Arizona Geological Society Newsletter

SEPTEMBER 2019

September 10th, 2019 DINNER MEETING

Who: **Kent J. McGrew** is the featured speaker. See abstract below.

Where: Sheraton Tucson Hotel and Suites, 5151 East Grant Road, (at the intersection of Grant and Rosemont on the North side of Grant in the **SABINO BALLROOM** (enter at northwest corner of the building) and go upstairs to the meeting room.

When: Cash Bar at 6 p.m.—Dinner at 7 p.m.—Talk at 8 p.m.

Cost: Members $30, Guests $33, Students Members free with online reservation ($10 without).

RESERVATIONS ARE REQUIRED: Reserve on the AGS website (http://www.arizonageologicalsoc.org/events) by 11 am on Friday, September 6th. Please indicate Regular (Miso Honey Glazed Chicken), Vegetarian (Stuffed Bell Pepper), or Salad (Cobb Salad) meal preference. Please cancel by **Friday, September 6th at 11 am** if you are unable to attend - no shows and late cancellations will be invoiced.

The September dinner meeting is sponsored by:

SKYLINE ASSAYERS & LABORATORIES

If you are interested in sponsoring future AGS dinner meetings, please contact:

vpmarketing@arizonageologicalsoc.org

Arizona Geological Survey presents:

In-Situ Recovery Basics

by Kent J. McGrew, P.E.

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ABSTRACT

Through the 1970s & 80s, ISR methodology pursued every metal lending itself to dissolution with lixiviants composed of oxidants and a complexing agent. Numerous tools were developed and employed to analyze well field performance. Uranium was the main target of the day. However, extensive efforts to recover gold, copper, and a host of other metals were pursued by the largest and most capable mining companies. Con Rio Australia (CRA) invested heavily in an ISR approach to mine the Australian deep gold leads, the continuation of the oxidized zones of buried placers that fueled the Australian gold rush of the mid-1850s.

This effort recounts the "Lessons Learned" through CRA research and how they apply to current efforts in Arizona to study and bring to fruition In-Situ leaching for the vast oxide copper resources. The resilient nature of the deep leads pushed lixiviant research for gold extraction and well field design and analyses to new levels of understanding. Chemical and physical phenomena that were experienced in the course of the research are reviewed. Long leach path testing was developed during this effort and provided the scientific evidence that eventually led to the abandonment of the CRA project Deep Leads Project.

The chemistry of copper leaching is reviewed along with the chemical reactions that attack the gangue minerals that can lead to fatal contamination of the recirculated leach solution and possible precipitation and plugging of the In-Situ leach ore. There is far more chemistry to be considered than can be realized in beaker or bottle roll testing. An alternate to sulfuric acid is presented, along with a unique recovery method to produce cathode copper from low grade acid copper solutions.

Mr. McGrew recounts the history and presents the lessons learned, humorously and thoroughly. Still involved in the ISR industry, Mr. McGrew makes the point, "There is science in the background of everything we do, whether we pay attention to it or not."

ABOUT THE SPEAKER

Mr. McGrew holds his B.S. and M.S. in an obscure corner of extractive metallurgy, dubbed Mineral Dressing Engineering many years ago by metallurgy professors that didn't want to melt rocks or test the hardness of metals and al-

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loys. Along with his formal training in mineral process plant engineering, he supplemented his rock breaking expertise with every chemistry course available at Montana School of Mines.

A burgeoning hydrometallurgy industry soon led him into first ion exchange for metal recovery and then into testing and design for some of the largest copper heap leach operations in Mainland China while working for Fluor Mining and Metals. Mr. McGrew was the project manager for the In-Situ, Inc. effort to develop a chemical system for ISL gold recovery for the deep leads in Australia. He brings to light a wealth of lessons learned from that experience from the late seventies and also innovated the long leach path testing method for evaluating the chromatographic effects experienced while pushing lixiviants through ore bodies.

Mr. McGrew built and operated the Wharf Resources gold recovery plant at the Annie Creek Mine in Lead, SD. He pioneered winter leaching and was the first to apply buried emitters for solution distribution of cyanide solution to the leach heaps.

Driven out of the Black Hills by his cruel mistress, asthma, Mr. McGrew has lived in the Arizona Desert for thirty years. He owned and operated ReagenTech, Inc. treating metal-waste waters from circuit board manufacturing and plating shops around the American West. He has been more or less retired for ten years but stays busy with consulting, writing, and administration of the Congress School District.

Society Announcements

GSA 2019
22-25 September
Phoenix, Arizona, USA

For anyone attending the Geological Society of America national conference in Phoenix this year, the Arizona Geological Society is sponsoring the following GSA 2019 Conference sessions and activities:

Topical Session - Poster Session and Oral Presentations:

Porphyry Copper and Related Mineral Deposits of Arizona, the Basin and Range Province, and Beyond - Hosted by Sarah Elizabeth Baxter and Michael Conway of the Arizona Geological Society

This session focuses on the geology of porphyry copper deposits, their related (and much larger) magmatic-hydrothermal systems, and their temporal evolution within and without the Basin and Range Province.

See the following pages for a directory of the research posters and presentations registered in the AGS topical session.

Field Trip:

Lava and Pyroclastic Flows of the Miocene Goldfield-Superstition Volcanic Province, Central Arizona—Saturday, September 21st - Led by R.V. Fodor of North Carolina State University, Michael T. Mohr, and Brian A. Dombroski.

Examine the volcanic rocks of the Miocene Goldfield-Superstition volcanic province east of Phoenix. Discussions at each field trip stop will include the volcanic geology, petrography, and petrology, and sharing of the most recent geochemical, petrological, mineralogical, volcanic stratigraphy, and geochronological research conducted by the co-leaders over the past decade. Rock types to see and sample during six field stops include rhyolite lava domes, crystal-rich and crystal-poor rhyolite ash-flow tuffs, andesite, basalt, and basement granite and conglomerate.

Arizona Geological Society, Poster Session
2019 Geological Society of America (GSA) Conference

T45. Porphyry Copper and Related Mineral Deposits of Arizona, the Basin and Range Province, and Beyond

Sponsor(s): GSA Environmental & Engineering Geology Division;
Arizona Geological Society

Wednesday, 25 September 2019: 9:00 AM - 6:30 PM, Phoenix Convention Center, Hall AB, North Building

FINANCIAL ANALYSIS OF THE PROPOSED RESOLUTION COPPER MINE, ARIZONA
EMERMAN, Steven H., Malach Consulting, Spanish Fork, UT 84660

DISTRIBUTION AND STYLES OF HYPOGENE ALTERATION IN THE MIAMI-INSPIRATION PORPHYRY CU (-MO) DEPOSIT, GLOBE-MIAMI DISTRICT, ARIZONA
SWAIM, Nathan T.1, RUNYON, Simone E.1 and STEGEN, Ralph J.2,
(1) Department of Geology and Geophysics, University of Wyoming
(2) Freeport-McMoRan Exploration, Oro Valley, AZ 85737

PRECIOUS METAL DEPORTMENT IN THE ANN MASON PORPHYRY COPPER DEPOSIT, YERINGTON, NEVADA
AIRD, Hannah M., PURCELL, Ceara K.Q., BERMUDEZ, Jocelyn E., MATTHEWS, James L., DE WITT, Nancy and MEISEL, Zachary,
Department of Geological and Environmental Science, CSU Chico

GEOLOGY, GEOCHEMISTRY, AND GEOCHRONOLOGY OF THE CONTACT COPPER PROSPECT: AN INVESTIGATION OF A POTENTIAL PORPHYRY ROOT, NEVADA, USA
ZENS, Zacharie A., & MAHER, Kierran C.,
Earth and Environmental Sciences, New Mexico Institute of Mining and Technology

TRACING THE ORIGINS OF PYRITE AT THE ROUND MOUNTAIN GOLD MINE, NEVADA: A MINERALOGICAL AND CHEMICAL INVESTIGATION
BLAKEMORE, Daniel1, MCLEOD, Claire1, SHAULIS, Barry2 and KREKELER, Mark P.S.1,
(1) Geology & Environmental Earth Science, Miami University - Ohio
(2) Department of Geosciences, University of Arkansas

PETROGRAPHIC ANALYSIS OF PYRITE MINERALIZATION IN ASSOCIATION WITH GOLD OF THE TYPE 3 GOLD ORE IN ROUND MOUNTAIN MINE, NEVADA
LINDEMAN, Carter, FOUHMBINDI, Mireille, BLAKEMORE, Daniel, MCLEOD, Claire and KREKELER, Mark P.S.
Geology & Environmental Earth Sciences, Miami University - Ohio

LARGE SCALE CENOZOIC EXTENSION IN SW NEW MEXICO AND THE TECTONIC SETTING OF A LARAMIDE PORPHYRY CU-AU SYSTEM IN THE MALONE AND TYRONE MINING DISTRICTS: A REGIONAL EXPLORATION SYNTHESIS
FAHEY, Patrick L., Consulting Economic Geologist, Palm Desert, CA 92260

2019 Geological Society of America (GSA) Conference
Arizona Geological Society, Topical Session

T45. Porphyry Copper and Related Mineral Deposits of Arizona, the Basin and Range Province, and Beyond

Sponsor(s): GSA Environmental & Engineering Geology Division;
Arizona Geological Society

Wednesday, 25 September 2019: 1:30 PM - 5:30 PM,
Phoenix Convention Center, Room 126ABC, North Building

Rationale: The Basin and Range Province includes four of the top five copper (Cu) producing states in the U.S. The bulk of copper production is from porphyry copper deposits, which also frequently yield substantial molybdenum, gold, silver, and base metals. The alteration zonation model of Lowell and Guilbert (1970) dominated thinking in the economic geology community for much of the last half-century, however, research continues to refine our understanding of the genesis of porphyry systems through a myriad of techniques (i.e., geologic mapping, structural analysis, trace element geochemistry, geobarometry, microanalytical techniques, geophysical studies). Considering Arizona's history of being at the forefront of porphyry copper-related research, we hope to put together a session examining the continued advances in research on porphyry deposits.

Description: This session focuses on the geology of porphyry copper deposits, their related (and much larger) magmatic-hydrothermal systems, and their temporal evolution within and without the Basin and Range Province.

GLOBAL COPPER RESOURCES AND RESERVES; DISCOVERY IS NOT THE ONLY CONTROL ON SUPPLY

JOWITT, Simon M., Department of Geosciences, University of Nevada - Las Vegas,
MUDD, Gavin M., Environmental Engineering, RMIT University, Melbourne, Australia

Copper (Cu) is vital to modern life and has an often irreplaceable role in everyday infrastructure and technology. However, although clearly the world's endowment of extractable Cu is finite, global Cu production has increased over the past century, an increase that has been (more than) matched by significant growth in estimated Cu mineral reserves and mineral resources. Globally, some 2,301 deposits contain reported Cu resources, split into 1,271 code-based (e.g. JORC, NI43-101) and 1,030 non-code-based resources. A further 393 deposits have both resources and code-based reserves and a further 14 deposits have non-code-based reserves. These deposits contain 3,034.7 Mt of Cu, up from the 1,861.3 Mt of Cu contained in global resources in 2010, including 640.9 Mt of contained Cu in reserves. These figures should also be considered a minimum given the lack of reporting of Cu resources from some countries and projects. Most mineral deposit types have also recorded an average increase in Cu resources between 2010 (Mudd et al., 2013) and 2015, although grades are often similar, slightly lower (by ~5%), or are significantly lower depending on mineral deposit type.

Porphyry deposits still dominate global Cu resources and reserves and host ~75% of the contained Cu in our database. Chile also dominates global Cu resources and reserves, followed by the USA and Peru, all which host copper resources and reserves dominated by porphyry systems, indicating the continued importance of this deposit type for global copper production (as well as Mo, Re, Au, and others). The increase in global Cu resources documented in this study is associated with deposit discovery, the incorporation of more resources within the database (i.e., better data coverage), and the growth of individual Cu resources (often coincident with production) by an average of ~13% between 2010 and 2015. Our data indicates that Cu resources continue to grow over time coincident with production, indicating that although discovery and (more importantly brownfields expansion) is clearly important in terms of meeting increasing demands for Cu, we need to move beyond merely considering grades and tonnages. Environmental, political, logistical, and economical factors (among many others) are likely to become increasingly influential controls on the conversion of resources to reserves and the future supply of Cu; in other words, reported Cu resources or reserves are not guaranteed to become copper production, with the reasons why this does or does not occur a key topic for future research.

THE ROLE OF SULFUR IN THE FORMATION OF PORPHYRY ORE DEPOSITS

FRANK,
Mark R. and EHLICH, Joshua J., Department of Geology and Environmental Geosciences, Northern Illinois University

Cu- and Au-rich porphyry ore deposits contain substantial mineralization in cupolas above a solidified igneous magma (granite, s.l.). The metals are transported from the magma to the cupola by a supercritical fluid, low-salinity vapor, or high-salinity brine. Reduced sulfur (S^{-2}) is required to form sulfide minerals, but the role of reduced or oxidized sulfur (+4 or +6) in the transport of metals to the cupola is contentious. Experiments were performed at 500-700 °C and 50-100 MPa to determine the equilibrium concentrations of Cu, Au, Fe, Mn, and Zn in vapors, brines, and supercritical fluids as a function of total chloride (Cl), oxygen (O_2) and sulfur (S_2) fugacity. Cu concentrations in brine and vapor ranged from 800 to 27000 µg/g and 40 to 1000 µg/g, respectively. Cu was strongly influenced by the total Cl of the fluid and was always greater in coexisting brine than vapor. Cu concentrations in supercritical fluids, 5 wt.% NaCl equivalent, were 120-3300 µg/g. Maximum Au concentrations were 152, 18, and 16 µg/g in brine, vapor, and supercritical fluid, respectively. Au behaved similarly to Cu as concentrations increased with increasing Cl and temperature, but was more affected by temperature changes than Cu. Variations in O_2, S_2, H_2S, and SO_2 fugacities that spanned orders of magnitude had little observable impact on Cu, Au, Fe, Mn, and Zn concentrations in the brine, vapor, or supercritical fluid. Thus, sulfur is not an effective ligand during the formation of porphyry deposits. We hypothesize that the temperature and Cl content of a hydrothermal fluid are the critical factors controlling the potential of a fluid to carry metals in the porphyry environment. Reduced sulfur (e.g., as H_2S) is required for the precipitation of sulfide minerals (e.g., chalcopyrite) by: $CuCl + FeCl_2 + 2\ H_2S \rightarrow CuFeS_2 + 3\ HCl + 0.5\ H_2$. Additionally, our experiments indicate that substantial Au (up to 5500 µg/g) can be incorporated into the crystal structures of bornite and chalcopyrite which may explain why Au is often found within sulfide minerals. Sulfur is likely sourced from the magma and transported with the metals by the hydrothermal fluid, with mineral formation induced by changes in temperature, oxidation, and/or acidity.

COPPER SULFIDE DEPOSITION TRIGGERED BY GROUNDWATER INCURSION IN MAGMATICALLY-DOMINATED HYDROTHERMAL SYSTEM (TONGCHANG PORPHYRY CU DEPOSIT, CHINA)

LIU, Xuan[1], RUSK, Brian[2], PIRONON, Jacques[1] and RICHARD, Antonin[1],
(1) GeoRessources Lab, Université de Lorraine, Vandœuvre-lès-Nancy, France,
(2) Geology Department, Western Washington University

Porphyry Cu deposits, the major repositories for base and precious metals, carry significant fingerprints for understanding magmatic-hydrothermal processes in the upper crust. While abundant evidence for the presence of meteoric water has been reported, the relative timing of meteoric incursion with respect to the entire fluid history and its role in sulfide deposition remains hotly debated due to complex overprints.

The Tongchang porphyry copper deposit represents an extreme case where primary magmatic-hydrothermal mineral assemblages are intensely modified. Six quartz depositing and two quartz-dissolving fluid events are recognized through detailed cathodoluminescence imaging. Thermobarometry (TitaniQ and fluid inclusion) and solubility analysis indicates that the fluid system underwent decompressional cooling (650 °C to 250°C) with intermittent pressurization and pressure fluctuation. Combined in-situ quartz O and anhydrite Sr isotopes revealed that the system was dominated by magmatic components in the early lithostatic environment, followed by major meteoric incursion (enriched in ^{18}O and radiogenic Sr) in a complete hydrostatic environment. The fluid mixing induced the major Cu mineralization due to enhanced cooling and fluid dilution. Subsequently, the system was dominated by meteoric water, which experienced Rayleigh distillation to produce quartz with the highest $\delta^{18}O$ (27‰) ever reported for porphyry systems.

GRASBERG PORPHYRY CU-AU OREBODY: FLUID-CHARGED CUPOLAS, PERVASIVE ALTERATION, AND STOCKWORK FORMATION

CLOOS, Mark, Geological Sciences, University of Texas at Austin, Austin, TX 78712

The Grasberg Igneous Complex (GIC) in the highlands of Papua Indonesia is host to a supergiant porphyry-type Cu-Au orebody. The GIC is about 2 km across at the surface near ~4000 m elevation and narrows to about 800 m at 3000 m. There were three distinct magmatic phases: Dalam, MGI, and Kali. The Dalam phase was prolonged and involved a period of volcanism in a maar-caldera. The MGI is a medial cone-shaped plug that widens upwards. The Kali is a composite of dikes forming a wedge with a tip near the GIC center. Plutonism was facilitated by concurrent strike-slip faulting.

The orebody is the product of two distinct pulses of mineralization. The first pre-dates emplacement of the MGI, has a high Cu/Au ratio with some Mo, and is dominated by infiltration of magmatic fluids that caused intense pervasive alteration. The second predates Kali-phase diking, produced the bulk of high-grade Cu+Au ore and involved voluminous infiltration and fracture fluid flow. Above 3500 m, a stockwork (defined as vein network recording a 3-D dilation) formed that is about 400 m across with an outer limit mapped where the vein volume exceeds 5% of the rock. Volumes of veins per cubic meter locally exceed 50%. The GIC stockwork, largely hosted in the MGI, involved two distinct stages, an early low-Cu episode that mostly produced qtz + mt and a later Cu+Au ore-stage. Upwards and outwards, the ore-related mineralization shows a progression from bor to ccp to pyr.

Concentric zones of intense pervasive alteration and stockwork veining are most simply explained as a manifestation of the existence of a cupola inside the stock (boundary of immobile and mobile magma) that is charged with magmatic fluid. When fluid volume is only enough to displace some of the melt in the porous mush at the top of the stock, infiltration alteration dominates. When fluid production rates are high enough to fill the porous zone and displace enough melt to form a pocket, episodic collapse of the roof of the cupola can occur that produces 3-D stockwork veining. The production of Cu-rich fluids happens when sidewall bubbling extends below depths of about 6 km. In the case of the GIC, ore-forming cupolas developed twice. The fluid-charged pre-MGI cupola was located SW of the center of the GIC at an elevation of about 2700 m. The fluid-charged pre-Kali cupola migrated down from above 3500 m to about 2700 m.

STOCKWORK VEIN ZONE OF THE GRASBERG PORPHYRY CU-AU DEPOSIT: STRUCTURAL AND CHEMICAL HISTORY

BOS ORENT, Eytan and CLOOS, Mark, Geological Sciences, University of Texas at Austin

The Grasberg Igneous Complex (GIC) is host to the largest (2+ billion tonnes with 1 wt. % Cu and 1 gm/tonne Au) ore deposit in the Ertsberg mining district of Papua, Indonesia. Most ore mineralization postdates the 3.2 Ma Main Grasberg Intrusion (MGI). The MGI is host to the stockwork zone, a 3-D network of abundant quartz and magnetite veining.

A sample suite of 75 polished slabs, mostly 10-15 cm long, was prepared from seven near-horizontal drill cores at the 3,700 meter elevation of the stockwork zone. Thin sections were also prepared for 38 samples. Samples with abundant veins (>50 vol%) come from a circular area ~300 m across in the center of the GIC. The 1,211 veins, about 16 per sample, range from veinlets (<1 mm) to about 15 mm thick. Quartz veins are commonly 5 to 10 mm wide. Numerous cross-cutting relationships indicate five stages of veining. Stage 1 consists of narrow (<1 mm) magnetite and biotite veinlets. Stage 2 consists of quartz veins with minor amounts of disseminated magnetite and/or chalcopyrite. Stage 3 veins are laminated with walls of magnetite and interior fills of quartz with disseminated magnetite and/or chalcopyrite. Stage 4 are quartz veins with narrow centerlines of chalcopyrite with varied amounts of magnetite or pyrite. Stage 5consist of narrow (up to 2 mm) veins and thin veinlets of chalcopyrite with varied amounts of biotite and/or pyrite. Some Stage 4 and 5 veins contain microscopic traces of bornite. They are localized to an area about 150 meters across in the center of the GIC. This observation, combined with the limits of abundant veining mapped zones of pervasive hydrothermal alteration, indicate there was a center of upwelling ore-forming mineralization that was centered near the tip of the wedge of crosscutting Kali dikes. Pervasive alteration in the Kali is minor, but much lesser veining indicates a similar succession of stages.

The random orientation of veins indicates near-isotropic state of stress during extension fracturing. The stockwork zone is interpreted as a product of episodic collapse of the roof above a fluid-charged cupola at the top of a cooling stock of magma. Over time the cupola migrated downward and repeated fracturing and veining produced the stockwork zone of intense mineralization. Stages 4 and 5 copper mineralization is explainable as a result of deeper seated sidewall bubbling.

EVALUATING TITANITE AS AN INDICATOR OF METAL FERTILITY AND RELATIVE OXYGEN FUGACITY IN THE WHITE PINE MO-W PORPHYRY DEPOSIT, UTAH

MARTIN, Alec J., KEITH, Jeffrey D., CHRISTIANSEN, Eric H., KOWALLIS, Bart J., JENSEN, Collin G., HENZE, Porter, CHADBURN, Ryan, MARTIN, Samuel G. and WEBB, Haley D.M., Department of Geological Sciences, Brigham Young University, Provo, UT 84602

Hosted within the Oligocene Little Cottonwood stock (LCS) of central Utah are two younger granitic phases, the White Pine and Red Pine porphyries. Whole rock compositions, zircon U-Pb ages, and titanite compositions suggest that rather than having differentiated from the LCS magma, the White Pine was generated from a separate magma pulse, as was the Red Pine ~2 m.y. later.

Low grade Mo-W mineralization and associated alteration form a roughly concentric pattern centered on the Red Pine. Molybdenite is limited to the area of the Red Pine, more widespread scheelite mineralization cuts across portions of the White Pine, and phyllic-QSP alteration extends even farther into portions of the LCS. Magmatic titanite crystallized in each of the intrusive phases and, due to slow diffusion rates and high closure temperature, retained element patterns characteristic of the parental magma. Thus, titanite in diverse clasts in phreatomagmatic pebble dikes associated with the mineralization has distinctive geochemical fingerprints that allow us to identify clasts from both the LCS and the White Pine.

Magmatic titanite and hydrothermal overgrowths attest to relatively oxidized conditions during their formation. On the other hand, the breakdown of White Pine and Red Pine titanite to quartz, apatite, ilmenite, rutile, allanite, and monazite and the absence of magnetite or hematite (as seen in altered titanite in the LCS), along with the lack of wolframite and powellite, are evidence for lower fO_2 at the time of alteration.

Titanite as an indicator mineral for metal fertility in intrusive bodies has also attracted attention in the last decade. However, complex intrusion patterns can obfuscate what metal concentrations in titanite indicate about economic potential. Moreover, care must be taken to distinguish between magmatic and hydrothermal zones of titanite which have significantly different compositions. LA-ICP-MS data on BSE- and EMPA-confirmed magmatic titanite shows that in the barren LCS, titanite averages ~40 ppm Mo and can reach over 60 ppm, whereas in the mineralizing Red Pine, titanite averages ~25 ppm Mo and rarely reaches above 40 ppm. This gives an incorrect indication of relative metal fertility in the LCS and Red Pine phases, which advises caution in the use of titanite as an indicator mineral.

POTENTIAL FOR LARAMIDE PORPHYRY COPPER DEPOSITS IN SOUTHWESTERN NEW MEXICO AND TRANS-PECOS TEXAS

MCLEMORE, Virginia T., New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, 801 Leroy Place, Socorro, NM 87801

New Mexico lies at the eastern edge of one of the world's great metal-bearing provinces, which extends into Arizona, Mexico, and Trans-Pecos Texas, thereby making copper one of NM's important commodities. More than 14 billion pounds of Cu have been produced from porphyry copper deposits in NM since the early 1800s. Three periods of porphyry copper deposits are found in NM and Texas. The oldest deposits in southwestern NM and Trans-Pecos Texas are 60-75 Ma, exhibit calc-alkaline geochemistry, and include the Copper Flat (Hillsboro, 74 Ma), Eureka (Oro in Little Hatchet Mns, 71.4 Ma) and Red Hills (Texas, 64.2–60.2 Ma) deposits. Exploration and/or permitting are underway in these districts. THEMAX has identified proven and probable reserves of 113 million short tons at 0.30% Cu, 0.009% Mo, 0.096 grams/ton Au, and 1.93 grams/ton Ag at Copper Flat. The next period of porphyry copper deposits in southwestern NM is 50-60 Ma, exhibit calc-alkaline geochemistry, and include the currently producing Chino (58.6 Ma), Tyrone—Little Rock (54.5 Ma), and Cobre (Hanover Mn, 57.55 Ma) deposits. Estimated proven and probable ROM leachable reserves in 2018 at Chino and Cobre are 121 million metric tons of 0.29% Cu; estimated proven and probable millable reserves are 274 million metric tons of 0.54% Cu, 0.04 grams/metric ton Au, 0.93 grams/metric ton Ag, and 0.01% Mo. In 2018, proven leaching reserves at Tyrone are estimated as 55 million metric tons of ore grading 0.25% Cu. Additional deposits formed during this period are in various stages of exploration (Lone Mn, 51.5–50.6 Ma; Lordsburg, 57.3–58.8 Ma). The ages of porphyry copper deposits found at Gold Lake (White Signal), Steins (McGhee Peak), and Mimbres Mns are unknown. The youngest porphyry copper deposits are found in central and eastern NM, are much smaller than Laramide deposits, exhibit alkaline geochemistry, and include the Organ (26-36.45 Ma), Cerrillos (29.8 Ma), and Orogrande (41.4-45.6 Ma) deposits. None of these deposits are active. Other areas in NM have potential for porphyry copper deposits, especially where Laramide polymetallic vein and skarn deposits are found. Numerous geophysical anomalies are found in southwestern NM that could be indicative of additional porphyry copper deposits in the subsurface. Development of these deposits will depend upon the copper market.

SUBDUCTION OF ARIZONA PORPHYRY COPPER DEPOSITS

KEITH, Stanley B. and RASMUSSEN, Jan, MagmaChem Exploration, Sonoita, AZ 85637

Evidence for tectonic burial by SW directed thrusting/subduction is present in the lower plate of the Santa Catalina crystalline complex. Here the Oracle Ridge/Marble Peak porphyry copper skarn system is present adjacent to the Leatherwood quartz diorite-granodiorite intrusive complex dated at 69 Ma. The Marble Peak Cu skarn is typical of Laramide copper skarns (eg. Twin Buttes, Mission-Pima, and Christmas formed between 450 and 300°C at 2-5 km depth (Force, 1997). However, the Leatherwood intrusions unlike other Laramide intrusions of similar age and petrochemistry in the upper plate contain an epidote-alkali feldspar assemblage and secondary amphibole produced from plagioclase breakdown (Hanson, 1966) interpreted as metamorphic and Anderson and others 1988 interpret as magmatic and equilibrated with a 21 km paleodepth. We accept the metamorphic model of Hanson and the 21 km paleodepth indicated by the mineral chemistry and argue that this deep metamorphism is induced by thrust burial between 65 and 55 Ma on a former shallowly emplaced porphyry copper system. The thrust burial was achieved by SW directed thrusting along the regionally distributed Maricopa Thrust system proposed by Keith (1983) and Keith and Wilt (1986). Formation of the Maricopa Thrust coincided with emplacement of very hydrous peraluminous magmatism and contact hydrous alkali metasomatism widely present in lower plate windows exposed between the leading edge of the Maricopa Thrust and the Colorado Plateau. In the Santa Catalina lower plate the local representative of the peraluminous magmatism is the Wilderness batholith complex of Keith and others (1980) where geobarometry indicates an emplacement of about 15 km (Anderson and others, 1988). In effect a significant amount of Arizona's porphyry copper metallogeny was subducted during plate scale flat subduction of the Farallon Plate that reached very shallow levels between about 60 and 34 Ma. Upward strain transfer from the SW vergent interface between the NE subducting the Farallon slab and the overriding North American plate resulted in at least 2 major trench/SW directed thrust systems within the North American plate: the Peninsular Range and Maricopa thrust systems. The effect of post-porphyry intraplate subduction has yet to be fully evaluated by the copper exploration industry.

COARSE MUSCOVITE ALTERATION IN PORPHYRY COPPER SYSTEMS OF ARIZONA: CHARACTERISTICS AND IMPLICATIONS

RUNYON, Simone E.[1], SEEDORFF, Eric[2], BARTON, Mark D.[3], LECUMBERRI-SANCHEZ, Pilar[4], STEELE-MACINNIS, Matthew[4] and MAZDAB, Frank K.[5], (1) Department of Geology and Geophysics, University of Wyoming, Laramie, WY 82071, (2) Department of Geosciences and Lowell Institute for Mineral Resources, University of Arizona, 1040 E. Fourth Street, Tucson, AZ 85721-0077, (3) Department of Geosciences, University of Arizona, 1040 E. 4th St., Tucson, AZ 85721, (4) Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB T6G 2E3, Canada, (5)Department of Geosciences, University of Arizona, 1040 E 4th St, Tucson, AZ 85721

Hydrothermal alteration styles and distribution are important tools for effective exploration for porphyry copper deposits. Many porphyry systems along the Laramide arc in Arizona have been dismembered and tilted by Basin and Range extension, exposing some porphyry systems to paleodepths of > 12 km. These exposures

have allowed documentation of varying forms of deep hydrothermal alteration, largely beneath copper ore bodies in porphyry copper systems, including coarse muscovite alteration. Recent documentation of coarse muscovite alteration allows for a more detailed understanding of the roots of porphyry systems.

Coarse muscovite veins and alteration have been documented in multiple porphyry copper systems across Arizona. These veins and alteration show spatial, temporal, and chemical patterns between districts. Coarse muscovite veins (muscovite-quartz-K-feldspar-albite-pyrite ± chalcopyrite) are spatially extensive and coarse muscovite wall-rock alteration is common but spatially restricted. Mineral assemblages indicate that coarse muscovite-forming fluids contain cation loads dominated by K and Na. The magmatic composition of associated Laramide stocks and plutons appears to relate to the mineral assemblages observed in coarse muscovite veins; veins associated with more mafic (quartz monzonitic to granodioritic) magmas contain a less diverse mineral assemblage whereas coarse muscovite alteration associated with more felsic (quartz monzonitic and granitic) magmas may also contain molybdenite ± fluorite ± scheelite ± wolframite ± sphalerite. Coarse muscovite veins are interpreted to have formed either in subhorizontal and/or subvertical orientations. Where timing relationships were observed, coarse muscovite veins tend to cut and offset potassic veins. Coarse muscovite veins are distinct from earlier sugary quartz veins in texture and mineral assemblage. Hydrogen isotope compositions of coarse hydrothermal muscovite and calculated hydrogen isotopic compositions of fluids in equilibrium with coarse muscovite suggest a magmatic origin for associated aqueous fluids. These data suggest that coarse muscovite-forming fluids are magmatic in origin, with mineral assemblages and compositions that vary with associated magmatic composition, and formed after the formation of porphyry copper ores.

THE SUNNYSIDE-TAYLOR-HARDSHELL SYSTEM: EXPLORATION IMPLICATIONS OF A REMARKABLY COMPLETE PORPHYRY COPPER-SKARN-CARBONATE REPLACEMENT MINERALIZATION SPECTRUM IN SOUTHERN ARIZONA

MEGAW, Peter, TEAL, Lewis, TROTMAN, Richard and WHITEHILL, Caroline, Barksdale Capital Corp., 610 - 815 West Hastings Street, Vancouver, BC V6C 1B4, Canada

The well-delimited, but weakly mineralized Sunnyside Porphyry Copper system was emplaced into a typical southeastern Arizona section of Paleozoic carbonates and nonreactive clastic units. These were complexly thrust-faulted in the Nevadan orogeny and subsequently eroded prior to being covered by Jurassic intermediate volcanic rocks. The Sunnyside porphyry was intruded in the late Laramide with exceptionally voluminous zoned skarn and carbonate replacement mineralization deposited coevally in the surrounding Paleozoic sedimentary rocks. The overall system shows a complete spectrum of ore types from Porphyry Copper mineralization, through proximal Cu-rich skarn, through Zn-Pb and Pb-Zn massive sulfide replacements, to distal primary (?) oxide Ag-Mn mineralization. Mineralization in the overlying Jurassic volcanic units consists of sulfide veins and well-developed metalliferous silicification.

The Taylor Manto is an enormous (>150 million tons) high-grade, tabular Cu-Zn-Pb-Ag sulfide-mineralized body that has been traced down-dip to roughly 1200m depth. It occurs in the uppermost part of the Paleozoic sequence approximately 1000m above the lower Paleozoic Escabrosa-Martin-Abrigo formations that host important the replacement mineralization at Bisbee, Morenci, and Magma. A significantly altered, nearly vertical, NW-striking outcrop of these units crops out less than 2 km south of the Taylor Manto, indicating that this potentially more productive host rock sequence may lie at shallow depths beneath Jurassic rocks elsewhere in the camp. Comparison with other copper porphyry-related skarn-replacement systems suggests that additional mineralized corridors may exist around the Sunnyside center and be explored by tracing mineralization in the Jurassic volcanics to depth into the underlying sedimentary rocks.

Perhaps the most important aspect of Sunnyside is the recognition that disproportionately large volumes of skarn and replacement mineralization can surround a relatively weak Porphyry Copper system. Recent 1:6000 scale mapping, geochemical sampling and NSAMT geophysics have identified multiple, skarn-CRD targets located around the margins of the Sunnyside porphyry complex and on-going work is focused on targeting mineralization located around additional porphyry centers.

PLUTONIC AND HYDROTHERMAL MINERAL STAGES IN METALUMINOUS CALC-ALKALIC HYDROUS OXIDIZED PORPHYRY CU-MO-AG, MINERAL SYSTEMS

RASMUSSEN, Jan C. and KEITH, Stanley B., MagmaChem Exploration, Sonoita, AZ 85637

Hydrothermal mineral zoning in porphyry copper systems reveals that alteration and mineral zoning is not related to a single concentrically zoned alteration zoning event as portrayed in the classic Lowell-Guilbert model. Rather, when integrated to the associated metaluminous calc-alkalic hydrous oxidized epizonal intrusive sequences, each igneous rock system exhibits its own hydrothermal fluid release that is systematically and consistently cross-cut by other compositionally distinct younger rock and hydrothermal systems. Fluid releases from each rock system induce freezing and, as a result, little time-equivalent volcanism is present. The following generic magmato-hydrothermal, fractionation/unmixing sequence has been repeated in some 50 case histories in N and S America: Stage 1 hbld gabbro unmixes less mafic Stage 2 magma (hbld-mag-sphene qtz diorite) which exsolves Stage 2 [Fe(Cu)] hydrothermal fluid that forms proximal Fe-Cu skarns and widespread peripheral propylitic alteration. Mineral assemblages include: proximal mag (cpy-mo) with more distal, and Fe-rich chl-ep-cal, and local distal Ag-argentite-cal veins/pipes. Stage 3 bt-hbld granodiorite releases fluids which form the familiar porphyry Cu-Mo(Re)-Ag deposits. Mineral assemblages are cpy-mo-K feldspar -phlogopite potassic alteration in intrusions and gar-cpy in skarns. Py-qtz-ser typically form a fringing phyllic assemblage with chalcopyrite abundance maximized at the pH transition from potassic to phyllic alteration. Decompression of Stage 3 bt hbld granodiorite unmixes a Stage 4 bt granodiorite porphyry commonly associated with the Stage 3 Cu-Mo zones. Stage 3 bt granodiorite also exsolves a Stage 4 [CuMoAg (PbZnAuAsMn(U,F,V)] hydrothermal fluid. Mineral assemblages include: early qtz-mus-mo-py followed by cpy-bn-en-qtz-mus followed by tn-gn-sph-argentite-py-qtz-mus followed by alabandite-rhod-Mn oxides-bar-cal followed by minor Au-py-qtz-Ag-argentite-cal. When Stage 4 magma (bt granodiorite) decompresses, a Stage 5 qtz-feld porphyry magma is produced that is spatially associated with Stage 4 polymetallic metallization. Finally, Stage 5 qtz-feld porphyry exsolves a 'last gasp' barren py-alun-clay low pH vapor assemblage which is common in 'lithocaps' of the now spent porphyry sequence.

CALC-SILICATE ALTERATION AND ORE CHARACTERIZATION, ASARCO MISSION COMPLEX, IMPLICATIONS ON THE OPTIMIZATION OF MO RECOVERY

BAXTER, Sarah Elizabeth, 2019 AGS President, Arizona Geological Society (AGS),

This study sought to better understand and characterize the skarns and associated Mo mineralization at ASARCO's Mission Complex. High grade Mo mineralization generally occurs in three modes: 1) disseminated masses in Clinopyroxene-Tremolite (± calcite, anhydrite) hornfels, 2) trace amounts in Garnet ± Clinopyroxene skarn locally closely associated with scheelite, and 3) as fracture controlled mineralization. Vein paragenesis plays an important role in ore characterization, which varies considerably throughout the deposit. Understanding the relationships between mineral assemblages in specific lithologies associated with Mo is the key to predicting and mitigating potential processing issue.

Register for GSA 2019 Conference here:

https://community.geosociety.org/gsa2019/attend/registration

Society Announcements

AGS Members Leading Post-GSA 2019 Conference Field Trip

Information provided by Eric Seedorf:

On behalf of the Lowell Program in Economic Geology, we take the opportunity to inform you of a unique, one-off field trip we are running as part of the GSA 2019 Annual Meeting in Phoenix, Arizona.

We are running Field Trip 26. Exploring Superimposed Laramide Contraction, Porphyry Copper Systems, and Cenozoic Extension in the Globe-Superior-Ray-San Manuel area, East-Central Arizona from Thursday, 26 September to Saturday, 28 September 2019. The leaders are Eric Seedorff, Carson Richardson, Dan Favorito, Mark Barton, and Roy Greig.

This three-day, post-meeting trip will focus on the well-mineralized segment of the Laramide arc in east-central Arizona. This segment of the Laramide arc includes the GlobeMiami, Pinto Valley, Resolution, Ray, Christmas, Chilito, San Manuel, and Copper Creek deposits, and numerous prospects with potential for future exploration. The key themes examined in this field trip include: Laramide tectonic setting and style/amount of crustal shortening, space-time-composition evolution of the Laramide arc and porphyry copper deposits, post-mineralization Cenozoic normal faults and associated tilting, hydrothermal systems and alteration, supergene processes and dispersion, and the mining life cycle.

This trip, while having some overlap with LPEG fieldtrips run through the Porphyry (± IOCG and Alkalic Cu-Au) December short course, offers a full day that will focus exclusively on the evidence for the style and timing of Laramide contractional deformation and consider its relationship to porphyry copper mineralization, including 4WD forays into the brush to observe key exposures of reverse faults and associated folds that support a basement-cored uplift interpretation. Additionally, while the December field trip usually visits the Ray mine, this trip will visit Resolution for a presentation and an examination of drill core from this deep, high-grade porphyry copper deposit that is currently being developed.

The field trip costs $595/person, which includes all meals, accommodation, and transportation to/from the Phoenix Convention Center. More information is available at

https://community.geosociety.org/gsa2019/learn/field

Click on **Field Trip #26**. The registration deadline is **August 19, 2019**, so register today to reserve your spot!

Society Announcements

Attention AGS Membership!!!

The Geological Society of America is **still seeking sponsors** for the Geological Society of America Annual Meeting & Exposition on 22-25 September in Phoenix, Arizona! **Sponsors play a vital role in supporting the success of GSA's Annual Meeting while gaining productive opportunities to represent their companies, products, and services to our members.**

Some of the benefits for sponsors include:

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For more information on sponsorship, visit the Geological Society of America's webpage listed. The webpage contains additional information on what types of sponsorships are available, and other benefits that are offered to GSA Conference sponsors:

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If you or your company is interested in sponsoring the Geological Society of America Annual Meeting & Exposition 2019, please contact:

Debbie Marcinkowski

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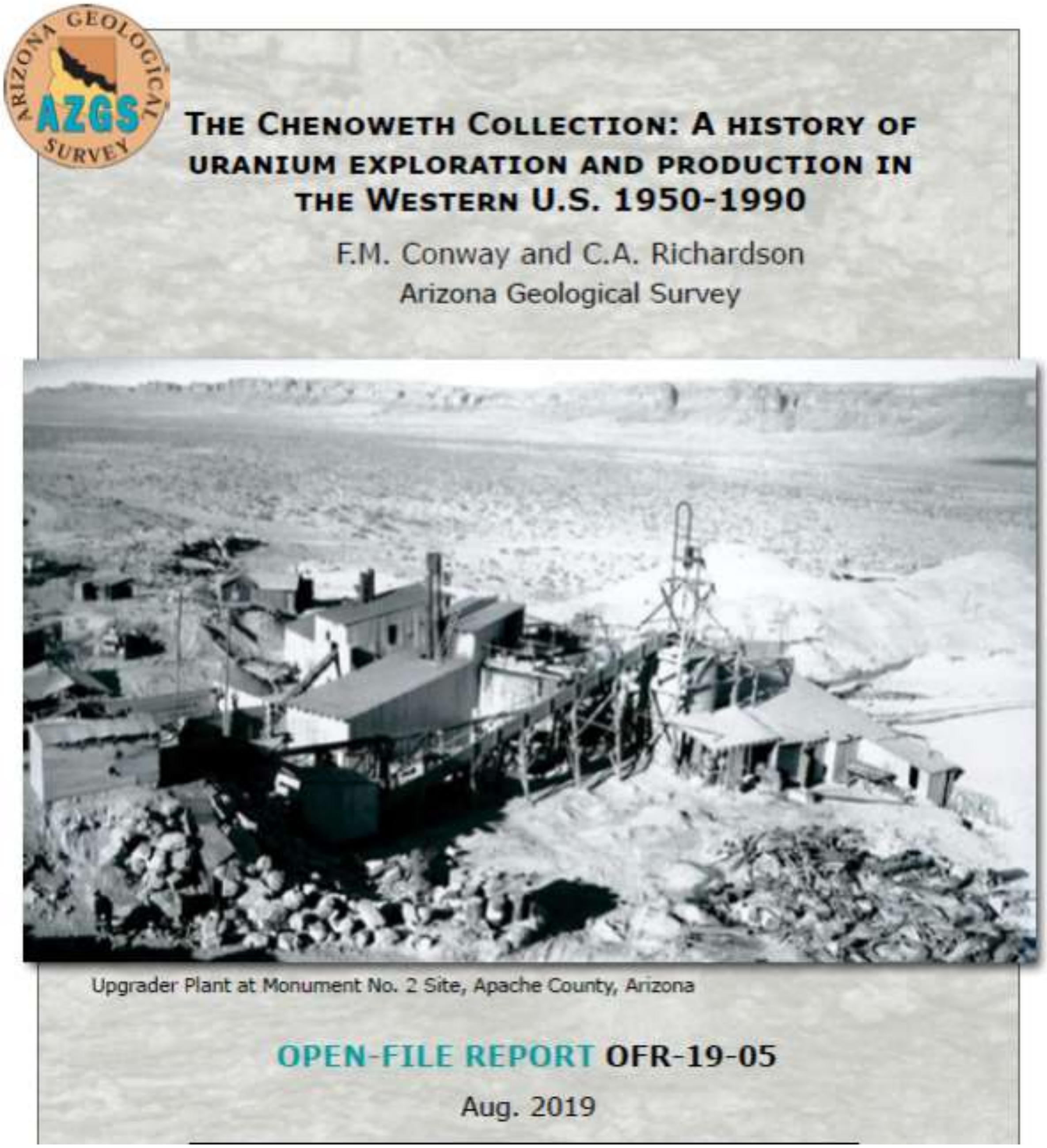
dmarcinkowski@geosociety.org

Bill Chenoweth's uranium reports - AZ, CO, NM, UT

by Arizona Geology e-Magazine, Arizona Geological Survey



AZGS newest Open-File Report, The Chenoweth Collection: A history of uranium exploration and production in the Western U.S. 1950-1990, comprises a bibliography of Bill Chenoweth's contributed reports to the state surveys and geological societies of Arizona, Colorado, New Mexico and Utah.

Continued on Page 16

For more than 50 years, William (Bill) L. Chenoweth (1928-2018) tramped across the southwestern U.S. hunting for uranium deposits. Bill's career began with the Atomic Energy Commission (AEC) in 1953; just as the Cold War was heating up. He retired from the U.S. Dept. of Energy in 1983. Post-retirement, he consulted, served on professional committees, and continued to publish reports and maps on uranium deposits in Arizona, Colorado, New Mexico, and Utah.

Between 1983 and 2018, Bill drafted ~ 150 uranium reports. He turned to the state surveys and geological societies in Arizona, Colorado, New Mexico, and Utah to publish those reports. His last contributed report for AZGS was published in May 2018: Geology, Exploration and Production History of the Uranium-Vanadium Mines of George R. Simpson and Gloria Emerson, NW Carrizo Mtns., Apache County, Arizona.

Read the report here:

http://repository.azgs.az.gov/uri_gin/azgs/dlio/1917

Read original blog post here:

https://blog.azgs.arizona.edu/blog/2019-08/bill-chenoweths-uranium-reports-az-co-nm-ut

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