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Global Mineral Resource Assessment

Sandstone Copper Assessment of the Chu-Sarysu Basin, Central Kazakhstan

Prepared in cooperation with the Centre for Russian and Central EurAsian Mineral Studies—Natural History Museum, London, United Kingdom, and Mining and Economic Consulting, Ltd., Almaty, Kazakhstan

Scientific Investigations Report 2010–5090–E

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

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Sandstone Copper Assessment of the Chu-Sarysu Basin, Central Kazakhstan

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Abstract

Mineral resource assessments represent a synthesis of available information to estimate the location, quality, and quantity of undiscovered mineral resources in the upper part of the Earth's crust. This report presents a probabilistic mineral resource assessment of undiscovered sandstone copper deposits within the late Paleozoic Chu-Sarysu Basin in central Kazakhstan by the U.S. Geological Survey as a contribution to a global assessment of mineral resources. The purposes of this study are to: (1) provide a database of known sandstone copper deposits and significant prospects in this area, (2) delineate permissive areas (tracts) for undiscovered sandstone copper deposits within 2 km of the surface at a scale of 1:1,000,000, (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), silver (Ag), and mineralized rock that could be contained in undiscovered deposits within each tract. The assessment uses the three-part form of mineral resource assessment based on mineral deposit models (Singer, 1993; Singer and Menzie, 2010).

Delineation of permissive tracts for resources is based on the distribution of a Carboniferous oxidized nonmarine clastic (red bed) stratigraphic sequence that lies between overlying Permian and underlying Devonian evaporite-bearing sequences. Subsurface information on the extent and depth of this red bed sequence and structural features that divide the basin into sub-basins was used to define four permissive tracts. Structure contour maps, mineral occurrence databases, drill hole lithologic logs, geophysical maps, soil geochemical maps, locations of producing gas fields, and evidence for former gas accumulations were considered in conjunction with descriptive deposit models and grade and tonnage models to guide the assessment team's estimates of undiscovered deposits in each tract.

The four permissive tracts are structural sub-basins of the Chu-Sarysu Basin and range in size from 750 to 65,000 km^2. Probabilistic estimates of numbers of undiscovered sandstone copper deposits were made for the four tracts by a group of experts. Using these probabilistic estimates, Monte Carlo simulation was used to estimate the amount of metal contained within each tract. The results of the simulation serve as the basis for estimates of the metal endowment.

The team estimates that 26 undiscovered deposits occur within the Chu-Sarysu Basin, and that these deposits contain an arithmetic mean of at least 21.5 million metric tons (Mt) of copper and 21,900 metric tons (t) of silver. The undiscovered deposits are in addition to the 7 known deposits that contain identified resources of 27.6 Mt of copper. Sixty percent of the estimated mean undiscovered copper resources are associated with the two permissive tracts that contain the identified resources; the remaining estimated resources are associated with the two tracts that have no known deposits. For the three tracts that contain 95 percent of the estimated undiscovered copper resources, the probability that each tract contains its estimated mean or more is about 40 percent. For the tract with 5 percent of the estimated undiscovered copper resources, the probability that it contains that amount or more is 25 percent.

Introduction

This report presents the results of an assessment of the late Paleozoic Chu-Sarysu sedimentary basin in central Kazakhstan for the occurrence of undiscovered sandstone copper deposits. The study was coordinated 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 nonfuel mineral resources. This research project is developing, testing, and (or) applying a variety of methods to assess undiscovered mineral

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resources quantitatively to a depth of 1 km or more below the Earth's surface (Briskey and others, 2001, 2007; Schulz and Briskey, 2003). The primary objectives are to identify the principal areas in the world that have potential for selected undiscovered mineral resources by using available compiled information about geology, geochemistry, geophysics, and previous exploration, and to present the results in the context of modern quantitative statistical models.

Regional assessment studies such as this one compile and integrate existing information by using Geographic Information Systems (GIS) technology so that results can be presented at a scale of 1:1,000,000. Data sets used in this study include databases and maps of the location, size, and geologic type of known mineral deposits and occurrences; maps and explanations of regional geology, metallogeny, petroleum geology, tectonics, geochemistry, and geophysics; and available information about regional mineral exploration history. 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 of the undiscovered resources. The resulting quantitative mineral resource assessment can then be evaluated using economic filters and cash flow models for economic and policy analysis, and can be applied to mineral supply, economic, environmental, and land-use planning. Such economic evaluations are not part of this report.

In this report, we first present an overview of the geologic setting and history of the Chu-Sarysu Basin in central Kazakhstan (fig. 1). This is followed by a review of the characteristic features of sandstone copper deposits in general, and of the giant Dzhezkazgan deposit within the basin in particular (see also Box and others, in press), in order to develop a generalized model for the origin of these deposits in this basin. We then briefly review the mineral assessment methodology that has been developed by researchers at the USGS. Next, we summarize our mineral resource assessment of undiscovered sandstone copper deposits in the Chu-Sarysu Basin. Brief descriptions are given of the data used in the assessment and of the criteria used to delineate the tracts that are permissive for the occurrence of undiscovered deposits of this type, and we compare the local deposits with the global grade-tonnage model to test its appropriateness. Finally, we review the results of the probabilistic assessments of the permissive tracts and the results of the Monte Carlo simulations of the contained metal endowment of each tract.

Appendix A includes biographical information about the team of experts who completed the mineral resource assessment. Appendixes B through E contain summary information for each tract, including the location, geologic feature assessed, rationale for tract delineation, tables and descriptions of known deposits and significant prospects, exploration history, model selection, rationale for the estimates, assessment results, and references. Appendix F contains a table of grade and tonnage data for the 70 sandstone copper deposits. The grade-tonnage model was constructed from those data and used to simulate undiscovered resources in the Chu-Sarysu Basin. Appendix G describes the accompanying geodatabase and included feature classes which provide permissive tract outlines, assessment results, and data for deposits and prospects in a GIS (ESRI) format.

Geologic Overview

The Chu-Sarysu Basin in central Kazakhstan (fig. 1) hosts the giant Dzhezkazgan sandstone copper deposit near its northern margin, as well as six other smaller deposits of the same type. All of the deposits occur within an Upper Carboniferous[6] (Pennsylvanian) fluvial clastic red bed sequence (Taskuduk and Dzhezkazgan Formations) within the basin (fig. 2). These clastic units are considered to constitute the permissive units for undiscovered deposits within the basin because they appear to have confined and focused the flow of brines and fluids in the basin. At present (2011), mining of these deposits occurs to nearly 1 km below the surface, and the assessment of undiscovered deposits is limited to 2 km below the surface. A structure contour map of the base of the ore host strata is shown in figure 1.

The ore host strata occur within a 3–6 km thick Lower Devonian to Upper Permian stratigraphic sequence (fig. 2) deposited in the Chu-Sarysu Basin. The axis of the basin coincides with the trace of an Ordovician suture between Proterozoic continental blocks (Windley and others, 2007). Basin strata rest unconformably on deformed Proterozoic to lower Paleozoic strata, intruded locally by Early Devonian granitic rocks. The stratigraphy of the Devonian-Permian fill of the Chu-Sarysu Basin can be divided into four depositional units. The lowest unit (1–2 km thick) consists of Early and Middle Devonian intermediate volcanic and volcaniclastic rocks under the eastern part of the basin (Windley and others, 2007) that interfinger westward with, and grade upward into, a Middle and Upper Devonian continental red bed sequence. The lower basinal volcanic and red bed strata were deposited within and beyond the present basin margins on the back-arc flank of an Early and Middle Devonian continental magmatic arc located to the east (Windley and others, 2007) that was generated by subduction beneath the east flank of the arc. Arc magmatism with similar subduction geometry stepped eastward a few hundred kilometers from Late Devonian through Permian time.

The second unit (1–2 km thick) of the Chu-Sarysu Basin consists of Upper Devonian-Mississippian limestones and dolomites with lagoonal evaporite facies in the lower part,

[6]In this report we use the western European and American subdivision of the Carboniferous Period into Lower [Mississippian] and Upper [Pennsylvanian] sub-periods (with no "Middle" sub-period). In the stratigraphic nomenclature developed in the former Soviet Union, the Carboniferous is divided into Lower, Middle, and Upper sub-periods, and the Middle and Upper sub-periods encompass our Upper Carboniferous (Pennsylvanian) sub-period, divided at the top of the Moscovian epoch (Harland and others, 1990).

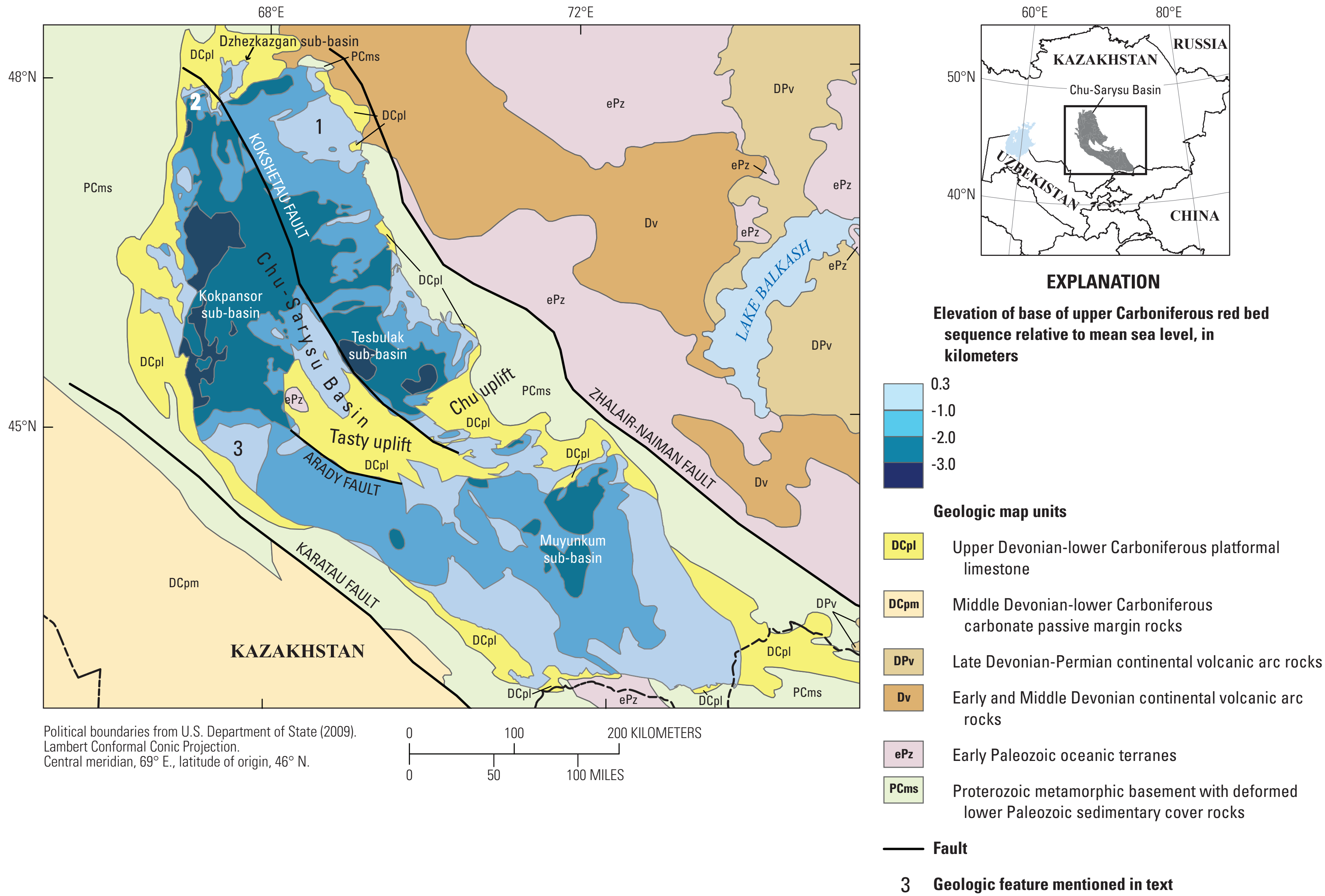


Figure 1. Geologic map of the region of the Chu-Sarysu Basin in central Kazakhstan (modified from Windley and others, 2007) with Permian and younger rocks removed. Within the basin area, defined by the subsurface presence of Pennsylvanian strata, structure contour intervals are shown on the base of Pennsylvanian strata (generalized from Syusyura and others, 2010; sub-basins from Sinitsyn, 1991). Small isolated areas of Pennsylvanian strata outside the contiguous Chu-Sarysu Basin are not shown (compare with assessment tracts of fig. 9). Numbered geologic features: 1, central Sarysu uplift; 2, Kumola synclinorium; 3, Buguldzhy uplift.

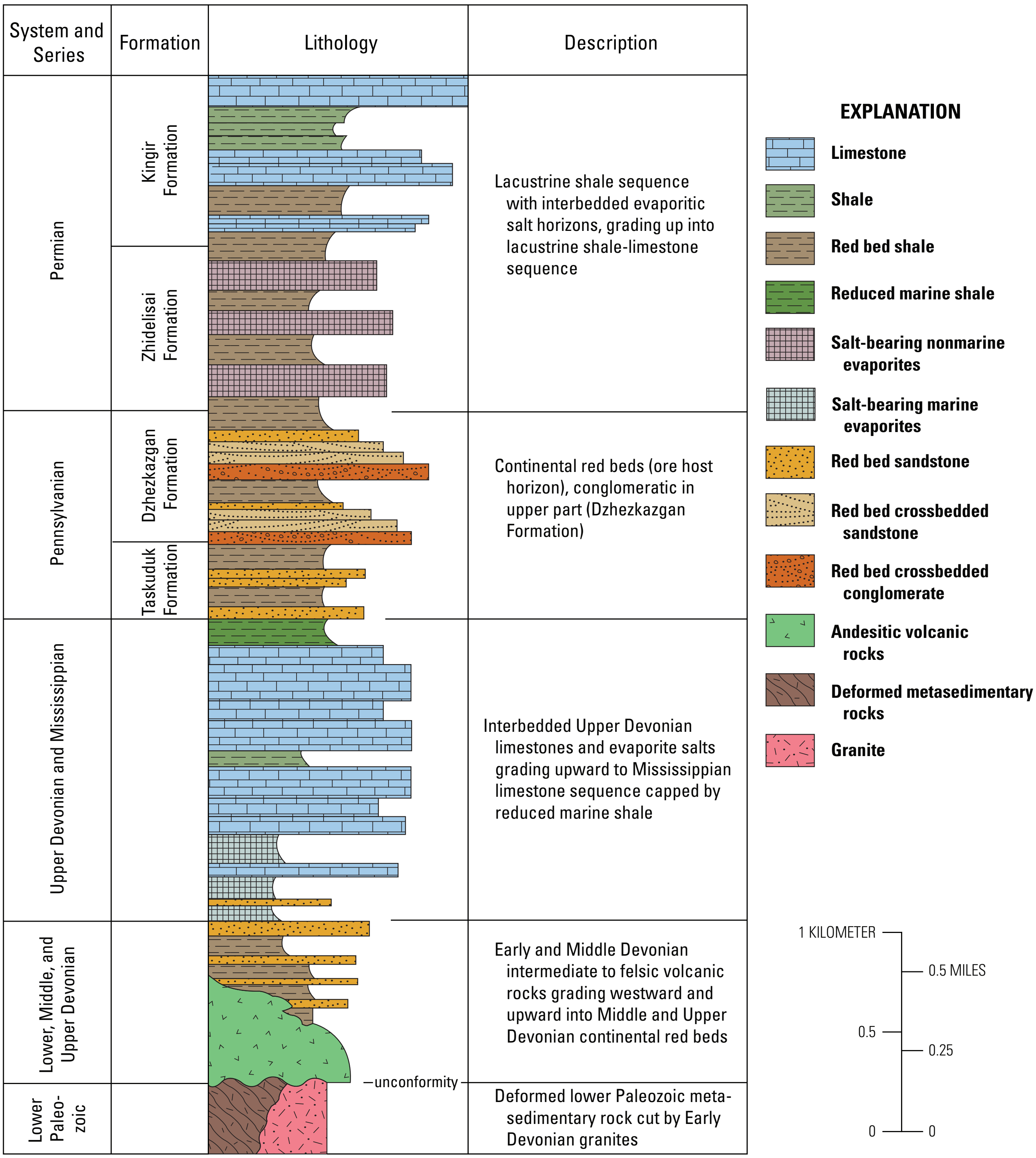


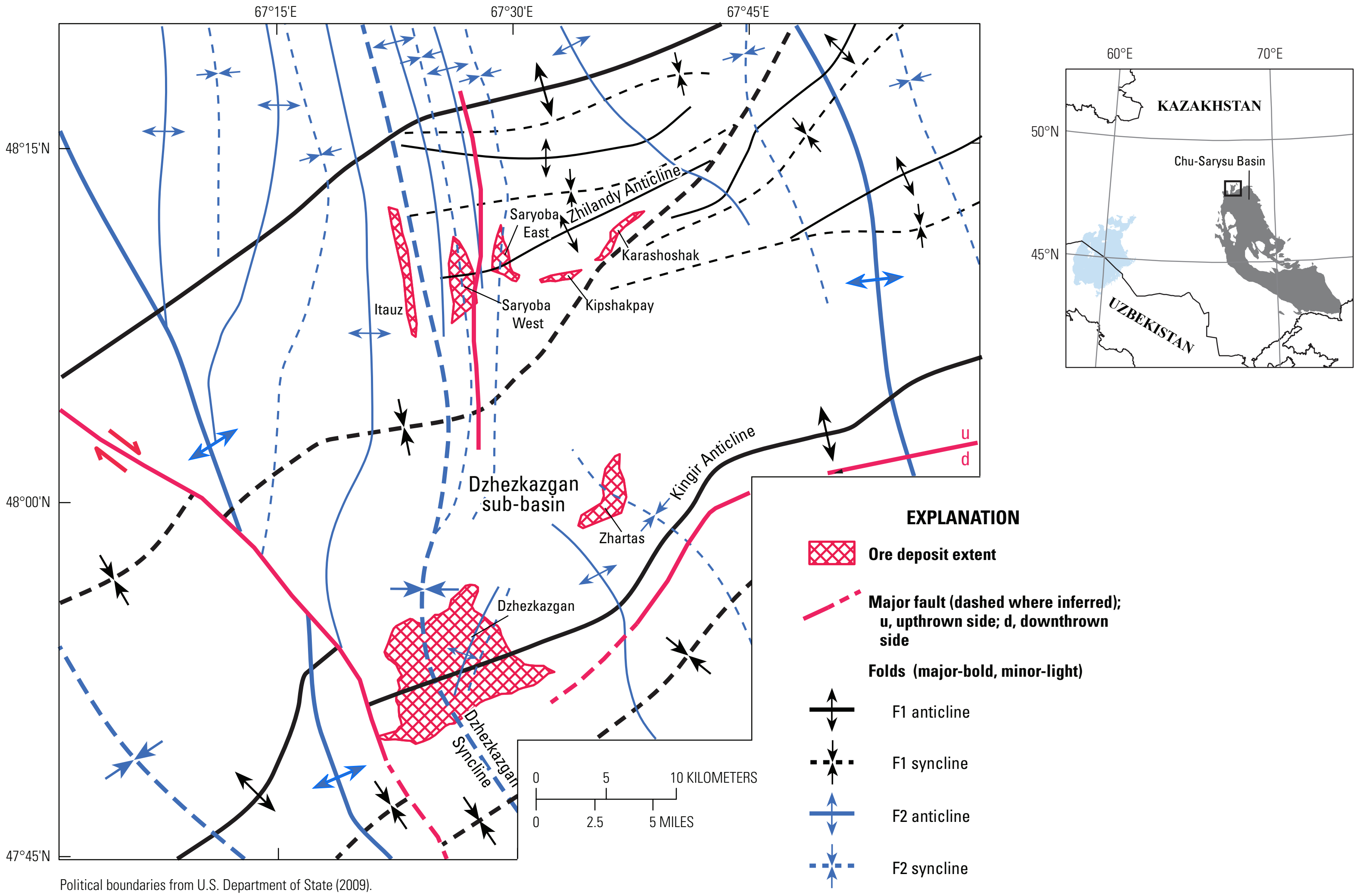
Figure 2. Generalized Paleozoic stratigraphic section of the Chu-Sarysu Basin, central Kazakhstan (compiled from Ditmar and Tikhomirov, 1967; Gablina, 1981; Bykadorov and others, 2003; Alexeiev and others, 2009; Syusyura and others, 2010). Known sandstone copper deposits are restricted to the Dzhezkazgan and Taskuduk Formations.

which is a component of a regional carbonate platform-slope sequence of a southwest-facing passive continental margin located to the west of the Chu-Sarysu Basin (Cook and others, 2002). Above a transitional reduced shale unit, the third unit (1 km thick) of the basin fill consists of Pennsylvanian continental red beds that host the copper mineralization. Pennsylvanian onset of northeast-side-down, basin-margin faulting along the Karatau Fault (fig. 1) and the absence of Pennsylvanian and Permian strata southwest of the fault are evidence of Pennsylvanian subsidence of a distinct Chu-Sarysu Basin, the locus of deposition of Pennsylvanian to Upper Permian fill (Alexeiev and others, 2009). The Pennsylvanian red bed sequence is characterized by alluvial facies deposited by paleo-rivers that flowed into the basin from its margins: eastward from the western basin margin (Alexeiev and others, 2009), southward from the northern basin margin (Narkelyun and Fatikov, 1989), and westward from the eastern basin margin (Glybovskiy and Syusyura, 1992).

Finally, the uppermost Paleozoic unit (1–2 km thick) consists of Permian fine-grained red bed lacustrine deposits with interlayered evaporitic salts. The deposits grade upward into interlayered nonmarine limestones, marl, and fine clastic rocks. Isopach thickness maps of Permian salt (Zharkov, 1984) show distinct depocenter maxima in the Muyunkum sub-basin in the south and straddling the Kokshetau Fault from the eastern half of the Kokpansor sub-basin across the northern part of the Tesbulak sub-basin. Folding of the basinal sequence began during deposition of the Pennsylvanian Dzhezkazgan Formation (Gablina, 1981) but continued after deposition of the Permian strata, ending prior to deposition of gently dipping Upper Cretaceous to lower Tertiary strata (<1 km thick).

The tectonic setting of late Paleozoic basin subsidence in the Chu-Sarysu Basin is unclear. The Devonian volcanic rocks and red beds and the Mississippian carbonate sequence extend beyond the Chu-Sarysu Basin margins, and these units are related to regional subsidence rather than to localized subsidence within the basin. Alexeiev and others (2009) documented Pennsylvanian northeast-directed thrusting on the southwestern flank of the Chu-Sarysu Basin; they interpreted basin subsidence to have taken place in a foreland basin setting, based on flanking conglomerates and the change from marine to nonmarine deposition in the Chu-Sarysu Basin. A thrust-belt foreland basin setting for Pennsylvanian subsidence of the Chu-Sarysu Basin is unlikely, however, because available isopach thickness data indicate that these strata thin toward the southwestern basin margin (Bykadorov and others, 2003) rather than thicken toward the associated thrust belt, as would be expected in a foreland basin setting. The Chu-Sarysu Basin is flanked on its northeast (Zhalair-Naiman Fault: Yakubchuk, 2004; Popov and others, 2009) and southwest (Karatau Fault: Allen and others, 2001; Alexeiev and others, 2009) margins by long parallel northwest-trending faults with complex histories (fig. 1). A down-to-the-east fault is buried under Tertiary strata in the central part of the basin (Kokshetau Fault) and parallels the basin-bounding faults. The Kokshetau Fault divides the northern half of the basin into two sub-basins (Syusyura and others, 2010). These faults may be associated with the formation of the depositional basin or may be related to post-depositional deformation of the basin, or both. Allen and others (2001) and Alexeiev and others (2009) suggest that the northwest-trending Karatau Fault along the southwestern basin margin experienced left-lateral transpression (nearly eastward compression) during onset of Pennsylvanian Chu-Sarysu Basin subsidence. Permian subsidence of distinct northern and southern salt depocenters in the Chu-Sarysu Basin implies the existence of a nearly east-west positive feature separating them, possibly an arch caused by a step-over between sinistral faults along the basin margin. Locally at the Dzhezkazgan copper deposit on the northern flank of the basin (fig. 3*A*), Pennsylvanian red bed strata appear to thin over the apparently syn-depositional, east-northeast-trending Kingir Anticline (Gablina, 1981). Such syn-depositional anticlines could indicate nearly north-south syn-depositional compression. Alternatively, the anticlines could reflect the trends of pre-existing or active normal faults that controlled syn-depositional diapirism of underlying Upper Devonian salts (Warren, 2000), reflecting earlier or active north-south extension. A better understanding of isopach thickness variations within the Chu-Sarysu Basin (see also Syusyura and others, 2010) and of the movement history of basin margin faults is necessary to resolve the cause(s) of Chu-Sarysu Basin subsidence.

The basinal strata were deformed by two nearly orthogonal trends of upright folds prior to mineralization: one set with east-northeast trends, and the other set with north to north-northwest trends (Allen and others, 2001; Alexeiev and others, 2009; Syusyura and others, 2010). Geologic maps of the basin margins and structure contour maps of the basin interior show evidence that these two fold trends affect upper Paleozoic strata throughout the basin, resulting in a dome-and-basin style of intersecting folds (Allen and others, 2001). The relative ages of the two fold trends are uncertain. Along the southwestern flank of the Chu-Sarysu Basin, the northerly set is deformed by the east-northeasterly set (Allen and others, 2001; Alexeiev and others, 2009). In the region of the Dzhezkazgan deposit, however, bleaching (iron reduction) of the Pennsylvanian ore host rock red bed sequence (shown by patterns in fig. 3*B*), inferred to have resulted from the former presence of a natural gas deposit within an anticlinal trap, is localized along the east-northeast-trending Kingir Anticline and continues across intersecting north-south synclines and anticlines. This suggests that the east-northeast trending folds formed first (F1), trapping natural gas deposits, and were crossed by later north-south folds (F2). The Dzhezkazgan sandstone copper deposit is localized along the trend of an F1 anticline where it is crossed by an F2 syncline (fig. 3), and therefore post-dates at least the onset of F2 folding. Throughout the basin, wavelengths of both fold sets are approximately 10–15 km, and the intersecting folds result in complex egg-carton-like basin-and-dome fold patterns of the pre-Mesozoic sequence. Within the main Chu-Sarysu Basin, these folded strata are overlain unconformably by gently dipping Upper Cretaceous-Paleogene and Neogene continental strata.



Political boundaries from U.S. Department of State (2009).
Asia North Lambert Conformal Conic Projection.
Central meridian, 67° E., latitude of origin, 30° N.

Figure 3*A*. Geologic map, fold trends and outlines of ore deposits within the Dzhezkazgan sub-basin of the Chu-Sarysu Basin, central Kazakhstan (Syusyura and others, 2010). Stratigraphic sub-units are distinguished by variations in color; the broader time-stratigraphic units are identified in figure 3*B*. The giant Dzhezkazgan sandstone copper deposit is localized in a structural saddle of the east-northeast-trending F1 Kingir Anticline, where it is crossed by the major north-trending F2 syncline that localizes the Dzhezkazgan sub-basin. The Zhartas deposit occurs farther east on the northern flank of the F1 Kingir Anticline, where it is crossed by another north-northwest-trending F2 syncline. The five deposits of the Zhilandy group are localized along another east-northeast-trending F1 anticline on the northern flank of the Dzhezkazgan sub-basin. The three western deposits (Itauz, Saryoba West, and Saryoba East) are elongate within and parallel to north-trending F2 synclines where they cross that F1 anticline. The two eastern deposits (Kipshakpay, Karashoshak) occur on the southeast flank of the same F1 anticline, but have no obvious F2 syncline intersections.

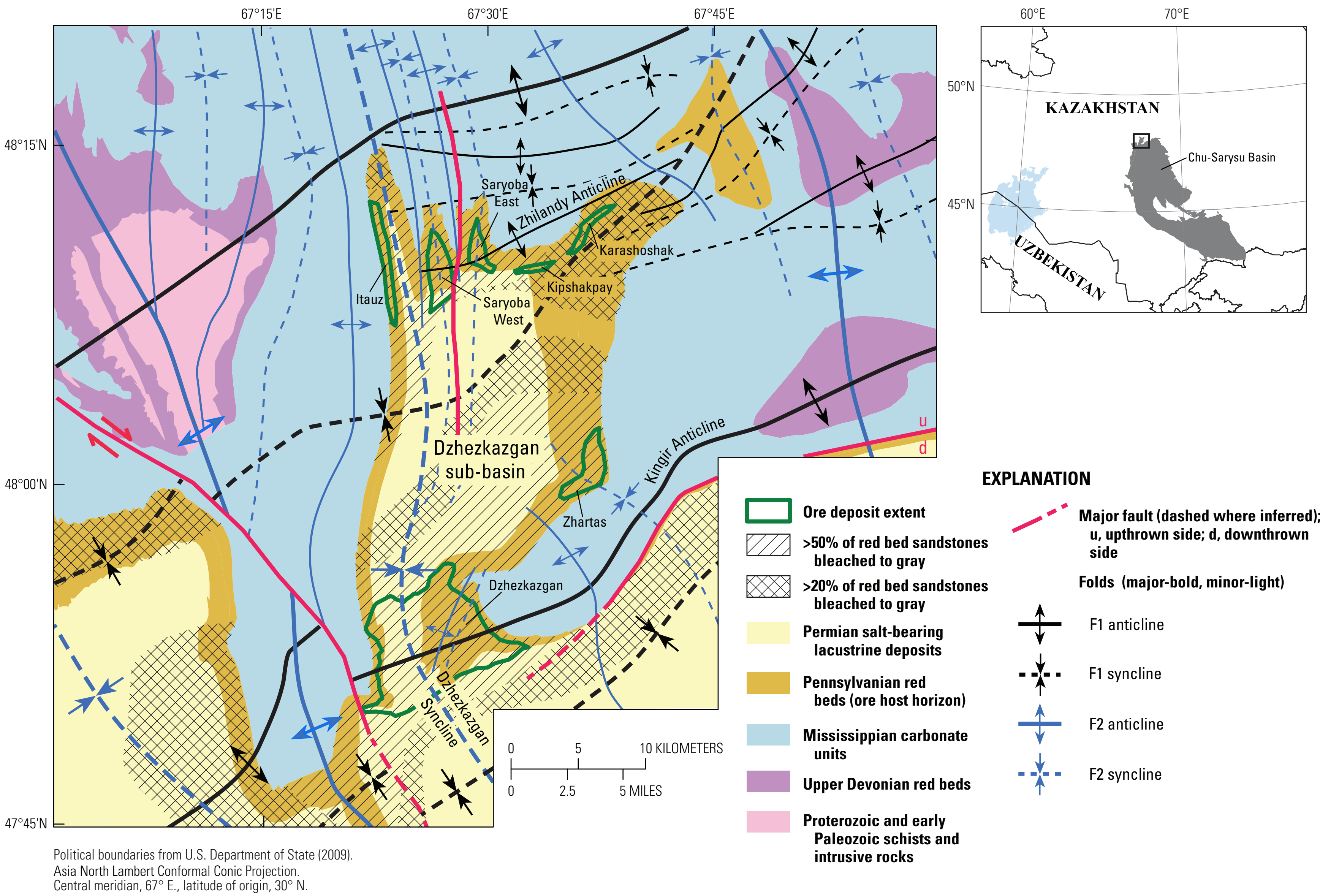


Figure 3*B*. Same as figure 3*A*, but with broader time-stratigraphic units identified. Areas of partial iron reduction (20 percent and 50 percent) within the Pennsylvanian red bed sequence are shown by different cross-hatched patterns. Note that areas of partial iron reduction are east-northeast-trending and track along F1 anticlines, even where crossed by F2 synclines.

A structure contour map of the base of the Pennsylvanian host strata for the copper mineralization (fig. 1) gives some idea of the complexity of basin structure. A northwest-elongate basement high, over which the ore host strata were eroded prior to Cretaceous overlap, occurs in the central basin. The central basin high plunges to the northwest and is bound on its northeast flank by the down-to-the-east Kokshetau Fault. This elongate high divides the northern half of the basin into west (Kokpansor) and east (Tesbulak) sub-basins (Sinitsyn, 1991), each of which is broadly tilted to the southwest. The pattern is complicated by the two orthogonal fold sets. The southern sub-basin (Muyunkum) generally is shallower than the northern sub-basins, with its deepest part toward the northeast. Isopach thickness maps of Permian salt (Zharkov, 1984) show a distinct depocenter maximum that straddles the Kokshetau Fault and the two northern structural sub-basins, indicating the fault and sub-basins are Early Permian or younger phenomena.

Mineral Deposit Model

Sediment-hosted stratabound copper deposits consist of copper-sulfide-bearing zones a few to tens of meters thick that are generally parallel to lithologic layering (Kirkham, 1989; Hitzman and others, 2005). The sulfides typically occur in reduced rocks near oxidation-reduction boundaries and commonly have an ore mineral zonation related to that oxidation boundary. Cox and others (2003) classified these deposits in three subtypes based on host lithology and type of reductant. The reduced-facies subtype typically is hosted in marine or lacustrine shale or carbonate rocks that contain disseminated organic carbon and (or) pyrite that overlie or are interbedded with red bed strata or subaerial basalt flows. The red bed subtype occurs within reduced zones in red bed sequences, typically centered on accumulations of woody plant detritus. The Revett subtype (referred to as sandstone copper subtype in this report) occur within sandstone host strata in red bed sequences that contain gray or green reduced-iron alteration zones. For the sandstone copper subtype, the host strata generally contain evidence for the former presence of fluid or gaseous hydrocarbons.

Hitzman and others (2005, 2010) present a general model for the origin of sediment-hosted copper deposits, with emphasis on the source, transport, and precipitation of the ore components within an evolving basinal hydrologic system. Continental, fluvial red bed sequences, commonly with interbedded mafic volcanic rocks, typically are considered to be the source of copper. Copper can be leached from these source rocks by low temperature (<93˚C) chloride-rich oxidized fluids (Rose, 1976). Chloride-rich groundwater brines can be produced from seawater by evolution of trapped connate waters, by dissolution of interstratified evaporites, or by incorporation of residual brines after evaporitic mineral precipitation. Some type of hydraulic pumping of the brines, probably density-driven, is necessary to circulate a sufficient volume of this fluid past the site of ore deposition. A source of sulfur and appropriate chemical and physical conditions must come together to focus and maintain metal precipitation at a particular site for a long enough period to develop a deposit of copper and silver.

The giant (estimated 20 Mt Cu) Dzhezkazgan sandstone copper deposit (fig. 3) in the Chu-Sarysu Basin is thoroughly studied (Gablina, 1981; Daukeev and others, 2004; Syusyura and others, 2010; Box and others, in press) and provides important constraints for understanding processes that led to formation of sediment-hosted copper deposits in this basin. The deposit is localized within a structural saddle along the east-northeast trending Kingir Anticline (fig. 3), where the marginal north-south Dzhezkazgan sub-basin connects to the larger Chu-Sarysu Basin to the south (figs. 1 and 3); thus, the ore body is located at the intersection of an east-northeast trending F1 anticline (that is, the Kingir Anticline) with a north-trending F2 syncline (that is, the Dzhezkazgan Syncline that localizes the Dzhezkazgan sub-basin). Sandstone beds within the Pennsylvanian red bed units that host the deposits have been altered to a gray color along the trend of the east-northeast anticline by reduction of iron minerals (fig. 3*B*). The reduction of iron minerals pre-dates ore deposition and appears to be related to the localization of natural gas accumulations within intergranular pore spaces of sandstone horizons along the east-northeast-trending anticline (Gablina, 1981). Mixing of the oxidized ore fluid with natural gas in intergranular pore spaces resulted in precipitation of the ore minerals.

The Dzhezkazgan sandstone copper deposit consists of 10 ore-bearing sandstone members, numbered 1 to 10 from stratigraphically lowest to highest, within a 600 m Pennsylvanian stratigraphic section (fig. 4). Two to four ore-bearing sandstone beds occur within each ore-bearing sandstone member, and these beds and their incorporated ore bodies ("Mineralization" in fig. 5) are given the sandstone member numeral and a Roman numeral increasing from lowest to highest. Ore bodies extend over an 80 km^2 area, with distinctly different distributions for each ore horizon (fig. 5). Ore bodies occur within the dipping ore-bearing section over about a 550-m vertical range from 400 m above to 150 m below sea level (Daukeev and others, 2004). Arcuate (concave to east-northeast) ore bodies 2-I, 4-I and 6-I (fig. 5) occur at progressively higher stratigraphic levels down the plunge of the Kingir Anticline to the west-southwest but at roughly similar (±100 m) elevations (fig. 6). Stratigraphically higher ore bodies (8-I and 9-I in fig. 5) have elongate, northeast-trending shapes along and parallel to the sharp, south-southeast-dipping limb of the Kingir Anticline. The ore bodies appear to trend smoothly across north- to north-northeast-trending monoclinal flexures (fig. 5; shown by closely spaced structure contours in fig. 7) which the assessment team classifies as F2 based on their orientation. Because these monoclinal flexures do not seem to control ore body trends, thickness variations (fig. 7), or ore mineral zonation (fig. 8), the team concludes that these monoclinal flexures post-date ore deposition. Mineralization is inferred to have occurred after the broader F2 Dzhezkazgan

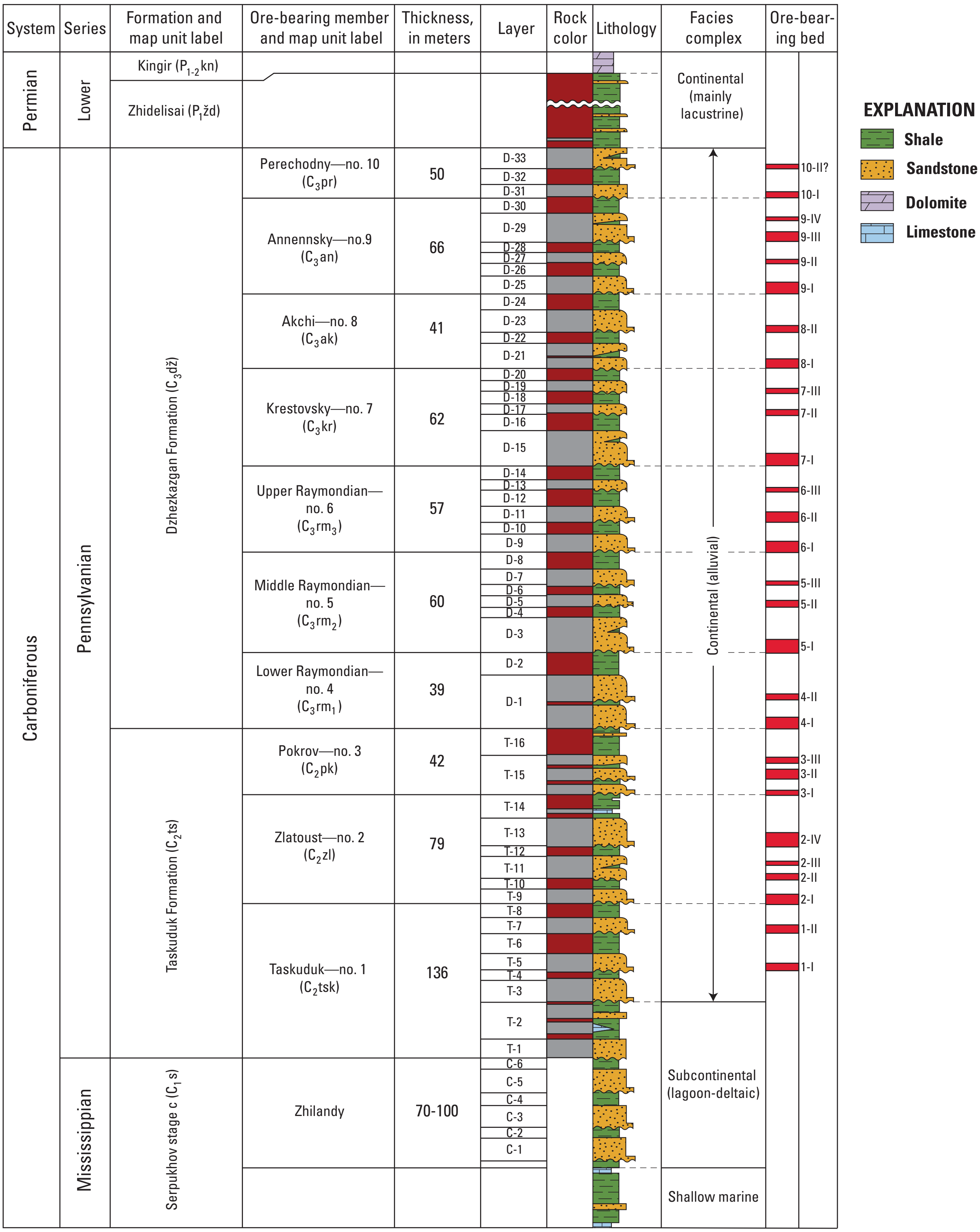


Figure 4. Carboniferous and Permian stratigraphic section in the Dzhezkazgan deposit area, central Kazakhstan showing the stratigraphic association of named ore bodies or ore-bearing beds with specific sandstone bodies in the Pennsylvanian section.

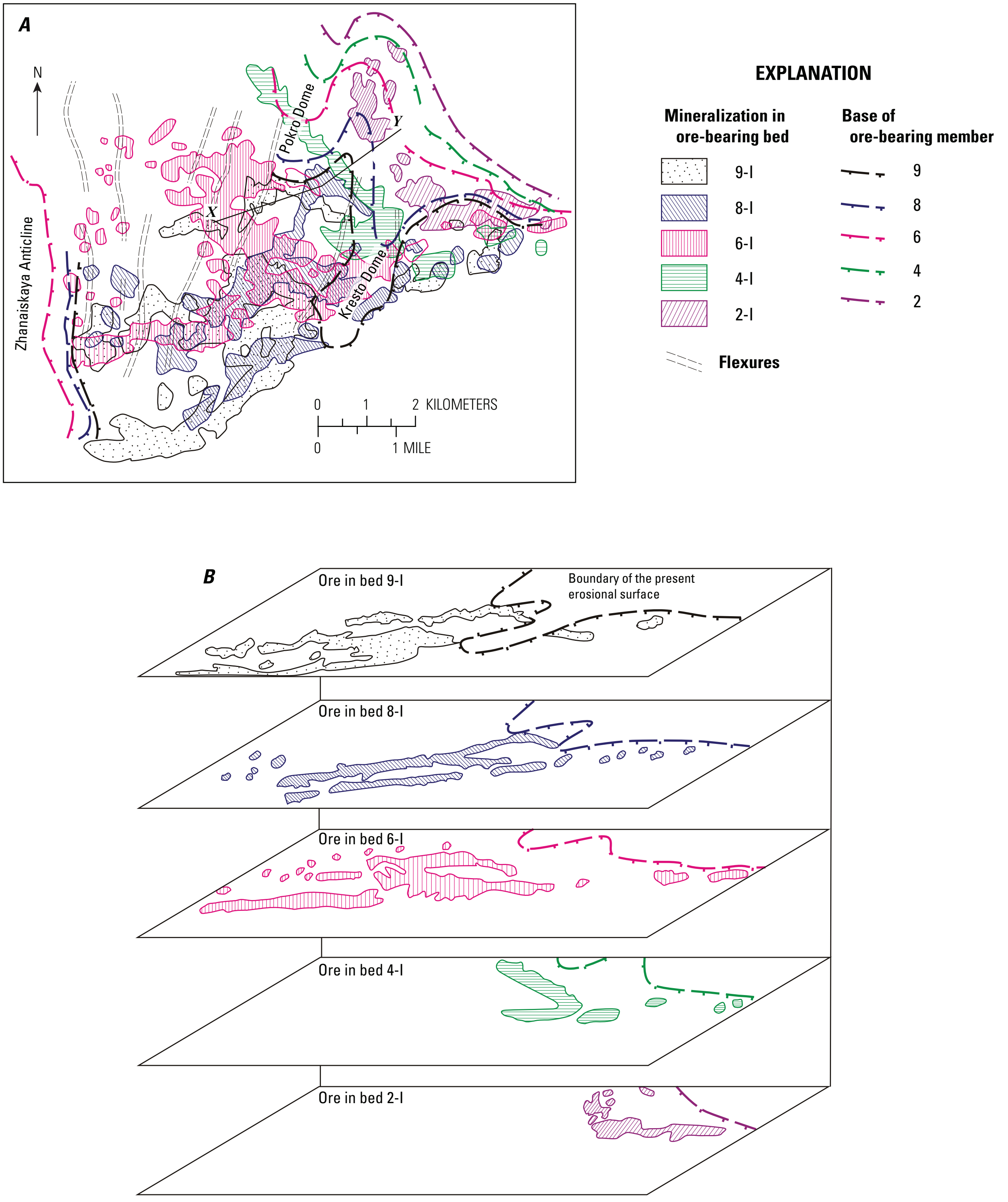


Figure 5. Geometry of ore bodies in selected stratigraphic layers (numbered upward from lowest; see fig. 4) within the Dzhezkazgan sandstone copper deposit, central Kazakhstan (from Daukeev and others, 2004). *A*, Combined plan view of ore bodies; also shown is the approximate location of cross section X–Y, which is illustrated in figure 6. *B*, Individual horizons from figure 5*A* shown as separate oblique-view maps.

Syncline had formed, or had begun to form, but before the sharp F2 subsidiary flexures had formed (that is, during the F2 folding episode). Detailed thickness variation within an individual ore body (fig. 7) shows puzzling irregularities along the broadly linear trends. Some authors (Daukeev and others, 2004) interpret the linear trends of ore bodies as resulting from fracture-controlled introduction of natural gas and H_2S into the copper-bearing brines, but this contradicts the mineral zonation evidence (below).

Ore mineral zonation occurs within each ore stratigraphic horizon at the Dzhezkazgan deposit (fig. 8), progressing from hematite to chalcocite to bornite to chalcopyrite to pyrite (Gablina, 1981; Daukeev and others, 2004). The presence of djurleite within ores at Dzhezkazgan defines an upper temperature limit of 93°C for precipitation of the ores (Gablina, 1981), although evidence that djurleite is a primary ore mineral and not a secondary mineral transformation (for example, Hatert, 2005) has not been presented. This progression of mineralogic zones reflects the progressive reduction of an oxidized copper-bearing solution (from hematite toward pyrite) in the presence of sulfate (Kirkham, 1989; Gablina, 1981) and indicates the direction of oxidized solution inflow. The reductant is inferred to have been mobile hydrocarbons (in particular, natural gas) within sandstone interbeds. The broad spread of sulfur isotopic values in the ore ($\delta S^{34} = -4.7$ to -20.1 ‰; Chukrov, 1971) suggests an origin by biogenic reduction of sulfate, probably associated with the hydrocarbon reductant. Within each ore horizon, mineral zones generally are parallel to the long dimension of the ore body, indicating flow of the copper-bearing brines across the strike of each ore body (fig. 8). Zonation in bodies elongate to the east-northeast indicates flow toward the north-northwest (out of the larger Chu-Sarysu Basin into the Dzhezkazgan sub-basin). Bodies elongate to the northwest have zonation indicative of northeastward flow, out of the saddle in the Kingir Anticline toward its culmination. Prolonged inflow of the copper-bearing solutions (and retreat of the reductant front?) resulted in forward migration of the chalcocite and bornite zones over the chalcopyrite zone over time, with leaching and reprecipitation of copper minerals producing the high-grade chalcocite-bornite ore bodies (fig. 8; Gablina, 1981). The gentle dip of the mineral zones toward the anticlinal culmination (cross section of ore body 4-I in fig. 8*C*) suggests the top of the ore brine encountered the bottom edge of the natural gas accumulation in the east-northeast-trending anticline, with ore minerals precipitating along that zone of brine-gas interaction (Gablina, 1981).

The team infers a simple model for the development of the mineralizing system within the geologic evolution of the basin. Localization of the Dzhezkazgan deposit at the intersection of an east-northeast-trending F1 anticline and a north-trending F2 syncline indicates that mineralization took place after development of the two orthogonal fold trends (possibly during the second fold event). New geochronological data

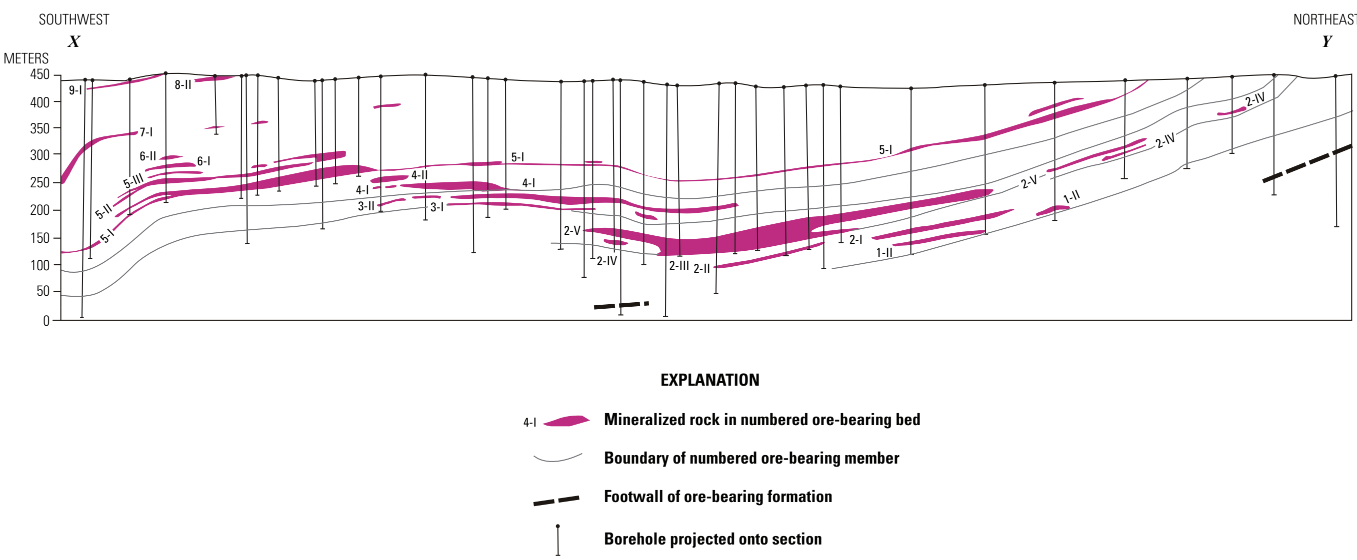


Figure 6. Cross section along southwest-northeast line X–Y across the Dzhezkazgan sandstone copper deposit, central Kazakhstan (from Daukeev and others, 2004; location in fig. 5*A*); ore bodies extend through about 350 vertical meters (m) within about 550 m of stratigraphic section (fig. 4). Note that the basal ore horizon climbs to progressively higher stratigraphic levels moving from northeast to southwest into the north-northwest-trending trough of the F2 Dzhezkazgan Syncline, central Kazakhstan (fig. 3). We interpret the downdip pinchout of ore in each horizon to reflect the approximate location of the natural gas-ore brine interface, and assume that a line connecting each such interface was subhorizontal at the time of ore deposition. The apparent bowing of that horizon results from post-ore folding associated with the sharp late F2 flexures.

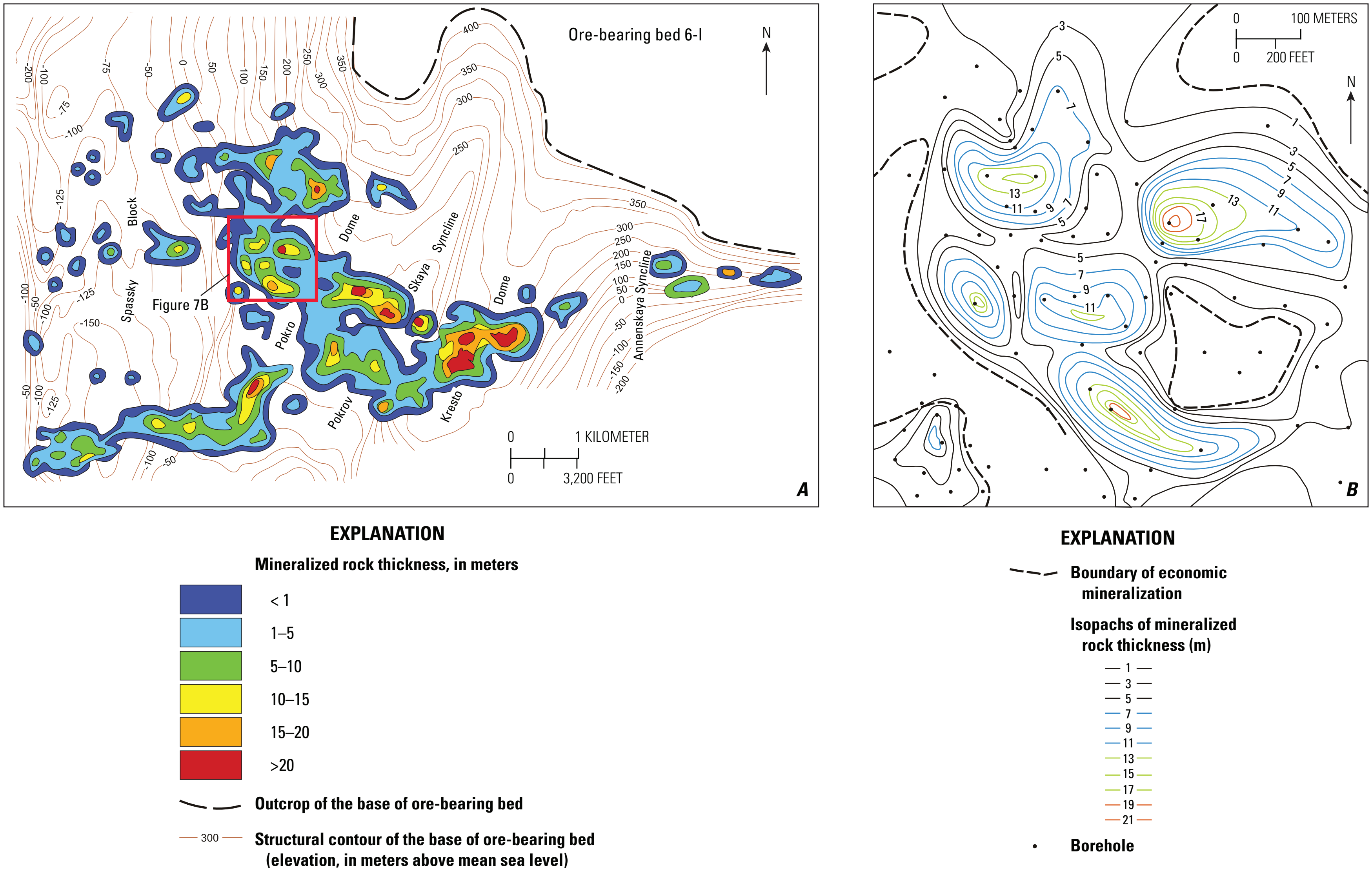


Figure 7. Thickness of mineralized rock within ore-bearing bed 6-1 of the Dzhezkazgan sandstone copper deposit, central Kazakhstan (from Daukeev and others, 2004; see fig. 5 for general location of ore body 6-1 and fig. 8 for mineralogical variation within the ore body). *A*, Thickness (m) of ore body 6-1 plotted over a map of structure contour intervals of the base of ore-bearing bed 6-1 (elevation in m above sea level); location of blow-up in figure 7*B* is shown by the red outline. Note how trend of ore body continues across and is not controlled by north-trending structural flexures, which are interpreted to post-date mineralization. *B*, Detailed contour map of the thickness (m) of one area of ore body 6-1.

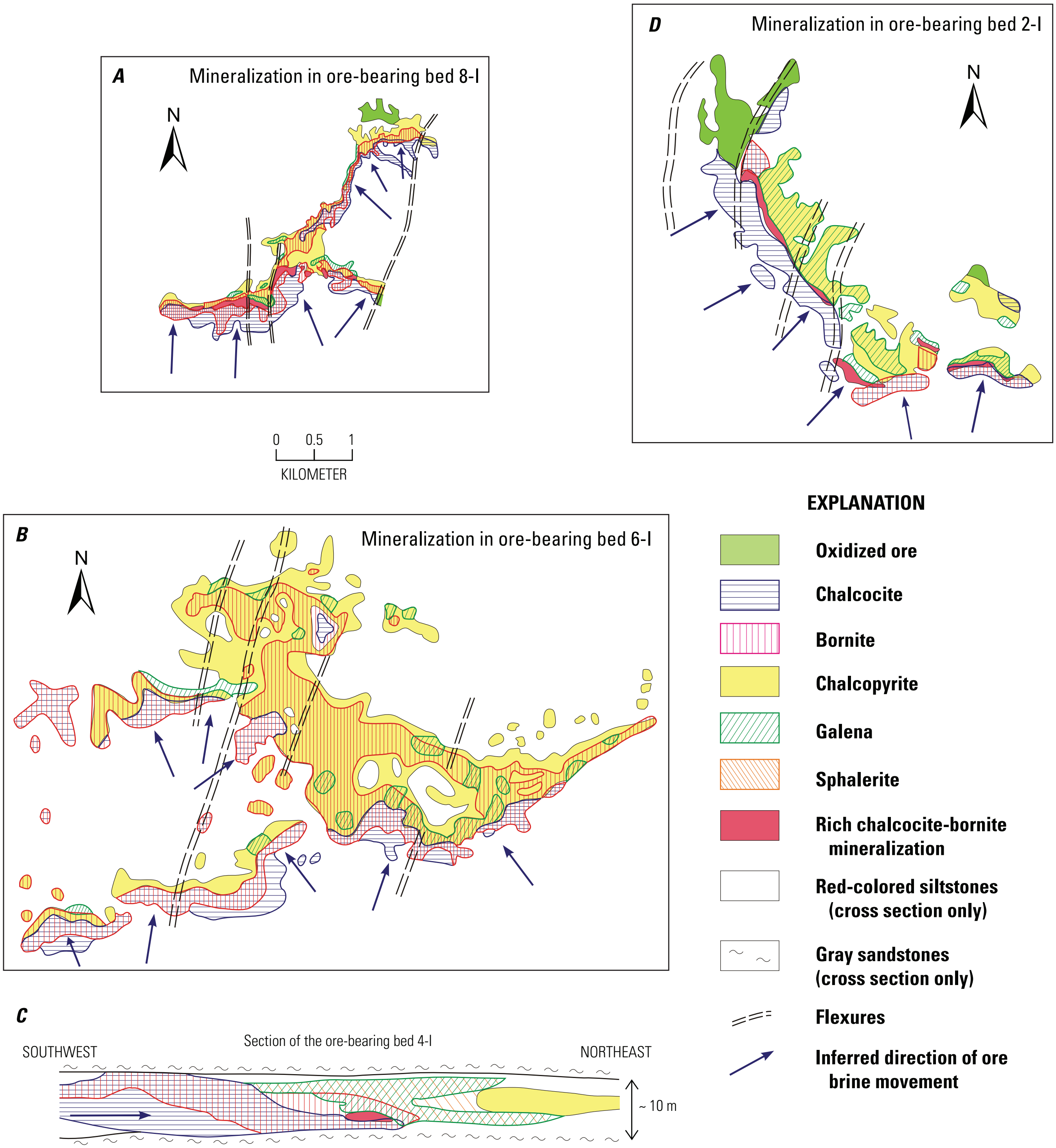


Figure 8. Mineralogical zoning of selected ore bodies of the Dzhezkazgan sandstone copper deposit, central Kazakhstan (from Daukeev and others, 2004). Scale for *A*, *B*, and *D* shown in *A*; scale of cross section in *C* shown on side (no vertical exaggeration). *A*, plan view of ore bodies within ore-bearing member 8-I; *B*, plan view of ore bodies within ore-bearing member 6-I; *C*, southwest-northeast cross section for 10-meter-thick ore body within ore-bearing member 4-I; and *D*, plan view of ore bodies within ore-bearing member 2-I. Arrows show inferred direction of ore-brine movement leading to sequential copper mineral precipitation from chalcocite to bornite to chalcopyrite as the oxidized fluid is gradually reduced by interaction with an inferred natural gas reductant within the sandstone beds. The geometry of mineralogical zones of ore body 4-1, which typically dips 10–15 degrees to the southwest, suggests that the oxidized ore brine interacted with the underside of the overlying natural gas reductant.

(obtained after the assessment was completed; Box and others, in press) indicate that mineralization at Dzhezkazgan took place at about the Pennsylvanian-Permian boundary. Maturation of hydrocarbon sources and migration of natural gas into F1 anticlinal crests occurred prior to development of F2 folds and prior to mineralization. Either dissolution of underlying Upper Devonian evaporitic salts or descent of evolved brines residual from earliest Permian evaporite deposition was responsible for development of the chloride-rich brines which evolved into the ore-bearing solutions. The thickest Lower Permian salt accumulation (>1,000 m) defines a northeast-elongate trough straddling the boundary between the northern parts of the Kokpansor and Tesbulak sub-basins (fig. 1; Zharkov, 1984), equidistant between the Dzhezkazgan and Zhaman-Aibat deposits (fig. 9). Groundwater-brine circulation occurred within the red bed strata within the basin and upflow of the dense brines was guided by structural troughs. Ore bodies formed where these troughs guided dense ore brines upward into anticlinal gas accumulations.

The Permian lacustrine-evaporitic strata above and Mississippian reduced marine shale below the Pennsylvanian red bed strata (fig. 2) acted as seals to trap brine circulation within the red bed strata, extracting copper sorbed on the iron oxides and resulting in elevated dissolved copper concentrations in the brines (Rose, 1976). The onset of north-trending F2 folding allowed the brines to migrate into the developing Dzhezkazgan sub-basin across the sagging saddle in the Kingir Anticline, within which natural gas previously had been trapped. Interaction within the Pennsylvanian strata of these dense copper-bearing brines with the underside of natural gas accumulations in the anticlinal culmination resulted in pore-space precipitation of the copper from solution and development of the sandstone copper deposits.

Assessment Methodology

For this mineral resource assessment, an assessment team (appendix A) was selected whose members' expertise includes the origins of ore deposits in general and of this deposit type in particular, the regional geology and exploration history of the assessed area, and the methodology of assessments of undiscovered mineral resources. The best available geological, geochemical, and geophysical data were integrated with the mineral deposit models. These data and the ideas of the assessment team, based on their experience, were combined to make predictions of the size and distribution of the undiscovered mineral resources of the area. The result is a probabilistic quantitative assessment of undiscovered copper, byproduct silver, and mineralized rock in sandstone host strata in the Chu-Sarysu Basin in central Kazakhstan.

The team used a three-part approach to mineral resource assessment (Singer, 1993) in which:

1. An area was delineated in which the geology would permit sandstone copper deposits to occur, and that area was subdivided into tracts based on geologic features that influence the favorability for the occurrence of this type mineral deposit; four such tracts were identified in the Chu-Sarysu Basin (fig. 9).
2. The grades and tonnages of known deposits in this basin (*n*=7) were compared with global grade and tonnage models for this deposit type (*n*=70; appendix F) to determine whether the deposits in the Chu-Sarysu Basin are statistically consistent with the global population of sandstone copper deposits. It was determined that the Chu-Sarysu deposits cannot be distinguished statistically from other deposits included in the model.
3. After considering the geologic information available for each tract, the team of experts made probabilistic estimates of the number of undiscovered deposits for each tract consistent with the grade and tonnage models.

A Monte Carlo simulation program [Economic Mineral Resource Simulator (EMINERS)] was used to combine the probability distributions of the estimated number of undiscovered deposits with the distributions of grades and the tonnages of the selected model to obtain the probability distributions of undiscovered metals in each tract (Root and others, 1992; Duval, 2012; Bawiec and Spanski, 2012).

Assessment Data

Specific information used to support this assessment can be found in Syusyura and others (2010); the file names of the maps and data from Syusyura and others (2010) referred to in this assessment are listed in table 1.

The assessment team utilized geologic maps at a variety of scales, most of which were published by the Soviet Union prior to 1991. The usefulness of these maps was limited by extensive cover of geologically younger units. Of considerable use was a geologic map of the northern two-thirds of the basin with Mesozoic and younger strata removed (CS-NCS_pre-Mz-geolmap.jpg; Syusyura and others, 2010). This map was compiled by Kazakhstani geologists based on a Soviet uranium exploration program that drilled holes throughout the basin with 1 km spacing down to Paleozoic rocks beneath the Mesozoic unconformity. Also included in Syusyura and others (2010) are other maps and information (data layers) used extensively in the assessment, including structure contour maps, mineral occurrence databases, drill hole lithologic logs, geophysical maps, soil geochemical maps, locations of producing gas fields, and other layers.

Grades and tonnages of known deposits in the Chu-Sarysu Basin are shown in table 2. The locations and brief descriptions of all known occurrences are given in appendixes B through E. Descriptions of the known deposits were found in the published literature (mostly in Russian), as well as in

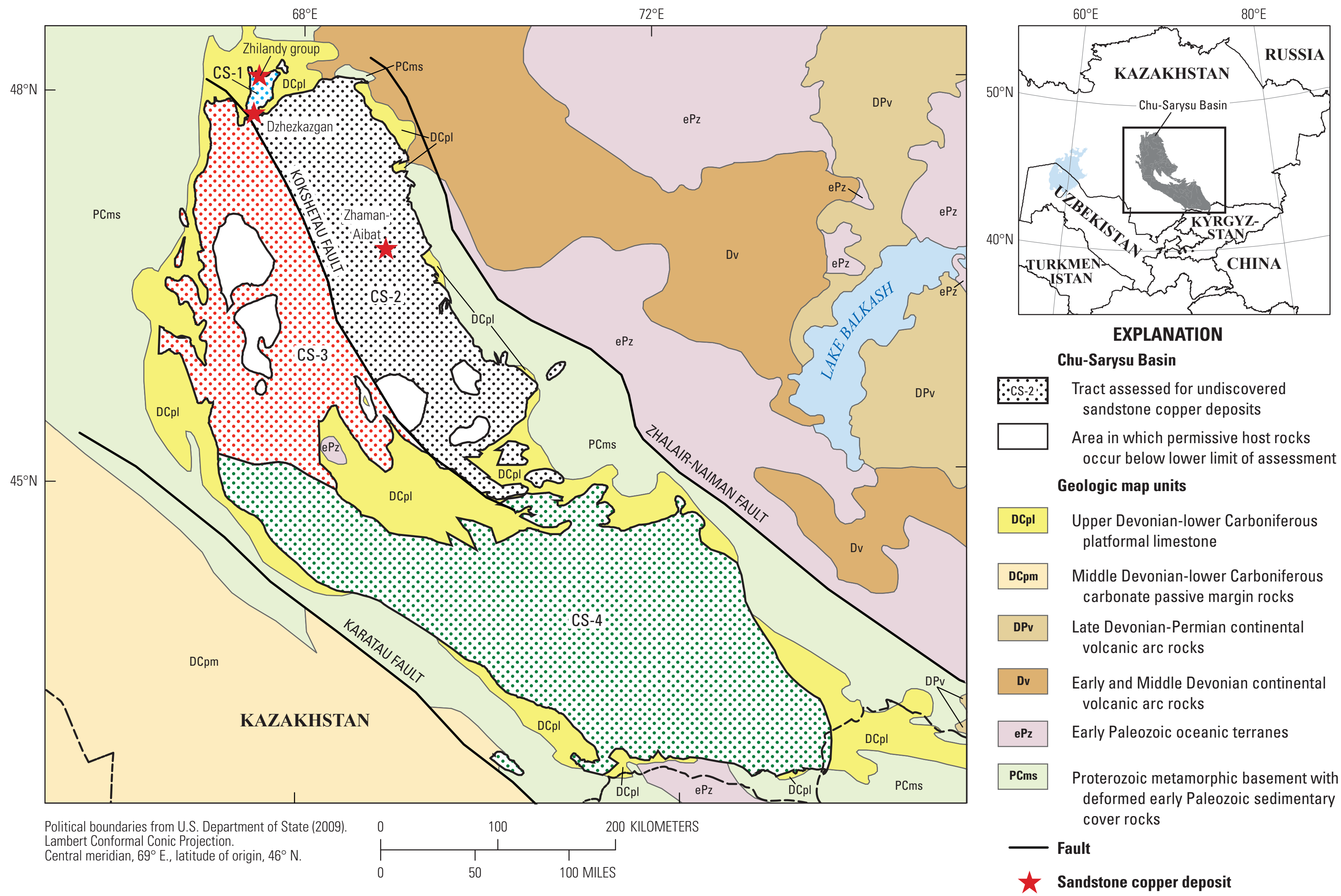


Figure 9. Tracts within the Chu-Sarysu Basin, central Kazakhstan, assessed for undiscovered sandstone copper deposits. Geologic map as in figure 1. Approximate locations of known sandstone copper deposits (Dzhezkazgan, Zhaman-Aibat) and a group of deposits (Zhilandy group) shown by red stars.

Table 1. Maps and digital data from Syusyura and others (2010) used to support the assessment of the Chu-Sarysu Basin, central Kazakhstan.

File name	Brief description of the information
CS_elev-base-mCarbonif.jpg	Structure contour map showing the elevation of the base of middle Carboniferous strata and locations of known natural gas fields in the Chu-Sarysu Basin.
CS_elev-base-Perm-salt.jpg	Structure contour map showing the elevation of the base of Permian salt and locations of known natural gas fields in the Chu-Sarysu Basin.
CS_seisprofile-borehmap.jpg	Map showing locations of seismic profiles and associated boreholes for the Chu-Sarysu Basin.
CS-ZA_strat-columns.jpg	Stratigraphic columns for boreholes in the area of the Zhaman-Aibat copper deposit in northern Chu-Sarysu Basin.
CS_boreholes-all.shp	All available borehole locations within the Chu-Sarysu Basin.
CS-DZ_geolmap.tif	Geologic map (no explanation) of the Dzhezkazgan sub-basin of the Chu-Sarysu Basin and surrounding area.
CS-DZ_minzonation.jpg	Map of metallic mineral zonations around the known sandstone-hosted copper ore bodies within the Dzhezkazgan sub-basin and nearby areas of the Chu-Sarysu Basin.
CS-IR_mineral-leaching.shp	Isolines of mineral leaching yield inferred from gravity measurements in the Irkuduk area of the west-central Chu-Sarysu Basin.
CS-KU_Cu-geochem-halos.shp	Copper geochemical halos from surficial sampling in the Kumola area of the northwestern Chu-Sarysu Basin.
CS-NCS_deps-occurrences.shp	Copper and other metal occurrences and deposits from northern part of Chu-Sarysu Basin.
CS-NCS_gravity-residual.jpg	Residual gravity anomalies (upward continued) for the northern part of the Chu-Sarysu Basin.
CS-NCS_mag-intensity.jpg	Contoured magnetic-intensity map for the northern Chu-Sarysu Basin.
CS-NCS_ne-strat-columns.jpg	Stratigraphic columns for boreholes in northeast part of northern Chu-Sarysu Basin.
CS-NCS_pre-Mz-geolmap.jpg	Sub-Mesozoic unconformity geologic map of the northern two-thirds of the Chu-Sarysu Basin, showing copper deposits and other features prospective for undiscovered deposits.
CS-WCS-KY_soilCu-anom.shp	Soil copper anomalies in the Dyusembay-Kyzylkak area in the western part of the northern Chu-Sarysu Basin.
CS-ZA_strat-columns.jpg	Stratigraphic columns for boreholes in the area of the Zhaman-Aibat copper deposit in northern Chu-Sarysu Basin.
CS-ZA_reserve-outlines.jpg	Map of ore-reserve areas within the Zhaman-Aibat sandstone-hosted copper deposit mine area.
CS_elev-base-Perm-salt.jpg	Structure contour map showing the elevation of the base of Permian salt and locations of known natural -gas fields in the Chu-Sarysu Basin.

Table 2. Grade and tonnage of known sandstone copper deposits, Chu-Sarysu Basin, central Kazakhstan.

[Mt, million metric tons; %, percent; ppm, parts per million; n.d., no data]

Name	Tract_ID	Latitude	Longitude	Ore tonnage (Mt)	Grade Cu (%)	Grade Ag (ppm)	Contained Cu (Mt)	Reference
Dzhezkazgan	CS-1	47.882	67.432	2,000	1.10	n.d.	22	Kirkham and Broughton, 2005
Itauz	CS-1	48.165	67.385	94.1	0.92	n.d.	0.87	Kirkham and Broughton, 2005
West Saryoba	CS-1	48.156	67.444	86.2	0.89	n.d.	0.77	Kirkham and Broughton, 2005
East Saryoba	CS-1	48.171	67.488	91.4	0.85	n.d.	0.78	Kirkham and Broughton, 2005
Kipshakpay	CS-1	48.158	67.549	38.5	0.94	n.d.	0.36	Kirkham and Broughton, 2005
Karashoshak	CS-1	48.188	67.610	8.9	1.46	n.d.	0.13	Kirkham and Broughton, 2005
Zhaman-Aibat	CS-2	46.850	68.941	161	1.69	19.1	2.72	A. Kim, Kazakhmys plc, written commun., 2009
Total				2,480	1.11		27.63	

materials obtained from the Web site of Kazakhmys, PLC. (www.kazakhmys.com), the company that currently operates the active mines in the basin. Estimates of prognostic or undiscovered resources were obtained from an unpublished 2009 report of Mining and Economic Consulting, Ltd. (MEC), of Almaty, Kazakhstan, relevant parts of which are extracted in the tract descriptions in appendixes B through E. In the ore classification system used in the former Soviet Union, prognostic resources are inferred from indirect indications (such as geochemical or geophysical data), mineral showings, or isolated sampling (Diatchkov, 1994; Jakubiak and Smakowski, 1994). The resource category of prognostic resources 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). In Diatchkov (1994) P1 resources may be adjacent to and extend beyond the limits of drill-indicated resources (“C” resources). P2 resources represent possible mineralized features in known mineral deposit or ore-bearing regions. Resources under the P3 category are any potential ore-bearing deposits based on the theoretical definition of a favorable geologic environment.

Delineation of Permissive Tracts

Based on the known occurrences of sandstone copper deposits in the Chu-Sarysu Basin, the mostly unexposed host red bed sequence (Pennsylvanian Taskuduk and Dzhezkazgan Formations) has the possibility of hosting other undiscovered deposits of this type. However, based on present and projected future economic mining depths, in this assessment the team evaluated the likelihood of undiscovered deposits of this type only where that sequence is less than 2 km below the land surface (“permissive” for minable undiscovered deposits of this type). The Pennsylvanian unit is 0.3–>1.5 km thick and is exposed discontinuously around the margin of the Chu-Sarysu Basin, dipping basinward beneath younger rocks. The combined extent of all the tracts (fig. 9) was drawn to include all areas in which the top of the host rock is less than 2 km below the surface, which is about 1 km below what presently are considered the deepest ore reserves at the Zhaman-Aibat deposit. Areas not included in the outlined tract are considered to be nonpermissive for this deposit type because either the host unit is not present, or the top of the host unit is too deep (>2 km) to be exploited economically using current technologies.

For the northern half of the basin (north of 44˚40′), the outer margin of the combined tract area is defined by the contact between unit C1—Mississippian (outside tract)—and unit C2ts—Pennsylvanian Taskuduk Suite on map CS-NCS_pre-Mz-geolmap.jpg (Syusyura and others, 2010). For the outer boundary on the west side of the basin (south of 44˚40′), the team defined the permissive tract boundary as the contact between unit C2b1—the Lower Tatarian of the Bashkir Stage (inside)—and unit C1v3-s—Visean, Upper Tatarian-Serpukhovian (outside) on the 1:1,000,000 scale pre-Quaternary geologic map of the Tashkent (K42-43) quadrangle (Klishevich and others, 1990). For the gap between the southern edge of map CS-NCS_pre-Mz-geolmap.jpg (Syusyura and others, 2010) and the northwest edge of the Tashkent (K42-43) quadrangle (Klishevich and others, 1990), the team placed the tract boundary along the line labeled “Depression border” on the map CS_elev-base-mCarbonif.jpg (Syusyura and others, 2010). For the outer boundary of the permissive tract on the east side of the basin (south of 44˚40′), the boundary is defined as the contact between unit C1n—Namyursky Suite (outside) and unit C2-3dz—Dzhezkazgan Suite (inside) on the 1:1,000,000 scale pre-Quaternary geologic map of the

Balkhash (L42-43) quadrangle (Yagovkin and others, 1978). For the area south of the southernmost exposure of unit C1 on the Balkhash map, the permissive tract boundary was placed along the line labeled “Depression border” on the map CS_elev-base-mCarbonif.jpg (Syusyura and others, 2010).

Areas within the Chu-Sarysu Basin where the top of the Pennsylvanian red bed sequence is deeper than 2 km (shown in white on fig. 9) were delineated using a structure contour map of the base of the overlying Permian salt sequence (CS_elev-base-Perm-salt.jpg; Syusyura and others, 2010). Because the surface elevation is approximately 0.35 km above sea level, the team used the –1.6 km elevation contour from map CS_elev-base-Perm-salt.jpg (Syusyura and others, 2010) to approximate the 2 km depth contour. Portions of the central area of the basin are not permissive because the Pennsylvanian strata are absent, having been eroded off a basement high beneath a late Mesozoic unconformity. The boundary of the excluded area north of 44°40′ was defined using the map CS-NCS_pre-Mz-geolmap.jpg (Syusyura and others, 2010); south of 44°40′ the boundary was defined using the map CS_elev-base-mCarbonif.jpg (Syusyura and others, 2010).

The mostly contiguous permissive area described above was subdivided into four assessment tracts (table 3, fig. 9) based on established sub-basins of the Chu-Sarysu Basin (Sinitsyn, 1991; Daukeev and others, 2004). Tract CS-1 (Dzhezkazgan sub-basin) extends northward from the larger Chu-Sarysu Basin and narrows across the Kingir Anticline at the junction of the sub-basin with the main basin. The southern tract boundary was placed along the southeastern flank of the Kingir Anticline along and extending parallel from the southeastern-most east-northeast-trending faults on the map CS-DZ_geolmap.tif (Syusyura and others, 2010). Tract CS-2 encompasses the Tesbulak sub-basin and is separated from the Kokpansor sub-basin to the west (tract CS-3) by the down-to-the-east Kokshetau Fault. Tract CS-4 in the southern half of the Chu-Sarysu Basin encompasses the Muyunkum sub-basin. It is separated physically from tract CS-2 because of erosion of the Pennsylvanian strata along the Chu uplift. The boundary between tracts CS-3 and CS-4 is the north flank of the Buguldzhy uplift, where the western continuation of the Arady Fault (fig. 1) trends into the 2-km-below-sea-level contour of the base of the Pennsylvanian strata (CS-NCS_depth-base-mCarbonif.mxd; Syusyura and others, 2010). Descriptions of each tract, its mineral deposits and prospects, and the estimate of and rationale for the number of undiscovered deposits are given in appendixes B through E.

Selection of Grade and Tonnage Model for Resource Assessment

As discussed in a previous section, all of the significant deposits and most of the occurrences in the Chu-Sarysu Basin are classified, based on their geologic characteristics, as the sandstone subtype of sediment-hosted copper deposits. Sandstone copper deposits occur in coarser grained, typically siliciclastic sedimentary rocks, such as sandstone, arenite, arkose, or quartzite. The organic reductant in these rocks was petroleum vapor or fluids that accumulated in structural or stratigraphic traps within a reservoir rock. Where observed, the organic material in the sandstone subtype deposits is “dead oil” or pyrobitumen. Red bed subtype deposits also occur in coarser grained, typically siliciclastic, sedimentary rocks; however, the organic reductant is carbonized terrestrial plant matter. Red bed subtype deposits commonly occur in Devonian or younger fluvial sandstone or conglomerate within the Chu-Sarysu Basin. One small mined deposit (Taskora; appendix C) is a reduced facies subtype deposit, and a few of the small copper occurrences in the basin are classified either as reduced facies or red bed subtype (appendixes B through E).

To estimate the amount of undiscovered resources quantitatively, grade and tonnage models must be constructed that can serve as analogs for undiscovered deposits of a given type. At the time of this assessment, the team identified 70 sandstone copper deposits worldwide for which tonnage and grade are reported; however, exploratory data analysis showed that these deposits did not form a coherent population. The team examined the deposits and decided to limit the comparison group to include only those that were thoroughly explored and had similar cutoff grades. Deposits with less than 50,000 t of contained copper were excluded from the model because the sites probably were underexplored or were small volumes of mineralized rock that would not be evaluated or explored given current economic conditions. Some sites in Africa were excluded because they are supergene-enriched deposits and were evaluated with a high cutoff grade. Conversely, some sites in North America were excluded because the reported cutoff grades were much lower than reported elsewhere. Using these strategies, 70 deposits, seven from the Chu-Sarysu Basin and 63 from other locations, were selected to model undiscovered sandstone copper resources in this assessment (appendix F). Student’s *t*-tests indicate that the deposits in the Chu-Sarysu Basin are not statistically different in grade and tonnage characteristics from other sandstone copper deposits.

Results of Probabilistic Assessments of Permissive Tracts

The assessment team evaluated the available data and made individual subjective estimates of the numbers of undiscovered deposits in each tract by using expert judgment. After compilation, the individual estimates were discussed by the team and a consensus estimate was agreed upon for each tract. The rationales for the estimates for each tract are presented in appendixes B through E.

Table 3. Permissive tracts for the assessment of undiscovered sandstone copper deposits, Chu-Sarysu Basin, central Kazakhstan.

[km^2, square kilometers]

User_ID	Tract name	Coded_ID	Tract area (km^2)	Permissive tract description and fundamental unit
CS-1	Dzhezkazgan sub-basin	142ssCu8001	753	Structural sub-basin extending north from the main body of the Chu-Sarysu Basin, upper Carboniferous nonmarine alluvial clastic sequence (red beds): Dzhezkazgan and Taskuduk Formations.
CS-2	Tesbulak sub-basin	142ssCu8002	31,680	Northeastern structural sub-basin of the Chu-Sarysu Basin, upper Carboniferous nonmarine alluvial clastic sequence (red beds): Dzhezkazgan and Taskuduk Formations.
CS-3	Kokpansor sub-basin	142ssCu8003	28,226	Northwestern structural sub-basin of the Chu-Sarysu Basin, upper Carboniferous nonmarine alluvial clastic sequence (red beds): Dzhezkazgan and Taskuduk Formations.
CS-4	Muyunkum sub-basin	142ssCu8004	64,855	Southern structural sub-basin of the Chu-Sarysu Basin, upper Carboniferous nonmarine alluvial clastic sequence (red beds): Dzhezkazgan and Taskuduk Formations.

In some cases, extensive drill evaluation of significant prospects has occurred, and this information was used to guide the estimates at the 90th and 50th percentiles. Drilling encountered some anticlinal areas in which initially oxidized red beds have been converted to reduced gray strata. This transformation was interpreted to identify horizons in which there were accumulations of natural gas, an important reductant that could have localized precipitation of ore minerals from migrating oxidized ore brines. Copper intercepts in drill holes also were interpreted as favorable indicators of migrating ore brines. Copper enrichments in soil and secondary sodium minerals at the surface (Beyseyev, 1967) also were considered as favorable indicators of the former presence of mineralizing brines. The presence of producing natural gas fields, either within or below the prospective ore horizon, also was considered to be a favorable indicator for the past presence of this important ore reductant.

During the assessment meeting, estimates of undiscovered deposits were made for 15 areas in the Chu-Sarysu Basin. Most of these are areas where detailed maps and other exploration information were compiled by MEC (Syusyura and others, 2010). These areas of focused study correspond to structural traps where copper mineralization might be expected. This strategy allowed the team to assess all the prospective areas in the basin systematically and to make separate estimates for areas with little exploration information.

When the individual assessments were complete, the results for the 15 areas were aggregated statistically for each of the four tracts (sub-basins) described above. The algorithms described by Root and others (1992) were used to convert percentile estimates made by the assessment team into a probability distribution function for undiscovered deposits. Geologists in the assessment team thought that there would be some level of correlation between the areas that were assessed, because the areas occur in the same sub-basin and (or) lie along the same fold or fault structure. As a result, the probability distribution functions could not be combined assuming either total independence or total dependence. Pair-wise correlations were specified for the assessed areas, and the deposit estimates were aggregated statistically (Schuenemeyer and others, 2011). The aggregated deposit estimates for each tract were used as input for Monte Carlo simulation.

Consensus estimates of the number of undiscovered deposits for each tract are presented in table 4, along with statistics that describe the mean expected number of undiscovered deposits, the standard deviation and coefficient of variation associated with the estimate, the number of known deposits, and the implied deposit density within each tract. The team estimated a mean expected total of 26 undiscovered sandstone copper deposits in all tracts, or 3.7 times as many as the seven known deposits. Note that the implied deposit densities range widely between tracts (from 0.3 to 147 deposits per 10,000 km^2), and deposit density is roughly inverse to the size of the tract and to the coefficient of variation of the estimate. Tract CS-1 is the most well-endowed tract, containing six of the seven known deposits in the Chu-Sarysu Basin, and its small size and maturity of exploration history give it the smallest coefficient of variation. Tracts CS-2 and CS-3 have smaller suggested deposit densities, similar to each other; the more intensive exploration history in tract CS-2 leads to its smaller coefficient of variation. The order-of-magnitude smaller deposit density estimated for tract CS-4 reflects the few known prospects there and the lack of significant mineral exploration. However the high coefficient of variation indicates the large uncertainty about the endowment of this tract, even though all indicators of mineralizing conditions are known to be present.

Table 4. Estimates of number of undiscovered sandstone copper deposits, Chu-Sarysu Basin, central Kazakhstan.

[N_{xx}, estimated number of deposits at the xxth percentile confidence; N_{und}, expected number of undiscovered deposits; s, standard deviation; $C_v\%$, coefficient of variance, in percent; N_{known}, number of known deposits that have identified resources within the tract; N_{total}, total of expected number of deposits plus knowndeposits; tract area, area of permissive tract in square kilometers; deposit density, reported as the total number of deposits per 10,000 square kilometers; N_{und}, s, and $C_v\%$ are calculated using a regression equation (Singer and Menzie, 2005)]

User_ID	Tract name	Coded_ID	Consensus undiscovered deposit estimate						Summary statistics				Tract area (km²)	Deposit density
			N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	$C_v\%$	N_{known}	N_{total}		
CS-1	Dzhezkazgan sub-basin	142ssCu8001	3	5	8	8	8	5.1	2.0	39	6	11.1	753	147
CS-2	Tesbulak sub-basin	142ssCu8002	5	10	16	18	22	10.3	4.5	43	1	11.3	31,681	3.6
CS-3	Kokpansor sub-basin	142ssCu8003	3	7	15	18	24	8.4	5.8	69	0	8.4	28,227	3.0
CS-4	Muyunkum sub-basin	142ssCu8004	0	1	5	7	10	2.1	2.7	130	0	2.1	64,856	0.3
Total								25.9			7		125,517	

Results of the Monte Carlo Simulation of Contained Metal

Simulation results for each tract are listed in tables of the individual tract descriptions (appendixes B through E). Results are reported at selected quantile intervals, along with the mean expected amount of metal, the probability of the mean, and the probability of no metal. The amount of metal reported at each quantile represents the minimum amount of metal expected. The quantile results represent ranked data from the 4,999 Monte Carlo simulations. The quantiles are linked to each tract simulation and, therefore, are not additive. Mean estimates, however, can be added to obtain total estimated amounts of metal and mineralized rock in undiscovered deposits. The mean estimates for undiscovered metal in the Chu-Sarysu Basin are 25.1 Mt of copper and 21,900 t of silver in 2,220 Mt of ore. Mean results for each tract are listed in table 5. For tracts CS-1, CS-2, and CS-3, there is about a 30 percent chance that the copper contained in undiscovered resources is equal to or greater than the mean amount of copper shown in table 5; for tract CS-4, there is about an 18 percent chance. The probability of no deposits with copper endowment is small (2–3 percent) for tracts CS-1, CS-2, and CS-3, and is distinctly larger (29 percent) for tract CS-4.

Identified resources in known deposits within each tract also are listed in table 5, on the basis of data reported for individual deposits (table 2). These identified resources are based on total past production and published data for measured and indicated reserves and resources at the lowest cutoff grade reported. Tract CS-1, the Dzhezkazgan sub-basin, contains 90 percent of the identified resources with its six known deposits. The Zhaman-Aibat deposit in tract CS-2, about 150 km southeast of the Dzhezkazgan sub-basin, is significant in that its discovery in the 1980s showed that deposits were not limited to the Dzhezkazgan sub-basin.

Resource estimates for undiscovered deposits are compared with identified resources by tract and in total in table 5 and are illustrated in figure 10. Tract CS-1 is inferred to have more than 40 percent of the copper endowment of the Chu-Sarysu Basin, roughly two-thirds of which has been identified. Tract CS-2 is inferred to hold about 30 percent of the copper endowment, of which only one-tenth has been identified. Tracts CS-3 and CS-4 are estimated to contain more than 20 percent and about 5 percent, respectively, of the total copper endowment of the Chu-Sarysu Basin, none of which has been identified. For the entire Chu-Sarysu Basin, the total copper endowment is inferred to be about 53 Mt of Cu, of which a little over one-half has been identified.

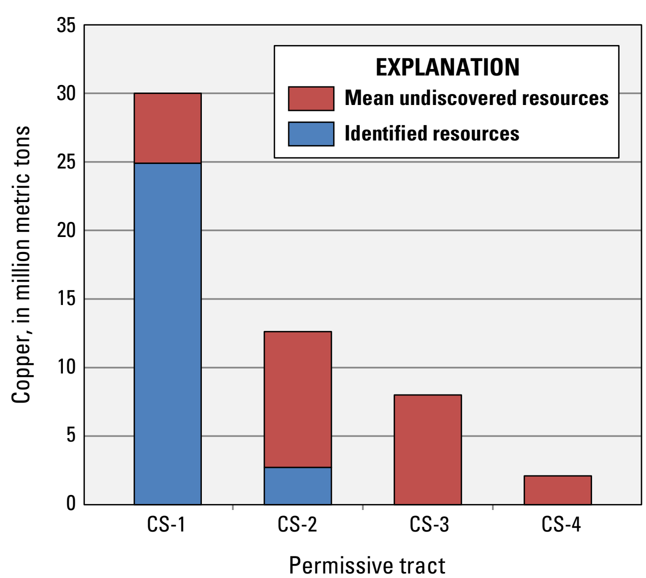


Figure 10. Copper endowment (in millions of metric tons copper) within the Chu-Sarysu Basin, central Kazakhstan, by tract, separated into identified resources (based on total past production and published data for measured and indicated reserves and resources at the lowest cutoff grade reported) and mean undiscovered resources as estimated in this report.

Table 5. Summary of mean expected amounts of undiscovered resources and of identified resources in each sandstone copper deposit assessment tract, Chu-Sarysu Basin, central Kazakhstan.

[Mean, arithmetic mean of Monte Carlo simulation results; Mt, million metric tons; t, metric tons; %, percent]

User_ID	Tract name	Coded_ID	Mean expected amounts			Identified resources			Cu endowment (% of total)
			Cu (t)	Ag (t)	Rock (Mt)	Cu (t)	Ag (t)	Rock (Mt)	
CS-1	Dzhezkazgan sub-basin	142ssCu8001	5,100,000	4,300	450	24,910,000	unknown	2,319	57
CS-2	Tesbulak sub-basin	142ssCu8002	9,900,000	8,500	870	2,720,000	308	161	24
CS-3	Kokpansor sub-basin	142ssCu8003	8,000,000	7,300	710	0	0	0	15
CS-4	Muyunkum sub-basin	142ssCu8004	2,100,000	1,800	190	0	0	0	4
Total			25,100,000	21,900	2,220	27,630,000		2,480	

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Appendixes A–G

Appendix A. Assessment Team

Stephen E. Box, Research Geologist, USGS, Spokane, Washington. Box has done field and laboratory research in mining districts in Alaska and the western United States and has been involved in mineral resource assessments there as well. He has participated in assessments for undiscovered sediment-hosted stratiform copper deposits in the Proterozoic Belt Basin of Montana, the Permian Kupferschiefer Basin of Poland and Germany, and the Early Proterozoic Udokan Basin in Russia.

Vladimir Chechetkin, Geologist, Russian Geological Society (RosGeo), Chita, Russia. Chechetkin directed exploration activities for sandstone-hosted copper deposits in the Kodar-Udokan region of Russia for many years.

Pamela M. Cossette, Geologist, USGS, Spokane, Wash. She received her degree in geology from Eastern Washington University. She is a GIS specialist.

Alla Dolgopolova, Researcher in Economic and Environmental Mineralogy, Mineralogy Department, Natural History Museum, London, United Kingdom. Dolgopolova works on mineral deposit research studies related to consultancy projects in Kazakhstan, Kyrgyzstan, Uzbekistan, Mongolia, and Russia. She participates in an industry-funded project titled “Metallogeny of the Altaids in central Asia” where her research focus is on isotope mapping as a tool in exploration targeting.

Timothy S. Hayes, Research Geologist, USGS, Tucson, Arizona. Hayes has researched (partly in private industry) red bed-associated stratabound copper deposits in the Belt Basin of Montana; in Permian rocks in Oklahoma; and in the Ablah Group, Saudi Arabia. He is principal author of the USGS descriptive model for red bed-associated stratabound copper deposits. He has participated in assessments for undiscovered deposits in the Kupferschiefer Basin of central Europe, the Udokan Basin in Russia, and the Central African Copper Belt.

Murray W. Hitzman, Charles Fogarty Professor of Economic Geology, Colorado School of Mines, Golden, Colorado. Hitzman has written numerous papers on sedimentary rock-hosted stratiform copper deposits. He has been involved in research on this deposit type in the African Copper belt during the past decade and has worked with graduate students on similar deposits worldwide.

Reimar Seltmann, Director, Centre for Russian and Central EurAsian Mineral Studies (CERCAMS) at the Natural History Museum, London, United Kingdom. Seltmann is an economic geologist focused on mineral deposit case studies related mainly to ore-bearing granitoids and metallogeny of central Asia. He coordinates an industry-funded research network “Metallogeny of the Altaids: Terrane reconstructions leading to new target regions,” where he contributed research on ore deposits, including Oyu Tolgoi, Almalyk, Dzhezkazgan, and Udokan. He has produced a number of original research papers, monographs, metallogenic maps, and reference guidebooks on metal provinces of the former Soviet Union, Mongolia, and China.

Boris Syusyura, Geologist, Mining and Economic Consulting Ltd., Almaty, Kazakhstan. Syusyura has done extensive research on the sandstone-hosted deposits and host rock strata within the Chu-Sarysu Basin since the early 1980s.

Cliff D. Taylor, Research Geologist, USGS, Denver, Colo. Taylor is an economic geologist with expertise in volcanogenic massive sulfide deposits. He led the USGS mineral resource assessment of sediment-hosted copper in the Central African Copper Belt.

John C. Wallis, Geographic Information System (GIS) specialist**,** USGS, Spokane, Wash. He received a degree in geology from Eastern Washington University.

Michael L. Zientek, Research Geologist, USGS, Spokane, Wash. Zientek is an economic geologist with expertise in magmatic ore deposits and mineral resource assessment. He is co-chief of the USGS Global Mineral Resource Assessment Project and is coordinating the assessment of sediment-hosted copper deposits in the Udokan region of Russia.

Appendix B. Sandstone Copper Assessment for Tract 142ssCu8001 (CS-1), Central Kazakhstan

By Stephen E. Box[1], Alla Dolgopolova[2], Timothy S. Hayes[1], Murray W. Hitzman[3], Reimar Seltmann[2], Boris Syusyura[4], Cliff D. Taylor[1], and Michael L. Zientek[1]

Deposit Type Assessed

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

Table B1. Summary of selected resource assessment results for tract 142ssCu8001 (CS-1), central Kazakhstan.

[km, kilometers; km², square kilometers; t, metric tons]

Date of assessment	Assessment depth (km)	Tract area (km²)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
October 2009	2	753	24,910,000	5,100,000	1,700,000

Location

Central Kazakhstan, about 450 km southwest of the capital city of Astana (fig. B1).

Geologic Feature Assessed

Pennsylvanian strata within the Dzhezkazgan sub-basin of the Upper Devonian-Upper Permian Chu-Sarysu Basin, Kazakhstan.

[1]U.S. Geological Survey.

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

[3]Colorado School of Mines, Golden, Colorado.

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

Delineation of the Permissive Tract

Geologic Criteria

Tract CS-1 (fig. B1) is drawn to include the Dzhezkazgan deposit and all of the Dzhezkazgan and Taskuduk Formations in the Dzhezkazgan sub-basin, a structural down warp extending northward from the broader Chu-Sarysu Basin (fig. 1). The Dzhezkazgan sub-basin is localized along the north-south Dzhezkazgan Syncline (fig. 3*A*). This sub-basin is separated from greater Chu-Sarysu depression by the east-northeast-trending Kingir Anticline. The host units are shallower than 2 km within this sub-basin (Syusyura and others, 2010).

The outer margin of tract CS-1 is defined by the contact between the Mississippian (unit C1), which is outside the tract, and the Pennsylvanian Taskuduk Suite (unit C2ts) on map CS-NCS_pre-Mz-geolmap.jpg (Syusyura and others, 2010). The tract extends northward from the larger Chu-Sarysu Basin and narrows across the Kingir Anticline at the junction of the sub-basin with the main basin. The southern boundary was placed along the southeastern flank of the Kingir Anticline, extending parallel from the southeastern-most east-northeast-trending faults on the map CS-DZ_geolmap.tif (Syusyura and others, 2010).

Known Deposits

Six sandstone copper deposits are known in tract CS-1, including the giant Dzhezkazgan deposit and the smaller but still significant deposits of the Zhilandy group: Itauz, West Saryoba, East Saryoba, Kipshakpay, and Karashoshak (fig. B1, table B2). The giant Dzhezkazgan sediment-hosted copper deposit is localized along the Kingir Anticline, where it is crossed by the Dzhezkazgan Syncline (fig. 3*A*). The five deposits of the Zhilandy group occur along an east-northeast trend on the northern flank of the Dzhezkazgan sub-basin, apparently along an unnamed east-northeast trending anticline. The three westernmost deposits (Itauz, West Saryoba, and East Saryoba) are elongate north-south along synclines that extend northward from the Dzhezkazgan Syncline and cross the east-northeast trending Zhilandy Anticline. The two easternmost deposits (Kipshakpay and Karashoshak) are elongate to the east-northeast on the southeast flank of the same unnamed anticline that faces into the Dzhezkazgan sub-basin.

The Zhilandy group deposits and the Dzhezkazgan deposit are localized within northern and southern anticlinal areas, respectively, where the oxidized, red-colored sandstone-siltstone-shale sequence of the Dzhezkazgan and Taskuduk Formations has been altered by reduction to a section of gray-colored sandstone beds interbedded with red-colored siltstone-shale. These alteration trends are interpreted to have resulted from entrapment of natural gas deposits within the permeable sandstone beds in the crestal portions of the east-northeast trending anticlines (Gablina, 1981). Interaction of these natural gas deposits with oxidized metal-bearing brines resulted in deposition of copper and other metals as solid sulfides in the zone of interaction. Mineral zonation of the southern part of the Dzhezkazgan deposit (Daukeev and others, 2004) indicates the mineralizing brines flowed from the south out of the larger and deeper Chu-Sarysu Basin into the Dzhezkazgan sub-basin. These brines entered the Dzhezkazgan sub-basin across the structural low area of the Kingir Anticline (Gablina, 1997). The brines flowed northward within the Dzhezkazgan and Taskuduk Formations across the anticlinal low, interacting with the flat bottom of the overlying natural gas deposit before proceeding northward into the Dzhezkazgan sub-basin. Similarly, the Zhilandy group of deposits record the northward and upward movement of the dense brines within the Dzhezkazgan and Taskuduk Formations along south-plunging synclines crossing the east-northeast trending northern anticlinorium, which hosted the pre-existing natural gas deposit (as indicated by the trend of the reduced-iron alteration area). Ore deposition was strongly controlled by structural features: first, by the east-northeast trending anticlines that trapped the natural gas deposits, and second, by the north-south trending synclines that provided low spots across the anticlines which were utilized by the migrating dense metal-bearing brines (Box and others, in press).

Prospects and Mineral Occurrences

The moderately well-explored Zhartas (Sorkuduk) prospect occurs to the northeast of the Dzhezkazgan deposit on the northwestern flank of the Kingir Anticline, where it is crossed by a northwest-trending syncline. The mineralization at this prospect is similar in style to that at Dzhezkazgan, although of significantly smaller size and with a narrower mineralized stratigraphic interval. A southern extension of West Saryoba also has been drilled extensively and is considered to hold significant prognostic resources. Deeper extensions of Itauz and other prospects southward (Kokdombak) and northward (Donyzaus) along the steep west basin flank have high potential for representing an undiscovered deposit, as do several prospects (Pektas 1, Pektas 2) that occur along the gently dipping east side of the sub-basin. The Taskuduk prospect of deeper occurrences of the mineralization band around the north side of the Kingir Anticline between Zhartas and Dzhezkazgan (figs. 3*A*, 3*B*, B1) also are highly prospective. A mining industry group in Kazakhstan estimated prognostic resources (Diatchkov, 1994) of 1.05 Mt Cu in P1-P3 categories down to 1.5 km within the Dzhezkazgan sub-basin (MEC, written commun., 2009).

Exploration History

The area is part of the concession owned by Kazakhmys, which operates the Dzhezkazgan Mine and manages exploration in the rest of the tract. The Dzhezkazgan deposit has been mined since ancient times, and the modern mine complex is

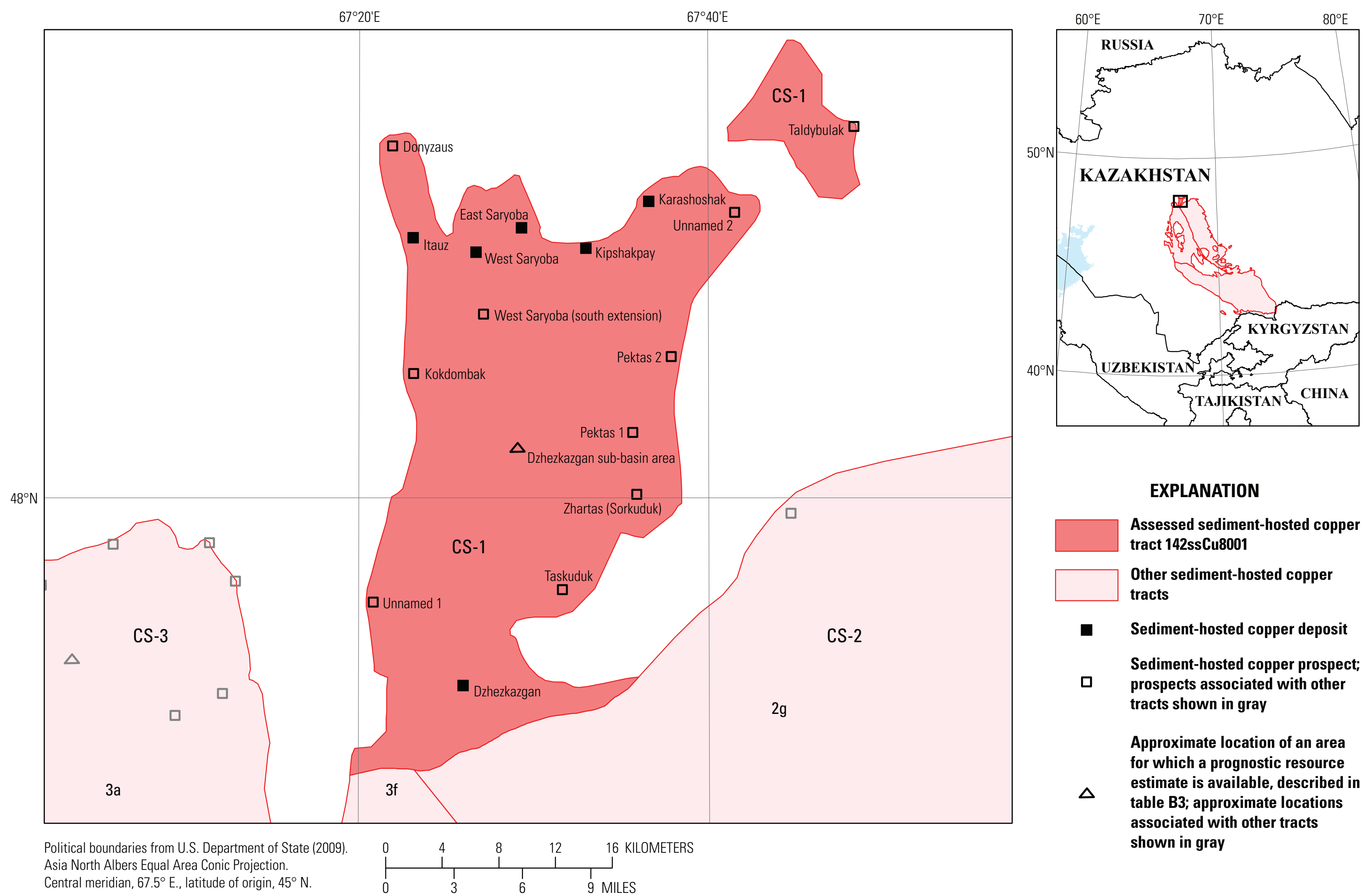

Figure B1. Location map for tract 142ssCu8001 (CS-1) and its known deposits and prospects, central Kazakhstan.

Table B2. Known sandstone copper deposits in tract 142ssCu8001 (CS-1), central Kazakhstan.

[Mt, million metric tons. Contained Cu is computed as tonnage (Mt) × Cu grade (%)/100]

Name	Latitude	Longitude	Tonnage (Mt)	Cu Grade (%)	Contain Cu (Mt)
Dzhezkazgan	47.882	67.432	2,000	1.1	22
Itauz	48.165	67.385	94.1	0.92	0.87
West Saryoba	48.156	67.444	86.2	0.89	0.77
East Saryoba	48.171	67.488	91.4	0.85	0.78
Kipshakpay	48.158	67.549	38.5	0.94	0.36
Karashoshak	48.188	67.610	8.9	1.46	0.13

Table B3. Significant prospects, occurrences, and areas with prognostic resource estimates in tract 142ssCu8001 (CS-1), central Kazakhstan.

[For the Dzhezkazgan sub-basin prognostic-resource-estimate area, latitude and longitude are provided for the centroid of the area. km^2, square kilometers; Mt, million metric tons]

Name	Latitude	Longitude	Comments
Dzhezkazgan sub-basin area	48.030	67.484	128 km^2 area estimated by Mining and Economic Consulting, Ltd., (written commun., 2009) to possess 1.05 Mt Cu in prognostic resource categories P1, P2, and P3.
Zhartas (Sorkuduk)	48.003	67.598	Dzhezkazgan and Taskuduk Formations
West Saryoba (south extension)	48.117	67.452	Taskuduk Formation
Taldybulak	48.235	67.806	Taskuduk Formation
Donyzaus	48.223	67.365	Taskuduk Formation
Kokdombak	48.079	67.385	Taskuduk Formation
Pektas l	48.042	67.594	Taskuduk Formation
Pektas 2	48.090	67.631	Reduced-facies Cu shale
Taskuduk	47.943	67.527	Dzhezkazgan and Taskuduk Formations
Unnamed 1	47.935	67.347	Taskuduk Formation
Unnamed 2	48.181	67.692	Dzhezkazgan and Taskuduk Formations

more than 100 years old. Exploration has been intense in the immediate mine area and in areas adjacent to the deposits of the Zhilandy group along the northern margin of the sub-basin. More than 130 drill holes occur within the tract outside the Dzhezkazgan mine area (Syusyura and others, 2010).

Sources of Information

Principal sources of information used by the assessment team for delineation of tract CS-1 are listed in table B4.

Grade and Tonnage Model Selection

The lithology and grain size of the rocks, along with evidence consistent with the presence of liquid or gaseous hydrocarbons, indicate the tract should be assessed for sandstone copper deposits. Seventy sandstone copper deposits from around the world were selected to create the tonnage and grade model for resource estimation (appendix F). Student's *t*-test indicates deposits in the Chu-Sarysu Basin cannot be distinguished statistically from other deposits that make up the grade and tonnage model.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Tract CS-1 is the most prospective area in the Chu-Sarysu Basin, given the number of known deposits and prospects along the outcrop trend of the host units. Zhartas (Sorkuduk) and a southern extension of West Saryoba are moderately well-explored and are considered to represent two deposits at the 90th percentile of certainty. Deeper extensions of Itauz and other prospects southward (Kokdombak) and northward (Donyzaus) along the steep west basin flank have high potential for being deposits, as do several prospects (Pektas 1, Pektas 2) that occur along the gentle east side of the sub-basin. Other deeper occurrences around the north side of the Kingir

Table B4. Principal sources of information used by the assessment team for delineation of tract 142ssCu8001 (CS-1), central Kazakhstan.

Theme	Name	Scale	Reference
Geology	CS-DZ_geolmap.tif	1:50,000	Syusyura and others, 2010
Mineral occurrences	CS-NCS_deps-occurrences.shp	1:50,000	Syusyura and others, 2010
Geochemistry	CS-DZ_minzonation.jpg	1:50,000	Syusyura and others, 2010
Geophysics	CS-NCS_gravity-residual.jpg; CS-NCS_mag-intensity.jpg	1:50,000	Syusyura and others, 2010
Exploration	Known drill hole locations (CS_boreholes-all.shp); Synopsis of prospective targets, Chu-Sarysu Basin	1:50,000	Syusyura and others, 2010; Mining and Economic Consulting, Ltd., written commun., 2009

Table B5. Deposit estimates by individual team members for tract 142ssCu8001 (CS-1), central Kazakhstan.

[N_{xx}, estimated number of deposits associated with the xxth percentile]

	Estimated number of undiscovered deposits				
Estimator	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Individual A	3	8	12	12	12
Individual B	2	3	4	4	4
Individual C	5	10	20	20	20
Individual D	3	5	7	7	7
Individual E	5	7	9	9	9
Individual F	4	6	10	10	10
Individual G	2	4	4	4	4
Individual H	1	3	4	4	4

Anticline (Taskuduk) between Zhartas and Dzhezkazgan also are highly prospective.

Probabilistic Assessment Simulation Results

Undiscovered resources for tract CS-1 were estimated by combining consensus estimates for numbers of undiscovered sandstone copper deposits (table B6) with the sandstone copper model (appendix F) using the Economic Mineral Resource Simulator (EMINERS) program (Root and others, 1992; Duval, 2012; Bawiec and Spanski, 2012). Selected simulation results are reported in table B7. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. B2). The cumulative frequency plot shows the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

The team's estimate of undiscovered resources in the upper 2 km of the Dzhezkazgan sub-basin is somewhat higher (median and mean estimates are 1.7 and 5.1 Mt Cu, respectively) than MEC's estimate of prognostic resources (1.05 Mt Cu) down to 1.5 km, and it is equal to about 7 percent and 20 percent, respectively, of the total resources of the 6 known deposits within the tract (25 Mt Cu). The abundance of known ore deposits, all essentially linked to expressions of ore at or very near the surface, led the team to their higher estimate of undiscovered, hidden deposits in the subsurface.

Table B6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 142ssCu8001 (CS-1), central Kazakhstan.

[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}, expected number of undiscovered deposits plus known deposits; area, area of permissive tract; deposit density, number of deposits per 10,000 km^2; m, meters; km^2, square kilometers. N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
3	5	8	8	8	5.1	2.0	39	6	11.1	753	147

Table B7. Results of Monte Carlo simulations of undiscovered resources for tract 142ssCu8001 (CS-1), central Kazakhstan.

[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, in t	130,000	320,000	1,700,000	16,000,000	22,000,000	5,100,000	0.25	0.03
Ag, in t	0	0	910	12,000	19,000	4,300	0.23	0.26
Rock, in Mt	11	26	150	1,400	1,900	450	0.27	0.03

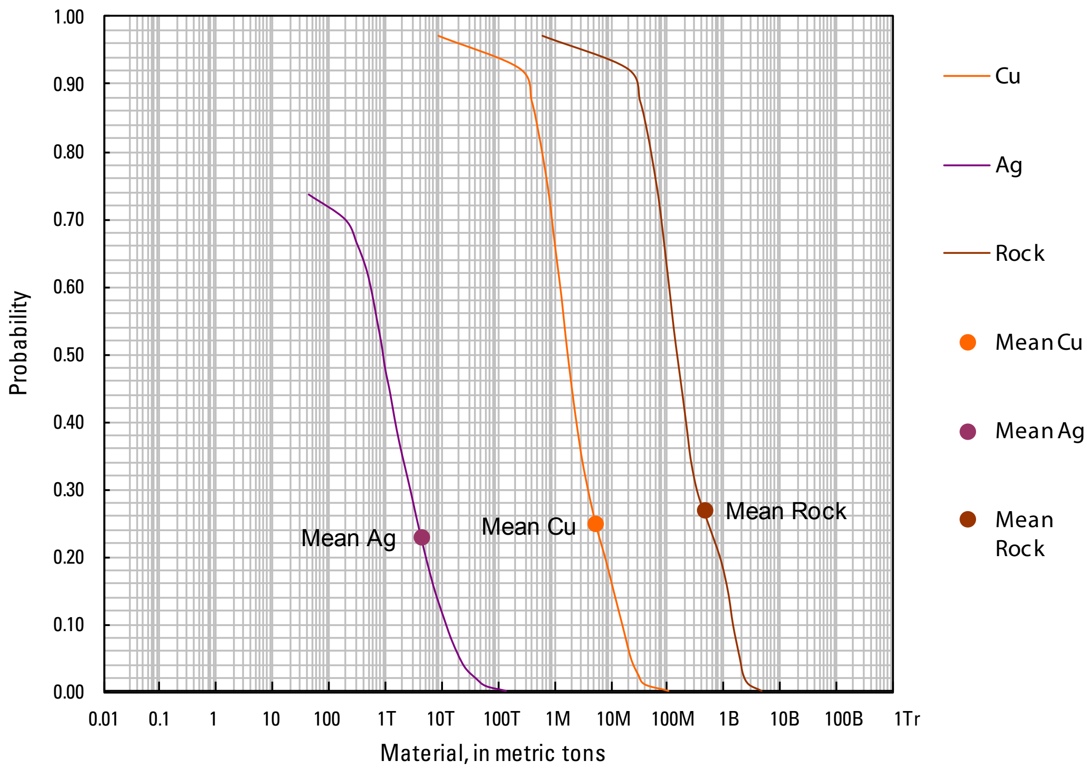

Figure B2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 142ssCu8001 (CS-1), central Kazakhstan.

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Appendix C. Sandstone Copper Assessment for Tract142ssCu8002 (CS-2), Central Kazakhstan

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Deposit Type Assessed

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

Table C1. Summary of selected resource assessment results for tract 142ssCu8002 (CS-2), central Kazakhstan.

[km, kilometers; km^2, square kilometers; t, metric tons]

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	31,680	2,720,000	9,900,000	4,800,000

Location

Central Kazakhstan, about 500 km south-southwest of the capital city of Astana (fig. C1).

Geologic Feature Assessed

Pennsylvanian strata within the northeastern part (Tesbulak sub-basin) of the Upper Devonian-Upper Permian Chu-Sarysu Basin, central Kazakhstan.

[1]U.S. Geological Survey.

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

[3]Colorado School of Mines, Golden, Colorado.

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

Delineation of the Permissive Tract

Geologic Criteria

Tract CS-2 (fig. C1) consists of the northeastern part of the Chu-Sarysu Basin (Tesbulak sub-basin), east of the Kokshetau Fault and north of the Chu uplift (fig. 1). The Kokshetau Fault is a north-northwest-trending fault that runs through the north-central part of the Chu-Sarysu Basin. South of 46.3° N the fault appears to be an east-dipping normal fault, separating Pennsylvanian strata more than 3 km deep on the east from the Tasty uplift, an antiformal feature over which those strata have been eroded on the west. North of 46.3° N, the base of Pennsylvanian strata occurs at greater depth on the west side of the fault, indicating west-side-down displacement. The Chu uplift is a broad, east-northeast trending anticlinorium between 45° N and 46° N. The Pennsylvanian strata have been eroded away over part of this uplift.

In the Tesbulak sub-basin, the base of Pennsylvanian strata generally dips to the west-southwest toward the Kokshetau Fault, but is wrinkled by east-northeast trending, west-plunging folds (CS-NCS_depth-base-mCarbonif.mxd; Syusyura and others, 2010). One of those anticlinal folds, the Zhaman-Aibat Anticline located just south of 47° N (fig. C2), is the host for the Zhaman-Aibat sandstone copper deposit (figs. C1 and C2, table C2) and the small reduced-facies Taskora deposit (figs. C1 and C2, table C2). Several parallel folds north and south of the Zhaman-Aibat Anticline have potential for undiscovered deposits. Because different levels of information exist for subareas within the tract, we divide the assessed tract into assessment subunits on figure C1 and these are discussed in more detail below.

Assessment Subunit 2a (Zhaman-Aibat)

Assessment subunit 2a (figs. C1 and C2) encompasses the east-northeast-trending Zhaman-Aibat Anticline (fig. C2) in the region of the Zhaman-Aibat and Taskora deposits. The subunit extends along that structure from the eastern limit of the Dzhezkazgan and Taskuduk Formations with a down-dip width (6–12 km) similar to the extent of the reduced (gray-colored) red bed sandstones, as shown on the pre-Mesozoic geologic map of the northern Chu-Sarysu Basin (CS-NCS_pre-Mz-geolmap.mxd; Syusyura and others, 2010). The western extent is taken to be the base of the steeply plunging section of the anticline, where the top of the ore horizon passes through 1.6 km below sea level, as shown on a structure contour map of the base of Permian salt (CS_elev-base-Perm-salt.mxd; Syusyura and others, 2010). The following description of the Zhaman-Aibat prognostic resource estimate area is from a mining industry group in Kazakhstan (MEC, written commun., 2009):

> The Zhaman-Aibat area is located 140 km southeast of Zhezkazgan city and comprises the Zhaman-Aibat deposit of copper-bearing sandstones and Taskora deposit of copper-bearing shale rocks, which together form the Zhaman-Aibat ore field. The Zhaman-Aibat deposit is localized within an east-northeast trending anticline of the same name near the eastern edge of the northeastern part of the Chu-Sarysu depression. The gentler southern flank of this asymmetric anticlinal structure exposes Carboniferous and Permian carbonate-terrigenous rocks dipping smoothly to the south. The northern flank is less studied and mostly covered by Mesozoic and Cenozoic deposits. A seismic survey across the northern part of the structure showed it to be a steep flexure (most probably a fault), across which the strata are dropped 500–1,000 m vertically. Drilling results show that the inclined strata within this flexure above the fault reach depths of 400 m and more below the surface.
>
> The Zhaman-Aibat structure is a west-southwest-plunging anticline on the geological map and is shown to have structural closure on the structure contour map of the base of the Carboniferous ore horizon[5]. It occurs near the eastern edge of the Chu-Sarysu depression with increased thickness of Carboniferous deposits. A seismic survey identified four anticlinal culminations, each with a positive gravity anomaly, along an anticlinal strike length of roughly 40 km. The largest of these are the Azat and Taskora anticlinal culminations near the eastern and western extents of this structure, respectively.

Assessment Subunit 2b (central Sarysu uplift)

Assessment subunit 2b (fig. C1) includes the surface and subsurface extent of the Dzhezkazgan and Taskuduk Formations in a broadly uplifted area of the central Sarysu uplift (fig. 1) in the northeastern part of the Chu-Sarysu Basin, extending down dip from the eastern limit of these formations south and west to where the base of those formations is about 1.8 km below the surface (based on CS-NCS_depth-base-mCarbonif.mxd; Syusyura and others, 2010).

Assessment Subunit 2c (Kulen)

Assessment subunit 2c (figs. C1 and C2) includes the Dzhezkazgan and Taskuduk Formations within a 6–12-km-wide swath along the Kulen Anticline (fig. C2), from their eastern outcrop edge down plunge to the west until the top of the Dzhezkazgan Formation, is about 2 km below the surface (based on the 1.6 km depth contour of CS-NCS_depth-base-mCarbonif.mxd; Syusyura and others, 2010). The following description of the Kulen prognostic resource estimate area is from a mining industry group in Kazakhstan (MEC, written commun., 2009):

[5]Shown in Syusyura and others (2010) as CS_elev-base-mCarbonif.mxd.

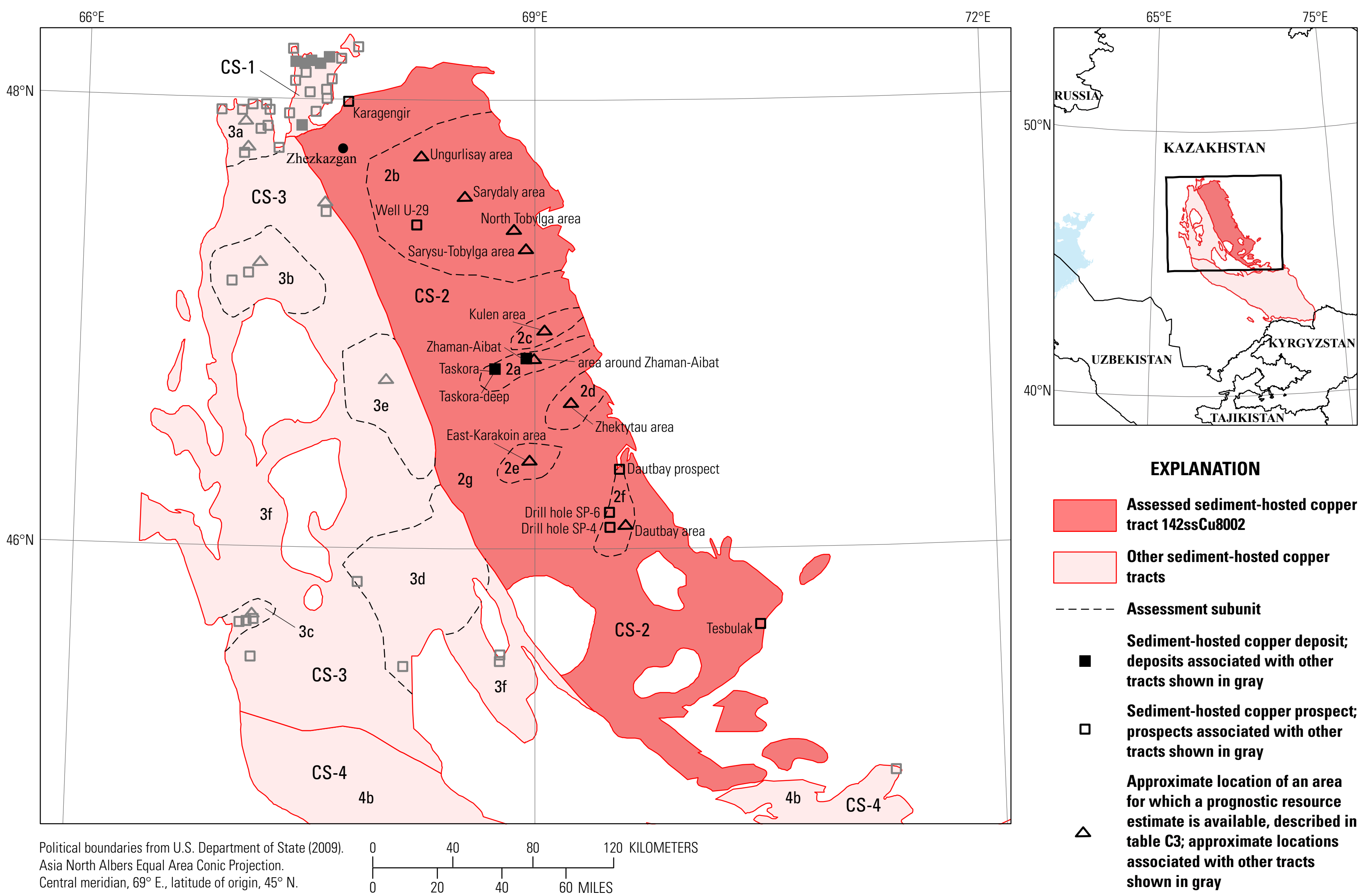

Figure C1. Location map for tract 142ssCu8002 (CS-2) and its known deposits and prospects, central Kazakhstan.

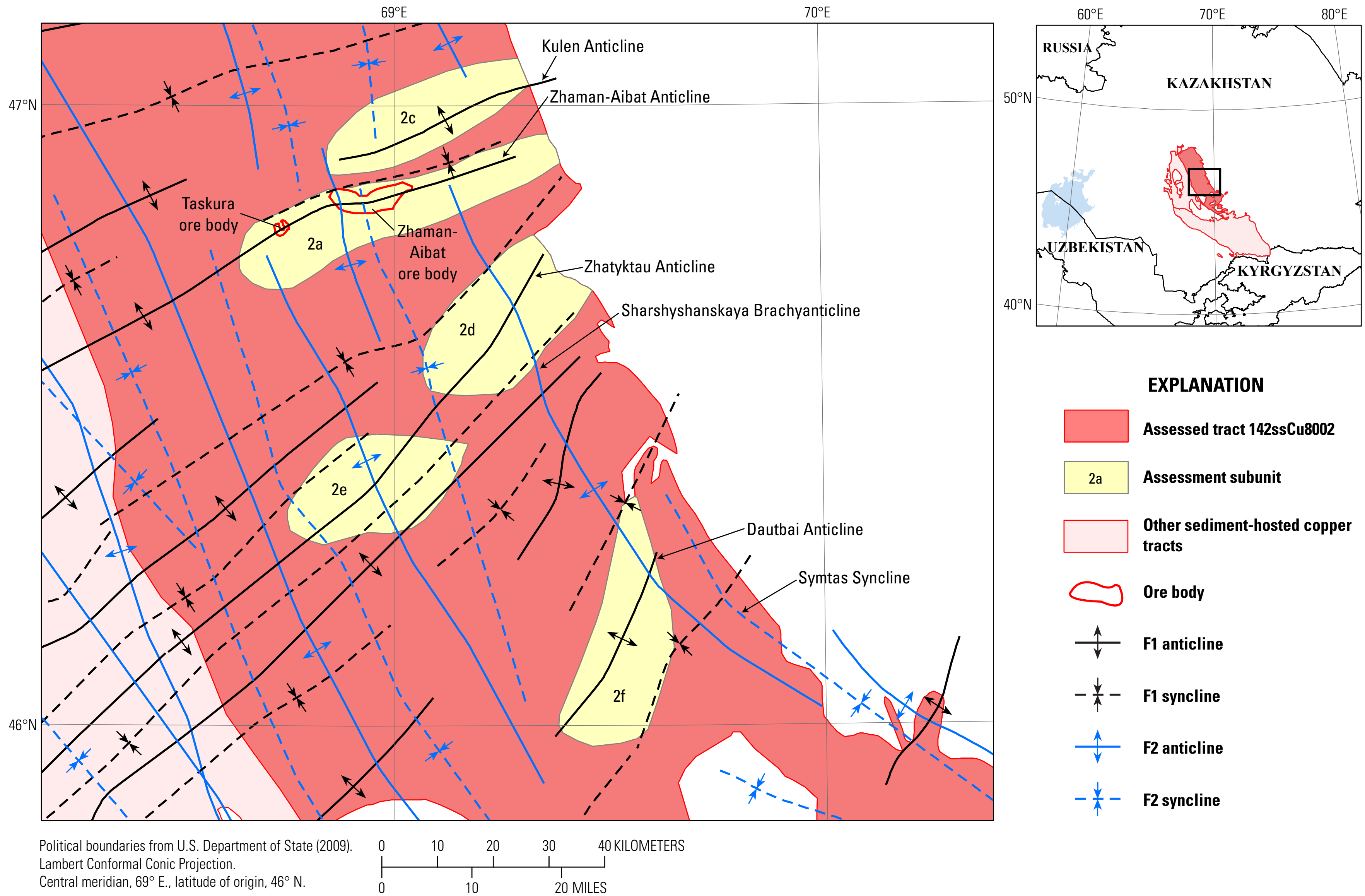

Figure C2. Locations of fold structures in tract 142ssCu8002 (CS-2), central Kazakhstan.

> The east-northeast-trending Kulen anticline 8 km north of Zhaman-Aibat anticline was identified by seismic profiling[5]. The Kulen anticline is flanked by the Azat flexure zone on the north side of the Zhaman-Aibat anticline to the south. The Muzkazgan flexure zone and fault flank the Kulen anticline on the north. The Kulen plunges moderately to the south, as shown on the geologic and structure contour maps[6]. In the east, the structure is enclosed by a down-fold with increased thickness of Carboniferous deposits. The anticline is about 26 km long, the closure is 1–1.5 km wide, and the uplift amplitude is more than 300 m in the east and 100 m in the west. The depth of the base of the mid-Carboniferous strata along the anticlinal crest is 1,450 m in the east, 1,850 m in the central part, and 2,150 m at the western closure. However a possible miscorrelation between the seismic lines and drill holes allows the possibility that the above depths could be less, namely 800, 1,200 and 1,450 m, respectively. As with Zhaman-Aibat anticline, the Carboniferous deposits thicken to the east along the Kulen anticline. The greatest increase in stratigraphic thickness is within [the] Taskuduk Formation, from 570 to 1,030 m. The Kulen structure is marked by a positive residual-gravity anomaly of about 2 mgal.

Assessment Subunit 2d (Zhaktykhau)

Assessment subunit 2d (figs. C1 and C2) is drawn to include the Dzhezkazgan and Taskuduk Formations within an 18-km-wide swath along the Zhatyktau Anticline (fig. C2) from their eastern outcrop edge down plunge to the west to where the base of the unit is about 1.8 km below sea level (using CS-NCS_depth-base-mCarbonif.mxd; Syusyura and others, 2010). The following brief description of the Zhaktyktau prognostic resource estimate area was provided by a mining industry group in Kazakhstan. (MEC, written commun., 2009):

> Zhaktyktau prospective area is situated 25 km southeast of the Zhaman-Aibat deposit coinciding with the SW trending anticline of the same name, faulted on its northwest side. A seismic reflection survey indicated the depth to the base of the Taskuduk Formation ranges from 1.4 up to 2.0 km within the site, and the structural amplitude is about 500 m.

Assessment Subunit 2e (East Karakoin)

Assessment subunit 2e is located southwest of assessment subunit 2d along a southwestward continuation of the Zhaktyktau Anticline (figs. C1 and C2). The following brief description of this prognostic resource estimate area was provided by a mining industry group in Kazakhstan (MEC, written commun., 2009):

> East Karakoin prospective area is located 10 km southwest of the Zhaktyktau area and encompasses two parallel east-northeast-trending anticlines with positive gravity anomalies up to 1.5 mgal.

Assessment Subunit 2f (Dautbay)

Assessment subunit 2f occurs over the Dautbay anticlinal structure along the eastern margin of the Chu-Sarysu Basin about 50 km south of subunit 2d (figs. C1 and C2). A brief review of prospecting in the Dautbay area is given below (MEC, written commun., 2009):

> The Dautbay anticline[7], located 70–90 km south-southeast of the Zhaman-Aibat deposit, was explored based on a 1:50,000 geological survey…, a seismic survey…, and limited drilling.

Assessment Subunit 2g

Assessment subunit 2g is the portion of tract CS-2 not encompassed within subunits 2a through 2f.

Known Deposits

The only known deposit of the sandstone copper type within tract CS-2 is the Zhaman-Aibat deposit (figs. C1 and C2, table C2). A small reduced-facies, shale-hosted copper deposit (Taskora: fig. C2, table C2) within the Permian section was mined from 2007 to 2009 in an open pit located about 10 km west of the western edge of the Zhaman-Aibat deposit along the crest of the Zhaman-Aibat Anticline (discussed more in following section). The following brief description of the Zhaman-Aibat deposit was provided by a mining industry group in Kazakhstan (MEC, written commun., 2009):

> The Zhaman-Aibat sandstone copper deposit is hosted in terrigenous variegated rocks of the Dzhezkazgan and Taskuduk Formations. Normally, these rocks consist of red, oxidized strata that are dominated by sandstone of variable grain size. Gravels and conglomerates occur less frequently and silty sandstones and siltstones are seldom observed. The deposit occurs within a large lens within which numerous grey-colored strata are interlayered with the normal section red beds. In plan, this variegated lens is elongated along the axis of the Zhaman-Aibat anticline. Within the lens, grey-colored rocks in the Taskuduk and Dzhezkazgan Formations

[5]Shown in Syusyura and others (2010) as CS-NCS_pre-Mz-geolmap.mxd.

[6]Shown in Syusyura and others (2010) as CS-NCS_pre-Mz-geolmap.jpg and CS_elev-base-mCarbonif-orig.jpg.

[7]Figure C2.

vary from 0 to more than 200 m in thickness. The thickest sections of gray-colored rocks are found in the eastern and the Taskora areas[8]. The eastern area with interlayered grey-colored strata covers the central and eastern parts of the anticline and follows the crest of the anticline, [with the total thickness of grey-colored Taskuduk and Dzhezkazgan Formation strata exceeding 200 m]. Ratio of total grey-colored rock thickness to the total thickness of the formations ranges from 1:9 at the periphery to 1:3 (with a local maximum of 1:1) in its central part.

At Zhaman-Aibat, 28 cyclothems were identified[9]. Each consists of a lower layer of grey-colored sandstones (often with conglomerates and gravelite at the base) and upper layer of siltstones (sometimes with interlayered argillite). Grey-colored varieties regularly transform into red-colored ones along the strike and down-dip. These cyclothems have been grouped into 10 ore horizons, 3 in Taskuduk Formation and 7 in the Dzhezkazgan Formation.

In general, copper mineralization of various grades occurs throughout most of the section and is usually associated with grey-colored sandstones and conglomerates. Commercial mineralization was found in five ore horizons (Nos. 1–5) and is localized in six ore shoots (1-II, 2-IV, 3-II, 3-III, 4-I, and 5-I; fig. C2). The main ore shoot, 4-I, contains about 70 percent of the commercial ores, and is localized in a persistent interlayer of Raymondian gravelites and conglomerates and its associated grey-colored sandstones. Ores are mostly copper-bearing, less frequently lead-copper and rarely lead and lead-zinc ores are found. Mean copper grade of other commercial shoots are considerably lower than those of ore shoot 4-I. Lower grade copper mineralization was discovered on the 2nd (ore shoot 2-II), 3rd (3-I), 4th (4-II), 5th (5-II), 9th (9-I) and 10th ore horizons. In the remaining sequences (shoots) of ore horizons, ore copper occurrence is represented by mineralization only at present time. Silver and rhenium are also associated with the copper mineralization at the Zhaman-Aibat deposit.

Commercial mineralization at the Zhaman-Aibat deposit is usually confined to the flanks of the Central and Eastern anticlinal culminations, surrounding them with several rings, 200–700 m wide in sections, with total Dzhezkazgan and Taskuduk Formation thickness from 60 to 160 m. The majority of holes drilled in the crest of these structures, where total thickness of grey-colored rocks is commonly the greatest and reaches 170–200 m and more, intersected no or only off-grade mineralization.

[8]Shown in CS-ZA_strat-columns.jpg; Syusyura and others, 2010.

[9]Figure C3.

Prospects, Mineral Occurrences, and Related Deposit Types

Assessment Subunit 2a (Zhaman-Aibat)

Prospects within assessment subunit 2a include copper mineralization intercepted in the Carboniferous Dzhezkazgan Formation at depth below the Taskora reduced-facies copper shale deposit in Permian strata, as well as undisclosed exploration targets adjacent to the Zhaman-Aibat deposit (discussed below).

The following brief description of the Zhaman-Aibat prognostic resource estimate area was provided by a mining industry group in Kazakhstan (MEC, written commun., 2009):

> The mineralization at the Zhaman-Aibat deposit, at a depth from 460 down to 950 m (mostly 600–700 m), is confined to the central part of the anticline between [the] Azat and Taskora culminations. Within [the] Taskora culmination, there is a small copper deposit (ore occurrence depth is up to 30 m, average thickness is 8.65 m, and Cu average grade is 0.76 percent) of the same name associated with grey-colored siltstones and marls of the lower part of the Permian Kingir suite. The Taskora deposit is considered to be shale-hosted, reduced-facies sediment-hosted copper-type mineralization.
>
> A similar situation is typical of the Taskora anticlinal culmination, where only 5 deep holes have been drilled. Three holes encountered off-grade mineralization at the level of the 4th Zhaman-Aibat ore horizon, and drill hole U-149 situated on the southern flank of this structure intersected 1.7 m with Cu grade of 2.89 percent[10]. This similarity to the geometry of the Zhaman-Aibat deposit suggests that ring shaped sandstone ore bodies of Dzhezkazgan type may also surround the Taskora culmination at depth regularity of location established for cupriferous sandstones of Dzhezkazgan type at the Zhaman-Aibat deposit but have not been sufficiently explored. It is also assumed that other ore ring zones may also be found in the vicinity of the Zhaman-Aibat deposit where not sufficiently explored by drilling.
>
> Zhaman-Aibat total probable copper resources of P1 + P2 + P3 categories (down to a depth of 1 km) are estimated at 1,200,000 t Cu, including 700,000 t of P2 off-grade ore reserves registered with the state balance of RoK Reserves Committee (Minutes of the Meeting No. 58-00-U, dated September 18, 2000).

[10]Shown in CS_ZA_strat-columns.jpg; Syusyura and others, 2010.

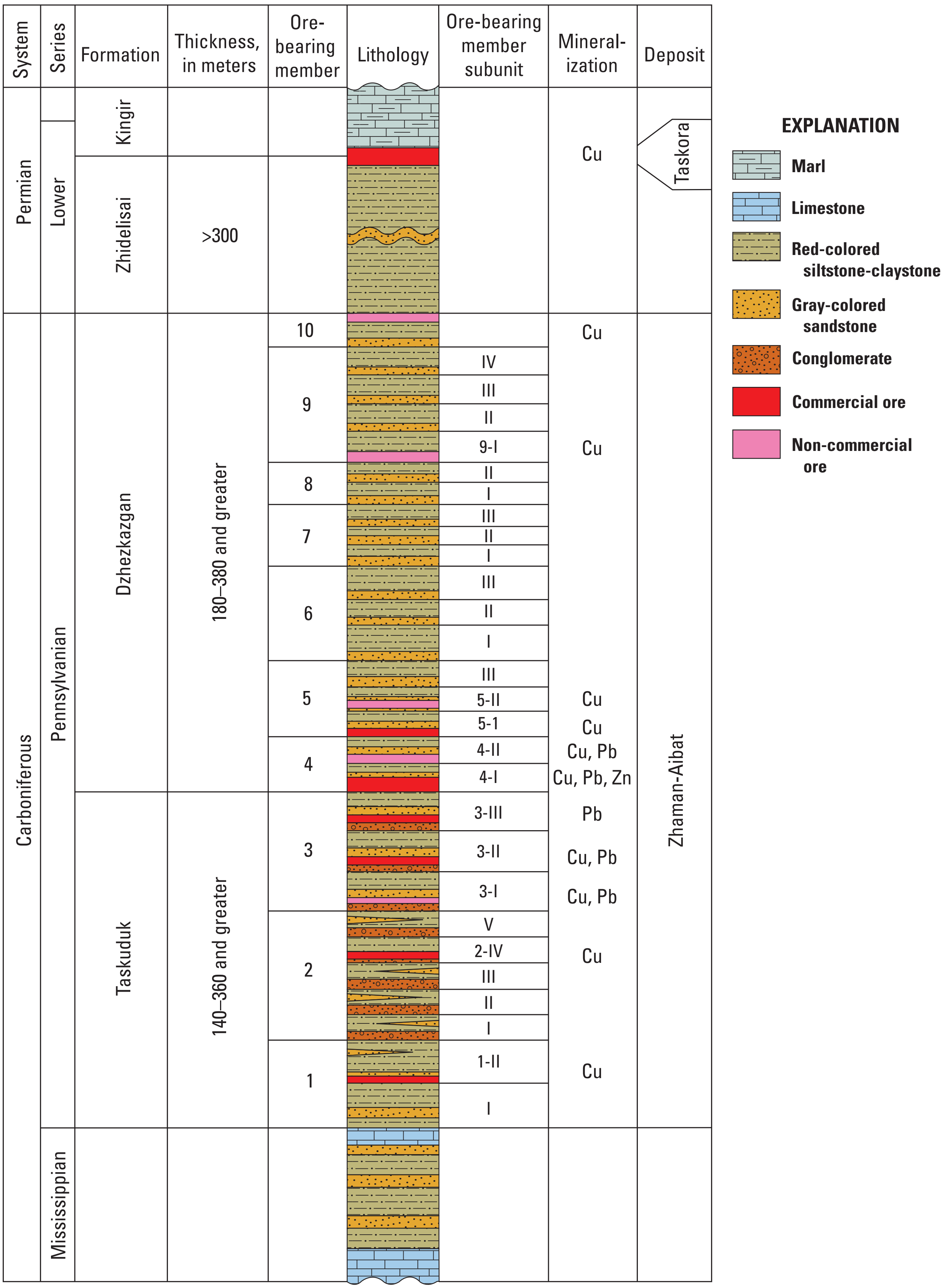

Figure C3. Stratigraphic column in the vicinity of the Zhaman-Aibat and Taskora deposits, showing positions of ore horizon subunits, Chu-Sarysu Basin, Kazakhstan.

Table C2. Known sediment-hosted copper deposits in tract 142ssCu8002 (CS-2), central Kazakhstan.

[Mt, million metric tons; t, metric ton. Contained Cu in metric tons is computed as tonnage (Mt×1,000,000) × Cu grade (%)/100; %, percent]

Name	Latitude	Longitude	Subtype	Tonnage (Mt)	Grade		Contained Cu (t)	Reference
					Cu (%)	Ag (%)		
Zhaman Aibat	46.850	68.941	Sandstone	161	1.69	0.00191	2.72	A. Kim, Kazakhmys, written commun., 2009
Taskora	46.802	68.734	Reduced facies	4	0.75	n.d.	0.03	Kazakhmys Web site: http://www.kazakhmys.com/uploads/kasplchalfyear-2008presentationfinal 28aug08.pdf

Assessment Subunit 2b

Within the subunit 2b, four northeast-trending anticlinal features (Ungurlisay, Sarydaly, North Tobylga, and Sarysu-Tobylga prognostic-resource-estimate areas in table C3 and on figure C1) are inferred by a mining industry group in Kazakhstan (MEC, written commun., 2009) to have prognostic Cu resources (Diatchkov, 1994) of 3,800,000 t Cu. The surface areas inferred to contain these prognostic resources range from 230 to 600 km^2. Five wells over a 60 km linear distance have uneconomic shows of copper mineralization (up to 0.1 percent Cu over a few meters) in either the Carboniferous or earliest Permian strata (Syusyura and others, 2010). Only sporadic intervals of gray, reduced red beds were encountered in the Carboniferous ore horizon.

Assessment Subunit 2c (Kulen)

A brief description of prospects within the Kulen prognostic resource estimate area is given below (MEC, written commun., 2009):

> As with [the] Zhaman-Aibat anticline, the Carboniferous deposits thicken to the east along the Kulen anticline. The greatest increase in stratigraphic thickness is within [the] Taskuduk Formation, from 570 m to 1,030 m. The Kulen structure is marked by a positive residual gravity anomaly of about 2 mgal.
>
> The Kulen anticline has potential for copper mineralization but exploration results are not conclusive. Thick coarse sandstones and conglomerates are found in drill holes 021, 022 and 015 situated in the eastern part of the anticline, however, grey-colored sandstones and siltstones within the Dzhezkazgan and Taskuduk Formations, as seen at Zhaman-Aibat, are not present[11]. The potential ore horizon in the deep western part of the anticline has not been completely penetrated by drill holes (07, 08, and 09). P3 category resources were estimated at 200,000 t Cu within this prospective area down to a depth of 1 km.

Assessment Subunit 2d (Zhaktykhau)

No copper mineralization was encountered within subunit 2d in the five known drill holes, one of which is far off the anticlinal axis (Syusyura and others, 2010). However, one of the drill holes (for oil exploration) near the anticlinal axis encountered gray-green (reduced) strata in the Taskuduk and lower Dzhezkazgan Formations in random core sampling. A brief synopsis of exploration within the Zhaktyktau prognostic-resource-estimate area is given below (MEC, written commun., 2009):

> In the northeastern part of the structure, three structural-prospecting holes U-51, 60 and 1-P Zhaktyktau (oil well) were drilled[12]. Drill holes U-51 and 60 did not identify any copper mineralization; however, drill hole U-60 is located well off the crest of the anticline. Sporadic core sampling in drill-hole 1-P recovered greenish-grey rocks, mainly in Taskuduk Formation and probably also in the lower part of Dzhezkazgan Formation P3 resources of 700,000 t Cu were estimated to occur within this prospective area down to a depth of 1 km.

Assessment Subunit 2e (East Karakoin)

No copper mineralization or iron reduction was encountered in four mineral exploration drill holes in the tract

[11]Shown in CS-NCS_pre-Mz-geolmap.mxd; Syusyura and others, 2010.

[12]Shown in CS-NCS_pre-Mz-geolmap.mxd; Syusyura and others, 2010.

(Syusyura and others, 2010). None is referred to for the three oil exploration holes, although it is not clear that those holes were tested for copper mineralization. Exploration within this prognostic-resource-estimate area (East Karakoin) is reviewed briefly below (MEC, written commun., 2009):

> During general prospecting for copper in the north-eastern part of East Karakoin site (P. I. Skirda and others, 1984)[13], structural-prospecting holes U-53, 55, 57, 58 were drilled.[14] The Taskuduk and Dzhezkazgan Formations in these holes are characterized by red color and coarse grain size, typical of the eastern edge of [the] Chu-Sarysu depression. P3 resources of 1,000,000 t Cu were estimated to occur within this prospective area down to a depth of 1 km.

Assessment Subunit 2f (Dautbay)

A review of prospecting of the Dautbay prognostic-resource-estimate area is given below (MEC, written commun., 2009):

> The Dautbay anticline, located 70-90 km south-southeast of the Zhaman-Aibat deposit, was explored based on a 1:50,000 geological survey (G. V. Belov and others, 1978–80), a seismic survey (N. N. Smirnova and others., 1991), and limited drilling, which resulted in identification of ore occurrences of lead, zinc, silver, barium, strontium and anomalous concentrations of copper in lithogeochemical samples, trenches and drill holes. Ore occurrences of polymetals (lead, zinc and silver) and strontium outcrop at the northern end of the Dautbay anticline, confined to carbonate-terrigenous formations that underlie the mid Carboniferous red bed strata. Probable resources of the ore occurrences were estimated as follows: P2 category—polymetals in the amount of 2,300,000 t of metal at summed average Pb and Zn grade of 4.16 percent and average thickness of 3.3 m; 1,500 t Ag at average grade of 27 g/t over a thickness of 9.8 m; P1 category—celestine (strontium sulfate) in the amount of 7,700,000 t at average grade of 21 percent and thickness of 9.0 m.
>
> Based on results of 1:50,000 and 1:10,000 lithogeochemical surveys, secondary copper halos at Cu grades from 0.06 up to 0.25 percent were determined within the limits of ore occurrences as well as in the north-western peripheral part of [the] Dautbay structure and at the northern termination of [the] Zholdybai anticline[15] in grey-colored terrigenous rocks of Dzhezkazgan and Taskuduk Formations. Primary copper halos with concentrations of 0.005–0.03 percent (thickness is 4–8 m), 0.03–0.1 percent (3.5 m) and 0.008–0.25 percent (10 m) and others were found in some of shallow prospecting drill-holes. Copper mineralization is represented by chalcopyrite dissemination.
>
> Within the described site, seismic survey by CDP (common depth point) method, electric survey by near-zone magnetic field method, gravity and magnetic survey on definite survey lines, as well as structural-prospecting drilling were performed to confirm the presence of copper occurrences and test down-dip extensions. Structural and prospecting drill holes U-62, 66 and SP-3, 4, 5, 6, 7, 8[16] tested anticline and syncline structures identified from the seismic survey, which can be associated here with mineralization of polymetals and copper. Also it was established that the greatest thickness of grey-colored rock varieties are observed within [the] Dzhezkazgan and Taskuduk Formations on the north-western flanks of [the] Dautbay and Zholdybai anticlines. Total thickness of grey-colored rocks in drill-holes SP-4 and SP-6 ranges from 10.2 up to 52 m. In drill hole SP-4 within the interval of 797.3–802.8 m, Cu grade makes up 0.04 percent, in drill-hole SP-6 within intervals of 514.4–517.4 m; 582.1–582.1 m; 637.2–640.2 m; 718.9–722.6 m, Cu grade varies from 0.015 up to 0.04 percent. Drill-holes U-62, (Symtas syncline[17]) and SP-7, and SP-8 (south extension of Dautbay anticline and Sharshyshanskaya brachyanticline[18]) did not show any positive results, and this southeastern part of Dautbay site was assessed negatively.
>
> Several favorable factors, such as positive structures limited by tectonic faults, positive local gravity anomalies and sometimes anomalies in the results of electric survey by near-zone magnetic field method, occurrences of grey-colored strata and increased grades of copper, polymetals and strontium within the Taskuduk and Dzhezkazgan Formations, resulted in an estimate of 500,000 t Cu resources in the P2 category down to 1 km in this prospective area.

Assessment Subunit 2g

Assessment subunit 2g is the portion of tract CS-2 that is not included in subunits 2a through 2f. Four widely scattered sediment-hosted copper prospects and one associated lead-zinc prospect are reported from within subunit 2g. Two prospects (Karagengir and Akbulak) occur on the southeast flank of the Kingir Anticline, the structure which hosts the supergiant Dzhezkazgan deposit about 25 km to the west.

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[13] No citation given; presumably a USSR government report.

[14] Shown in CS-NCS_pre-Mz-geolmap.mxd; Syusyura and others, 2010.

[15] A branch of the Dautbay Anticline; figure C2.

[16] Shown in CS-NCS_pre-Mz-geolmap.mxd; Syusyura and others, 2010.

[17] Figure C2.

[18] Figure C2.

Exploration History

Assessment subunit 2a is part of the concession owned by Kazakhmys, which operates the Zhaman-Aibat Mine and conducts exploration in the rest of tract CS-2. Assessment subunit 2b also is part of the concession owned by Kazakhmys, which operates the Dzhezkazgan and Zhaman-Aibat Mines. Kazakhmys explores in this tract, with drilling activity in 2009 and more drilling planned in 2010 (Steve McRobbie, Kazakhmys, oral comm., 2009). Exploration for natural gas also has occurred in this area. At least 25 wells are known within the tract. Five wells have uneconomic shows of copper mineralization (up to 0.1 percent Cu over a few meters) in either the Carboniferous or earliest Permian strata (Syusyura and others, 2010).

At least nine drill holes are known within assessment subunit 2c, with the eastern ones completely penetrating the Dzhezkazgan-Taskuduk Formations and the western ones partly penetrating the horizon (Syusyura and others, 2010). Although the host horizon is thick and coarse, no copper mineralization or gray-altered sandstone horizons were encountered in the drill holes. The prospective anticlinal structure is well-defined from surface mapping on the east and from regional oil exploration seismic surveys where the units are in the subsurface.

At least five drill holes, most of which are oil-exploration holes, are scattered across assessment subunit 2d (Syusyura and others, 2010). Seismic surveys over the tract were adequate to define the prospective anticlinal structure. It is unknown how much of the drill cuttings or core samples mentioned above were analyzed for copper mineralization.

Seven drill holes (four for mineral exploration, three for oil exploration) are known in assessment subunit 2e (Syusyura and others, 2010). Seismic and gravity data are sufficient to define the structural features of the tract.

Assessment subunit 2f was explored in the 1980s and early 1990s (MEC, written commun., 2009). It is not clear whether any exploration has occurred since the early 1990s.

Some parts of assessment subunit 2g have been explored by surface sampling, oil and gas drilling, or mineral-exploration drilling (Syusyura and others, 2010), but most of this large tract is untested. For the most part, this tract represents those parts of the northern Chu-Sarysu Basin that have not had additional exploration activities related to evaluation of sediment-hosted copper prospects. However, the area has been covered by regional exploration related to oil and gas in or below the host horizon for the sediment-hosted copper deposits and by exploration for uranium in overlying units.

Sources of Information

Principal sources of information used by the assessment team for delineation of tract CS-2 are listed in table C4.

Grade and Tonnage Model Selection

The lithology and grain size of the rocks, along with evidence consistent with the presence of liquid or gaseous hydrocarbons, indicate that the tract should be assessed for sandstone copper deposits. Seventy sandstone copper deposits from around the world were selected to create the tonnage and grade model for resource estimation (appendix F). Student's *t*-test indicates deposits in the Chu-Sarysu Basin cannot be distinguished statistically from other deposits that make up the grade and tonnage model.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Estimates were made by the assessment group for each of the assessment subunits based on the data summarized above. The consensus estimate of numbers of undiscovered deposits for each of the assessment subunits is shown in table C5. Those consensus estimates were aggregated statistically using the correlation matrix specified in table C6, representing the level of correlation between assessment subunits (Schuenemeyer and others, 2011). The resultant aggregated estimate for the number of undiscovered deposits in the entire tract is given in table C7.

Several factors led the assessment group to the overall high estimate of the number of undiscovered deposits in tract CS-2. The presence of the large Zhaman-Aibat deposit and the position of the lightly explored northern part of the tract between that deposit and the supergiant Dzhezkazgan deposit gave the group optimism that prerequisite conditions for the formation of sandstone copper deposits were operative in this area. The group favored a model of generation of the metal-transporting brines within the deeper portion of the northeastern Chu-Sarysu Basin associated with Devonian and (or) Permian evaporite sections, and hydraulic pumping of these brines into the shallower up-dip portions of the basin. Each of the northeast-trending anticlines plunging into the deep western part of this northeastern sub-basin has the potential of having trapped a natural gas deposit, which in turn could have caused precipitation of metals from the oxidized, metal-bearing brines during up-dip migration. Each assessment subunit was evaluated for evidence that such an ore-forming system might have operated. In the case of assessment subunit 2a, where the presence of the Zhaman-Aibat deposit indicates that such an ore-forming system did operate, the estimate is based on an evaluation of evidence that other ore-localization processes operated beyond the immediate vicinity of the Zhaman-Aibat deposit.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered sandstone copper deposits (table C7) with the sandstone copper model (appendix F) using the Economic Mineral Resource

Table C3. Significant prospects, occurrences, and areas with prognostic resource estimates in tract 142ssCu8002 (CS-2), central Kazakhstan.

[For areas with prognostic resource estimates, latitude and longitude are provided for the centroid of each area named. m, meter; Mt, million metric tons; MEC, Mining and Economic Consulting, Ltd.]

Name	Latitude	Longitude	Comments (grade and tonnage data, if available)	Reference
Area around Zhaman-Aibat	46.850	68.941	P1 (0.7 Mt Cu) and P3 (0.5 Mt Cu) resources in a 224 km^2 area down-dip and along strike from the Zhaman-Aibat deposit	MEC, written commun., 2009
Taskora-deep	46.802	68.735	Drill hole intercept 1.7 m at 2.89% Cu	MEC, written commun., 2009
Ungurlisay area	47.750	68.236	257 km^2 area with P3 resources (0.8 Mt Cu)	MEC, written commun., 2009
Sarydaly area	47.572	68.530	230 km^2 area with P3 resources (1.0 Mt Cu)	MEC, written commun., 2009
North Tobylga area	47.423	68.858	322 km^2 area with P3 resources (1.0 Mt Cu)	MEC, written commun., 2009
Sarysu-Tobylga area	47.337	68.939	600 km^2 area with P3 resources (1.0 Mt Cu)	MEC, written commun., 2009
Kulen area	46.974	69.061	46 km^2 area with P3 resources (0.2 Mt Cu)	MEC, written commun., 2009
Zhektytau area	46.650	69.235	305 km^2 area with P3 resources (0.7Mt Cu)	MEC, written commun., 2009
East Karakoin area	46.392	68.961	415 km^2 area with P3 resources (1.0 Mt Cu)	MEC, written commun., 2009
Dautbay prospect	46.355	69.549	Cu prospect in Taskuduk Formation and Pb-Zn prospect in underlying Serpukhovian carbonate sequence	MEC, written commun., 2009
Drill hole SP-4	46.095	69.485	5.5 m intercept with 0.04% Cu	Syusyura and others, 2010
Drill hole SP-6	46.164	69.485	(4) 3–4 m intercepts with 0.015–0.04% Cu	Syusyura and others, 2010
Dautbay area	46.105	69.588	420 km^2 area with P3 resources (0.5 Mt Cu)	MEC, written commun., 2009
Karakengir	47.991	67.745	Non-economic copper sandstone occurrences in Dzhezkazgan and Taskuduk Formations	Syusyura and others, 2010; CS-NCS_pre-Mz-geolmap.mxd
Tesbulak	45.659	70.456	Non-economic copper sandstone occurrence in Taskuduk Formation	Syusyura and others, 2010
Well U-29	47.442	68.209	Non-economic copper occurrence in drill hole	Syusyura and others, 2010

Table C4. Principal sources of information used by the assessment team for delineation of tract 142ssCu8002 (CS-2), central Kazakhstan.

Theme	Name or Title	Scale	Reference
Geology	CS-ZA_geolmap.mxd	1:200,000	Syusyura and others, 2010
Mineral occurrences	CS-NCS_deps-occurrences.shp; CS-ZA_geolmap.mxd	1:50,000	Syusyura and others, 2010
Geochemistry	CS-ZA_strat-column-chem.jpg	1:50,000	Syusyura and others, 2010
Geophysics	CS-NCS_gravity-residual.jpg; CS-NCS_mag-intensity.jpg	1:50,000	Syusyura and others, 2010
Exploration	Known drill hole locations (CS_bore-holes-all.shp); Synopsis of prospective targets, Chu-Sarysu Basin	1:50,000	Syusyura and others, 2010; Mining and Economic Consulting, Ltd. (written commun., 2009)

Table C5. Undiscovered deposit estimates for individual assessment subunits, tract 142ssCu8002 (CS-2), central Kazakhstan.

[N_{xx}, estimated number of deposits associated with the xxth percentile]

Assessment subunit	Consensus estimated number of undiscovered deposits for each subunit				
	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
2a	3	4	5	5	5
2b	0	1	3	5	5
2c	0	1	2	2	3
2d	0	0	1	2	2
2e	0	1	1	2	5
2f	0	1	2	3	5
2g	0	2	2	5	5

Table C6. Correlation matrix used to combine undiscovered deposit estimates statistically for assessment subunits in tract 142ssCu8002 (CS-2), central Kazakhstan.

	2a	2b	2c	2d	2e	2f	2g
2a	1						
2b	0.5	1					
2c	0.75	0.5	1				
2d	0.6	0.2	0.6	1			
2e	0.6	0.2	0.6	0.75	1		
2f	0.2	0.2	0.2	0.6	0.5	1	
2g	0.2	0.2	0.2	0.2	0.2	0.2	1

Table C7. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 142ssCu8002 (CS-2), central Kazakhstan.

[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}, expected number of undiscovered deposits plus known deposits; area, area of permissive tract; deposit density, number of deposits per 10,000 km^2; m, meters; km^2, square kilometers. N_{und}, s, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Aggregated undiscovered deposit estimate					Summary statistics					Area, (km^2)	Deposit density
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
5	10	16	18	22	10.3	4.5	43	1	11	31,680	3.6

Table C8. Results of Monte Carlo simulations of undiscovered resources in tract 142ssCu8002 (CS-2), central Kazakhstan.

[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, in t	360,000	820,000	4,800,000	26,000,000	34,000,000	9,900,000	0.33	0.02
Ag, in t	0	0	3,300	22,000	36,000	8,500	0.28	0.11
Rock, in Mt	32	70	430	2,200	2,900	870	0.36	0.02

Simulator (EMINERS) program (Root and others, 1992; Duval, 2012; Bawiec and Spanski, 2012). Selected simulation results are reported in table C8. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. C4). The cumulative frequency plot shows 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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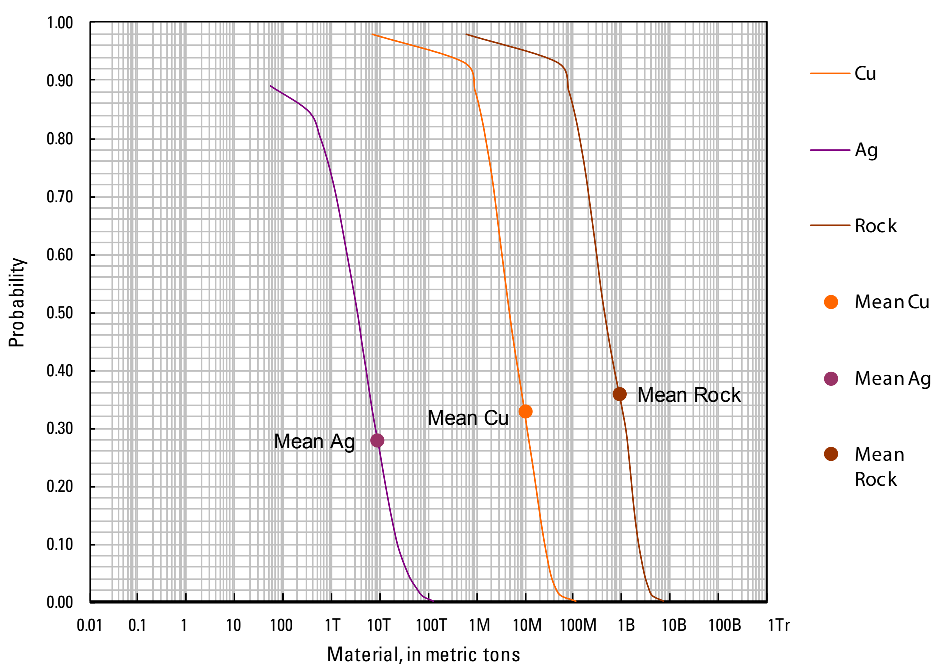

Figure C4. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 142ssCu8002 (CS-2), Kazakhstan.

Appendix D. Sandstone Copper Assessment for Tract 142ssCu8003 (CS-3), Central Kazakhstan

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Deposit Type Assessed

Deposit type: Sediment-hosted stratabound copper
Descriptive model: Sediment-hosted copper, Revett copper subtype (Cox and others, 2003)
Grade and tonnage model: Sediment-hosted stratabound copper, sandstone subtype (see appendix F)
Table D1 summarizes selected assessment results.

Table D1. Summary of selected resource assessment results for tract 142ssCu8003 (CS-3), central Kazakhstan.

[km, kilometers; km^2, square kilometers; t, metric tons]

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	28,226	0	8,000,000	3,200,000

Location

Central Kazakhstan, about 600 km south-southwest of the capital city of Astana (fig. D1).

Geologic Feature Assessed

Pennsylvanian strata in the northwestern part (Kokpansor sub-basin) of the Upper Devonian-Upper Permian Chu-Sarysu Basin, central Kazakhstan

[1]U.S. Geological Survey.

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

[3]Colorado School of Mines, Golden, Colorado.

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

Delineation of the Permissive Tract

Geologic Criteria

Tract CS-3 (fig. D1) includes the surface and subsurface extent of the Dzhezkazgan and Taskuduk Formations in the northwestern part of the Chu-Sarysu Basin (Kokpansor sub-basin), west of the major down-to-the-east Kokshetau Fault. The southern boundary of the Kokpansor sub-basin was taken as the north flank of the Buguldzhy Uplift (fig. 1), where the western continuation of the Arady Fault trends into the 2-km-below-sea-level contour of the base of the Pennsylvanian strata (CS-NCS_depth-base-mCarbonif.mxd; Syusyura and others, 2010). Because different levels of information are available for subareas with the tract, we divide the assessed tract into assessment subunits on figure D1 and these are discussed in more detail below.

Assessment Subunit 3a (South Kumoly)

Assessment subunit 3a is located at the northern end of tract CS-3 (fig. D1), where the north-northwest trending Kumola Synclinorium indents the margin of the Chu-Sarysu Basin (fig. 1).

Assessment Subunit 3b (Kyzylkak)

Assessment subunit 3b is located south of assessment subunit 3a, along the western basin margin (fig. D1), where three anticlinal culminations expose the Pennsylvanian red bed strata up to 35 km east of the western basin margin (CS-WCS-KY_geolmap.mxd; Syusyura and others, 2010).

Assessment Subunit 3c (Irkuduk)

Assessment subunit 3c is located close to the southern boundary of tract CS-3 along the western basin margin (fig. D1).

Assessment Subunit 3d

Assessment subunit 3d (fig. D1)includes the northern end of the north-northwest-plunging Tasty anticlinorium (fig. 1), the large central basin uplift.

Assessment Subunit 3e

Assessment subunit 3e includes the northward extension of the Tasty anticlinorium that was outlined in assessment subunit 3d (fig. D1).

Assessment Subunit 3f

Assessment subunit 3f includes all of the remaining area of tract CS-3 outside of the assessment subunits described above.

Known Deposits

Although no deposits are known in tract CS-3, deposits do occur to the northeast in tract CS-1 (Dzhezkazgan and associated deposits) and to the east in tract CS-2 (Zhaman-Aibat deposit).

Prospects, Mineral Occurrences, and Related Deposit Types

Assessment Subunit 3a (South Kumoly)

A number of copper prospects are known where the Pennsylvanian red bed horizon is exposed along the edge of the assessment subunit 3a (fig. D1, table D2). Soil sampling has revealed an almost continuous band of copper enrichment (Cu >0.01 percent) along the Taskuduk Formation exposed along the northern and eastern edge of the sub-basin (CS-KU_geolmap.mxd; Syusyura and others, 2010). Iron reduction to produce gray sandstone intervals also occurs discontinuously along the eastern and northern edges of the sub-basin, mostly within the Taskuduk Formation. Tremolite or sodic amphibole ("rhodusite" or magnesioriebeckite) occurrences within Permian strata in the central part of the Kumola synclinorium near the Kumola north and south prospects are interpreted to indicate that significant volumes of sodium-bearing brines moved through these rocks. Prognostic resources of 0.3 Mt Cu along the low-grade copper-mineralized Taskuduk Formation along the northern and eastern basin margins, and 0.5 Mt Cu in the basin subsurface in the vicinity of the Kumola north and south prospects were estimated in the upper 1 km of assessment subunit 3a (MEC, written commun., 2009).

Assessment Subunit 3b (Kyzylkak)

Two drill holes in assessment subunit 3b intercepted subeconomic copper mineralization (fig. D1, table D2). A few discrete gray iron-reduced sandstone beds occur in the vicinity of the western drill hole (U-23), whereas the eastern hole (U-22) penetrated more than 500 m of section with gray iron-reduced sandstones. Soil sampling from 3 to 8 km south of the western drill hole, where the overlying Permian strata are exposed, showed areas of copper enrichment (copper "halos" >0.006 percent; CS-WCS-KY_soilCu-anom.shp; Syusyura and others, 2010). Prognostic resources of 1.0 Mt Cu were estimated within assessment subunit 3b down to a depth of 1 km (MEC, written commun., 2009).

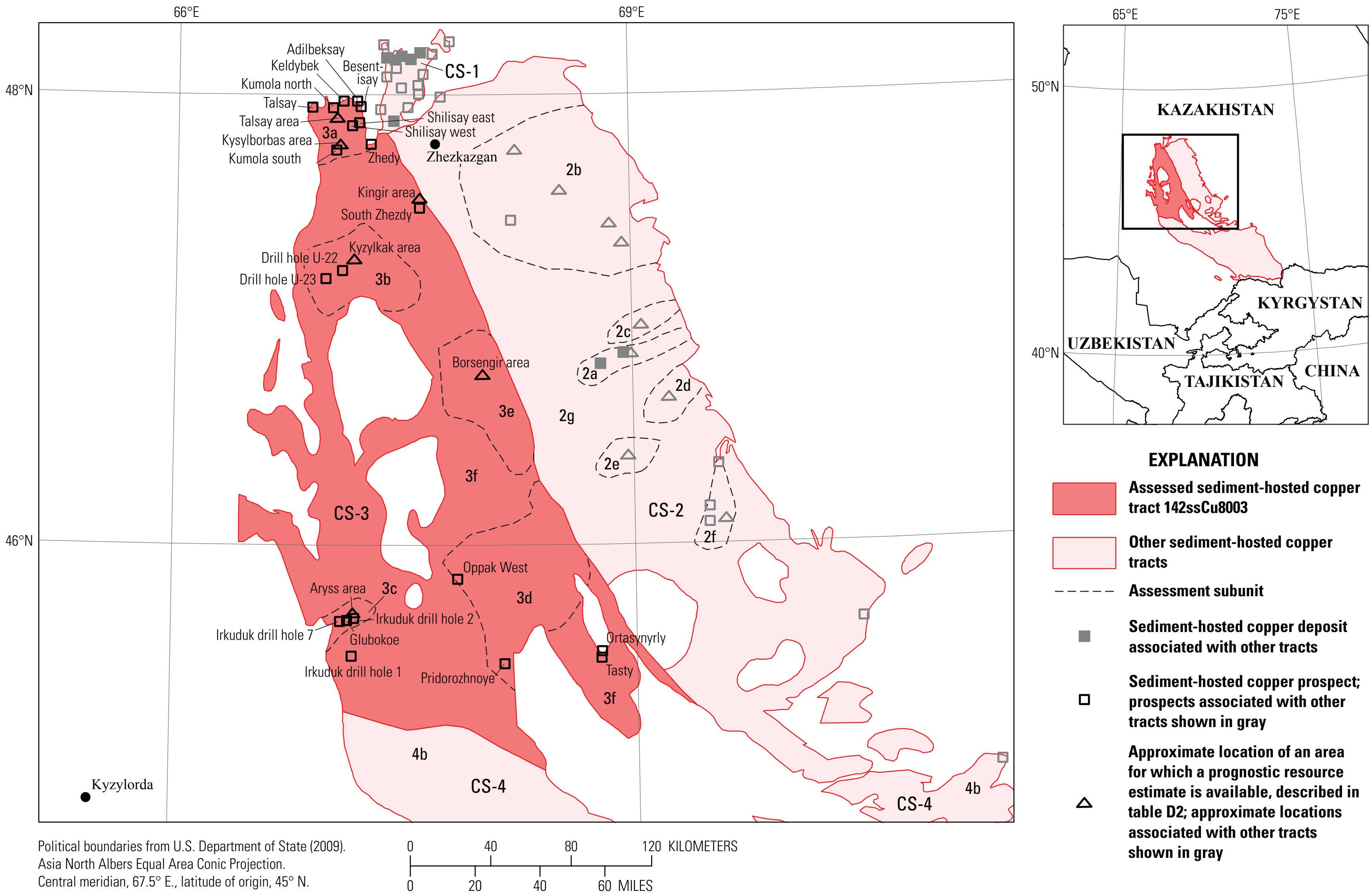

Figure D1. Location map for tract CS-3 and its known prospects in central Kazakhstan.

Table D2. Significant prospects, occurrences, and areas with prognostic resource estimates in tract 142ssCU8003 (CS-3), central Kazakhstan.

[For areas with prognostic resource estimates, latitude and longitude are provided for the centroid of each area named. m, meter; Mt; million metric tons; km2, square kilometers; MEC, Mining and Economic Consulting, Ltd.]

Name	Latitude	Longitude	Comments (grade and tonnage data, if available)	Reference
Talsay	47.945	66.892	Non-economic copper sandstone surface prospect in Taskuduk Formation	Syusyura and others, 2010
Keldybek	47.971	67.099	Non-economic copper sandstone surface prospect in Taskuduk Formation	Syusyura and others, 2010
Adilbeksay	47.972	67.191	Non-economic copper sandstone surface prospect in Taskuduk Formation	Syusyura and others, 2010
Besentisay	47.948	67.216	Non-economic copper sandstone surface prospect in Taskuduk Formation	Syusyura and others, 2010
Shilisay east	47.877	67.204	Non-economic copper sandstone surface prospect in Taskuduk Formation	Syusyura and others, 2010
Shilisay west	47.863	67.159	Non-economic copper sandstone sub-surface occurrences in Dzhezkazgan and Taskuduk Formations	Syusyura and others, 2010
Kumola north	47.945	67.031	Reduced-facies Cu shale surface prospect in Permian strata overlying ore target horizon	Syusyura and others, 2010
Kumola south	47.753	67.052	Reduced-facies Cu shale surface prospect in Permian strata overlying ore target horizon	Syusyura and others, 2010
Zhezdy	47.78	67.283	Non-economic copper sandstone surface prospect in Taskuduk Formation	Syusyura and others, 2010
South Zhezdy	47.497	67.606	Non-economic reduced-facies Cu shale occurrence in the Permian Kingir Formation	Syusyura and others, 2010; CS-NCS_pre-Mz-geolmap.mxd
Kingir area	47.538	67.605	2,000 km^2 area with P3 resources (0.8 Mt Cu)	Mining and Economic Consulting, Ltd. (MEC), written commun., 2009
Kysylborbas area	47.779	67.077	76 km^2 area with P3 resources (0.5 Mt Cu)	MEC, written commun., 2009
Talsay area	47.898	67.061	51 km^2 area with P3 resources (0.3 Mt Cu)	MEC, written commun., 2009
Drill hole U-22	47.220	67.097	Unknown length of 0.1% Cu intercept	Syusyura and others, 2010
Drill hole U-23	47.184	66.987	15 m of 0.2% Cu intercept	Syusyura and others, 2010
Kyzlkak area	47.269	67.174	1158 km^2 area with P3 resources (1.0 Mt Cu)	MEC, written commun., 2009
Glubokoe	45.667	67.133	Reduced-facies Cu shale occurrence	Syusyura and others, 2010
Aryss area	45.696	67.169	Broad area (3–4 times the area of 3c) noted as containing 1.0 Mt Cu in P2 resources	Republic of Kazakhstan, 2008
Irkuduk drill hole 7	45.661	67.088	Vein-type copper along fault has narrow interval of 3% Cu	Syusyura and others, 2010
Irkuduk drill hole 2	45.676	67.177	Subeconomic Cu mineralization in Fe-reduced sandstone beds	Syusyura and others, 2010
Irkuduk drill hole 1	45.508	67.163	Four levels of subeconomic Cu mineralization in 10 m thick zones	Syusyura and others, 2010
Oppak West	45.850	67.847	Producing natural gas field in Upper Devonian and Mississippian carbonates	Syusyura and others, 2010
Pridorozhnoye	45.473	68.147	Producing natural gas field in Upper Devonian sandstone and Pennsylvanian limestone	Syusyura and others, 2010
Borsengir area	46.755	68.017	247 km^2 area with P3 resources (0.5 Mt Cu)	MEC, written commun., 2009
Ortasynyrly	45.527	68.773	Non-economic limestone-hosted Pb-Zn mineralization in drill intercept	Syusyura and others, 2010
Tasty	45.498	68.770	Non-economic copper sandstone subsurface occurrences in Dzhezkazgan and Taskuduk Formations	Syusyura and others, 2010

Assessment Subunit 3c (Irkuduk)

Three of seven drill holes in or near assessment subunit 3c yielded subeconomic indications of copper mineralization (fig. D1, table D2). Drill hole 7 has vein-type copper mineralization along a fault with up to 3 percent copper in narrow intervals. Drill hole 1, located south of the assessment subunit, cut four levels of subeconomic copper mineralization each up to 10 m thick in gray, iron-reduced sandstone horizons. Drill hole 2 also had iron-reduced sandstone and subeconomic copper mineralization, but in lesser amounts than drill hole 1. A reduced-facies copper-shale prospect (Glubokoe; fig. D1, table D2) occurs within the tract in Permian strata between drill holes 2 and 7, defining an apparent east-northeast mineralization trend.

Assessment Subunit 3d

This subunit has no known prospects, but two prospects occur just to the south of this subunit within the larger assessment subunit 3f. Those two nearby prospects (Ortasynyrly and Tasty) indicate that metal-bearing fluids have migrated through this area. However, extensive followup exploration in the immediate vicinity of those occurrences did not find evidence of economic mineralization. The presence of two producing natural gas fields (Oppak West and Pridorozhnoye) within this subunit, with gas production from Mississippian limestones below the Pennsylvanian red bed sequence being assessed, is taken as evidence for possible natural gas entrapments within the red bed sequence, which in turn might have caused ore precipitation that has not yet been identified.

Assessment Subunit 3e

No prospects or mineral occurrences are known in assessment subunit 3e. However, its position along the central basin anticlinorium, its position along the deeply penetrating Kokshetau Fault on its eastern flank, and its location 50–60 km west and along trend of the productive Zhaman-Aibat deposit are inferred to be favorable factors for the occurrence of undiscovered mineralization. These favorable characteristics led to estimation of prognostic P3 resources of 0.5 Mt Cu within the northern 20 percent of the tract down to 1 km (MEC, written commun., 2009).

Assessment Subunit 3f

This assessment subunit includes the Tasty prospect, a sandstone copper occurrence within the Dzhezkazgan Formation on the flank of the Tasty anticlinorium in the center of the Chu-Sarysu Basin, and the Ortasynyrly prospect, a lead-zinc occurrence nearby within Mississippian limestones along the tract boundary.

Exploration History

Assessment Subunit 3a (South Kumoly)

More than 50 drill holes occur within assessment subunit 3a (Syusyura and others, 2010), clustered along the edge of the sub-basin and in a couple of smaller areas within the deeper basin. Seismic profiling for oil exploration was used to define the structure of the sub-basin. The area lies immediately west of the supergiant Dzhezkazgan deposit, where modern mining has occurred for more than a century. The sub-basin lies within the current mining concession of Kazakhmys PLC, which operates the Dzhezkazgan and Zhaman-Aibat deposits. Surface exposures have been thoroughly explored, but large areas in the subsurface are untested.

Assessment Subunit 3b (Kyzylkak)

Assessment subunit 3b has been explored with a seismic survey spaced on 4–5 km intervals and with 1:50,000 gravity and magnetic surveys. Shallow prospect drilling was undertaken on a 4- by1-km grid, and 12 drill holes were completed in the 1960s and mid-1990s. The western part of the tract was covered by a 1:50,000 scale lithogeochemical soil survey. The area is noted as containing potential resources on the Republic of Kazakhstan Ministry of Energy and Mineral Resources map of mining concessions and potential mineral-resource areas (Republic of Kazakhstan, 2008).

Assessment Subunit 3c (Irkuduk)

Assessment subunit 3c has seismic data that covers only about 40 percent of the tract (south and east), so the structure of the northern and western parts should be considered uncertain. Five drill holes are known in the tract, three of which are known to contain copper occurrences. Gravity and magnetic maps cover the area. The area is noted as containing potential resources on the Republic of Kazakhstan Ministry of Energy and Mineral Resources map of mining concessions and potential mineral-resource areas (Republic of Kazakhstan, 2008).

Assessment Subunit 3d

Twenty wells are known from assessment subunit 3d, mostly gas exploration holes (two gas fields occur within the tract and are listed in table D2). Considerable drilling occurred around the two drill holes that intercepted base-metal mineralization, but no more mineralization was encountered and that area is now considered to be of low potential. The northern extension of the Tasty uplift has not been tested adequately.

Assessment Subunit 3e

Eight oil and gas exploration drill holes are known from assessment subunit 3e. Adequate seismic, gravity and magnetic surveying over the tract allows for good understanding of the structure of the tract. It is uncertain if any sampling for copper has occurred in any of these drill holes.

Assessment Subunit 3f

Some parts of assessment subunit 3f have been explored by surface sampling, oil and gas drilling, or mineral-exploration drilling (Syusyura and others, 2010), but most of this large tract essentially is untested. For the most part, this tract represents those areas of the northern Chu-Sarysu Basin that have not had exploration activities specific to evaluation of sediment-hosted copper prospects. The area has been covered by regional exploration related to oil and gas in or below the host horizon for the sediment-hosted copper deposits and by exploration for uranium in overlying units.

Sources of Information

Principal sources of information used by the assessment team for delineation of CS-3 are listed in table D3.

Grade and Tonnage Model Selection

The lithology and grain size of the rocks, along with evidence consistent with the presence of liquid or gaseous hydrocarbons, indicate that the tract should be assessed for sandstone copper deposits. Seventy sandstone copper deposits from around the world were selected to create the tonnage and grade model for resource estimation (appendix F). Student's *t*-test indicates deposits in the Chu-Sarysu Basin cannot be distinguished statistically from other deposits that make up the grade and tonnage model.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Estimates were made by the assessment team for each of the assessment subunits based on the data summarized above. The consensus estimate of numbers of undiscovered deposits for each of the assessment subunits is given in table D4. Those consensus estimates were aggregated statistically using the correlation matrix specified in table D5, representing the level of correlation between assessment subunits (Schuenemeyer and others, 2011). The aggregated estimate for the number of undiscovered deposits in the entire tract is given in table D6.

Although tracts CS-2 and CS-3 are similar in size and in geologic characteristics, there are a few indications that led the assessors to be less optimistic about the estimated number of undiscovered deposits in tract CS-3 than in tract CS-2. First, there are no known deposits within tract CS-3 (although the supergiant Dzhezkazgan deposit borders the northeastern corner of this tract). Second, the structure of the northwestern part of the Chu-Sarysu Basin (CS-3) is more complex than that in the northeastern part (CS-2), and there is more uncertainty in predicting how that might have influenced the migration and upwelling of any mineralizing brines. Third, Devonian lavas, a potential source of copper to the mineralizing brines, are known to occur under the northeastern part of the basin, but are absent or thin under the northwestern part of the basin. These factors led to the somewhat lower deposit estimates and to a higher uncertainty level for the northwestern sub-basin (tract CS-3), reflected in its lower estimated-deposit density and its higher coefficient of variance than those of tract CS-2.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered sandstone copper deposits (table D6) with the sandstone copper model (appendix F) using the Economic Mineral Resource Simulator (EMINERS) program (Root and others, 1992; Duval, 2012; Bawiec and Spanski, 2012). Selected simulation results are reported in table D7. Results of the Monte Carlo simulation are presented as a cumulative frequency plots (fig. D2). 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 D3. Principal sources of information used by the assessment team for delineation of tract 142ssCU8003 (CS-3), central Kazakhstan.

Theme	Name or Title	Scale	Reference
Geology	CS-NCS_pre-Mz-geolmap.jpg; CS-NCS_depth-base-mCarbonif.mxd	1:500,000	Syusyura and others, 2010
Mineral occurrences	CS-NCS_deps-occurrences.shp	1:500,000	Syusyura and others, 2010
Geochemistry	CS-KU_Cu-geochem-halos.shp; CS-WCS-KY_soilCu-anom.shp; CS-IR_mineral-leaching.shp	1:50,000	Syusyura and others, 2010
Geophysics	CS_gravity.jpg; CS_seisprofile-borehmap.jpg; CS-NCS_mag-intensity.jpg	1:500,000	Syusyura and others, 2010
Exploration	CS-NCS_ne-strat-columns.jpg; CS-NCS_boreholes.shp; Synopsis of prospective sediment-hosted copper targets, Chu-Sarysu Basin	1:500,000	Syusyura and others, 2010; Mining and Economic Consulting, Ltd., written commun., 2009

Table D4. Undiscovered deposit estimates for individual assessment subunits, tract 142ssCu8003 (CS-3), central Kazakhstan.

[N_{xx}, estimated number of deposits associated with the xxth percentile]

Assessment subunit	Estimated number of undiscovered deposits				
	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
3a	0	1	1	1	2
3b	0	1	2	3	4
3c	0	2	4	6	6
3d	0	0	3	4	6
3e	0	1	3	5	10
3f	0	2	2	5	5

Table D5. Correlation matrix used to combine undiscovered deposit estimates statistically for assessment subunits in tract 142ssCu8003 (CS-3), central Kazakhstan.

	3a	3b	3c	3d	3e	3f
3a (Kumoly)	1					
3b (Dyusembay-Kyzylkak)	0.2	1				
3c (Irkuduk)	0.2	0.2	1			
3d (Tasty south)	0.2	0.4	0.5	1		
3e (Tasty north)	0.2	0.2	0.2	0.6	1	
3f (Chu-Sarysu north, beyond)	0.2	0.2	0.2	0.2	0.2	1

Table D6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 142ssCu8003 (CS-3), central Kazakhstan.

[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}, expected number of undiscovered deposits plus known deposits; area, area of permissive tract; deposit density, number of deposits per 10,000 km^2; m, meters; km^2, square kilometers. N_{und}, s, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Aggregated undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
3	7	15	18	24	8.4	5.8	69	0	8.4	28,226	3.0

Table D7. Results of Monte Carlo simulations of undiscovered resources in tract 142ssCu8003 (CS-3), central Kazakhstan.

[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)	150,000	400,000	3,200,000	23,000,000	31,000,000	8,000,000	0.30	0.03
Ag (t)	0	0	2,100	20,000	33,000	7,300	0.26	0.18
Rock (Mt)	12	33	280	2,000	2,600	710	0.33	0.03

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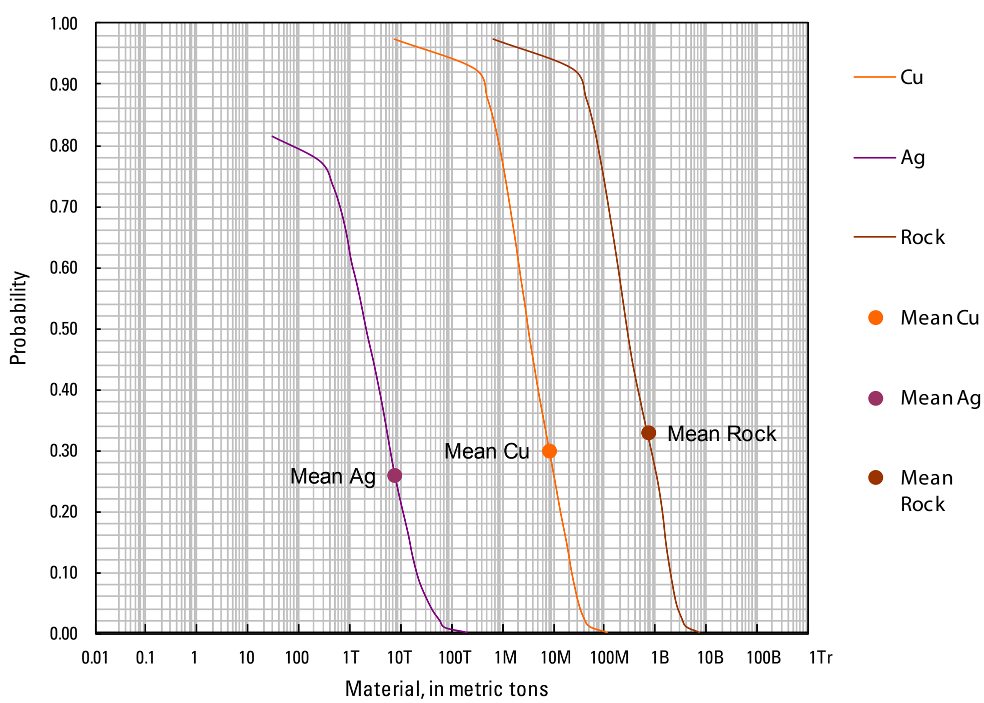


Figure D2. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 142ssCu8003 (CS-3), Kazakhstan.

Appendix E. Sandstone Copper Assessment for Tract 142ssCu8004 (CS-4), central Kazakhstan

By Stephen E. Box[1], Alla Dolgopolova[2], Timothy S. Hayes[1], Murray W. Hitzman[3], Reimar Seltmann[2], Boris Syusyura[4], Cliff D. Taylor[1], and Michael L. Zientek[1]

Deposit Type Assessed

Deposit type: Sediment-hosted stratabound copper.
Descriptive model: Sediment-hosted copper, Revett copper subtype (Cox and others, 2003).
Grade and tonnage model: Sediment-hosted stratabound copper, sandstone subtype (see appendix F).
Table E1 summarizes selected assessment results.

Table E1. Summary of selected resource assessment results for tract 142ssCu8004 (CS-4), central Kazakhstan.

[km, kilometers; km^2, square kilometers; t, metric tons]

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	64,855	0	2,100,000	210,000

Location

Central Kazakhstan, about 800 km south of the capital city of Astana.

Geologic Feature Assessed

Pennsylvanian strata within the southern part (Muyunkum sub-basin) of the Upper Devonian-Upper Permian Chu-Sarysu Basin, central Kazakhstan.

[1]U.S. Geological Survey.

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

[3]Colorado School of Mines, Golden, Colorado.

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

Delineation of the Permissive Tract

Geologic Criteria

Tract CS-4 includes the full extent of the Dzhezkazgan and Taskuduk Formations shallower than 2 km (based on elevation of base of Permian salt shallower than 1.6 km; Syusyura and others, 2010) within the southern half of the Chu-Sarysu Basin. Because different levels of information are available for subareas with the tract, we divide the assessed tract into assessment subunits on figure E1. Assessment subunit 4a delineates an area along an east-northeast trending anticline; assessment subunit 4b constitutes the remainder of the tract.

Known Deposits

There are no known deposits in tract CS-4.

Prospects, Mineral Occurrences, and Related Deposit Types

Assessment Subunit 4a

Four drill holes define a 10-km-long trend of uneconomic copper mineralization in the Taskuduk Formation on the flank of an east-northeast trending anticline (fig. E1, table E2). Copper grades in the mineralized intervals are less than 0.1 percent over a few meters, except for one intercept of 3 m of 0.2 percent copper. The mineralized and iron-reduced interval is only partially penetrated in three of the holes, where it is up to 260 m thick. The Maldybay gas field, with gas hosted in the Taskuduk Formation, occupies the axis of the next parallel anticline to the south, within about 10 km of the weak copper mineralized trend.

Assessment Subunit 4b

Assessment subunit 4b is the portion of the tract CS-4 that does not include subunit 4a. Several natural gas fields (Barkhannoye, Amangeldy, Ayrakty, Kumyrly, Usharal Kemprtobe, and Usharal North) occur in the central part of this assessment subunit (some in production, some being developed for future production) and are hosted in part by sandstones of the Taskuduk Formation. These fields are localized in anticlinal culminations along a 100-km east-northeast trend extending from the southwestern end of assessment subunit 4a.

Exploration history

The northeastern quarter of tract CS-4 has been explored extensively for oil and natural gas, based on a basin-wide map of seismic profiles and associated stratigraphic test wells (CS_seisprofile-borehmap.mxd; Syusyura and others, 2010). Within that northeastern quarter, assessment subunit 4a is moderately well explored, with 16 known oil and gas drill holes and 7 mineral exploration drill holes. A seismic profile grid covers most of assessment subunit 4a. Two producing gas fields occur within the assessment subunit and are hosted in sandstone or carbonate lithologies within the lower part of the ore target horizon near and parallel to the subunit’s southeastern margin.

Seismic profiling and drilling are spaced widely over the rest of the tract, so most of assessment subunit 4b essentially is untested. Most of the exploration activities appear to be related either to oil and gas evaluation at or below the host horizon for the sediment-hosted copper deposits, or to exploration for uranium in overlying units. It is unknown whether any exploration has focused on the discovery of sediment-hosted copper deposits within the Pennsylvanian red bed units that localize the sediment-hosted copper deposits elsewhere in the Chu-Sarysu Basin.

Sources of Information

Principal sources of information used by the assessment team for delineation of tract CS-4 are listed in table E3.

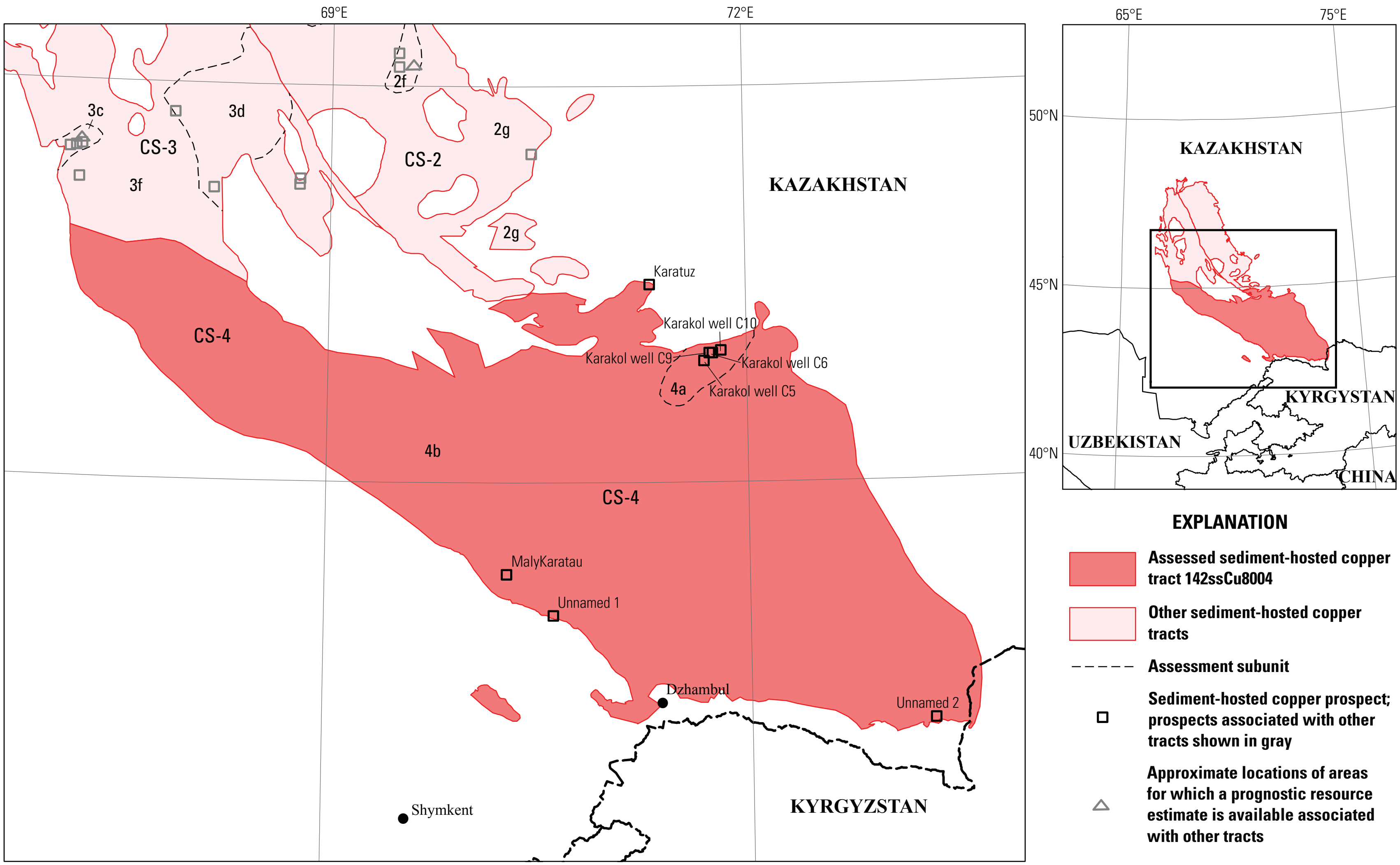
Grade and Tonnage Model Selection

The lithology and grain size of the rocks, along with evidence consistence with the presence of liquid or gaseous hydrocarbons, indicate the tract should be assessed for sandstone copper deposits. Seventy sandstone copper deposits from around the world were selected to create the tonnage and grade model for resource estimation (appendix F). Student’s *t*-test indicates deposits in the Chu-Sarysu Basin cannot be distinguished statistically from other deposits that make up the grade and tonnage model.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Estimates were made by the assessment team for both assessment subunits based on the data summarized above. The consensus estimate of numbers of undiscovered deposits for each



Political boundaries from U.S. Department of State (2009).
Asia North Albers Equal Area Conic Projection.
Central meridian, 70.5° E., latitude of origin, 45° N.

Figure E1. Location map for tract 142ssCu8004 (CS-4) and its known prospects in central Kazakhstan.

Table E2. Significant prospects and occurrences in tract 142ssCu8004 (CS-4), central Kazakhstan.

[m, meter; %, percent; all data from Syusyura and others, 2010]

Name	Latitude	Longitude	Comments (grade and tonnage data, if available)
Karakol well C5	44.614	71.694	~40 m interval of gray-altered Taskuduk Formation
Karakol well C6	44.654	71.755	3 m of 0.2% Cu, 6 m of 0.08% Cu, and 2 m of 0.06% Cu in >260 m interval of gray-altered Taskuduk Formation
Karakol well C9	44.653	71.732	3 m of 0.04% Cu in >130 m interval of gray-altered Taskuduk Formation
Karakol well C10	44.666	71.814	>135 m interval of gray-altered Taskuduk Formation
Karatuz	44.999	71.305	Non-economic copper sandstone occurrence in Taskuduk Formation
MalyKaratau	43.537	70.283	Non-economic copper occurrence in Pennsylvanian sandstone
Unnamed 1	43.330	70.610	Non-economic copper occurrence in Carboniferous strata of uncertain type
Unnamed 2	42.791	73.275	Non-economic copper occurrence in Carboniferous strata of uncertain type

Table E3. Principal sources of information used by the assessment team for delineation of tract 142ssCu8004 (CS-4), central Kazakhstan.

[NA, not available]

Theme	Name	Scale	Citation
Geology	CS_elev-base-mCarbonif.mxd	1:500,000	Syusyura and others, 2010
Mineral occurrences	CS-NCS_deps-occurrences.shp	1:500,000	Syusyura and others, 2010
Geochemistry	NA	NA	NA
Geophysics	CS_gravity.mxd; ussr_mag_2500m.grd;	1:500,000	Syusyura and others, 2010
Exploration	CS_seisprofile-borehmap.mxd	1:500,000	Syusyura and others, 2010

of the assessment subunits is given in table E4. Those consensus estimates were aggregated statistically using the correlation matrix specified in table E5, representing the level of correlation between assessment subunits (Schuenemeyer and others, 2011). The resultant consensus aggregated estimate for the number of undiscovered deposits in the entire tract is given in table E6.

Several factors led the assessment team to estimate a much lower number of undiscovered deposits for the southern part of the Chu-Sarysu Basin, as compared with the other tracts in the basin. This is based primarily on the lack of known sandstone copper deposits in that part of the basin and the few known prospects. Factors that are viewed as favorable to the presence of undiscovered deposits in the southern part of the Chu-Sarysu Basin are: (1) the similarity in the ore horizon lithology, stratigraphy, and structural geology to that in the northern assessment subunits; (2) the presence of evaporitic salt depocenters in both the Devonian and the Permian sections; and (3) the abundance of natural gas fields in anticlinal traps within the Pennsylvanian red bed sequence. Because of the above factors, the assessment team estimated a deposit density in the southern part of the basin that is an order of magnitude less than was estimated for either the northeastern or northwestern parts of the basin. The coefficient of variation for tract CS-4 is twice as high as that of tract CS-3 and four times as high as that of tract CS-2.

Probabilistic Assessment Simulation Results

Undiscovered resources for tract CS-4 were estimated by combining consensus estimates for numbers of undiscovered sandstone copper deposits (table E6) with the sandstone copper model (appendix F) using the Economic Mineral Resource Simulator (EMINERS) program (Root and others, 1992; Duval, 2012; Bawiec and Spanski, 2012). Selected simulation results are reported in table E7. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. E2). The cumulative frequency plot shows the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table E4. Undiscovered deposit estimates for individual assessment subunits, tract 142ssCu8004 (CS-4), central Kazakhstan.

[N_{xx}, estimated number of deposits associated with the xxth percentile]

Assessment subunit	Estimated number of undiscovered deposits N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
4a	0	0	1	4	6
4b	0	1	3	6	6

Table E 5. Correlation matrix used to combine undiscovered deposit estimates statistically for assessment subunits in tract 142ssCu8004 (CS-4), central Kazakhstan.

	4a	4b
4a	1	
4b	0.2	1

Table E6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 142ssCu8004 (CS-4), central Kazakhstan.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, expected number of undiscovered deposits plus known deposits; area, area of permissive tract; deposit density, number of deposits per 10,000 km^2; m, meters; km^2, square kilometers. N_{und}, s, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Aggregated undiscovered deposit estimate						Summary statistics				Area (km^2)	Deposit density
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
0	1	5	7	10	2.1	2.7	130	0	2.1	64,855	0.3

Table E7. Results of Monte Carlo simulations of undiscovered resources in tract 142ssCu8004 (CS-4), central Kazakhstan.

[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	0	210,000	5,500,000	13,000,000	2,100,000	0.18	0.29
Ag (t)	0	0	0	3,800	9,800	1,800	0.15	0.63
Rock (Mt)	0	0	18	600	1,300	190	0.18	0.29

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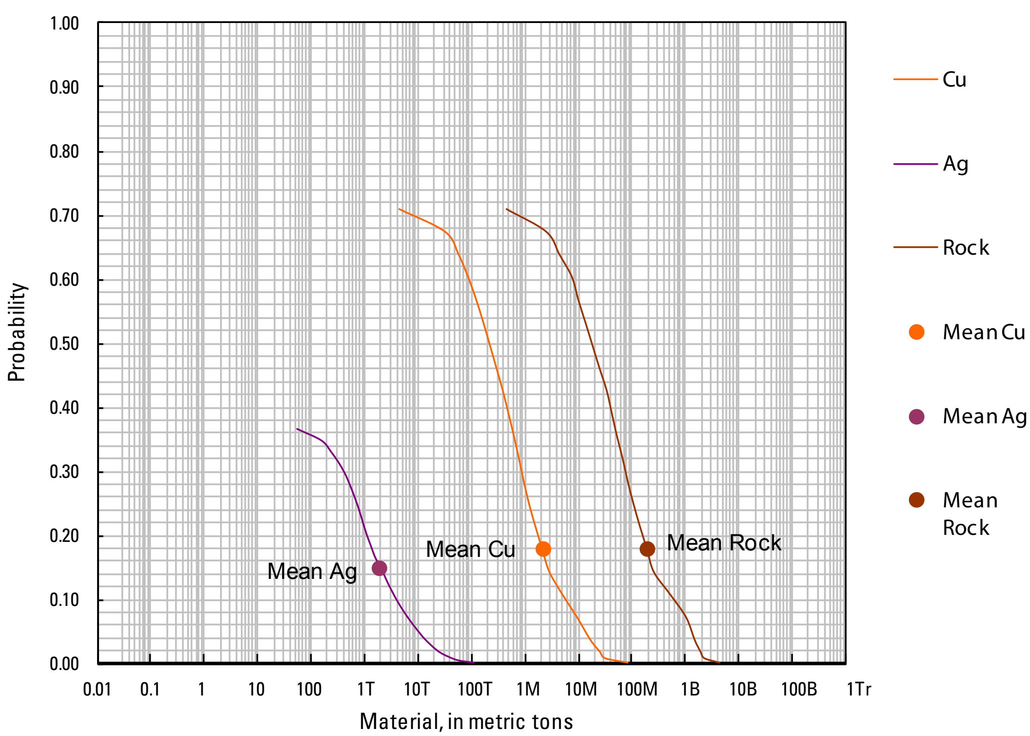

Figure E2. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 142ssCU8004 (CS-4), central Kazakhstan.

Appendix F. Deposit Data Used to Develop a Grade and Tonnage Model for Sandstone Copper Deposits

Table F1. Table of deposits (*n* = 70), and their tonnages and metal grades, used to develop a grade and tonnage model for sandstone copper deposits.

[*, site includes multiple deposits that were aggregated using a 500-m spatial separation rule; DRC, Democratic Republic of the Congo; n.d., no data]

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

Table F1. Table of deposits (*n* = 70), and their tonnages and metal grades, used to develop a grade and tonnage model for sandstone copper deposits.—Continued

[*, site includes multiple deposits that were aggregated using a 500-m spatial separation rule; DRC, Democratic Republic of the Congo; n.d., no data]

Deposit name	Site	Country	Ore (metric tons)	Copper grade (percent)	Silver grade (grams per metric ton)
Mokambo North		Zambia	3,854,000	1.70	n.d.
Mokambo Project—Mokambo South	*	Zambia	20,900,000	1.64	n.d.
Moudin		China	14,414,063	1.28	n.d.
Mufulira		Zambia	332,586,652	2.66	n.d.
Mutundu North		Zambia	4,300,000	1.44	n.d.
Mwambashi B		Zambia	14,210,000	1.78	n.d.
Mwerkera		Zambia	7,100,000	1.53	n.d.
Ndola East		Zambia	40,000,000	0.76	n.d.
Niagara		United States	17,000,000	0.47	16.0
Norah		Zimbabwe	10,000,000	1.20	n.d.
Nsato		Zambia	8,400,000	1.61	n.d.
Oamites		Namibia	6,100,000	1.33	12.3
Okasewa		Namibia	6,000,000	1.80	n.d.
Pitanda South		Zambia	7,060,000	1.58	n.d.
Qingshuihe		China	969,136	1.62	n.d.
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	n.d.
Sebembere		Zambia	5,700,000	1.70	n.d.
Sentinel		United States	4,465,000	0.40	n.d.
Shackleton		Zimbabwe	3,400,000	1.20	n.d.
Shimenkan		China	1,000,000	1.09	n.d.
Silverside		Zimbabwe	900,000	1.80	n.d.
Spar Lake		United States	80,600,000	0.63	46.0
Tordillos		Argentina	9,350,000	0.42	n.d.
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	n.d.
West Sary Oba		Kazakhstan	86,200,000	0.89	n.d.
Witvlei Pos		Namibia	2,800,000	1.50	n.d.
Zhaman-Aibat		Kazakhstan	193,000,000	1.40	16.0
Zhangjiachunsh-engjiping		China	1,836,735	0.98	n.d.

Appendix G. Description of GIS Files

A single file geodatabase and a representative ESRI map document (.mxd) are included with this report. The file geodatabase comprises one feature dataset within which there are three feature classes. These files and associated support documents may be downloaded from the USGS Web site as zipped file **SIR2010-5090-E_gis.zip**.

The feature classes are as follows:

CS_Assessed_Tracts describes the permissive tracts with respect to their shared spatial relationships and to both the subunits and all deposit and prospect point locations. Attributes include the tract identifiers, tract name, a brief description of the basis for tract delineation, and assessment results. Attributes are defined in the metadata that accompanies the feature class and data package.

CS_Assessed_Tracts_Subunits describes assessment subunits. Assessment subunits are areas within assessed tracts that have been the target of some exploration activities and are, therefore, more prospective. Attributes are defined in the metadata that accompanies the feature class and data package.

CS_Deposits_Prospects_AreasPrognosticResourceEstimate holds point locations for known deposits (identified resources that have well-defined tonnage and copper grade), prospects and areas with prognostic resource estimates. The deposits and prospects are listed in appendix F of this report. Attributes include the assigned tract, alternate site names, information about grades and tonnages, age, mineralogy, site status, comments fields, data sources and references. Attributes are defined in the metadata that accompanies the feature class and data package.

These data are included in an ESRI map document (ESRI ArcMAP 10.0, ArcGIS Desktop 10 Service pack 4): **GIS_SIR2010-5090-E.mxd**.

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