Arizona Geological Society Newsletter

MARCH 2014

MARCH 4, 2014 DINNER MEETING

Who: **John Dreier** will speak about "Copper Deposits of the Coast Ranges of Chile; A trip through time, space, and ore deposit nomenclature."

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 ***PIMA 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 $27, guests $30, Students free with online reservation ($10 without).

RESERVATIONS are REQUIRED: CALL (520) 663-5295 by 11 a.m. by Friday, February 28 or reserve on the AGS website (www.arizonageologicalsoc.org). Please indicate regular (Sliced beef brisket with garlic herb mashed potatoes and chef's choice vegetables), vegetarian, or cobb salad meal preference. Please cancel by Friday, February 28 at 11 a.m. if you are unable to attend—no shows and late cancellations will be invoiced.

The March dinner meeting is sponsored by:

MAJOR DRILLING GROUP INTERNATIONAL, INC.

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AGS is grateful for Major Drilling's sponsorship, which helps us to offset dinner meeting costs. Learn more about Major Drilling at http://www.majordrilling.com.

Abstract

Copper Deposits of the Coast Ranges of Chile
A trip through time, space, and ore deposit nomenclature

Dr. John Dreier, Private Consultant

The Coast Ranges of Chile, extending for about 3000 km along western South America from the Peruvian border (latitude 18° S) to Tierra del Fuego (latitude 55° S), are largely underlain by volcanic and plutonic rocks of a Jurassic-Lower-Mid Cretaceous subduction-related volcanic arc complex. For slightly less than half that distance, from 18° S to ~35° S, the Jurassic-Cretaceous arc hosts numerous copper deposits (perhaps well into the thousands), which contain variable amounts of specularite and/or magnetite plus the common wall

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rock alteration/gangue minerals, albite, K-feldspar, chlorite, epidote, calcite, apatite, sericite, biotite, actinolite, and scapolite. Some of these mineral deposits have Au as an important byproduct, others contain Ag, a few are Ag-dominant, and some were mined for Mn. In form, the deposits include veins, mantos, stockworks, and breccias pipes.

The copper deposits of the Coast Ranges vary in structural control according to age of formation. Jurassic deposits are dominantly related to and/or controlled by ENE or WSW-trending strike slip faults of apparently small displacement, whereas the Cretaceous deposits tend to be controlled by regional-scale northerly -trending high-angle transpressional faults or reverse faults related to the compression and uplift of the volcanic arc and the closure of a Jurassic-lower Cretaceous back arc basin located to the east of the volcanic arc. Within intrusive rocks, mineralization is localized in veins, whereas in volcanics and sediments, mineralization occurs as mantos, stockworks, and breccia pipes in addition to veins (all often in close proximity to each other). In general, copper mineralization in the Coast Ranges differs from porphyry-style deposits in that it is not focused on a point source; rather it is widely dispersed over very large areas (hundreds of sq km). In many such districts it is possible to follow vein systems for many km along strike within batholiths and have the veins morph into vein-manto-chimney systems when they pass into the volcanic and sedimentary wall rocks adjacent to the batholiths. An important feature of the Coast Ranges deposits is mineralogical zoning of wall rock alteration and mineralization, which is in addition to the vertical zoning of deposit morphology.

Deep-Level deposits are 1-5 m wide veins hosted by intermediate-composition plutonic bodies plus volcanics and sediments metamorphosed to greenschist or higher facies. Wall rock alteration selvages adjacent to the deep-level veins are generally narrow and consist of biotite, K and/or Na-feldspar, and actinolite. Vein minerals include quartz, calcite, apatite, actinolite, magnetite, chalcopyrite, and bornite. Individual deep-level veins or vein clusters may contain up to 50,000 tonnes of Cu metal as chalcopyrite and lesser bornite plus 60,000 ounces of gold. The Coast Ranges batholiths and their metamorphic host rocks contain hundreds or perhaps thousands of such individual vein deposits. About 10 of these deposits are in production by milling operations, which process 2,000 – 3,000 TPD of ore grading ~1.5% Cu and 0.5 to 1 g/t Au and ship 4,000 – 5,000 TPM of concentrate to smelters. Geologic relationships and other features suggest depths of formation in the range of 6 km to possibly as deep as 10 km.

Intermediate-level deposits vary in form from veins to mantos and chimneys. Ore minerals of the intermediate-level deposits include chalcopyrite, bornite, and minor hypogene chalcocite; gangue/alteration minerals include magnetite, specularite, K-feldspar, albite, biotite, scapolite, chlorite, epidote, and calcite. The bulk minable intermediate-level deposits are hosted by volcanic and sedimentary rocks. In detail, mineralization in the intermediate level deposits is controlled by structures and certain favorable beds or stratigraphic units; vesicular lava flow tops and brecciated lava flow tops and bottoms are very common and important ore hosts. The deposits typically contain 0.2 - 0.3 g/t Au and up to 20 g/t Ag. Important intermediate-level deposits include Candelaria, Atacama Kozan, Santa, and others in the Tierra Amarilla district. Cumulatively, Intermediate-Level Cu deposits of the Coast Ranges have produced 2-4 M tonnes of Cu metal, and many of these deposits are (or were in the past) mined by bulk methods.

High-level deposits assume a variety of forms, including veins, breccia pipes, and mantos and the breccias appear to be multi-generational and magmato-hydrothermal in origin. The stratigraphic control to the high

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-level deposits is similar to that of the intermediate-level deposits, especially in respect of control by lava flow tops and bottoms. Common ore minerals in the high-level deposits include hypogene chalcocite, digenite, bornite, lesser chalcopyrite, and minor native silver, plus hematite. In some high-level deposits, a portion of the mineralization is intimately related to hydrocarbons. The high-level deposits lack Au and may contain up to 150 g/t Ag. At least one high-level district contains deposits that resemble epithermal veins in form and ore texture and, like many epithermal veins, the veins terminate upward by pinching out. Near their tops, the veins in this district have adjacent mantos that were mined for Ag, Cu, and Mn. Common gangue/wall rock alteration minerals in the high-level deposits include quartz, calcite, chlorite, sericite, K-feldspar, albite, and epidote, plus galena and sphalerite. Rocks surrounding the high-level deposits are commonly affected by regional zeolite/pumpellyite alteration/metamorphism. High-level systems include Michilla, Buena Esperanza, Mantos Blancos, Frankenstein, El Soldado, and Cerro Negro (sur), and Chañarcillo. Total production from these deposits is > 4 M t Cu metal and >>100M oz Ag. Recent exploration in some former Chilean Ag districts indicates that these represent upper halos above Cu-Fe systems.

Geological relationships evident throughout the Coast Ranges make it abundantly clear that the mineral systems are vertical zoned with respect to form, mineralization, and gangue/wall rock alteration mineralogy. Thus, IOCG-like characteristics predominate in the lower levels of the systems but gradually give way upward first, to Cu-Au-Ag, then to Cu-Ag, then to Ag, and finally, in the upper-most regions, to Mn mantos or Mn-rich chalcedony veins. A full understanding of the vertical zoning and the principal structural and stratigraphic controls to mineralization is a requisite for successful exploration.

The Coast Ranges deposits are enigmatic in their placement within the classification of mineral deposits. Historically they were described as either veins or Chilean Manto-Type Cu Deposits, but within the past 15 years or so, spurred by work at Candelaria, they were reclassified as IOCG deposits. The evident zonal nature of these deposits and the absence of gold in many of the important ones provide evidence that the Coast Ranges ore systems extend beyond the bounds of the IOCG designation and thus their place within the world of ore deposits should be given further consideration. An additional complication to the categorization of the Coast Ranges copper deposits is that several of them have porphyry-like characteristics while others are located in close proximity to well-recognized Cretaceous age porphyries.

The copper deposits of Chile have played an important role in the development of the Chilean copper industry. Copper mining in Chile began in the 1830's in the Coast Ranges with small-scale operations focused on high-grade veins of oxide and secondary enriched sulfides that treated hand-sorted ore in small smelters scattered along the coast or shipped raw ore to Wales for smelting. Beginning in the 1960's, production from the small-scale operations was progressively supplanted by increasingly larger-scale mine-for-leach operations, which have produced a total of ~8 M tonnes of Cu metal, mostly from mine-for-leach/SXEW operations. Large modern operations include Michilla, Mantos Blancos, Manto Verde, and El Soldado. Modern intermediate-scale operations include Ivan-Zar, Mantos de la Luna, Sierra Valenzuela (closed), Sierra Miranda, Las Luces, Frankenstein (recently failed SXEW operation), Santa, Atacama Kozan and other operations in theTierra Amarilla area, Cinabrio, Cabildo, Cerro Negro, and Pudahuel (closed). Small-scale operations are numbered in the hundreds and include the many small mines which ship hand sorted oxide ore to ENAMI (government-operated) leaching plants at various points along the Coast Ranges.

About the March Dinner Meeting Speaker

Mr. Dreier received a bachelor's degree in geology from Union College (1964), a Masters in geology from the University of Wyoming (1965), and a Ph. D. in Geosciences from the University of Arizona (1976). He began his career in economic geology with Inco in northern Manitoba and the Northwest Territories of Canada exploring for nickel deposits. After completing his M. S. he went to work for Bear Creek Mining Co. exploring for sediment hosted copper deposits in the northwest U. S. and later for porphyry copper deposits in Arizona and New Mexico. During this time, he also worked as a mine geologist at Ray, Arizona, where his interest in copper leaching took root. At the University of Arizona he became interested in the application of thermodynamics to geological problems. However, as thermodynamic data in the early 1970's stopped at about 300 – 350^{o} C he decided to employ the then new approach of collecting data on ore forming fluids by the study of fluid inclusions in samples from an epithermal system (porphyry copper deposits were formed at temperatures higher than upper reaches of the thermo. data set). Spence Titley then brought up Pachuca and Spence and John Guilbert obtained funding from Guillermo Salas, Director of the Consejo de Recursos no Renovables de Mexico. With the promise of funding and Spanish 1A and 1B under his belt, Mr. Dreier jumped in his 65 Mustang and drove down to Pachuca, camping out on the way to save money. After many experiences, some of them of the near-death type and others of a more pleasurable kind, he returned from Mexico, completed his Ph.D. and went on to cofound Sage Associates with Dave Hackman and Perry Durning with the purpose of exploring for epithermal silver deposits in the Western U. S. SAGE came up with a number of good epithermal targets, but the program was gradually enlarged to include Carlin systems and a placer gold deposit in Alaska.

His experience in Chile began in the mid 1980's when he briefly consulted there for Cyprus Minerals and he has worked on the Coast Ranges copper deposits on and off ever since then. From 2004 to 2009, he managed a program to explore for and acquire oxide copper deposits in the Chilean Coast Ranges first on behalf of Newcrest Mining, and later for a private group. These exploration/acquisition programs took Mr. Dreier to a great majority of the copper districts in the Coast Ranges. These programs and subsequent work in the Chilean Coast Ranges form the basis for tonight's talk. His work with oxide copper deposits lead him to a study of copper leaching the geochemistry and geometallurgy of copper leaching, to designing and managing copper leach metallurgical test programs, and to working as a consultant to copper leaching projects and operations. He has taught the chemistry and geometallurgy of copper leaching in the SME Copper Heap Leach short course since 1990 and is presently the course organizer.

Save the Date - GeoDaze 2014 at UA Student Union Grand Ballroom. Join the UA Department of Geoscience students, faculty, alumni, and friends at the 42nd annual student presentation forum to be held on April 10-11, 2014; the field trip will be held on Saturday April 12th. Registration will open soon. See http://earth.geo.arizona.edu/geodaze/14/index.html

MEMBER NEWS - Congratulations to AGS Life Member, Spencer R. Titley, who will receive the Mineral Industry Education Award at the 2014 SME/AIME awards ceremony in Salt Lake City in late February. AGS member, Rohini Sharma will also recognized as a SME Distinguished Member at this event.

AGS Spring Field Trip

On Saturday, April 26, 2014, the AGS spring field trip is planned for Freeport-McMoRan's Christmas porphyry copper deposit in Gila County, Arizona.

The Christmas deposit is situated at the southeastern end of the Dripping Springs Mountains and is one of the last largely undeveloped deposits remaining in the prolific porphyry copper province of southeastern Arizona. The planned program will include an examination of core and stops at significant geologic outcrops in the vicinity of the mine.

For information about this event, please visit our events page .

Selected Arizona Geological Survey News

On 12 February, we released a special episode of the Arizona Mining Review with Dr. Peter Megaw, Exhibits Chair Tucson Gem and Mineral Show. Peter joined host Lee Allison to discuss the 60th Annual TGM show, " 60 Years of Diamonds, Gems, Silver and Gold".

Origin of the lower Colorado River. On February 10, AZGS geoscientists Jon Spencer & Phil Pearthree joined Georgia Davis on KUAT's Arizona Illustrated to describe the origin of the lower Colorado River. (The interview begins at about the 20-minute mark in the program).

On 15 February, AZGS hosted the annual meeting of the Arizona Chapter of the American Institute of Professional Geologists.

On 14 February, Lee Allison provided an "Arizona Mining Update," at the Mining Appreciation Celebration event hosted by the Southern Arizona Business Coalition at the Viscount Suites Hotel, Tucson, AZ.

New Publications from AZGS (Available online at the AZGS Document Repository)

Kyle, J.R. and McBride, E.F., 2014, Geology of the Voca Frac Sand District, western Llano Uplift, Texas, in, Conway, F.M., ed., Proceedings of the 48th Annual Forum on the Geology of Industrial Minerals, Phoenix, Arizona, April 30 - May 4, 2012. Arizona Geological Survey Special Paper #9, Chapter 2, p. 1-13.

Arizona Geological Survey, 2014, Earth Fissure Map of the North Sulphur Springs Valley Study Area, Cochise County, Arizona. Arizona Geological Survey Digital Map Series - Earth Fissure Map 26 (DM-EF-26), map scale 1:24,000.

Thank You for Your Donation to the Courtright and AGS Scholarship Funds

Carmon Bonanno	Clay Conway	Eric Seedorff
David Briggs	Jerry Mohling	Bruce Walker

ANNOUNCEMENTS

Welcome New AGS Members

Jim Bliss	Kevin Meazell	Nadine Warneke
Beth Boyd	Susan Miller	Chuck Whipple
Geno Castillo	Eric Ruud	Linton Wildrick
Hayden Falk	Alfredo Villalobos	David Williams
Dwight Hoxie	Don Wagstaff	

Arizona Geological Society is grateful to Freeport-McMoRan Copper and Gold for their generous support of our student members!

Freeport-McMoRan is sponsoring student dinners for the 2014 AGS monthly meetings.

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2014 AGS MEMBERSHIP APPLICATION OR RENEWAL FORM

Please mail check with membership form to: Arizona Geological Society, PO Box 40952, Tucson, AZ 85717

Dues (check box) ☐ 1 year: $20; ☐ 2 years, $35; ☐ 3 years: $50; ☐ full-time student (membership is free)

NEW MEMBER or RENEWAL? (circle one) Date of submittal _____

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All newsletters will be sent by email. If you do not have an email address, we will mail a hard copy to you, but we cannot guarantee timeliness.

If registered geologist/engineer, indicate registration number and State: _____

Enclosed is a _____ tax-deductible contribution to the J. Harold Courtright Scholarship Fund.