



Guidebook

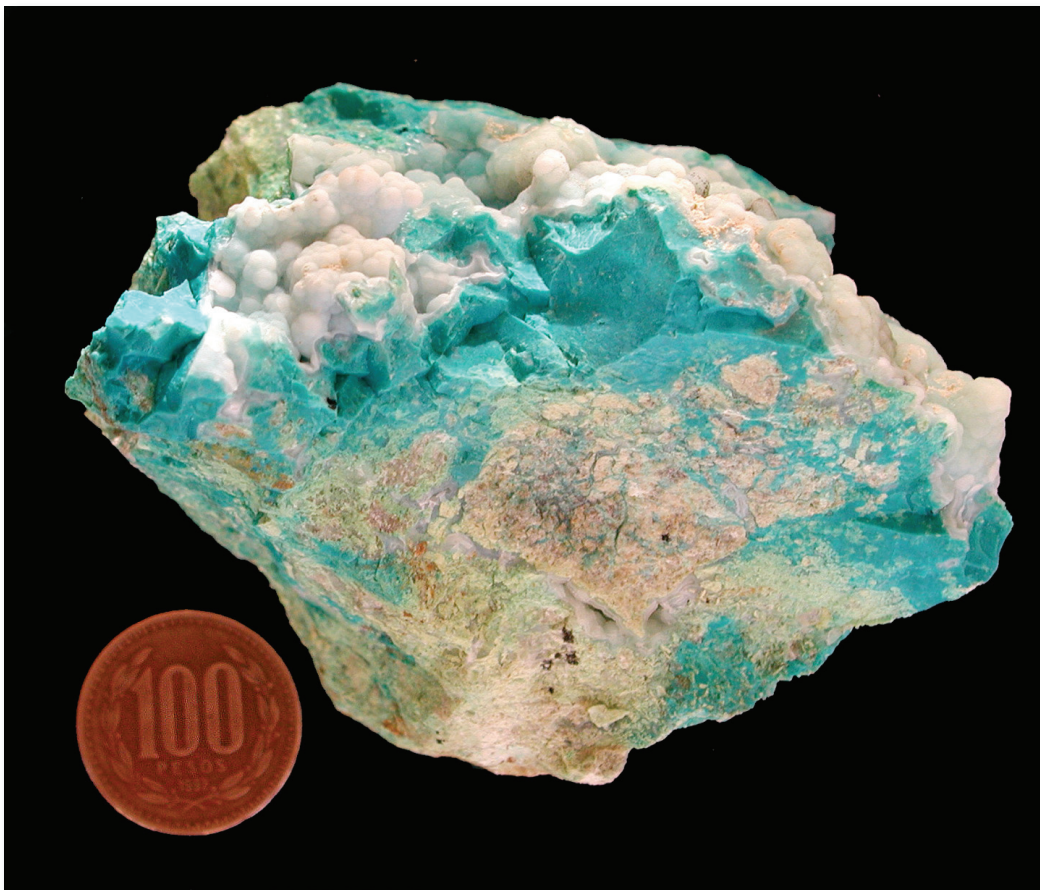
**Society of Economic Geologists Foundation, Inc.
Student-Dedicated Field Course –
Ore Deposits of Northern Chile**

January 5-13, 2007

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Welcome

Welcome to the inaugural SEG Field Trip Course – Ore Deposits of Northern Chile running January 5 to 13, 2007.

The field trip course is organized and co-lead by Drs. William X. Chavez, Jr. (New Mexico Tech) and Erich U. Petersen (University of Utah).

We will visit a variety of copper deposits in the Antofagasta and Calama area. We begin with the Lomas Bayas porphyry Cu-Mo system on Saturday and travel on to Calama. On Sunday we will visit the Quetena Cu-breccia system. Early Monday we will visit El Abra, a copper oxide/porphyry Cu-Mo system. The office and milling complex lies at an elevation of 3,000 masl but the mine is located at 4,400 masl. The Radomiro Tomic copper oxide/porphyry system is closely associated with the Chuquicamata system. Spence, which we will visit on Wednesday, is one of the newest deposits to come into production. El Tesoro represents an exotic copper system and is near the Sierra Gorda tourmaline breccia Cu-Mo systems. We will wrap up on Friday with a visit to Zaldivar which lies “across the highway” from the giant Escondida system.

The course starts in Antofagasta where most of the course participants will be staying at the Costa Marfil Hotel in downtown Antofagasta. We will begin with an orientation meeting at 7:00 PM at the El Tatio Hotel. Travel is by chartered bus.

Entrance to the mine sites can be quite bureaucratic; please be patient. At the mines we will receive safety training, a geological/engineering presentation, and a high elevation mines a brief medical checkup (pulse, pressure, oxygen). Following the presentations we will enter the mine. We will ask, but in general, participants can take pictures and collect samples. Everyone is responsible for their own samples (be aware of weight limits if you plan to take samples back with you). Weight limits are much lower on Chilean air routes than on international routes!!

Participants

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<http://www.mines.utah.edu/pyrite/chile2006a/>

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<u>Date</u>	<u>Itinerary</u>	<u>Overnight</u>
5 January Friday	Antofagasta , Chile : 7:00PM – Meeting to discuss course itinerary and logistics, safety issues. Meet at Hotel El Tatio (56-55419-111) <u>Contact:</u> hotelcostamarfil.yahoo.es (Sra. Erika Corrales Poblete) Teléfono: 56-55-225569 (púbico) ó -283590 ó 269-361 (oficina)	Hotel Costa Márfil Antofagasta
6 January Saturday	06:00AM Visit Lomas Bayas (Paleocene) porphyry Cu-Mo system ; travel to Calama. Discuss porphyry systems and importance of regional structures in control of porphyry emplacement, timing. <u>Contact:</u> Hotel El Loa , Abaroa 1617, Calama Teléfono: 56-55-341963 Hostería Calama (Lorena ó María Soledad) 56-55-341-511 or FAX: 56-55-342-033 or hcalama@tie.cl	Hostal El Loa Calama
7 January Sunday	09:00AM Visit Quetena Cu breccia system ; discuss “Toki Cluster” porphyry Cu-Mo deposits adjacent to Domeyko Fault Zone	Hostal El Loa Calama
8 January Monday	07:00AM - Visit El Abra copper oxide/porphyry Cu-Mo system ; discuss copper oxide zone genesis and supergene enrichment.	Hostal El Loa Calama
9 January Tuesday	07:00AM - Visit Radomiro Tomic copper oxide/porphyry deposit ; discuss Chuquicamata porphyry system; Oligocene Belt porphyries	Hostal El Loa Calama
10 January Wednesday	07:00AM - Visit El Tesoro exotic copper deposit and Sierra Gorda tourmaline breccia Mo-Cu systems ; discuss exotic copper systems and metals mobility	Hostal El Loa Calama
11 January Thursday	07:00AM - Visit Spence (Paleocene) Cu-Mo porphyry deposit ; discuss Paleocene/Oligocene age porphyry “belts” , review	Hostal Costa Marfil Antofagasta
12 January Friday	05:30AM - Visit Zaldivar porphyry Cu-Mo system and associated enrichment formation. Leached capping evaluation and the geochemistry of supergene oxidation processes; copper oxide genesis and preservation.	Hostal Costa Márfil Antofagasta
13 January Saturday	Course ends; participants return at their discretion	

Logistics

◆ **Safety and Logistics Meeting:** We will meet at the Hotel El Tatio (1000 Avenida Grecia; telephone: 56-55-419-111) at **7:00PM on Friday evening, 5th January.**

◆ Our first night in Antofagasta will be at the **Hotel Costa Marfil**, Calle Arturo Prat 950. Telephone: 56-55- 283-590 or -269-361

◆ **ALL** participants **must** have a hardhat, reflective red or orange vest, and steel toe boots.

◆ **ALL** participants **must** bring a medical clearance form stating that they are apt for travel to elevations greater than 4000 meters.

◆ **Water and Meals:** Tap water is generally safe to use for personal hygiene; use bottled water for drinking. Foods are also usually safe, but mayonnaise should be avoided; “completos” should not be consumed under any circumstances unless a participant wishes to test the efficacy of their hepatitis vaccination.

◆ **Arrival in Santiago via air:** Some foreigners will have to pay the Reciprocity Fee before going through passport control (it is at the bottom of the stairway, to the left as you get to the bottom; it is CASH only, so be sure to have the appropriate amount (~US\$100 or so) in dollars or pesos or whatever. Be sure that you receive a receipt for your fee, and that it is stamped or stapled into your passport.

◆ **Money Change:** You may exchange money at any of the kiosks at the airport; you may also do so using ATM machines, which may offer better rates. You will need some money for some meals, laundry, incidentals, and trinkets.

◆ **Lodging: Please stay with you assigned rooms;** we have a budget for lodging, and can not accommodate additional rooms for students.; if you wish to change rooms, you must do amongst yourselves, although we will attempt to arrange rooms equitably.

◆ **Photographs and sample collection:** Although generally permitted, we always check with mine staff regarding photography; in some cases, we will need to register our cameras with the mine security, usually at the entrance gate. Samples may be collected everywhere, but care must be taken to avoid overweight charges if transporting samples by air!

◆ **First Aid:** We will carry a first aid kit during the course. Please report any injuries or concerns to field course leaders so that we might take appropriate action immediately. All mines have a “Policlínico” capable of rendering first aid and providing ambulance service if necessary.

Acknowledgements

We wish to acknowledge the many individuals and organizations that made this field trip course possible. Major funding was provided by The Society of Economic Geologists Foundation, Inc. John Thoms and the organizing committee processed all the registration applications. Sue Courtney was coordinator of communications.

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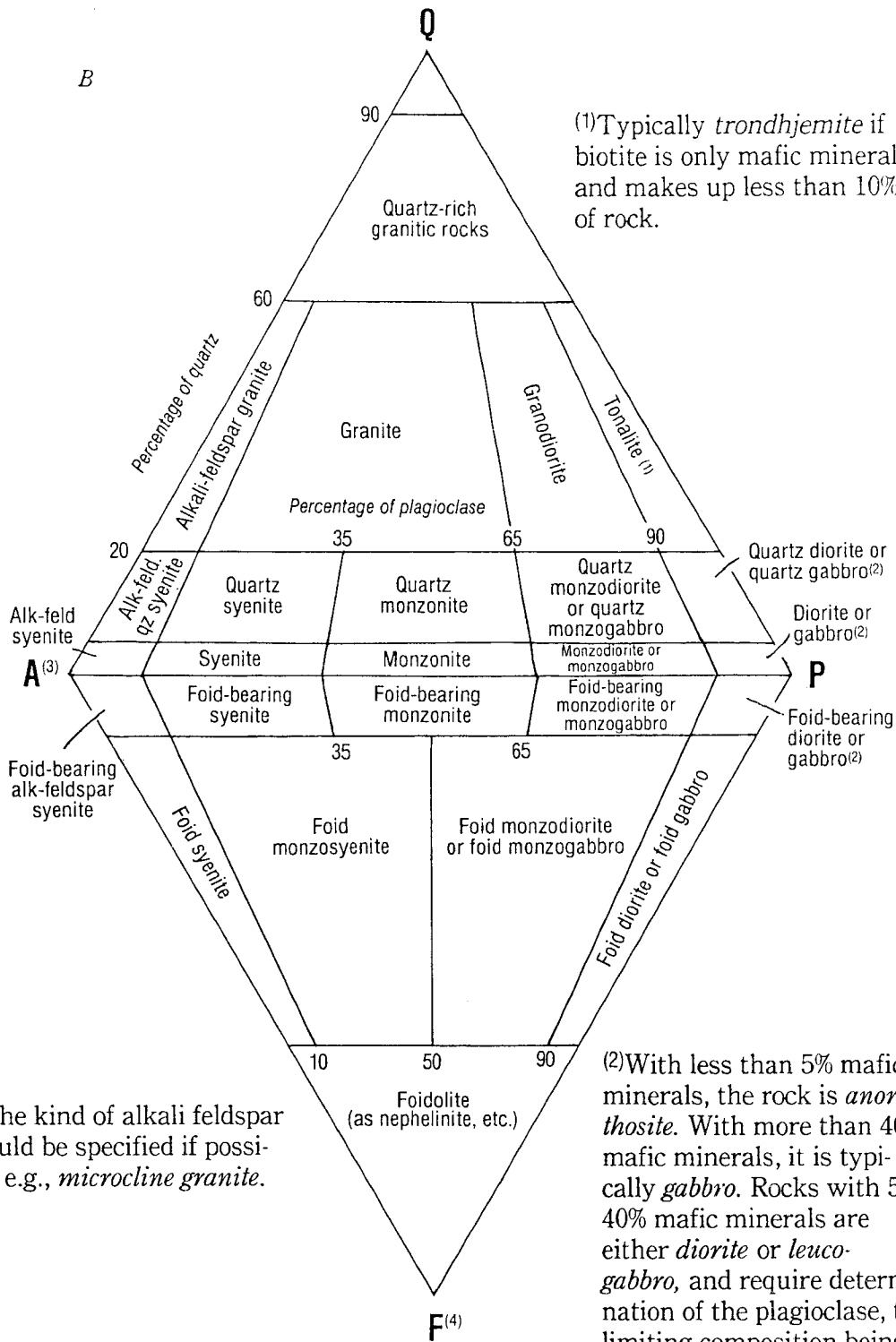
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Minerals Commonly Found in the Oxide Zone of Copper Deposits

Alunite	$\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$
Antlerite	$\text{Cu}_3\text{SO}_4(\text{OH})_4$
Atacamite (paraatacamite, botallackite)	$\text{Cu}_2\text{Cl}(\text{OH})_3$
Bonattite	$\text{CuSO}_4 \cdot 3\text{H}_2\text{O}$
Brochanite	$\text{Cu}_4\text{SO}_4(\text{OH})_6$
Ceruleite	$\text{Cu}_2\text{Al}_7(\text{AsO}_4)_4(\text{OH})_{13} \cdot 12\text{H}_2\text{O}$
Chalcanthite	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$
Chalcosiderite (compare to turquoise)	$\text{CuFe}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4\text{H}_2\text{O}$
Chenevixite	$\text{Cu}_2\text{Fe}_2(\text{AsO}_4)_2(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
Chrysocolla (mineraloid)	$\text{Cu}(\text{Fe},\text{Mn})\text{O}_x \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$, with copper content varying from ~20-40 wt % Cu
Copiapite	$\text{Fe}_5(\text{SO}_4)_6(\text{OH})_2 \cdot 20\text{H}_2\text{O}$
Coquimbite	$\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$
Goethite	$\alpha\text{-FeOOH}$
Jarosite	$(\text{K},\text{Na})\text{Al}_3(\text{SO}_4)_2(\text{OH})_6$
Kröhnkite	$\text{Na}_2\text{Cu}(\text{SO}_4)_2 \cdot 2\text{H}_2\text{O}$
Levandulite	$\text{NaCaCu}_5(\text{AsO}_4)_4\text{Cl} \cdot 5\text{H}_2\text{O}$
Libethinite	$\text{Cu}_2\text{PO}_4(\text{OH})$
Paramelanconite	Cu_4O_3 (see tenorite (CuO) and cuprite (Cu_2O))
Poitevinite	$(\text{Cu},\text{Fe},\text{Zn})\text{SO}_4 \cdot \text{H}_2\text{O}$
Posnjakite	$\text{Cu}_4\text{SO}_4(\text{OH})_6 \cdot \text{H}_2\text{O}$
Pseudomalachite	$\text{Cu}_5(\text{PO}_4)_2(\text{OH})_4$
Scorodite	$\text{FeASO}_4 \cdot 2\text{H}_2\text{O}$
Turquoise	$\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4\text{H}_2\text{O}$
Voltaite	$\text{K}_2\text{Fe}_8\text{Al}(\text{SO}_4)_{12} \cdot 18\text{H}_2\text{O}$
Wroewolfeite (Langite)	$\text{Cu}_4\text{SO}_4(\text{OH})_6 \cdot 2\text{H}_2\text{O}$

Some Common Mineral Formulas

Chlorite	$(\text{Mg,Fe})_3(\text{Al,Si})_4\text{O}_{10}(\text{OH})_2 \cdot (\text{Mg,Fe})_3(\text{OH})_6$
Biotite.....	$\text{KFe}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2$
Muscovite.....	$\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$
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	Cu_5FeS_4
Chalcopyrite.....	CuFeS_2
Chalcocite	Cu_2S
Covellite.....	CuS
Cuprite	Cu_2O
Tenorite.....	CuO

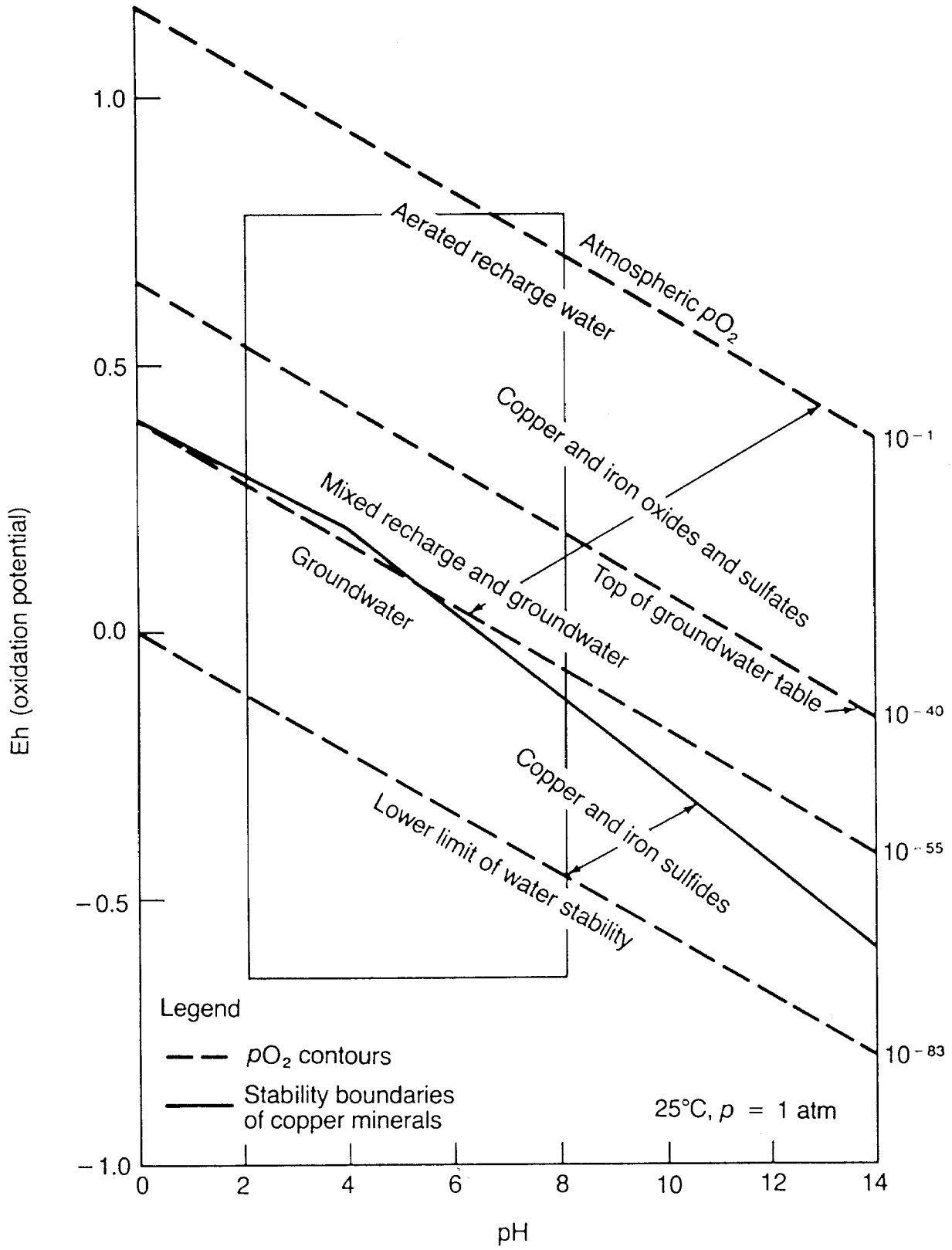


(1) Typically *trondhjemite* if biotite is only mafic mineral and makes up less than 10% of rock.

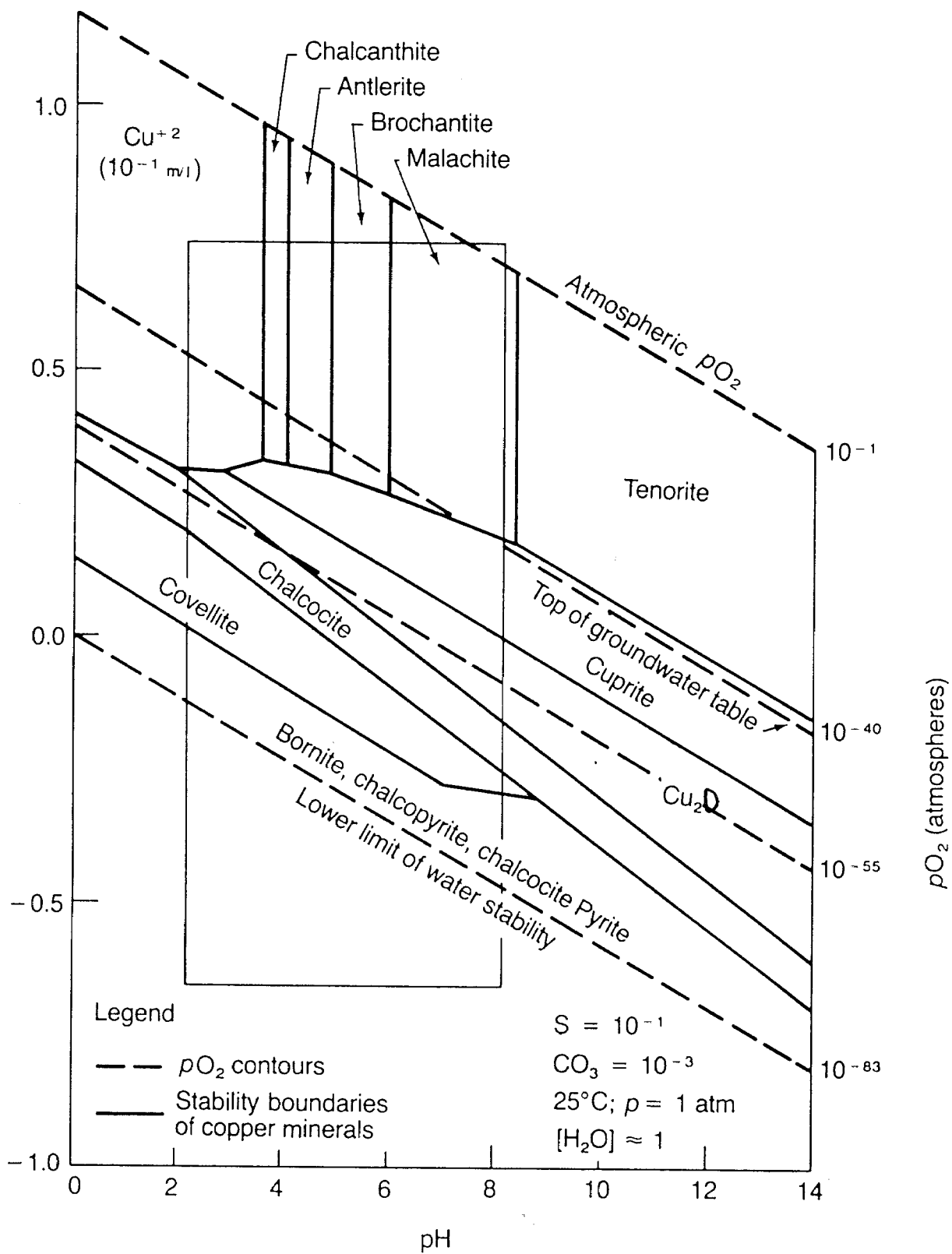
(3) The kind of alkali feldspar should be specified if possible; e.g., *microcline granite*.

(4) The feldspathoid should be specified in each rock name; e.g., *nepheline syenite*.

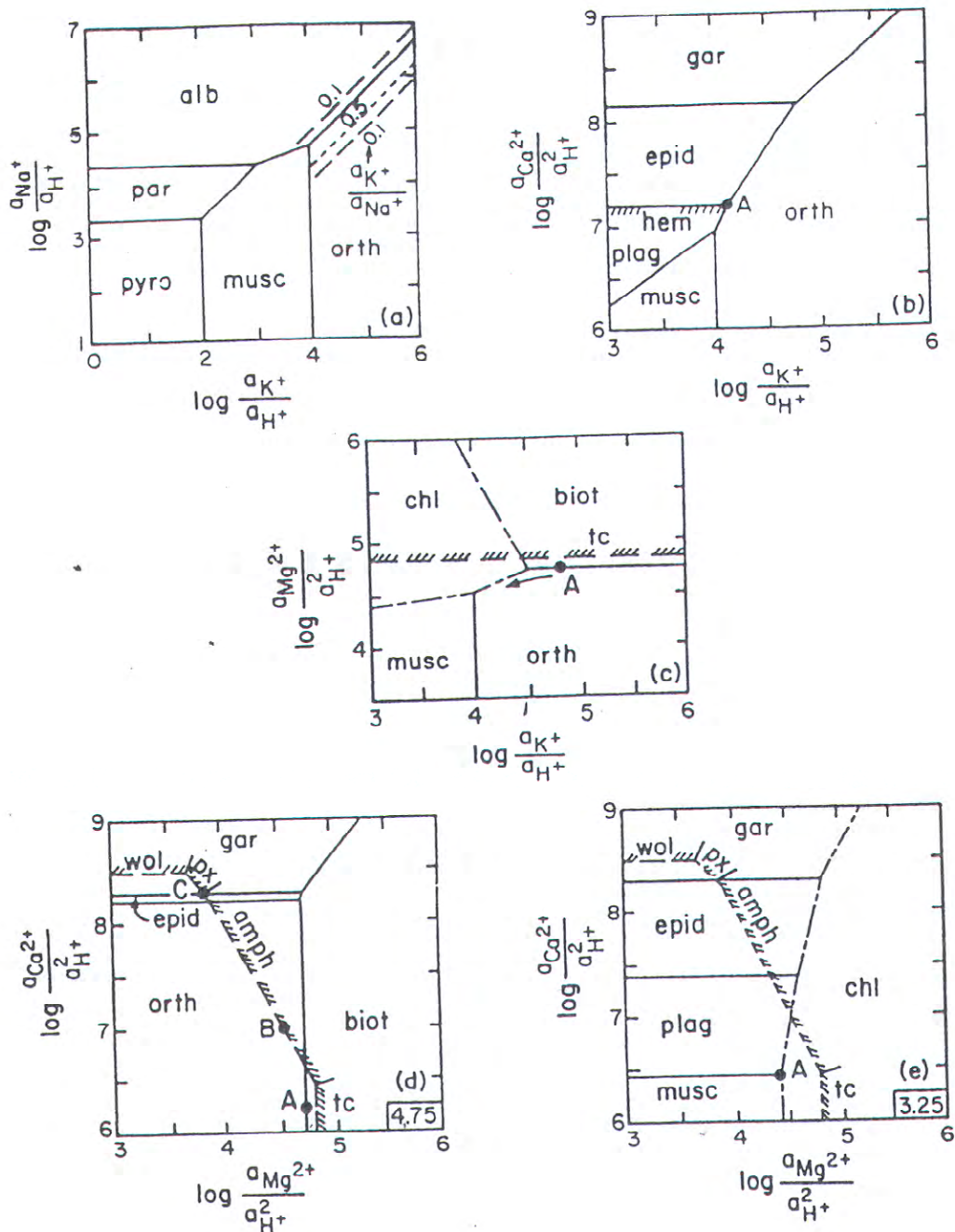
(2) With less than 5% mafic minerals, the rock is *anorthosite*. With more than 40% mafic minerals, it is typically *gabbro*. Rocks with 5-40% mafic minerals are either *diorite* or *leucogabbro*, and require determination of the plagioclase, the limiting composition being An_{50} .



(a)



(b)



Activity-activity diagrams showing stabilities of silicate minerals at 350°C, 500 bars pressure, and quartz saturation. Aluminum conserved among solids. Diagrams calculated using thermodynamic data given by Helgeson et al. (1978), except where noted. Alkali cation: hydrogen pairs include the following: (a) $a(K^+)/a(H^+)$ vs. $a(Na^+)/a(H^+)$; dashed lines show $a(K^+)/a(Na^+)$ of solution; the short-dashed line should be labeled 1.0. (b) $a(K^+)/a(H^+)$ vs. $a(Ca^{2+})/a^2(H^+)$; solid solution effects as described for Figure 22d; hematite saturation occurs at the epidote-plagioclase boundary (see text and Fig. 22d explanation). (c) $a(K^+)/a(H^+)$ vs. $a(Mg^{2+})/a^2(H^+)$; chlorite stability field is schematic based on compatibility with K-feldspar at 350°C, as discussed in text; dashed line shows talc saturation. Biotite: $K(Mg_{0.88}Fe_{0.12}^{2+}Fe_{0.12}^{3+})AlSi_3O_{10}(OH)_2$; activity calculated using data from Beane (1974 and unpublished data); in natural environments, $(Mg/Fe)_{chl} \approx (Mg/Fe)_{biot} \approx 1.5 - 3.0$. (d) $a(Mg^{2+})/a^2(H^+)$ vs. $a(Ca^{2+})/a^2(H^+)$ at $a(K^+)/a(H^+) = 10^{4.75}$; garnet, epidote, and biotite solid solution effects as described from Figures 22d and 23c; dashed lines show saturation boundaries for wollastonite, salite, tremolite, and talc. Pyroxene: $Ca(Mg_{0.8}Fe_{0.2})Si_2O_6$; $a(di) = 0.2$. Amphibole: $Ca_2(Mg_{0.5}Fe_{0.5})_2Si_6O_{22}(OH)_2$; $a(tr) = 0.03$, ideal site mixing. (e) $a(Mg^{2+})/a^2(H^+)$ vs. $a(Ca^{2+})/a^2(H^+)$ at $a(K^+)/a(H^+) = 10^{3.25}$; solid solution effects as described for (d) above; chlorite stability as indicated for (c) above.

Iron Oxide Characterization Chart

The identification of iron oxides is critical in the interpretation of leached capping and gossan protolith mineralogy. By collecting iron oxide “smudges” from various geochemical environments, one can characterize the geochemical setting of weathering-related oxidation; this, in turn, permits one to interpret the potential for metals mobility attributable to supergene oxidation and transport.

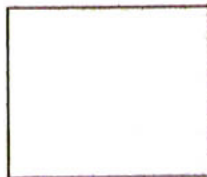
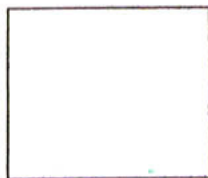
Use the squares below for iron oxide smudges derived from leached outcrops and drill hole intervals, comparing the field smudges to those of the standard iron oxides shown. Note that the standard smudges are derived from leached capping environments, and represent XRD-analysed end-member iron oxides. Mixtures of red hematite, goethite, and jarosite will produce the gradational colors as shown in the standard box. Remember that the *complete* oxidation of one mole of pyrite will produce four moles of protons (H^+), and that the oxidation of other sulfides will always result in lesser total acid production *because of the important ferrolysis of Fe^{+++}* . Also, all geochemical roads lead to goethite as a stable iron oxide, although *dehydration* of goethite produces red hematite as an end product.



Hematite

Goethite

Jarosite



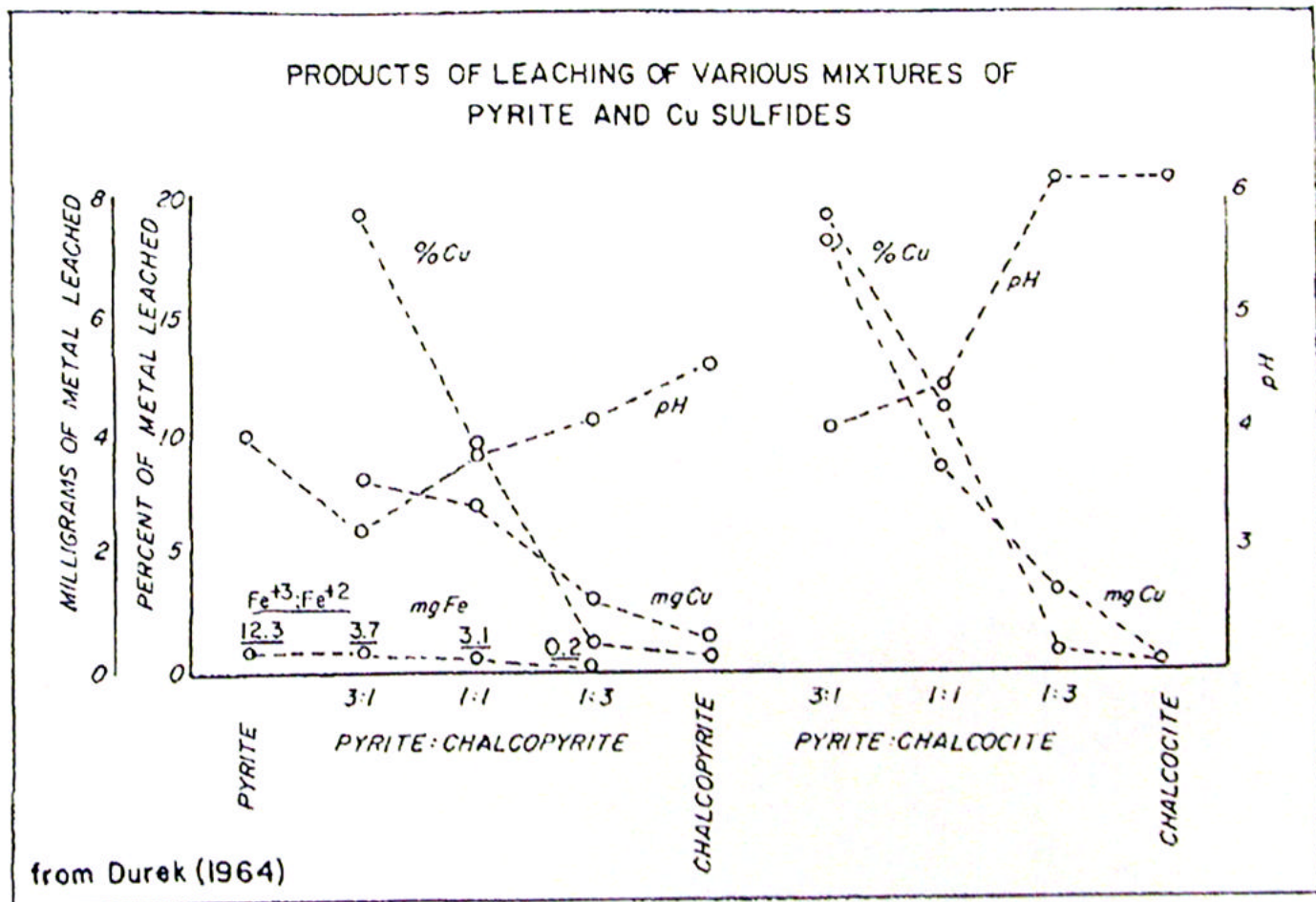


Figure 4. Copper solubility diagram for mixtures of various proportions of chalcopyrite and pyrite (left) and chalcocite and pyrite (right). Values

across the bottom of the left side of the figure are ferrous-ferric ra determined in leach solutions. Redrafted from Durek (1964).

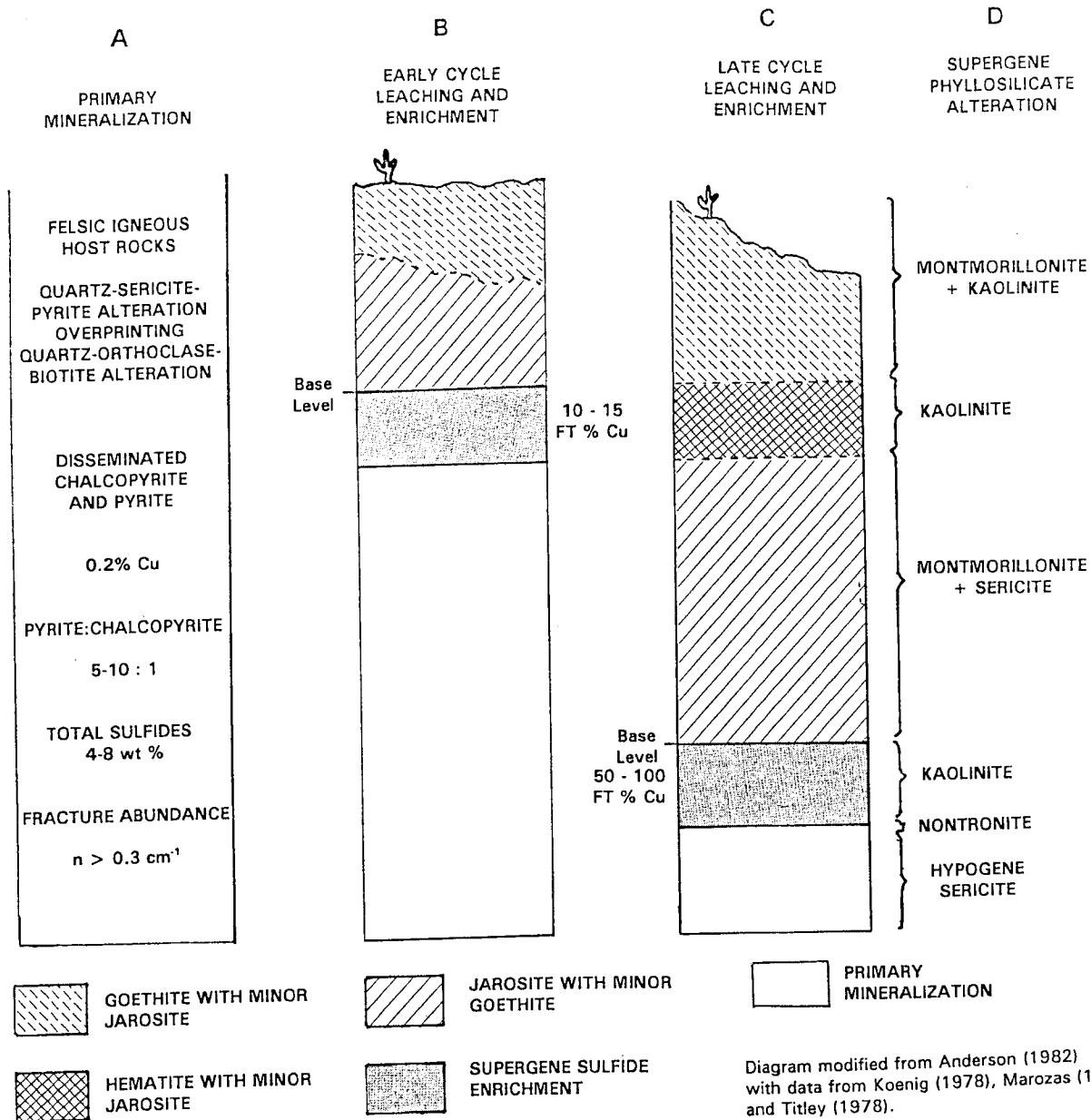


Figure 1. Generalized vertical sections showing relevant characteristics of: (A) a hypogene profile through quartz-sericite-pyrite altered felsic igneous rocks; (B) early stage weathering and development of early cycle enrichment; and (C) late cycle enrichment. Column D shows locations of principal phyllosilicate alteration phases across the profiles. Profiles B and C show the

position of early and late supergene blankets with weathering of Data are generalized from the authors' observations, mineralogic Koenig (1980), a study at North San Xavier deposit, and the Marozas (1982) at Silver Bell. No specific vertical scale is implied. files may range from 50 meters to several hundreds of meters in thi

Useful References

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