XVII Congreso Peruano de Geología
"Alberto Benavides de la Quintana"
12 al 15 de Octubre de 2014, Lima, Peru

Overview of the main Peruvian copper porphyry belts and deposits

Alberto BUSTAMANTE[2], Miguel CARDOZO[1, 2] & *Jorge ACOSTA(3)*

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(3) INGEMMET

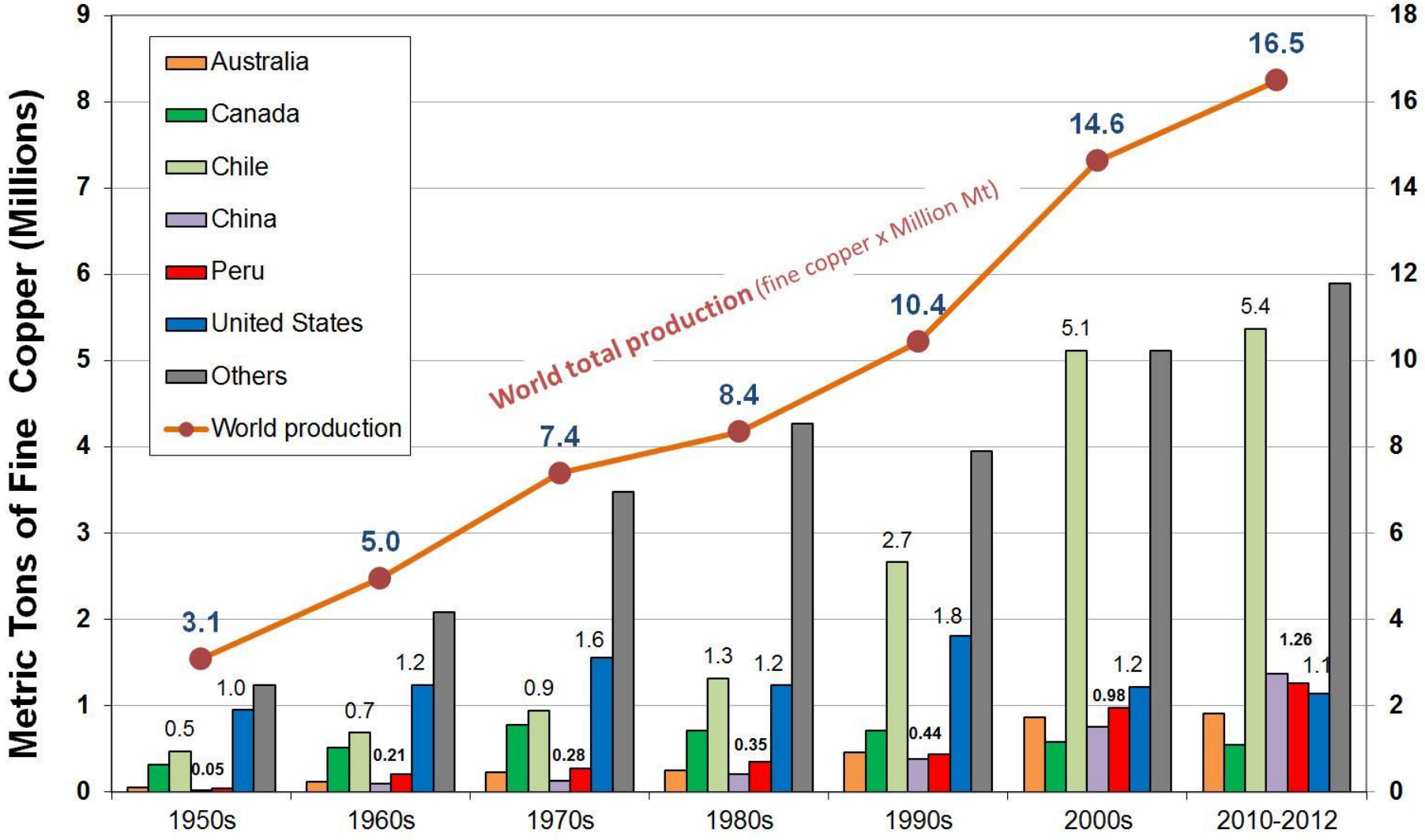
A member of

Content

- Relevance of copper mining in Peru
- Peruvian main copper belts and deposits
- Geological models of the main porphyry belts in Peru
- Facts and challenges

Worldwide Copper Production Trends

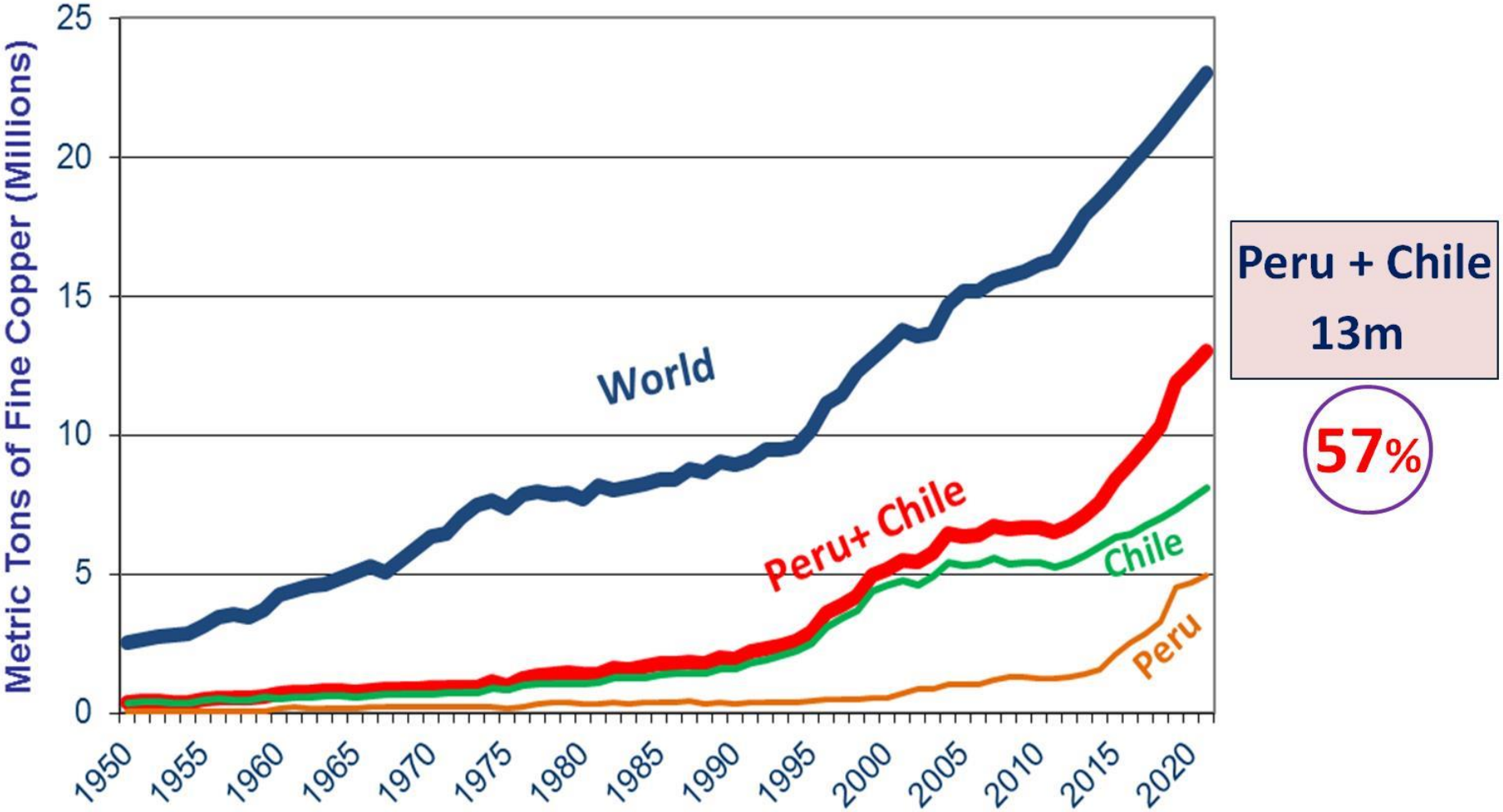
(average for each 10 years)



Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

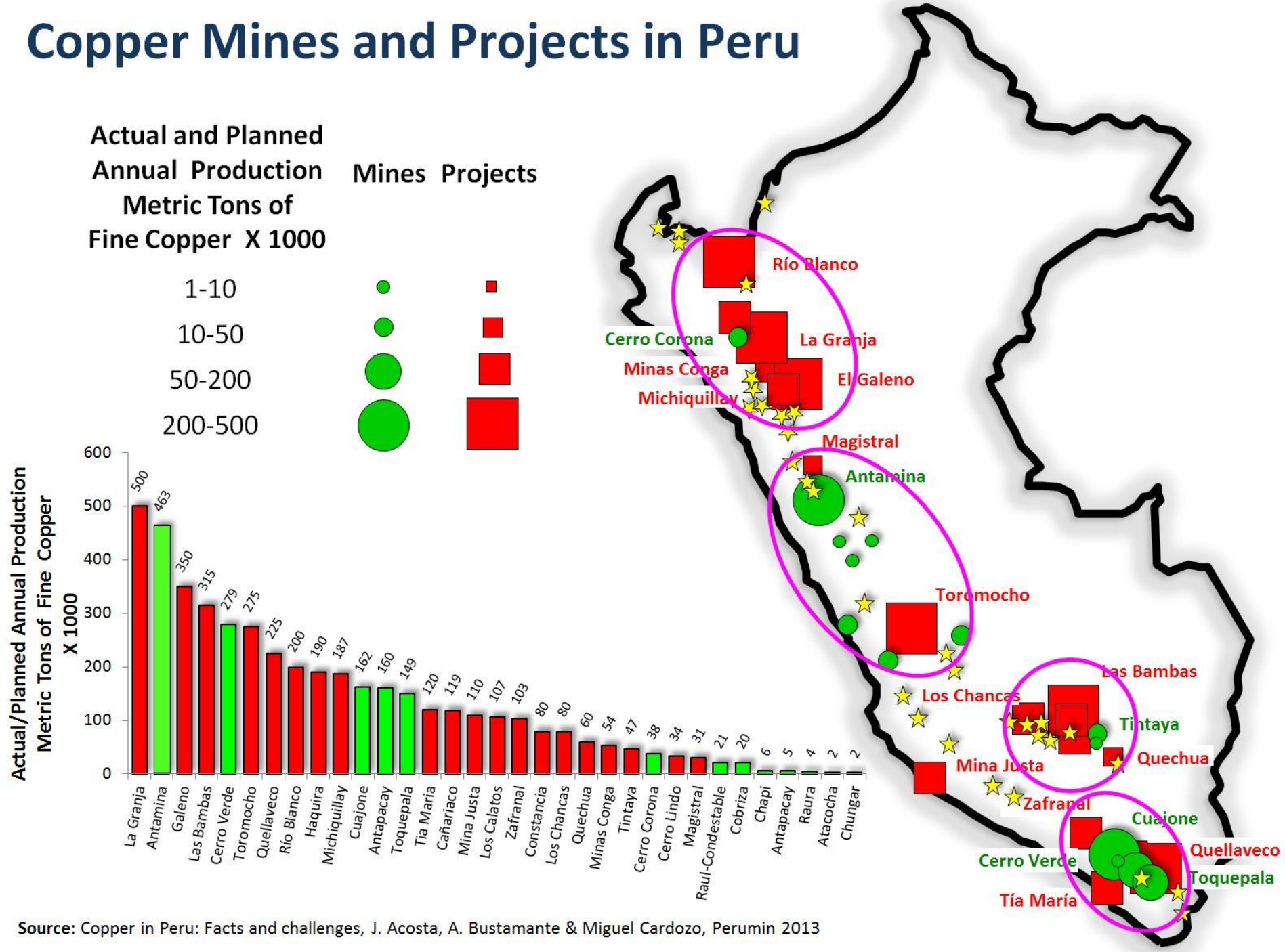
Peru and Chile Copper Production to 2021

(actual + forecast)



Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

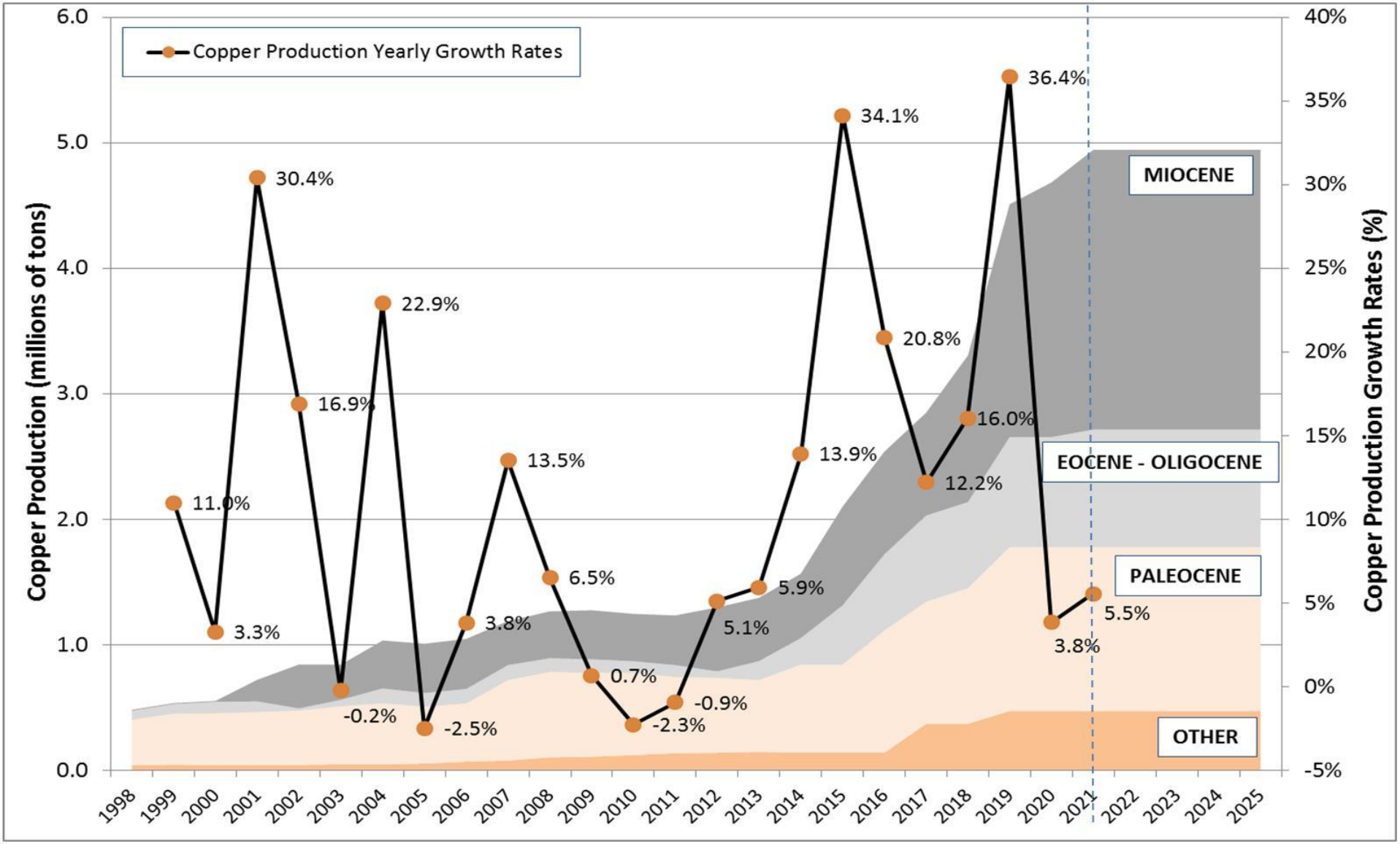
Copper Mines and Projects in Peru



Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

Peru Copper Production and Yearly Growth Rates

(actual until 2013 + forecast until 2021)

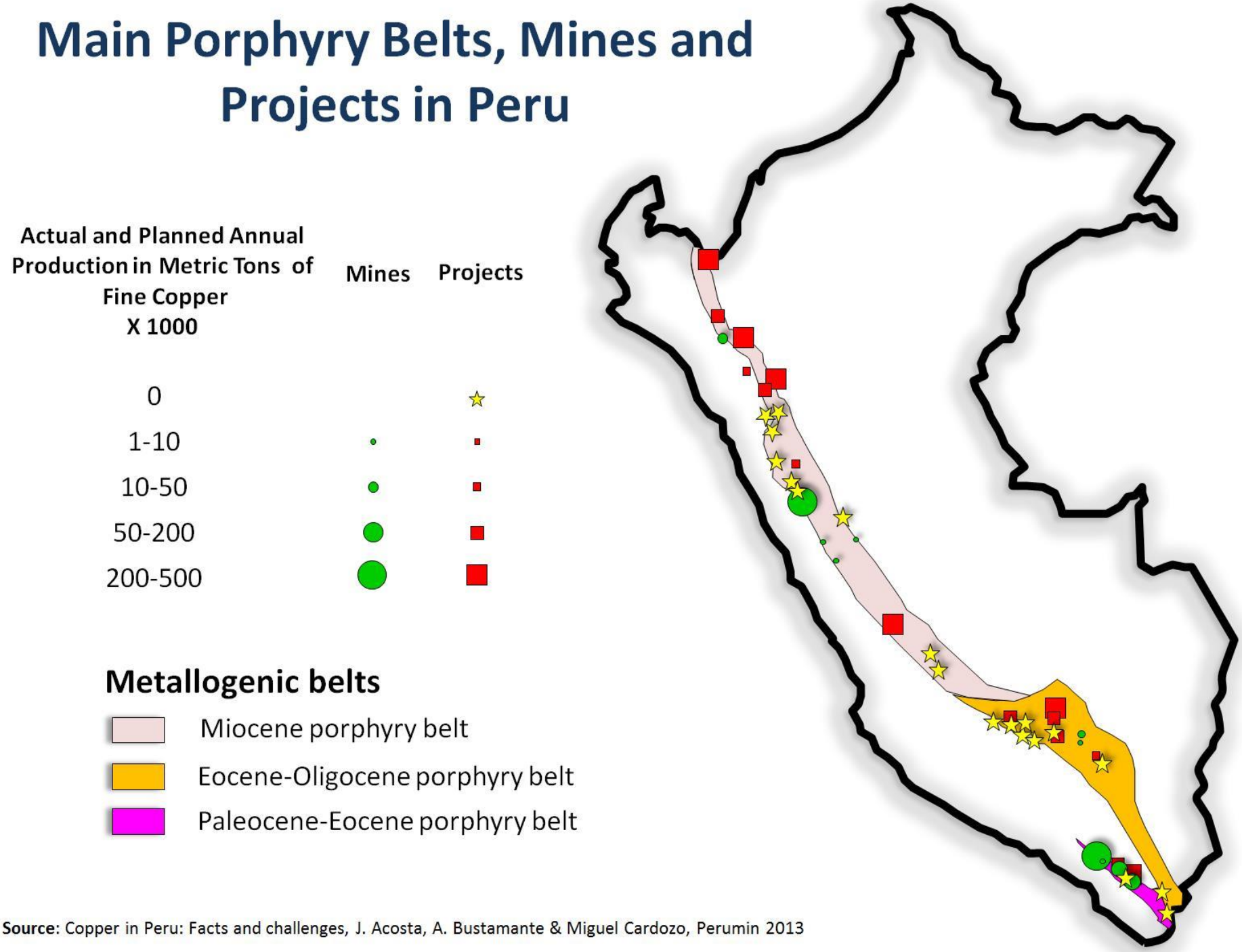


Gold and Silver Content of Porphyry Deposits

PORPHYRY BELT	PROJECT	Au g/t	Ag g/t	Mo %
Miocene N-Peru	Cerro Corona	1.00		
	Minas Conga	0.71	2.05	
	Galeno	0.12	2.50	0.014
	Michiquillay	0.05-0.10	2.00-4.00	0.01-0.02
	La Granja	0.04	3.70	
	Magistral			0.060
	Cañariaco	0.06	1.6	
	La Arena	0.27	0.70	0.004
Miocene Central Peru	Toromocho		6.90	
	Antamina		10.3	0.021
Eocene-Oligocene Apurimac	Las Bambas	0.08	4.74	0.018
	Cotabambas	0.23	2.74	0.001
	Antapaccay	0.13	1.51	0.010
	Los Chancas	0.04		0.040
	Antilla			0.009
	Haquira	0.04	1.79	0.001
	Constancia	0.05	3.60	0.011
Paleocene SW-Peru	Los Calatos			0.021
	Cuajone	0.03	3.10	0.020
	Toquepala	0.03	2.30	0.020
	Quellaveco		2.19	0.023
	Cerro Verde		1.46	0.010

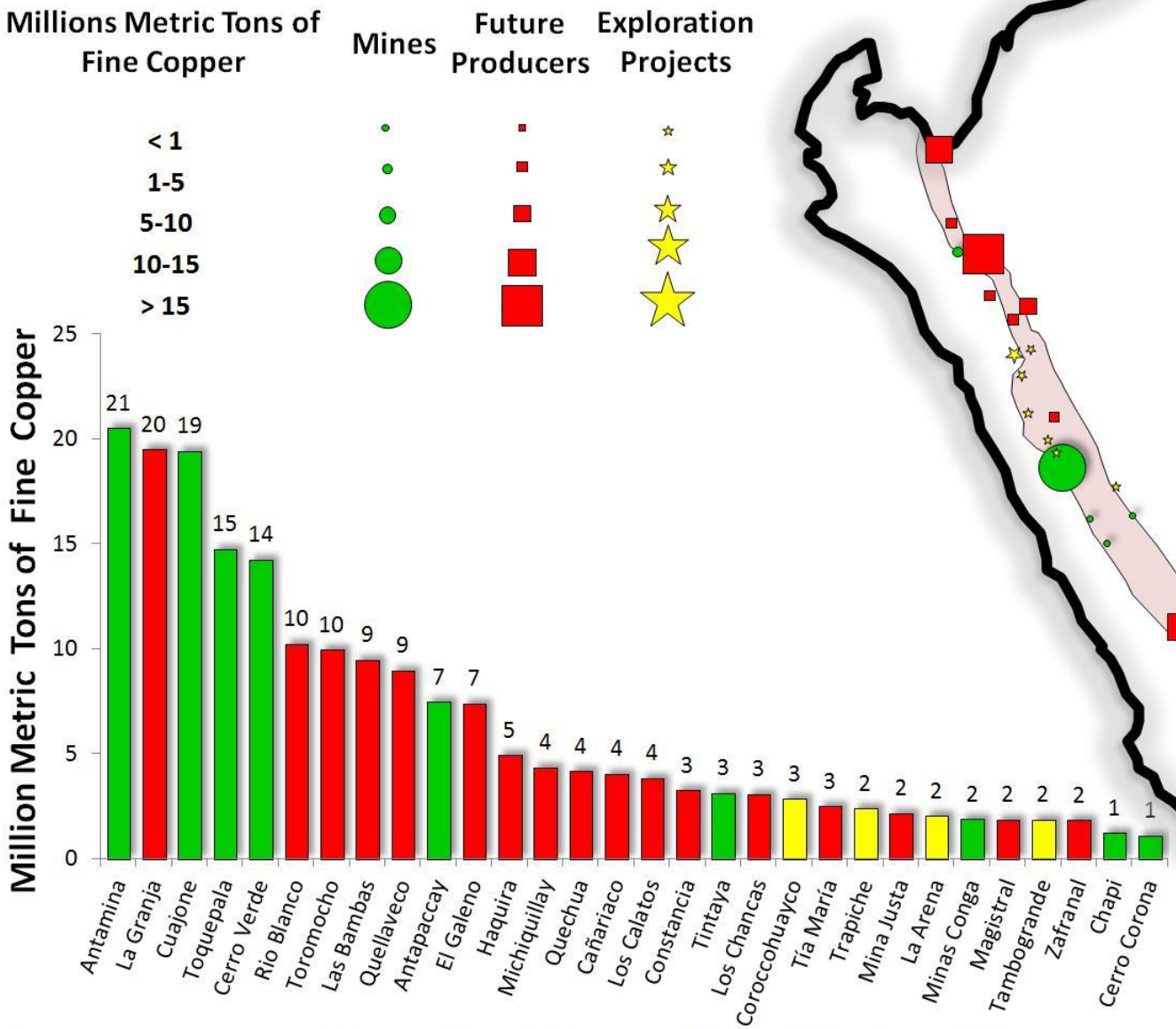
Projected yearly production from pophyries/skarns of the 3 main copper porphyry belts by 2021	Gold ('000 ounces)	Silver ('000 ounces)	Molybdenum ('000 tons)
Millions of Ounces	1.6	40	40 -50
% of total gold and silver by 2021	30%	25%	100%

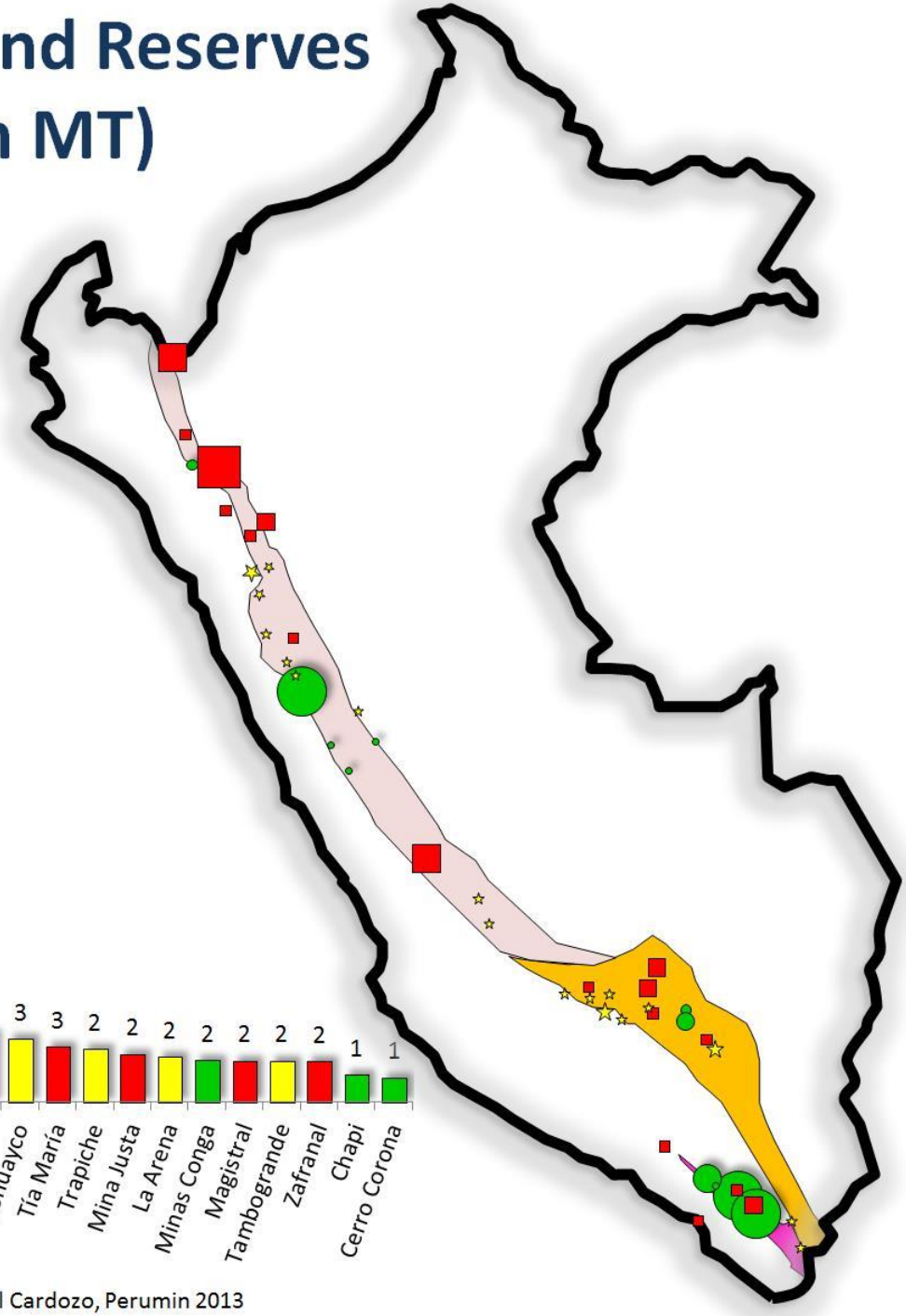
Main Porphyry Belts, Mines and Projects in Peru



Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

Main Copper Resources and Reserves in Peru (> 1 Million MT)

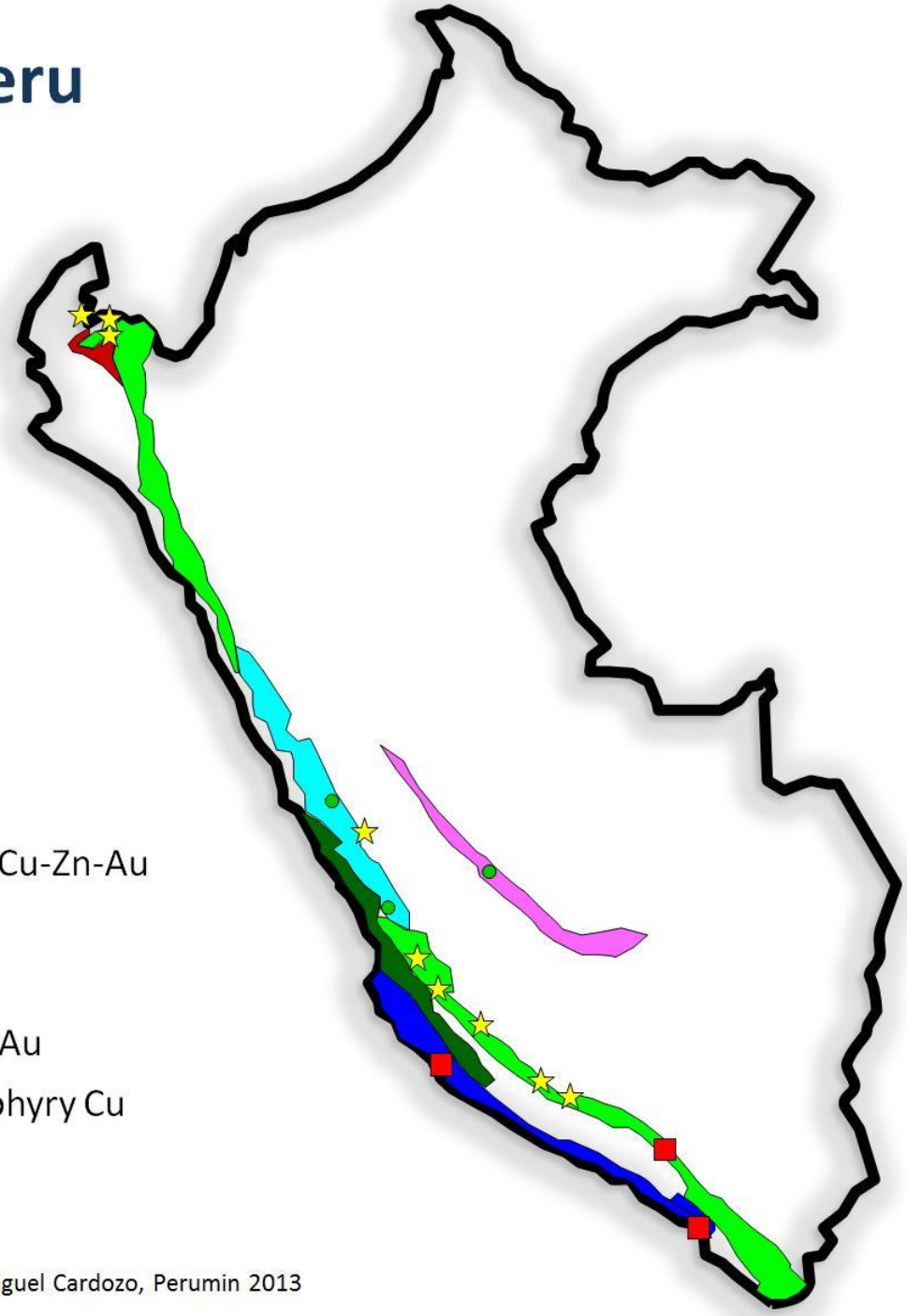




Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

Other Copper Belts in Peru

Metric Tons of Fine Copper X 1000	Mines	Projects
0		☆
1-10	•	▪
10-50	●	■
50-200	●	■
200-500	●	■



Metallogenic belts

- Upper Cretaceous-Paleocene VMS Cu-Zn-Au
- Upper Cretaceous Porphyry Cu
- Lower Cretaceous IOCG
- Upper Jurassic - Albian VMS Cu-Zn-Au
- Upper-Middle Jurassic IOCG & Porphyry Cu
- Permian skarns Cu

Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

Historic Cumulative Copper Production in Peru

Total Production in Peru

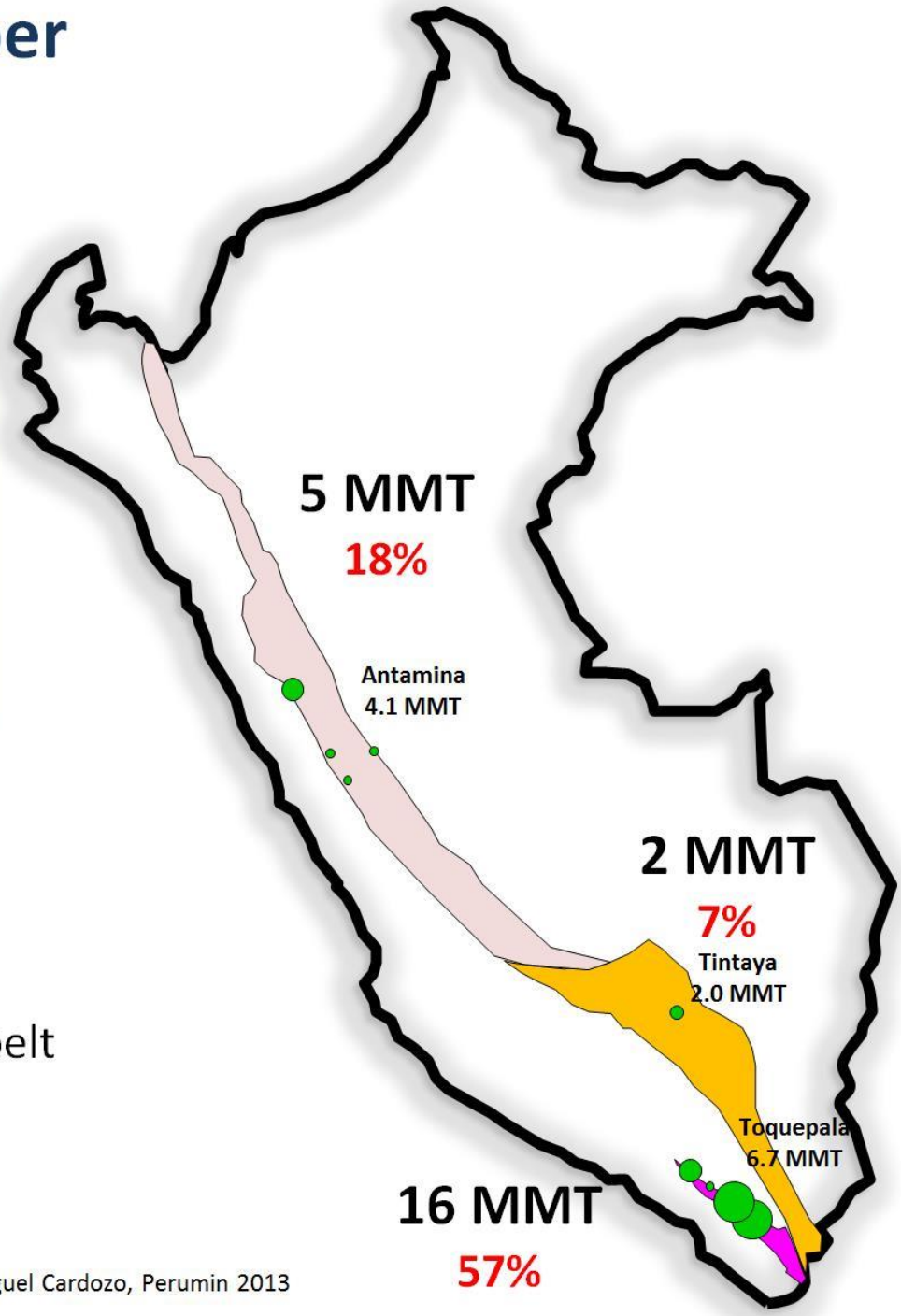
28 MMT (100%)

Production from main porphyry belts

23 MMT (82%)

Other Cu belts: 2 MMT (7%)

Other non-Cu belts: 3 MMT (11%)



Metallogenic belts

- Miocene porphyry belt
- Eocene-oligocene porphyry belt
- Paleocene porphyry belt

Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

Copper Resources and Reserves in the Main Porphyry Belts in Peru

Total reported resources in Peru

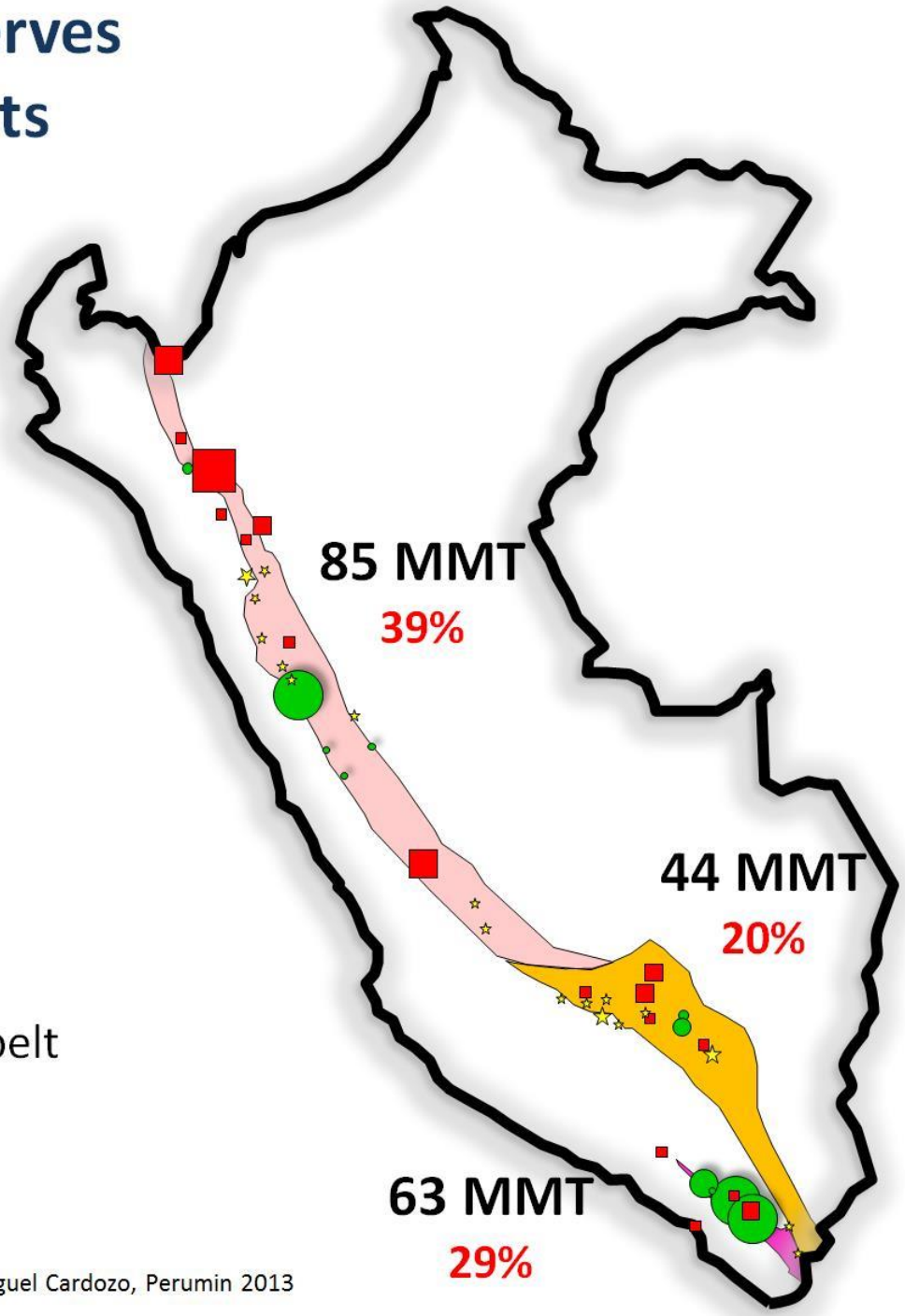
218 MMT (100%)

Resources from porphyry belts

192 MMT (88%)

Other Cu belts: 11 MMT (5%)

Other non-Cu belts: 15 MMT (7%)



Metallogenic belts

- Miocene porphyry belt
- Eocene-oligocene porphyry belt
- Paleocene porphyry belt

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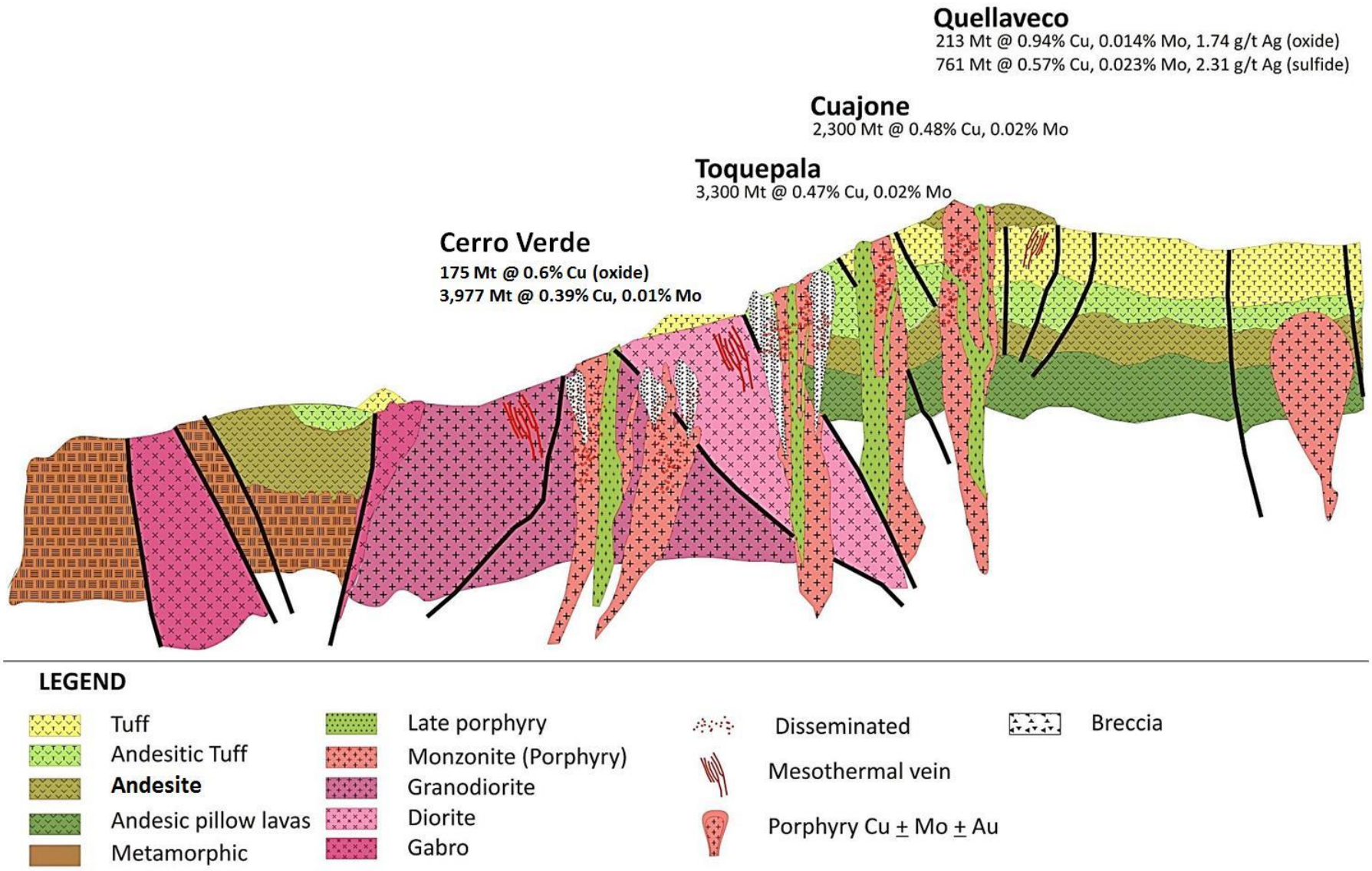
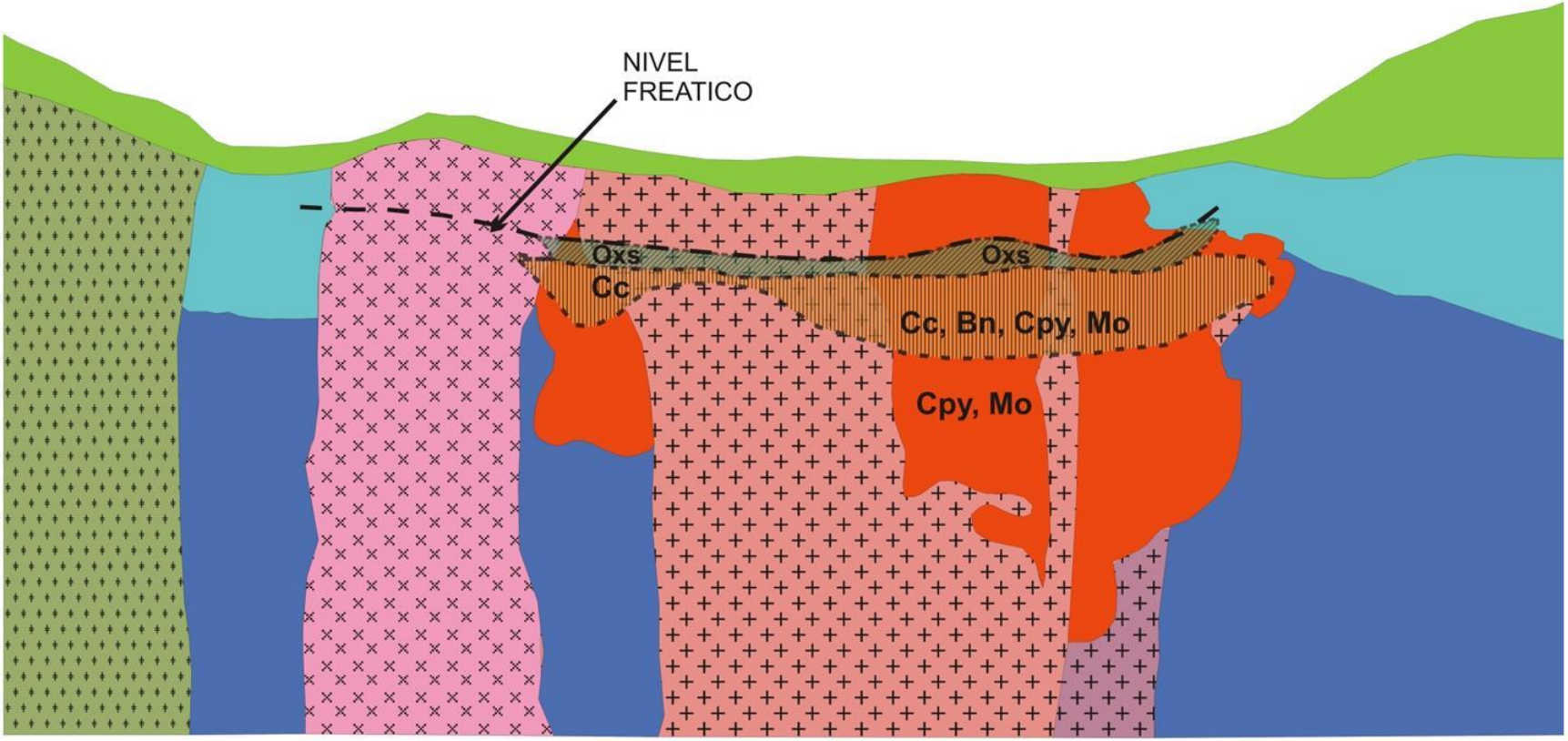
Geological Models - Paleocene Magmatic Belt



Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

General Geological Model of Paleocene Cu-Porphyries

(Cuajone Example)



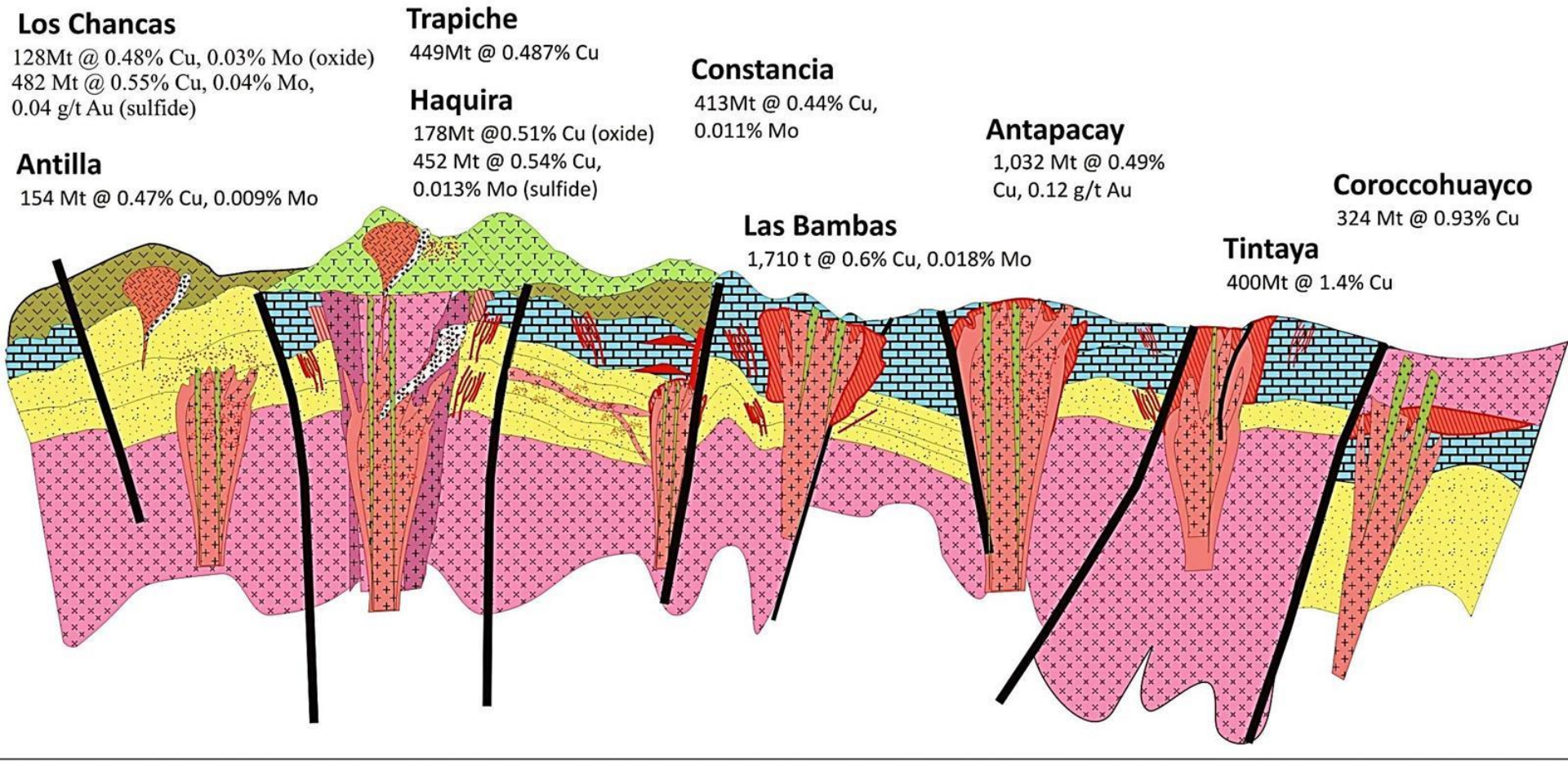
LEGEND

- Huaylillas Volc.
- Porphyritic rhyolite
- Basaltic Andesite
- Porphyritic latite 3
- Porphyritic latite 2
- Porphyritic latite 1
- Diorite
- Oxidation zone
- Enrichment zone
- Primary mineralization

500 m

Modified Concha, O., Valle,J.,Bernabe, H., 1999

Geological Models - Eocene-Oligocene Magmatic Belt

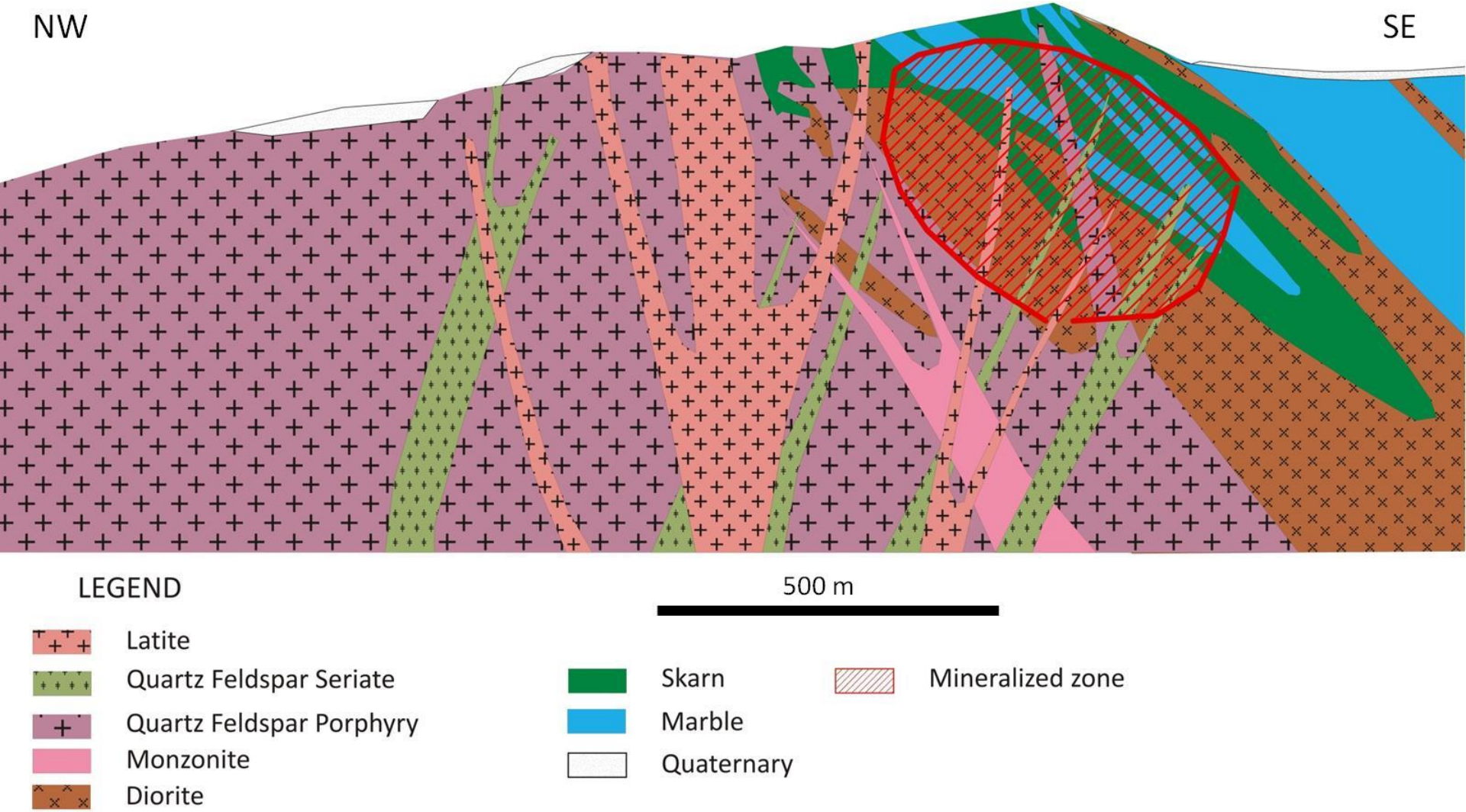


LEGEND

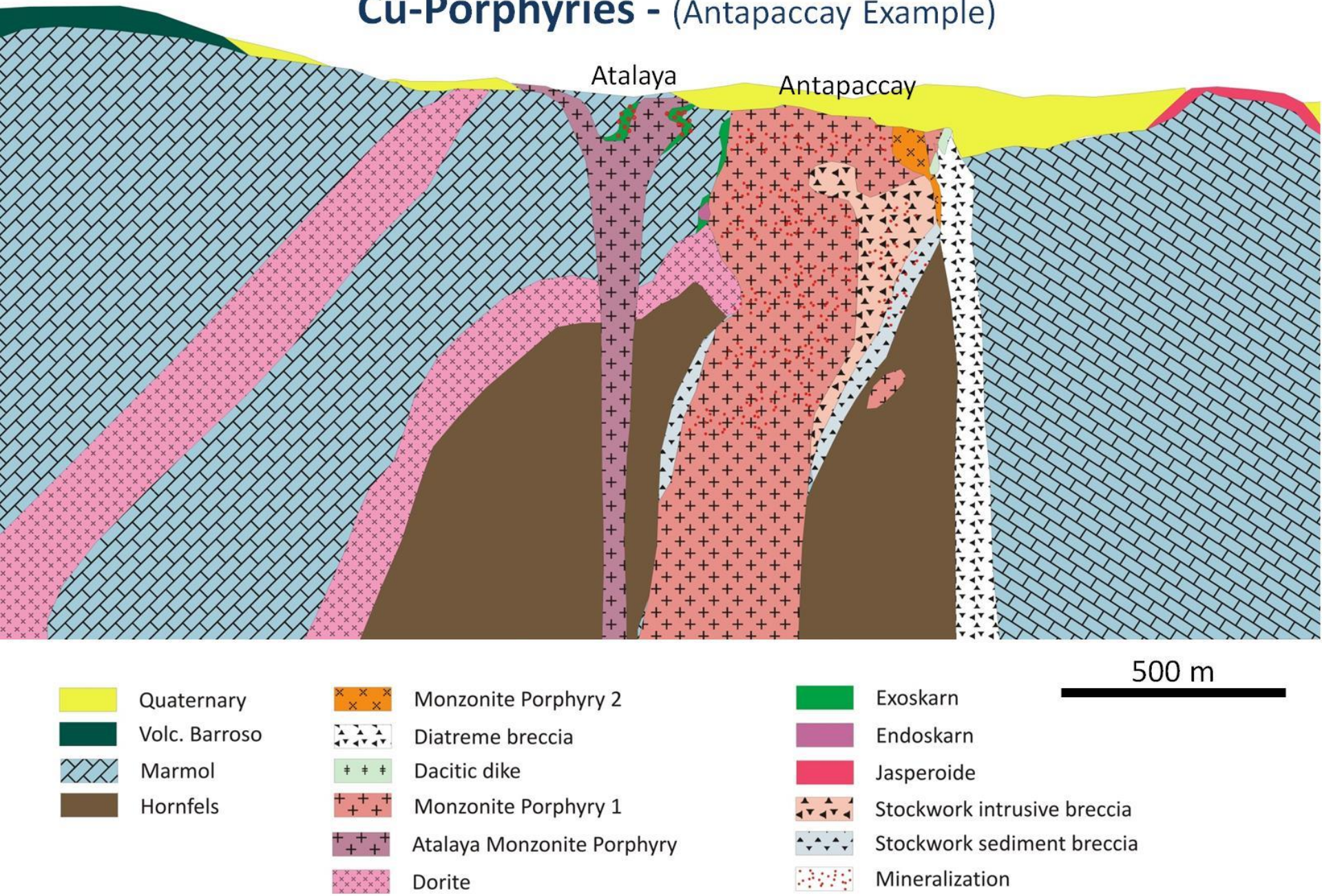
- Tuff
- **Andesite**
- Dome
- Carbonate
- Sandstone
- Breccia
- Late porphyry
- Monzonite (Porphyry)
- Monzodiorite
- Diorite
- Disseminated
- Vein/ disseminated
- Skarn
- Replacement
- Epithermal/mesothermal vein
- Porphyry Cu ± Mo ± Au

Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

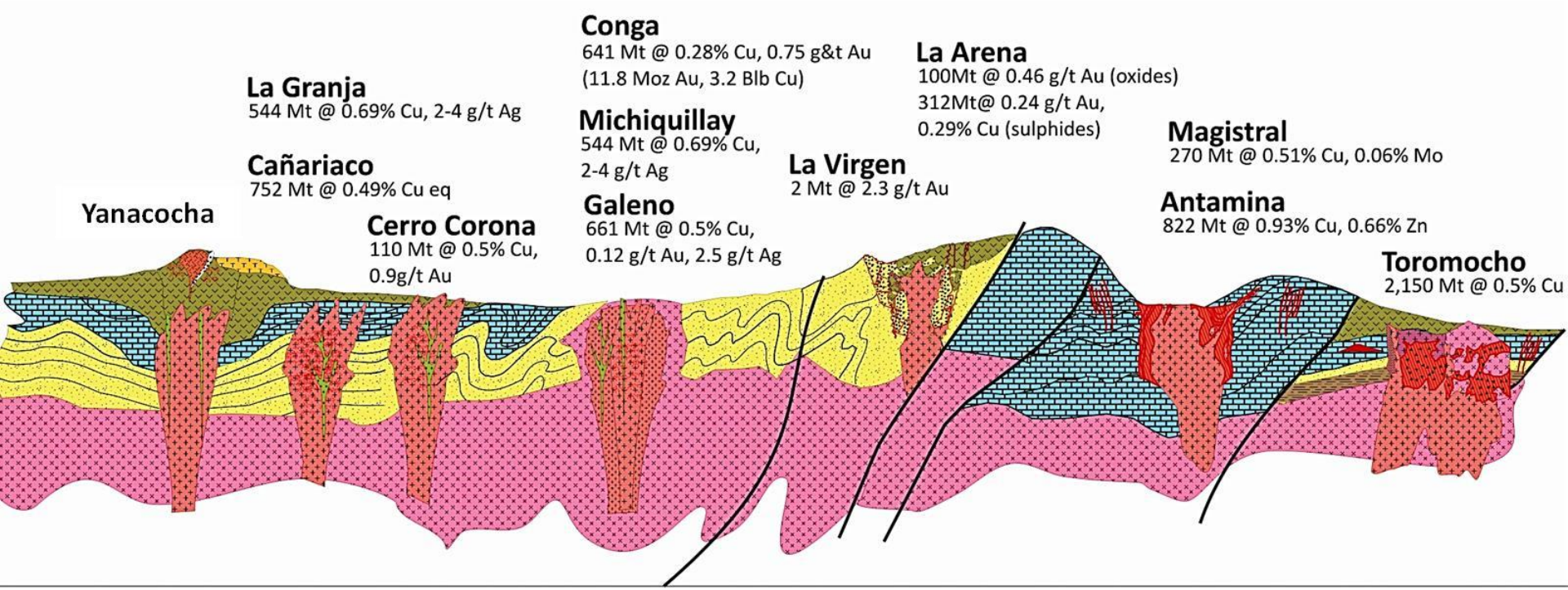
General Geological Model of Eocene-Oligocene Cu-Porphyries - (Las Bambas -Sulfobamba - Example)



General Geological Model of Eocene-Oligocene Cu-Porphyries - (Antapaccay Example)



Geological Models - Miocene Magmatic Belt



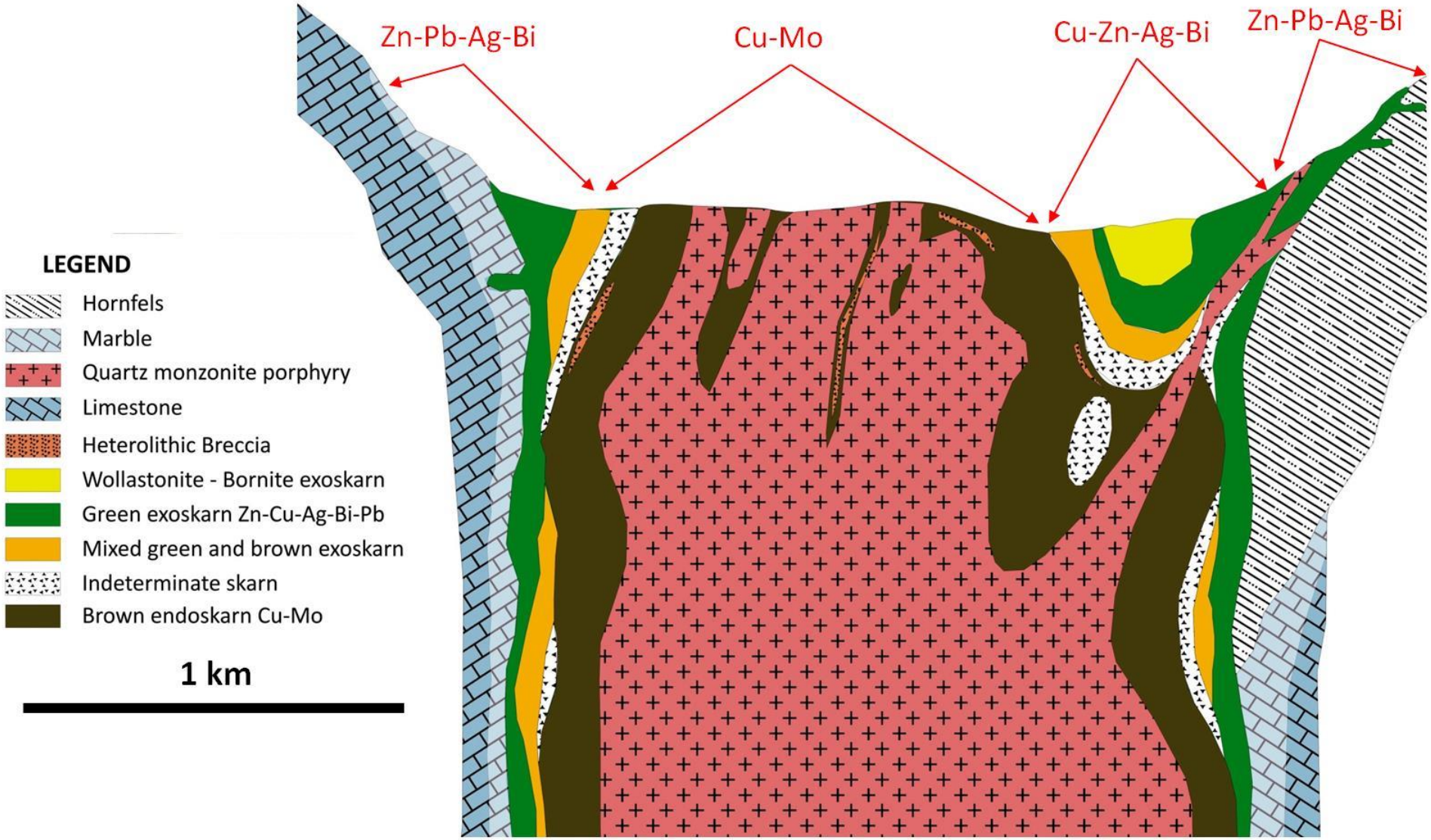
LEGEND

- Tuff
- **Andesite**
- Dome
- Carbonate
- Sandstone
- Shale
- Late porphyry
- Monzonite (Porphyry)
- Monzodiorite
- Diorite
- Breccia
- Disseminated
- Vein
- Skarn
- Replacement
- Epithermal/mesothermal vein
- Porphyry Cu ± Mo ± Au

Source: Copper in Peru: Facts and challenges, J. Acosta, A. Bustamante & Miguel Cardozo, Perumin 2013

General Geological Model of Miocene Cu - Porphyry/ Skarn

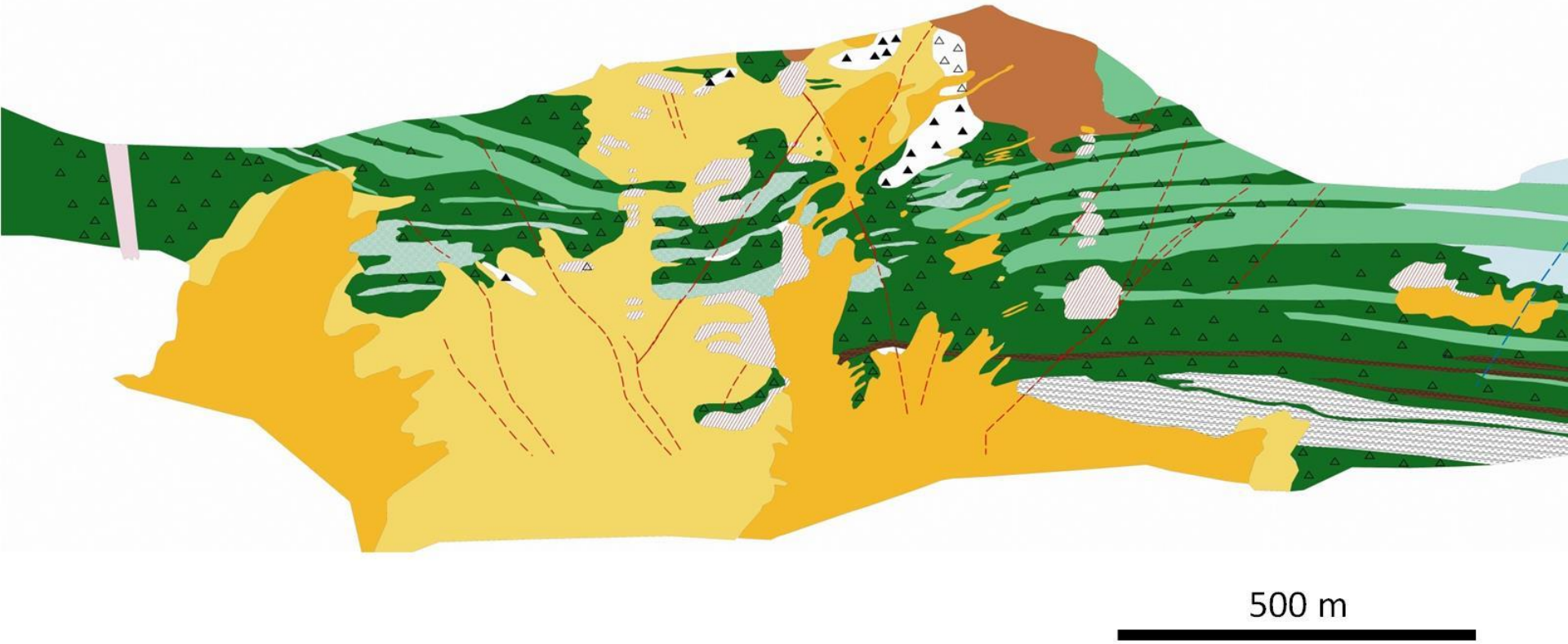
(Antamina Example)



Source: Jhon Espinoza, Geology Department , CM Antamina

General Geological Model of Miocene Cu - Porphyry/ Skarn

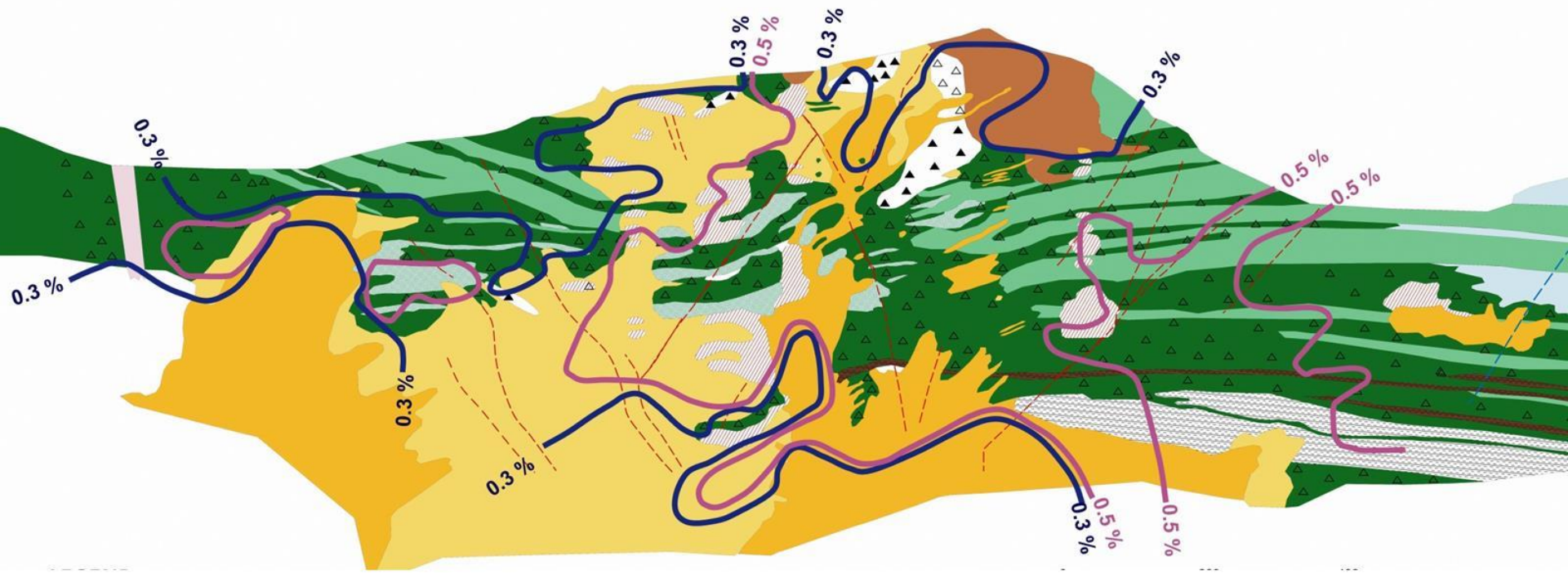
(Toromocho Example)



Diorite/andesitic porphyry
Granodiorite
Feldspar Porphyry
Dacitic porphyry
Hornfels
Skarn
Magnetite skarn
Endoskarn
Calcareous sediments
Shale
Anhydrite/gypsum
Veins
Polimictic Breccia
Monomictic Breccia
Fault

General Geological Model of Miocene Cu - Porphyry/ Skarn

(Toromocho Example)

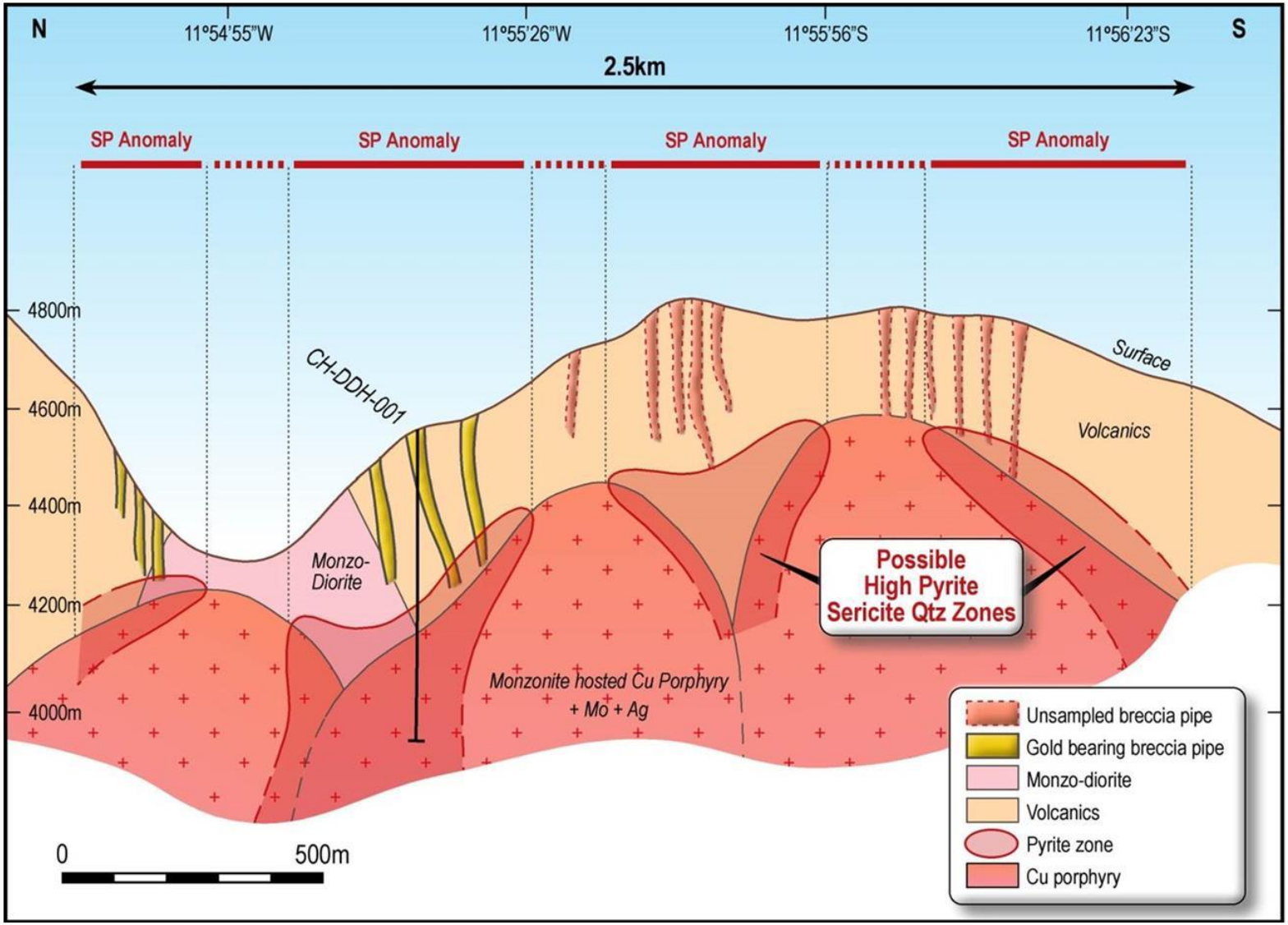


500 m

Diorite/andesitic porphyry
Granodiorite
Feldspar Porphyry
Dacitic porphyry
Hornfels
Skarn
Magnetite skarn
Endoskarn
Calcareous sediments
Shale
Anhydrite/gypsum
Veins
Polimictic Breccia
Monomictic Breccia
Fault

General Geological Model of Miocene Cu - Porphyry/ Skarn

(Chanape Example)



Source: Inca Minerals webpage

Distinctive Features of Main Deposit Belts and Types (1)

	Main Porphyry Belts in Peru		
	Paleocene	**Eocene - Oligocene**	**Miocene**
Magmatism	calc-alkaline	calc-alkaline	calc-alkaline (eventually alkaline component)
Mineralization age	65-55 Ma	42-30 Ma	22-5 Ma
Mineralization/Ore type	Disseminated, stockwork, hydrothermal and magmatic brecccias	Disseminated, stockwork, hydrothermal and magmatic brecccias and skarn bodies	Disseminated, stockwork, hydrothermal brecccias and skarn bodies
High-grade association	hydrothermal breccias, oxides and secondary enrichment zones	skarns, hydrothermal breccias, epithermal overprint, replacement bodies and marginal veins, frequent transitions to large, HS epithermal gold-silver	copper-gold and polymetallic skarns, hydrothermal breccias, porphyry centered zones of polymetallic mineralization
Hydrothermal alteration	Sericite-clay-chlorite, potassic, quartz-sericitic, calcic-potassic, advanced argillic and propylitic assemblages.	Potassic, quartz-sericitic,advanced argillic, propylitic and calc-silicate assemblages with skarn-type	Sericite-clay-chlorite, potassic, quartz-sericitic,advanced argillic, propylitic and calc-silicate assemblages with skarn-type

Distinctive Features of Main Deposit Belts and Types (2)

	Main Porphyry Belts in Peru		
	Paleocene	**Eocene - Oligocene**	**Miocene**
Host rock	Volcanic complex: Gpo. Toquepala Volcano-sedimentary sequences: Fm. Moquegua, Fm. Huaylillas	Cretaceous clastic and carbonate sequences: Gpo. Yura, Fm. Ferrobamba.	Cretaceous sediments: Fm. Goyllarisquizga Eocene Miocene volcanics: Gpo. Calipuy
Tectonic evolution	Magmatic arc: neutral-compressional regime Thick crust : <40km Convergence velocity : 10cm/y	Magmatic arc: compressional regime Thick crust : >40km Convergence velocity : 10cm/y	Magmatic arc: compressional regime Thick crust : >40km Convergence velocity : 15cm/y
Structural controls	Inca Puquio fault: NW-SE	Andean structures NW-SE , changes to E-W.Cusco-Lagunillas-Mañazo system and its extensional known Abancay-Andahuaylas-Totos	NW-SE system: Cordillera Blanca and Marañon faults Punre-Canchis fault Yauli Dome
Size	Mostly large to very large, +300Mt to 4,000Mt	Mid- to large, +400Mt to 1,800Mt	Mid- to very large, +400Mt to 4,000Mt
Average grades			
Copper	0.39 - 0.47 % Cu	0.44 - 0.93 % Cu	0.28 - 0.69 % Cu
Gold	0.03 g/t Au	0.04 - 0.25 g/t Au	0.05 - 0.90 g/t Au
Silver	2.20 - 3.10 g/t Ag	1.45 - 4.75 g/t Ag	1.24 - 6.90 g/t Ag
Moly	0.02 % Mo	0.013 - 0.030 % Mo	up to 0.010 % Mo

Distinctive Features of Main Deposit Belts and Types (3)

	Main Porphyry Belts in Peru		
	Paleocene	**Eocene - Oligocene**	**Miocene**
Geometry	Clusters of mid- to large-sized porphyry. Mineralization occurs in the intrusives as well as in their country rocks.	Complex mineralized skam bodies are small- to mid-size and irregular, mostly above porphyries but also underneath intrusive bodies. Gold mineralization occurs	Structurally aligned porphyries. Mineralization occurs in the intrusives as well as in their country rocks. Gold mineralization in sandstones and bulk-tonnage, polymetallic mineralization in skarns frequently associated
Historic Cumulative Copper Production	16 MT	2 MT	5 MT
Copper contained in Reported resources	63 MT	44 MT	85 MT
Deposit examples	Cuajone, Toquepala, Cerro Verde, Quellaveco, Los Calatos	Las Bambas, Antapaccay, Haquira, Quechua, Los Chancas, Coroccohuayco, Constancia	La Granja, Toromocho, El Galeno, Michiquillay, Minas Conga, Rio Blanco, Cañariaco, Cerro Corona

Exploration Challenges

- Guarantee the implementation of future copper producers in Peru
- Ensure that initial exploration projects become mining operations.
- Increase investment in mineral exploration to expand reserves and resources and discovery of new deposits.
- Worldwide investment in mineral exploration dropped in 2013 and 2014.
- Promoting mineral exploration is essential to increase both metal production and long-term resources.
- Both financial and technical incentives are required and excessive social-environmental barriers have to be removed to allow the development of a modern, competitive, responsible and sustainable mining industry.
- Mining will still be for several decades a solid base for the economic development of the country.

Exploration Challenges

- INGEMMET offers 1:100,000 and 1:50,000 scale regional maps covering the whole of the country and most of the territory is also covered by drainage geochemical sampling.
- Regional geophysical surveys (magnetic and radiometric) are insufficient.
- As exploration matures, the need to improve, innovate and implement new geophysical methods will increase.
- Radiometric age data is extensive, but still needs to be expanded.
- Isotopic studies useful to distinguish most productive mineralized systems and to identify mineralization sources are still very limited.
- Studies of magmatic arcs related to mineralized systems are insufficient.
- Companies, INGEMMET and the academia urgently need to joint efforts for a sound scientific and technical development of Peru.

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