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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SEGF Student-dedicated Field Trip Course
Porphyry Systems of Southern Peru

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 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 Sternicki, 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

Henry Montano Vela

University of Utah

New Mexico Tech

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SEG Foundation Field Course
Porphyry Systems of Southern Perú
16-22 September, 2012

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

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

Participants	University	Country	Email
Andreeva Elena	Hokkaido University	Japan	
Daniela Anguita	University of Utah	U.S.A.	
Kathryn Ann Bradbury	Colorado School of Mines	U.S.A.	
Michael John Buschette	University of Minnesota, Duluth	U.S.A.	
Laurisha Jaisene Nneka Bynoe	University of Western Ontario	Canada	
Maria del Pilar Escobar Lopez	Universidad Nacional de Mexico	Mexico	
Fayol Noémie	University of Quebec, Montreal	Canada	
Timothy Garrison Gross	Colorado School of Mines	U.S.A.	
Adrian Gutierrez	University of Texas, El Paso	U.S.A.	
Harold Phillip Hanneman	Colorado School of Mines	U.S.A.	
Carlos Andres Jimenez Torres	University of Tasmania, CODES	Australia	
Laura Rachel Katz	Laurentian University	Canada	
Rebecca Scott Morris	New Mexico Tech	U.S.A.	
Demian Alan Nelson	University of California, San Diego	U.S.A.	
Alicia Anne Newton	University of Auckland	New Zealand	
Marta SoÅ›nicka	AGH Univ. Science Technology	Poland	
Juan Javier Canales Quispe	Compania Minera Milpo, S.A.A.	Peru	
Hamisch Robert Martin	Resolution Copper	U.S.A.	
Henry Montano Vela	Newmont / Minera Yanacocha	Peru	
Camilo Correia Trouw	BHP Billiton Brazil/Dutch		
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Minerals Commonly Found in the Oxide Zone of Copper Deposits

Alunite	$KAl_3(SO_4)_2(OH)_6$
Antlerite	$Cu_3SO_4(OH)_4$
Atacamite (paraatacamite, botallackite)	$Cu_2Cl(OH)_3$
Bonattite	$CuSO_4.3H_2O$
Brochanite	$Cu_4SO_4(OH)_6$
Ceruleite	$Cu_2Al_7(AsO_4)_4(OH)_{13}.12H_2O$
Chalcanthite	$CuSO_4.5H_2O$
Chalcosiderite (compare to tourquoise)	$CuFe_6(PO_4)_4(OH)_8.4H_2O$
Chenevixite	$Cu_2Fe_2(AsO_4)_2(OH4.H_2O$
Chrysocolla (mineraloid)	$Cu(Fe,Mn)O_x$-SiO_2-H_2O, with copper content varying from ~20-40 wt % Cu
Copiapite	$Fe_5(SO_4)_6(OH)_2.20H_2O$
Coquimbite	$Fe_2(SO_4)_3.9H_2O$
Goethite	a-FeOOH
Jarosite	$(K,Na)Al_3(SO_4)_2(OH)_6$
Kröhnkite	$Na_2Cu(SO_4)_2.2H_2O$
Levandulite	$NaCaCu_5(AsO_4)_4Cl.5H_2O$
Libethinite	$Cu_2PO_4(OH)$
Paramelanconite	Cu_4O_3 (see tenorite (CuO) and cuprite (Cu_2O)
Poitevinite	$(Cu,Fe,Zn)SO_4.H_2O$
Posnjakite	$Cu_4SO_4(OH)_6.H_2O$
Pseudomalachite	$Cu_5(PO_4)_2(OH)_4$
Scorodite	$FeASO_4.2H_2O$
Turquoise	$CuAl_6(PO_4)_4(OH)_8.4H_2O$
Voltaite	$K_2Fe_8Al(SO_4)_{12}.18H_2O$
Wroewolfeite (Langite)	$Cu_4SO_4(OH)_6.2H_2O$

Some Common Mineral Formulas

Chlorite ..... $(Mg,Fe)_3(Al,Si)_4O_{10}(OH)_2.(Mg,Fe)_3(OH)_6$

Biotite..... $KFe_3AlSi_3O_{10}(OH)_2$

Muscovite..... KAl3Si3O10(OH)2

Kaolinite..... $Al_2Si_2O_5(OH)_4$

Alkali feldspar..... $(K,Na)AlSi_3O_8$

Plagioclase ..... $CaAl_2Si_2O_8$

Dumortierite..... $Al_7O_3(BO_3)(SiO_4)_3$

Tourmaline..... $(Na,Ca)(Li,Mg,Al)(Al,Fe,Mn)_6(BO_3)_3(Si_6O_{18})(OH)_4$

Bornite ..... Cu_5FeS_4

Chalcopyrite..... $CuFeS_2$

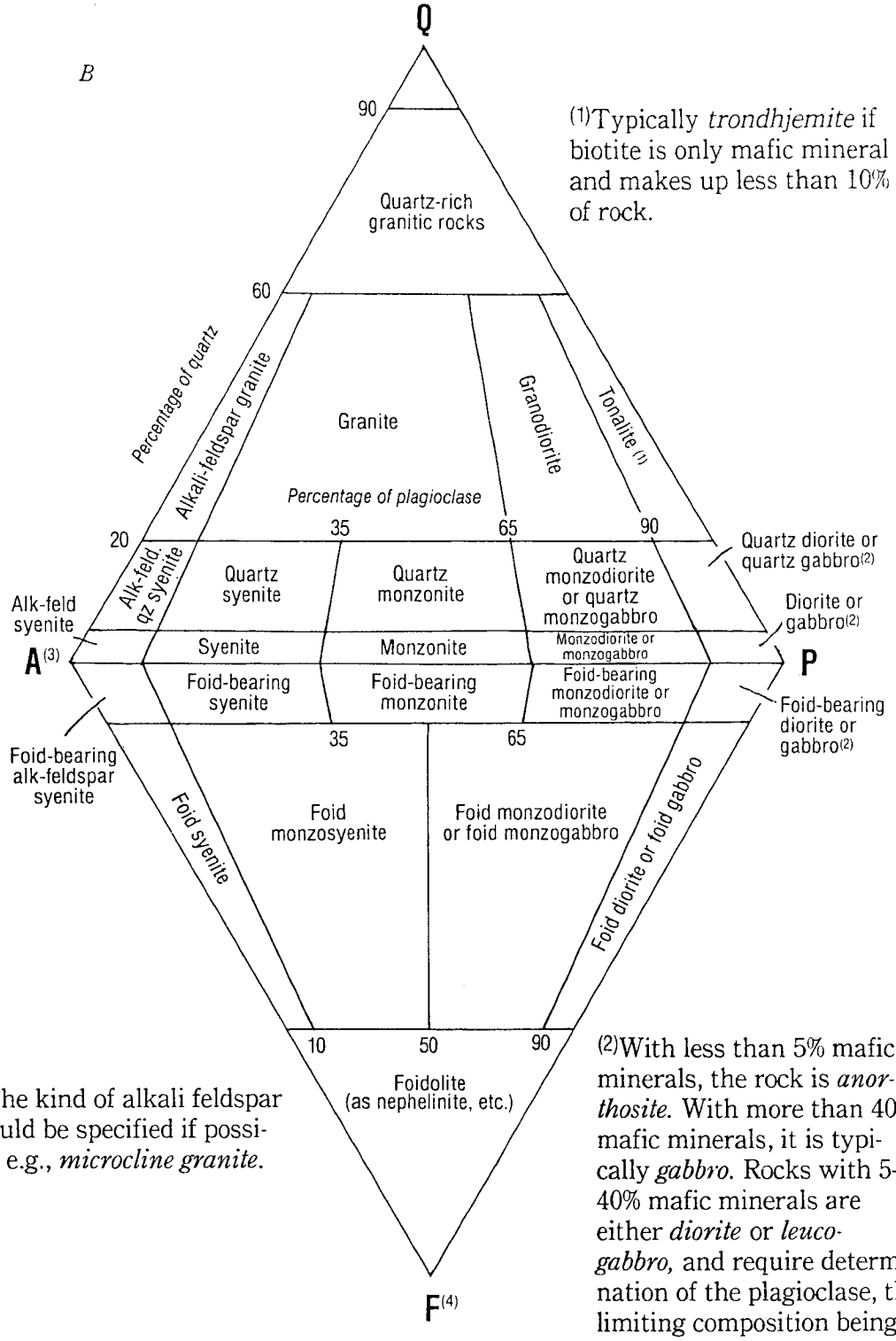
Chalcocite ..... Cu_2S

Covellite..... CuS

Cuprite ..... Cu_2O

Tenorite..... CuO

B

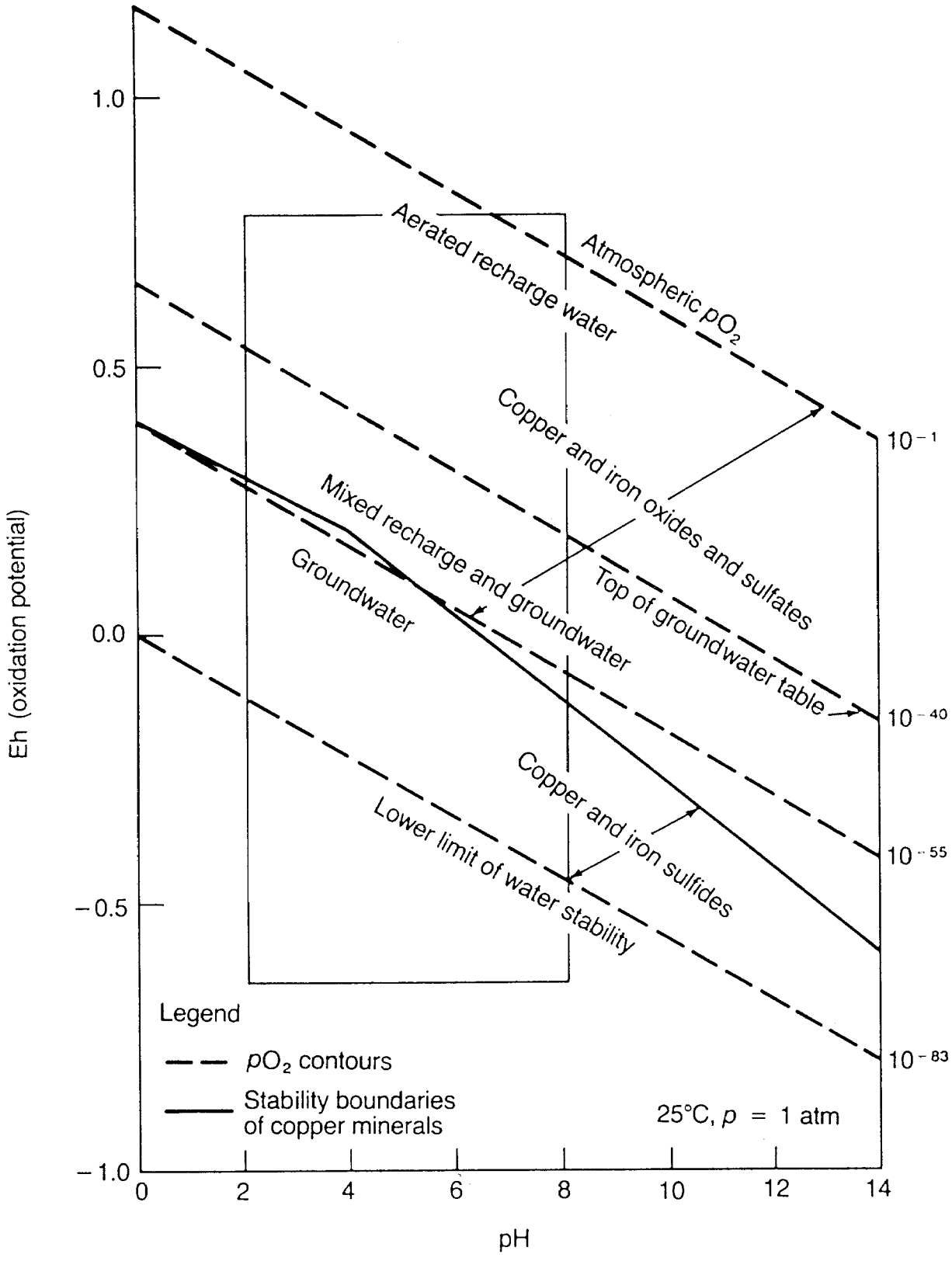


(1)Typically *trondhjemite* if biotite is only mafic mineral and makes up less than 10% of rock.

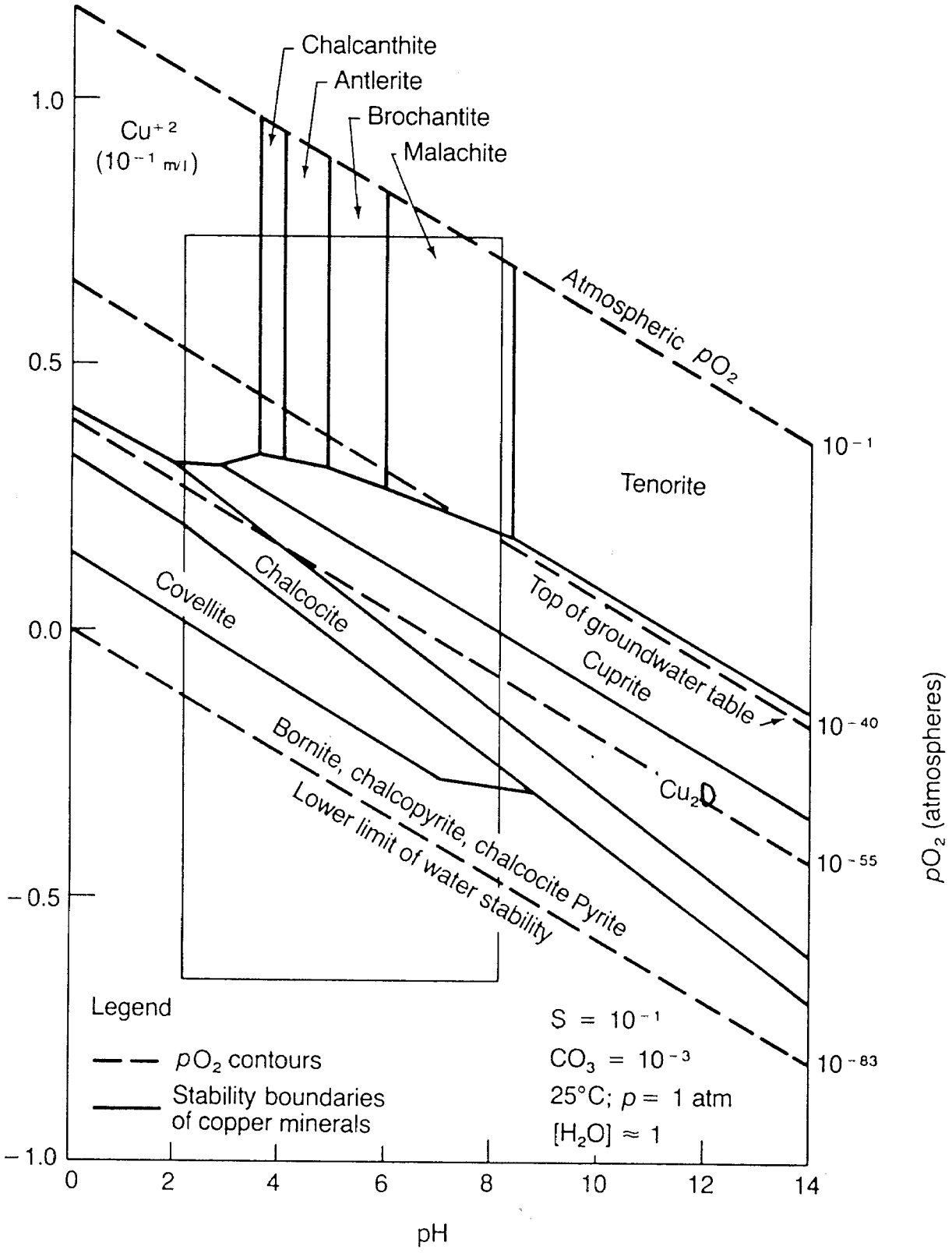
(2)With less than 5% mafic minerals, the rock is *anorthosite.* With more than 40% mafic minerals, it is typically *gabbro.* Rocks with 5-40% mafic minerals are either *diorite* or *leucogabbro,* and require determination of the plagioclase, the limiting composition being An_{50}.

(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.*


Eh (oxidation potential)
1.0
0.5
0.0
−0.5
−1.0
0
2
4
6
8
10
12
14
pH
Aerated recharge water
Atmospheric pO_2
Copper and iron oxides and sulfates
Top of groundwater table
Mixed recharge and groundwater
Groundwater
Copper and iron sulfides
Lower limit of water stability
10^{-1}
10^{-40}
10^{-55}
10^{-83}
Legend
pO_2 contours
Stability boundaries of copper minerals
25°C, p = 1 atm

(*a*)


Chalcanthite
Antlerite
Brochantite
Malachite
Cu+2
(10−1 m/l)
Atmospheric pO2
Tenorite
Top of groundwater table
Cuprite
Chalcocite
Covellite
Cu2O
Bornite, chalcopyrite, chalcocite Pyrite
Lower limit of water stability
10−1
10−40
10−55
10−83
1.0
0.5
0.0
−0.5
−1.0
0
2
4
6
8
10
12
14
pH
pO2 (atmospheres)
Legend
pO2 contours
Stability boundaries of copper minerals
S = 10−1
CO3 = 10−3
25°C; p = 1 atm
[H2O] ≈ 1

(*b*)

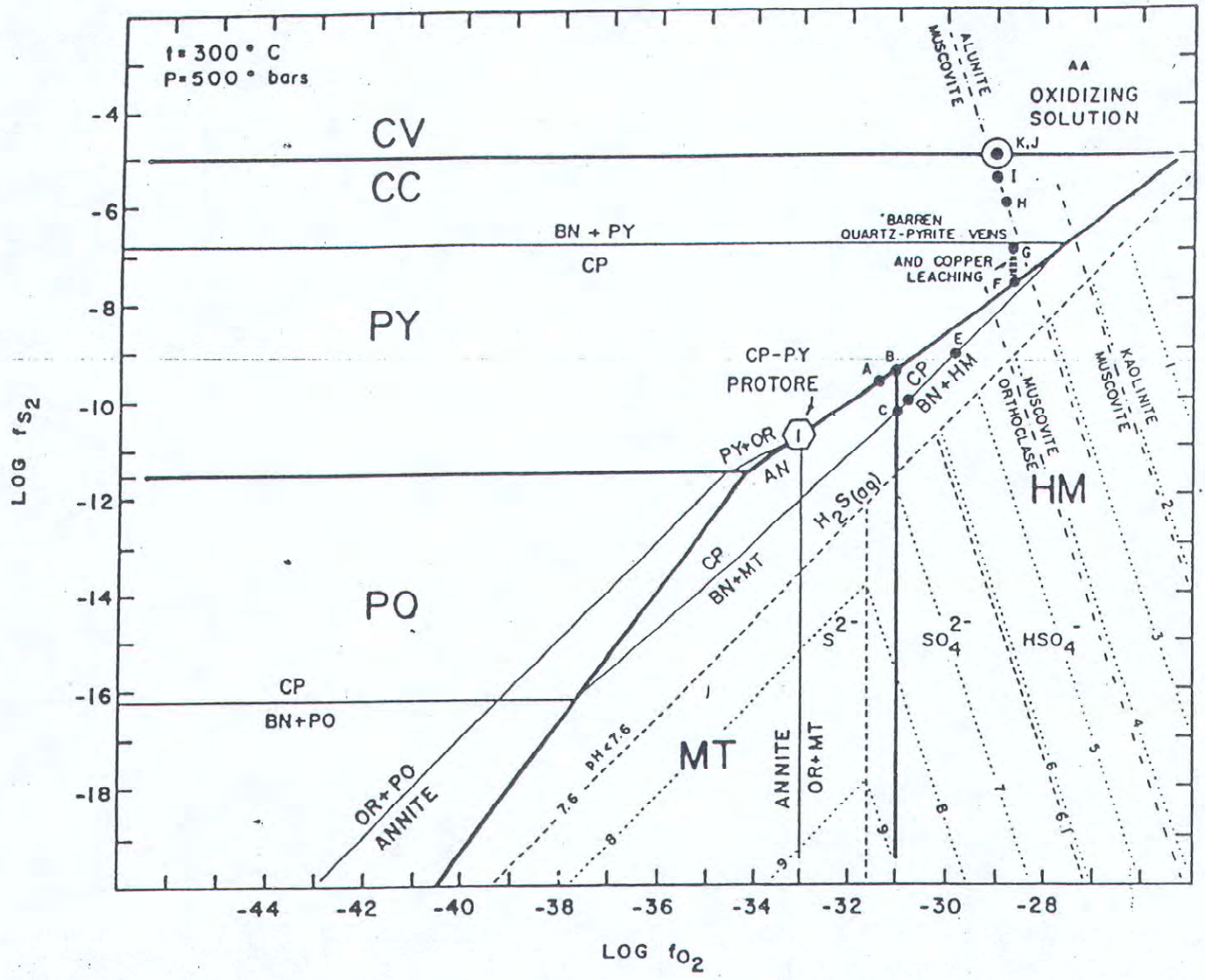


Figure 34. Isothermal isobaric fugacity diagram showing the stability fields of covellite (CV), chalcocite (CC), pyrite (PY), pyrrhotite (PO), magnetite (MT), and hematite (HM). Chalcopyrite field is surrounded by bornite plus an additional sulfide. Annite stability field is surrounded by orthoclase plus sulfides and oxides. Position of potassium-silicate protore at Butte, Montana is given at 1. Position of advanced argillic alteration assemblage and Main Stage oxidizing fluid is at the intersection of CV-CC phase boundary and that of alunite- muscovite. From Brimhall (1980) and Brimhall and Ghiorso (1983).

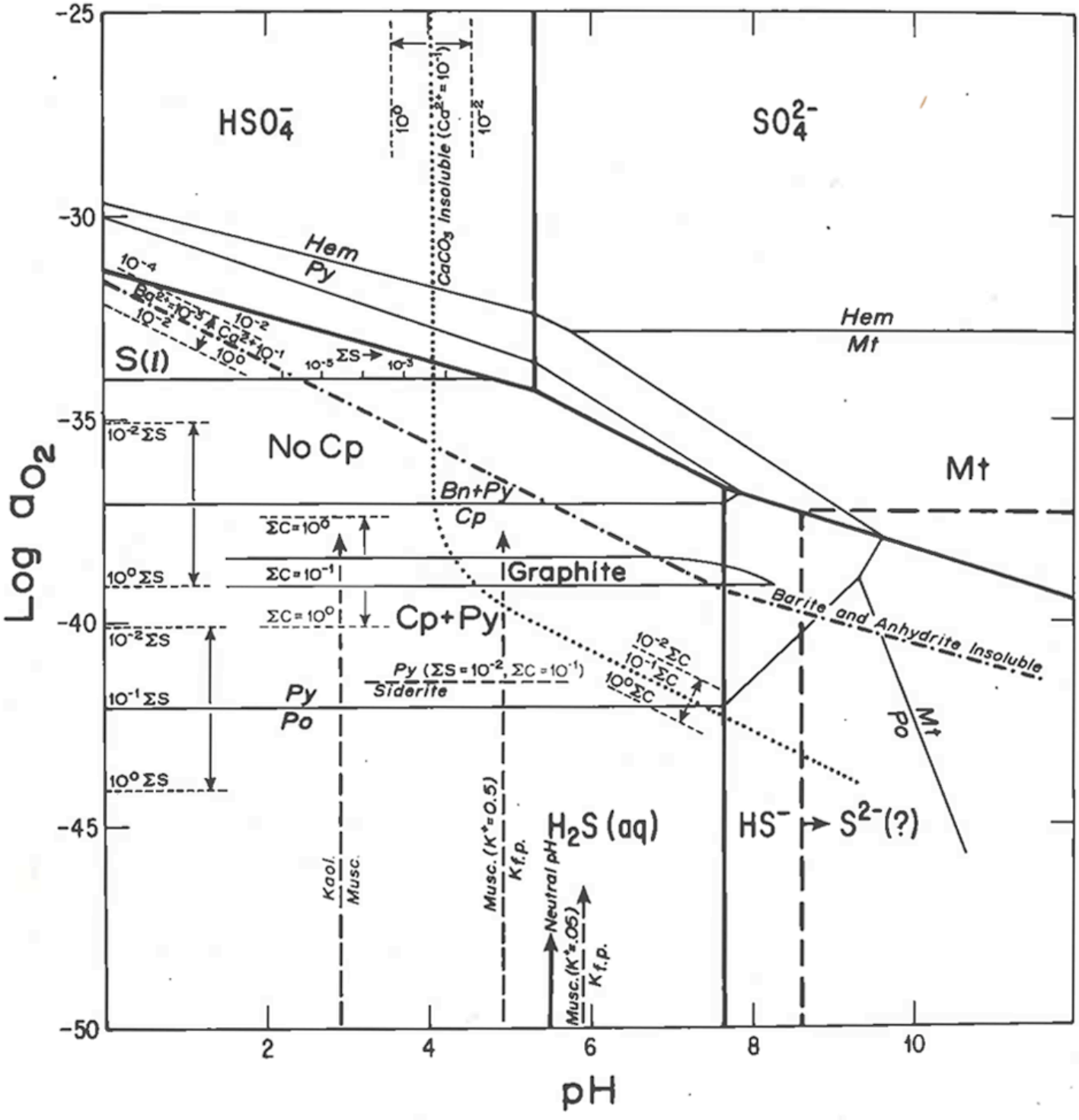


FIG. 8.6 The stabilities of minerals from porphyry copper deposits at 250°C. The solid boundaries and those with longer dashes represent activities respectively of $\Sigma S = 0.1$, $\Sigma C = 0.1$, $K^+ = 0.5$, $Ca^{2+} = 0.1$, and $Ba^{2+} = 0.001$. A change of $\pm$ 10x in activity is indicated by the light lines of shorter dashes. (Modified from Crerar and Barnes, *Econ. Geol., 71,* 772-794.)

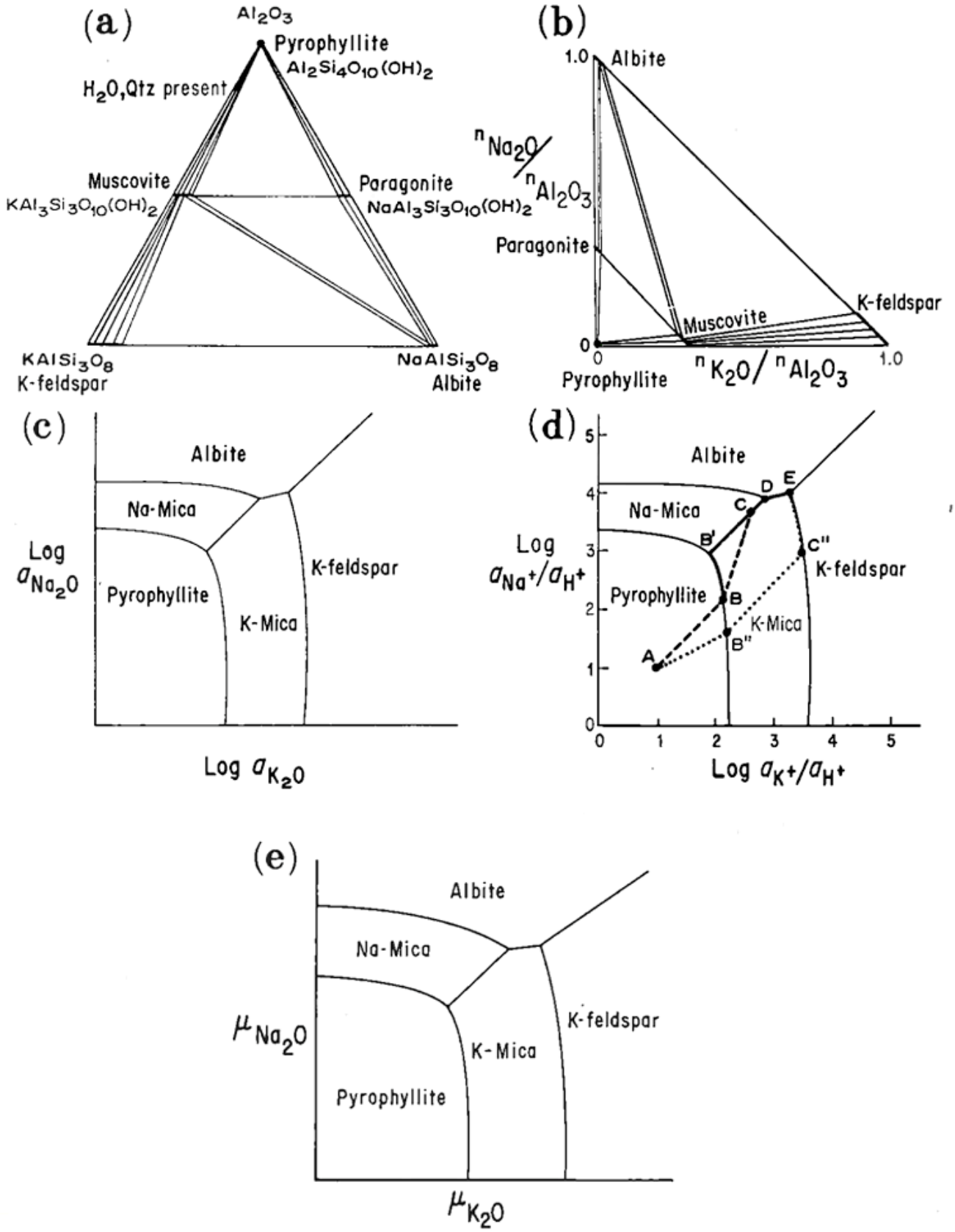
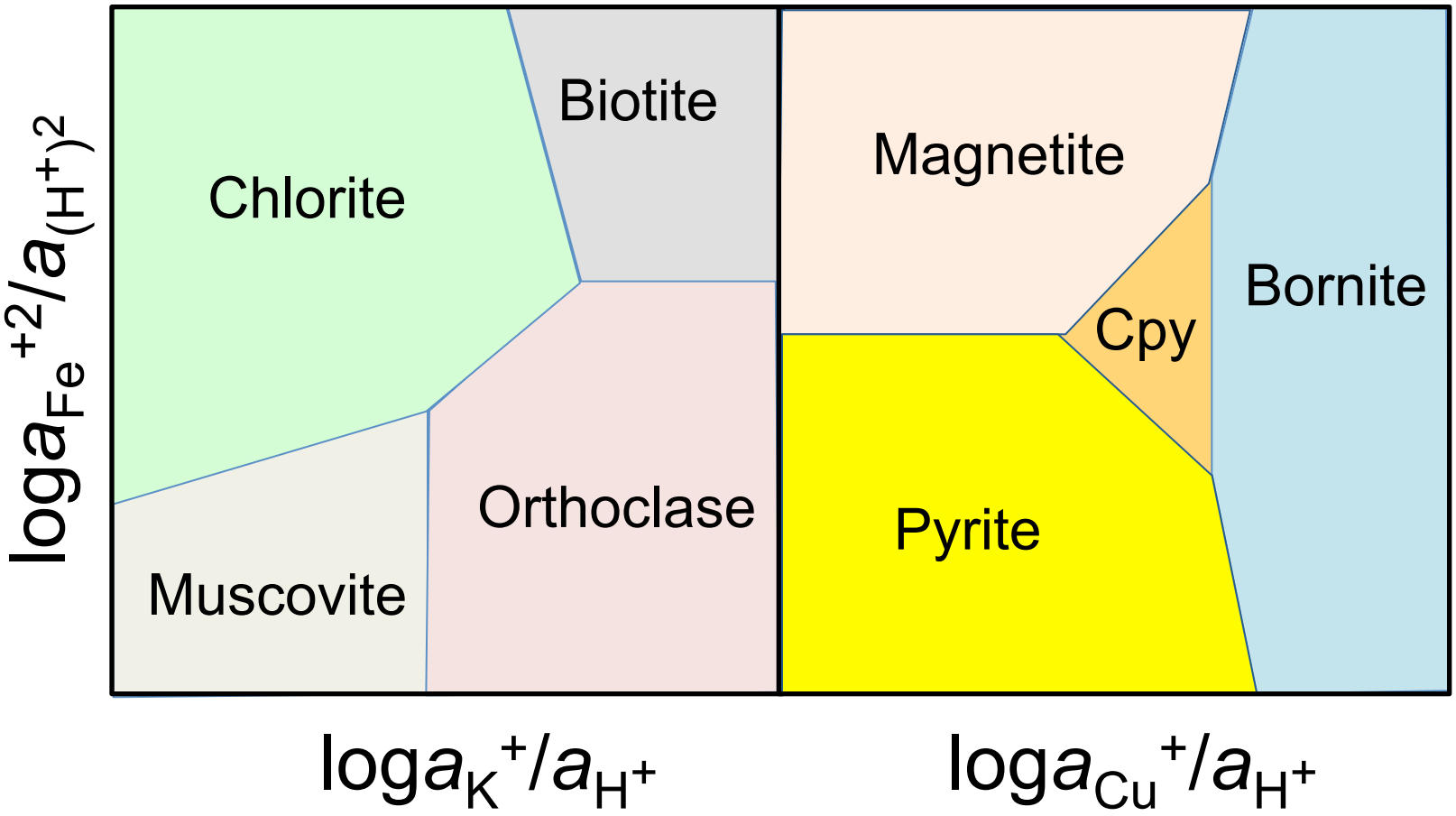


Fig. 5.5 Schematic stability relations in the system K_2O-Na_2O-Al_2O_3-SiO_2-H_2O-HCl at 400°C and 1 kb. Pyrophyllite is metastable. (a) Triangular mole fraction diagram, showing solid assemblages with quartz present. (b) Similar plot of molar Na_2O/Al_2O_3 vs. K_2O/Al_2O_3. (c) Stability of phases as a function of a_{Na_2O} vs a_{K_2O}. (d) Stability of phases as a function of log a_{Na^+}/a_{H^+} vs log a_{K^+}/a_{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 μ_{Na_2O} vs μ_{K_2O}. Figures based on data in Helgeson (1974), Meyer and Hemley (1967), and Montoya and Hemley (1974).


Chlorite
Biotite
Magnetite
Bornite
Cpy
Orthoclase
Pyrite
Muscovite
$\log a_{Fe}^{+2}/a_{(H^+)^2}$
$\log a_{K}^{+}/a_{H^+}$
$\log a_{Cu}^{+}/a_{H^+}$

Readings

Chavez, W.X., Jr., 2000, Supergene oxidation of copper deposits: zoning and distribution of copper oxide minerals. SEG NEWSLETTER, 41.

Sillitoe, R.H., 2010, Porphyry Copper Systems. Economic Geology, 105, 3 - 41.

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.

AQM Copper Inc., 2011, Zafranal Copper Project Peru. Technical Report December 2010 Resource Estimate, Document No. 60246-00000-23-002-001, 173 p.

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.