Guidebook

Society of Economic Geologists Foundation, Inc.
Student-Dedicated Field Trip Course –
Porphyry Copper Deposits of Southern Peru

September 16 - 22, 2012

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William X. Chávez, Jr.²

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Welcome to the Society of Economic Geologists Foundation, Inc. Field Trip Course – Porphyry Systems of Southern Peru, September 16 to 22, 2012. This field trip course is the tenth in Society of Economic Geologists Foundations Series that was established as a response to a student petition at the 2006 SEG Conference held in Keystone, Colorado, to provide more support for field trips to important mining districts.

The course starts in Tacna. An organizational and safety meeting for all participants will take place at 6:00 pm on Sunday the 16th at the Hotel Maximo in Tacna. At 6:00 am the next morning we depart for Toquepala. Tuesday we will visit Quellaveco and Wednesday we will visit Cuajone. On Thursday and Friday we will visit the Zafranal and Don Javier prospects, respectively. The field trip course ends on Friday evening with participants departing on Saturday.

Entrance to the mine sites usually follows a specific protocol; please be patient. At the mines we will receive safety training and a geological/engineering presentation. Do not take any pictures of the presentations unless and until we clear this point with company personnel. We will ask, but in general, participants can take pictures and collect samples on company property. Participants are responsible for their own samples (be aware of weight limits if you plan to take samples back with you).

We will have VERY LIMITED . . . REPEAT: VERY LIMITED . . . space for luggage, so you should bring clothing and field gear ONLY IN DUFFLE BAGS - NO HARD-SIDED LUGGAGE. See you in Tacna.

View of Cuajone Pit looking east (ca. 2000)

Cover: Misti Volcano, Arequipa. All photos by Erich U. Petersen
Acknowledgements

This field trip is generously supported through the Society of Economic Geologists Foundation through the SEGF Student Field Trip Fund. We thank the companies that provided access to their operations in Peru and the many company representatives that gave generously of their time to make this trip a success. Special thanks are due to Borden Putnam, Brian Hoal, John Thoms Vicky Ster Nicki, David Braxton, Alvaro Fernandez-Baca, Sergio Godoy, Jose Hector Figueroa, Wu Bin.

The Society of Economic Geologists Foundation, Inc.

Anglo American
AQM Copper Inc.
Freeport McMoran
Grupo Mexico
BHP Billiton
Rio Tinto
SPCC
Minas de Toquepala
Minas Cerro Verde
Minas Cuajone
Junefield Mineral Resources Holdings Limited
Compania Minera Milpo, S.A.A.
Newmont, Minera Yanacocha
Juan Javier Canales Quispe
Camilo Correira Trouw
Hamish Robert Martin
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**SEG Foundation Field Course**  
**Porphyry Systems of Southern Perú**  
**16-22 September, 2012**

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<table>
<thead>
<tr>
<th>Date</th>
<th>Itinerary</th>
<th>Overnight</th>
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<tbody>
<tr>
<td>16 September</td>
<td>6:00 PM – Safety and Logistics meeting – Maximo Hotel.</td>
<td>Tacna</td>
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<tr>
<td>Sunday</td>
<td>Discuss course content and expectations, course logistics.</td>
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<tr>
<td>17 September</td>
<td><strong>7:00AM</strong> - Depart for Toquepala Cu-Mo porphyry system,</td>
<td>Toquepala</td>
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<tr>
<td>Monday</td>
<td>Paleocene-age intrusion complex. Discuss structural controls on</td>
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<td>regional distribution of porphyry systems and Incapuquio Fault System.</td>
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<tr>
<td>18 September</td>
<td>07:00AM – Depart for Quellaveco porphyry Cu-Mo property</td>
<td>Moquegua</td>
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<tr>
<td>Tuesday</td>
<td>Leached capping examination and discussion of supergene processes</td>
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<tr>
<td>19 September</td>
<td><strong>6:30AM</strong> – Depart for Cuajone Cu-Mo porphyry system; discuss geomorphologic development of southern Perú, post-enrichment erosional processes.</td>
<td>Pedernales</td>
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<tr>
<td>Wednesday</td>
<td>7:00AM - Visit Zafranál porphyry Cu-Mo system.</td>
<td>Arequipa</td>
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<tr>
<td>20 September</td>
<td>Visita a Don Javier, porphyry Cu-Mo prospect.</td>
<td>Arequipa</td>
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<tr>
<td>Thursday</td>
<td>Review core from various regions within the Don Javier system; discuss</td>
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<td></td>
<td>interpretation of alteration assemblages with regard to location</td>
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<tr>
<td></td>
<td>within a porphyry environment.</td>
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<tr>
<td>22 September</td>
<td>Course ends</td>
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<tr>
<td>Saturday</td>
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**NOTES:**

- Participants must arrive at the Hotel Maximo in Tacna by 6:00 PM on the 16th of September for a safety and logistics meeting.
♦ All participants MUST – REPEAT…MUST - bring hardhat, STEEL-TOE BOOTS, reflective vest, gloves, and eye protection. DO NOT plan to obtain these items during the course, as there is no time to do so!

♦ All participants MUST bring and wear long pants and long-sleeve shirts for the mine visits.

♦ Participants must provide proof of insurance coverage valid in Perú PRIOR to participation in the course. Please bring your insurance card ID with you.

♦ Please bring all prescription medications and your written prescriptions – carry these with you, do not place in your checked baggage. If there is any conditions that might affect you during the course, please advise SEG prior to the course.

♦ All participants must sign a liability waiver form that will be provided by SEGF prior to participation in the course.

♦ Participants will need money for incidental expenses. SEGF provides transportation during the course, plus lodging and some breakfasts; most mines provide lunches, but prospects may not have facilities to do so. As such, you will need CASH (not credit cards) for your meal and other incidental expenses. You may change money at the Lima airport, in the Baggage Claim area, where there are two kiosks that offer decent exchange rates.

♦ Participants will need to check on Perú visa requirements well in advance of their travel to Peru; for some nationalities, the visa may be obtained on the flight to Perú.

♦ All participants will need to submit their passport information (name, country of issue) to SEGF so that this information may be passed along to the mining companies as a part of our mine entrance procedures.

♦ The weather in southern Perú during September is generally balmy and warm; nights may be cool. Please bring layers of clothing for warm days and cool evenings.

♦ It is recommended that participants bring sun screen/block, as well as a hat or cap for sun protection.

♦ Please bring a towel and toiletries for our stays in hosterías / hotels.

♦ Pack Lightly – we have LIMITED SPACE on the bus, so you will need to pack appropriately. Only duffle bags will be allowed on the bus. If you are staying for the conference, you may deposit clothing and other materials in hard luggage at the convention hotel (Westin) prior to your departure for Tacna, saving you the hassle of excess baggage.

♦ Students are recommended to purchase a Perú guide or tour book for reference – these guides make your travels within Peru easier, have hints about bus connections and restaurants, and usually contain vignettes on local history and culture.
## Participants

<table>
<thead>
<tr>
<th>Participants</th>
<th>University</th>
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<th>Email</th>
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<tbody>
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<td>Newmont / Minera Yanacocha</td>
<td>Peru</td>
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<tr>
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<td>BHP Billiton Brazil/Dutch</td>
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Minerals Commonly Found in the Oxide Zone of Copper Deposits

Alunite ........................................................... KAl$_3$(SO$_4$)$_2$(OH)$_6$
Antlerite .......................................................... Cu$_3$SO$_4$(OH)$_4$
Atacamite (paraatacamite, botallackite) ....... Cu$_2$Cl(OH)$_3$
Bonattite........................................................... CuSO$_4$.3H$_2$O
Brochanite........................................................... Cu$_4$SO$_4$(OH)$_6$
Ceruleite ........................................................... Cu$_2$Al$_7$(AsO$_4$)$_4$(OH)$_{13}$.12H$_2$O
Chalcanthite ........................................................ CuSO$_4$.5H$_2$O
Chalcosiderite (compare to turquoise)....... CuFe$_6$(PO$_4$)$_4$(OH)$_8$.4H$_2$O
Chenevixite ........................................................ Cu$_2$Fe$_2$(AsO$_4$)$_2$(OH4.H$_2$O
Chrysocolla (mineraloid) ......................... Cu(Fe,Mn)O$_x$-SiO$_2$-H$_2$O, with copper content varying from ~20-40 wt % Cu
Copiapite ........................................................... Fe$_5$(SO$_4$)$_6$(OH)$_2$.20H$_2$O
Coquimbite ......................................................... Fe$_3$(SO$_4$)$_3$.9H$_2$O
Goethite ............................................................... a-FeOOH
Jarosite ............................................................... (K,Na)Al$_3$(SO$_4$)$_2$(OH)$_6$
Kröhnkite ............................................................ Na$_2$Cu(SO$_4$)$_2$.2H$_2$O
Levandulite ........................................................... NaCaCu$_5$(AsO$_4$)$_4$Cl.5H$_2$O
Libethinite ........................................................... Cu$_2$PO$_4$(OH)
Paramelanconite .................................................. Cu$_4$O$_3$ (see tenorite (CuO) and cuprite (Cu$_2$O)
Poitevinite .......................................................... (Cu,Fe,Zn)SO$_4$.H$_2$O
Posnjakite ........................................................... Cu$_4$SO$_4$(OH)$_6$.H$_2$O
Pseudomalachite .................................................... Cu$_5$(PO$_4$)$_2$(OH)$_4$
Scorodite ............................................................... FeASO$_4$.2H$_2$O
Turquoise ............................................................. CuAl$_6$(PO$_4$)$_4$(OH)$_8$.4H$_2$O
Voltaite ............................................................... K$_2$Fe$_8$Al(SO$_4$)$_12$.18H$_2$O
Wroewolfeite (Langite) ................................. Cu$_4$SO$_4$(OH)$_6$.2H$_2$O
Some Common Mineral Formulas

Chlorite ..................................  \((\text{Mg,Fe})_3(\text{Al,Si})_4\text{O}_{10}(\text{OH})_2(\text{Mg,Fe})_3(\text{OH})_6\)

Biotite ..................................  \(\text{KFe}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2\)

Muscovite ..............................  \(\text{KA}_3\text{Si}_3\text{O}_{10}(\text{OH})_2\)

Kaolinite .............................  \(\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4\)

Alkali feldspar .......................  \((\text{K,Na})\text{AlSi}_3\text{O}_8\)

Plagioclase ............................  \(\text{CaAl}_2\text{Si}_2\text{O}_8\)

Dumortierite ..........................  \(\text{Al}_7\text{O}_3(\text{BO}_3)(\text{SiO}_4)_3\)

Tourmaline ............................  \((\text{Na,Ca})(\text{Li,Mg,Al})(\text{Al,Fe,Mn})_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4\)

Bornite ...............................  \(\text{Cu}_5\text{FeS}_4\)

Chalcopyrite ..........................  \(\text{CuFeS}_2\)

Chalcocite ............................  \(\text{Cu}_2\text{S}\)

Covellite ...............................  \(\text{CuS}\)

Cuprite .................................  \(\text{Cu}_2\text{O}\)

Tenorite ...............................  \(\text{CuO}\)
(1) Typically trondhjemite if biotite is only mafic mineral and makes up less than 10% of rock.

(2) With less than 5% mafic minerals, the rock is anorthosite. With more than 40% mafic minerals, it is typically gabbro. Rocks with 5-40% mafic minerals are either diorite or leucogabbro, and require determination of the plagioclase, the limiting composition being An50.

(3) The kind of alkali feldspar should be specified if possible; e.g., microcline granite.

(4) The feldspathoid should be specified in each rock name; e.g., nepheline syenite.
Figure 34. Isothermal isobaric fugacity diagram showing the stability fields of covellite (CV), chalcocite (CC), pyrite (PY), pyrrhotite (PO), magnetite (MT), and hematite (HM). Chalcopyrite field is surrounded by bornite plus an additional sulfide. Annite stability field is surrounded by orthocata cle plus sulfides and oxides. Position of potassium-silicate protore at Butte, Montana is given at I. Position of advanced argillite alteration assemblage and Main Stage oxidizing fluid is at the intersection of CV-CC phase boundary and that of annite-muscovite. From Brimhall (1980) and Brimhall and Ghiorso (1983).
FIG. 8.6 The stabilities of minerals from porphyry copper deposits at 250°C. The solid boundaries and those with longer dashes represent activities respectively of $\Sigma S = 0.1$, $\Sigma C = 0.1$, $K^+ = 0.5$, $Ca^{2+} = 0.1$, and $Ba^{2+} = 0.001$. A change of $\pm 10x$ in activity is indicated by the light lines of shorter dashes. (Modified from Crerar and Barnes, *Econ. Geol.*, 71, 772-794.)
Fig. 5.5 Schematic stability relations in the system K$_2$O-Na$_2$O-Al$_2$O$_3$-SiO$_2$-H$_2$O-HCl at 400°C and 1 kb. Pyrophyllite is metastable. (a) Triangular mole fraction diagram, showing solid assemblages with quartz present. (b) Similar plot of molar Na$_2$O/Al$_2$O$_3$ vs. K$_2$O/Al$_2$O$_3$. (c) Stability of phases as a function of $a_{\text{Na}_2\text{O}}$ vs $a_{\text{K}_2\text{O}}$. (d) Stability of phases as a function of $\log a_{\text{Na}^+}/a_{\text{H}^+}$ vs $\log a_{\text{K}^+}/a_{\text{H}^+}$. See text for discussion of the paths of solution composition during reaction of solution A with a mixture of feldspars. (e) Stability as a function of $\mu_{\text{Na}_2\text{O}}$ vs $\mu_{\text{K}_2\text{O}}$. Figures based on data in Helgeson (1974), Meyer and Hemley (1967), and Montoya and Hemley (1974).
Readings


Clark, A.H., 1990, Geomorphological, Environmental and Age of Supergene Enrichment of the Cuajone, Quellaveco, and Toquepala Porphyry Copper Deposits, Southeastern Peru. Economic Geology, 85, 1604-1628.


Dune field northeast of Majes. Cusp to cusp distance is 30 meters. North is up.
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At the end of the trip, and as soon as possible, please send a brief e-mail to Borden Putnam with a copy to Brian Hoal and John Thoms describing your experience on the trip and acknowledging the support of the Society of Economic Geologists. This is very important, as the feedback received by SEG is critical for the planning of future field course trips. You will also find that maintaining contact in this manner will greatly benefit your career whatever course it may follow. Your note may be in your native language.