Abstracts of presentations by *EMERSC* scientists at GSA meeting, Denver, Oct 28-30, 2013

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Shown in order of presentation date/time

Paper No. 109-11, Session No. 109: Geophysical/Remote Sensing Characterization of Rare Earth Element and Other Critical Mineral Deposits, Monday, 28 October 2013: 8:00 AM-12:00 PM

Presentation Time: 11:10 AM

SPECTRAL FEATURES OF THE KHANNESHIN CARBONATITE VOLCANO, AFGHANISTAN

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Advanced Spaceborne Thermal and Reflection Radiometer (ASTER) data were used to identify and map carbonate rocks within the early Quaternary Khanneshin carbonatite volcano located in southern Afghanistan. The carbonatitic rocks are characterized by CO3 absorption features near 11.2 micrometers and 2.31-2.33 micrometers. Some of the carbonatite flows at Khanneshin contain neodymium Rare-Earth-Element (REE) spectral absorption features in the 0.45 to 0.54 micrometer region measured from samples collected in the field on an Analytical Spectral Devices spectrometer.

Calcitic and ankeritic carbonatite were identified and mapped using the short wave infrared (SWIR) region of the ASTER data due to a slight shift of the CO3 absorption feature toward 2.26 micrometers (ASTER band 7) in the ankeritic carbonatite spectra. Spectral assessment using ASTER SWIR data suggests that the area is covered by extensive carbonatite flows that contain calcite, ankerite, and muscovite, though some areas mapped as ankeritic carbonatite on a pre-existing geologic map were not identified in the ASTER data. A contact aureole shown on the geologic map was defined using an ASTER false color composite image (R=6, G=3, B=1) and a logical operator byte image. The contact aureole rocks exhibit Fe2+, Al-OH, and CO3 spectral absorption features at 1.65, 2.2 and 2.33 micrometers, respectively, which suggest that the contact aureole rocks contain muscovite, epidote, and chlorite.

Visible through short-wave infrared spectral features were used to map: (1) laterally extensive calcitic carbonatite that covers most of the crater and areas northeast of the crater; (2) ankeritic carbonatite located southeast and north of the crater and some small deposits located within the crater; (3) agglomerate that primarily covers the inside rim of the crater and a small area west of the crater; (4) a crater rim that consists mostly of epidote-chlorite-muscovite-rich metamorphosed argillite and sandstone; and (5) iron (Fe3+) and muscovite-illite-rich rocks and iron-rich eolian sands surrounding the western part of the volcano. Thermal infrared spectral features were used to map laterally extensive carbonatitic and mafic rocks surrounded by quartz-rich eolian and fluvial reworked sediments.

Paper No. 173-15, Session No. 173, Sediment-Hosted Base Metal Deposits, on Monday, 28 October 2013: 1:00 PM-5:00 PM……..Presentation Time: 4:45 PM

THE ORIGIN OF VANADIUM HYPER-ENRICHED BLACK SHALES

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Vanadium is a critical transition metal utilized in the production of high-strength steel, chemical catalysts, and vanadium redox flow batteries, a promising technology for large-scale storage of electricity generated by renewable and intermittent sources such as wind and solar. Vanadium concentrations of 100 to 200 ppm are common in reduced sediments deposited throughout Earth's history, but some Phanerozoic black shales are hyper-enriched, with concentrations ranging from 1,000 to 10,000 ppm. These concentrations are within the range of vanadiferous titanomagnetite deposits that are currently the principal source of vanadium. Vanadium is the second most abundant transition metal in seawater and the vanadium in hyper-enriched black shales is likely derived from normal seawater under a specific suite of environmental conditions. However, because vanadium hyper-enrichment does not occur in modern sediments, one or more crucial environmental variables must be absent. To identify the missing variables, we compare theoretical considerations of vanadium speciation and complexation to the geochemistry of modern marine environments and Phanerozoic black shales, with a focus on the Upper Mississippian Heath Formation. A survey of Phanerozoic black shales demonstrates that hyper-enrichments are associated with euxinic conditions. The absence of hyper-enrichment in the euxinic Cariaco Basin, Venezuela suggests that the accumulation of high concentrations of H2S (>60 µM) in the water column is required to reduce V4+ to V3+, consistent with laboratory studies of vanadium reduction by H2S. Because dissolved organic matter can form complexes with V4+, preventing further reduction, low concentrations of dissolved organic matter are also required. V3+ is primarily hosted by organic matter and/or authigenic clays, rather than sulfide minerals. Our detailed study of the Heath Formation suggests that a sharp and fluctuating redoxcline may also be required. Beyond the economic potential of hyper-enriched shales, their identification in the rock record has the potential to provide valuable information on environmental variables unique to the Phanerozoic.

Session No. 207. Evolution of REE-Enriched Carbonatite-Alkalic Rock Systems: In Honor of Daniel R. Shawe, Tuesday, 29 October 2013: 8:00 AM-12:00 PM -------- Paper No. 207-1, Presentation Time: 8:15 AM

A NEW LOOK AT IRON OXIDE-APATITE AND IRON OXIDE-COPPER-GOLD-RARE EARTH ELEMENT DEPOSITS IN THE MESOPROTEROZOIC ST. FRANCOIS MOUNTAINS TERRANE OF SOUTHEAST MISSOURI

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Large iron oxide-apatite (IOA) and iron oxide-copper-gold (IOCG) deposits in southeastern Missouri are hosted within ~1.47 Ga volcanic rocks of the St. Francois Mountains terrane. A current USGS project is studying these deposits using newly acquired data from U-Pb, Re-Os, and Ar-Ar geochronology, geophysics, whole rock and mineral chemistry, stable and radiogenic isotopes, and fluid inclusions. The deposits occur in the Eastern Granite-Rhyolite Province, near the western margin of a regional crustal boundary between eastern and western Proterozoic basements having TDM ages of <1.55 Ga and >1.55 Ga, respectively. Structural control by Proterozoic basement is suggested by broad spatial association of the deposits with northwest-trending gravity and magnetic anomalies. Some deposits are buried ca. 300-500 m beneath Cambrian sedimentary rocks. The IOA group includes the 136-Mt Pea Ridge, 30-Mt Iron Mountain, and 20-Mt lower Pilot Knob deposits, all of which are massive to brecciated bodies chiefly in rhyolite or trachyte, with magnetite being the predominant iron oxide mineral accompanied by minor apatite, albite, calcite, and sparse pyrite and chalcopyrite. Altered wall rocks, best developed at Pea Ridge, include zones rich in hematite, amphibole, K-feldspar, and/or quartz. Margins of the magnetite-apatite orebody at Pea Ridge also contain four unmined REE-rich breccia pipes that together constitute 600,000 t @ 12% REO having relatively high HREE/LREE ratios, abundant barite, and locally high Au (to 10.8 oz/t), Mo (to 1500 ppm), Sn (to 4090 ppm), Th (to 1.59 wt %), and U (to 610 ppm); REE reside in monazite, lesser xenotime and allanite, and sparse bastnäsite and synchysite. Stratiform hematite deposits, hosted in rhyolitic volcanic rocks, include upper Pilot Knob and Cedar Hill. The largest known IOCG deposit is Boss-Bixby (40 Mt @ 0.8% Cu with minor Co, Au, and REE) that occurs mainly in trachyte; the Bourbon Fe-Cu-REE-Th-U deposit may belong to the IOCG group.

Geological settings and nature of the IOA and IOCG deposits in southeast Missouri are similar to those in the Stuart Shelf region of South Australia and the Norbotten-Kolari region of northern Sweden and adjacent Finland. Significant potential exists for undiscovered REE-rich IOCG deposits in southeast Missouri, hidden under Cambrian sedimentary rocks.

Paper No. 207-4, Presentation Time: 9:00 AM

U-PB AND RE-OS GEOCHRONOLOGY OF REE-RICH BRECCIA PIPES FROM THE MESOPROTEROZOIC PEA RIDGE FE-REE-AU DEPOSIT, ST. FRANCOIS MOUNTAINS, MISSOURI

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Rare Earth Element (REE)-rich breccia pipes (600,000 t @ 12% REO) occur along the margins of the 136-Mt Pea Ridge magnetite-apatite deposit, within ~1.47 Ga volcanic-plutonic rocks of the St. Francois Mountains terrane of southeastern Missouri. Previous underground mapping has shown that the breccia pipes (ca. 50 x 200 m in cross-section) cut the host rhyolite, magnetite ore, and alteration zones associated with the iron-ore system. Two varieties of breccia pipes are recognized: “soft” (SBP; n=3) and “hard” (HBP; n=1).

Grains of monazite and xenotime were extracted from samples collected from both SBP and HBP for SHRIMP U-Pb geochronology; both minerals were also dated in a polished thin section from the HBP. Separated grains of monazite occur in two morphologies: (1) coarse granular grains composed of numerous small (<50 μm) crystallites, together with rare xenotime, thorite, apatite, and magnetite; and (2) coarse glassy, bright yellow grains similar to typical igneous and metamorphic monazite. In addition, zircon grains from two samples of rhyolite and two late, pre-breccia pipe, aplite dikes collected underground at Pea Ridge were dated.

Ages obtained by SHRIMP U-Pb analysis are: (1) SBP, pale yellow granular monazite—1464.9 ± 3.3 Ma; (2) HBP, reddish granular monazite—1461.2 ± 3.8 Ma, associated xenotime—1453 ± 11 Ma; (3) HBP, glassy yellow monazite—1464.8 ± 2.7, 1461.9 ± 2.5 Ma, and a few grains at 1447 ± 6 Ma; (4) HBP matrix monazite (in situ) 1462.9 ± 3.5 Ma, matrix xenotime (in situ) 1466 ± 13 Ma. The younger generation of glassy monazite coincides with a new Re-Os age of 1440.6 ± 9.2 Ma for fine-grained molybdenite that occurs within quartz and allanite in the HBP. Zircon from the two host rhyolite samples have SHRIMP U-Pb ages of 1473.6 ± 8.0 and 1472.7 ± 5.6 Ma, whereas the late aplites yield ages of 1480 ± 8 and 1477.1 ± 6.6 Ma, establishing the temporal framework of local igneous activity.

We propose that the granular grains of monazite and xenotime are fragments of REE-rich mineralization that predated brecciation, whereas the older of the two glassy monazite populations may have formed as new growth during emplacement of the breccia pipes. A second growth episode of glassy monazite (plus molybdenite) occurred at ca. 1443 Ma, possibly during faulting and fluid flow that rebrecciated the pipes.

Paper No. 223-16, Presentation Time: 9:00 AM-6:30 PM

GEOPHYSICAL SETTING OF IRON OXIDE-COPPER-COBALT-GOLD-RARE EARTH ELEMENT DEPOSITS OF SOUTHEAST MISSOURI

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The consensus among many workers is that the iron-copper-cobalt-gold-rare earth element (REE) deposits of southeast Missouri belong to the iron oxide-copper-gold (IOCG) family of mineral deposits. The deposits are hosted in Mesoproterozoic granite-rhyolite igneous basement rocks of the St. Francois Mountains terrane. The largest of the known concealed deposits is the Pea Ridge iron ore deposit, which contains rare earth element (REE)-rich minerals that occur in both breccia pipes and in apatite within magnetite ore. Key facets of the geologic setting, resource potential, and ages of these deposits remain uncertain owing to their poor exposure. Among the 12 known iron deposits and prospects, the majority are covered by a thick Paleozoic sedimentary sequence that blankets the basement surface. Depth to the top of mineralized deposits, prospects, and occurrences at Pea Ridge, Bourbon, Camel's Hump, Boss-Bixby, and Kratz Spring vary from 325 to 415 m below the topographic surface. However, the depth to and topography on the basement surface for much of the prospective terrane is poorly constrained and can range from a few hundred meters to more than 700 m in the southeast part of the study area. This year, the U.S. Geological Survey Mineral Resource Program began a three-year project to investigate the geological setting, origin, and geophysical signature of iron-copper-cobalt-gold-REE deposits in southeast Missouri. The geophysical component includes compilation and interpretation of existing magnetic and gravity data to determine overall basement architecture. The quality and resolution of the airborne magnetic and ground gravity data are adequate to establish where large basement features occur and are used to impart refinement on the present basement geologic map. Petrophysical measurements have been made on an inventory of several hundred drill core, surface, and underground mine samples collected by the USGS over the last decades. Data obtained on these samples are analyzed statistically to determine relationships between petrophysical properties and alteration assemblages, ore mineralogy, and chemistry. The petrophysical data will be used as input to a deposit scale 3-D geophysical model of the Pea Ridge Fe-REE deposit. Session No. 223--Booth# 16 Economic Geology (Posters)----Tuesday, 29 October 2013: 9:00 AM-6:30 PM

Session No. 236: Tuesday, 29 October 2013: 9:00 AM-6:30 PM – (Global rollout)

WHAT'S LEFT? HANDS ON WITH THE RESULTS OF THE FIRST GLOBAL MINERAL RESOURCE ASSESSMENT (DIGITAL POSTERS)

U.S. Geological Survey

Poster presentations in this session:

236-1 DP1

GLOBAL MINERAL RESOURCE ASSESSMENTS--WHO NEEDS THEM AND WHY?

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In response to growing concern about the sustainability of nonfuel mineral production and the simultaneous increase in demand for worldwide mineral-resource information and raw materials, the U.S. Geological Survey partnered with geological surveys and private sector companies from around the world to conduct the first geologically based global assessment of undiscovered copper, platinum-group element, and potash resources. The assessment provides (1) permissive areas (tracts) for undiscovered resources at 1:1,000,000 scale; (2) databases of known deposits and significant prospects; and (3) probabilistic estimates of the amounts of undiscovered material that could be contained in undiscovered deposits. Where possible, filtering has been used to define the part of the undiscovered resource that could be economic under current conditions. Regional assessment reports, available at http://minerals.usgs.gov/global/, include overviews and summaries of regions assessed; databases of tracts, deposits, significant prospects, and assessment results that can be incorporated into a geographic information system; and appendixes documenting the rationale, estimates, and references for each tract.

The results of this assessment are intended to (1) provide technical information for geoscientists interested in sources of undiscovered resources, (2) illustrate the likely extent of global availability of copper, platinum-group elements, and potash for both technical and nontechnical users, and (3) inform policy makers engaged in regional- to global-scale debate and decisions on topics as diverse as land use, biodiversity, and water resources. Successful planning and decisions about resource development will require a long term, global perspective and unbiased information on the worldwide distribution of identified and undiscovered resources. This study is the first to provide that worldwide information.

236-2 DP2

UNDISCOVERED PORPHYRY COPPER RESOURCES—A GLOBAL ASSESSMENT

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Porphyry copper deposits are the most significant source of copper on earth. Tracts permissive for Phanerozoic porphyry copper deposits were delineated in 176 areas of North and South America, Europe, Asia, and Oceania at a scale of 1:1 million. Tracts were constructed by analyzing geologic data at various scales to identify appropriate geologic settings for porphyry copper deposits (continental-margin arcs, island arcs, postconvergent magmatic belts). Tract areas range from about 1,000 to 1,000,000 km2 with a median of 40,000 km2. The tracts host 455 known deposits (with well-defined identified resources) that contain about 1.8 billion metric tons of copper, some of which has already been produced. About 30% of the tracts contain 3 or more known deposits, whereas about 30% of the tracts contain none. The assessment predicts a mean of 812 undiscovered deposits within the uppermost kilometer of the earth's surface. Results of combining estimates of numbers of undiscovered deposits with grade and tonnage models using Monte Carlo simulation on a tract by tract basis indicate that the estimated amount of copper (arithmetic mean) in undiscovered porphyry copper deposits is about 3.1 billion metric tons, which represents about 180 times 2012 global copper production from all types of copper deposits. The Andes region is a major source of both known and predicted deposits along with parts of Central America, the southwestern U.S. and northern Mexico, and Alaska. The Pacific margin areas of Russia and China, Tibet, the Central Asian Orogenic Belt of China and Mongolia, and the Philippines host about 60% of tracts that are estimated to contain 24 million metric tons of copper or more. Economic filters indicate that no more than 70% of the estimated resources may be economic, depending on assumptions about depth distributions of the deposits and local infrastructure. Permissive tracts, a database of deposits and prospects, and assessment results are available in a GIS.

236-3 DP3

A COLLISIONAL COLLAGE—GEODYNAMIC SETTINGS FOR PORPHYRY COPPER DEPOSITS IN SOUTHEAST ASIA, MELANESIA, AND EASTERN AUSTRALIA

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The southwestern Pacific region hosts world-class porphyry copper deposits (Batu Hijau, Grasberg, Cadia) that formed in a variety of tectonic settings: subduction-related magmatic arcs developed on continental or oceanic crust, postconvergent magmatic belts unrelated to an identified subduction zone, and composite/accreted arcs and belts. Permissive igneous map units that occur in these settings are the basis for delineating geographic areas (permissive tracts) for assessment of undiscovered porphyry copper deposits. Early Paleozoic orogenic events formed the Tasmanides of eastern Australia, where the Macquarie arc hosts nine porphyry copper deposits. Late Paleozoic subduction of the Paleotethyan Ocean and Mesozoic subduction of the Pacific Plate produced arcs of the Indochina Peninsula, none of which has been thoroughly explored. Igneous rocks associated with Cenozoic island arc-continent collisions, subduction-related magmatic arc systems (Sunda-Banda, Ambon, Halmahera, Sulawesi-Sangihe, Maramuni, Inner and Outer Melanesia), and postconvergent magmatic belts (Medial New Guinea, Central Kalimantan) define permissive tracts for Miocene-Pliocene porphyry copper deposits. Deposits are known in 18 of the 26 permissive tracts; these 47 deposits contain 100 million metric tons (Mt) of copper. An estimated 300 Mt or more of in-place copper in undiscovered deposits is predicted across the 26 tracts. About 40 Mt of undiscovered copper is estimated for a postconvergent belt that outlines hundreds of small Late Oligocene-Pliocene intrusions and volcanic rocks in Central Kalimantan; this tract, an area of active exploration, represents the most prospective tract in the study area. Other highly prospective tracts in the region outline composite arcs on the Indochina Peninsula, the accreted Macquarie island arc, a continental arc on Sumatra, and the postconvergent eastern Medial New Guinea Magmatic Belt. High costs may limit the economic viability of development in some areas.

236-4 , POST-CONVERGENT PORPHYRY COPPER DEPOSITS—WHAT, WHERE, WHY

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Geological Survey, Spokane, WA 99201 Although most porphyry copper deposits worldwide are the products of arc magmatism related to subduction of oceanic lithosphere, an important subset are not related directly to subduction. These porphyry copper deposits are similar to those found in magmatic arcs. The magmas that sourced the deposits are generally hydrous, oxidized, and calc-alkaline to alkaline; they show evidence for partial melting of protoliths that contained hornblende, as exemplified by relatively elevated (Sr/Y). However, the tectonic setting for the origin of these magmas is quite different than for those associated with subduction. Origins postulated for these magmas include 1) melting of thickened mafic lower crust or 2) delaminated lower crust, modified by the inclusion of varying amounts of mantle component or 3) melting of previously metasomatized mantle. Suggested triggers for these various styles of melting include 1) lithospheric thickening, 2) extension, 3) delamination, 4) aesthenospheric upwelling, or 5) translithospheric strike-slip and/or normal faulting.

The 60 post-convergent deposits that we have identified appear to have significantly higher Mo, Au, and Ag grades, although the Cu grade and tonnage distributions for these deposits are not significantly different than those for subduction-related deposits. The differences in Au and Ag grades in particular, are based on a few rich deposits, and we do not yet propose a separate grade and tonnage model.

These deposits are found throughout much of the world, and have ages ranging from Miocene to as old as Jurassic. The most important localities are the Jurassic and Early Cretaceous of Eastern China, the Tertiary of the Tibetan Plateau (Gangdese, Dali, and Yulong belts), the Tertiary of the western United States (Great Basin and Rocky Mountains), and the Tertiary of Eastern Europe (Northern Carpathians, Apuseni Mountains, and Aegean region). These and other areas may be the site of new discoveries of this recently recognized variety of porphyry deposit. We will explore the settings and characteristics of these deposits by comparing their characteristics to those of deposits formed in more conventional settings using the large databases compiled by the Global Mineral Resource Assessment Project of the USGS.

236-5 DP5

TECTONO-MAGMATIC EVOLUTION AND DISTRIBUTION OF PORPHYRY CU SYSTEMS IN THE CENTRAL TETHYS REGION OF TURKEY, THE CAUCASUS, IRAN, AND SOUTHERN PAKISTAN

ZURCHER, Lukas1, BOOKSTROM, Arthur A.2, ***HAMMARSTROM, Jane M.3,*** ***MARS, John C***.4, LUDINGTON, Steve5, ZIENTEK, Michael L.2, DUNLAP, Pamela1, and WALLIS, John C.2, (1) U.S. Geological Survey, Tucson, AZ 85745, lzurcher@usgs.gov, (2) U.S. Geological Survey, Spokane, WA 99201, (3) U.S. Geological Survey, 954 National Center, Reston, VA 20192, (4) U.S. Geological Survey, Reston, VA 20192, (5) U.S. Geological Survey, Menlo Park, CA 94025 Recent compilation of geodynamic, geochemical, geochronologic, and ore deposits data provided an opportunity to review the continental margin, intra-oceanic, and post-collisional tectonic settings in the Central Tethys Region. These settings formed during sequential rifting of microcontinents from the passive margin of Gondwana, their northward transport across the Neo-Tethys Ocean, and their collision with the active margin of Eurasia.

Integration of these data with the location of 41 identified porphyry Cu deposits—including the giant Reko Diq (Pakistan), and world-class Sar Cheshmeh (Iran), Sungun (Iran), and Kadjaran (Armenia) systems—and 317 porphyry Cu prospects shows that magmatism can be explained in terms of plate tectonic principles, including post-subduction processes, which also played a key role in porphyry generation. However, uplift and burial events also contributed to observed metallogenic patterns.

Twenty six partially overlapping Late Triassic to recent magmatic belts were recognized as permissive for porphyry mineralization. About 65% of all porphyry sites occur in only 5 belts, which also host most of the known Cu resources. 60% are related to continental arcs; 20% to island arcs or backarcs; and 20% to post-collisional settings. Of the known porphyry Cu deposits, sub-equal fractions are distributed among these three settings. As elsewhere around the world, the largest deposits occur in either compressional continental arc or extensional post-collisional environments.

Distribution of known porphyry occurrences is also related to the level of erosion currently exposed by the interaction of exhumation and burial processes. Magmatic belts with numerous known porphyries exhibit sub-equal areas of coeval plutonic and volcanic units and lesser cover rocks. Belts with fewer known porphyries display either high or low volcanic-to-plutonic ratios and/or greater cover, pointing to crustal levels that are too shallow or too deep for exposure of porphyry-related mineralization.

This study contributes to the understanding of the distribution and nature of magmatism and associated porphyry mineralization in the Central Tethys, a region that is receiving renewed attention. It also provides an improved framework for establishing comparisons with other porphyry belts worldwide.

236-6 DP6

USING ASTER REMOTE SENSING DATA IN A PORPHYRY COPPER ASSESSMENT

MARS, John C., U.S. Geological Survey, Reston, VA 20192, jmars@usgs.gov Advanced Spaceborne Thermal Emission and Reflection (ASTER) data were used to identify and characterize hydrothermal alteration patterns in Kazakhstan, Tajikistan, Uzbekistan and Kyrgyzstan as part of an assessment of undiscovered porphyry copper resources. ASTER data consist of three bands in the 0.52 - 0.86 micrometer wavelength region (VNIR); six bands in the 1.6 - 2.43 micrometer wavelength region (SWIR); and five bands of emitted radiation in the 8.125-11.65 micrometer wavelength region (TIR) with 15 m, 30 m, and 90 m resolution, respectively. Interactive Data Language logical operator algorithms were used to map Al-O-H, and quartz restrahlen spectral reflectance absorption features in hydrothermally altered rocks. Argillic and phyllic hydrothermally altered rocks were mapped using 225 scenes of ASTER data at 30 m spatial resolution, and hydrothermal silica-rich rocks were mapped in 150 scenes at 90 m spatial resolution.

The resulting ASTER hydrothermal alteration mineral map of the region typically consists of elliptical to circular patterns of argillic- and phyllic-altered rocks with minor amounts (< 10 percent) of hydrothermal silica-rich rocks. The shape of these ASTER alteration patterns in Kazakhstan are similar to hydrothermal alteration patterns of known porphyry copper deposits in the Central Iranian Volcanic Belt, which are consistent with predicted patterns in variably exhumed porphyry copper deposit models. Thus, matching similar ASTER alteration patterns to alteration signatures of known porphyry copper deposits provided a powerful tool for identifying the location and estimating numbers of undiscovered deposits over large areas over which the porphyry copper assessment was conducted.

A total of 302 potential porphyry copper sites were identified with the ASTER hydrothermal alteration maps, with 240 potential sites located in tracts permissive for porphyry copper mineralization. Mineral databases indicated that of the 240 potential porphyry copper sites selected using ASTER data, approximately 60 sites are associated with known copper mineralization. The 180 potential porphyry sites not associated with copper mineralization would not have been included in the assessment if ASTER data and analysis had not been used.

236-8 DP8

DATA AVAILABILITY AND QUALITY – A TALE OF TWO ASSESSMENTS

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236-9 DP9

THE ROLE OF GIS IN THE GLOBAL MINERAL-RESOURCE ASSESSMENT—A PORPHYRY COPPER EXAMPLE

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A global assessment for copper, platinum-group elements, and potash was completed by U.S. Geological Survey (USGS) and partner organizations in 2013. A worldwide assessment of copper in undiscovered porphyry deposits was a major part of this project. This global porphyry copper assessment was based on mineral deposit models using the USGS form of mineral resource assessment. Minimum data requirements for this type of assessment include (1) 1:1,000,000 scale geologic maps or larger; (2) deposit, prospect and mineral occurrences databases; and (3) grade and tonnage models. Where available, geophysical and other data can be used to outline the subsurface extent of permissive rocks.

Geographic information systems (GIS) provide users with tools to analyze, visualize and interpret many data types. Map unit polygons from digital geologic maps were extracted and classified as permissive or non-permissive for porphyry copper mineralization. Once permissive units were identified and grouped by age, an interim map of permissive rocks was made. Extensions of map boundaries under younger cover rocks were edited based on geophysical or structural data or by applying digital buffers. Then, existing deposit and prospect databases and other available information were used to refine the preliminary permissive tract. Preliminary areas were aggregated, smoothed and edited to define the final permissive tract. Tract areas were calculated in a local equal-area projection to assure accurate areas. After permissive tracts were finalized and known resources identified, undiscovered porphyry copper deposit estimates were produced by an assessment team and combined with grade and tonnage models to create the probabilistic assessment of undiscovered porphyry copper resources. GIS products include shapefiles and/or geodatabases of permissive tracts attributed with tract name, age, grade and tonnage model used, areas and probabilistic undiscovered deposit estimates, point locations of deposit and prospects attributed with age, commodity, location and comments and joined data tables of assessment results.

236-10 DP10

ECONOMIC EVALUATION OF PORPHYRY COPPER DEPOSIT RESOURCE ASSESSMENT RESULTS FROM THE U.S. GEOLOGICAL SURVEY (USGS) GLOBAL MINERAL RESOURCE ASSESSMENT

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Economic evaluation of undiscovered resource estimates is important for assessing the location, amount, adequacy, and availability of mineral supplies that might be economic to extract. Simplified engineering cost models, updated with a cost index, were used to estimate the economic fraction of resources contained in undiscovered porphyry copper deposits as predicted in the USGS assessment of global copper resources. The simplified engineering cost models can be applied to a variety of deposit types and mining methods, and require only limited design and setting parameters.

The USGS three-part form of assessment used for the global porphyry copper study relies on deposit-type-specific models of grades and tonnages and probabilistic estimates of numbers of undiscovered deposits. Distributions for grades, tonnages, and numbers of undiscovered deposits are combined using Monte Carlo simulation to estimate in-place undiscovered mineral resources. For each permissive area (tract), the assessment process provides estimates of undiscovered deposits at different confidence levels, their relative distribution by depth, a grade-tonnage model that is used to simulate the undiscovered resources contained in these deposits, and a mine cost setting parameter based on location and infrastructure features, all combined to estimate undiscovered economic resources. An economic filter for both open-pit and block caving mining methods was applied to the simulated undiscovered porphyry copper deposit resources.

Results of the Monte Carlo simulation and economic filter analysis provide an estimate of undiscovered resources, potential economic resources, Net-Present-Value (NPV), and the probability of failure (probability of no economic resource) for each tract. The mean NPV of undiscovered deposits can be discounted by the probability of failure and normalized by area to rank the relative economic potential of each tract.

236-11 DP11

ESTIMATING THE UNDISCOVERED COPPER RESOURCES OF THE CENTRAL AFRICAN COPPERBELT: RESULTS OF THE USGS GLOBAL MINERAL RESOURCE ASSESSMENT PROJECT (GMRAP)

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236-12 DP12

ASSESSMENT OF UNDISCOVERED METALS IN AN UNDEREXPLORED PART OF THE WORLD: EXPERIENCE FROM THE ASSESSMENT OF COPPER, ZINC AND NICKEL IN GREENLAND

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236-14 DP14

PLATINUM-GROUP ELEMENTS IN SOUTHERN AFRICA—MINERAL INVENTORY AND AN ASSESSMENT OF UNDISCOVERED MINERAL RESOURCES

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236-15 DP15

CHALLENGES AND APPROACHES TO ASSESSING INDUSTRIAL MINERALS—THE USGS GLOBAL POTASH ASSESSMENT DATABASES

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236-16 DP16

GEOLOGY AND POTASH RESERVES OF THE UPPER DEVONIAN PRIPYAT BASIN, BELARUS

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Paper No. 245-10, Presentation Time: 11:15 AM

BASELINE GEOCHEMISTRY OF AN UNDEVELOPED ORE DEPOSIT: LESSONS FROM THE COLES HILL URANIUM DEPOSIT, VIRGINIA

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Assessing the baseline environmental geochemistry of an ore deposit prior to mining provides a record that can be used to establish operational monitoring and post-closure reclamation goals. Pre-mining baseline studies are distinct from studies to distinguish natural geochemical background or identify geochemical anomalies in that they include the full geologic history of the area, including ore formation, weathering processes, and anthropogenic influences.

Recently, a baseline geochemical study was conducted on surface water, stream sediments, and soils at the Coles Hill uranium deposit in Pittsylvania County, Virginia. Samples were collected within and distant from areas impacted by the deposit. Results suggest that the Coles Hill deposit creates a statistically significant signature of elevated U, Ba, V, Pb, and radionuclide concentrations near and downstream of the deposit in the media studied. However, the deposit lies on a fault between two geologic provinces, and comparisons between downstream and reference sites within the same geologic province show no significant difference in stream water and sediment element concentrations. Statistically significant temporal differences in stream water concentrations were also found in element concentrations between monthly collections, but variations can be mostly accounted for by differences in discharge, which is negatively correlated with many elements.

During this study, a number of challenges arose, many of which are relevant to other studies of this type. One particular issue is that “baseline” lacks a specific definition, and so there are a number of ways in which results can be presented and interpreted. Another difficulty was that the deposit is located in an area with diverse geology, land use, and climate, all of which can complicate environmental signatures. Selection of appropriate reference or background sites can aid in distinguishing these signals. Another challenge was the prevalence of non-detect concentrations in surface water. Non-standard statistical methods, particularly regression on order statistics, were employed to meaningfully and

robustly analyze these data. However, comparisons of statistics calculated using this method show that as the fraction of data below detection increases, results become more uncertain.

Paper No. 379-1, Presentation Time: 1:00 PM Wednesday, 30 October 2013

HIGH-RESOLUTION, MULTI-METHOD GEOPHYSICAL IMAGING OF A PORTION OF THE NORTHEAST IOWA INTRUSIVE COMPLEX

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Numerous large amplitude regional aeromagnetic anomalies and ground gravity highs over northeast Iowa and southeast Minnesota suggest the presence of a buried intrusive complex made up of mafic/ultramafic rocks. This complex is known as the northeast Iowa Intrusive Complex (NE IIC). The NE IIC lies along the eastern margin of the Midcontinent Rift System (MRS) and occupies a minimum estimated area of 17,000 square kilometers, making it comparable in size to the Duluth Complex. Country rocks are thought to be accreted island arc terranes of the Paleoproterozoic Yavapai Province (1.8-1.7 Ga), implying at least a somewhat younger age for the NE IIC. While not yet directly dated, these considerations suggest that a Keweenawan (MRS) age for some or all of the NE IIC is possible and imply significant potential for undiscovered Ni-Cu-PGE deposits. The NE IIC may also include Mesoproterozoic intrusions like the Wolf River Batholith in Wisconsin, or alkaline Cambrian plutons. Only four boreholes are known to reach the complex, which is covered by 200-500 meters of sedimentary rocks and sediments. Geophysical methods are critical to developing a better understanding of the nature and resource potential of the NE IIC. A high-resolution, multi-method geophysical mapping program was initiated in 2012 as a collaborative effort between the U.S. Geological Survey Mineral Resources Program, the Iowa Geological and Water Survey, and the Minnesota Geological Survey. An initial airborne data collection campaign in the region of Decorah, Iowa, included magnetic, gravity gradient (AGG), and time-domain electromagnetic (TDEM) data along flight lines spaced 400 m apart. Geophysical data show numerous magnetic anomalies that are paired with AGG highs, indicating widespread strongly magnetized and dense rocks of likely mafic composition. In the Decorah region, a prominent horseshoe-shaped, 15 kilometer diameter magnetic- and gravity-field high is correlated with the occurrence of basement rocks that have been described as gabbro and troctolite, suggesting a ring-shaped anomaly source with similarities to MRS alkaline complexes. A Yavapai age layered(?)

metagabbro pluton is suspected to produce complex magnetic and gravity anomalies with different forms than the other basement rocks nearby.

Session No. 391, Wednesday, 30 October 2013: 1:00 PM-5:00 PM

GEOCHEMICAL MAPPING AT REGIONAL TO CONTINENTAL SCALES

Geochemical Society; International Association of GeoChemistry

David B. Smith and ***Laurel G. Woodruff,*** Advocates

Paper No. 391-1, Presentation Time: 1:05 PM

NEW SOIL GEOCHEMISTRY AND MINERALOGY FOR THE CONTERMINOUS UNITED STATES

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The U.S. Geological Survey has completed a low-density (about 1 site per 1600 km2) geochemical and mineralogical survey of soils of the conterminous United States. Soil samples were collected from 2007 to 2010 at 4857 randomly selected sites in a spatially balanced array using consistent sampling protocols. At each site, three samples were collected: 1) a sample from a depth of 0 to 5 cm, regardless of soil horizon, 2) a composite of the soil A horizon (uppermost mineral soil), and 3) a sample of deeper subsoil typically from 80 to 100 cm depth (soil B or C horizon). The < 2 mm fraction of each sample was analyzed for more than 45 major and trace elements using a near-total digestion method. Major mineralogical components were quantified in soil A and B/C horizons by X-ray diffractometry. A split of each sample is archived for future research.

The data array provides a three-dimensional framework of soil geochemistry and mineralogy. Spatial differences in geochemistry and mineralogy at continental and regional scales can be tied to distinctive soil parent materials modified by climate-related processes such as weathering (driven by hemisphere-wide gradients of temperature and precipitation) and glaciation. Element distributions among the three soil samples from each site reveal human influences superimposed on natural soil background concentrations. Anthropogenic influences, such as atmospheric deposition from industry and mining, agricultural practices, and changes in land use, have resulted in input and accumulation of a number of elements in surface soils, some (for example, As, Cd, P, Pb, and Hg) of environmental concern to

ecosystem and human health. Soil mineralogy exerts control on both soil chemical and physical properties. Quantitative mineralogy allied with element concentrations allows inference of mineralogical hosts for many major and trace elements.

All geochemical and mineralogical data with accompanying land use/land type information will be publically released in 2013 as downloadable files. This new data set for the conterminous U.S. represents a major step forward from prior national-scale soil geochemistry data and, along with the soil archive, provides a robust soil data framework for the U.S. now and into the future.

Paper No. 391-2, Presentation Time: 1:20 PM

QUARTZ DISTRIBUTION IN A-HORIZON SOILS OF THE CONTERMINOUS U.S.—ITS EFFECT ON MAJOR AND TRACE ELEMENT DISTRIBUTION PATTERNS

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As an adjunct to geochemical data for soils produced by the Conterminous U.S. Soil Geochemical Landscapes project of the USGS we determined the mineralogy, including the quartz content, of the < 2mm size fraction of 4,791 A-horizon soils by Rietveld refinement calculations from x-ray diffraction data. The average quartz content is 49.4 wt. % and varies from 100% to < 0.2%. Thus, quartz content is one of the most significant variables in this large data set. Because of the chemical simplicity of quartz (it contains essentially no elements other than Si and O) it causes variable dilution of all other elements, which reside entirely in the non-quartz fraction of soil. Quartz shows very prominent regional patterns, being very high, for instance, in the Atlantic and Gulf of Mexico Coastal Plains, where it commonly forms more than 95% of soil, and very low in much of the Pacific Northwest, where it commonly makes up less than 20% of soils. The reciprocal of this pattern is shown by many other elements, especially lithophile elements, indicating that their concentrations reflect, in large part, variable dilution by quartz of the minerals that contain them. Interpreting the cause of national- and regional-scale variations of element concentrations should take into account the degree to which these different concentrations reflect only variable quartz dilution. Quantitative data on the quartz content of our analyzed soils allows us to calculate the chemical composition of the non-quartz soil fraction by assigning all elements to that portion of the soil not composed of quartz. National maps of the chemical composition of the non-quartz fraction of soil generally differ greatly from maps of the composition of bulk soils and reveal significant patterns of enrichment and depletion that commonly are masked by variable quartz dilution in the chemistry of the bulk soil. These maps may be particularly significant in studies of agriculture and plant growth because plants derive nutrients and potentially deleterious elements solely from the non-quartz fraction of soil and presumably respond to the composition of that fraction more than to the composition of the bulk soil

Paper No. 391-3, Presentation Time: 1:35 PM

CHARACTERIZATION AND CLASSIFICATION OF SOIL GEOCHEMISTRY WITHIN THE CONTERMINOUS UNITED STATES

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A multi-element soil geochemical survey was conducted over the conterminous United States for which samples were collected from (1) a depth of 0-5 cm, (2) the soil A horizon, and (3) the soil C horizon. The survey sampled 4,857 sites representing a density of approximately 1 site per 1600 km2. Each sample was analyzed for Ag, Al, As, Ba, Be, Bi, Total Carbon, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, S, Sb, Sc, Se, Sn, Sr, Te, Th, Ti, Tl, U, V, W, Y, and Zn by methods that yielded the total, or near-total, elemental content. Silver and Te were dropped from further evaluation because most values were reported at less than the detection limits. Censored analytical values were replaced using the R package “robCompositions.” A log-centered transform was applied to the data followed by the application of a principal component analysis that yielded 6 significant components. Principal component analysis reveals continental-scale contrasts in soil composition that reflect distinctive geochemical features including soil horizon, bedrock source variability, and weathering. The first principal component identifies the contrast between mafic lithologies (relative Ni, Co, Cr enrichment) and felsic intrusive lithologies (relative REE enrichment). The second principal component reveals relative enrichment of Hg, Ti, Mo, Cd, As that is associated with the weathered sedimentary rocks of the southern Appalachian mountains in North Carolina, South Carolina, Georgia and northern Florida. The application of discriminant analysis provides a probability-based approach in classifying the soil geochemistry in terms of bioclimatic indices that reflect zones of humidity and temperature variability (ombrotypes, thermotypes), terrestrial ecosystems, and surface lithology. Classification accuracy is variable between the different classes of bioclimatic indices and surface lithologies; however, maps displaying the probability of occurrence are consistent with the observed data.

Paper No. 391-4, Presentation Time: 1:50 PM

A DYNAMIC DATABASE FOR GEOCHEMICAL AND MINERALOGICAL DATA FOR SOILS OF THE CONTERMINOUS UNITED STATES COLLECTED FOR THE USGS GEOCHEMICAL LANDSCAPES PROJECT

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New geochemical and mineralogical data will soon be released to the public as part of the U.S. Geological Survey Data Series, “Geochemical and Mineralogical Data for Soils of the Conterminous United States”. This low-density national-scale soil survey visited 4,857 sites (approximately one site per 1,600 sq. km.). Each site included: (1) a composite sample from the top 5 cm, (2) a composite of the soil A horizon, and (3) a sample from the soil C horizon or a sample from about 80-100 cm if the C horizon was deeper than 1 meter. The <2 millimeter fraction of each sample was analyzed for 45 major and trace elements using ICP-MS, ICP-AES, and selected analytical techniques for As, C, Hg, and Se. Additional splits from the samples of the A and C horizons were also analyzed for the mineralogical content using the quantitative X-ray diffraction method with Rietveld refinements.

The results of the chemical and mineralogical analyses will be available to the public as a set of three tables (0-5 cm depth, soil A horizon, and soil C horizon) downloadable from the USGS Mineral Resources On-Line Spatial Data website (mrdata.usgs.gov). All tables have an identical structure to allow the users to readily combine them into larger files.

A .kml file that opens with Google Earth®, ArcGlobe®, or other mapping software packages will also be available. This file greatly facilitates the visualization of the data, which then can be combined with other digital layers such as geologic maps or mineral occurrences. A digital geochemical and mineralogical soil atlas will be published on-line for the conterminous United States, with interpolated maps of the distribution of the analyzed chemical elements and the major minerals found in the soil samples as well as descriptive statistics and plots.

Paper No. 391-5, Presentation Time: 2:05 PM

MAPPING THE DISTRIBUTION OF ARSENIC IN SOILS OF THE CONTERMINOUS UNITED STATES

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Understanding the abundance and spatial variation of arsenic in soils at scales ranging from local to global is critical for environmental regulators, public health specialists, and the agricultural/food safety community. The U.S. Geological Survey recently completed a soil geochemical survey of the conterminous United States based on 4,857 sample sites (1 site per approximately 1,600 km2). At each site, a sample from a depth of 0 to 5 cm was collected along with samples from the soil A and C horizons. Each sample was sieved to <2 mm and then ground to <150 µm prior to chemical analysis for 45 major and trace elements by methods that yielded the total elemental content. Arsenic was analyzed by hydride-generation atomic absorption spectrometry following fusion in a mixture of sodium peroxide and sodium hydroxide. For all three sample types, arsenic varied by approximately three orders of

magnitude from less than 0.6 mg/kg (the method detection limit) to about 1,000 mg/kg, with a median of 5.2 mg/kg for the 0-5-cm and A-horizon soils and 5.7 mg/kg for the soil C horizon. The dominant process controlling the spatial distribution of arsenic is weathering of soil parent material of various compositions. The highest arsenic concentrations were found in soils formed on mineralized bedrock (e.g., western Montana and parts of Nevada) and marine shales (e.g., portions of Ohio, Pennsylvania, and South Dakota). Soils collected from the rice-growing region along the Mississippi River in Arkansas, Mississippi, and Louisiana were also elevated in arsenic. These higher arsenic concentrations are likely caused by a combination of factors including elevated concentrations of iron and clay minerals in these alluvial soils that lead to adsorption of arsenic and other elements, input from arsenical pesticides, and contributions from upstream natural sources and industrial activities. The lowest arsenic concentrations were found in soils formed from quartz-rich sediments (e.g., Florida, South Carolina). Anthropogenic arsenic input is superimposed on this highly variable background distribution and, at the national scale of the USGS survey, is not easily recognized.

Paper No. 391-11, Presentation Time: 4:00 PM

GEOCHEMISTRY AND MINERALOGY IN SOILS FROM A N/S TRANS-ALASKA TRANSECT

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Geochemical variations along soil transects have been used to 1) delineate the natural range in elemental variation relative to bedrock, surficial deposits, and areas of mineralization, and 2) identify variations arising from ecosystem and anthropogenic factors. The objective of this study is to explore regional geochemical variations in soils along a transect that followed the Richardson, Elliott, and Dalton highways of Alaska from the Beaufort Sea to Prince William Sound (70oN to 61oN latitude). This is the first regional-scale geochemical soils transect in Alaska. The major, minor, and trace-element chemistry of the mineral soil horizons (A, B/C) was analyzed by ICP-MS following either a four-acid or sinter digestion. Quantitative bulk soil mineralogy was determined by powder X-ray diffraction analysis. Relative to quartz, the carbonate minerals (calcium carbonate and dolomite) are consistently elevated in soils of the coastal plain and the dolomite/quartz ratio is consistently elevated in soils of the southern Alaska Range and Copper River Basin. The plagioclase/quartz and the K-feldspar/quartz ratios are elevated through the southern Alaska Range and Copper River Basin and K-feldspar/quartz is elevated in the vicinity of the alkaline granites of the Ray Mountains. The latitudinal variations in major elements

mirror those of the primary mineralogy: Ca and Mg, and K and Na vary with variations in the carbonate and feldspar mineralogy, respectively. Only Ca, S, P, Hg, Mo, and Cd are enriched in the A horizon, relative to the deeper horizon. Strontium concentrations are enriched throughout the southern Alaska Range and Copper River Basin – a geochemical signature which is identifiable in fish otoliths from this area– and there is a muted but discernible rise in Cr, Ni, Cu through the mafic igneous rocks of the southern Alaska Range. The U, Th, Nb, and total rare earth element (REE) concentrations are greatest near the alkaline granites of the Ray Mountains. In summary, geochemical variations along the transect predominantly reflect variations in the parent material, as opposed to ecosystem or anthropogenic factors.