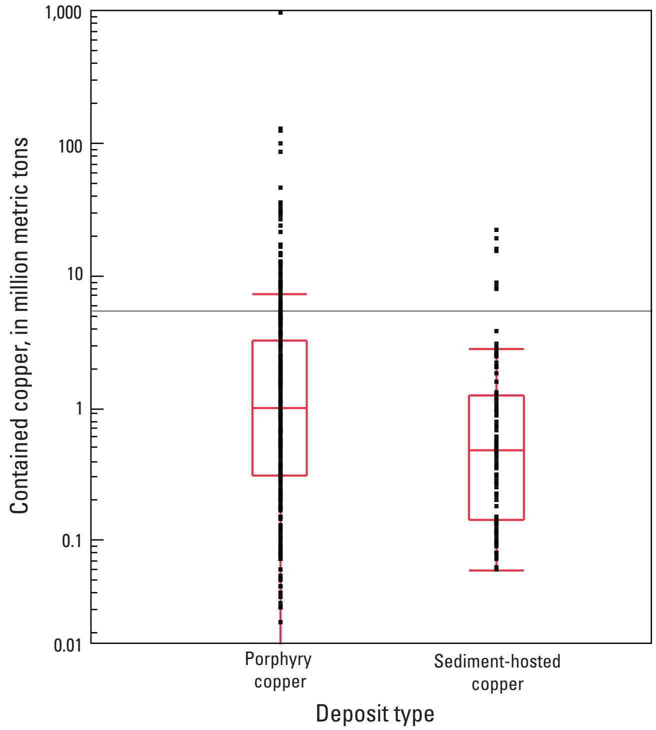
Global Perspective

In 2010, world production of copper exceeded 16,000,000 metric tons (U.S. Geological Survey, 2011), roughly the same as the resources identified in the Udokan deposit. If the mean estimated amount of undiscovered resources in the Kodar-Udokan area were discovered, it would represent less than two years of annual world production.

How common is this type of deposit worldwide, and what is its importance to the global supply of copper? Most of the world's copper production is derived from porphyry copper deposits. Sediment-hosted stratabound copper deposits, as a deposit type, contain less copper than porphyry copper deposits (fig. 15) and are, by comparison, less common. Singer and others (2008) provided information for more than 400 porphyry deposits that have reported tonnage and grade data. In contrast, only about 100 sediment-hosted copper deposits with reported mineral inventory are reported by Cox and others (2003).

Only a few sedimentary basins worldwide contain significant amounts of copper in sediment-hosted copper deposits (fig. 16). The Katanga Basin in central Africa and the Southern Permian Basin in Europe host deposits that contain most of the copper discovered of this type; other basins having important deposits include the Belt Basin in the United States, the Chu-Sarysu Basin in Kazakhstan, and the Kodar-Udokan Trough (Hitzman and others, 2010). Relative to the other copper-bearing basins, the areal extent of the Kodar-Udokan Trough is small, which limits the potential for undiscovered resources that may be present (fig. 17). Despite their small areal extent, strata in this trough preserve the remnants of a large hydrothermal system that formed the world-class Udokan deposit, several significant prospects, and close to 100 sediment-hosted copper occurrences.

This assessment suggests that about 21 undiscovered sandstone copper deposits may exist within the upper 2 km of the surface in the Kodar-Udokan area. This estimate is the numbers of deposits that are likely to exist, not necessarily those likely to be discovered (Singer, 2007). Only a small percentage of exploration expenditure leads to discovery of an economic ore body and the development of a mine (Penny and others, 2007). Can anything be said about when and if these deposits might be found?



Deposit type	Contained copper, in metric tons				
	10%	25%	Median	75%	90%
Porphyry copper	118,840	320,960	1,027,260	3,300,000	8,036,960
Sediment-hosted copper	95,714	146,010	495,600	1,283,532	6,199,597

Figure 15. Box and whisker plots comparing contained copper in porphyry copper and sediment-hosted copper deposit types. Summary table reports quantile values of the distribution of contained copper for the two deposit types.

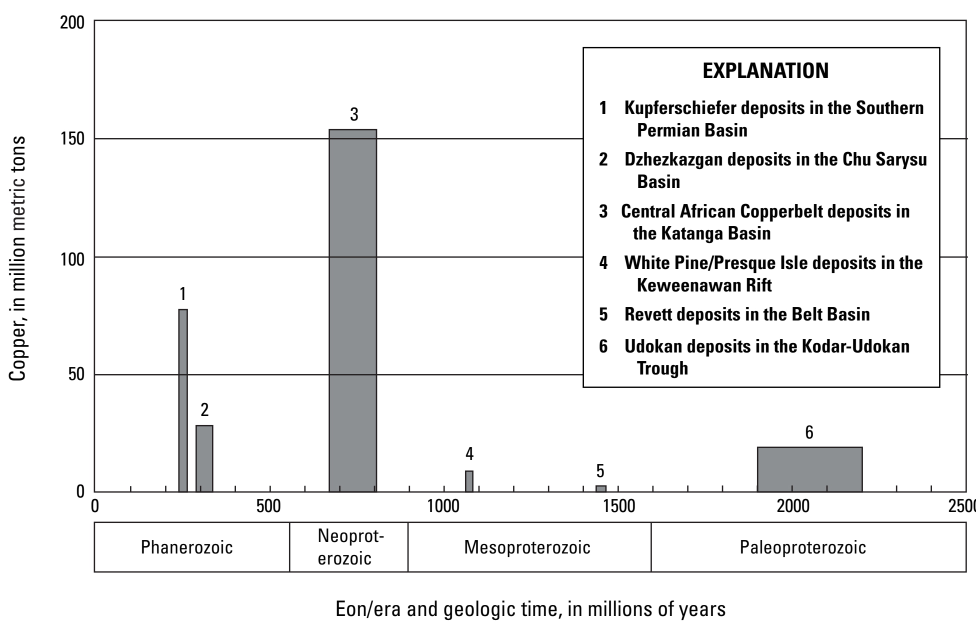


Figure 16. Time chart showing contained copper in the sediment-hosted copper deposits in various sedimentary basins (modified from Hitzman and others, 2010 and Zientek and others, 2012).

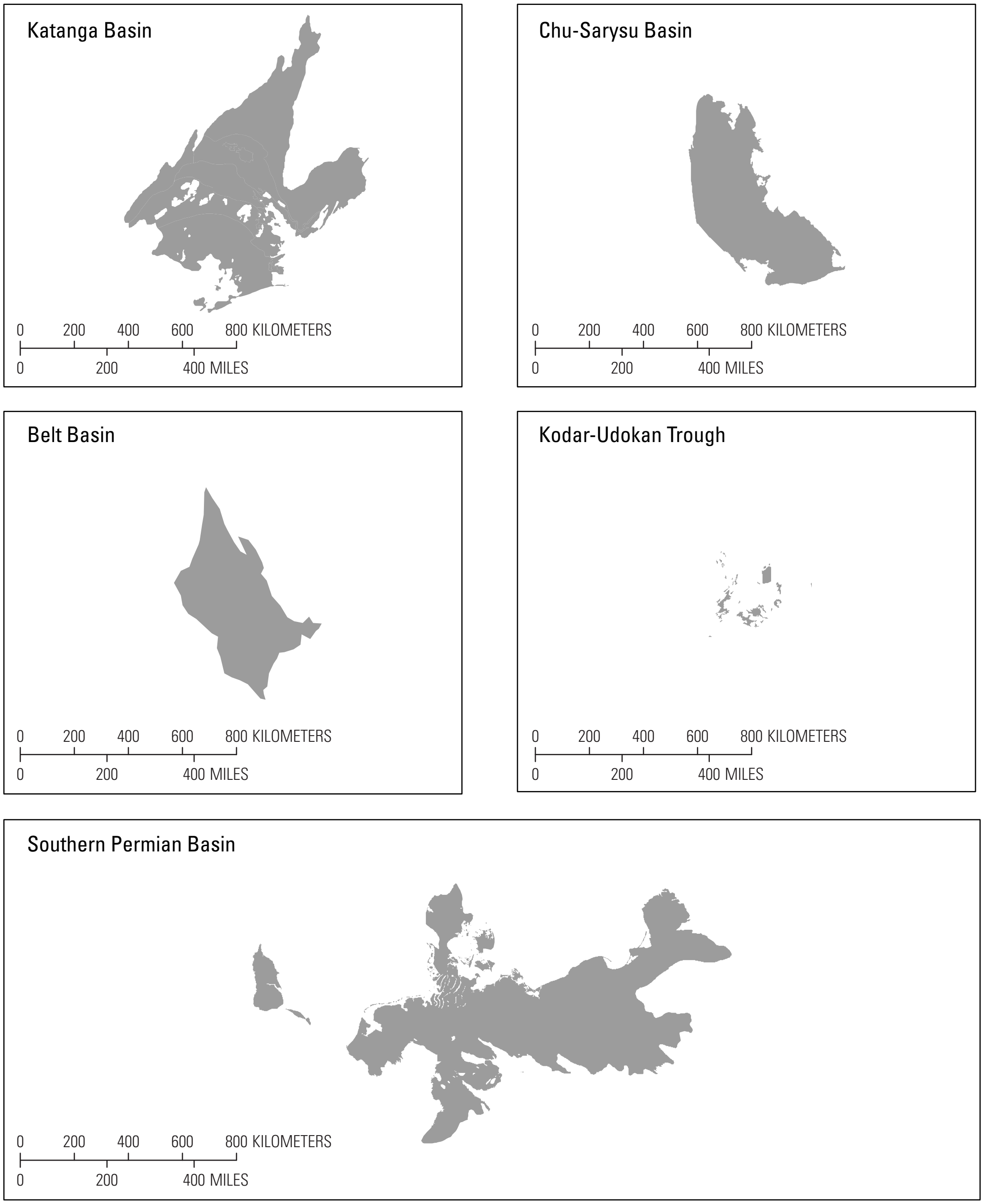


Figure 17. Maps comparing, at the same scale, the areal extents of the sedimentary basins that host major sediment-hosted copper deposits.

Mineral exploration is an economic activity involving risk and uncertainty; an evaluation of risk will determine, in part, when and where exploration occurs (Singer and Kouda, 1999; Penny and others, 2007; Cervantes and McMahon, 2011). Risk includes our uncertainty regarding the potential of a region to host an economic mineral deposit, as well as factors related to political, legal, and economic systems. The expected profitability of a mining project is affected by factors such as metal price; the character of the ore body, which determines the choice of mining method; metallurgy of the ores; infrastructure requirements; taxes and royalties; mining costs; and costs of mine development (Penny and others, 2007). Metal prices may determine whether funds will be available for exploration work, and geological processes will determine if an area has mineral potential. However, the final decision on where to conduct exploration will be determined by government regulations and policies and by institutional frameworks that enable mineral exploration and extraction. Penny and others (2007) and Cervantes and McMahon (2011) summarize many of the nongeological factors that affect mineral exploration decisions (table 9).

The quantitative estimate in this mineral assessment provides information on the uncertainty associated with the mineral potential of the Kodar-Udokan area by expressing contained metal at different probability levels. Estimates of undiscovered resources having a high degree of confidence are based on the presence of near-surface prospects for which some level of exploration was conducted. Exploration activity at these sites was deferred after discovery of the Udokan deposit; most exploration expenditures were subsequently focused on this giant deposit. If exploration is resumed in the region, it is likely that additional copper resources with grades and tonnages similar to those expressed at the high levels of confidence in this undiscovered resource estimate will be delineated. On the other hand, discovering new deposits equal to the number of deposits estimated at the mean or lower degrees of confidence (such as the 10th percentile) would be difficult. Many such undiscovered deposits would occur at depth, concealed by thick sections of nonmineralized rock. Geologic, geochemical, and geophysical features that guide the exploration geologist to mineralized rock are subtle and may not be well suited to revealing deeply buried deposits.

Table 9. Ranking of investment decision factors for exploration and mining (from Penny and others, 2007).

[–, not applicable]

Decision criteria	Rank (out of 60 criteria)	
	Exploration	Mining
Geological potential for target mineral	1	–
Security of tenure	2	1
Ability to repatriate profits	3	2
Measure of profitability	–	3
Consistency and constancy of minerals policies	4	9
Company has management control	5	7
Minerals ownership	6	11
Realistic foreign exchange regulations	7	6
Stability of exploration/mining terms	8	4
Ability to predetermine tax liability	9	5
Ability to predetermine environmental obligations	10	8
Stability of fiscal regime	11	10
Ability to raise external financing	12	12
Long term national stability	13	16
Established minerals titles system	14	17
Ability to apply geological assessment techniques	15	–
Method and level of tax levies	16	13
Import/export policies	17	15
Majority equity ownership held by company	18	18
Right to transfer ownership	19	21
Internal (armed) conflicts	20	20
Permitted external accounts	21	14
Modern minerals legislation	22	19

Deposit depth is one factor that affects the application of geological assessment techniques. Other factors include infrastructure, terrain, land cover, and climate. Rocks permissive for undiscovered copper deposits in the Kodar-Udokan area are far from existing infrastructure, and the land is characterized by steep and elevated terrain (fig. 18). Bare ground is exposed in parts of the area that are less accessible and have the highest elevations and steepest slopes; however, the more reachable areas are forested. The local climate would limit most field activities to summers.

The present-day economic viability of the worldwide copper deposits used to construct the sediment-hosted copper model varies widely, so care must be exercised when using results of this assessment to address questions that involve economics. The typical geometry of this type of mineralization is generally more suited to underground development, which requires a higher value of ore in order to recover costs.

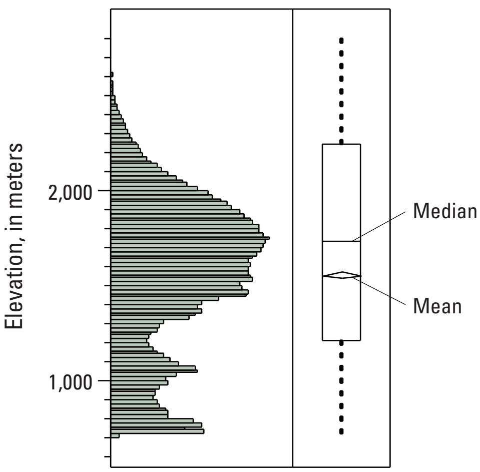


Figure 18. Histogram showing the distribution of elevations in the six combined Kodar-Udokan sandstone copper permissive tracts.

Considerations for Users of this Assessment

This report, like others in this series, represents a synthesis of current, readily available information. Our assessment of undiscovered copper resources is based on the deposit models, maps, and data represented in this report. Different datasets would yield a different assessment. Ideally, assessments are done on a recurring basis, at a variety of scales, because available data change over time.

The scientific hypotheses used in this report differ from those used by workers who first mapped the rocks and described the deposits in the Kodar-Udokan area. For example, the geologic maps used for this assessment were published before the theory of plate tectonics was widely accepted. The structural interpretation of the map units emphasized vertical crustal movement; large thrust faults that displace rocks horizontally were not mapped. Similarly, we consider sedimentary copper deposits to be hydrothermal in origin, having formed late in the diagenetic evolution of a sedimentary basin. At the time fieldwork was conducted, scientists working on these deposits hypothesized that the mineralization was syngenetic. To some extent, working hypotheses influence what data are collected and how they are presented. In this report, we have tried to apply different working models to data that were collected under a different paradigm.

Permissive tracts as delineated in this report are based on geology, irrespective of current land-use conditions. Therefore, tracts may include lands that have been developed for other uses or have been withdrawn from mineral development as protected areas.

The tracts presented herein are compiled for display at a scale of 1:1,000,000. Even though higher resolution information may have been used in the compilations, this information is intended for use at this small scale.

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Appendix A. Sediment-Hosted Stratabound Copper Assessment for Tract 150ssCu0001, Sulban—Kodar-Udokan Area, Russia

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Deposit Type Assessed: Sediment-Hosted Stratabound Copper

Descriptive model: Sediment-hosted copper, Revett subtype (Cox and others, 2003)
Grade and tonnage model: Sediment-hosted stratabound copper, sandstone copper subtype (Zientek and others, 2013; appendix G)
Table A1 summarizes selected assessment results.

Table A1. Summary of selected resource assessment results for tract 150ssCu0001, Sulban—Kodar-Udokan area, Russia.

[km, kilometer; km^2, square kilometer; t, metric ton; –, none]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
October 2009	2	591	–	5,300,000	1,800,000

Location

The tract is located in southeastern Russia, approximately 475 km east-northeast of the northern tip of Lake Baikal. It is approximately 50 km southeast of the city Oron and spans the boundary between Irkutsk Oblast and Chita Oblast (fig. A1). The Sulban River flows north-south through the eastern part of the tract.

Geologic Feature Assessed

Siliciclastic rocks in the Chinei and Kemen Groups of the Udokan Complex.

[1] U.S. Geological Survey, Spokane, Washington, United States.

[2] Russian Geological Society (RosGeo), Chita, Russia.

[3] Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London, United Kingdom.

[4] U.S. Geological Survey, Tucson, Arizona, United States.

[5] Mining and Economic Consulting Ltd., Almaty, Kazakhstan.

[6] U.S. Geological Survey, Denver, Colorado, United States.

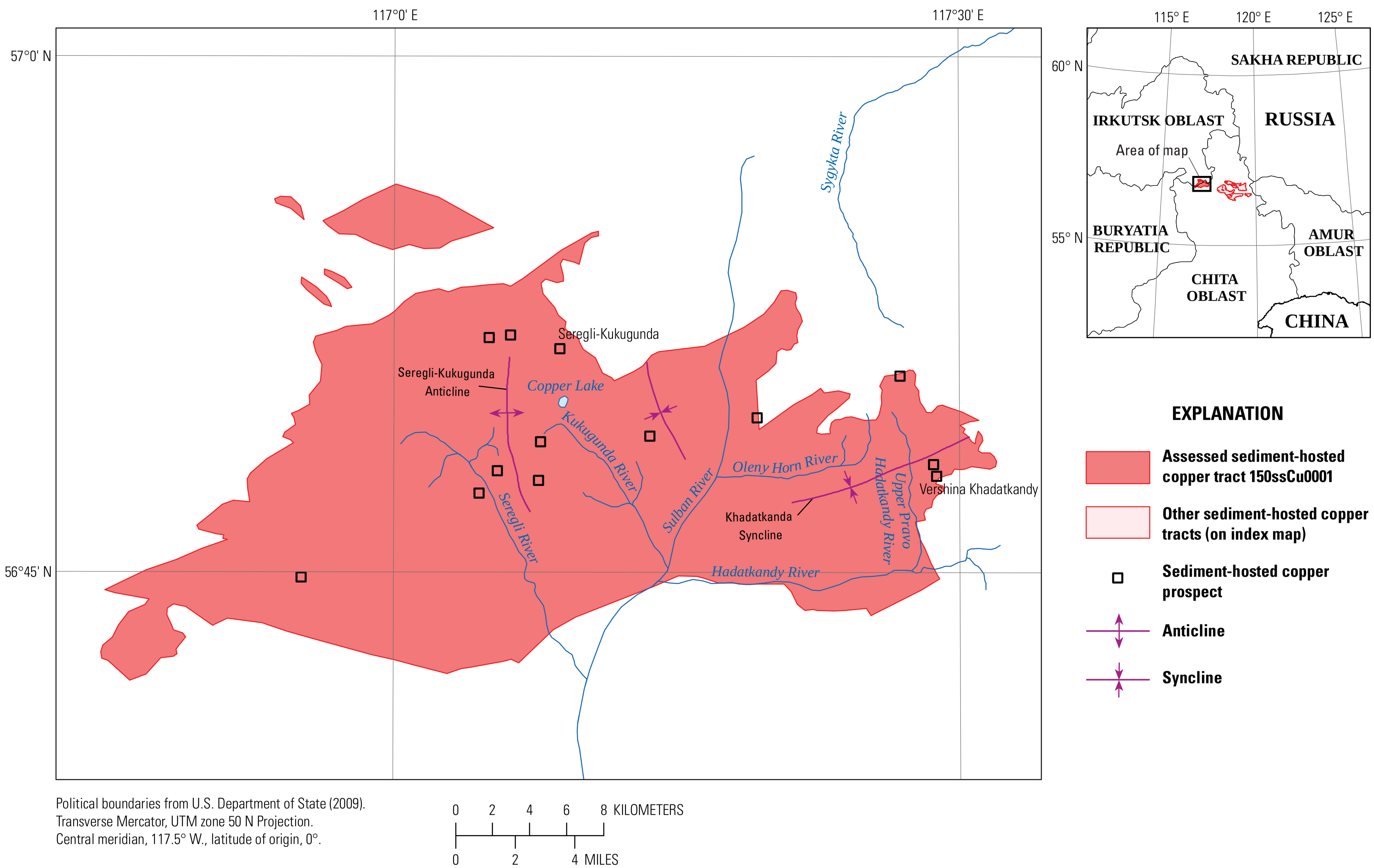

Figure A1. Map showing the assessed sediment-hosted stratabound copper permissive tract and associated prospects in tract 150ssCu0001, Sulban—Kodar-Udokan area, Russia.

Delineation of the Permissive Tract

Geologic Criteria

The tract was delineated on the basis of the mapped extent of the Chitkanda, Aleksandrov, Butun, and Sakukan Formations (fig. A1). The tract was extended under Quaternary cover that occurs on a broad alluvial area adjacent to the Sulban River.

Known Deposits

There are no known deposits.

Prospects, Mineral Occurrences, and Related Deposit Types

The Aleksandrov Formation contains thin layers and lenses of sandstone, with isolated sulfide disseminations. The Aleksandrov Formation is subdivided into eight members. Members 2, 4, and 7 contain the lower, middle, and upper copper-bearing intervals, respectively. In the Seregli-Kukugunda area, the middle copper-bearing interval has the richest copper content. At the Vershina Khadatkandy area, economic concentration of copper occurs within the upper copper-bearing interval. The main ore minerals are chalcopyrite-pyrite, chalcopyrite-pyrrhotite, chalcopyrite-magnetite, chalcopyrite-bornite, and bornite-chalcocite. Molybdenum, silver, and gold occur in elevated amounts within the ore layers.

Two sites within the Aleksandrov Formation, Seregli-Kukugunda and Vershina Khadatkandy, have prognostic resources (table A2). Feoktistov and Chechetkin (1984) show an additional 11 unnamed point locations (table A3). Nine of these occur within the Chitkanda Formation, one is in the Talakan Formation, and one is in the Aleksandrov Formation. The size of these sites is unknown.

Seregli-Kukugunda Study Area

The Seregli-Kukugunda anticline is located in the upper plate of a thrust sheet in the Seregli-Kukugunda River watershed in the central part of the permissive tract. The anticline axial trace lies between the Seregli River to the west and the Kukugunda River to the east (fig. A1). In the upper part of the watershed, Paleoproterozoic rocks are exposed. However, the southeastern part of this structure is covered by Cenozoic deposits of the Upper Sulban Basin.

From south to north, the fold exposes the Chitkanda, Aleksandrov, Butun, and Talakan Formations. Bedding is subhorizontal in the core of the anticline on the left bank of the Seregli River. The average dip is 45˚, but it varies from 20˚ to 60˚ and gradually increases outward from the core of the anticline. To the east, the Sakukan Formation crops out in a subparallel syncline located between the Kukugunda and Sulban Rivers. In this eastern area, the Butun Formation is thrust over the Sakukan Formation deposits along a steep, southwest-dipping fault structure. Near the hinge of the Seregli-Kukugunda anticline, this same structure is continued, with cataclasite zones that range in thickness from one to several tens of meters.

Member 2 of the Aleksandrov Formation consists of metasiltstone with interbedded arkosic and polymictic metasandstones and lenticular interbedded quartzite sandstone with thin irregular disseminations of chalcopyrite that make up the lower copper-bearing interval. The thickness of the quartzite sandstone is typically less than 1 m. Outcrops of these quartzite-sandstones are found north of Copper Lake. Because of the low concentrations of copper (hundredths to less than a tenth of a percent) and the thin quartzite sandstone interval, this area has not been considered for further exploration. But considering the high variability of facies in this suite of rocks, this stratigraphic level in adjacent areas could potentially contain economic mineralization.

The middle copper-bearing interval is confined to member 4 in the Aleksandrov Formation. Outcrops are located on the west side of the upper Kukugunda River, on the upper west part of the source of Copper Lake, and on the west side of the Seregli River (fig. A1). As with all layers of the Aleksandrov Formation, the copper-bearing interval in the core of the anticline is gently inclined. However, 1–2 km from the core, the layers dip at 40–45° in the direction of the fold periphery. The Seregli-Kukugunda area has an extent of 4,776 m^2 and an average copper content of 0.72 percent. The outcrops of the copper-bearing interval are often displaced by offset of large tectonic blocks; therefore the interval is delineated within individual blocks.

Five sites from the upper copper-bearing interval (member 7) were tested in a detailed study located at an elevation of 2,107 m in the west side of the Seregli River. Four are characterized by low copper content, and only the easternmost contained economic mineralization. These sites contained consistent and high amounts of molybdenum and, to a lesser extent, silver. The outcrops of this copper-bearing interval on the east side of the Seregli River are thin, with copper content of not more than 0.3 percent.

Vershina Khadatkandy Study Area

The Khadatkanda syncline is located in the eastern part of the permissive tract. Paleoproterozoic metasedimentary outcrops are isolated, largely covered by moraine, and cut by intrusions. The center of the syncline is composed of the Sakukan Formation and, to the north, Butun Formation limestones and Aleksandrov Formation metasiltstones. Bedding dips gently in the syncline center, 5–20˚, and 30–50˚ on the limbs. In the eastern part, the structure is complicated by

Table A2. Sites with P category (prognostic) resources in tract 150ssCu0001, Sulban—Kodar-Udokan, Russia.

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994; Henley and Young, 2006). Cu, copper; t, metric ton; Mt, million metric tons; %, percent. P1 is a Russian mineral resource category which is analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS. These prognostic mineral resources estimates refer to extensions to inferred resources and are based on limited direct geological evidence]

Prospect name	Category of resources	Ore (Mt)	Cu grade (%)	Contained Cu (t)
1. Seregli-Kukugunda	P1	66.8	0.72	481,200
2. Vershina Khadatkandy	P1	27.5	1.90	522,800

Table A3. Point locations of sediment-hosted copper occurrences in tract 150ssCu0001, Sulban—Kodar-Udokan area, Russia.

Name	Latitude	Longitude	Unit
Unknown	56.86437	117.08396	Chitkanda Formation
Unknown	56.81676	117.22638	Talakan Formation
Unknown	56.78906	117.07538	Chitkanda Formation
Unknown	56.79997	117.09131	Chitkanda Formation
Unknown	56.79515	117.12788	Chitkanda Formation
Unknown	56.81406	117.12976	Chitkanda Formation
Unknown	56.86562	117.10277	Chitkanda Formation
Unknown	56.82553	117.32102	Chitkanda Formation
Unknown	56.84560	117.44732	Chitkanda Formation
Unknown	56.74806	116.91835	Aleksandrov Formation
Unknown	56.80278	117.47708	Chitkanda Formation

gently dipping, short-wavelength folds. Copper-bearing strata in the upper Aleksandrov Formation (Upper Pravo Hadatkandy River, Oleny Horn River) abruptly dip (40–50˚) to the south and generally strike between the steep walls of the upper Pravo Hadatkandy River. In places, the copper-bearing strata are almost completely buried under thick glacial deposits.

The upper copper-bearing interval in member 7 of the Alekandrov Formation has an area of 4,410 m^2 and an average copper content of 1.9 percent. The mineralized interval crops out at the head of the Hadatkandy and Oleny Horn Rivers and on the drainage divide between the Hadatkandy, Oleny Horn, and the Sygykta Rivers (fig. A1). The length of the copper-bearing interval is 2.6 km, with the northeastern part being near the Sygykta River, where the copper-bearing interval can be clearly observed but is inaccessible because of the steep slopes. Samples taken at the foot of the slope indicate a modest increase in the copper mineralization in the north-easterly direction.

The copper-bearing interval contains quartzite-sandstones interbedded with polymictic and calcareous sandstone. It has variable thickness, which slightly decreases from west to east. Alongside the Oleny Horn River, the thickness of the quartzite-sandstones in exploration trenches exceeds 18 m, decreases to 3 m, increases to 8 m, decreases to 3.7 m, and decreases further to 3.3 m.

Mineralization is usually confined to the quartzite-sandstone and less frequently to the polymictic sandstones containing flakes of biotite. In general, mineralization in this interval has a high copper content. The major copper-bearing minerals are chalcopyrite, bornite, and chalcocite.

Sources of Information

Principal sources of information used by the assessment team for delineation of the Sulban tract are listed in table A4.

Table A4. Principal sources of information used by the assessment team for tract 150ssCu0001, Sulban—Kodar-Udokan area, Russia.

Name or title	Scale	Reference
	Geology	
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
Geological map of the USSR, Bodaybo series, sheet O-50-XXVII	1:200,000	Enikeev (1973)
Geological map of the USSR, Bodaybo series, sheet O-51-XIII Mouth of the Choroudy River	1:1,000,000	Reutov (1976)
State geological map of the USSR, new series, sheet N-49,(50) Chita, Map of the pre-Quaternary rocks	1:1,000,000	Efimov and others (1990)
State geological map of the USSR, new series, sheet O-49(50) Bodaybo, Map of Quaternary deposits	1:1,000,000	Kornutova and Tsvetkov (1984)
Geological map of the USSR, new series, sheet O-(50),51 Aldan, Map of the pre-Quaternary rocks	1:1,000,000	Lagzdina and others (1978)
	Mineral occurrences	
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
	Geophysics	
Gravitational field map	1:1,000,000	Pis'mennyi (2003)
Magnetic anomaly map	1:1,000,000	Schupak and others (2003)

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Undiscovered deposit estimates were subjectively determined by a panel of scientists (table A5). Estimates at the 90th percentile were constrained by the two sites where Russian geologists had sufficient information to forecast prognostic resources. The assessors assumed that some significant portion of the 11 mineral occurrences may be indications of deposits at depth because less exploration activity has been directed at this area.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered sediment-hosted stratabound copper deposits with the sandstone copper model (Zientek and others, 2013; appendix G) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table A6. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. A2). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table A5. Undiscovered deposit estimates, deposit numbers, and tract area for tract 150ssCu0001, Sulban—Kodar-Udokan area, Russia.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers. N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005). In cases where individual estimates were tallied in addition to the input for EMINERS, individual estimates are listed]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	*s*	C_v%	N_{known}	N_{total}	
3	6	8	8	8	5.5	1.9	34	0	5.5	591

Estimator	Estimated number of undiscovered deposits				
	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
other	1	2	4		
other	1	4	6		
USGS	2	3	5	8	
Input for EMINERS	3	6	8		
other	3	4	5		
USGS	3	4	6		
USGS	3	5	7	10	
USGS	3	6	9		

Table A6. Results of Monte Carlo simulations of undiscovered resources in tract 150ssCu0001, Sulban—Kodar-Udokan area, Russia.

[Cu, copper; Ag, silver; t, metric tons; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	120,000	320,000	1,800,000	16,000,000	24,000,000	5,300,000	0.25	0.03
Ag (t)	0	0	1,100	12,000	20,000	4,500	0.25	0.24
Rock (Mt)	9	28	160	1,500	2,000	470	0.26	0.03

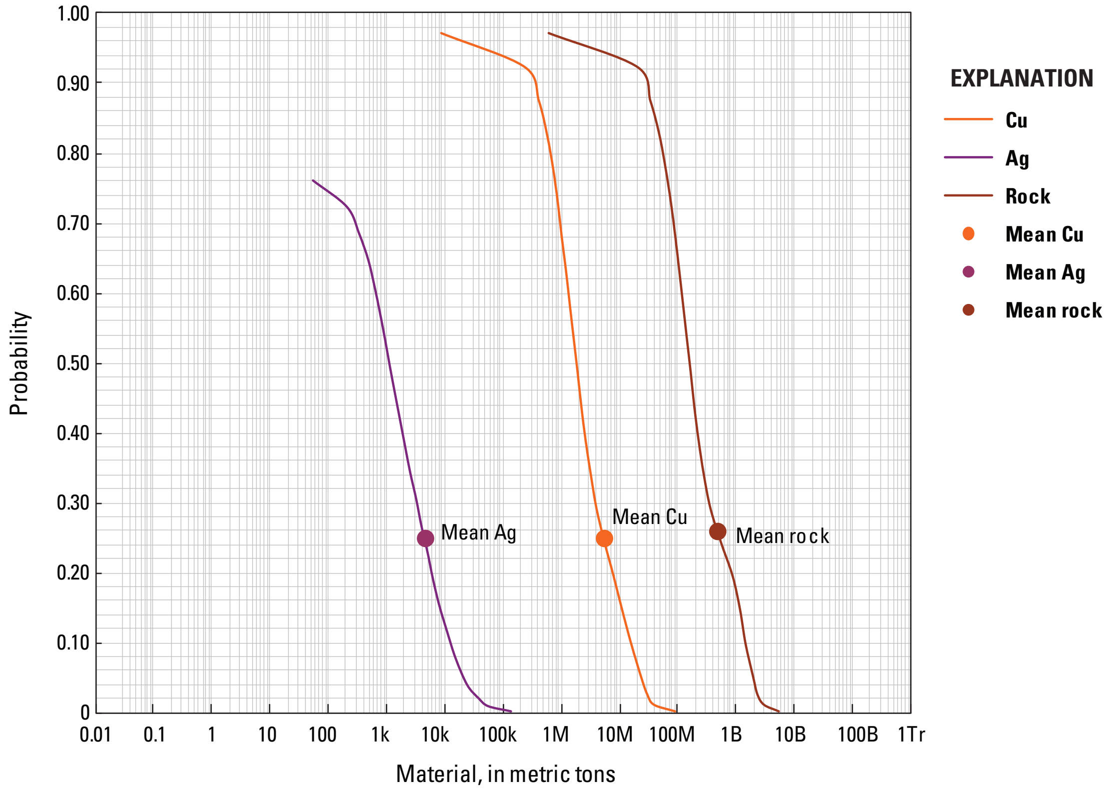

Figure A2. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 150ssCu0001, Sulban—Kodar-Udokan area, Russia. k, thousand; M, million; B, billion; Tr, trillion.

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Appendix B. Sediment-Hosted Stratabound Copper Assessment for Tract 150ssCu0002, Saku—Kodar-Udokan Area, Russia

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Deposit Type Assessed: Sediment-Hosted Stratabound Copper

Descriptive model: Sediment-hosted copper, Revett subtype (Cox and others, 2003)
Grade and tonnage model: Sediment-hosted stratabound copper, sandstone copper subtype (Zientek and others, 2013; appendix G)
Table B1 summarizes selected assessment results.

Table B1. Summary of selected resource assessment results for tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[km, kilometer; km^2, square kilometer; t, metric ton]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
October 2009	2	827	18,875,000	4,700,000	1,500,000

Location

The tract is located in southeastern Russia, approximately 525 km east-northeast of the northern tip of Lake Baikal. It is approximately 25 km southeast of the city Chara and lies in northernmost Chita Oblast. The town of Naminga is located in the central part of the tract, near the Udokan deposit. The Chara River flows along the northwestern edge of the tract, and the Ingamakit River flows along the southwestern and southern edges of the tract (fig. B1).

Geologic Feature Assessed

Siliciclastic rocks in the Kemen Group of the Udokan Complex.

[1] U.S. Geological Survey, Spokane, Washington, United States.

[2] Russian Geological Society (RosGeo), Chita, Russia.

[3] Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London, United Kingdom.

[4] U.S. Geological Survey, Tucson, Arizona, United States.

[5] Mining and Economic Consulting Ltd., Almaty, Kazakhstan.

[6] U.S. Geological Survey, Denver, Colorado, United States.

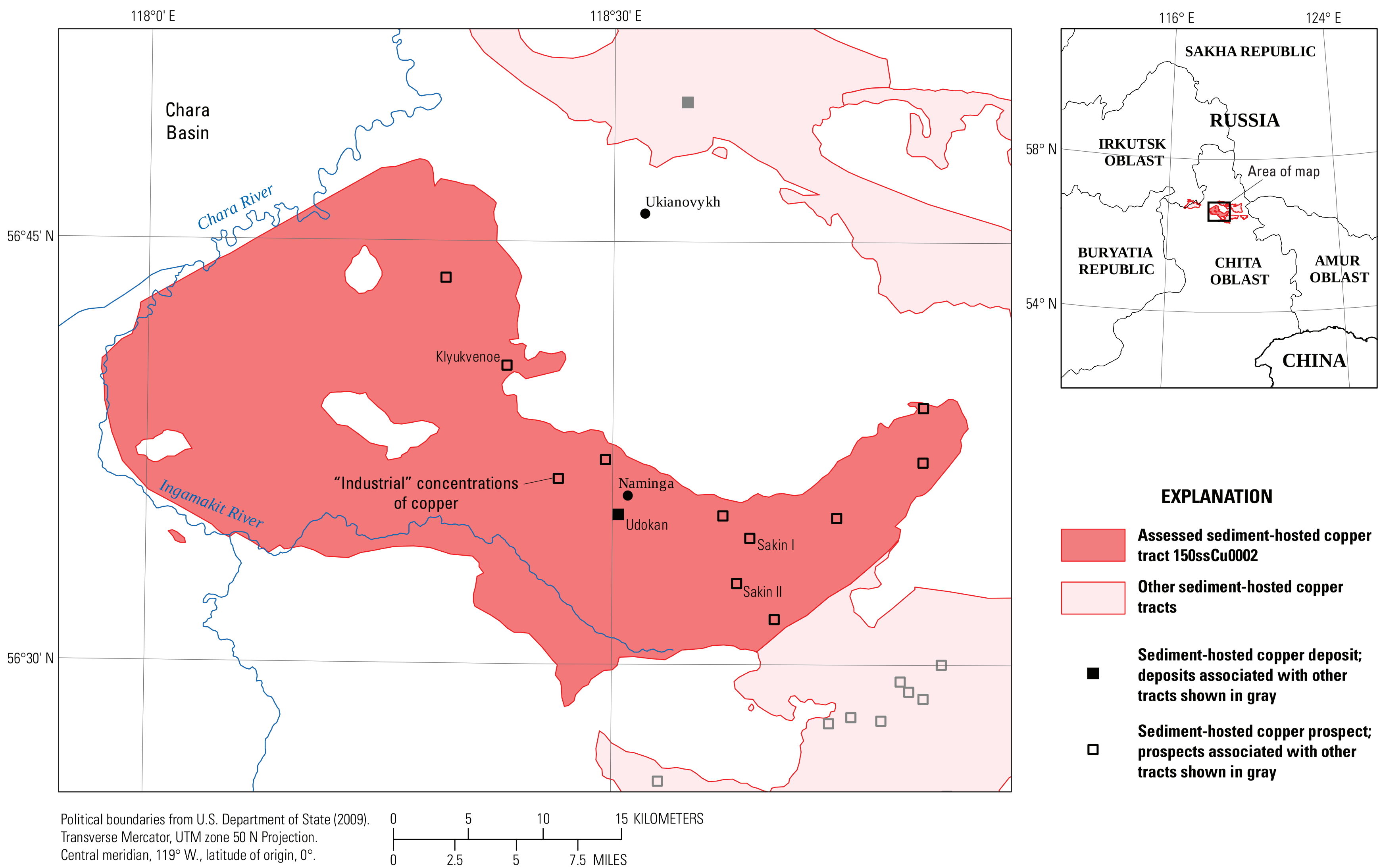

Figure B1. Map showing the assessed and adjacent sediment-hosted stratabound copper permissive tracts, and associated deposit and prospects in tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

Delineation of the Permissive Tract

Geologic Criteria

The tract is based on the mapped distribution of Kemen Group rocks in the northwest-trending Namingen Syncline and northeast-trending Sakun Syncline (figs. B1 and B2). Almost all the exposed rocks belong to the Sakukan Formation; small areas of Naminga Formation are found along the axes of the synclines. A small area in a fault-bounded block near the margin of the Chara Basin has been mapped as Aleksandrov Formation. The northwestern boundary of the tract extends under cover into the Chara Basin to the estimated position of a northeast-trending fault shown on the geologic map and cross section of the 1:200,000-scale O-50-XXIX sheet (Shul'gina, 1975). This approximately coincides with the 250-m depth of cover contour as shown on Feoktistov and Chechetkin (1984) and with magnetic gradients shown on regional aeromagnetic maps (Schupak and others, 2003) that may be related to a fault that occurs along the southern margin of the Chara Basin. The eastern margin of the tract with the adjacent Ingamakit tract is also defined by a high-angle fault, shown as a first-order fault on figure 1 in Burmistrov and Apol'skiy (1986) and as the Ingamakit Fault on figure 1 of Konnikov (1986).

Known Deposits

The Udokan deposit contains about 19 million metric tons of copper and is a giant sandstone copper deposit (tables B2 and B3; figs. B1and B3), similar in size to other large sandstone copper deposits, such as Dzhezkazgan (Kazakhstan) and Mufulira (Zambia).

The Udokan deposit underlies an elliptical area of about 30 km^2 where the Upper Sakukan and Lower Naminga subformations are exposed in the Namingen Syncline (fig. B2; Bakun and others, 1966; Bogdanov and others, 1966; Gablina and Mikhaylova, 1994; Volodin and others, 1994; Chechetkin and others, 2000). On the northwestern limb of the syncline, rocks of the Upper Sakukan and Lower Naminga subformations dip at angles ranging from 10° to 40° to the southwest. The southwestern limb of the syncline is overturned with dips varying from 30° to 80° toward the southwest (fig. B4).

The Upper Sakukan subformation is composed of fine-grained gray, occasionally pink sandstones, more or less arkosic, with subordinate siltstones and shales. The subformation is 750–800 m thick. Lenticular bodies of calcite-cemented sandstones with angular shale fragments are a characteristic feature of these rocks. Sedimentary structures include cross-, wavy and horizontal bedding, with ripple marks and mud cracks exposed in some facies (Bogdanov and others, 1966; Gablina and Mikhaylova, 1994, Volodin and others, 1994).

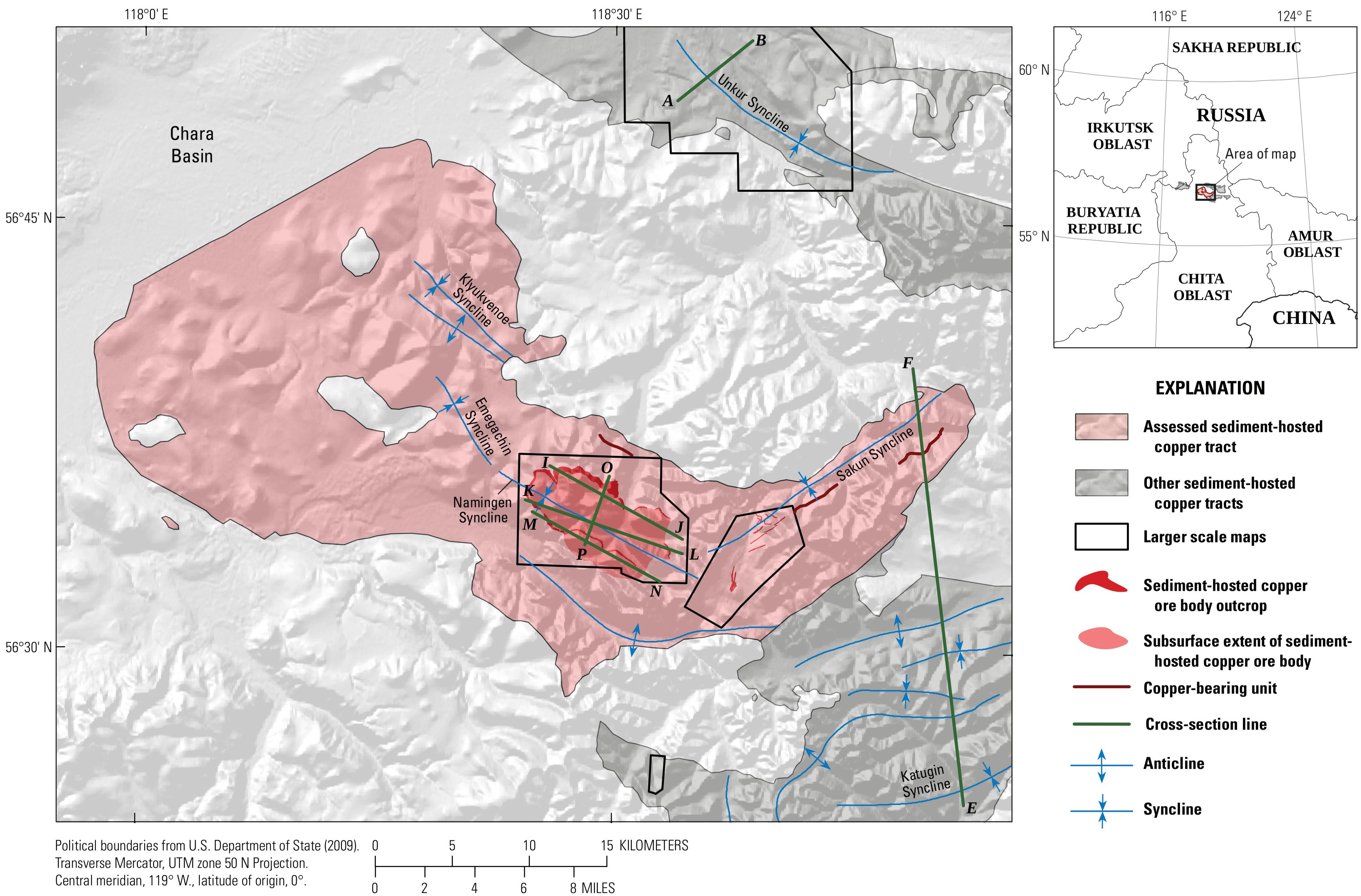

Figure B2. Map showing the assessed and adjacent sediment-hosted stratabound copper permissive tracts, surface and subsurface extent of ore bodies, and copper-bearing units in tract 150ssCu0002, Saku—Kodar-Udokan area, Russia (modified from Bakun and others, 1966; Bufeev and Shcherbakova, 1973; Chechetkin, written comm., 2009; and Volodin and others, 1994).

Table B2. Sites with B, C, and P category resources in tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994; Henley and Young, 2006). Cu, copper; Ag, silver; Mt, million metric tons; %, percent; ppm, parts per million; t, metric ton. B, C1, C2, and P1 are Russian mineral resource categories. B, C1, and C2 are analogous to measured, indicated, and inferred mineral resources as defined by CRIRSCO, respectively. P1 is analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS and are estimates associated with extensions to inferred resources]

Deposit name	Category of resources	Ore (Mt)	Cu grade (%)	Ag grade (ppm)	Contained Cu (Mt)	Contained Ag (t)
Udokan	B+C1+C2	1,310.8	1.44	13	18.87	17,400
	C1 sub economic	770.6	0.38	4	2.94	3,100
	P1	217.2	1.20	10	2.6	2,170

Table B3. Mineral resource inventory for the Udokan deposit, January 1, 2002 (Arkhangel'skaya and others, 2004).

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994; Henley and Young, 2006). Cu, copper; Mt, million metric tons; %, percent. B, C1, and C2, are Russian mineral resource categories. B, C1, and C2 are analogous to measured, indicated, and inferred mineral resources as defined by CRIRSCO, respectively]

Categories	Total ore (Mt)	Total Cu (Mt)	Cu content (%)	Sulfide ore (Mt)	Cu in sulfide ore (Mt)	Mixed ore (Mt)	Cu in mixed ores (Mt)	Oxidized ore (Mt)	Cu in oxidized ore (Mt)
B	170.630	3.009	1.76	75.128	1.573	69.531	1.055	25.972	0.373
C1	754.407	11.470	1.52	311.563	5.404	296.101	4.052	146.743	2.014
C2	385.746	5.260	1.36	254.254	3.437	97.712	1.350	33.780	0.473
B+C1+C2	1,310.784	19.730	1.44	640.945	10.414	463.344	6.457	206.494	2.861
C1 (subeconomic)	770.608	2.944	0.38	18.259	0.456	510.247	19.449	142.103	0.539

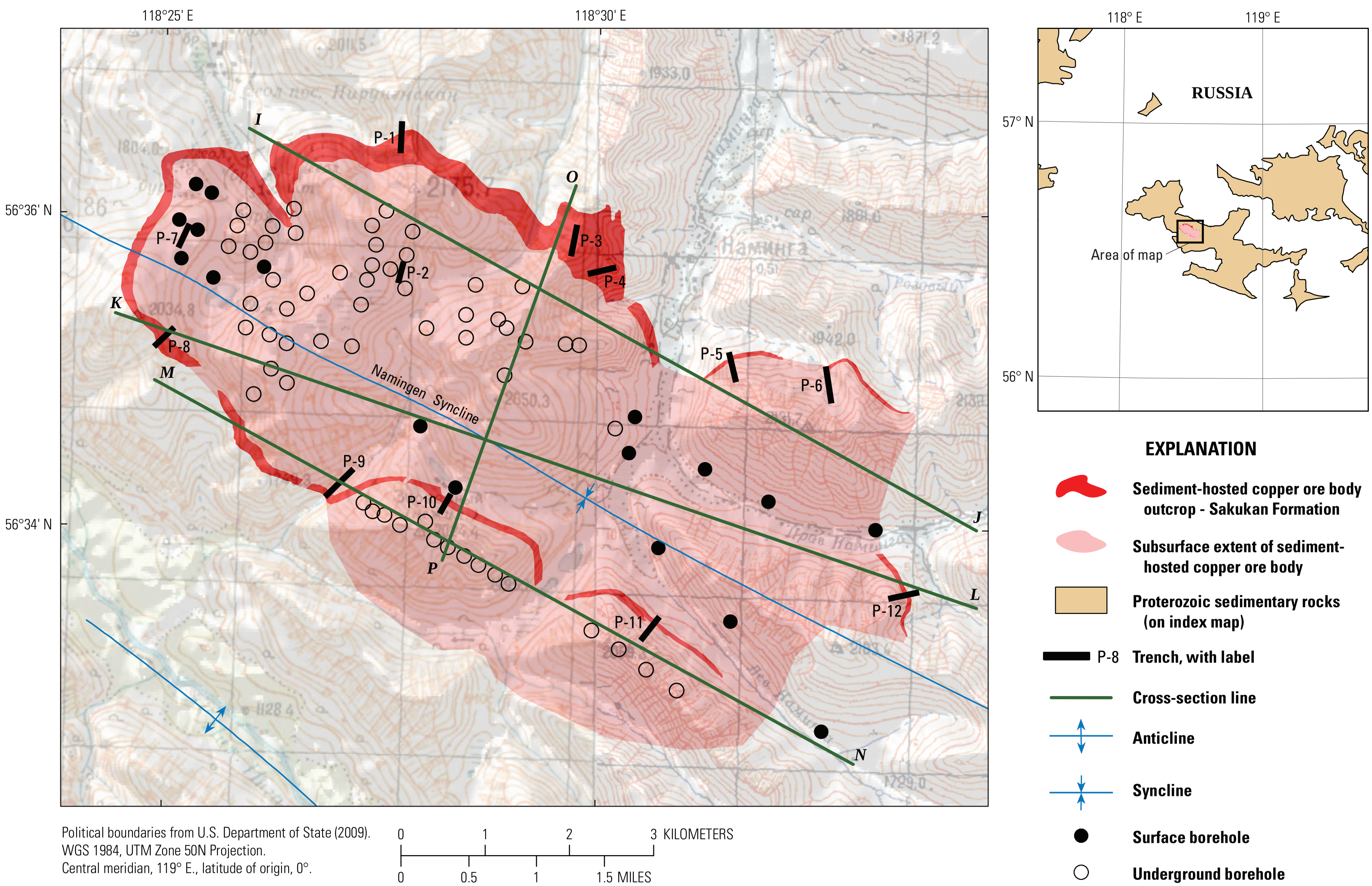

Figure B3. Map showing boreholes, trenches, and the surface and subsurface extent of the Udokan ore body in the Sakukan Formation, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia (modified from Bakun and others, 1966; Volodin and others, 1994; and Arkhangel'skaya and others, 2004).

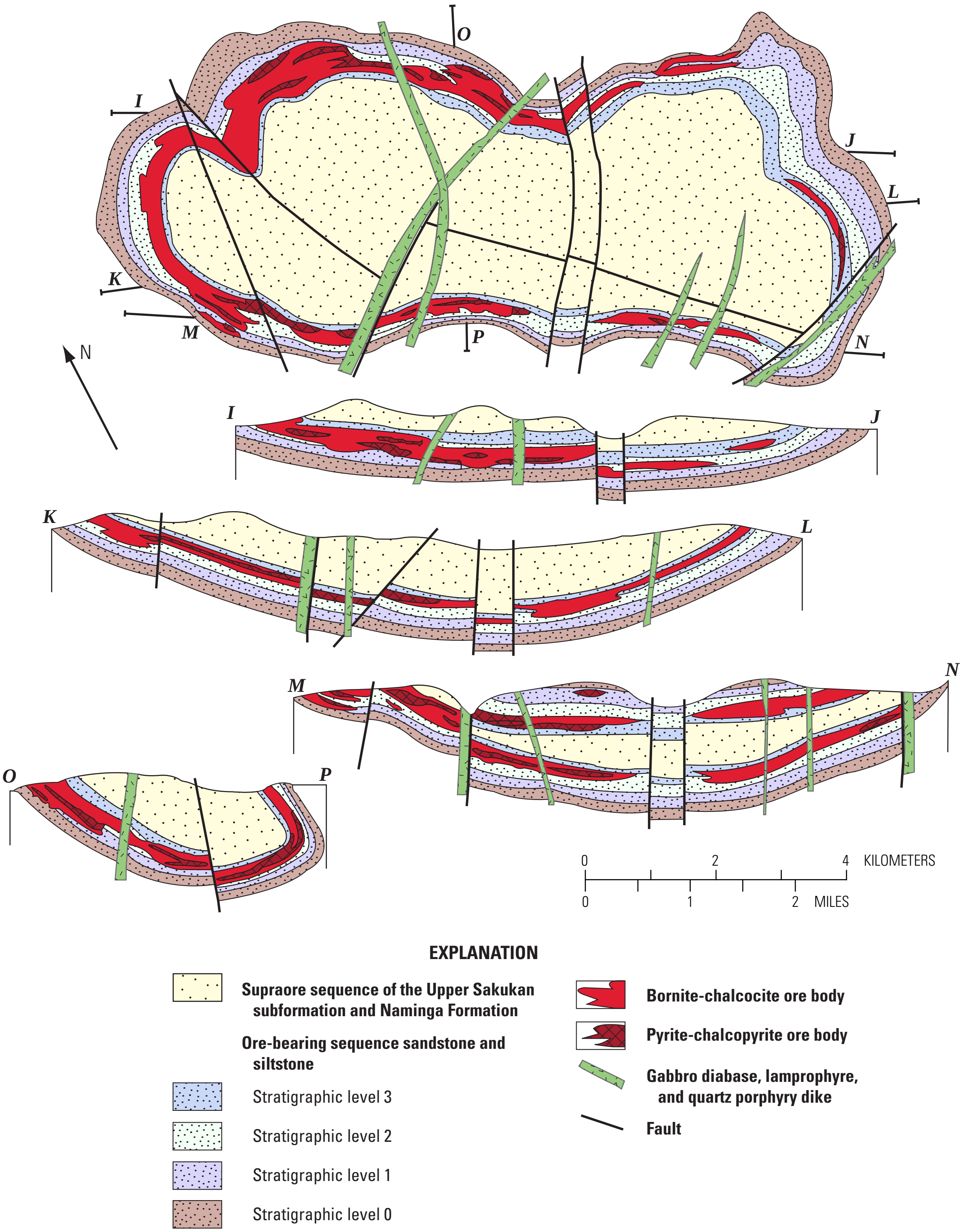

Figure B4. Geologic map and cross sections (from figure B3) through the Udokan deposit, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia (modified from Volodin and others, 1994).

Ore Lodes

The Upper Sakukan subformation is divided into three packages based on the position of cupriferous sandstones in the section: the lower (1 or subore), the middle (2 or ore-bearing), and the upper (3 or supraore) (fig. B5). However, the middle (ore-bearing) unit is not uniformly mineralized (Bogdanov and others, 1966; Volodin and others, 1994). Within the copper-bearing stratigraphic unit, the distribution of economic-grade ores, cutoff-grade ores, and copper-poor sandstones have been mapped for the major ore lodes for stratigraphic levels 1, 2, and 3 using drill holes and underground workings (fig. B6; Bogdanov and others, 1966; Volodin and others, 1994). The horizontal and vertical outlines of ore masses are irregular, forming long, lenticular ore bodies. The en echelon arrangement of several lenticular mineralized bodies with small cross-sections can form large, long, and thick ore bodies (Bogdanov and others, 1966). The ore bodies are 300–2,000 m in size and extend 400–2,500 m downdip, with thicknesses from 16 to 52 m (Chechetkin and others, 2000).

Depositional Environment

Most of the higher grade copper mineralization in the major ore lodes is associated with a package of rhythmically layered rock that extends from the northeastern to the southwestern limb of the syncline. These rhythmites have an erosional base overlain by lenses (0.1–0.5 m thick) of intraformational conglomerates consisting of a matrix of medium- to fine-grained calcareous sandstone with clasts of argillaceous rocks. The conglomerates grade upward into cross-bedded arkosic sandstones that decrease in grain-size upsection (Gablina and Mikhaylova, 1994; Bogdanov and others, 1966; Volodin and others, 1994; Chechetkin and others, 2000). In addition, the proportion of calcite cement decreases upsection, from about 20 to no more than 10 percent. As the proportion of calcite cement decreases, the proportion of quartz-mica and quartz-feldspar-mica in the rock matrix increases. The scale of cross-bedding also decreases upsection; the sedimentary structures transition from cross-bedding lower in the rhythmites to fine oblique, oblique-wavy, and horizontal bedding emphasized by layers of magnetite (martite) or siltstone near the top. The uppermost part of the rhythmites consists of black argillite or siltite layers that are occasionally overlain by a wavy and parallel-bedded layer consisting of a fine alternation of sandstone and siltstone characterized by ripple marks and mudcracks (Volodin and others, 1994). Sediment transport direction indicated by the orientation of cross-bedding is consistent between rhythmic units (Bakun and others, 1966). These units vary in thickness from 3 to 15 m, gradually thinning upward, and pinching out laterally (Bogdanov and others, 1966). The thickness of the rhythmically layered facies decreases from north to south and to southwest. In the north, the thickness of these deposits is as much as 1,000 m (Bakun and others, 1966). A typical section may have dozens of rhythmites (Boris Syusyura, written commun., 2009).

Along strike, the rhythmites are replaced by quartzite-like and calcareous sandstones (occasionally rosy); cross-bedded red sandstones distinguished by a high degree of sorting and rounding of the detrital grains and concentrations of heavy mineral laminae; and layers and lenses of siltstones and argillites (Bakun and others, 1966; Volodin and others, 1994). Sedimentary structures include horizontal (parallel), oblique, and oblique-wavy (trough-like) bedding. Ripple marks are commonly preserved on bedding planes. Cross-bedding does not show consistent sediment-transport direction (Bakun and others, 1966).

A deltaic depositional environment is proposed for the rocks in this subformation (Bakun and others, 1966; Volodin and others, 1994). The rhythmites may represent fluvial-dominated distributary-channel fill deposits (Bhattacharya and Walker, 1992), whereas the adjacent deposits are likely to have formed in delta plains, shoreline beaches, and barrier bars.

Ore Mineralogy, Textures, and Weathering

The principal copper-bearing ore-forming minerals are sulfides of the chalcocite series (djurleite and digenite), bornite, chalcopyrite, and covellite (Gablina and Mikhaylova, 1994); the other common sulfide mineral is pyrite. The common mineral associations are bornite-chalcocite, which constitutes most of the economic mineralization, and chalcopyrite-pyrite, which rarely has copper concentrations high enough to be included in ore resource calculations (Volodin and others, 1994; Chechetkin and others, 2000). The mineral associations commonly occur in a zoned sequence that varies from pyrite to chalcopyrite-pyrite to chalcopyrite-bornite to bornite-chalcocite (fig. B7; Gablina and Mikhaylova, 1994; Volodin and others, 1994). Silver, gold, and bismuth are concentrated in the bornite-chalcocite ores; lead and indium are associated with bornite and chalcopyrite, whereas the pyrite-chalcopyrite ores are more enriched in cobalt, nickel, zinc, selenium, and rhenium (Volodin and others, 1994).

The ore minerals occur as part of the cement filling the interstitial space between clastic grains, but also as pockets and lenses of sulfide minerals. The sulfide minerals often enhance stratification, ripple marks, and other similar features. The copper sulfides commonly form fringes on the argillite clasts in conglomerates and may form the cement of brecciated sandstones. Quartz sulfide veinlets are locally developed in cleavage fractures within layered sulfide ores (Bogdanov and others, 1966; Volodin and others, 1994).

Oxidized ores have been found in underground workings as much as 500 m below the surface, and malachite and iron hydroxides were observed in the boreholes that intersected the copper-bearing unit at depths of 1,000–1,200 m (Volodin and others, 1994). The average extent of oxidation of ore decreased with depth from approximately 70 percent at the surface to approximately 10 percent at the 670-m level (Gablina and Mikhaylova, 1994). Malachite, azurite, chrysocolla, covellite, secondary chalcocite, bornite, chalcopyrite,

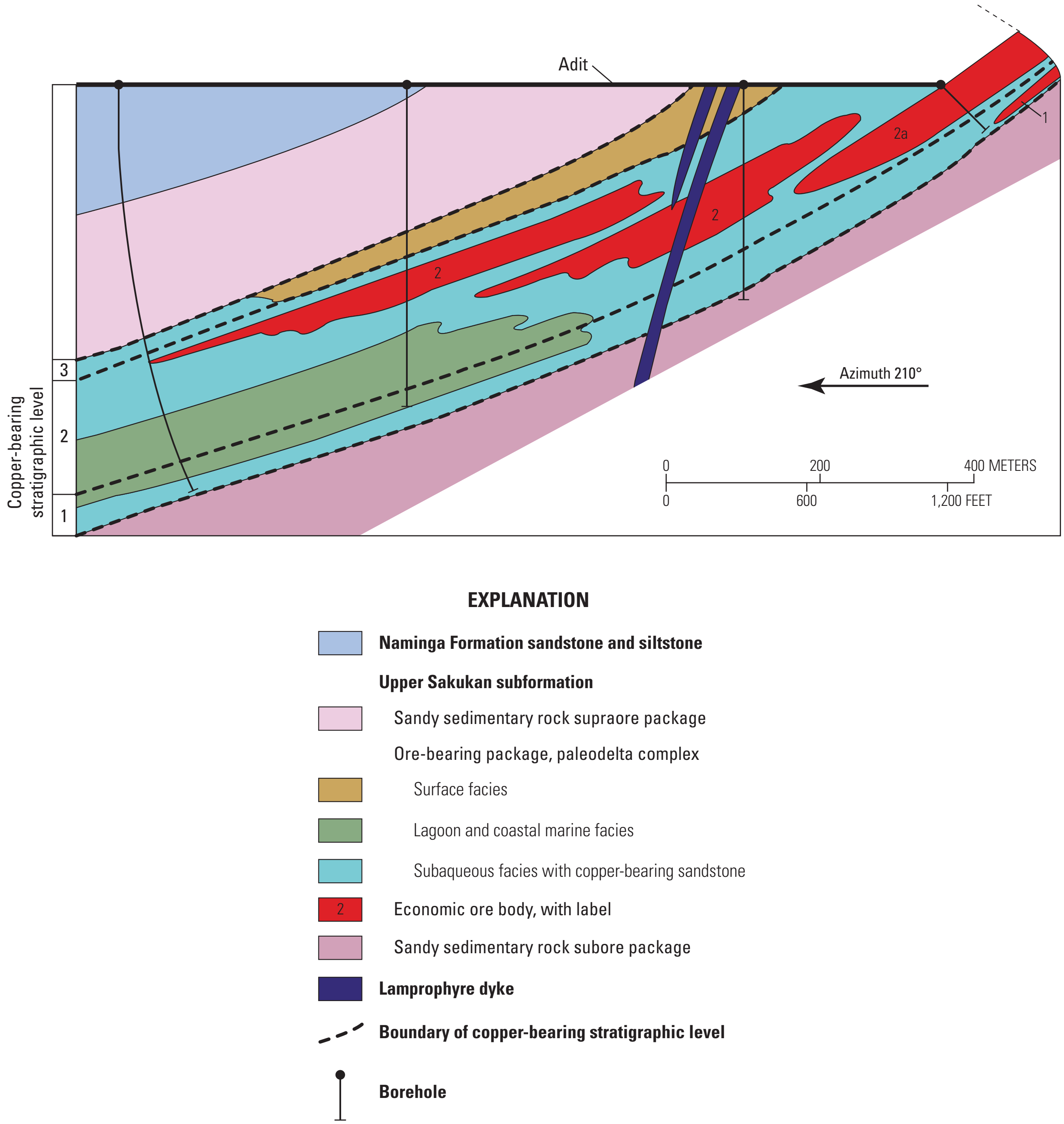

Figure B5. Cross section through the Udokan deposit, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia, showing the relation of mineralization to stratigraphic unit and sedimentary facies in the Upper Sakukan subformation (modified from Arkhangel'skaya and others, 2004).

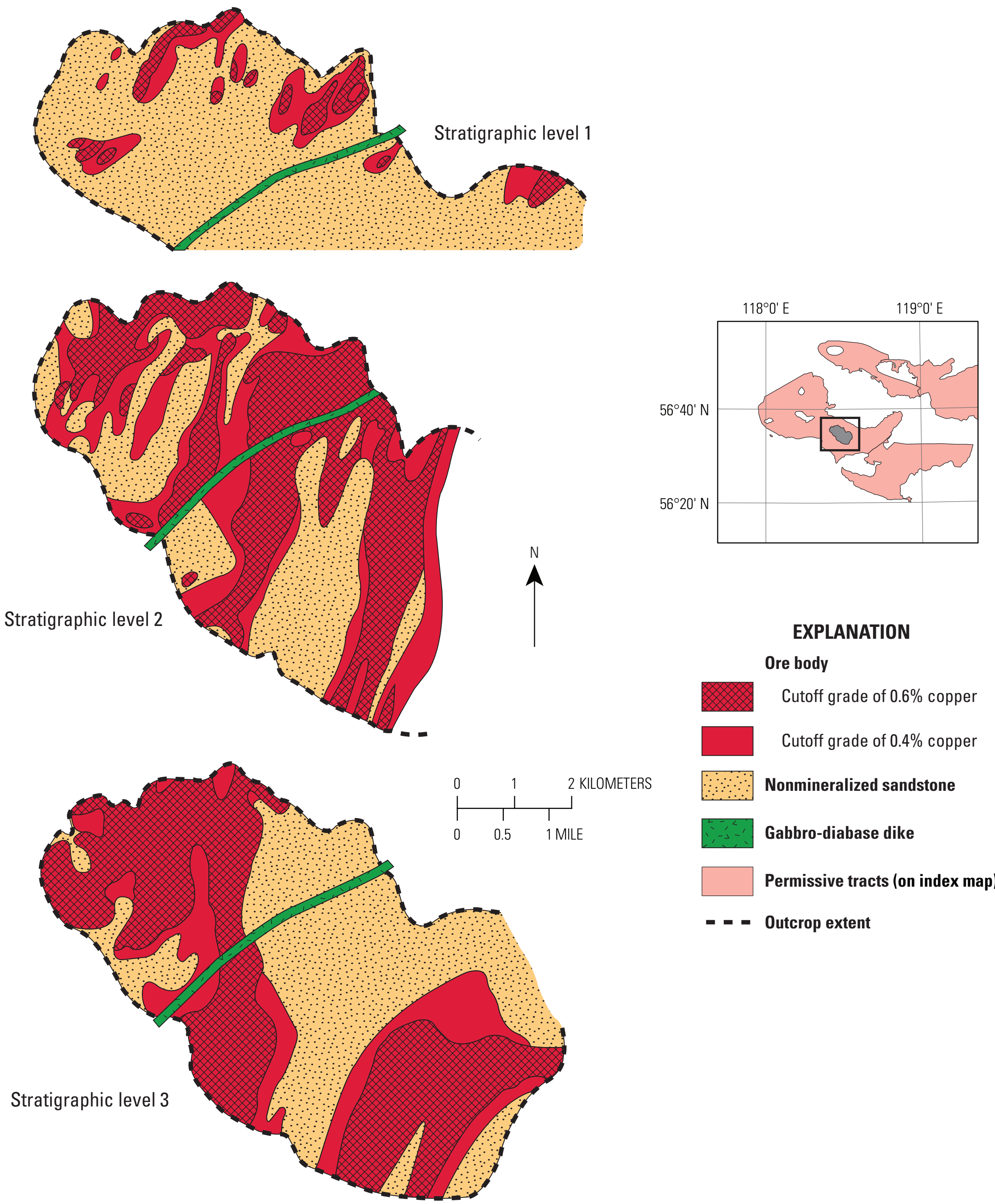

Figure B6. Location and morphology of ore bodies at the copper-bearing stratigraphic levels 1, 2, and 3 of the Udokan deposit, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia (modified from Volodin and others, 1994). The overturned southwestern limb of the syncline is projected on a horizontal plane.

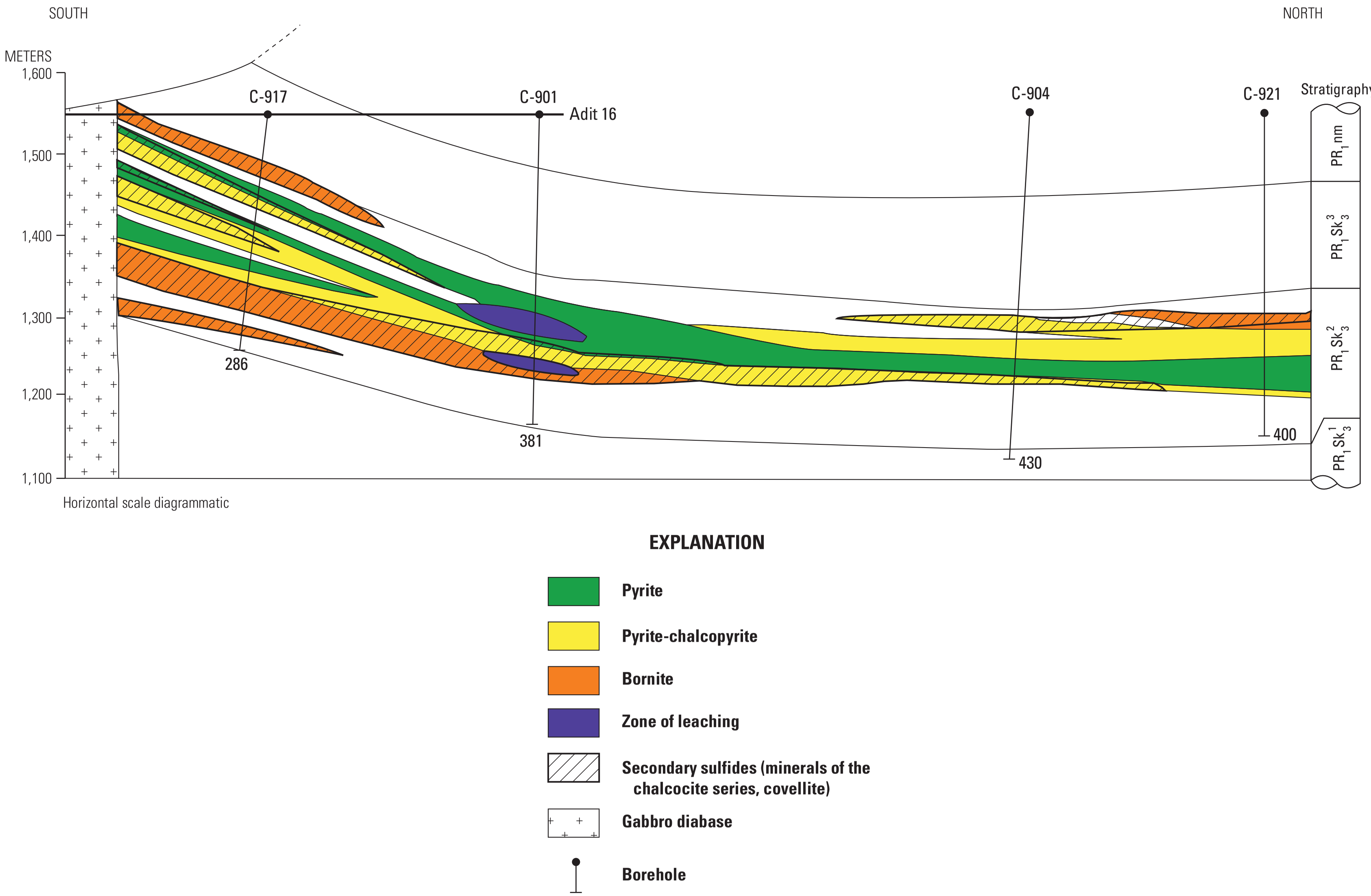

Figure B7. Cross sections through the southern flank of the Udokan deposit, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia, showing zoning of sulfide minerals (modified from Gablina and Mikhaylova, 1994).

martite, iron and manganese hydroxides, native copper, cuprite, tenorite, cerrussite, bismuthopherite, and gypsum may have developed when climatic conditions were humid and warm (Volodin and others, 1994).

The present day oxidation zone, developed in conditions characterized by cold temperatures, zones of permafrost, and physical weathering, penetrates from a few meters to 10–20 m below the surface. The mineral association includes brochantite, antlerite, chalcanthite, udokanite, melanterite, gypsum, jarosite, and less commonly malachite, azurite, as well as iron and manganese hydroxides (Volodin and others, 1994).

Alteration Associated with Ore

Silicification is spatially confined to pyritic, chalcopyritic, and bornitic zones of copper sulfide ore and is most intense in parts of the deposit with thick bornite mineralization (figs. B7 and B8; Gablina and Mikhaylova, 1994). The zone of silicification is restricted to the rhythmically layered ore member and is most commonly developed in interlayers of fine and very fine grained sandstones located in non-ore parts of the rhythmites. Gablina and Mikhaylova (1994) use a different stratigraphic nomenclature from what is shown on the 1:200,000-scale geologic maps (Bufeev and Shcherbakova, 1973; Shul'gina, 1975); table B4 correlates the terminology. In another study, increased concentrations of sulfide minerals were related to albitization and decalcitization (Chechetkin and others, 2000).

Elevated Carbon

The sedimentary rocks of the Upper Sakukan subformation have moderate concentrations of organic carbon; however, samples with elevated copper concentrations have higher organic carbon content. Volodin and others (1994) report that the content of organic carbon ranges from 0.02 to 0.12 percent in ordinary ores, from 0.02 to 0.11 percent in low-mineralized sandstones, and from 0.01 to 0.05 percent in country rocks. Data from Boris Syusyura (written commun., 2009) for the Upper Sakukan and Lower Naminga subformations and data for Udokan copper mineralization from Arkhangel'skaya and others (2004) also show that mineralized samples have higher organic carbon, exceeding 2 percent in one sample of bornite-chalcocite ore (Arkhangel'skaya and others, 2004; fig. B9).

Tonnages and Grades

Copper is the principal commodity in the Udokan deposit; sulfur, silver, gold, and rhenium can be recovered from the copper concentrate. The deposit includes 1,310 million metric tons of ore containing 19.7 million metric tons of copper and 17.4 kilotons of silver (Chechetkin and others, 2000; table B2). On average, indicated mineral resources contain 1.5 percent copper, 12 parts per million (ppm) silver, and 0.05 ppm gold (Chechetkin and others, 2000).

Table B4. Comparison of terminology for Sakukan Formation. Subformation and member from Bufeev and Shcherbakova (1973) and Shul'gina (1975); unit labels from Gablina and Mikhaylova (1994).

Subformation	Member	Unit label
Upper	5	Sk_3^2
		Sk_3^1
Lower	4	Sk_2^2
	3	Sk_2^1
	2	Sk_1^2
	1	Sk_1^1

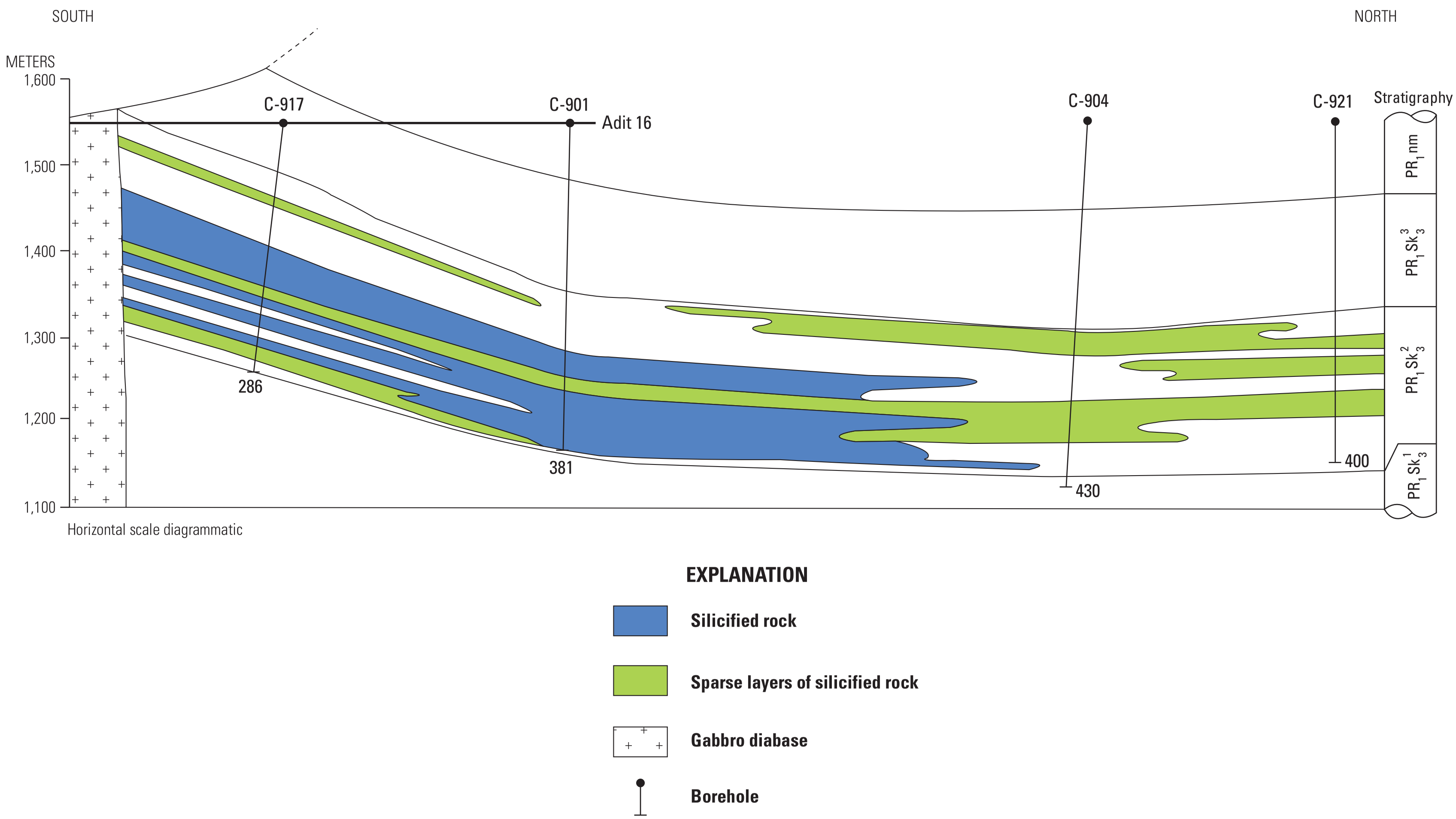

Figure B8. Cross sections through the southern flank of the Udokan deposit, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia, showing silicification associated with mineralization (modified from Gablina and Mikhaylova, 1994).

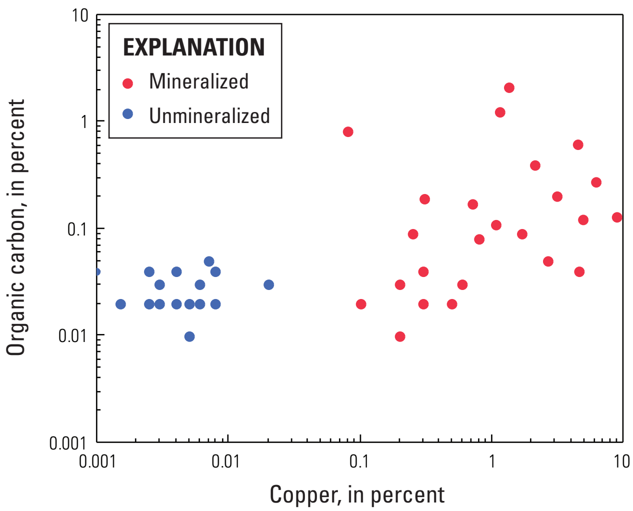

Figure B9. Bivariate plot comparing the concentrations of copper and organic carbon in nonmineralized samples of the Upper Sakukan subformation and the Naminga Formation relative to mineralized samples from the Udokan deposit, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

Prospects, Mineral Occurrences, and Related Deposit Types

Two sites, Sakin I and Sakin II, have prognostic resources (figs. B10 and B11; tables B5 and B6). Bufeev and Shcherbakova (1973), Feoktistov and Chechetkin (1984), and Shul'gina (1975) show eight additional sites, the names of which are unknown, and one named site, Klyukvenoe, (table B7; fig. B1). Two of these sites occur within the Sakukan Formation, member 5, three are in the Sakukan Formation, members 3 and 4, one is in the Sakukan Formation, members 1and 2, two are in Sakukan Formation, member 2, and the other is in the Talakan Formation. The size category for one of the sites is "industrial layers-large," five are categorized as "manifestations of useful minerals," and the sizes of the other three are unknown.

Sakin I Prospect

The Sakin I prospect contains six copper-bearing units; the lowest, PT1, is in the Sakukan Formation, and the other five, PT2 to PT6, are in the overlying Naminga Formation (fig. B10). They have an average thickness of 0.5–3.0 m. The copper-bearing units are layered and lenticular in shape. Prognostic resources of copper were estimated for four of the copper-bearing units (including PT3, PT4, PT5), with thickness ranging from 1.5 to 2 m and copper concentrations that vary between 0.4 and 0.7 percent. The copper-bearing intervals are separated by sections of waste rock ranging in thickness from 30 to 300 meters.

Bornite and chalcocite predominate in the mineralized rocks at Sakin I; chalcopyrite occurs less often, and pyrite is rare. Silver (table B8), gold, and molybdenite are rare and associated with zones of bornite-chalcocite.

Sakin II Prospect

The Sakin II prospect contains three higher grade copper-bearing units in the Upper Sakukan subformation, P.3.I, P.3.II, and P.3.III (fig. B11). The copper-bearing units dip to the west at angles of 55–63° and form layered, lenticular deposits that extend from a few hundred meters to almost 2 kilometers. The total thickness ranges from 10 m in borehole C-17 to 250 m in borehole C-8.

The most common copper sulfides are chalcopyrite and bornite, which make up the bulk of the mineralized rocks. Usually a number of chalcocite minerals (djurleite, digenite) are at the periphery of the mineralized lenses, which are most extensively developed near the surface (trenches K-2 to K-5). The mineralogy of the copper-bearing units is summarized in table B9.

The P.3.I mineralized unit is located at the base of the mineralized package in the Sakin II prospect. It has a complex lenticular shape that can be traced for almost 500 m along strike. The mineralized rocks dip 55º to the west and have been traced along dip between the elevations of 600 and 1,200 m. The unit's thickness ranges from 3.8 to 33 m, including the economic ores with thickness varying from 3.8 to 29.6 m. The copper content varies from 0.65 to 1.60 percent, with an average of 1.10 percent. Noneconomic mineralized layers are found near the surface, which have a thickness of 4.4–19.4 m and a copper content of 0.26–0.33 percent.

The P.3.II mineralized unit occurs in the middle of the mineralized package. It is stratabound and extends for 1,000 m along strike at the surface, and for 350 m along strike at a depth of 1,400 m. The mineralized rocks dip 55° to the west and can be traced for 350 m in the downdip direction in the central part of the ore lens and for 60 m along its western flank. Both in the south and in the north direction, the mineralized unit thins out along strike. The thickness varies from 2.6 m on the flanks of the mineralized lens to 89.3 m in the middle, and the average copper content is 0.8 percent.

The P.3.III mineralized unit is thin, extends for 1.3 km on strike, and is located at the top of the mineralized package. This unit is the main mineralized unit in the prospect. The mineralized rocks dip 55–63º to the west and can be traced along dip from 400 to 1,270 m elevation. Mineralization is likely to continue to the west, down dip, and to the north-northeast, along strike. The thickness of the unit ranges from 2.9 to 22.1 m, and the average copper content is 1.10 percent.

Sources of Information

Principal sources of information used by the assessment team for delineation of the Saku tract are listed in table B10.

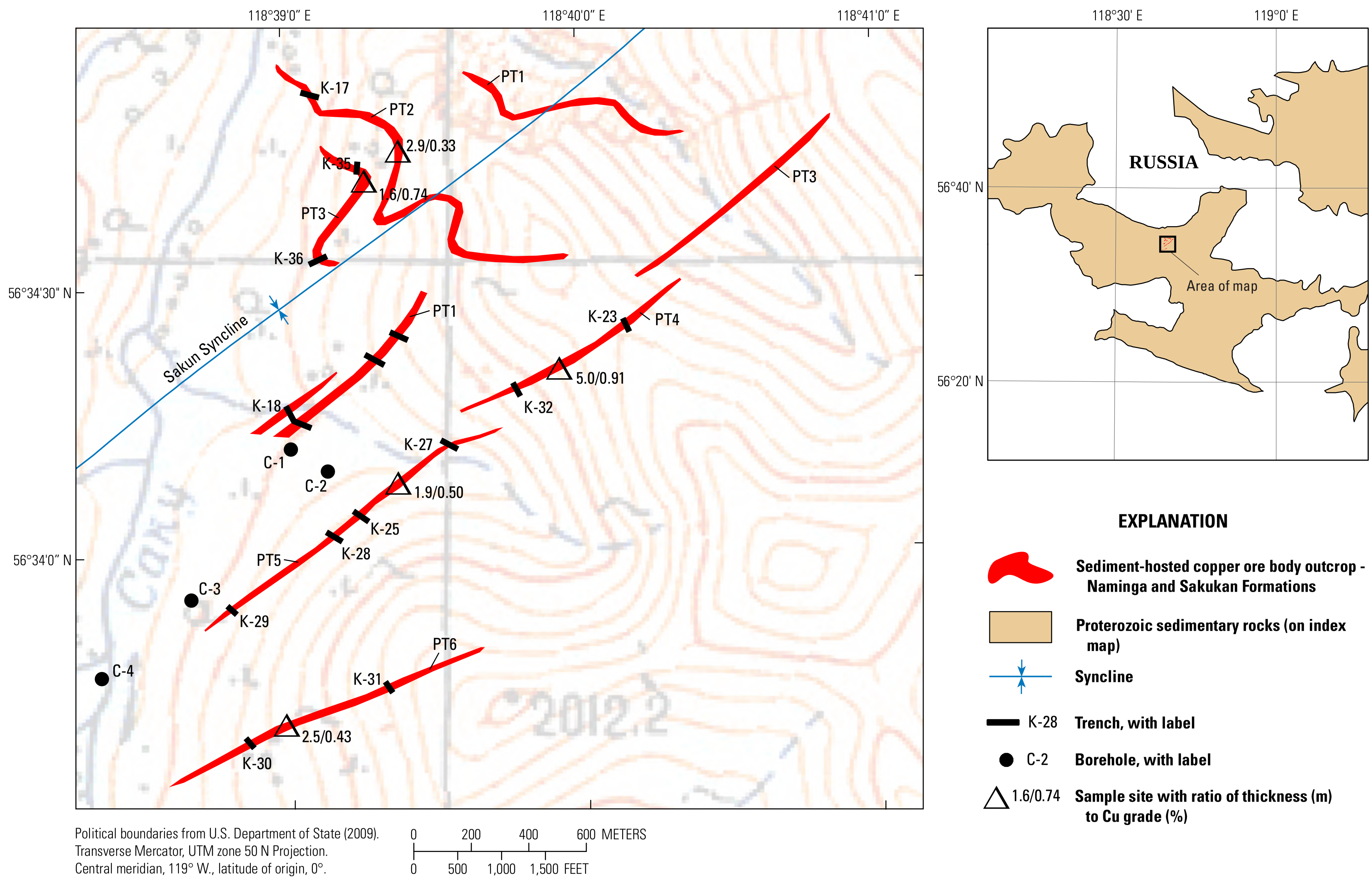

Figure B10. Map showing boreholes, trenches, and the surface extent of Sakin I ore bodies in the Naminga and Sakukan Formations, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia (modified from Chechetkin, written commun., 2009).

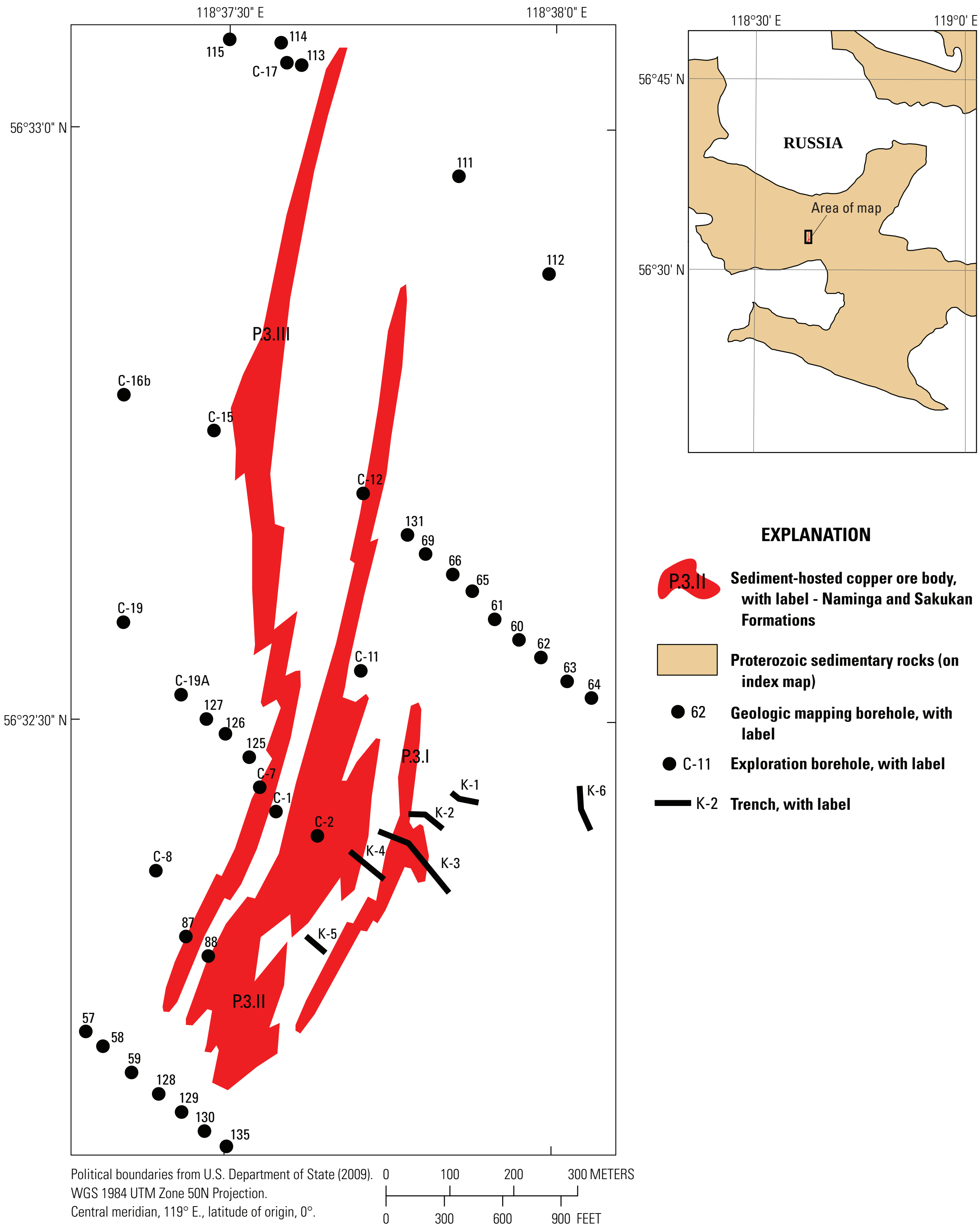

Figure B11. Map showing geologic mapping boreholes, exploration boreholes, trenches, and the surface extent of Sakin II ore bodies in the Naminga and Sakukan Formations, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia (modified from Chechetkin, written commun., 2009).

Table B5. Sites with P category resources in tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994; Henley and Young, 2006). Cu, copper; Ag, silver; Mt, metric tons; %, percent; ppm, parts per million; t, metric ton. P1 and P2 are Russian mineral resource categories that are analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS. P1 refers to estimates associated with extensions to inferred resources. P2 resources are estimated for exploration targets]

Prospect name	Category of resources	Ore (Mt)	Cu grade (%)	Ag grade (ppm)	Contained Cu (t)	Contained Ag (t)
Sakin I	P1	56.4	0.81	10.9	457,400	264.0
Sakin II	P1	41.1	0.98	3.1	404,400	86.4
	P2	24.7	0.98	3.9	242,000	96.3
	P1+ P2	65.8	0.98	3.9	646,004	182.7

Table B6. Comparison of parameters used for identified mineral resource estimation in the deposits and prospects in tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

Key conditional indicators	Udokan	Sakin I	Sakin II
Cutoff grade (percent)	0.6	0.42	0.4
Minimum ore body thickness included in contour calculations (meters)	10	1.1	5
Maximum thickness of non-copper bearing interlayers and nonstandard ores (meters)	10	Not included	5
Minimum economic grade content in estimation block (percent)	0.6	0.67	0.6
Copper content for non-economic ores (percent)	0.2		0.2

Table B7. Point locations of sediment-hosted copper occurrences in tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[NA, not available]

Name	Latitude	Longitude	Unit	Size
Unknown	56.60981	118.44162	Sakukan Formation, member 5	Industrial layers—large
Unknown	56.61991	118.83345	Sakukan Formation, member 5	Occurrences of useful minerals
Unknown	56.58826	118.61843	Sakukan Formation, members 3+4	Occurrences of useful minerals
Unknown	56.62114	118.4923	Sakukan Formation, members 3+4	Occurrences of useful minerals
Klyukvenoe	56.67646	118.38578	Sakukan Formation, members 3+4	Occurrences of useful minerals
Unknown	56.72836	118.31919	Sakukan Formation, members 1+2	Occurrences of useful minerals
Unknown	56.58707	118.74068	Sakukan Formation, member 2	NA
Unknown	56.65218	118.83351	Sakukan Formation, member 2	NA
Unknown	56.52714	118.67403	Talakan Formation	NA

Table B8. Silver content of mineralization at the Sakin I prospect, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[ppm, parts per million]

Sample site trench number	Copper-bearing unit	Silver content (ppm)
K 18	PT1	0.8
K 27	PT5	8.2
K 32	PT4	10.4
K 23	PT4	15.4

Table B9. Ore minerals in the Sakin II prospect, tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[%, percent]

Quantity	Primary minerals	Secondary minerals, oxidation zone
Major (> 30%)	Bornite, chalcopyrite, chalcocite, magnetite	Malachite, iron hydroxides, chalcocite, covellite
Minor (10–30%)	Hematite	Chalcopyrite, hematite, azurite
Rare (1–3%)	Digenite, pyrite, sphene, ilmenite, molybdenite, galena, marcasite	Brochantite, antlerite, secondary bornite, native copper, chrysocolla, cuprite

Table B10. Principal sources of information used by the assessment team for tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[NA, not applicable]

Name or title	Scale	Reference
	Geology	
Lithofacies map of Udokan ore field	1:42,000	Bakun and others (1966)
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXIX	1:200,000	Shul'gina (1975)
Map of mineral resources of the USSR, Bodaybo series, Sheet O-50-XXXV	1:200,000	Bufeev and Shcherbakova (1973)
State geological map of the USSR, new series, sheet N-49,(50) Chita, Map of the pre-Quaternary rocks	1:1,000,000	Efimov and others (1990)
State geological map of the USSR, new series, sheet O-49(50) Bodaybo, Map of Quaternary deposits	1:1,000,000	Kornutova and Tsvetkov (1984)
Geological map of the USSR, new series, sheet O-(50),51 Aldan, Map of the pre-Quaternary rocks	1:1,000,000	Lagzdina and others (1978)
	Mineral occurrences	
Global distribution of sediment-hosted stratiform copper deposits and occurrences	NA	Kirkham and others (1994)
Sediment-hosted copper deposits of the world: Deposit models and database	NA	Cox and others (2003)
World distribution of sediment-hosted, stratiform copper deposits and occurrences	NA	Kirkham and others (2003)
Map of mineral resources of the USSR, Bodaybo series, Sheet O-50-XXXV	1:200,000	Bufeev and Shcherbakova (1973)
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXIX	1:200,000	Shul'gina (1975)
	Geophysics	
Gravitational field map	1:1,000,000	Pis'mennyi (2003)
Magnetic anomaly map	1:1,000,000	Schupak and others (2003)
	Exploration	
Schematic geologic map of the Sakin sandstone-hosted copper deposit	1:10,000	Chechetkin, written commun., 2009

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Undiscovered deposit estimates were subjectively determined by a panel of scientists (table B11). Estimates at the 90th percentile were constrained by the two sites, Sakin I and Sakin II, where Russian geologists had sufficient information to forecast prognostic resources. Another mapped occurrence is recognized to be significant because the map symbol indicates it is made up of "industrial layers—large". All assessors recognized that Udokan, the known deposit in the tract, will have significant reserve growth. Some of the assessment team increased their estimates to account for extensions to the Udokan deposit. Other assessors limited their estimates to undiscovered deposits that may be outside of the Udokan deposit. The simulation input was selected to focus on the resources not associated with Udokan. Exploration activity has been thorough in this area because of the presence of the Udokan deposit; as a result, estimates at the 50th and 10th percentile were somewhat conservative.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered sediment-hosted stratabound copper deposits with the sandstone copper model (this report) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table B12. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. B12). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table B11. Undiscovered deposit estimates, deposit numbers, and tract area for tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers. N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005). In cases where individual estimates were tallied in addition to the input for EMINERS, individual estimates are listed]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km^2)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}	
2	5	8	8	8	4.9	2.2	45	1	5.9	827

Estimator	Estimated number of undiscovered deposits				
	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
other	1	2	3		
other	1	2	3		
other	1	4	6		
USGS	2	4	8		
Input for EMINERS	2	5	8		
USGS	8	12	16	24	
USGS	10	15	20	30	
USGS	10	15	20		

Table B12. Results of Monte Carlo simulations of undiscovered resources in tract 150ssCu0002, Saku—Kodar-Udokan area, Russia.

[t, metric ton; Mt, metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	52,000	190,000	1,500,000	15,000,000	21,000,000	4,700,000	0.24	0.04
Ag (t)	0	0	790	12,000	19,000	4,100	0.23	0.29
Rock (Mt)	4	15	130	1,400	1,900	420	0.24	0.04

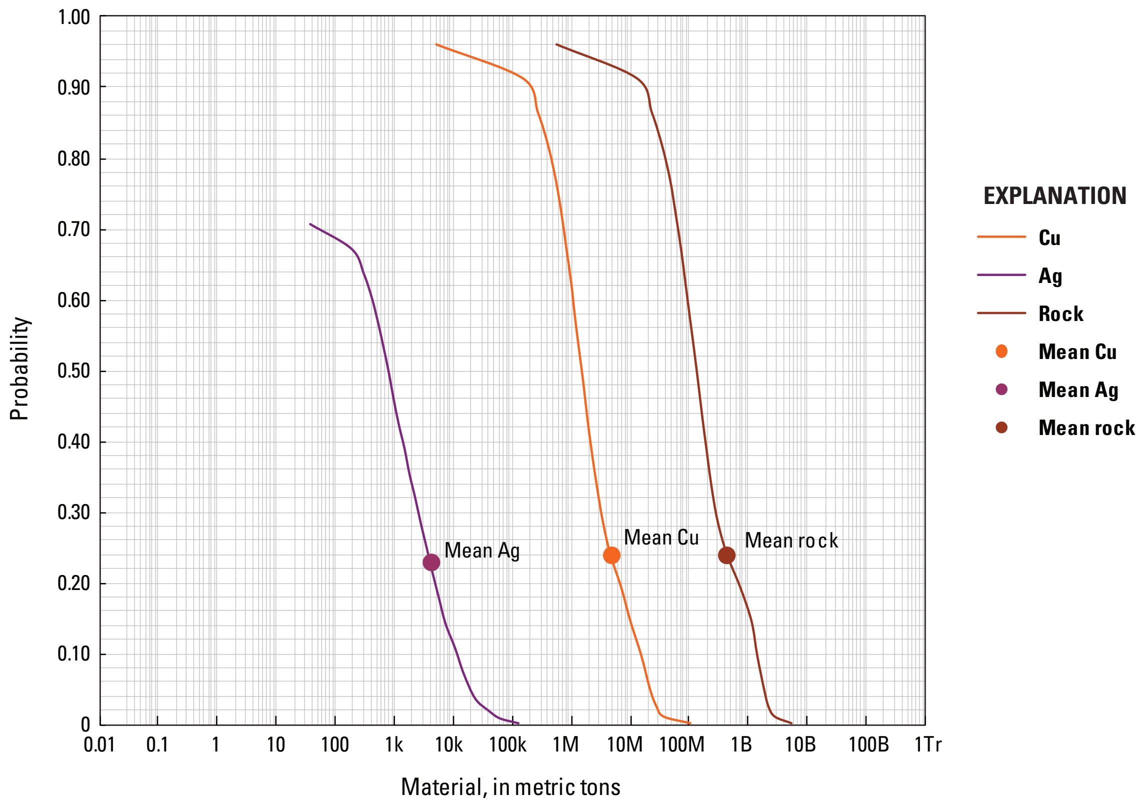

Figure B12. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 150ssCu0002, Saku—Kodar-Udokan area, Russia. k, thousand; M, million; B, billion; Tr, trillion.

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Appendix C. Sediment-Hosted Stratabound Copper Assessment for Tract 150ssCu0003, Ingamakit—Kodar-Udokan Area, Russia

By Michael L. Zientek[1], Vladimir S. Chechetkin[2], Heather L. Parks[1], Stephen E. Box[1], Deborah A. Briggs[1], Pamela M. Cossette[1], Alla Dolgopolova[3], Timothy S. Hayes[4], Reimar Seltmann[3], Boris Syusyura[5], Cliff D. Taylor[6], and Niki E. Wintzer[1]

Deposit Type Assessed: Sediment-Hosted Stratabound Copper

Descriptive model: Sediment-hosted copper, Revett subtype (Cox and others, 2003)
Grade and tonnage model: Sediment-hosted stratabound copper, sandstone copper subtype (Zientek and others, 2013; appendix G)
Table C1 summarizes selected assessment results.

Table C1. Summary of selected resource assessment results for tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

[km, kilometer; km^2, square kilometer; t, metric ton; –, none]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
October 2009	2	553	–	3,900,000	1,100,000

Location

The tract is located in southeast Russia, approximately 560 km east-northeast of the northern tip of Lake Baikal. It is approximately 20 km east-southeast of the city Naminga and lies in the northern region of Chita Oblast. The China and Kalar Rivers run along the northern edge of the tract (fig. C1).

Geologic Feature Assessed

Siliciclastic rocks in the Chinei and Kemen Groups of the Udokan Complex.

[1] U.S. Geological Survey, Spokane, Washington, United States.

[2] Russian Geological Society (RosGeo), Chita, Russia.

[3] Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London, United Kingdom.

[4] U.S. Geological Survey, Tucson, Arizona, United States.

[5] Mining and Economic Consulting Ltd., Almaty, Kazakhstan.

[6] U.S. Geological Survey, Denver, Colorado, United States.

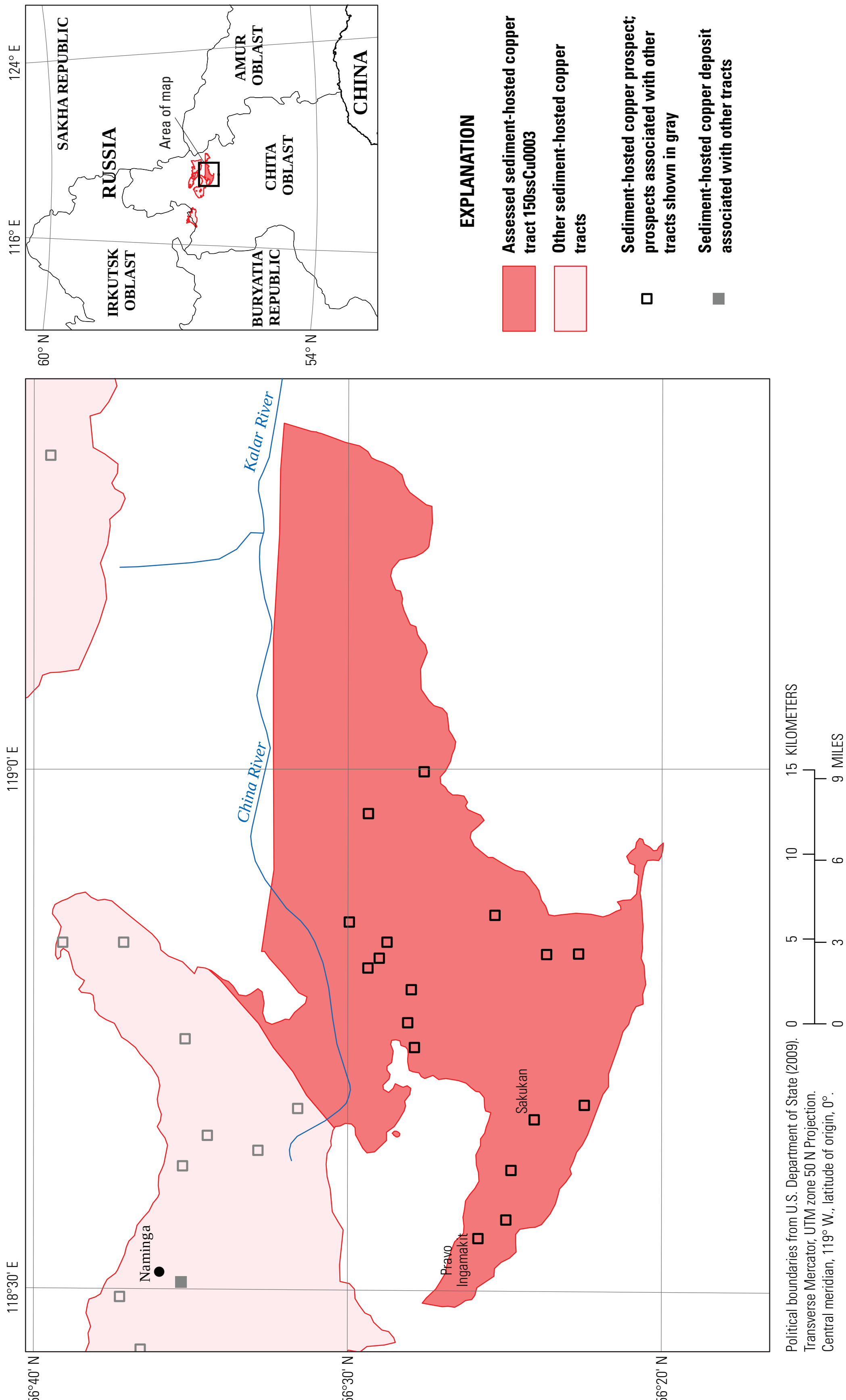

Figure C1. Map showing the assessed and adjacent sediment-hosted stratabound copper permissive tracts, and associated prospects in tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

Delineation of the Permissive Tract

Geologic Criteria

The tract is based on the distribution of the Chitkanda, Aleksandrov, Butun, Sakukan, and Naminga Formations on the maps by Bufeev and Shcherbakova (1973) and Fedorovskiy (1976) (figs. C1 and C2). The central part of the tract is underlain by the southwest-northeast-trending Katugin Syncline (fig. C2). Within the northern limb of the syncline, complex parasitic folds deform the rocks. Fold axes are oriented northwest-southeast in the part of the tract south of the Chinei intrusion.

The northern boundary of the tract extends under cover into Verkerhne-Kalar Graben to a near-vertical structure that occurs along the southern margin of the graben. The western margin of the tract, along with the adjacent Saku tract, are defined by a high-angle fault, shown as a first-order fault on figure 1 in Burmistrov and Apol'skiy (1986) and as the Ingamakit Fault on figure 1 of Konnikov (1986).

Known Deposits

There are no known deposits.

Prospects, Mineral Occurrences, and Related Deposit Types

Three distinct copper-bearing units have been mapped in the southwestern part of the tract. The Pravo Ingamakit copper-bearing unit occurs in the Lower Chitkanda subformation and has a prognostic resource estimate (figs. C1, C2, and C3; and table C2). The Sakukan copper-bearing unit occurs in the Upper Chitkanda subformation. Another cupriferous unit is mapped in the overlying Aleksandrov Formation.

Fedorovskiy (1976) and Feoktistov and Chechetkin (1984) show more than a dozen point locations for other sediment-hosted stratabound copper occurrences in the central part of the tract (table C3). Two of these sites occur within the Sakukan Formation, seven are in the Aleksandrov Formation, five are in the Chitkanda Formation, and two are in the Talakan Formation. The sizes of these sites are unknown.

Pravo Ingamakit Layer and Prospects

Pravo Ingamakit refers to a 40–80-m thick copper-enriched unit in the middle subformation of the Chitkanda Formation that crops out on the south side of the Chinei gabbroic intrusion massif (figs. C2 and C3; Konnikov, 1986; Gongalsky and others, 2007). This subformation contains altered and metamorphosed polymictic and oligomictic quartz-rich sandstone and siltstone that have been affected by multiphase folding events.

Copper mineralization consisting of disseminations of chalcopyrite, bornite, and chalcocite occurs in a narrow zone of increased schistosity that can be traced intermittently for about 7 km, from the contact of the Chinei gabbroic intrusion to the headwaters of the Pravo Ingamakit and Sukakan Rivers (Konnikov, 1986). Mineralized rocks have been silicified, albitized, epidotized, and chloritized. The mineralized rocks dip steeply at 65–70° and have been drilled to depths of 700 m.

Economic grade mineralization occurs discontinuously within the mineralized unit. Stratified, lenticular ore bodies range in thickness from 1 to 30 m. Average copper content of the sandstones is 0.88 percent, although the copper content of individual prospects ranges from 0.5 to 1.5 percent. Silver in samples varies from 7 to 70 parts per million (ppm), with averages within ore bodies ranging from 13 to 32 ppm (table C4). Gold values up to 0.5–3 ppm were found in some samples.

The Pravo Ingamakit area was explored by the Udokan Expedition in the 1960s. Their work delineated three areas, or sections, of higher grade mineralization with a total strike length of 4.5 km. From north to south, the sections are Boulder (figs. C3 and C4), Basaltic, and Pravo-Ingamakit (in the drainage divide between the Pravo Ingamakit and Sukakan Rivers). Between these sections, intervals of higher grade copper mineralization pinch out or are truncated by faults.

Boulder Section

The main mineralized layer at the Boulder site was tested in several trenches (figs. C3 and C5). Its maximum thickness (14.2 m) is in trench K-47-K-32. The main ore layer abruptly pinches out to the north (between trenches K-47-K-32 and K-49-K-39) and gradually thins to 4.7 m in the southernmost trench (K-24), where pyritic mineralization is predominant.

Between trenches K-34 and K-27, the layer is partly covered, complexly folded, and displaced by faults. The thickness of the mineralized layer is not fully exposed in trench K-34, because of complex folding (visible in the trench), and in trench K-27, because of a thick cover of glacial deposits. Anticlines are exposed within trench K-34 and trenches K-44 and K-27. The displacement on the faults is estimated to be 50–70 m vertically (as much as 100 m horizontally).

In the northwestern part of the area, trench K-58 exposed another cupriferous lens within sandstone that is 14 m thick and extends about 200 m along strike.

Basaltic Section

In the Basaltic section, two 20-m-thick ore bodies lie within the northwestern limb of an overturned anticline (fig. C3). They are separated by a subeconomic cupriferous interval. The thickness of the first ore body increases to the northeast from 1.1 m (with 2.07 percent copper) to 13.2 m and then to 30 m in three trenches. The second ore body is 7.5 m thick and thins and pinches out in fold limbs. However, in the fold closure, the mineralization has a structural thickness of 30 m.

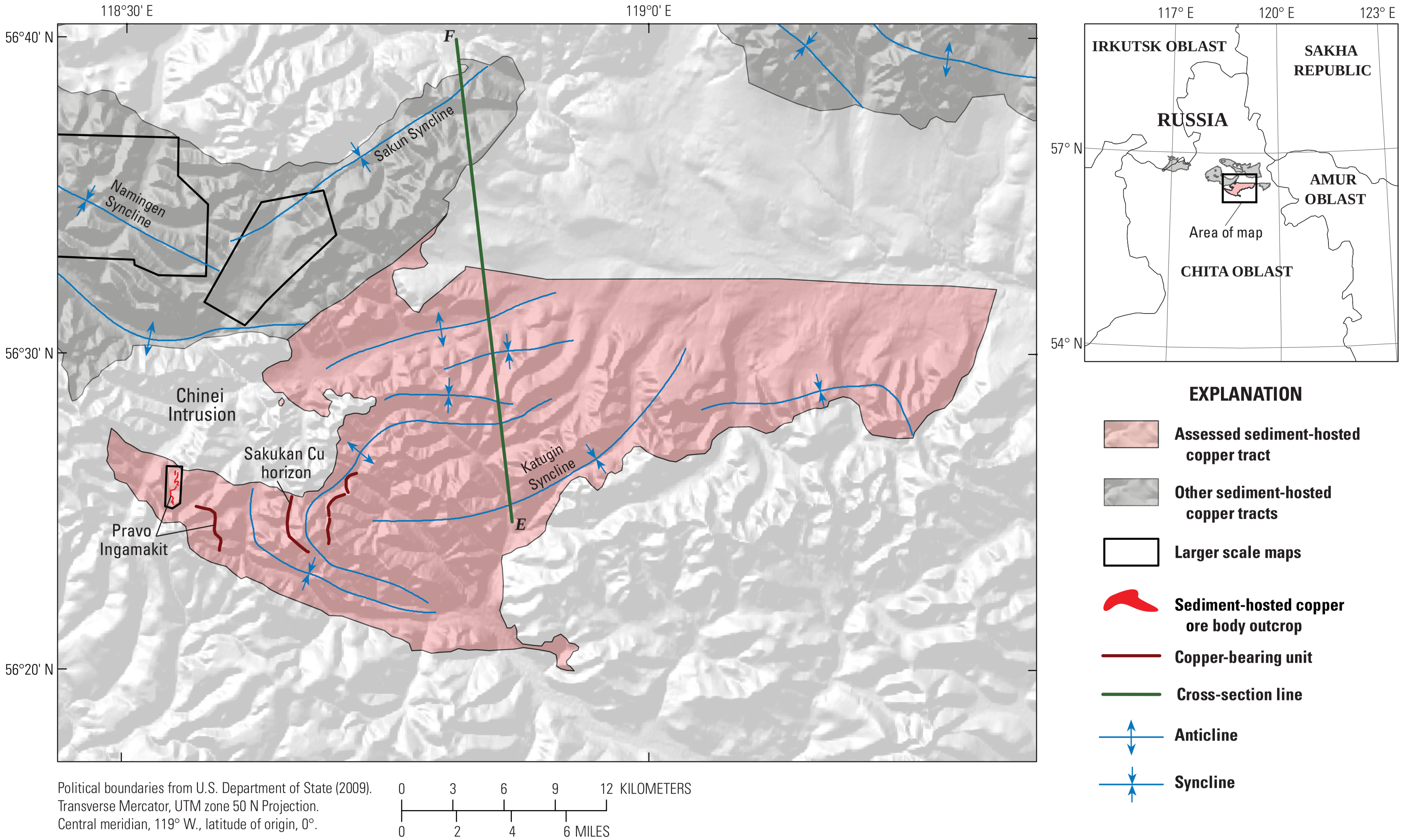

Figure C2. Map showing the assessed and adjacent sediment-hosted stratabound copper permissive tracts, surface extent of ore bodies, and copper-bearing units in tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia (modified from Bufeev and Shcherbakova, 1973; and Konnikov, 1986).

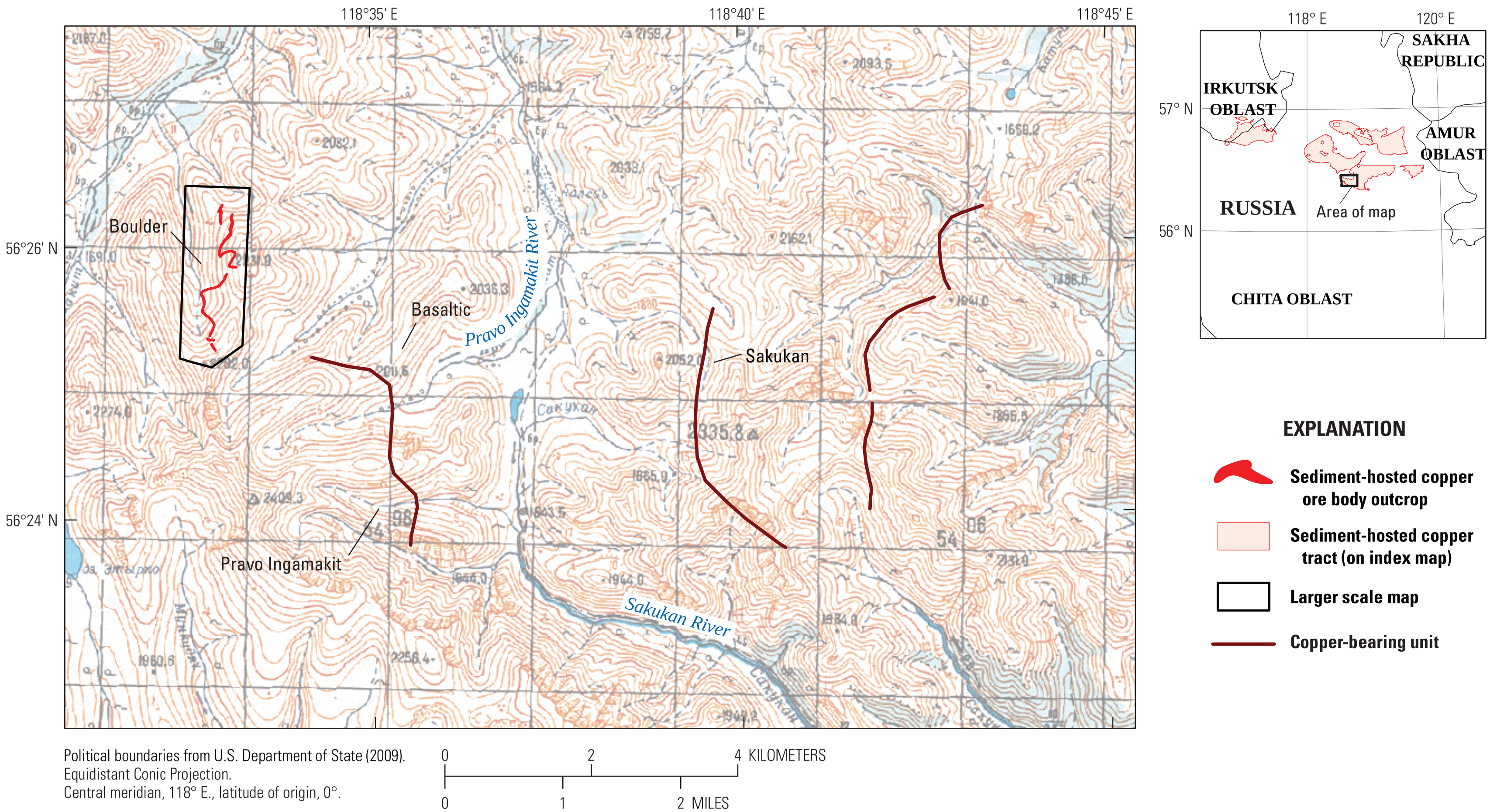

Figure C3. Map showing surface extent of ore bodies and copper-bearing units in the Pravo Ingamakit area, tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia (modified from Bufeev and Shcherbakova, 1973; and Konnikov, 1986).

Table C2. C and P category resources associated with the Pravo-Ingamakit prospect, tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994; Henley and Young, 2006). Cu, copper; Ag, silver; Mt, million metric tons; %, percent; ppm, parts per million; t, metric ton. C2 and P1 are Russian mineral resource categories. C2 is analogous to inferred mineral resources as defined by CRIRSCO. P1 is analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS and are estimates associated with extensions to inferred resources]

Prospect name	Resource category	Ore (Mt)	Cu grade (%)	Ag grade (ppm)	Contained Cu (t)	Contained Ag (t)
Pravo Ingamakit	C2	54.3	0.88	23.9	477,900	1,298.0
	P1	69.1	0.88	23.9	608,000	1,651.4
	C2+ P1	123.4	0.88	23.9	1,085,900	2,949.4

Table C3. Point locations of sediment-hosted copper occurrences in tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

Name	Latitude	Longitude	Unit
Unknown	56.46038	118.99727	Sakukan Formation, member 2
Unknown	56.42279	118.85985	Sakukan Formation, member 1
Unknown	56.50023	118.85339	Aleksandrov Formation
Unknown	56.49031	118.80917	Aleksandrov Formation
Unknown	56.48424	118.81842	Aleksandrov Formation
Unknown	56.48008	118.83387	Aleksandrov Formation
Unknown	56.46723	118.78874	Aleksandrov Formation
Unknown	56.46905	118.75683	Aleksandrov Formation
Unknown	56.46546	118.73301	Chitkanda Formation
Unknown	56.49006	118.95758	Talakan Formation
Unknown	56.39546	118.82237	Talakan Formation
Unknown	56.37841	118.82317	Chitkanda Formation
Unknown	56.41651	118.56814	Chitkanda Formation
Sakukan	56.40159	118.66448	Chitkanda Formation
Unknown	56.37507	118.67864	Chitkanda Formation
Unknown	56.41385	118.61581	Aleksandrov Formation

Table C4. C2 category copper and silver content of areas that make up the Pravo-Ingamakit prospect, tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994). km^2, square kilometers; m, meter; %, percent; ppm, parts per million]

Name	Area (km^2)	Ore body thickness (m)	Copper content (%)	Silver content (ppm)
Boulder	776.2	8.4	0.69	13.4
Basaltic	601.3	11.8	1.0	32.3
Pravo Ingamakit	391.5	9.0	0.99	26.3

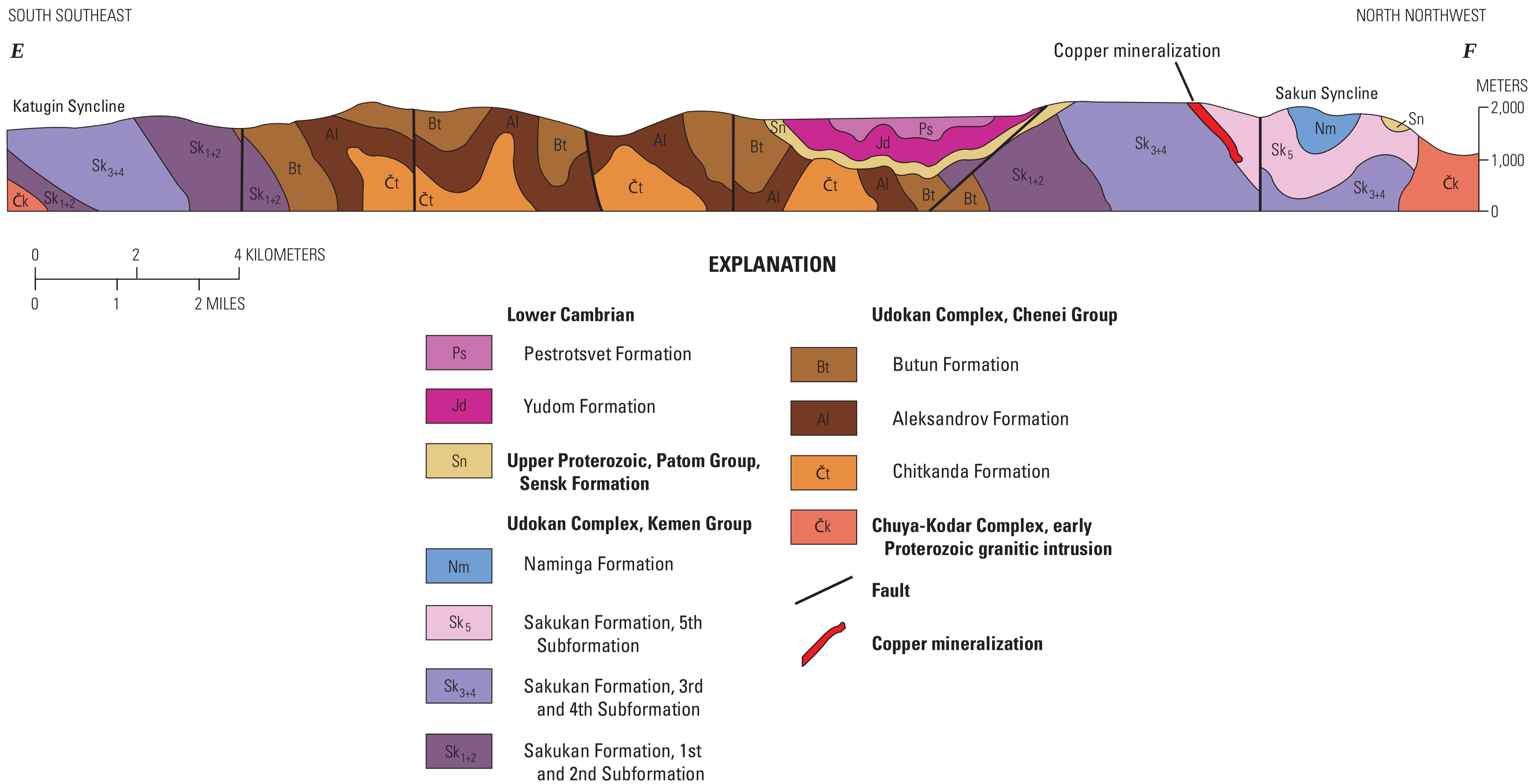

Figure C4. Cross section of the western half of tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia, showing folded Kodar-Udokan basin deposits and the younger intrusive and erosional contacts surrounding the folded Udokan Complex, (modified from Bufeev and Shcherbakova, 1973).

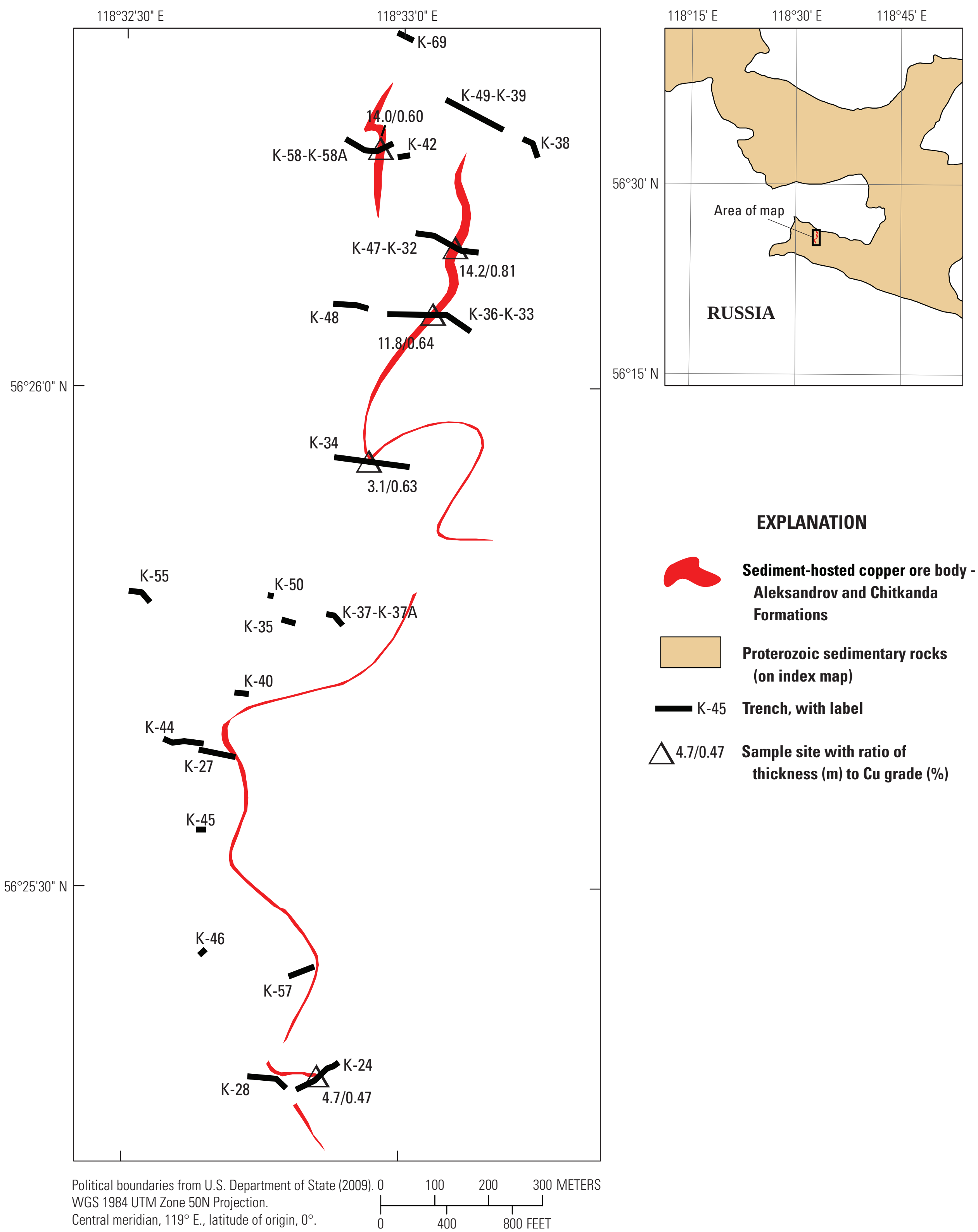

Figure C5. Map showing trenches and the surface extent of ore bodies in the Aleksandrov and Chitkanda Formations in the Boulder prospect, tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

Pravo Ingamakit Section

Two mineralized units can be traced for 440 m in the Pravo Ingamakit section in the area between two trenches (fig. C3). The northwestern end is truncated by a fault. In the northwestern trench, the mineralized unit 1 is 16.4 m thick and the second mineralized unit is significantly thinner (2.6 m). In the southeastern trench, the thickness of mineralized unit 1 decreases to 9.7 m, whereas the thickness of the second mineralized unit increases to 5.2 m. To the southeast, the cupriferous units and their associated facies thin out.

Both mineralized units are bounded by thrust faults parallel to fold axes. The hanging wall rocks contain the cupriferous unit within an overturned fold, in which the mineralized unit is a single layer ranging from 3.0 to 4.5 m thick. The hanging wall mineralized unit also thins to the southeast.

Ore Mineralogy

The cupriferous units and lenses are characterized by finely disseminated ore textures with irregularly dispersed ore minerals. Grain size varies from microns to several millimeters. In intensely folded and faulted sections, the ore minerals occur as veinlets and nodules.

The dominant ore mineral is chalcopyrite, yet some areas contain bornite-chalcopyrite and bornite-chalcocite assemblages. Chalcopyrite usually occurs as isolated grains, but some are intergrown with pyrite and magnetite. Some of the chalcopyrite occurs as interstitial cement between nonmetallic grains. Almost everywhere, with varying degree of intensity, chalcopyrite is replaced by secondary copper sulfides and bornite with chalcocite.

Sakukan Layer and Prospects

The Sakukan layer is located east of the Pravo Ingamakit layer and prospects and is confined to a bed of carbonaceous schist in what was identified as the Butun Formation (Konnikov, 1986, his fig. 1) (fig. C2). However, the layer is within the Chitkanda Formation on maps by Bufeev and Shcherbakova, (1973) and Feoktistov and Chechetkin (1984). The northern end of the zone is crosscut by the Chinei gabbro-diabase intrusion, and the southern end terminates against a fault (Konnikov, 1986).

The cupriferous unit is 0.5–2 km long and 3–50 m thick; individual mineralized layers range from 2.2–2.8 m thick with 0.58 percent copper to 21 m thick with 0.3–0.5 percent copper.

Copper-Enriched Units in the Aleksandrov Formation

In the lower subformation of the Aleksandrov Formation to the east of the Chinei Intrusion, a 50-m-thick cupriferous unit has been traced for 1 km, with an enriched interval containing 0.3–0.8 percent copper over a thickness of 10.2 m. Another 44-m-thick cupriferous unit has been traced for 2.5 km in the middle subformation of the Aleksandrov Formation. It contains an enriched interval with 0.3–0.5 percent copper over a thickness of 15 m.

Sources of Information

Principal sources of information used by the assessment team for delineation of the Ingamakit tract are listed in table C5.

Table C5. Principal sources of information used by the assessment team for tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

Name or title	Scale	Reference
Geology		
Map of mineral resources of the USSR, Bodaybo series, Sheet O-50-XXXV	1:200,000	Bufeev and Shcherbakova (1973)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXXVI	1:200,000	Fedorovskiy (1976)
State geological map of the USSR, new series, sheet N-49,(50) Chita, Map of the pre-Quaternary rocks	1:1,000,000	Efimov and others (1990)
State geological map of the USSR, new series, sheet O-49(50) Bodaybo, Map of Quaternary deposits	1:1,000,000	Kornutova and Tsvetkov (1984)
Geological map of the USSR, new series, sheet O-(50),51 Aldan, Map of the pre-Quaternary rocks	1:1,000,000	Lagzdina and others (1978)
Mineral occurrences		
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
Geophysics		
Gravitational field map	1:1,000,000	Pis'mennyi (2003)
Magnetic anomaly map	1:1,000,000	Schupak and others (2003)
Exploration		
Site geology and initial testing of the Pravo Ingamakit, Boulder Section	1:2,000	

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Undiscovered deposit estimates were subjectively determined by a panel of scientists (table C6). Estimates at the 90th percentile were constrained by one site, Pravo Ingamakit, where Russian geologists had sufficient information to forecast prognostic resources. Values at the 50th percentile reflect the presence of the mapped mineralized units at Sakukan and within the Aleksandrov Formation. Fifteen occurrences, in three different formations, indicate that mineralization systems that could form sediment-hosted stratabound copper deposits are widespread in the tract and throughout the stratigraphic section. Some exploration activity has been conducted in this area because of its proximity to the Udokan deposit and the Chinei intrusion; however, the northern part of the tract is covered by shallow cover in the Verkerhne-Kalar Graben and is an obvious place for further exploration. Accordingly, the 10th percentile estimate was somewhat higher to reflect uncertainty.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered sediment-hosted stratabound copper deposits with the sandstone copper model (this report) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table C7. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. C6). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table C6. Undiscovered deposit estimates, deposit numbers, and tract area for tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers. N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005). In cases where individual estimates were tallied in addition to the input for EMINERS, individual estimates are listed]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	*s*	C_v%	N_{known}	N_{total}	
1	4	7	7	7	3.9	2.2	55	0	3.9	553

Estimator	Estimated number of undiscovered deposits				
	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
other	0	1	3		
other	1	2	3	5	
other	1	3	5		
Input for EMINERS	1	4	7		
USGS	2	5	7	10	
USGS	2	5	10		
USGS	3	4	8		
USGS	3	6	12	20	

Table C7. Results of Monte Carlo simulations of undiscovered resources in tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia.

[Cu, copper; Ag, silver; t, metric ton; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	69,000	1,100,000	12,000,000	19,000,000	3,900,000	0.23	0.06
Ag (t)	0	0	520	9,100	18,000	3,600	0.20	0.37
Rock (Mt)	0	7	97	1,300	1,700	350	0.23	0.06

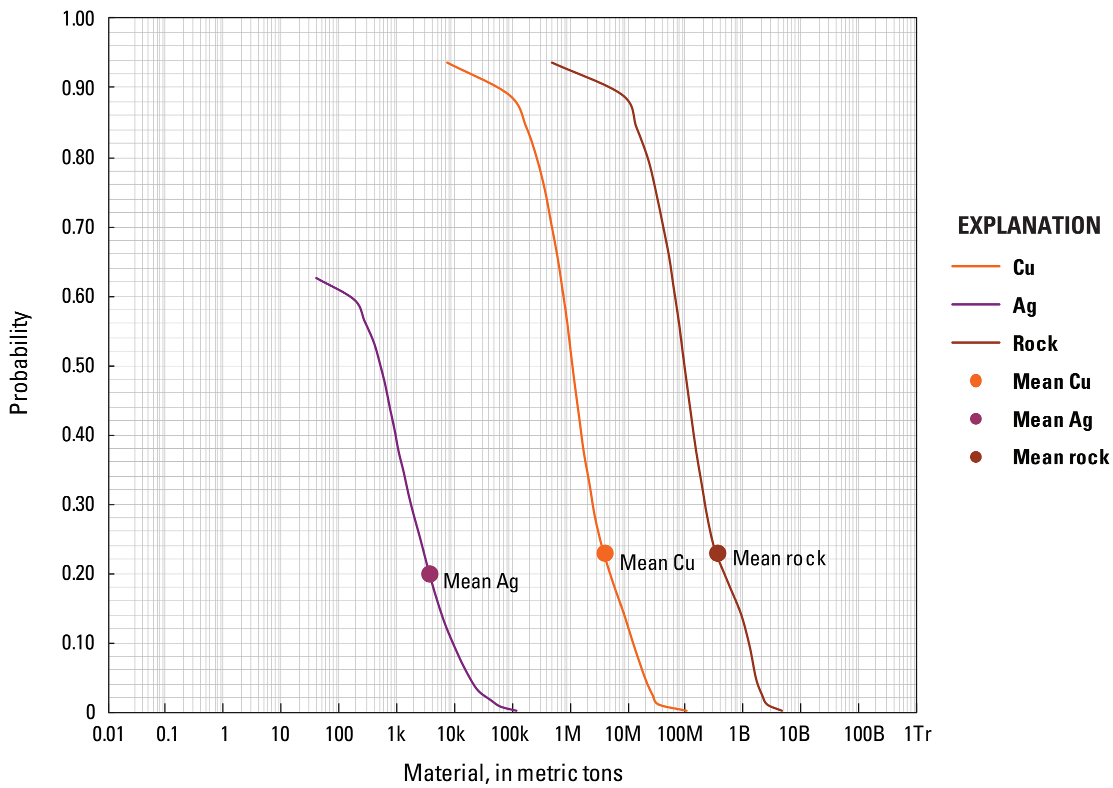

Figure C6. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 150ssCu0003, Ingamakit—Kodar-Udokan area, Russia. k, thousand; M, million; B, billion; Tr, trillion.

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Appendix D. Sediment-Hosted Stratabound Copper Assessment for Tract 150ssCu0004 Unkur—Kodar-Udokan Area, Russia

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Deposit Type Assessed: Sediment-Hosted Stratabound Copper

Descriptive model: Sediment-hosted copper, Revett subtype (Cox and others, 2003)
Grade and tonnage model: Sediment-hosted stratabound copper, sandstone copper subtype (Zientek and others, 2013; appendix G)
Table D1 summarizes selected assessment results.

Table D1. Summary of selected resource assessment results for tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia.

[km, kilometer; km^2, square kilometer; t, metric ton]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
October 2009	2	303	682,000	1,800,000	290,000

Location

The tract is located in southeastern Russia, approximately 575 km east-northeast of the northern tip of Lake Baikal. It is approximately 25 km west-northwest of the city Chara and lies in the northern region of Chita Oblast. The Kemen River runs north-south through the central area of the tract (fig. D1).

Geologic Feature Assessed

Siliciclastic rocks in the Kemen Group of the Udokan Complex.

[1] U.S. Geological Survey, Spokane, Washington, United States.

[2] Russian Geological Society (RosGeo), Chita, Russia.

[3] Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London, United Kingdom.

[4] U.S. Geological Survey, Tucson, Arizona, United States.

[5] Mining and Economic Consulting Ltd., Almaty, Kazakhstan.

[6] U.S. Geological Survey, Denver, Colorado, United States.

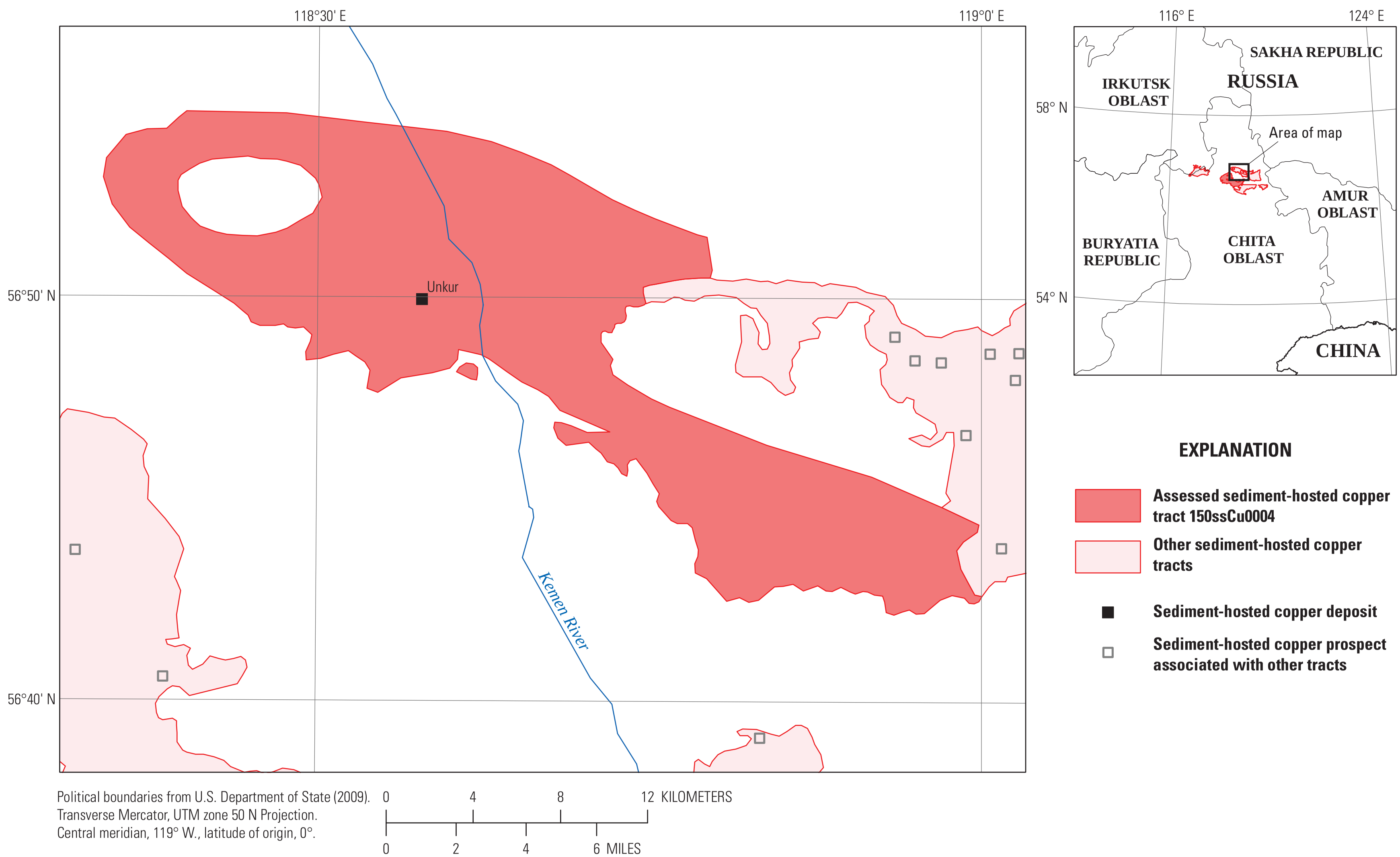

Figure D1. Map showing the assessed and adjacent sediment-hosted stratabound copper permissive tracts, and associated deposit and prospects in tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia.

Delineation of the Permissive Tract

Geologic Criteria

The extent of the southeastern part of the tract (figs. D1 and D2) is based on the mapped distribution of the Sakukan Formation as shown by Shul'gina (1975). However, most of the tract lying to the northwest is covered by alluvial deposits. The tract is confidently extended in the subsurface to the extent of the Sakukan Formation as shown on a 1:25,000-scale exploration map of the area around the Unkur deposit. The northern boundary of the tract was placed at a fault shown on Shul'gina (1975). A pronounced magnetic high in the northwestern part of the tract corresponds to a buried gabbroic intrusion; the magnetic data were used to exclude an area of the tract. The northwesternmost edge of the tract lies between the 250-m and 500-m depth contours of cover as shown on Feoktistov and Chechetkin (1984).

Known Deposits

One site, Unkur, has been explored and has C2 category resources in excess of estimated prognostic resources (table D2; figs. D3 and D4).

The Unkur deposit is largely concealed by glacial deposits where the Kemen River emerges from mountainous areas to the southeast. Mineralization was discovered in an isolated outcrop about 3 km from the river. Drilling was conducted to map bedrock geology under cover and to evaluate the copper mineralization.

The exploration work revealed a broad, slightly asymmetric syncline in the Sakukan Formation (fig. D2). Copper-bearing sandstones and siltstones occur within the middle of the upper package of the lower subformation of the Sakukan. Overall, the lower subformation consists of thin interbedded calcareous sandstone, silty sandstone, siltite interbeds, and martite-magnetite sandstones. Lithologic characteristics indicate a coastal-sea and lagoonal facies for the rocks hosting the cupriferous strata.

The 20–50-m-thick cupriferous unit is traced along the southwestern limb of the Unkur Syncline for about 7 km and has been drilled to a depth of 350 m (fig. D2). Higher grade mineralized strata form steeply dipping (45–60°) sheet-like deposits with an average thickness of 8.5 m. They are traced throughout the entire cupriferous unit, although continuity is affected by secondary flexural-slip, high-order folding, and consequent fracturing. Ore minerals include chalcopyrite, bornite, and rare chalcocite that form interspersed, disseminated, veinlet, and partially layered ore types. Sulfide minerals are oxidized on the surface. To the northwest, borehole C-118 (fig. D3) displays an increase in ore thickness and copper content (up to 2 percent for individual samples; average copper content is 0.75 percent).

The cupriferous unit has also been identified and traced for about 1.6 km along the northeastern limb of the syncline. The unpublished Unkur exploration map (V.S. Chechetkin, written commun., 2009) refers to the layer as "manifestations of copper mineralization," which implies that grades and thicknesses did not meet cut-off values for continued exploration work.

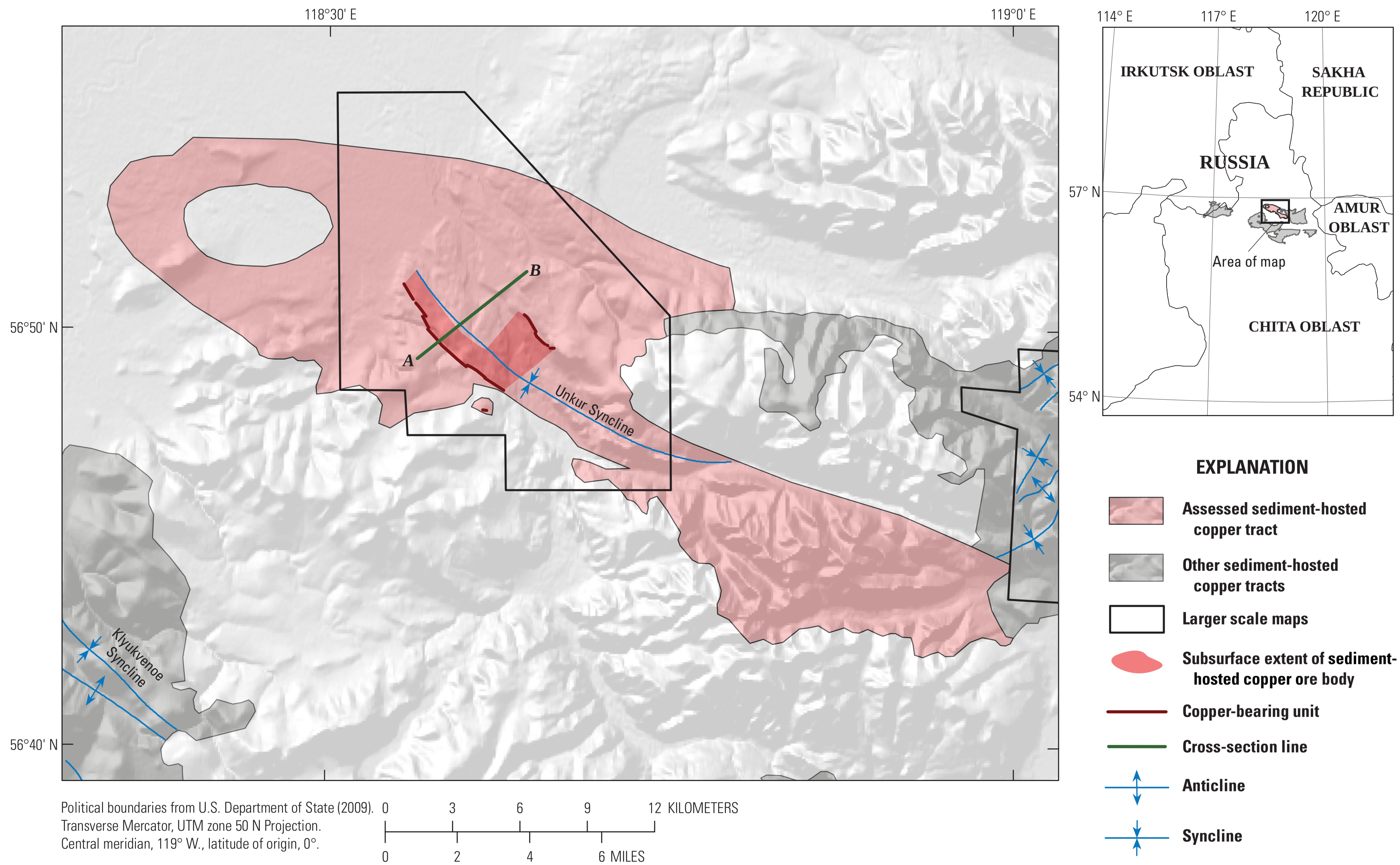

Figure D2. Map showing the assessed and adjacent sediment-hosted stratabound copper permissive tracts, subsurface ore body extent, and copper-bearing units in tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia.

Table D2. C and P category resources in the Unkur deposit, tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia.

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994; Henley and Young, 2006). Cu, copper; Ag, silver; Mt, million metric tons; %, percent; ppm, parts per million; t, metric ton. C2 and P1 are Russian mineral resource categories. C2 is analogous to inferred mineral resources as defined by CRIRSCO. P1 is analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS and are estimates associated with extensions to inferred resources]

Deposit name	Category of resources	Ore (Mt)	Cu grade (%)	Ag grade (ppm)	Contained Cu (t)	Contained Ag (t)
Unkur	C2	90.9	0.75	70.8	682,000	6,363
	P1	52.5	0.75	70.8	393,800	3,937
	C2+P1	143.4	0.75	63.8	1,075,800	10,300

Prospects, Mineral Occurrences, and Related Deposit Types

There are no known prospects.

Sources of Information

Principal sources of information used by the assessment team for delineation of the Unkur tract are listed in table D3.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Undiscovered deposit estimates were subjectively determined by a panel of scientists (table D4). The known deposit, Unkur, is open to the northwest and southeast. Additional undiscovered resources are expected in the same stratigraphic horizon on strike. However, the areal extent of the tract limits the number of additional deposits that may be present.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered sediment-hosted stratabound copper deposits with the sandstone copper model (this report) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table D5. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. D5). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

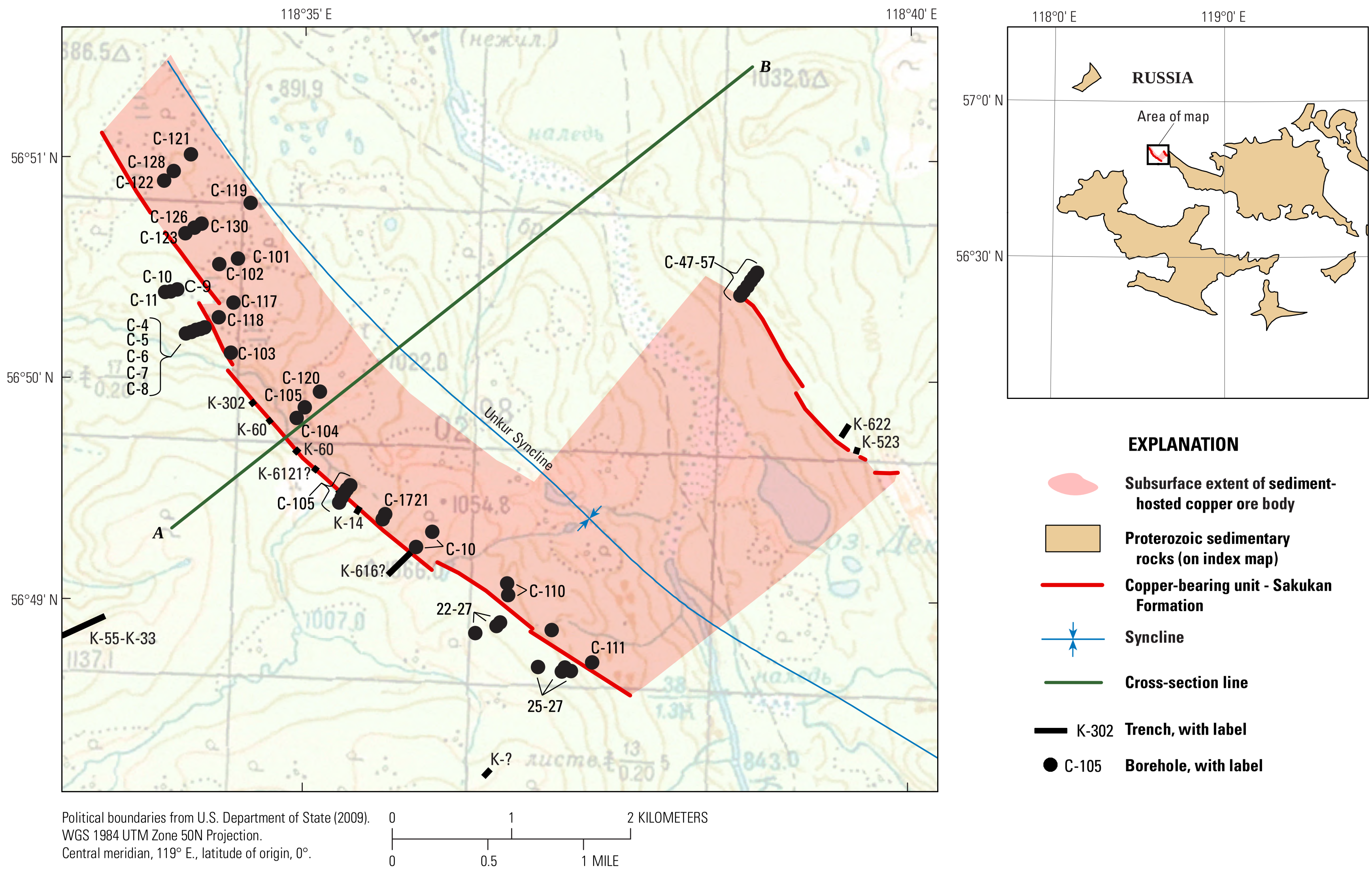

Figure D3. Map showing geologic mapping boreholes, exploration boreholes, trenches, the subsurface ore body extent, and copper-bearing units in the Sakukan Formation, tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia.

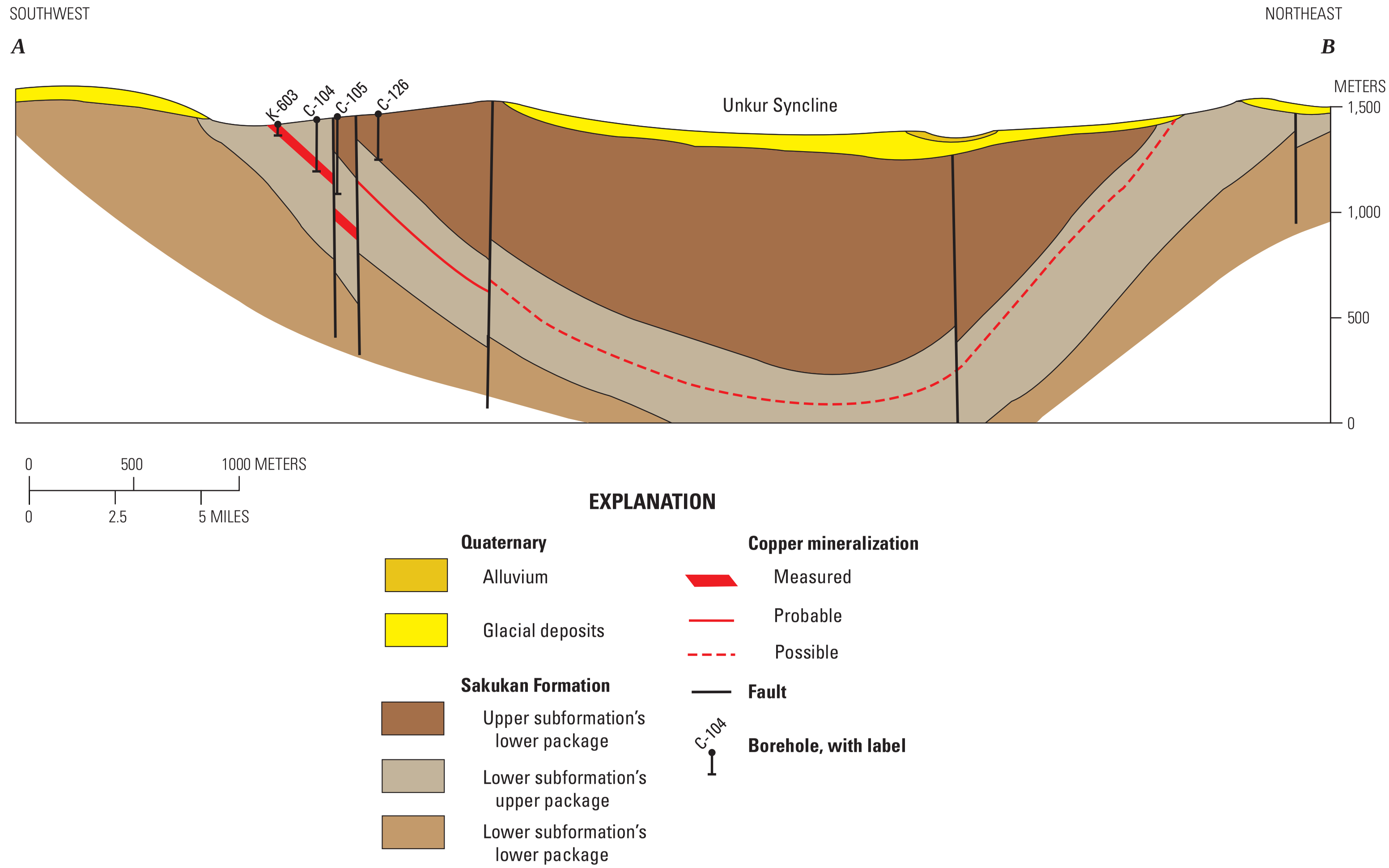

Figure D4. Geologic section through tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia. For location of section line, see figure D3.

Table D3. Principal sources of information used by the assessment team for tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia.

Name or title	Scale	Reference
Geology		
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXIX	1:200,000	Shul'gina (1975)
State geological map of the USSR, new series, sheet N-49,(50) Chita, Map of the pre-Quaternary rocks	1:1,000,000	Efimov and others (1990)
State geological map of the USSR, new series, sheet O-49(50) Bodaybo, Map of Quaternary deposits	1:1,000,000	Kornutova and Tsvetkov (1984)
Geological map of the USSR, new series, sheet O-(50),51 Aldan, Map of the pre-Quaternary rocks	1:1,000,000	Lagzdina and others (1978)
Mineral occurrences		
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXIX	1:200,000	Shul'gina (1975)
Geophysics		
Gravitational field map	1:1,000,000	Pis'mennyi (2003)
Magnetic anomaly map	1:1,000,000	Schupak and others (2003)
Exploration		
Schematic geologic map of the Unkurskogo sandstone-hosted copper deposit	1:25,000	V.S. Chechetkin, written commun. (2009)

Table D4. Undiscovered deposit estimates, deposit numbers, and tract area for tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers. N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005). In cases where individual estimates were tallied in addition to the input for EMINERS, individual estimates are listed]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	*s*	C_v%	N_{known}	N_{total}	
0	2	3	6	6	1.9	1.7	86	1	2.9	303

Estimator	Estimated number of undiscovered deposits				
	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Input for EMINERS	0	2	3	6	
other	1	2	3	6	
USGS	1	2	3		
USGS	1	2	3		
USGS	1	2	3		
other	1	2	4		
USGS	1	3	4		
USGS	3	5	12		

Table D5. Results of Monte Carlo simulations of undiscovered resources in tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia.

[Cu, copper; Ag, silver; t, metric ton; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	290,000	3,700,000	11,000,000	1,800,000	0.15	0.19
Ag (t)	0	0	0	3,200	7,900	1,600	0.15	0.63
Rock (Mt)	0	0	24	330	1,200	160	0.17	0.19

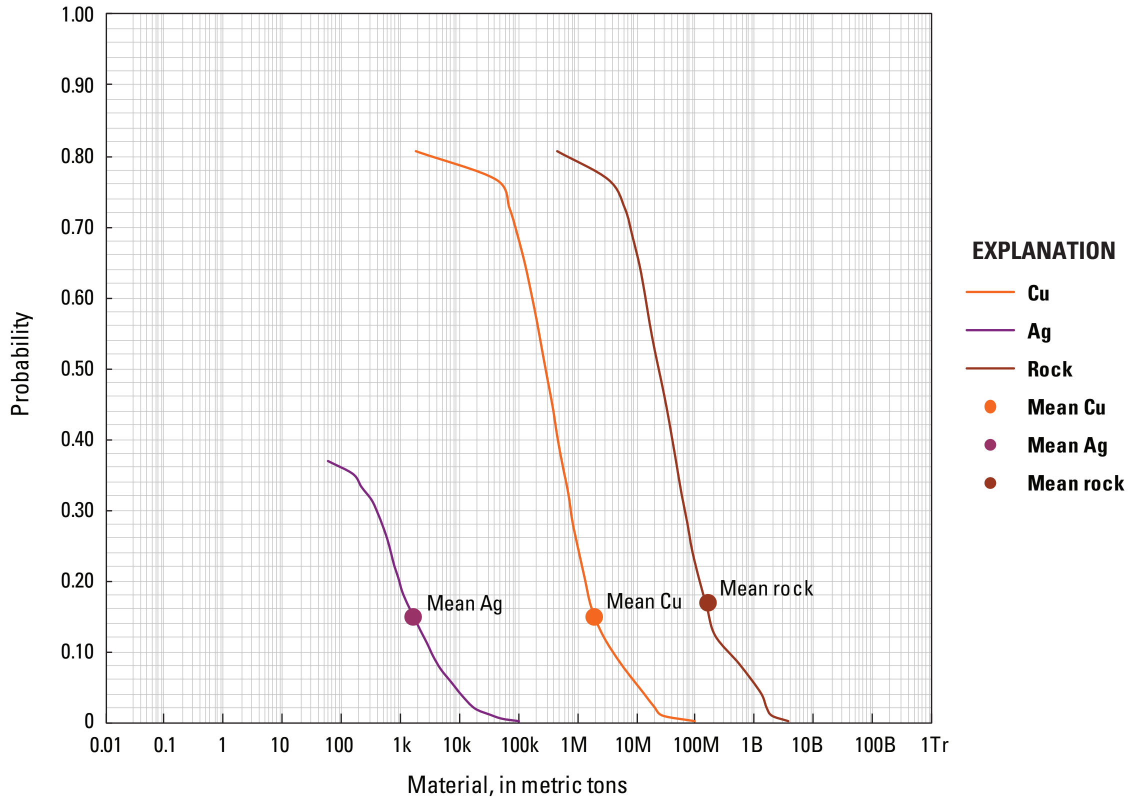

Figure D5. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 150ssCu0004, Unkur—Kodar-Udokan area, Russia. k, thousand; M, million; B, billion; Tr, trillion.

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Appendix E. Sediment-Hosted Copper Assessment for Tract 150ssCu0005, Krasnoe—Kodar-Udokan Area, Russia

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Deposit Type Assessed: Sediment-Hosted Copper

Descriptive model: Sediment-hosted copper, Revett subtype (Cox and others, 2003)
Grade and tonnage model: Sediment-hosted copper, sandstone copper subtype (Zientek and others, 2013; appendix G)
Table E1 summarizes selected assessment results.

Table E1. Summary of selected resource assessment results for tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia.

[km, kilometer; km^2, square kilometer; t, metric ton; –, none]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
January 2010	2	603	–	3,600,000	970,000

Location

The tract is located in southeastern Russia, approximately 600 km east-northeast of the northern tip of Lake Baikal. It is approximately 60 km east-southeast of the city Chara and lies in the northern region of Chita Oblast. The Chitkanda River runs north-south along the easternmost part of the tract, and the Kalar and China Rivers run east-west approximately 8 km south of the southern edge of the tract (fig. E1).

Geologic Feature Assessed

Siliciclastic rocks in the Chinei and Kemen Groups of the Udokan Complex.

[1] U.S. Geological Survey, Spokane, Washington, United States.

[2] Russian Geological Society (RosGeo), Chita, Russia.

[3] Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London, United Kingdom.

[4] U.S. Geological Survey, Tucson, Arizona, United States.

[5] Mining and Economic Consulting Ltd., Almaty, Kazakhstan.

[6] U.S. Geological Survey, Denver, Colorado, United States.

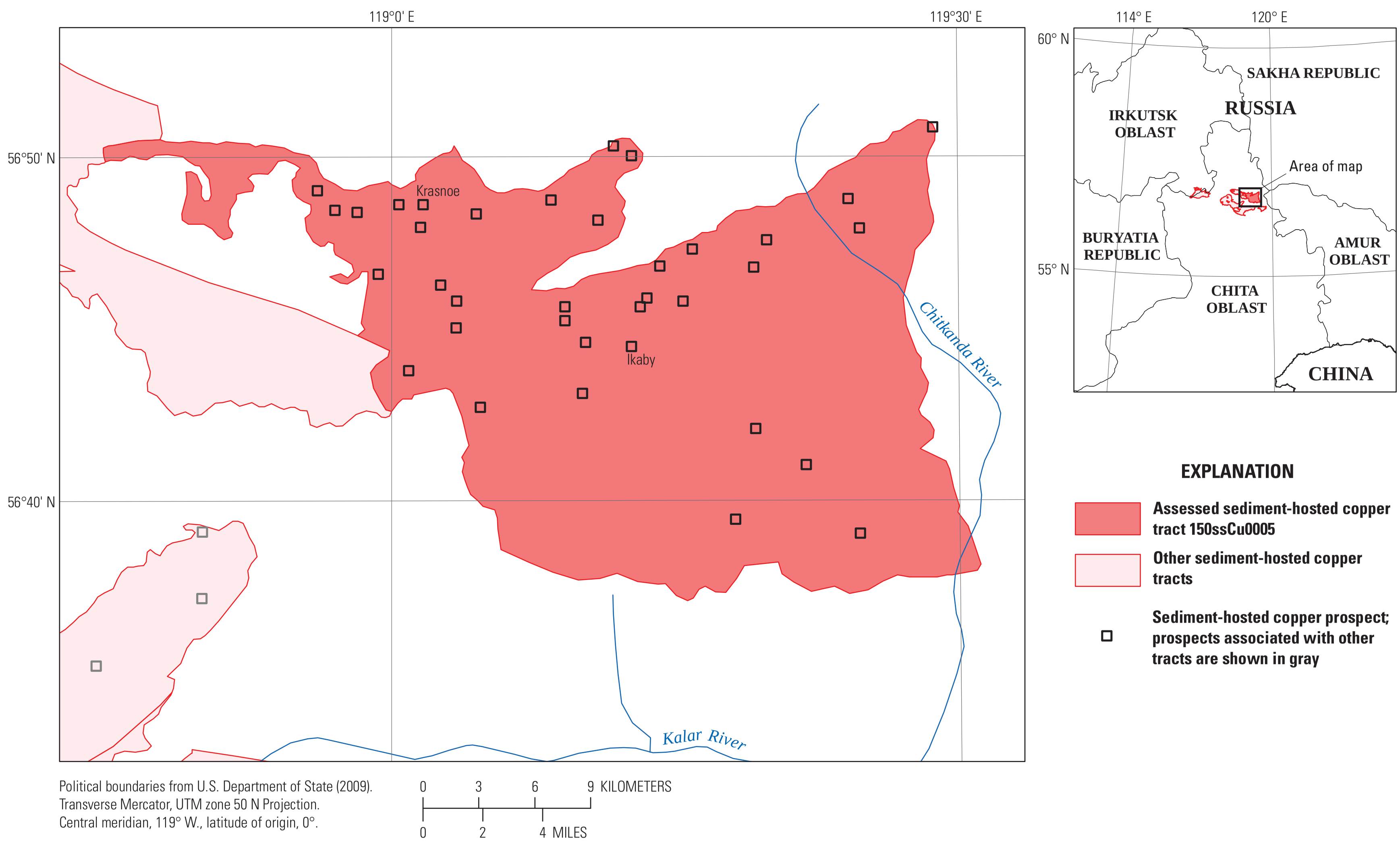

Figure E1. Map showing the assessed and adjacent sediment-hosted copper permissive tracts, and associated prospects in tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia.

Delineation of the Permissive Tract

Geologic Criteria

The tract extent is primarily based on the mapped distribution of the Chitkanda, Aleksandrov, Butun, and Sakukan Formations as shown on 1:200,000-scale maps (figs. E1 and E2). The Chitkanda, Aleksandrov, and Butun Formations are exposed in the northern part of the tract in the area covered by the exploration map (fig. E2). To the south, elevations become higher and the Sakukan Formation is exposed at the surface. The tract was extended under Quaternary deposits that occur along river valleys. However, the tract was not extended to the south into the Verkerhne-Kalar Graben. On the basis of map patterns and cross sections, the southern boundary of the tract corresponds to a regional fault that dips steeply to the north.

Known Deposits

There are no known deposits.

Prospects, Mineral Occurrences, and Related Deposit Types

One site, Krasnoe, has prognostic resources (fig. E3; table E2). Fedorovskiy (1976), Feoktistov and Chechetkin (1984), Glukhovskiy (1973), and Shul'gina (1975) show 34 additional unnamed sites and 1 named site, Ikaby (table E3). Of these sites, 5 occur within the Sakukan Formation (3 are in member 1, and 2 are in member 2), 16 are in the Chitkanda Formation, 1 is in the Inyr Formation, 11 are in the Aleksandrov Formation, and 2 are in the Butun Formation. Thirty of the sites are categorized as "manifestations of useful minerals" and five sites are unknown.

Krasnoe Prospect

This prospect is located in subformation 2 of the Chitkanda Formation (fig. E4). The Chitkanda Formation at this locality consists of 425–630 m of gray, dark gray, and greenish-gray fine-grained (rarely medium-grained) arkosic (rarely calcareous) sandstone and siltstone. The Chitkanda Formation is interpreted to have formed in a deltaic depositional environment.

In this area, the Chitkanda Formation is divided into three subformations (fig. E4). Subformation 1 ($Čt_1$) consists of thin-interbedded gray to light gray arkosic and calcareous sandstones and siltstones. Subformation 2 ($Čt_2$) comprises gray to greenish-gray, fine-grained arkosic, rarely calcareous sandstone and siltstone with intervals of copper-bearing sandstone. Subformation 3 ($Čt_3$) is made up of fine-grained pink to gray arkosic sandstones, siltstones, and rare interbeds of calcareous sandstone. This unit also has interlayers of magnetite-bearing sandstone.

The Krasnoe prospect is exposed for more than 1,000 m along strike on a canyon wall northeast of the Bol'shaya Ikab'ya River (*Бол. Икабья* on fig. E3). The area is characterized by sharply dissected canyon valleys and rocky watershed crests. The ore body is 200 m thick, its area is approximately 47,200 m^2, and the average copper content is 1.07 percent (fig. E3). Primary ore minerals include chalcopyrite, bornite, pyrrhotite, pyrite, tetrahedrite, chalcocite, magnetite, hematite, arsenopyrite, ilmenite, and cobaltite. Secondary minerals include covellite, and copper- and iron-hydroxides.

All the ore minerals form small scattered or clustered disseminations in the rock matrix and are sometimes grouped in nodules, lenticular-shaped veins, veinlets, and concretions. The minerals can be found as individual grains and as intergrowths with each other. The grain size varies from hundredths to tenths of a millimeter, sometimes forming nodules and concretions which range in size from millimeters to centimeters.

Other Occurrences in Subformation 2 of the Chitkanda Formation

Mineralized lenses and layers in subformation 2 of the Chitkanda Formation have been mapped intermittently over a distance of 25 km, east to the Chitkanda River (figs. E1 and E2). Lenticular bodies of mineralized rock in subformation 2 of the Chitkanda Formation have been mapped 3.5 and 8 km southeast and 8 km east-southeast of the Krasnoe prospect (fig. E3).

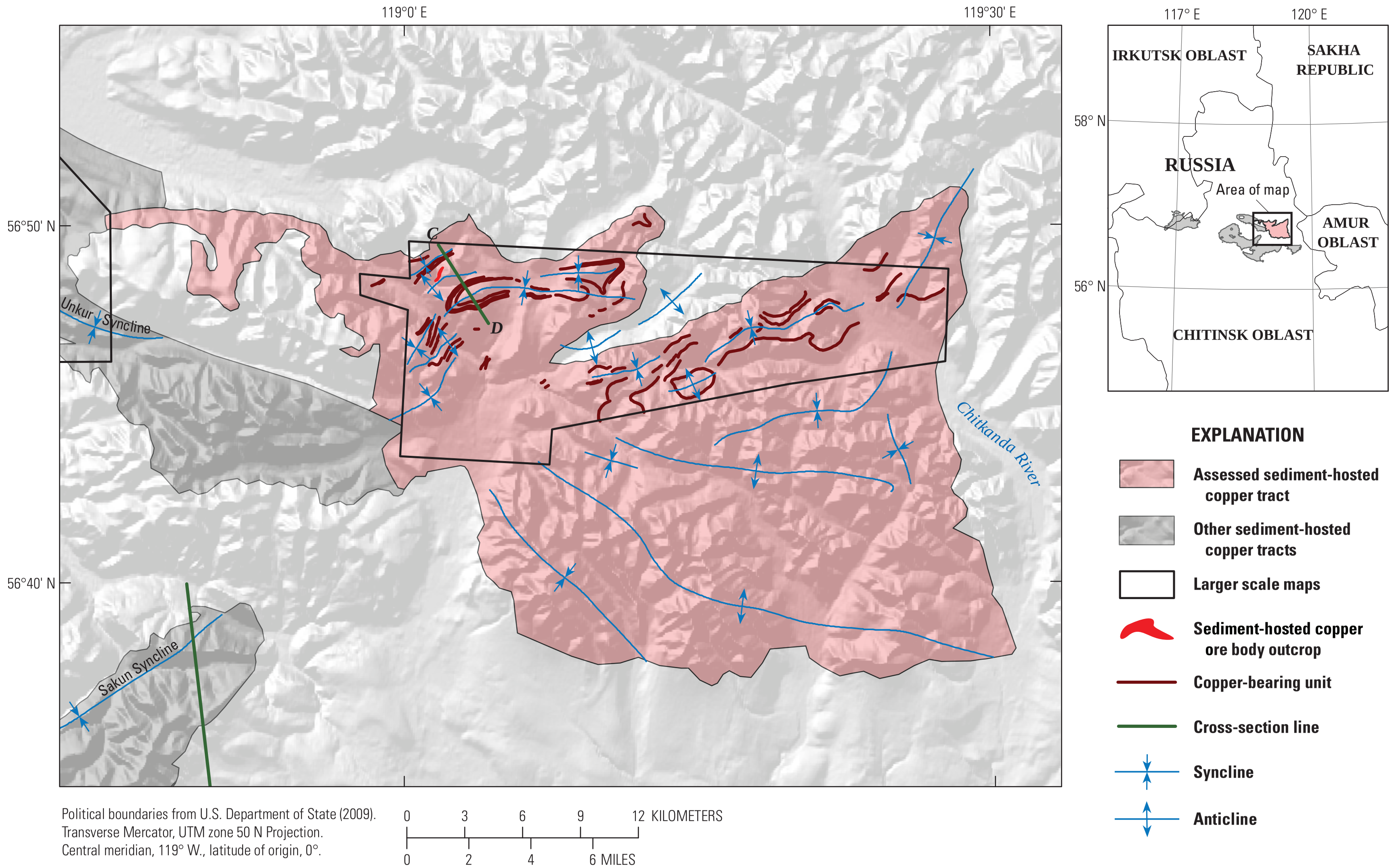

Figure E2. Map showing the assessed and adjacent sediment-hosted copper permissive tracts, surface extent of ore bodies, and copper-bearing units in tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia (modified from Glukhovskiy, 1973).

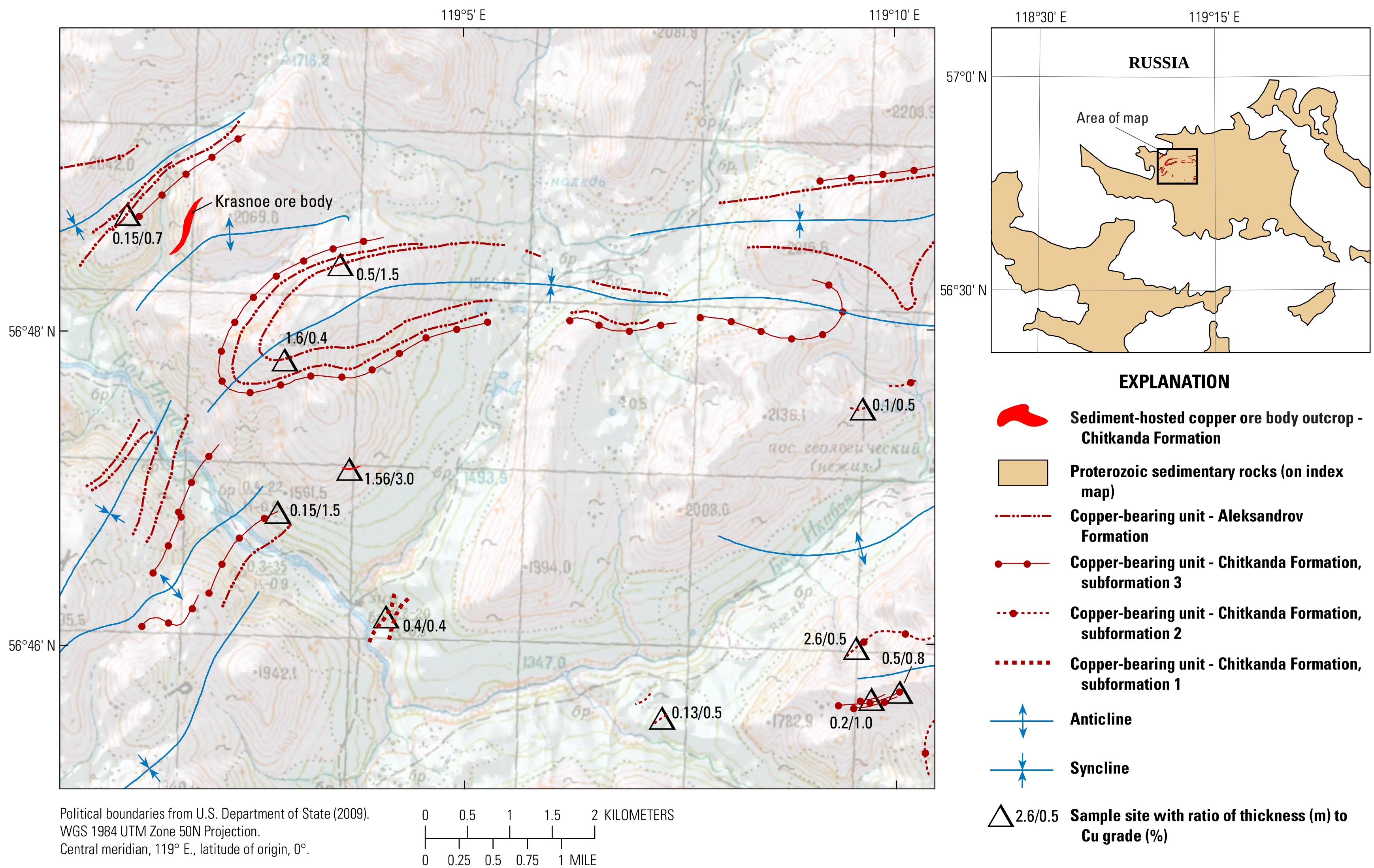

Figure E3. Map showing copper-grade sampling sites, surface extent of ore bodies, and mineralized copper layers in the Aleksandrov and Chitkanda Formations, tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia.

Table E2. P category resources at the Krasnoe prospect, tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia.

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994; Henley and Young, 2006). Cu, copper; Ag, silver; Mt, million metric tons; %, percent; ppm, parts per million; t, metric ton; NA, not available. Russian mineral resource category which is analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS. These prognostic mineral resources estimates refer to extensions to inferred resources and are based on limited direct geological evidence]

Prospect name	Resource category	Ore (Mt)	Cu grade (%)	Ag grade (ppm)	Contained Cu (t)	Contained Ag (t)
Krasnoe	P1	33	1.50	NA	500,000	NA

Table E3. Point locations of sediment-hosted copper occurrences in tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia.

[NA, not available]

Name	Latitude	Longitude	Unit	Size
Unknown	56.71283	119.07815	Sakukan Formation, member 1	occurrences of useful minerals
Unknown	56.70218	119.32048	Sakukan Formation, member 1	occurrences of useful minerals
Unknown	56.68437	119.36473	Sakukan Formation, member 1	occurrences of useful minerals
Unknown	56.83451	119.21174	Chitkanda Formation	occurrences of useful minerals
Unknown	56.84763	119.47818	Inyr Formation	occurrences of useful minerals
Unknown	56.81314	119.40284	Chitkanda Formation	occurrences of useful minerals
Unknown	56.80326	119.18232	Chitkanda Formation	occurrences of useful minerals
Unknown	56.7441	119.17093	Chitkanda Formation	occurrences of useful minerals
Unknown	56.813	119.14063	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.76125	119.15264	Chitkanda Formation	occurrences of useful minerals
Unknown	56.75457	119.15301	Chitkanda Formation	occurrences of useful minerals
Unknown	56.78086	119.23663	Chitkanda Formation	occurrences of useful minerals
Unknown	56.76119	119.21917	Chitkanda Formation	occurrences of useful minerals
Ikaby	56.74195	119.21119	Butun Formation	occurrences of useful minerals
Unknown	56.71935	119.16807	Chitkanda Formation	occurrences of useful minerals
Unknown	56.81079	119.00639	Butun Formation	occurrences of useful minerals
Unknown	56.80642	119.0748	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.79999	119.02555	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.77187	119.04347	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.76415	119.0574	Chitkanda Formation	occurrences of useful minerals
Unknown	56.75128	119.05687	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.73046	119.0151	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.7639	119.25705	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.79353	119.33072	Chitkanda Formation	occurrences of useful minerals
Unknown	56.78019	119.31965	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.65121	119.41216	Sakukan Formation, member 2	occurrences of useful minerals
Unknown	56.65815	119.30257	Sakukan Formation, member 2	occurrences of useful minerals
Unknown	56.81773	118.93464	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.80723	118.96954	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.77722	118.98828	Aleksandrov Formation	occurrences of useful minerals
Unknown	56.79887	119.41299	Chitkanda Formation	NA
Unknown	56.78914	119.2652	Chitkanda Formation	NA
Unknown	56.7654	119.22499	Chitkanda Formation	NA
Unknown	56.83927	119.19581	Chitkanda Formation	NA
Unknown	56.80809	118.94991	Chitkanda Formation	NA

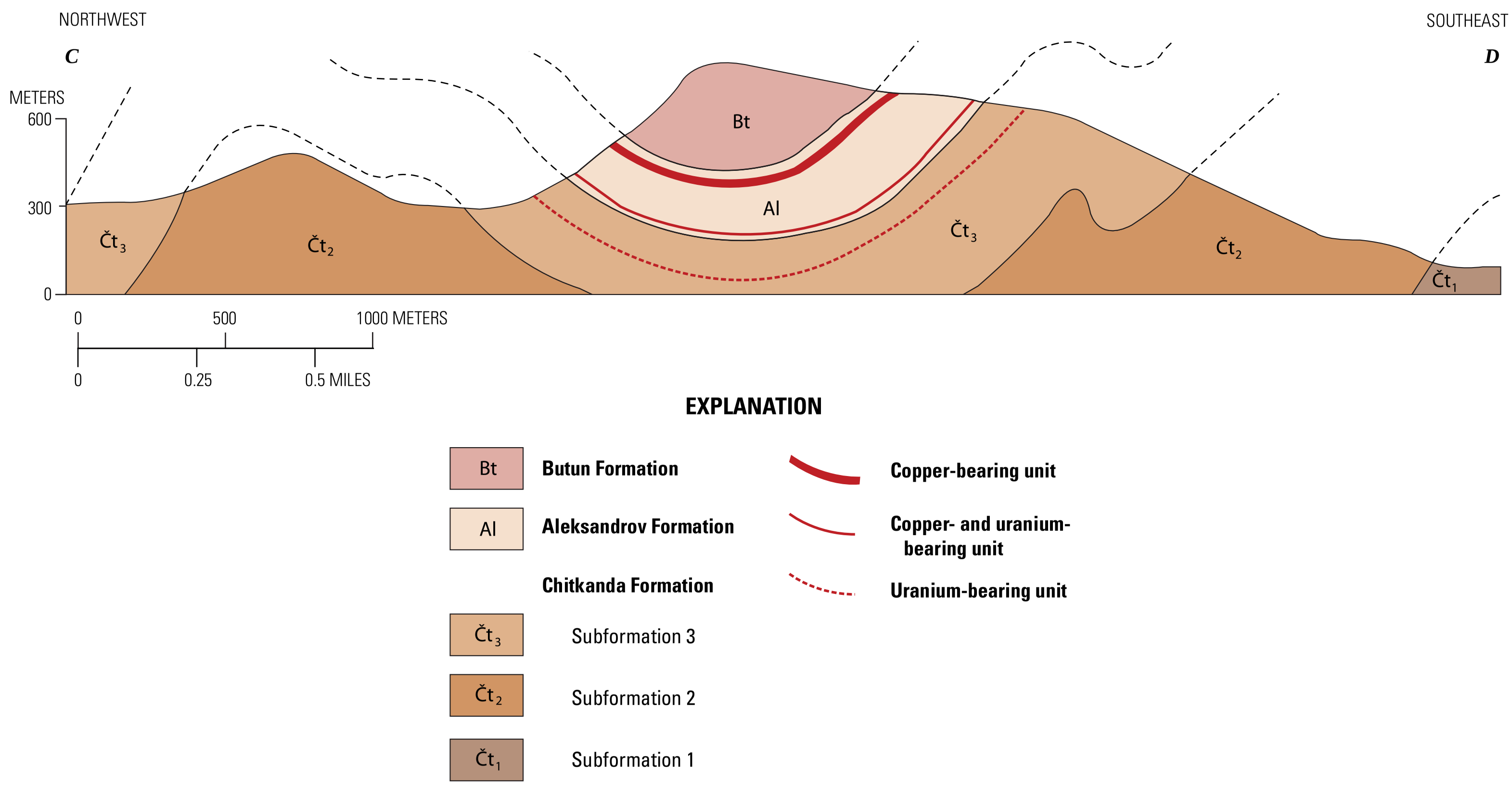

Figure E4. Cross section through the northern part of tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia, that displays intensive folding of the Udokan Complex units. Location of section line is shown on figure E2.

Thin Continuous Layers in the Chitkanda and Aleksandrov Formations

Three thin, but laterally continuous layers of copper-uranium mineralization are found upsection of the mineralized strata in subformation 2 of the Chitkanda Formation (figs. E2, E3, and E4). The lowest layer, near the top of subformation 3 ($Čt_3$) of the Chitkanda Formation, is enriched in uranium. The other two layers occur in the overlying Aleksandrov Formation, which consists of thin-bedded, fine-grained arkosic and calcareous sandstones and siltstones with thin layers and lenses of dolomite. A lagoonal depositional environment is proposed for these rocks. The mineralized layer near the base of the formation is enriched in copper and uranium; the mineralized layer near the top is anomalous in copper. The uranium mineral brannerite has been identified in these layers. Although the mineralization shows great continuity and has copper grades similar to mineralized units in other tracts, thicknesses are much less than those found in other prospects in the Kodar-Udokan area (fig. E5). Weighted copper concentrations in the mineralized intervals plotted in figure E5 can be calculated by multiplying the thickness, the grade, and the bulk density of the mineralized formation (assumed to be 2.6 t/m^3). The weighted copper concentrations, or copper surface densities, in these thin mineralized intervals in this tract are an order of magnitude less than mineralized intervals in the other Kodar-Udokan tracts (fig. E6). Nevertheless, the extent of mineralized rocks indicates fluid flow systems operating on the scale of tens of kilometers in this tract.

Sources of Information

Principal sources of information used by the assessment team for delineation of the Krasnoe tract are listed in table E4.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Estimates of undiscovered deposits were subjectively determined by a panel of scientists (table E5). Estimates at the 90th percentile were constrained by the Krasnoe occurrence in the Chitkanda Formation, for which the Russians have made a forecast of prognostic resources. The 50th percentile was constrained by the presence of other mapped occurrences of lenticular masses of mineralized rock in subformation 2 of the Chitkanda Formation. One site on a south-facing slope approximately 3.5 km southeast of Krasnoe appears to be an outcrop of another sandstone copper deposit. Two potential sandstone copper occurrences are mapped 8 km south and 8 km east-southeast of Krasnoe.

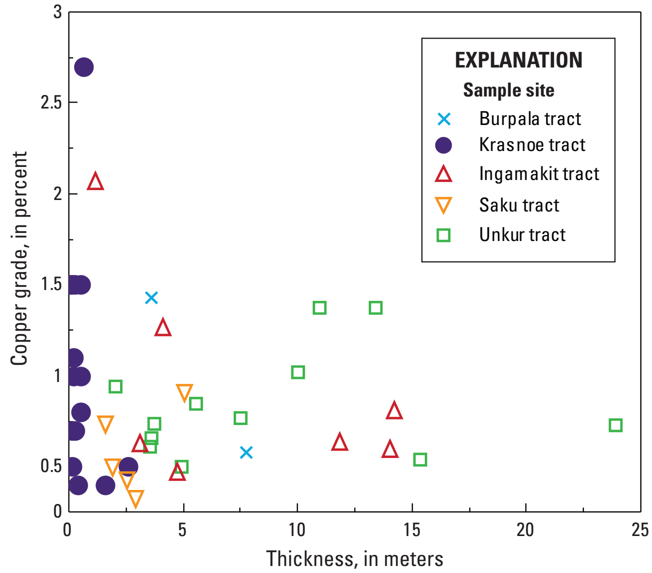

Figure E5. Bivariate plot of copper grade versus thickness comparing the thin mineralized intervals in the northern part of tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia, to sedimentary copper prospects in other parts of the Kodar-Udokan area.

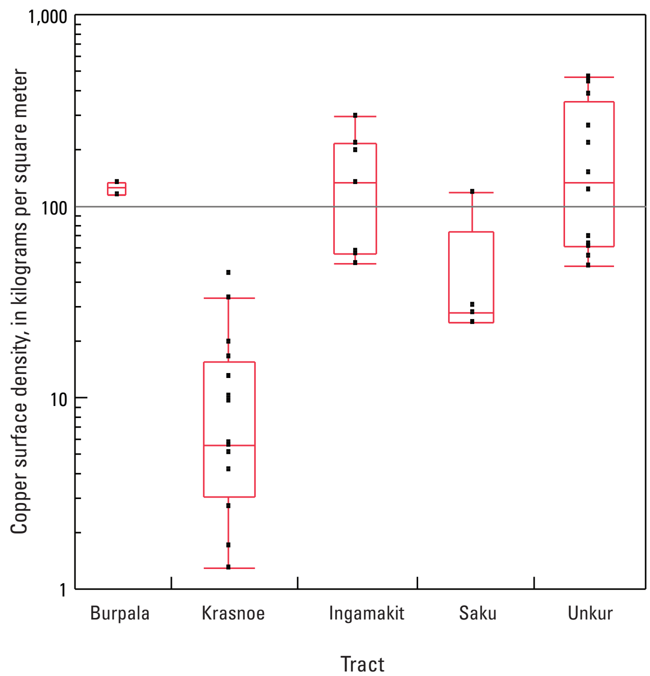

Figure E6. Box and whisker plots comparing copper surface density for thin mineralized intervals in the northern part of tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia, to sedimentary copper prospects in other parts of the Kodar-Udokan area.

Table E4. Principal sources of information used by the assessment team for tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia.

Name or title	Scale	Reference
	Geology	
Lithofacies map of Udokan ore field	1:42,000	Bakun and others (1966)
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXIX	1:200,000	Shul'gina (1975)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXX	1:200,000	Glukhovskiy (1973)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXXVI	1:200,000	Fedorovskiy (1976)
Geological map of the USSR, Bodaybo series, sheet O-51-XIII Mouth of the Choroudy River	1:1,000,000	Reutov (1976)
State geological map of the USSR, new series, sheet N-49,(50) Chita, Map of the pre-Quaternary rocks	1:1,000,000	Efimov and others (1990)
State geological map of the USSR, new series, sheet O-49(50) Bodaybo, Map of Quaternary deposits	1:1,000,000	Kornutova and Tsvetkov (1984)
Geological map of the USSR, new series, sheet O-(50),51 Aldan, Map of the pre-Quaternary rocks	1:1,000,000	Lagzdina and others (1978)
	Mineral occurrences	
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXXVI	1:200,000	Fedorovskiy (1976)
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXX	1:200,000	Glukhovskiy (1973)
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXIX	1:200,000	Shul'gina (1975)
	Geophysics	
Gravitational field map	1:1,000,000	Pis'mennyi (2003)
Magnetic anomaly map	1:1,000,000	Schupak and others (2003)
	Exploration	
Schematic geologic map and data sampling of the Ikabya-Chitkandaskogo area	1:25,000	V.S. Chechetkin, written commun. (2009)

Table E5. Undiscovered deposit estimates, deposit numbers, and tract area for tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers. N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005). In cases where individual estimates were tallied in addition to the input for EMINERS, individual estimates are listed]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}	
1	4	6	6	6	3.6	1.8	49	0	3.6	603

Estimator	Estimated number of undiscovered deposits				
	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
USGS	1	2	4	6	
other	1	3	4		
Input for EMINERS	1	4	6		
other	2	3	4	5	
other	2	3	5		
USGS	2	4	8		
USGS	3	5	12	15	
USGS	5	7	10		

Table E6. Results of Monte Carlo simulations of undiscovered resources in tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia.

[Cu, copper; Ag, silver; t, metric tons; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	58,000	970,000	11,000,000	19,000,000	3,600,000	0.21	0.07
Ag (t)	0	0	430	8,300	16,000	3,200	0.20	0.40
Rock (Mt)	0	5	85	1,200	1,600	310	0.21	0.07

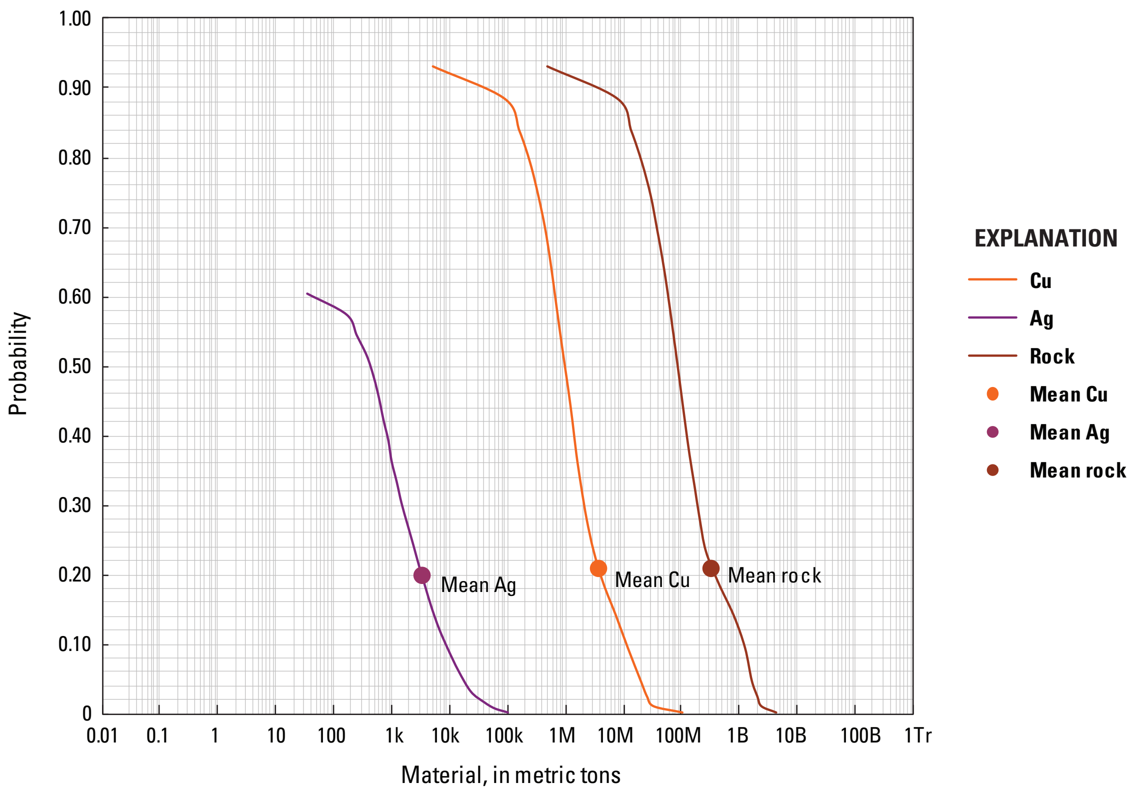

Figure E7. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 150ssCu0005, Krasnoe—Kodar-Udokan area, Russia. k, thousand; M, million; B, billion; Tr, trillion.

Three laterally continuous mineralized layers, one in the upper part of the Chitkanda Formation and two in the overlying Aleksandrov Formation, are indications of the presence of mineralizing fluids but are too thin (generally less than 0.5 m) to be included in resource forecasts (fig. E6). Their geometry is not consistent with typical sandstone copper mineralization but may be analogous to green-bed mineralization in the Belt Basin, Montana (Lange and others, 1987; Tysdal and others, 1996). However, the widespread mineralization in the Aleksandrov Formation suggests additional sandstone copper deposits are likely to be present in the underlying Chitkanda Formation. Exploration in this area has been limited to mapping and surface sampling, so the resource potential at depth has not been thoroughly evaluated.

Quantitative Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered sediment-hosted copper deposits with the sandstone copper model (this report) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table E6. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. E7). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

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Appendix F. Sediment-Hosted Stratabound Copper Assessment for Tract 150ssCu0006, Burpala—Kodar-Udokan Area, Russia

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Deposit Type Assessed: Sediment-Hosted Stratabound Copper

Descriptive model: Sediment-hosted copper, Revett subtype (Cox and others, 2003)
Grade and tonnage model: Sediment-hosted stratabound copper, sandstone copper subtype (Zientek and others, 2013; appendix G)
Table F1 summarizes selected assessment results.

Table F1. Summary of selected resource assessment results for tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

[km, kilometer; km^2, square kilometer; t, metric ton; –, none]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
October 2009	2	129	–	1,300,000	180,000

Location

The tract is located in southeastern Russia, approximately 610 km east-northeast of the northern tip of Lake Baikal. It is approximately 65 km east-northeast of the city of Naminga and lies in the northern region of Chita Oblast. The western tip of the tract is located near the confluence of the Kalar and Chitkanda Rivers (fig. F1).

Geologic Feature Assessed

Siliciclastic rocks in the Chinei and Kemen Groups of the Udokan Complex.

[1] U.S. Geological Survey, Spokane, Washington, United States.

[2] Russian Geological Society (RosGeo), Chita, Russia.

[3] Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London, United Kingdom.

[4] U.S. Geological Survey, Tucson, Arizona, United States.

[5] Mining and Economic Consulting Ltd., Almaty, Kazakhstan.

[6] U.S. Geological Survey, Denver, Colorado, United States.

Political boundaries from U.S. Department of State (2009).
Transverse Mercator, UTM zone 50 N Projection.
Central meridian, 119° W., latitude of origin, 0°.

Figure F1. Map showing the assessed sediment-hosted stratabound copper permissive tract and associated prospects in tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

Delineation of the Permissive Tract

Geologic Criteria

The tract extent is based on the mapped distribution of the Sakukan Formation in a tectonically disrupted east-trending syncline (figs. F1 and F2). The tract was extended to include a thin veneer of Cambrian sedimentary rocks that cover the axis of the syncline. The northern boundary of the tract is limited by an east-trending, near-vertical structure that occurs along the southern margin of the Verkerhne-Kalar Graben.

Known Deposits

There are no known deposits.

Prospects, Mineral Occurrences, and Related Deposit Types

The tract includes eight sites with known or suspected sandstone-hosted copper deposits. One site, Burpala, has prognostic resources (figs. F3 and F4; table F2). Fedorovskiy (1976) and Feoktistov and Chechetkin (1984) show seven additional sites whose names are unknown (table F3).

Burpala Prospect

In the Burpala area, the upper member (SK_1^2) of the Lower Sakukan subformation consists of fine-grained quartz-feldspar quartzite, phyllitic sandstone, and cupriferous sandstones. Metamorphism is more intense than in the area near the Udokan deposit (see appendix B). Rocks are strongly sheared and extensively phyllitized. In some localities, schists contain interlayers of green talc.

The copper-bearing sandstone unit is 100–150 m thick and extends approximately 7 km along strike. Copper mineralization is confined to linear folds, with the thick accumulations of cupriferous sandstone more commonly found in the troughs of folds.

Numerous Proterozoic gabbro-diabase sills and dikes intrude the Udokan Complex in the Burpala area. Most intrusions are generally concordant to layering in the metasedimentary rocks, although some dikes have also been mapped. The proximity of the copper mineralization in the sandstones to the contacts of the sills created some initial ambiguity about the genesis of the copper mineralization, especially where a sill-like gabbro-diabase intrudes the cupriferous sandstones. Drilling and mapping shows that the mineralization is stratigraphically controlled and concordant with the enclosing sandstone deposits. In one drill section, a gabbro-diabase dike clearly crosscuts the sandstone and its associated copper mineralization. However, the intrusion of the gabbro-diabase has locally remobilized copper mineralization. Crosscutting gabbro-diabase dikes contain 0.005–0.05 percent copper; in one instance the concentration is 0.21 percent, apparently due to assimilation of copper minerals from within the sandstone.

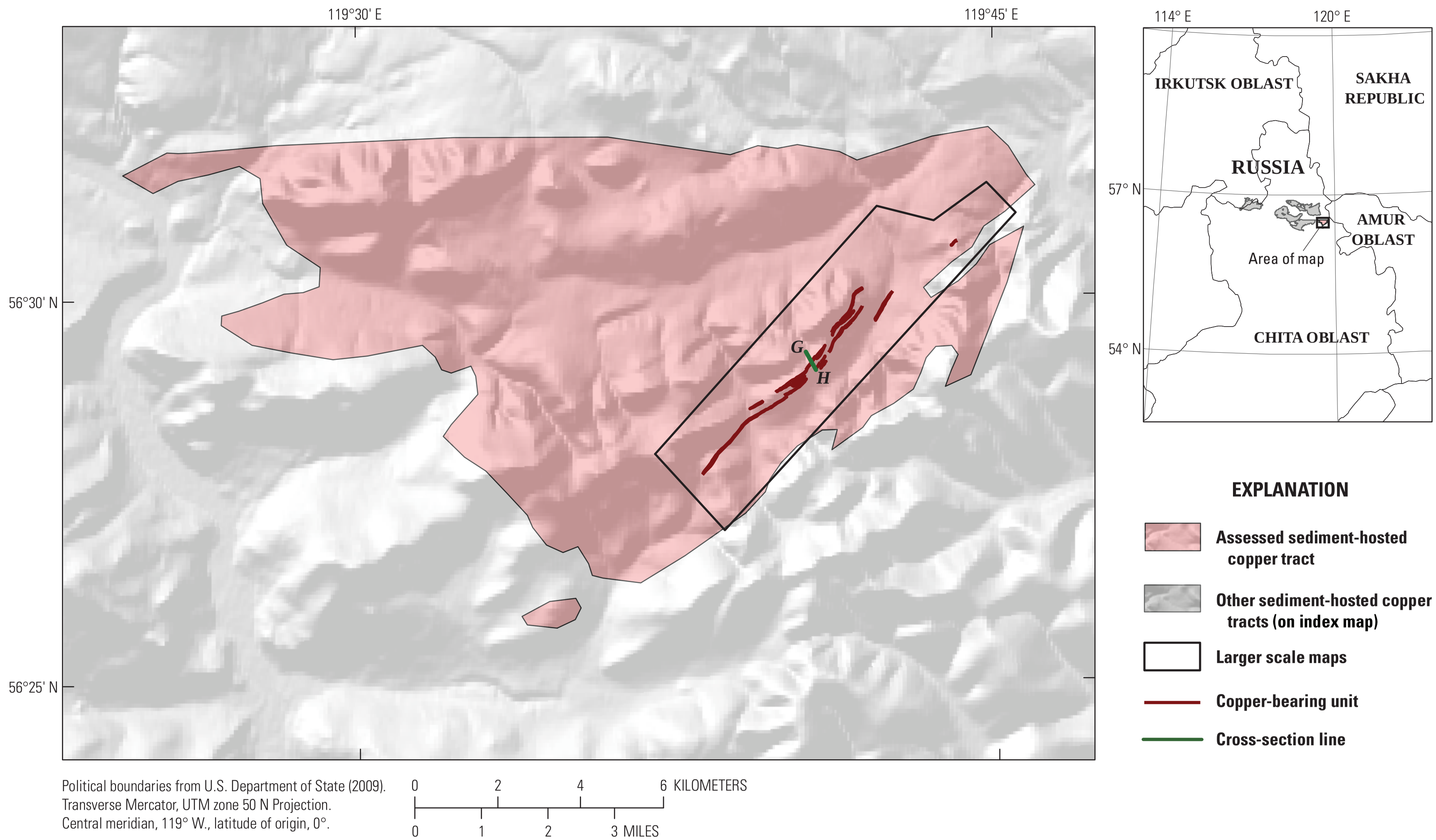

Figure F2. Map showing the assessed sediment-hosted copper stratabound permissive tract and copper–bearing units in tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia. The box for larger scale maps includes the area shown in figure F3.

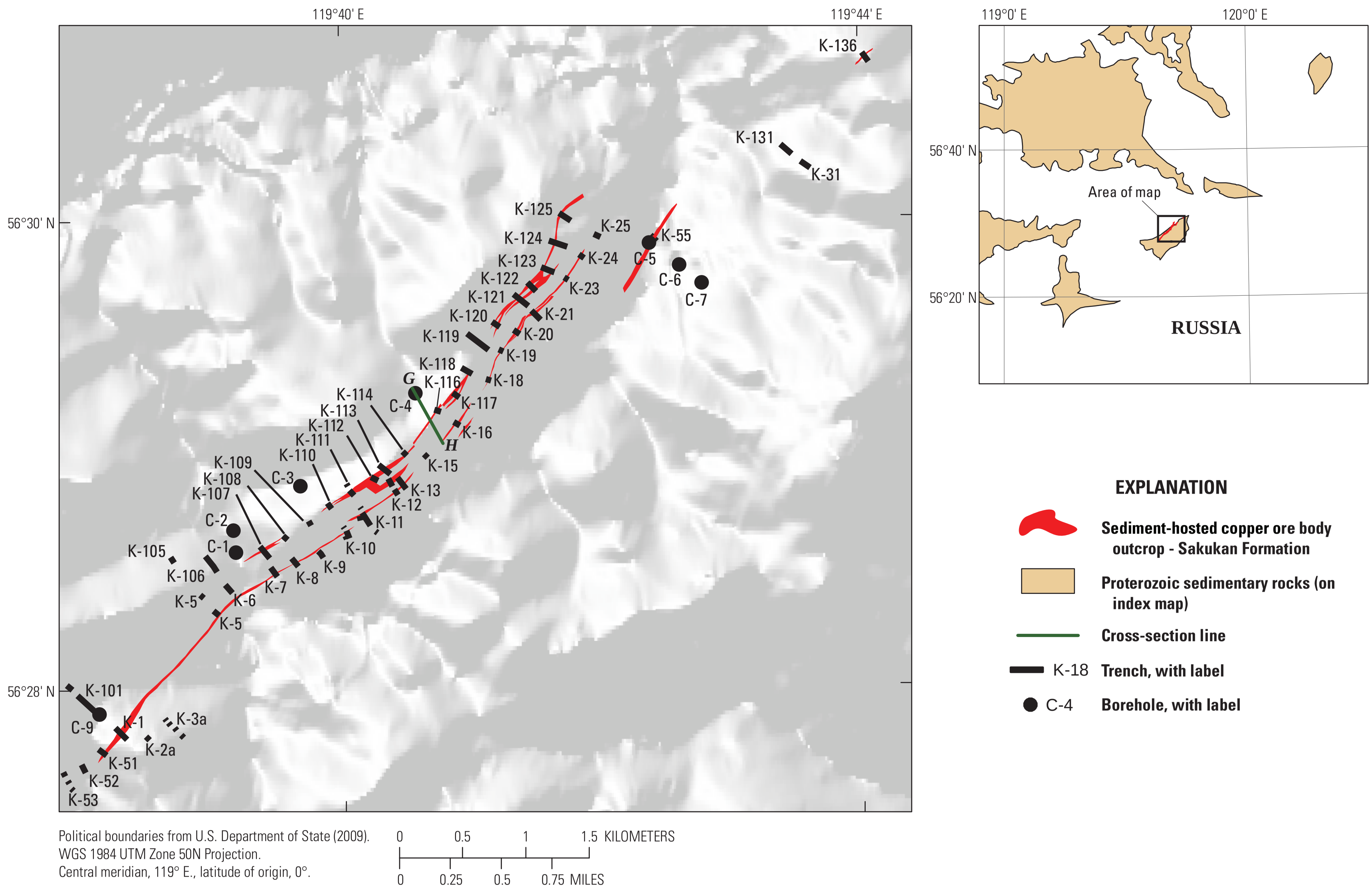

Figure F3. Map showing boreholes, trenches, and surface extent of ore bodies in the Sakukan Formation, tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia. Figure F4 is a cross section along line G-H.

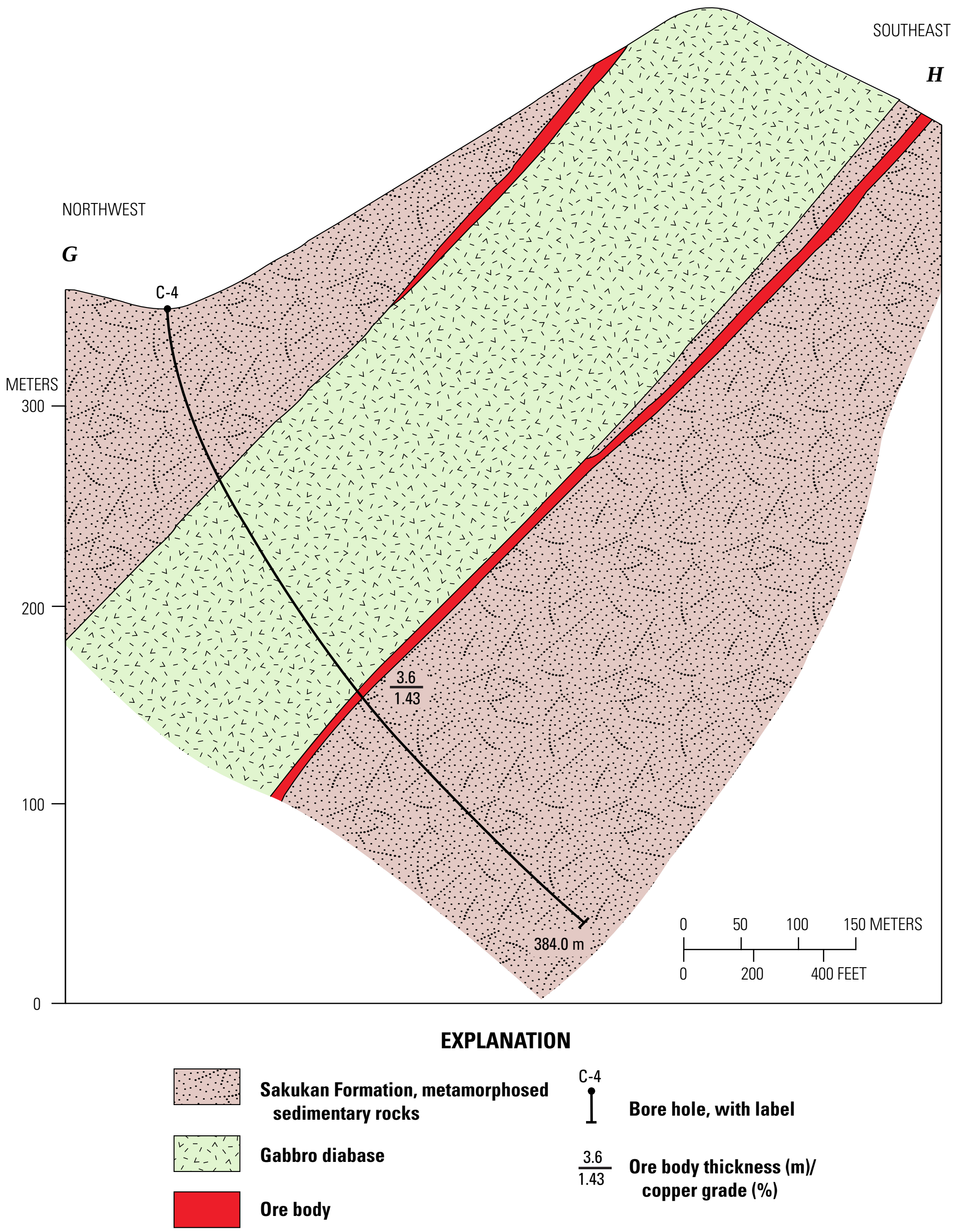

Figure F4. Cross section showing gabbro-diabase sill separating sediment-hosted stratabound copper mineralizations in tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia. Line of section is shown in figure F3.

Table F2. C and P category resources associated with the Burpala prospect, tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

[Categories based on resource classification system used for COMECON countries (Jakubiak and Smakowski, 1994; Henley and Young, 2006). Cu, copper; Ag, silver; Mt, million metric tons; %, percent; ppm, parts per million. C2 and P1 are Russian mineral resource categories. C2 is analogous to inferred mineral resources as defined by CRIRSCO. P1 is analogous to exploration results as defined by CRIRSCO or undiscovered mineral resources as used by the USGS and are estimates associated with extensions to inferred resources]

Prospect name	Category of reserves, resources	Ore (Mt)	Cu grade, (%)	Ag grade, (ppm)
Burpala	C2	15.9	1.26	67.9
	P1	27.5	1.15	49.7
	C2+ P1	43.4	1.19	56.3

Table F3. Other sediment-hosted copper occurrences in the tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

[NA, not available]

Name	Latitude	Longitude	Unit	Size
Unknown	56.49347	119.59894	Sakukan Formation, member 5	occurrences of useful minerals
Unknown	56.48477	119.60949	Sakukan Formation, member 3	occurrences of useful minerals
Unknown	56.49329	119.55961	Sakukan Formation, member 5	non-industrial deposits
Unknown	56.52543	119.76149	Chitkanda Formation	NA
Unknown	56.50289	119.74632	Chitkanda Formation	NA
Unknown	56.45323	119.60011	Chitkanda Formation	NA
Unknown	56.44119	119.59429	Chitkanda Formation	NA

Isolated bodies of mineralized rocks with higher concentrations of copper occur in the central portion of the copper-bearing unit. These bodies are lenticular, bifurcate along strike in some places, and can be separated by barren interlayers. The lenses of mineralized rock are locally cut by the gabbro-diabase intrusions; with a portion of the mineralization occurring in the hanging wall of the intrusion and the remainder of the same lens in the footwall (fig. F4; tables F4 and F5).

Most of the ore minerals are copper sulfides, with chalcopyrite being the most abundant. Bornite, chalcocite, and covellite occur but are less common. Oxidized minerals such as malachite and bornite are widely developed on oxidized surfaces; azurite, chrysocolla, chalcocite, and cuprite are also present. Pyrite, magnetite, hematite, hydroxides, minor marcasite, and ilmenite occur extensively.

Data from assay samples indicate silver in small quantities (tens of ppm, reaching up to 100–200 ppm) in bornite-chalcocite ores, oxidized ores formed from bornite-chalcocite, and pyrite-chalcocite mineralized rocks. Gold was found in rare cases (about one sample every 20–30 analyses), with the contained gold amount from 0.2 to 0.8 ppm.

Other Prospects

Three of the seven sites reported by Fedorovskiy (1976) and Feoktistov and Chechetkin (1984) occur within the Sakukan Formation, member 5, and the other four are in the Chitkanda Formation. The size category for two of the sites is “manifestations of useful minerals,” one is categorized as “non-industrial deposits,” and the sizes of the other four sites are unknown.

Table F4. Extent, thickness, and grade of sedimentary copper mineralization that occurs in the hanging wall of the gabbro-diabase intrusions, Burpala prospect, tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

[Locations of trenches shown in figure F3, each trench number prefaced by K (for example, K-108); m, meter; %, percent]

Trench number	Extent of the mineralized lens (m)	True thickness (m)	Copper grade (%)	Note
108, 109	600–650	4.8–11.8	0.80–1.86	In trenches 120, 121 and 122, three separate lenses are contained within the total thickness
114, 116, 117	about 800	5.3–10.3	0.72–1.66	
120, 121, 122	about 550	2.5–24.8	1.0–1.18	

Table F5. Extent, thickness, and grade of sedimentary copper mineralization that occurs in the footwall of the gabbro-diabase intrusions, Burpala prospect, tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

[Locations of trenches shown in figure F3, each trench number prefaced by K (for example, K-108); m, meter; %, percent]

Trench number	Extent of the mineralized lens (m)	True thickness (m)	Copper grade (%)	Note
11, 18	about 600	6.8–9.4	1.4–1.74	Trench K-11 shows the total thickness of the ore lenses to be 2 m, separated by an offshoot of gabbro-diabase with a thickness of 5.3 m
16	about 350	4.8	0.82	
19, 20, 21, 23, 24	about 1,150	1.8–6.1	0.77–0.87	Trench K-20 shows the total thickness of two ore lenses

Sources of Information

Principal sources of information used by the assessment team for delineation of the Burpala tract are listed in table F6.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Undiscovered deposit estimates were subjectively determined by a panel of scientists (table F7). Estimates at the 90th percentile were constrained by the occurrence at Burpala in the Sakukan Formation, which has been explored and has been partially delineated. This occurrence is found on the southeastern limb of a northeast-trending syncline; the northwestern limb is tectonically disrupted and covered by Cambrian sedimentary rocks.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered sediment-hosted stratabound copper deposits with the sandstone copper model (this report) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table F8. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. F5). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table F6. Principal sources of information used by the assessment team for tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

Name or title	Scale	Reference
Geology		
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXXVI	1:200,000	Fedorovskiy (1976)
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
State geological map of the USSR, new series, sheet N-49,(50) Chita, Map of the pre-Quaternary rocks	1:1,000,000	Efimov and others (1990)
State geological map of the USSR, new series, sheet O-49(50) Bodaybo, Map of Quaternary deposits	1:1,000,000	Kornutova and Tsvetkov (1984)
Geological map of the USSR, new series, sheet O-(50),51 Aldan, Map of the pre-Quaternary rocks	1:1,000,000	Lagzdina and others (1978)
Mineral occurrences		
Map of mineral resources of the USSR, Bodaybo series, sheet O-50-XXXVI	1:200,000	Fedorovskiy (1976)
Metallogenic map Kodar-Udokan trough and its surroundings	1:200,000	Feoktistov and Chechetkin (1984)
Geophysics		
Gravitational field map	1:1,000,000	Pis'mennyi (2003)
Magnetic anomaly map	1:1,000,000	Schupak and others (2003)
Exploration		
Schematic geologic map of the Burpalinsk sandstone-hosted copper deposit	1:10,000	V.S. Chechetkin, written commun. (2009)

Table F7. Undiscovered deposit estimates, deposit numbers, and tract area for tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers. N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005). In cases where individual estimates were tallied in addition to the input for EMINERS, individual estimates are listed]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km^2)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	*s*	C_v%	N_{known}	N_{total}	
1	1	2	3	3	1.30	0.75	57.0	0	1.30	129

Estimator	Estimated number of undiscovered deposits				
	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
other	1	2	3	4	
other	1	2			
USGS	1	3	5	7	
Input for EMINERS	1	1	2	3	3
USGS	2	3	4		
other	2	3	5		
USGS	2	4	6		
USGS	3	4	8	10	

Table F8. Results of Monte Carlo simulations of undiscovered resources in tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia.

[Cu, copper; Ag, silver; t, metric tons; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	16,000	180,000	2,100,000	7,400,000	1,300,000	0.14	0.07
Ag (t)	0	0	0	2,000	5,200	1,200	0.13	0.69
Rock (Mt)	0	1	14	180	790	110	0.14	0.07

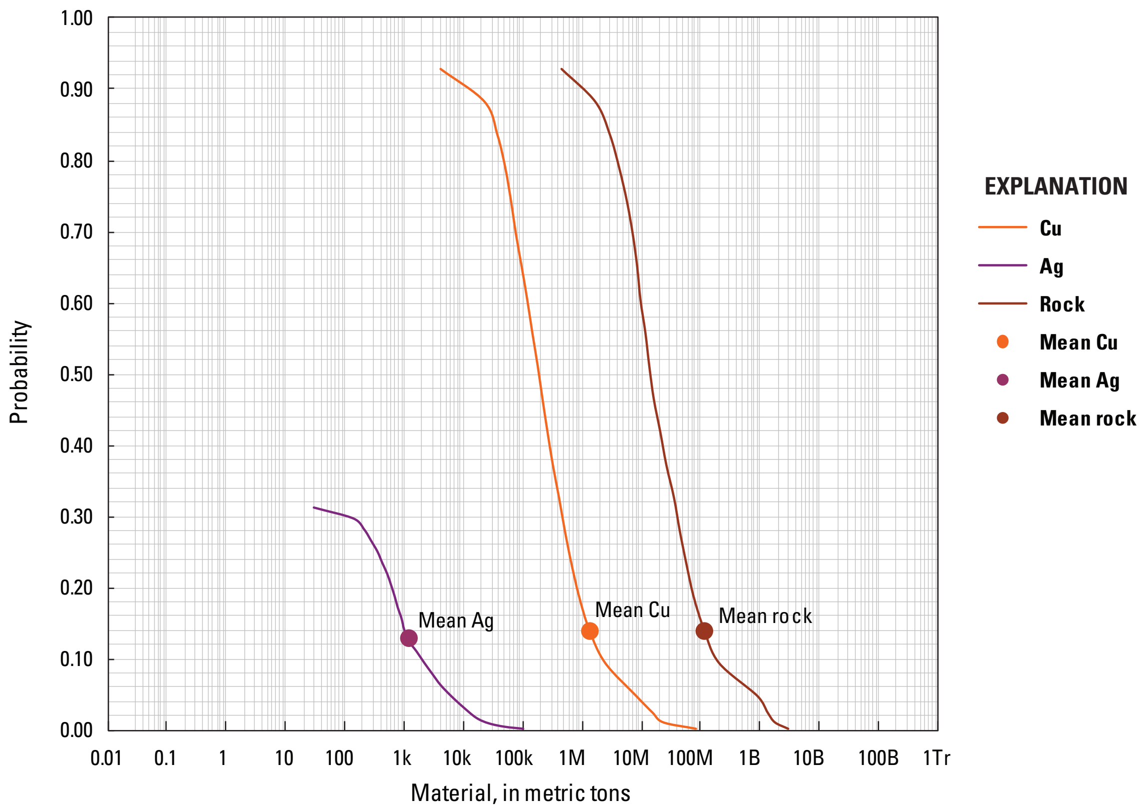

Figure F5. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 150ssCu0006, Burpala—Kodar-Udokan area, Russia. k, thousand; M, million; B, billion; Tr, trillion.

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Appendix G. Grade and Tonnage Model for Sandstone Copper Deposits

By Michael L. Zientek[1], Vladimir S. Chechetkin[2], Heather L. Parks[1], Stephen E. Box[1], Deborah A. Briggs[1], Pamela M. Cossette[1], Alla Dolgopolova[3], Timothy S. Hayes[4], Reimar Seltmann[3], Boris Syusyura[5], Cliff D. Taylor[6], and Niki E. Wintzer[1]

Description

The grade and tonnage model used for this assessment is based on 70 sandstone copper deposits (table G1; Zientek and others, 2013). This model is based on resource estimates that were available through the end of 2011.

Spatial aggregation rules are applied to try to ensure that deposits in grade and tonnage and spatial density models correspond to deposits as geologic entities. These rules are essential in order to have an assessment in which the estimated number of undiscovered deposits is consistent with the grade and tonnage model (Singer and Menzie, 2010). For this dataset, a 500-m aggregation rule, measuring either from the edge of a deposit polygon or between points representing deposit locations, was used. Aggregated deposits are labeled "*" in the Site column in table G1.

Mean and median values for ore tonnage are 77 and 10 million metric tons, respectively. Mean and median copper grades are 1.4 and 1.2 percent copper, respectively. Distributions of ore tonnage, copper grade, and contained copper are all positively skewed and consistent with a normal model. Cobalt and silver data are missing for 96 and 73 percent of the samples, respectively. Cobalt is not included in table G1. Log-transformed values of copper and cobalt grades do not show significant correlation with log-transformed values of tonnage. The grade and tonnage distributions are illustrated as cumulative frequency plots in figure G1.

[1] U.S. Geological Survey, Spokane, Washington, United States.

[2] Russian Geological Society (RosGeo), Chita, Russia.

[3] Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London, United Kingdom.

[4] U.S. Geological Survey, Tucson, Arizona, United States.

[5] Mining and Economic Consulting Ltd., Almaty, Kazakhstan.

[6] U.S. Geological Survey, Denver, Colorado, United States.

Table G1. Deposit data used to develop a grade and tonnage model for sandstone copper deposits.

[*, in the site column, indicates the site includes multiple deposits that were aggregated using the 500-m spatial separation rule; t, metric ton; %, percent; ppm, parts per million; –, no data; DRC, Democratic Republic of the Congo]

Deposit name	Site	Country	Ore (t)	Copper grade (%)	Silver grade (ppm)
Bwana Mkubwa		Zambia	8,600,000	3.34	–
Cashin		United States	7,141,000	0.53	–
Cattle Grid		Australia	7,200,000	1.90	8.0
Centennial		United States	24,415,944	0.59	–
Chejiang		China	3,022,321	1.12	–
Chibuluma South		Zambia	7,365,766	3.70	–
Chibuluma—Chibuluma West	*	Zambia	19,922,000	3.69	–
Chifupu		Zambia	1,936,000	3.05	–
Christiadore		Namibia	1,200,000	2.30	–
Copper Gulch		United States	13,608,000	0.53	51.4
Dacun		China	12,777,778	1.80	–
Datongchang		China	14,810,833	1.20	–
Dzhezkazgan		Kazakhstan	2,000,000,000	1.10	–
East Sary Oba		Kazakhstan	91,400,000	0.85	–
Fitula		Zambia	4,500,000	5.00	–
Geyiza		China	3,120,000	1.00	–
GTO		United States	4,463,000	0.84	–
Haojiahe		China	14,101,852	1.08	–
Horizon Basin		United States	10,069,920	0.60	61.7
Itauz		Kazakhstan	94,140,000	0.92	–
Itawa		Zambia	40,000,000	0.76	–
JF		United States	13,600,000	0.40	44.6
Jiuquwan		China	10,076,923	1.17	–
Juramento		Argentina	44,700,000	0.80	21.8
Karshoshak		Kazakhstan	8,900,000	1.46	–
Kasaria—Luansobe		Zambia	21,500,000	2.31	–
Kinsenda		DRC	35,000,000	5.50	–
Kipshakpai		Kazakhstan	38,500,000	0.94	–
Laoqingshan		China	1,377,049	1.22	–
Liuju		China	30,860,000	1.32	–
Lubembe		DRC	47,500,000	2.20	–
Malachite Pan		Namibia	3,000,000	2.10	–
Mangula		Zimbabwe	62,000,000	1.20	12.0
Mimbula	*	Zambia	46,850,000	1.20	–
Missoula National		United States	4,500,000	0.50	34.0
Mokambo North		Zambia	3,854,000	1.70	–
Mokambo Project—Mokambo South	*	Zambia	20,900,000	1.64	–
Moudin		China	14,414,063	1.28	–
Mufulira		Zambia	332,586,652	2.66	–
Mutundu North		Zambia	4,300,000	1.44	–
Mwambashi B		Zambia	14,210,000	1.78	–

Table G1. Deposit data used to develop a grade and tonnage model for sandstone copper deposits.—Continued

[*, in the site column, indicates the site includes multiple deposits that were aggregated using the 500-m spatial separation rule; t, metric ton; %, percent; ppm, parts per million; –, no data; DRC, Democratic Republic of the Congo]

Deposit name	Site	Country	Ore (t)	Copper grade (%)	Silver grade (ppm)
Mwerkera		Zambia	7,100,000	1.53	–
Ndola East		Zambia	40,000,000	0.76	–
Niagara		United States	17,000,000	0.47	16.0
Norah		Zimbabwe	10,000,000	1.20	–
Nsato		Zambia	8,400,000	1.61	–
Oamites		Namibia	6,100,000	1.33	12.3
Okasewa		Namibia	6,000,000	1.80	–
Pitanda South		Zambia	7,060,000	1.58	–
Qingshuihe		China	969,136	1.62	–
Repparfjord		Norway	10,000,000	0.72	70.0
Rock Creek/Montanore		United States	299,000,000	0.81	71.0
Rock Peak		United States	9,888,480	0.65	92.6
Sauzal Bonito		Argentina	2,000,000	0.50	–
Sebembere		Zambia	5,700,000	1.70	–
Sentinel		United States	4,465,000	0.40	–
Shackleton		Zimbabwe	3,400,000	1.20	–
Shimenkan		China	1,000,000	1.09	–
Silverside		Zimbabwe	900,000	1.80	–
Spar Lake		United States	80,600,000	0.63	46.0
Tordillos		Argentina	9,350,000	0.42	–
Tschudi		Namibia	57,000,000	0.72	11.0
Udokan		Russia	1,300,000,000	1.45	13.0
Unkur		Russia	90,900,000	0.75	70.8
Vermilion River		United States	13,600,000	0.50	30.8
Wadi Abu Khushaybah		Jordan	8,000,000	0.65	–
West Sary Oba		Kazakhstan	86,200,000	0.89	–
Witvlei Pos		Namibia	2,800,000	1.50	–
Zhaman—Aibat		Kazakhstan	193,000,000	1.40	16.0
Zhangjiachunshengjiping		China	1,836,735	0.98	–

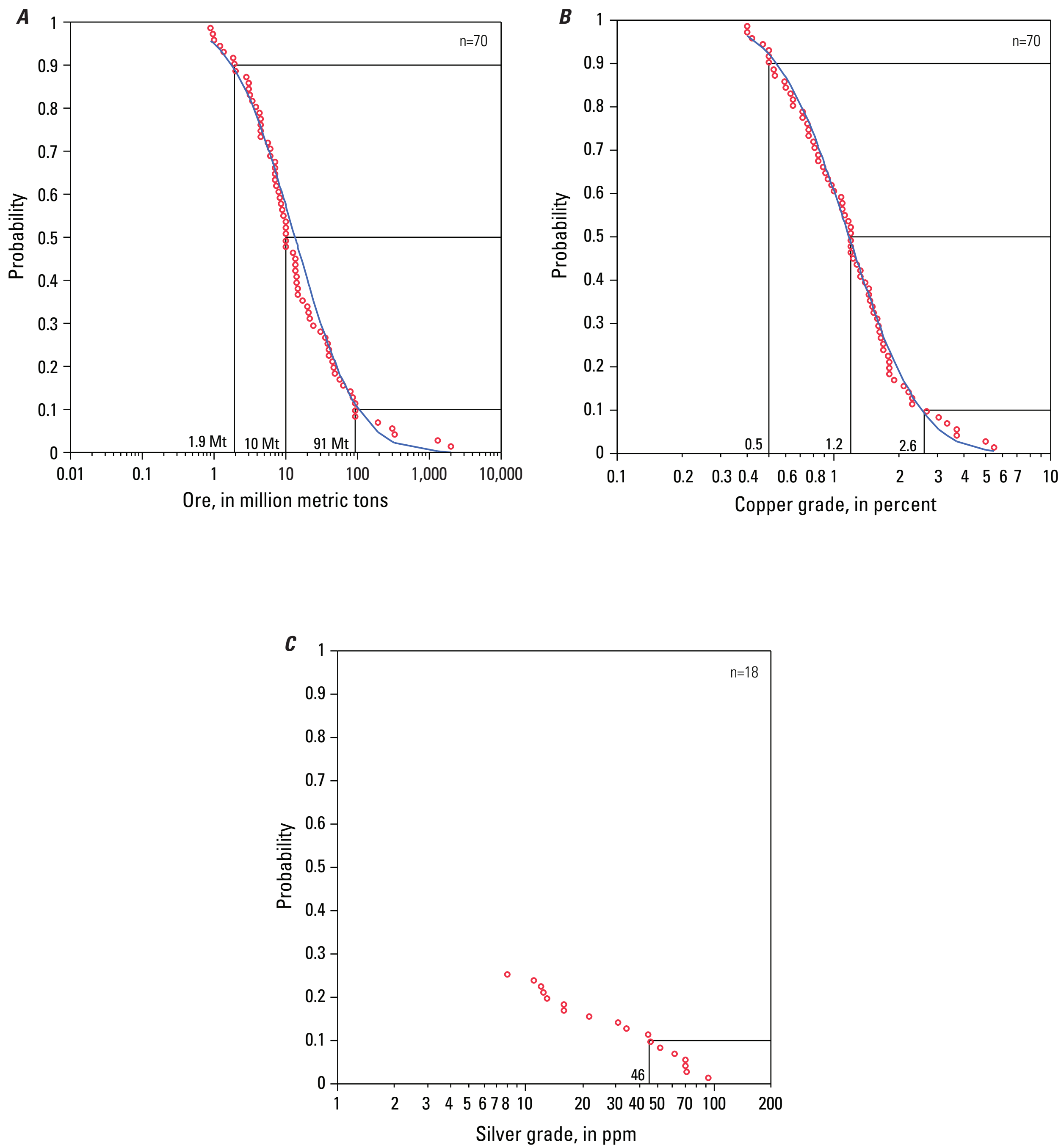

Figure G1. Cumulative frequency plots of tonnage (*A*), copper grade (*B*), and silver grade (*C*) for 50 sandstone copper deposits. Each red circle is data point for a deposit; the blue curve is the calculated lognormal distribution based on the population parameters of the data. Values for tonnage and grade for the 90th, 50th, and 10th probability values of the distribution are illustrated by extending a horizontal line from the vertical axis to the data points, then drawing a vertical line to the horizontal axis. The value for the point where the vertical line intersects the horizontal axis is labeled. Values for silver are not reported for some deposits, resulting in a censored or truncated dataset. However, the probability values for silver are based on the full set of 70 deposits.

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Appendix H. Description of GIS Files

By Michael L. Zientek[1], Vladimir S. Chechetkin[2], Heather L. Parks[1], Stephen E. Box[1], Deborah A. Briggs[1], Pamela M. Cossette[1], Alla Dolgopolova[3], Timothy S. Hayes[4], Reimar Seltmann[3], Boris Syusyura[5], Cliff D. Taylor[6], and Niki E. Wintzer[1]

Eleven ESRI shapefiles (.shp) are included with this report. These may be downloaded from the U.S. Geological Survey (USGS) website as zipped file **sir2010-5090-M_gis.zip**.

Sedimentary Copper Deposits and Prospects, Kodar-Udokan, Russia (KU_deposits_prospects)

This dataset includes points that describe sedimentary copper deposits and prospects in the Kodar-Udokan area, Russia. Its purpose is to constrain estimates of mineral resource endowment by compiling the location of mineralized rock associated with sandstone copper-type deposits.

This file was created by manually digitizing points in a geographic information system (GIS) from georeferenced maps. Locations have not been verified using the satellite imagery that was publically available for this area because the resolution was too coarse to verify most point locations. The deposits and prospects are attributed with information shown in table H1, which was derived from the maps and reports listed in the Ref_short field.

Permissive Tracts for Sandstone Copper, Kodar-Udokan, Russia (KU_permissive_tracts)

This dataset includes polygons that describe permissive tracts for sandstone-type copper deposits in the Kodar-Udokan area, Russia. Its purpose is to delineate where undiscovered deposits of sandstone copper may occur within the upper 2 km of the Earth's crust.

This file was created by scanning and registering 1:200,000-scale geologic, 1:200,000-scale metallogenic, 1:10,000- to 1:50,000-scale exploration, and 1:500,000-scale aeromagnetic maps using georeferencing tools in ArcGIS9. The exploration maps were registered using hydrologic and topographic features. The aeromagnetic, geologic, and metallogenic maps were registered using grid information on the maps. Areas of the metallogenic map were cropped out and individually registered against features in the geologic maps to increase location accuracy of the metallogenic map.

[1] U.S. Geological Survey, Spokane, Washington, United States.

[2] Russian Geological Society (RosGeo), Chita, Russia.

[3] Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, London, United Kingdom.

[4] U.S. Geological Survey, Tucson, Arizona, United States.

[5] Mining and Economic Consulting Ltd., Almaty, Kazakhstan.

[6] U.S. Geological Survey, Denver, Colorado, United States.

Table H1. Definitions of user-defined attribute fields in the shapefile KU_deposits_prospects.shp.

Field name	Description
GMRAP_ID	User-defined, unique identifier assigned to the site.
Tract_ID	User-defined, unique identifier assigned to permissive tract within which the site is located.
Coded_ID	Coded, unique identifier assigned to permissive tract within which the site is located.
Name	Name of site.
Belongs_to	Name of district, belt, trend, and so on.
Type	Mineral deposit type.
Subtype	Sediment-hosted copper subtype.
SiteStatus	Prospect or deposit. Prospect if no grade and tonnage values provided. Deposit if it has grade and tonnage.
Latitude	Latitude in decimal degrees. -90.0000 to 90.0000. Negative south of the equator.
Longitude	Longitude in decimal degrees. -180.0000 to 180.0000. Negative west of the Greenwich meridian.
Code_cntry	Two character code from International Organization for Standardization – ISO 3166.
Country	Country in which the site is located.
State_Prov	State or province in which the site is located.
Comm_major	Major commodities in decreasing order of economic importance.
Tonnage_Mt	Ore tonnage in millions of metric tons.
Cu_pct	Average copper grade in weight percent.
Ag_g_t	Average silver grade in ppm (=grams per ton).
Con_Cu_t	Million metric tons of contained copper.
Comments	Miscellaneous comments.
Unit	Geologic map unit site is located in.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.

Features were digitized as shapefiles on screen using the georeferenced images as a guide. These include:

- A polygon file comprising all Paleoproterozoic sedimentary units above the Inyr Formation, in which rocks of the Chinei and Kemen Groups were distinguished to help understand fold geometry.
- A polygon file of the contours of basin fill.
- A line file for the locations of cross-sections.
- A line file for faults having obvious offset at 1:200,000-scale.
- A line file of the trace of fold axes created by interpreting the pattern of map units and measurements of strikes and dips from the georeferenced maps.

The shapefiles were attributed using the descriptions from the original source maps as a guide. A geologist then projected the bedrock units from the 1:200,000-scale maps under Quaternary cover using all the registered maps, the cross sections published with the maps, contours of basin fill, and an image of a 1:500,000-scale aeromagnetic survey. The interpretation was integrated with the shapefile of geologic units to produce the permissive tracts. The polygons are attributed with information shown in table H2.

Surface Extent of Sandstone Copper Ore Bodies, Kodar-Udokan, Russia (KU_orebodies)

This dataset includes polygons that show the surface area of sandstone copper ore bodies in the Kodar-Udokan area, Russia. Its purpose is to document the spatial extent of mineralized rock in sandstone copper deposits and significant prospects and to constrain estimates of mineral resource endowment.

This shapefile was created by manually digitizing the ore bodies shown on georeferenced maps. The ore bodies are attributed with information shown in table H3, which was derived from the maps and other reports listed in the field Ref_short.

Table H2. Definitions of user-defined attribute fields in the shapefile KU_permissive_tracts.shp.

Field name	Description
Tract_ID	User-defined, unique identifier assigned to permissive tract.
Coded_ID	Coded, unique identifier assigned to permissive tract.
Tract_name	Informal name of permissive tract.
Unregcode	Three digit UN code for the region that underlies most of the permissive tract.
Country	Country(ies) in which the permissive tract is located.
Commodity	Primary commodity being assessed.
Dep_type	Name of the deposit type assessed.
GT_model	Grade-tonnage model used for the undiscovered deposit estimate.
Geology	Geologic feature assessed.
Age	Age of the assessed geologic feature.
Asmt_date	Year assessment was conducted.
Asmt_depth	Maximum depth beneath the Earth's surface used for the assessment, in kilometers.
Est_levels	The set of percentile (probability) levels at which undiscovered deposit estimates were made.
N90	Estimated number of deposits associated with the 90th percentile (90 percent chance of at least the indicated number of deposits).
N50	Estimated number of deposits associated with the 50th percentile (50 percent chance of at least the indicated number of deposits).
N10	Estimated number of deposits associated with the 10th percentile (10 percent chance of at least the indicated number of deposits).
N05	Estimated number of deposits associated with the 5th percentile (5 percent chance of at least the indicated number of deposits).
N01	Estimated number of deposits associated with the 1st percentile (1 percent chance of at least the indicated number of deposits).
N_expected	Expected (mean) number of deposits. N_Expected = (0.233*N90) + (0.4*N50) + (0.225*N10) + (0.045*N05) + (0.03*N01)
s	Standard deviation. s = 0.121 - (0.237*N90) - (0.093*N50) + (0.183*N10) + (0.073*N05) + (0.123*N01)
Cv_percent	Coefficient of variance, in percent. Cv = (s/N_Expected) * 100
N_known	Number of known deposits in the tract.
N_total	Total number of deposits. N_total = N_Expected + N_Known
Area_km2	Area of permissive tract, in square kilometers.
DepDensity	Deposit density (total number of deposits per square kilometer). DepDensity = N_total/Area_km2
DepDen10E5	Deposit density per 100,000 square kilometers. DepDen10E5 = DepDensity*100,000
Estimators	Names of people on the estimation team.

Table H3. Definitions of user-defined attribute fields in the shapefile KU_orebodies.shp.

Field name	Description
Name	Name of the ore body.
label	Label for ore lens or layer in ore body.
Area_km^2	Area of the surface extent of the ore body in square kilometers.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of this chapter.

Subsurface Extent of Sandstone Copper Ore Bodies, Kodar-Udokan, Russia (KU_subsurface_orebodies)

This dataset includes polygons showing the subsurface area of sandstone copper ore bodies in the Kodar-Udokan area, Russia. Its purpose is to document the spatial extent of mineralized rock in sandstone copper deposits and significant prospects and to constrain estimates of mineral resource endowment.

This shapefile was created by manually digitizing the subsurface extent of ore bodies based upon the mapped distribution of ore-bearing units and ore bodies shown on georeferenced maps. The subsurface ore bodies are attributed with information shown in table H4, which was derived from the maps and other reports listed in the field Ref_short.

Trace of Copper-Bearing Units, Kodar-Udokan, Russia (KU_copper_bearing_units)

This dataset includes polylines that show the trace of copper-bearing units in the Kodar-Udokan area, Russia. Its purpose is to document the spatial extent of mineralized rock in sandstone copper prospects and to constrain estimates of mineral resource endowment.

This shapefile was created by manually digitizing the copper-bearing units shown on georeferenced maps. The units are attributed with information shown in table H5, which was derived from the maps and other reports listed in the field Ref_short.

Mineral Exploration Drill Holes, Kodar-Udokan, Russia (KU_boreholes)

This dataset includes points that describe the collar locations of mineral exploration drill holes in the Kodar-Udokan area, Russia. Its purpose is to document mineral exploration activity for sandstone copper deposits.

This shapefile was created by manually digitizing the locations of boreholes shown on georeferenced maps. The boreholes are attributed with information shown in table H6, which was derived from the maps and other reports listed in the field Ref_short.

Mineral Exploration Trenches, Kodar-Udokan, Russia (KU_trenches)

This dataset includes polylines that describe the locations of mineral exploration trenches in the Kodar-Udokan area, Russia. Its purpose is to document mineral exploration activity for sandstone copper deposits.

This shapefile was created by manually digitizing the locations of trenches shown on georeferenced maps. The trenches are attributed with information shown in table H7, which was derived from the maps and other reports listed in the field Ref_short.

Grade and Thickness of Mineralized Exposures, Kodar-Udokan, Russia (KU_thickness_grade)

This dataset includes points that describe the thickness and grade of sedimentary copper mineralization determined by near-surface mineral exploration in the Kodar-Udokan area, Russia. Its purpose is to document results of mineral exploration activity for sandstone copper deposits.

This shapefile was created by manually digitizing the test sites shown on georeferenced maps. The sites are attributed with information shown in table H8, which was derived from the maps and other reports listed in the field Ref_short.

Geologic Cross-Section Lines, Kodar-Udokan, Russia (KU_cross_sections)

This dataset includes polylines that show the locations of geologic cross sections in the Kodar-Udokan area, Russia. Its purpose is to document where geologists have made interpretations of the subsurface geometry of the rocks.

This shapefile was created by manually digitizing the section lines shown on georeferenced maps. The cross sections are attributed with information shown in table H9, which was derived from the maps and other reports listed in the field Ref_short.

Fold Axes in Udokan Complex Rocks, Kodar-Udokan, Russia (KU_fold_axes)

This dataset includes polylines that show the location of selected fold axes in rocks of the Udokan Complex in the Kodar-Udokan area, Russia. Its purpose is to document patterns of folding that have affected the sedimentary rocks that may host sedimentary copper mineralization.

The fold axes were manually digitized on the basis of interpretations by the authors of this report from the patterns of map units and measurements of strikes and dips shown on georeferenced maps. The polylines are attributed with information shown in table H10.

Faults, Kodar-Udokan, Russia (KU_faults)

This dataset includes polylines that show the location of selected faults in the Kodar-Udokan area, Russia. Its purpose is to document where the continuity of the sedimentary rocks that may host sedimentary copper mineralization is significantly disrupted by faults.

This shapefile was created by manually digitizing the faults shown on georeferenced maps that exhibited obvious offset at 1:200,000-scale. The polylines are attributed with information shown in table H11.

Table H4. Definitions of user-defined attribute fields in the shapefile KU_subsurface_orebodies.shp.

Field name	Description
Name	Name of subsurface ore body.
Area_km^2	Area of the surface extent of the subsurface ore body in square kilometers.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.

Table H5. Definitions of user-defined attribute fields in the shapefile KU_copper_bearing_units.shp.

Field name	Description
Tract	Name of the permissive tract within which the copper-bearing unit lies.
Formation	Geologic formation where the copper-bearing unit is located.
Commodity	Major commodities in decreasing order of economic importance.
Length_km	Copper-bearing unit trace length in kilometers.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.

Table H6. Definitions of user-defined attribute fields in the shapefile KU_boreholes.shp.

Field name	Description
Name	Name of the borehole.
Type	Type of borehole, "surface" or "underground" for mineral exploration; "mapping" for mapping geology under cover
Surv_prty	Surveying party responsible for creating borehole.
Latitude	Latitude in decimal degrees. -90.0000 to 90.0000. Negative south of the equator.
Longitude	Longitude in decimal degrees. -180.0000 to 180.0000. Negative west of the Greenwich meridian.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.

Table H7. Definitions of user-defined attribute fields in the shapefile KU_trenches.shp.

Field name	Description
Name	Name of the trench.
Surv_prty	Surveying party responsible for creating the trench.
Length_km	Trench length in kilometers.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.

Table H8. Definitions of user-defined attribute fields in the shapefile KU_thickness_grade.shp.

Field name	Description
Tract	Name of permissive tract within which the test site is located.
Grd_ratio	Ratio of thickness in meters per copper grade in percent found at test site.
Formation	Geologic formation within which the test site is located.
Latitude	Latitude in decimal degrees. -90.0000 to 90.0000. Negative south of the equator.
Longitude	Longitude in decimal degrees. -180.0000 to 180.0000. Negative west of the Greenwich meridian.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.

Table H9. Definitions of user-defined attribute fields in the shapefile KU_cross_sections.shp.

Field name	Description
Orig_label	Cross section letters from the original source document.
Fig_label	Cross section letters used on figures shown in this report.
Length_km	Cross section length in kilometers.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.

Table H10. Definitions of user-defined attribute fields in the shapefile KU_fold_axes.shp.

Field name	Description
Type	The type of fold - syncline or anticline.
Name	Name of the fold axis.
Length_km	Fold axis length in kilometers.
Ref_short	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.

Table H11. Definitions of user-defined attribute fields in the shapefile KU_faults.shp.

Field name	Description
TBFault	Was the fault used for tract delineation - "yes" if it was used, "no" if it was not.
Length_km	Fault length in kilometers.
Ref_short1	Abbreviated reference listing author's last name(s) and date of publication. Full references are listed in references cited section of appendix H.
Ref_short2	Overflow field for abbreviated references that do not fit into Ref_short1 field. Full references are listed in references cited section of appendix H.

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Appendix I. Author Biographies

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