Delineation of Tracts and Estimating Number of Deposits

Donald A. Singer

Plan

- Principles of delineation
- Delineation of covered areas
- An assessment
- Estimating undiscovered mineral deposits
- Guides for estimating number of deposits
- Appropriate grade and tonnage model?
- Biased estimates of number of deposits
- Example of estimation of number of deposits

General Problem in Mineral Assessments

- Integrate geology, geochemistry, geophysics, exploration history, and known deposits and occurrences
- One powerful way is to use deposit types

Permissive Tract Delineation

- To be consistent, permissive areas are delineated where geology allows existence of one or more specified types
- Areas are delineated based on geologic criteria from deposit models
- Permissive boundaries are defined such that the probability of deposits occurring outside boundary is negligible

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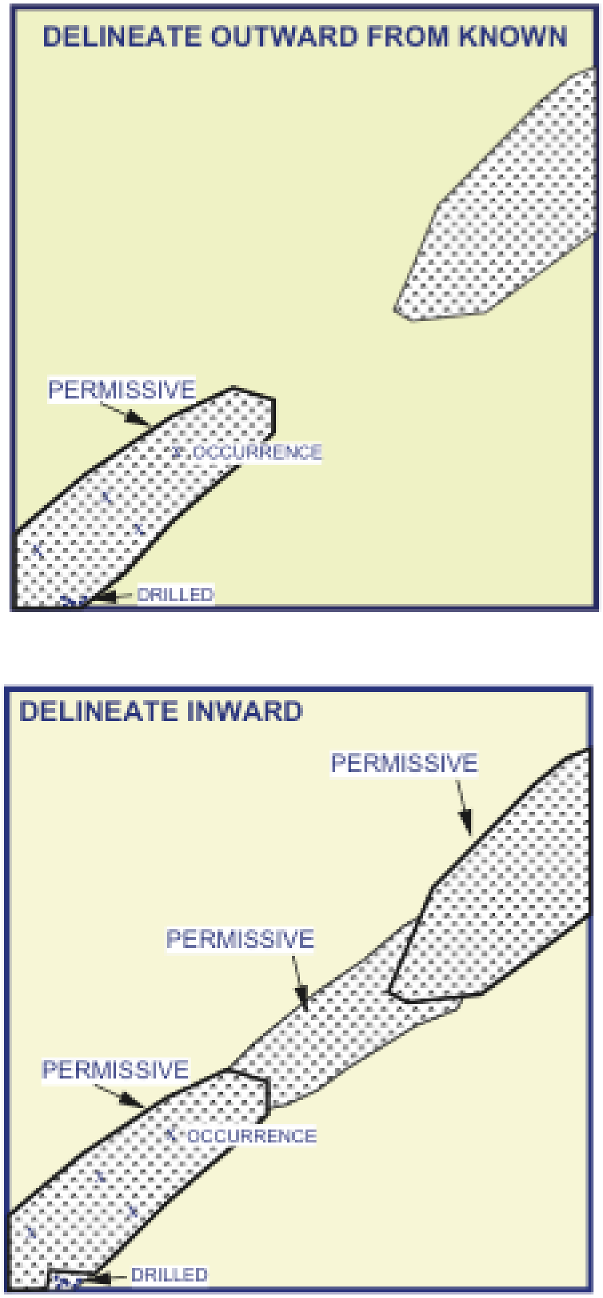
Principles of Delineation

Delineation

In order to be able to consistently assess undiscovered mineral resources of regions, areas are delineated where geology *permits* the existence of deposits of one or more specified types. Focus is on what types of deposits *could* be in the region rather than upon what types of deposits are *known* to occur.



Delineation of permissive tracts. Upper plot shows the strategy of moving outward from known deposits, lower plot the strategy of moving inward from permissive rocks.

Delineating Tracts

- Boundaries of a permissive tracts are drawn such that the probability of the deposit occurring outside the boundary is negligible; that is less than 1 in 100,000 to 1,000,000

- Preliminary tracts should be examined to determine if parts have been explored so thoroughly that they can be confidently said to lack deposits—if so eliminate. When drawing our tracts, we must consider spatial differences in the:
  1. Probability of occurrence, and
  2. Probable distribution of undiscovered deposits

Delineating Tracts

- Designation of a tract as permissive does not imply any special favorability for the occurrence of a deposit, nor does it address the likelihood that a deposit will be discovered there if it exists

- Favorability for a deposit type is represented by the number of undiscovered deposits perceived to exist in a tract

- In three-part assessments, it is desirable to subdivide a permissive tract into two or more new tracts if they have different kinds of information, different numbers of undiscovered deposits, or possibly different amounts of uncertainty about the number of deposits

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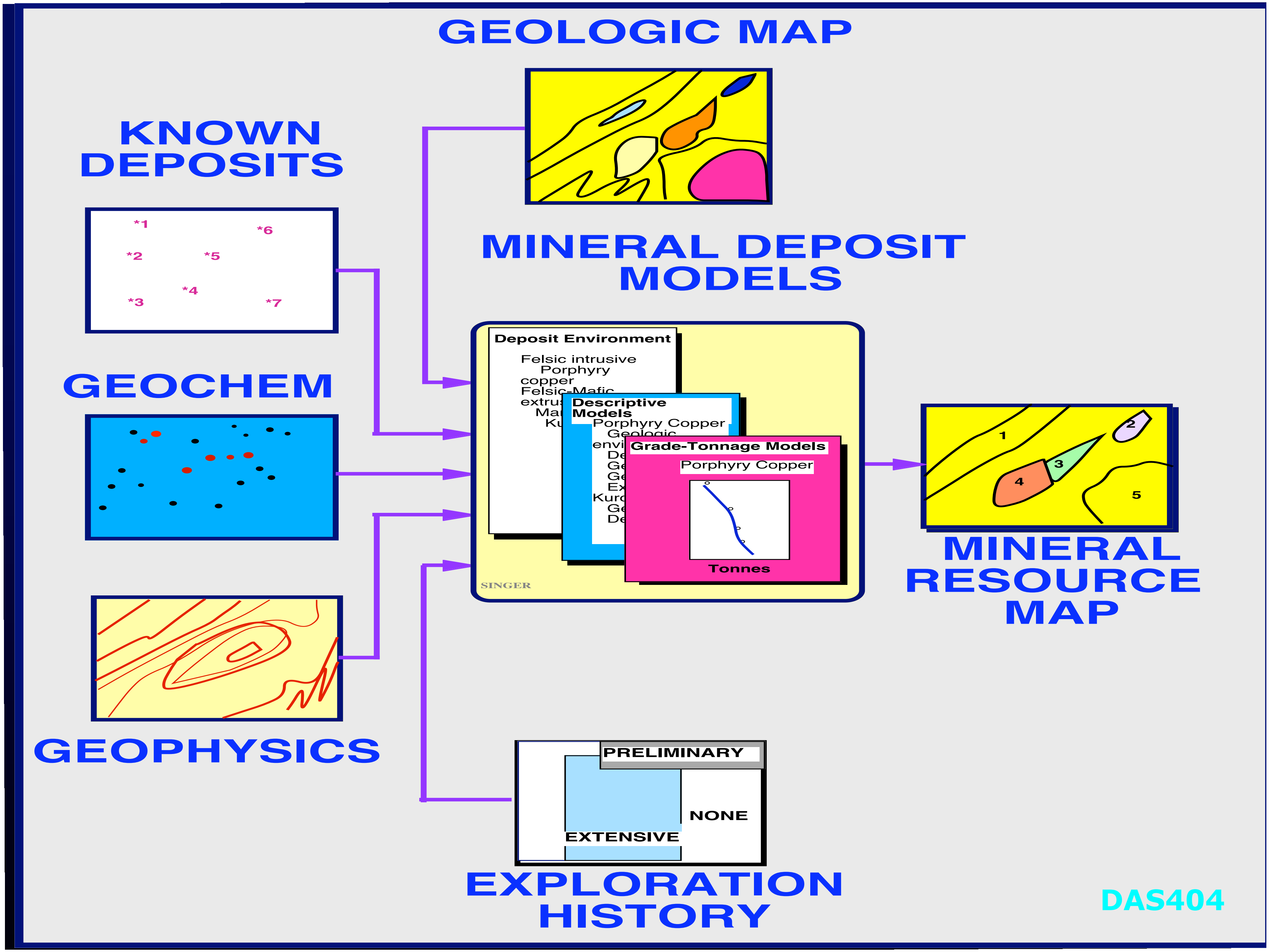
GEOLOGIC MAP
KNOWN DEPOSITS
*1
*6
*2
*5
*4
*3
*7
GEOCHEM
GEOPHYSICS
MINERAL DEPOSIT MODELS
Deposit Environment
Felsic intrusive
Porphyry
copper
Descriptive Models
Porphyry Copper
Grade-Tonnage Models
Porphyry Copper
Tonnes
SINGER
MINERAL RESOURCE MAP
1
2
3
4
5
PRELIMINARY
NONE
EXTENSIVE
EXPLORATION HISTORY
DAS404

Delineating Tracts

- Strategies to develop a list of candidate deposit types--
  - Classification of known deposits in or near tract
  - Comparison with areas of broadly similar geology
  - Projection of deposit types from adjacent regions whose geology extends into the region, and
  - Use of deposits associations to infer types that have yet to be discovered in the tract

Delineating Tracts

- A task in delineating tracts that may contain undiscovered deposits is to identify the mapped units, or combinations of units, from the geologic map that form the broad ore controls for each candidate deposit type. The geologic environment section of the descriptive mineral deposit model will assist with this task

Menzie, 2005

Delineating Tracts

- The boundaries of mapped rock units form the primary basis for drawing boundaries of the tract. These preliminary tract boundaries should then be extended using geophysical surveys, such as aeromagnetics, to identify where the permissive rocks are concealed by younger rocks or sediments.

Delineating Tracts

- Finally the preliminary tracts should be examined to determine if parts have been previously explored for the deposits type under consideration. If parts of the tract have been explored so thoroughly that they can be confidently said to lack deposits, they should be eliminated from the tract.

Delineating Tracts

- It is important to remember that the scale of a geologic map affects which units are portrayed
- Therefore it is critical to carefully read the rock unit descriptions to identify permissive settings
- In some cases, classified deposit types can identify a geologic setting not shown on a geologic map. For example, skarn deposits indicate intrusive rocks perhaps not shown on the map
- Calibration of operators very important

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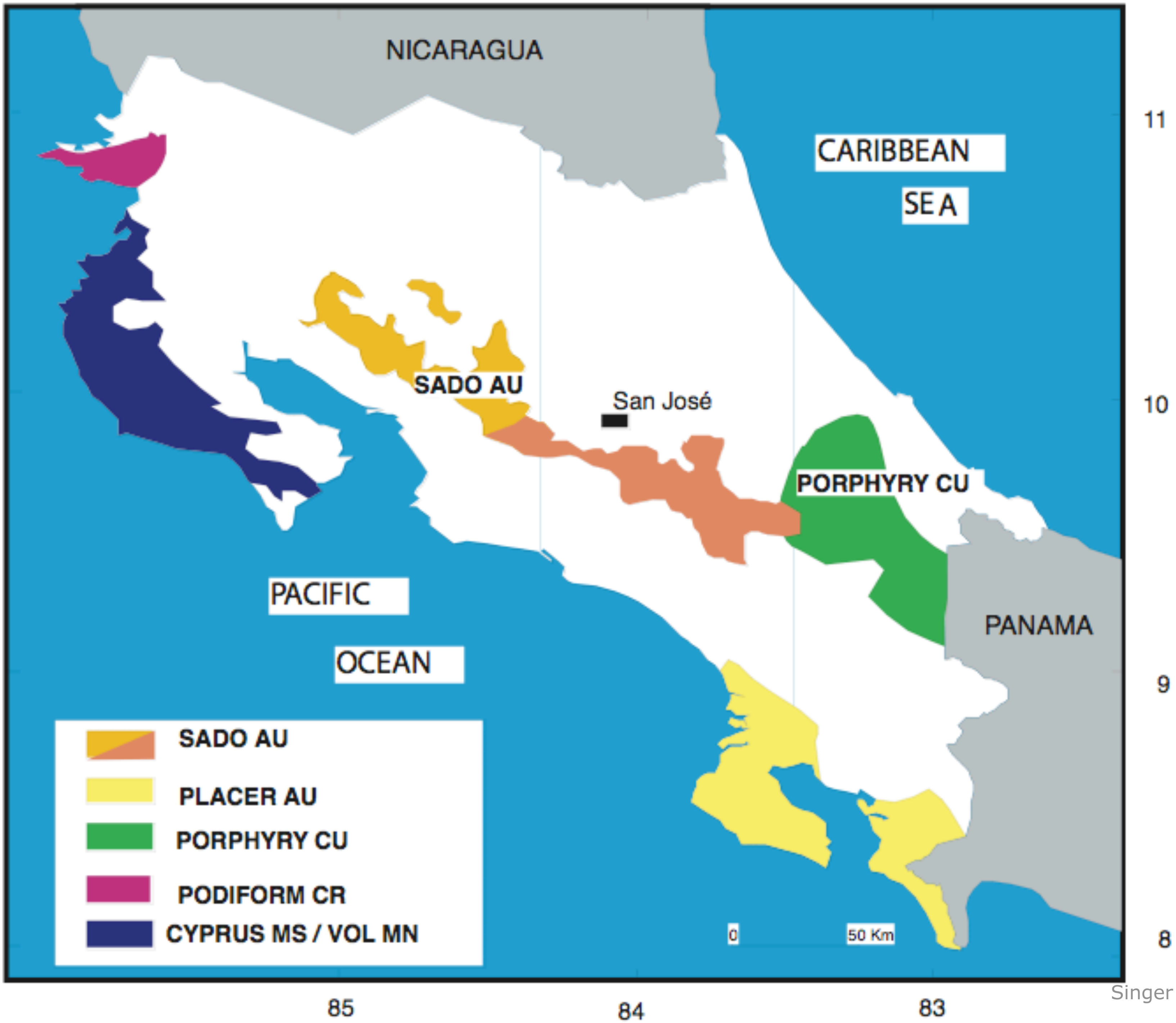
Some tracts in Costa Rica



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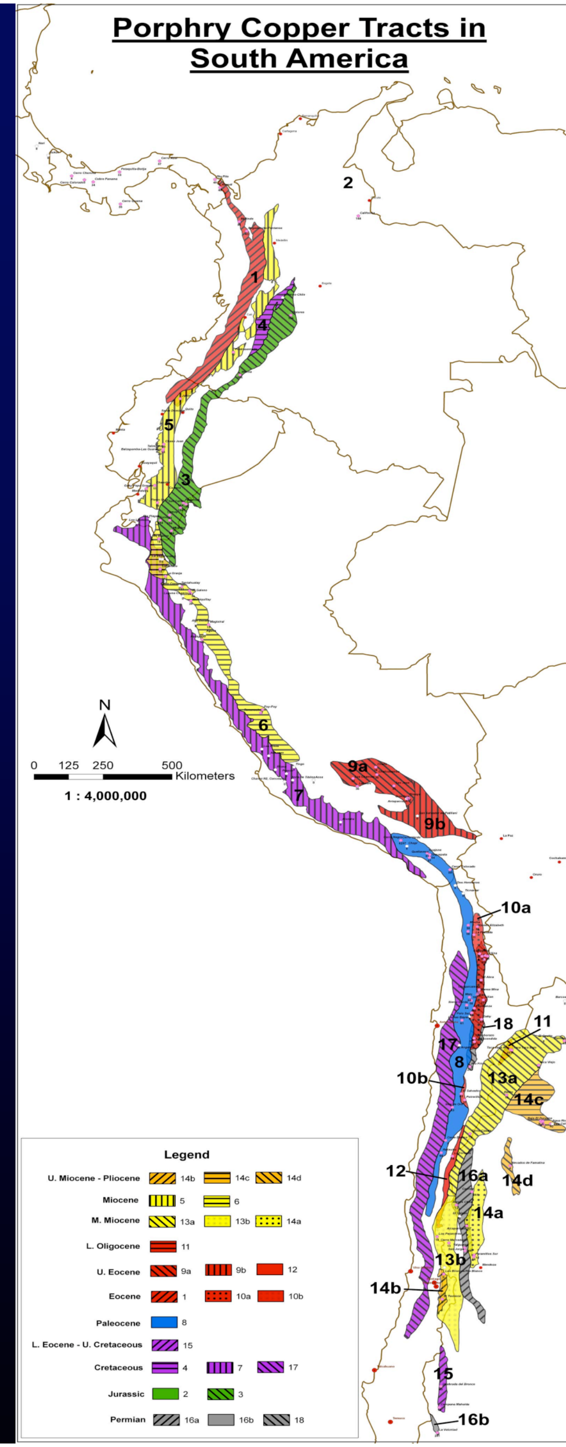
Broad volcanic arcs that formed at approximately the same time are the fundamental unit for the delineation of permissive areas for porphyry copper deposits



Cunningham et al., 2007

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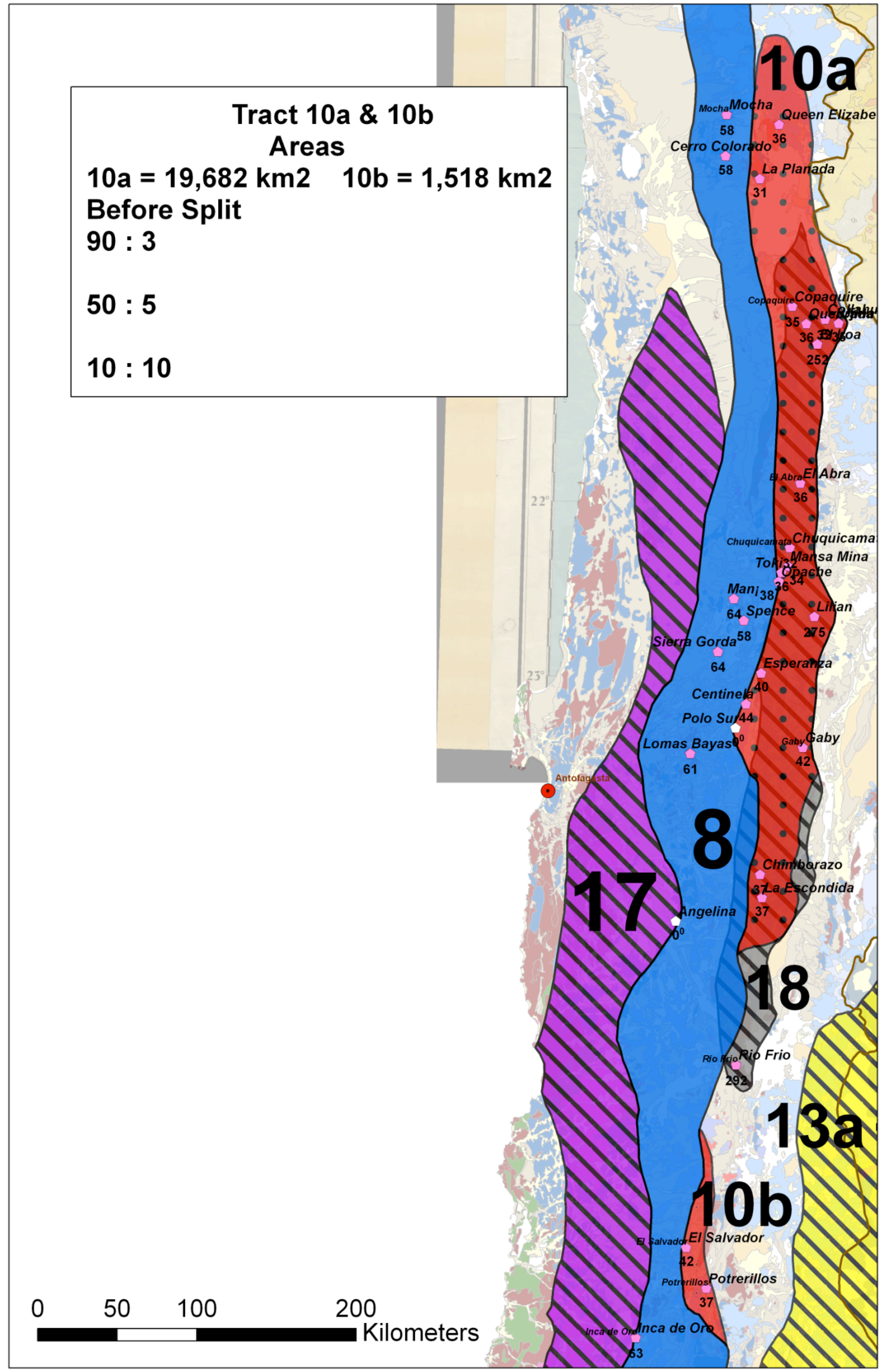
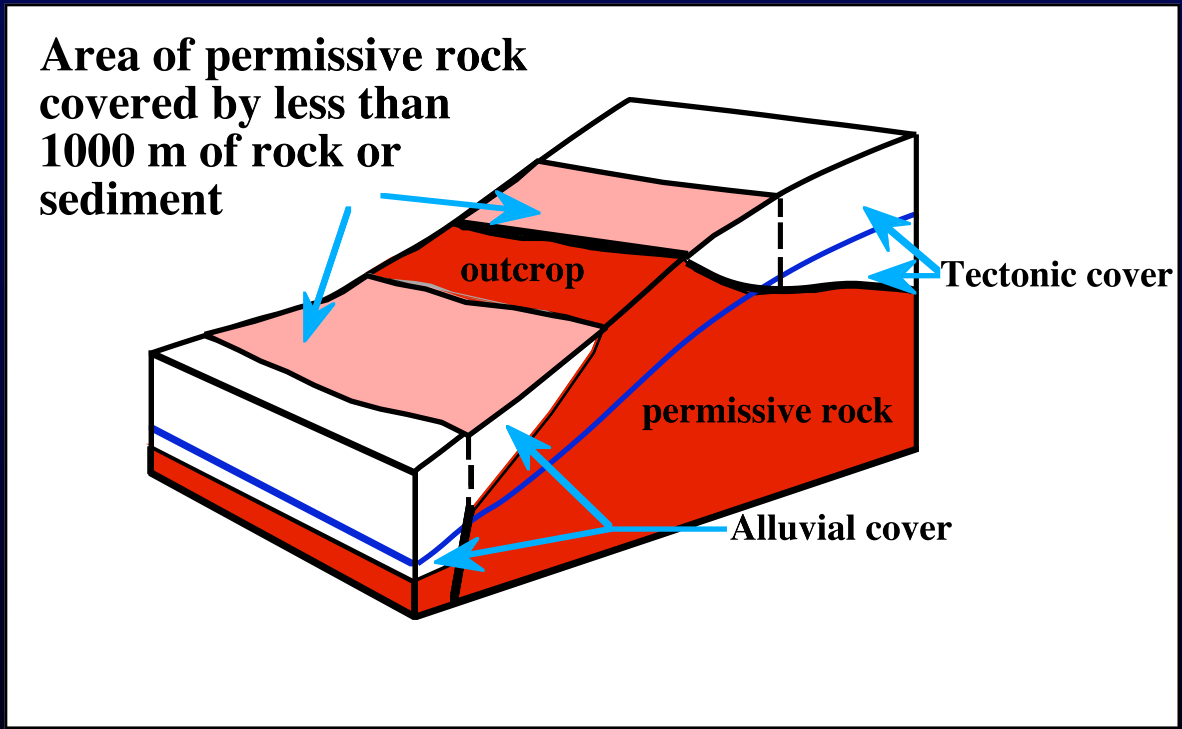
Tracts can be split into parts



Cunningham et al., 2007

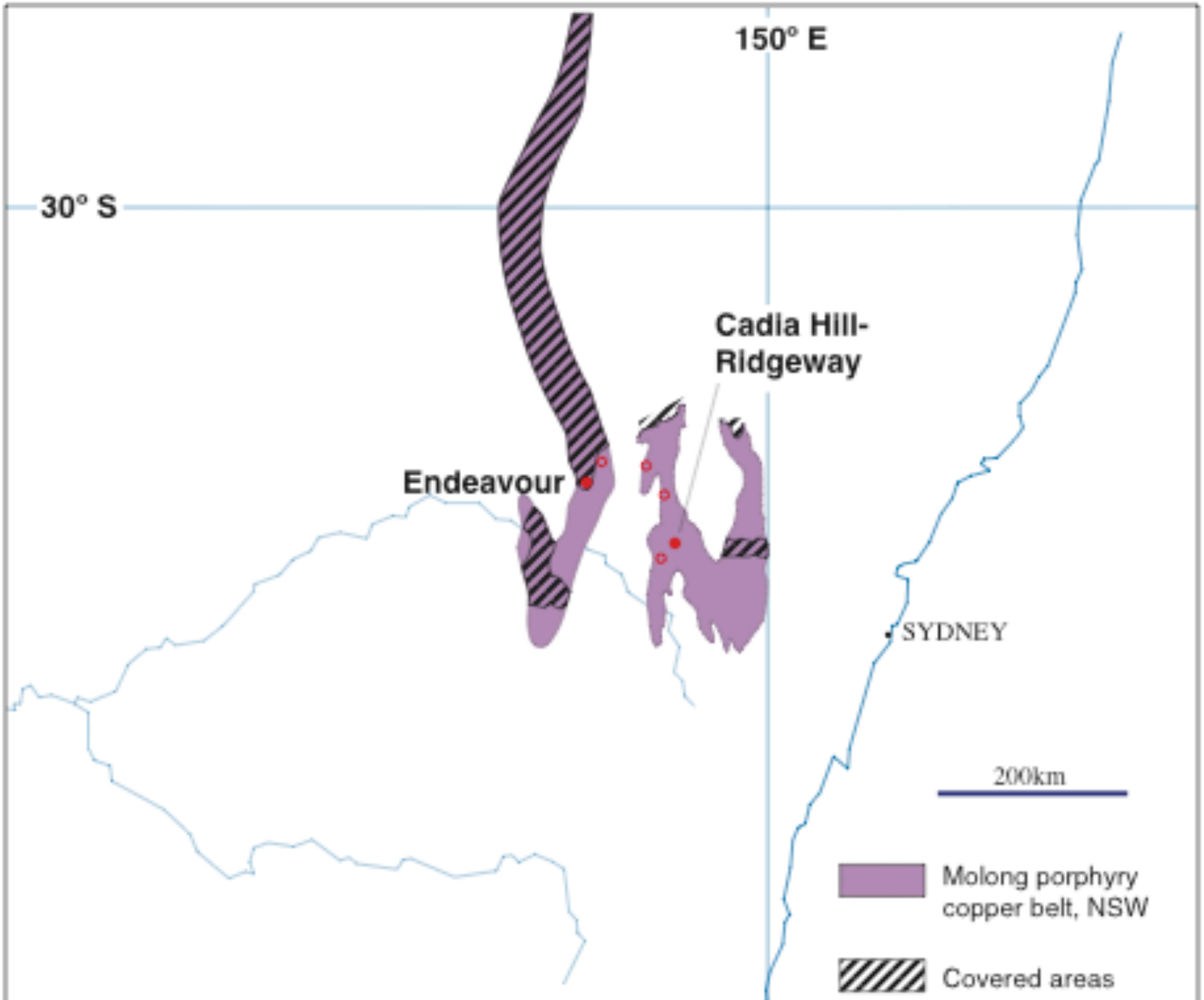
Delineation of Covered Areas

Covered Areas Need to Be Included Where Permissive



Aids for Estimating Resources Under Cover:

- Geology from geophysics, drill holes, and extrapolation
- Structural controls from geophysics and extrapolation
- Metallogenic map interpolations
- Mineral deposit densities



Interpreted Ordovician volcanic arc and intrusive rocks (beneath cover), based on aeromagnetic data New South Wales, Australia

(modified after Scheibner, E., 1998, Geology of New South Wales - synthesis. Volume 2, Geological evolution: Geological Survey of New South Wales, Memoir Geology 13(2), 666 p.)

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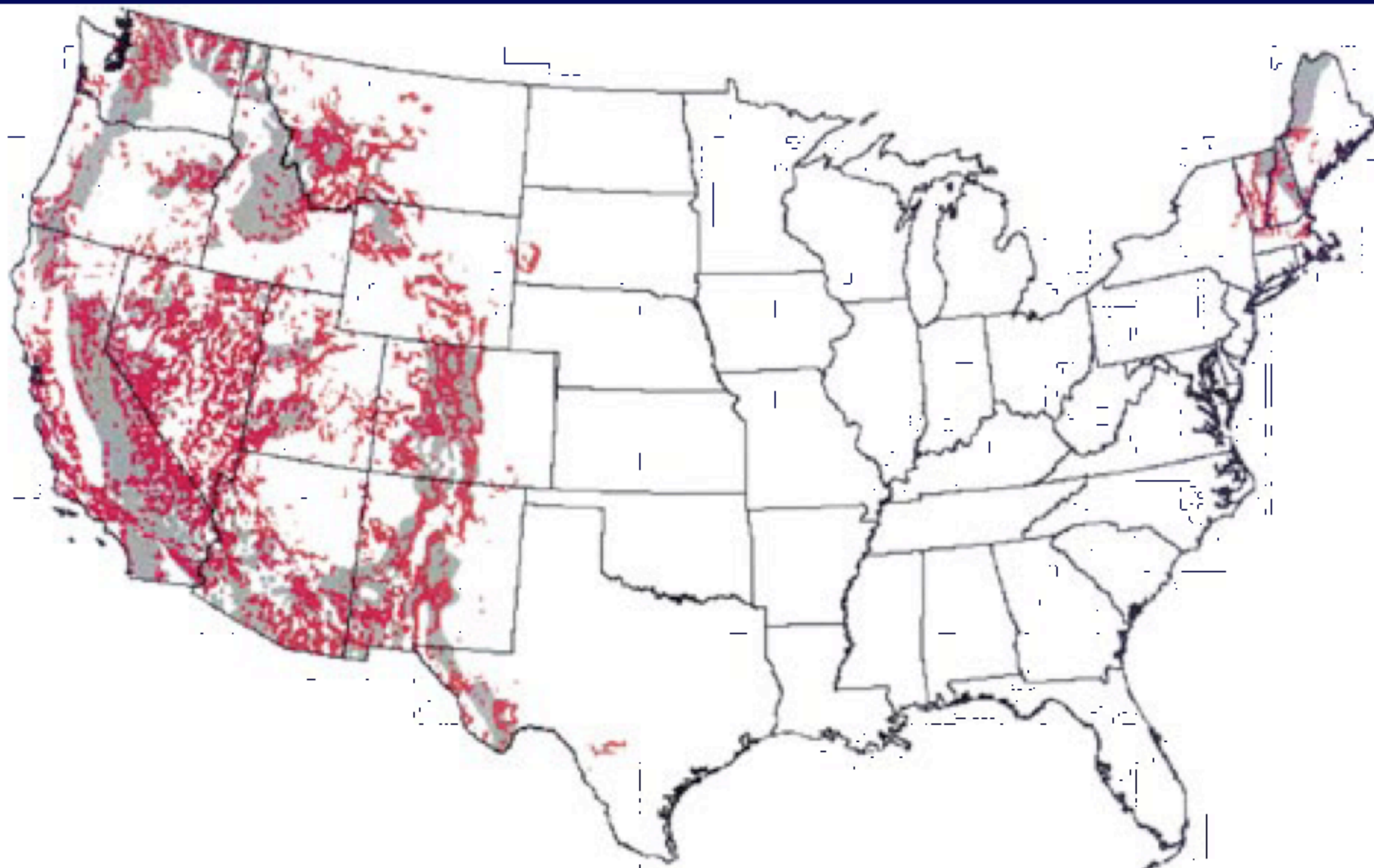
Example Automatic Delineation



Calculated permissive tracts (red) defined by this analysis overlaid on expert permissive tracts (gray).

Raines, G.L., and Mihalasky, M.J. Natural Resources Research, v. 11, no. 4, 2004, p241-248.

Issue of Covered Areas in Example

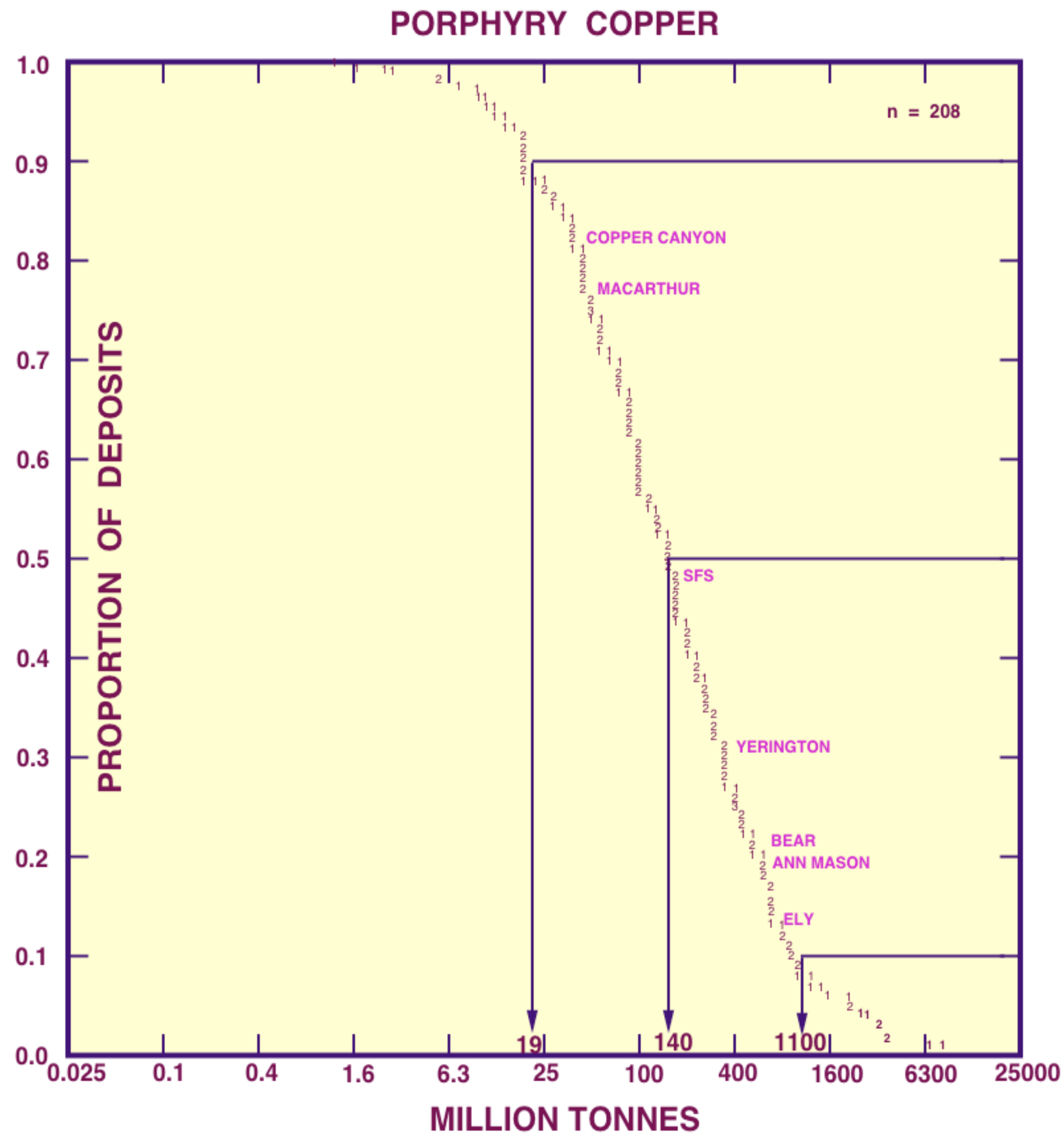
- Permissive is defined as areas where probability of undiscovered deposits existing outside boundary is negligible (ie. less than 1 in 100,000 to 1,000,000)
- Previous slide has 63% of expert determined "permissive" area incorrectly classed as non-permissive by the automatic system
- Much of permissive area classed as non-permissive in example is in covered areas
- In USGS assessment, majority of undiscovered resources that were estimated were likely to exist in covered areas
- The automatic system almost completely missed the areas that matter for undiscovered resources—covered permissive areas

An Assessment

Preparation to Meeting

- Known deposits are classed into types
- Determine if known deposits fit the grade and tonnage model with plots and “t” test
- If known deposits do not fit global model, build an appropriate model
- Make preliminary delineation
- Make preliminary estimates

Comparison of tonnages of the porphyry copper deposits in Nevada to the global grade and tonnage model (Singer et al., 1996) prior to the assessment



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Test Of Appropriateness Of Global Porphyry Copper Grade And Tonnage Model To Nevada's Deposits

t = (8.1749 – 8.3545) / 0.2572 = -0.698

206 degrees of freedom (= $n_1 + n_2 - 2$),
mean tonnage of Nevada deposits = 8.35451,
mean tonnage of the world = 8.17495, pooled standard error = 0.25724

The probability of t = -0.698 with 206 df is 0.486

We conclude that differences as large as seen here between tonnages of porphyry copper deposits in Nevada and world-wide porphyry copper deposits happen by chance alone about 49 percent of the time

Therefore we accept the global model as appropriate for undiscovered porphyry copper deposits of Nevada. (Similar results were observed for Cu grades.)

Overview Of An Assessment

- Pre-meeting: deposit typing, testing-building, delineation
- Discussion of ground rules, purpose, & goals
- Review geology, known deposits geophysics, geochemistry, & exploration history
- Review geologic settings of deposit type
- Delineate tracts permissive for deposit type
- Review grade & tonnage models & other appropriate guidelines
- Make estimates of number of undiscovered deposits
- Review estimates–revise if appropriate

Discussion of Ground Rules, Purpose, and Goals for Meeting

- **To assess undiscovered mineral deposits of Area X in three-part form of assessment**
- **Grade & tonnage models finished before meeting**
- **In meeting, team of experts revise delineated tracts permissive for different kinds of deposits**
- **Estimate number of undiscovered deposits located in the tracts to a depth of *n* km after reviewing guidelines**
- **After—reviews of relevant geoscience information and followed by review and revision of results, if necessary**

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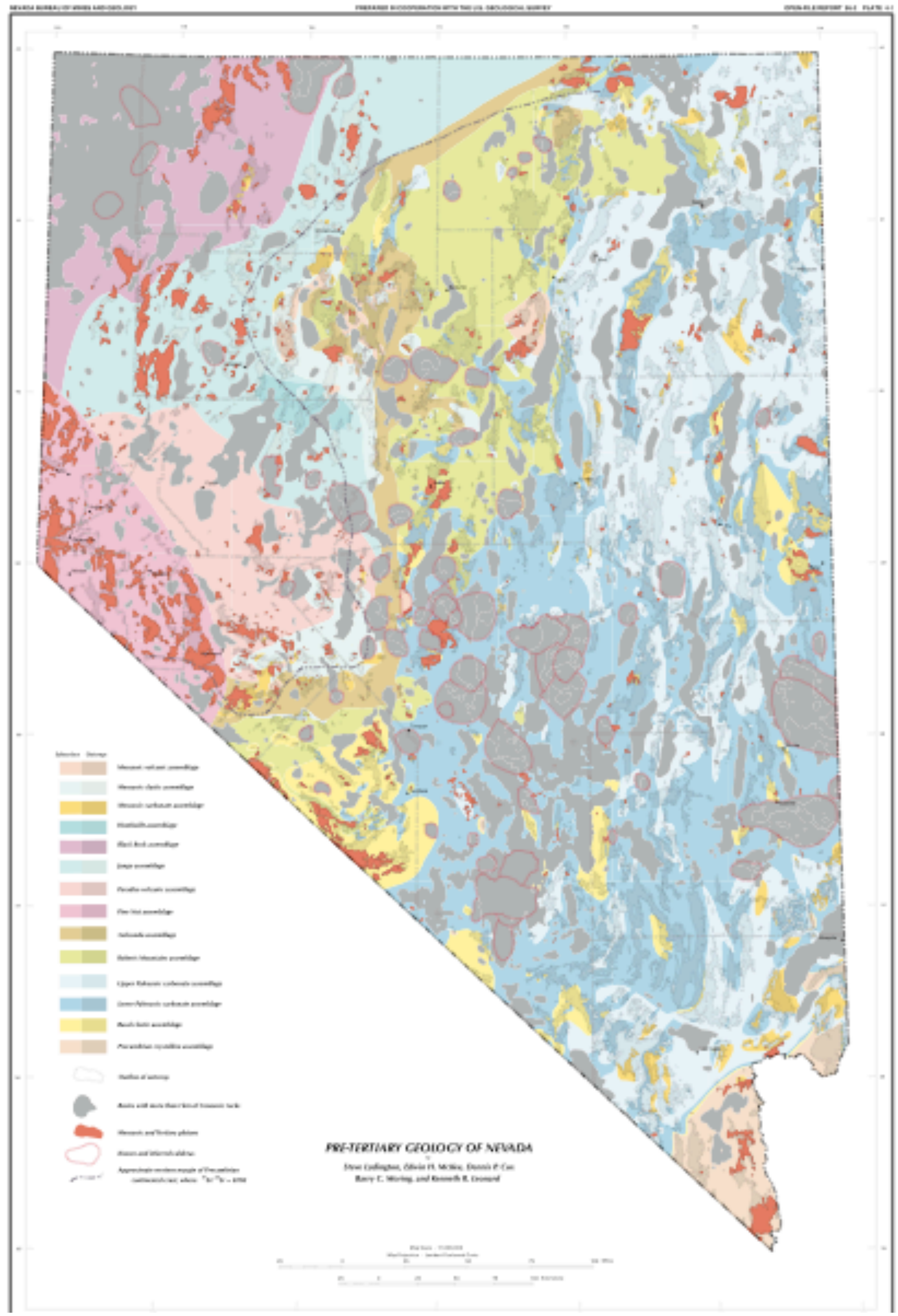
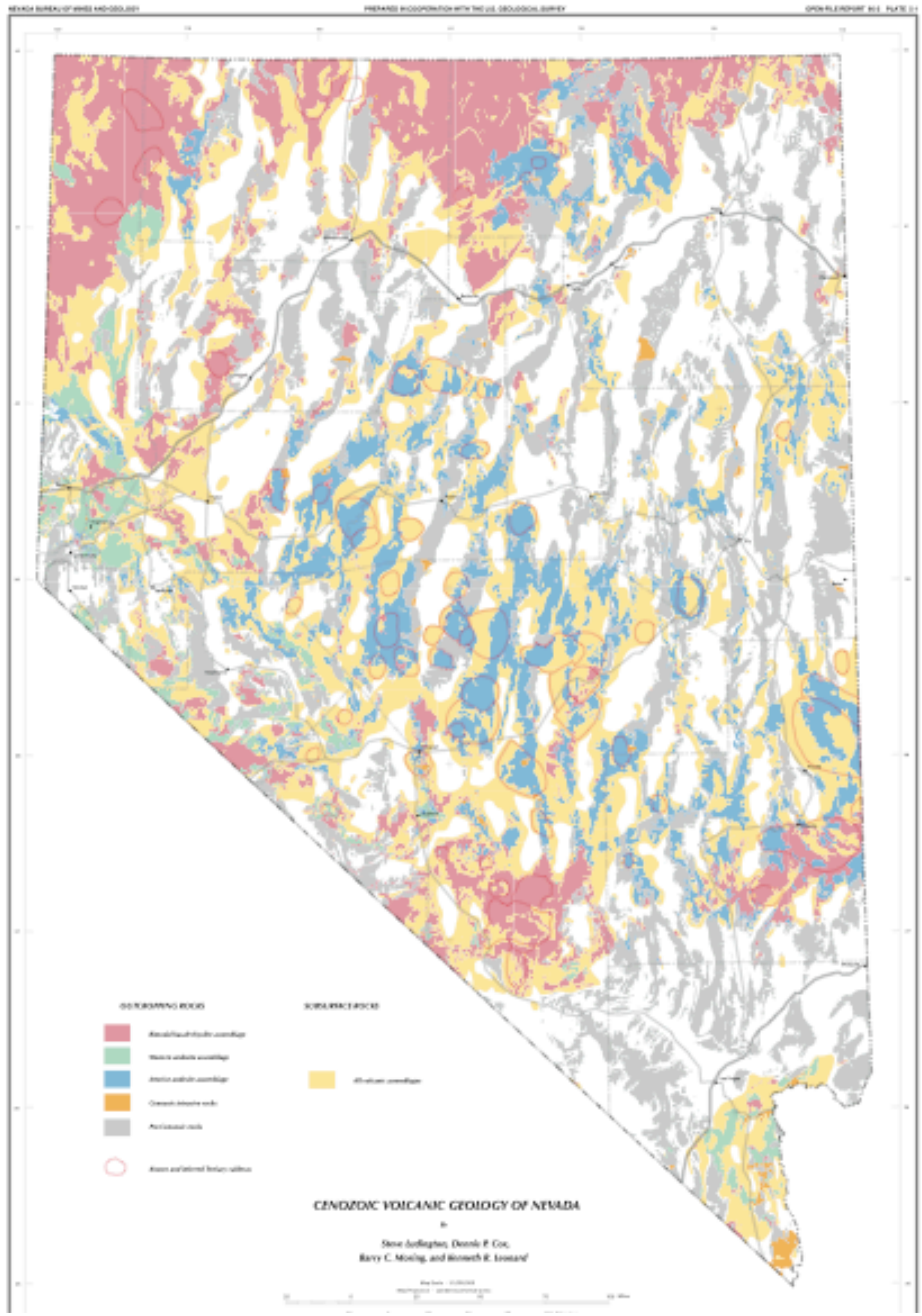
Pre-Tertiary Geology of Nevada (Ludington et al., 1996)



Tertiary Geology of Nevada, Ludington et al., 1996)



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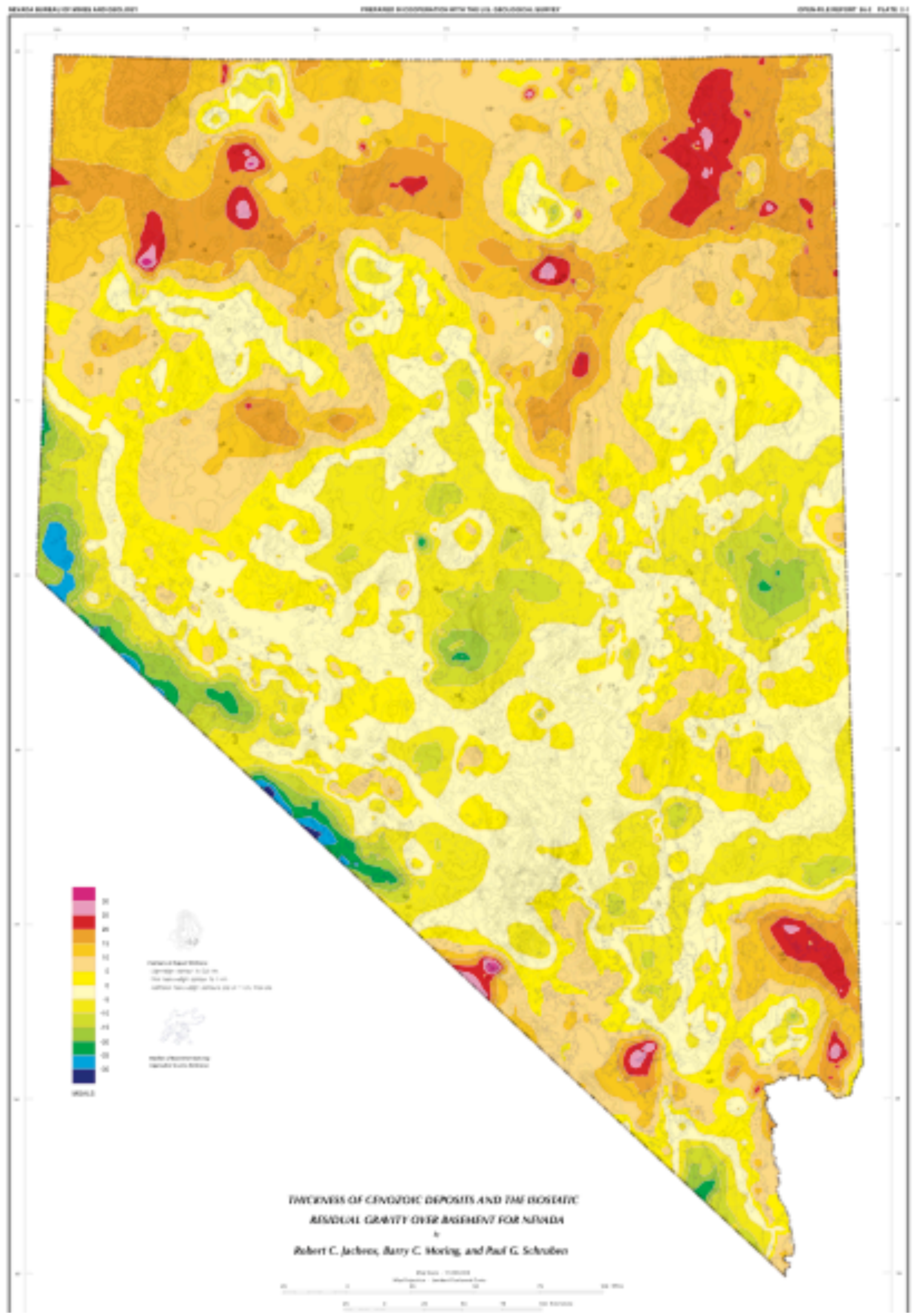
Gravity and Thickness of Cover in Nevada (Jachens et al., 1996)



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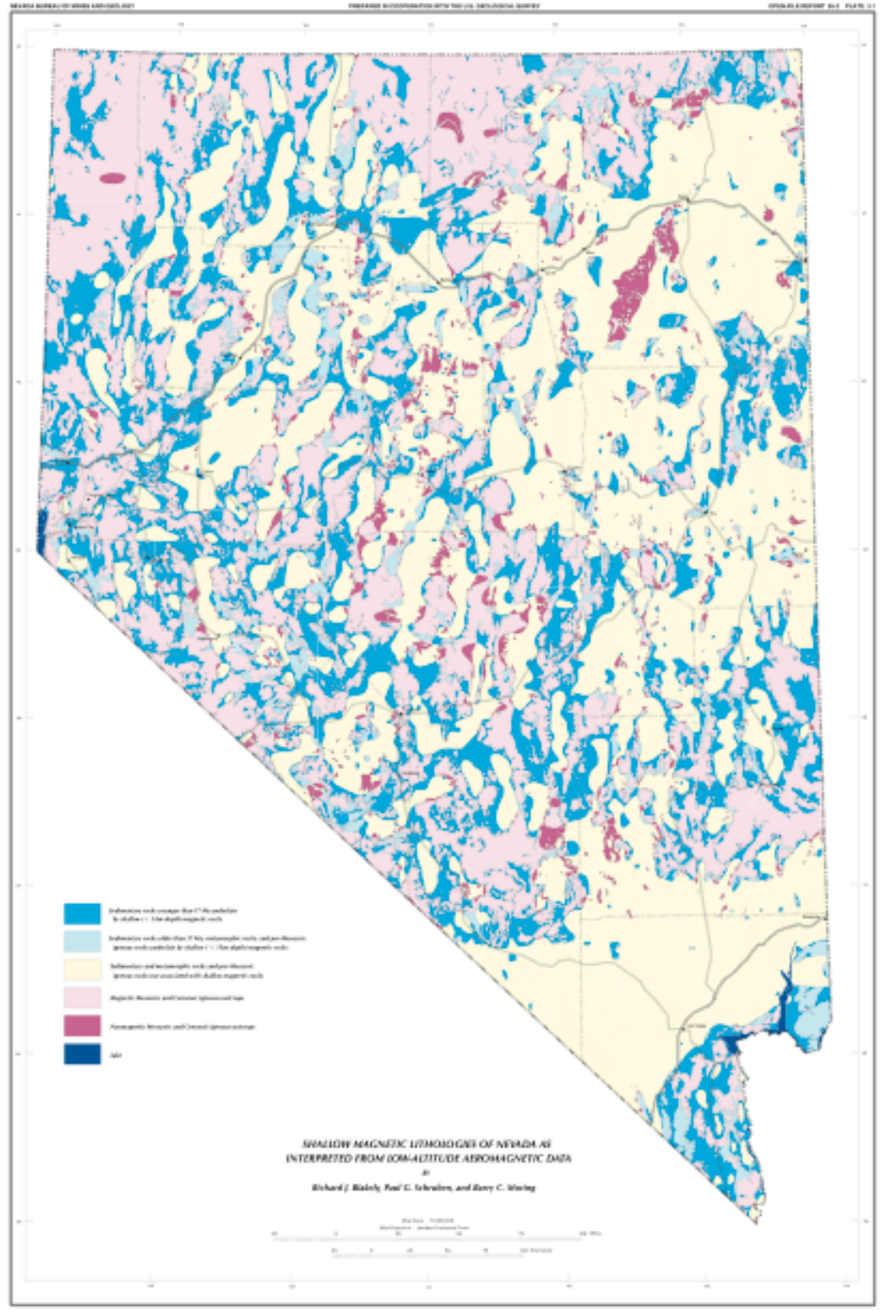
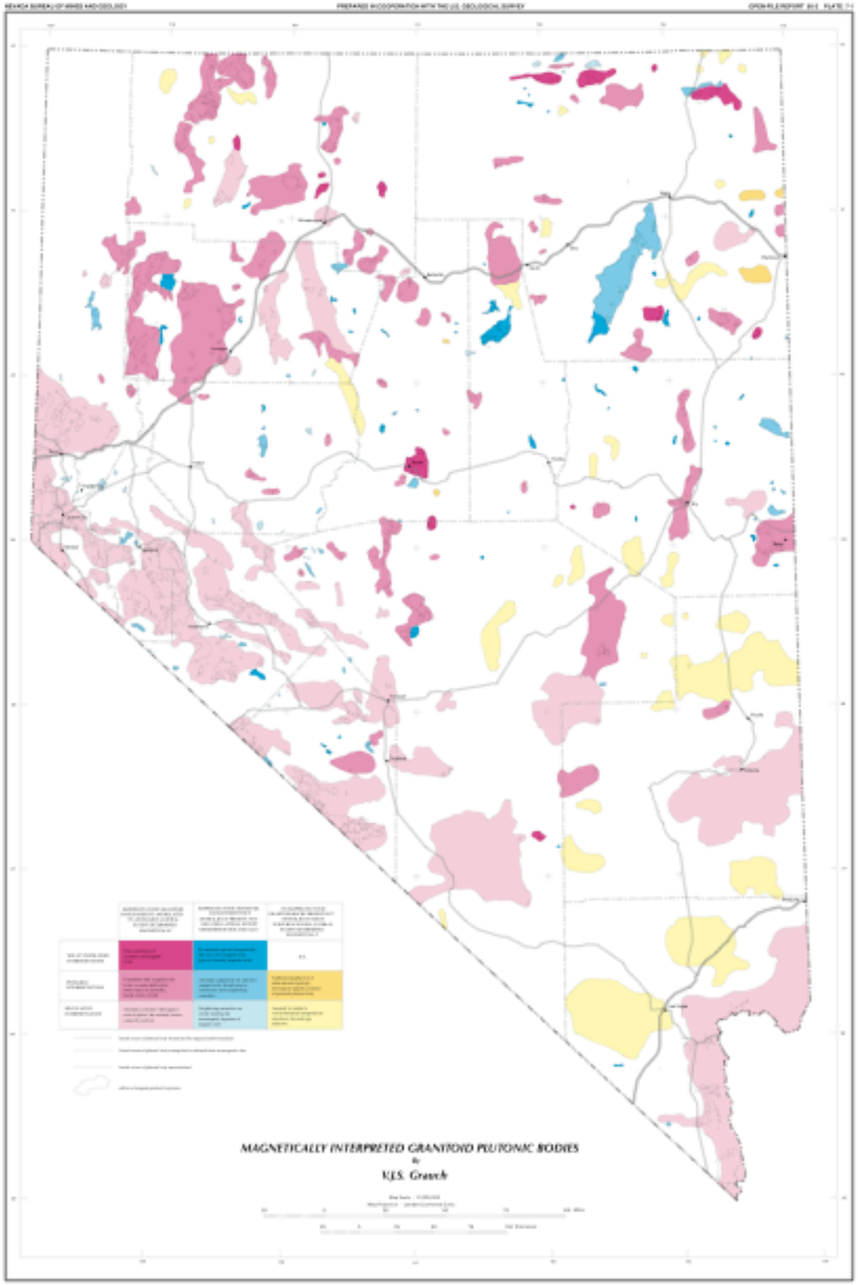
Shallow Intrusives Determined by Aeromagnetics (Blakely et al., 1996)



Magnetically Interpreted Granitoid Plutons in Nevada (V.J. Grauch)



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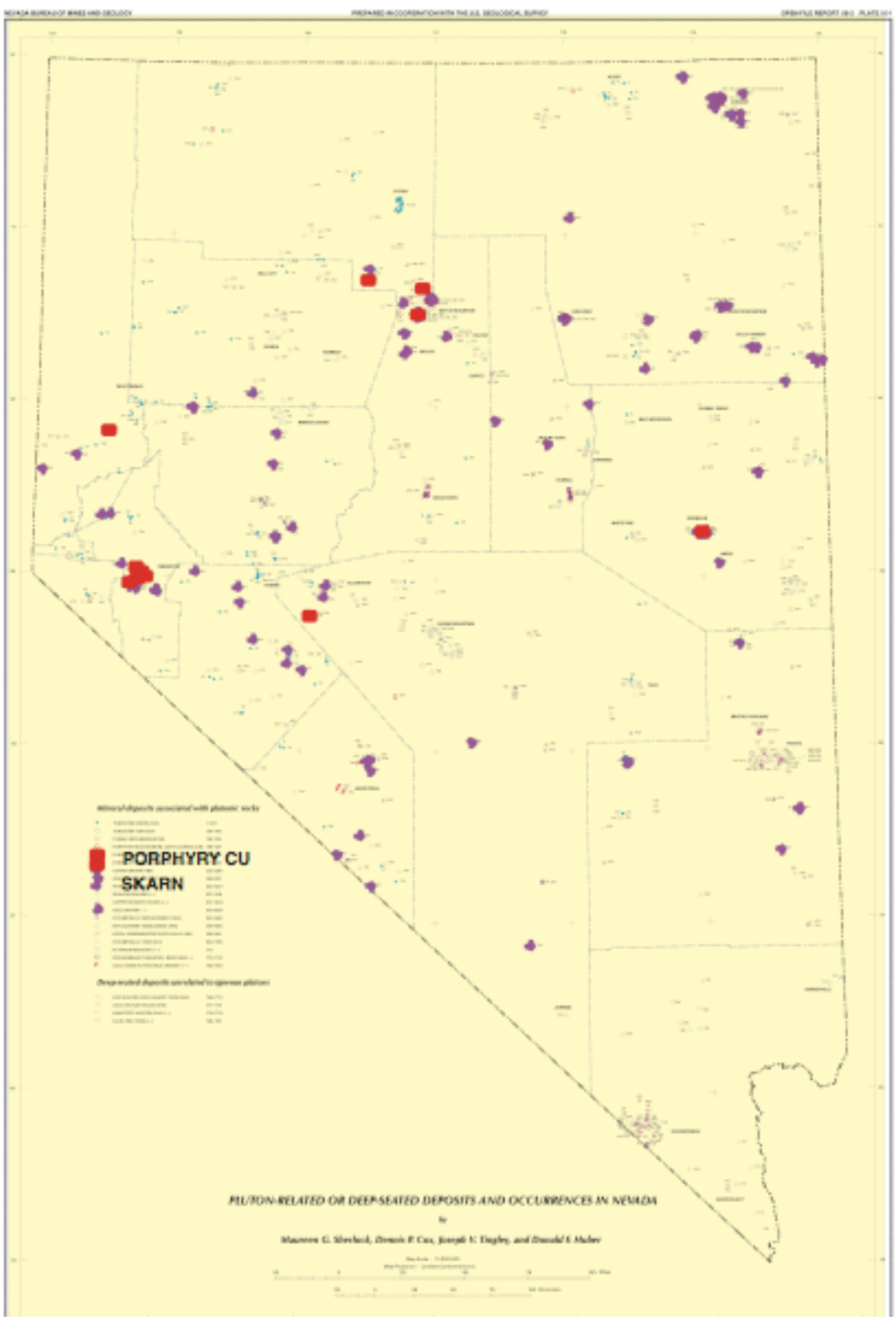
Porphyry Cu Deposits and Other Deposits and Occurrences in Nevada (Sherlock et al.,1996)



Porphyry Copper Deposits

- Stockwork, disseminated, and breccia-hosted copper mineralization together with K-silicate alteration that is generally restricted to porphyritic stocks and their immediate wall rocks
- May have parts that contain skarn
- May be derived from, or affected by, supergene processes

Porphyry Copper Tract Delineation

- Porphyry copper deposits form in island and continental volcanic-arc subduction-boundary zones
- Arc widths, from the volcanic front to the back-arc, vary from ≈10 km to ≈200 km
- Deposits are present in narrow as well as broad volcanic arcs and not just along volcanic front
- Deposits are localized by strike-slip and related faults within volcano-plutonic arc complexes
- Broad volcanic arcs formed at approximately the same time are the fundamental unit for delineation of tracts permissive for porphyry copper deposits
- Permissive tracts are outlined along borders of magmatic arcs with modifications on the basis of deposit ages and distributions of major structures

Singer et al, 2005

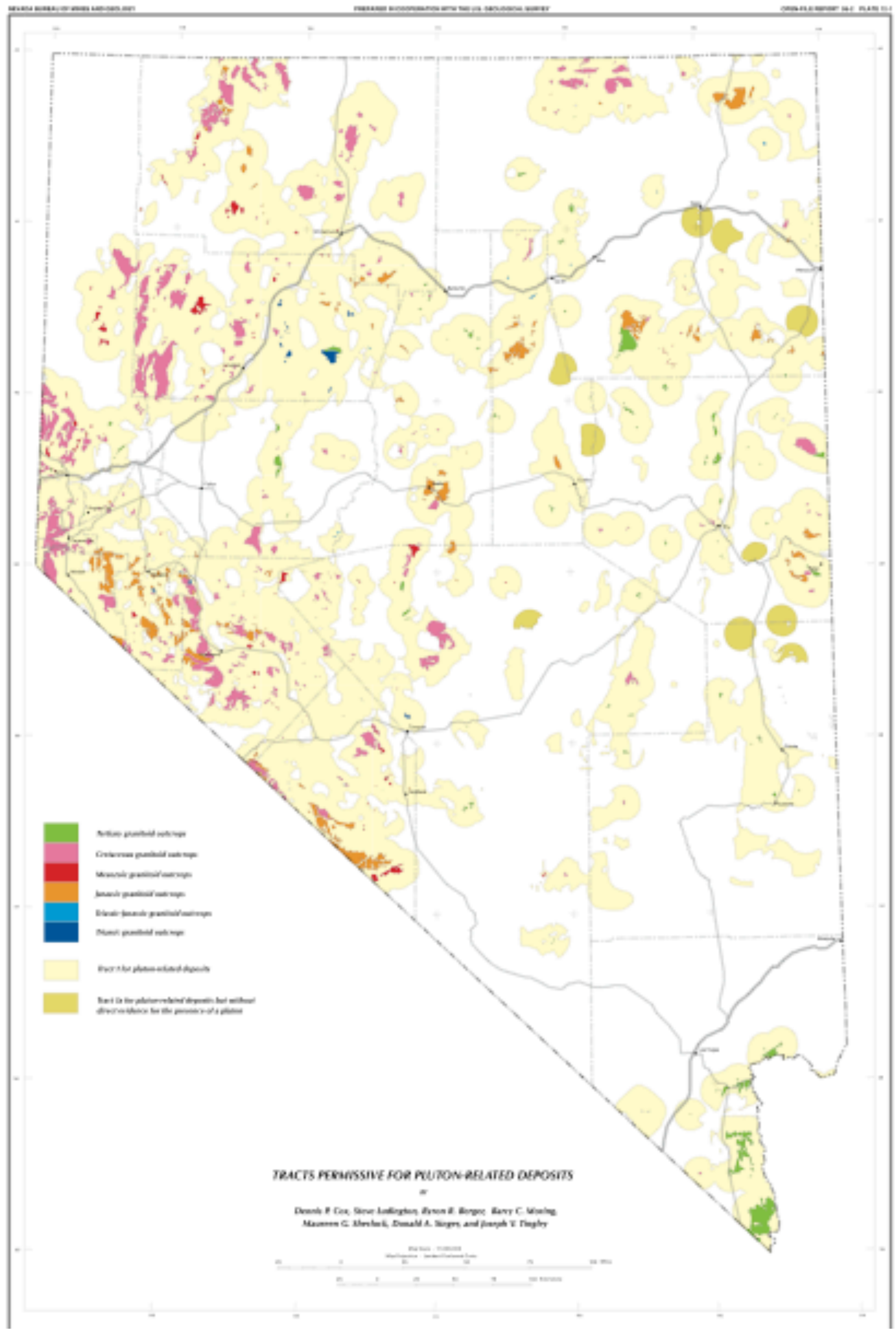
Delineate Tracts Permissive for Porphyry Copper Deposits

- **Because of tendency for different types of pluton-related deposits to occur together and because of statewide scale (1:1,000,000) only one permissive tract was delineated (tract 1)**
- **Tract is defined as extending 10 km outward from outcrop of a pluton, or, where pluton has geophysical expression (see Grauch (1996), from inferred subsurface pluton boundary based on its geophysical expression. Also includes areas around plutons inferred from geophysics (Grauch, 1996) or from occurrence of skarn mineralization (Sherlock et al., 1996)**

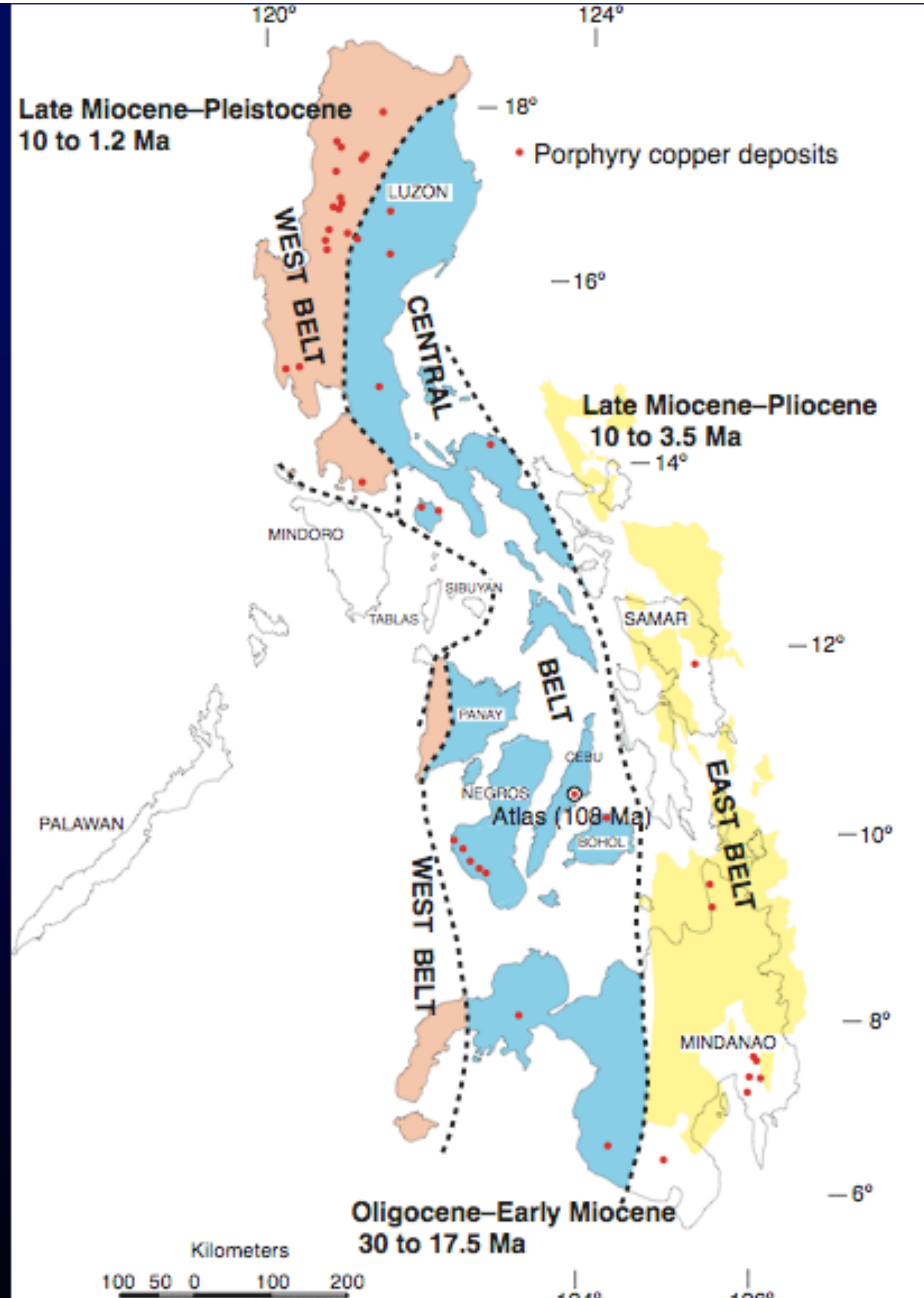
Delineate Tracts Permissive for Porphyry Copper Deposits

- Some pluton-related deposit types such as skarns are known to occur less than 10 km from the pluton contact; however, could not portray a more appropriate boundary at the published map scales
- Porphyry copper deposits in Nevada are typically related to porphyritic granitoids belonging to Ishihara's magnetite-series
- Tract covers about 41 percent of the area of the state

Tracts Permissive for Pluton-related Deposits in Nevada (Cox et al., 1996)



Delineation of 3 tracts permissive for porphyry copper deposits in the Philippines



Based on B.R. Berger (in Singer et al) 2005).

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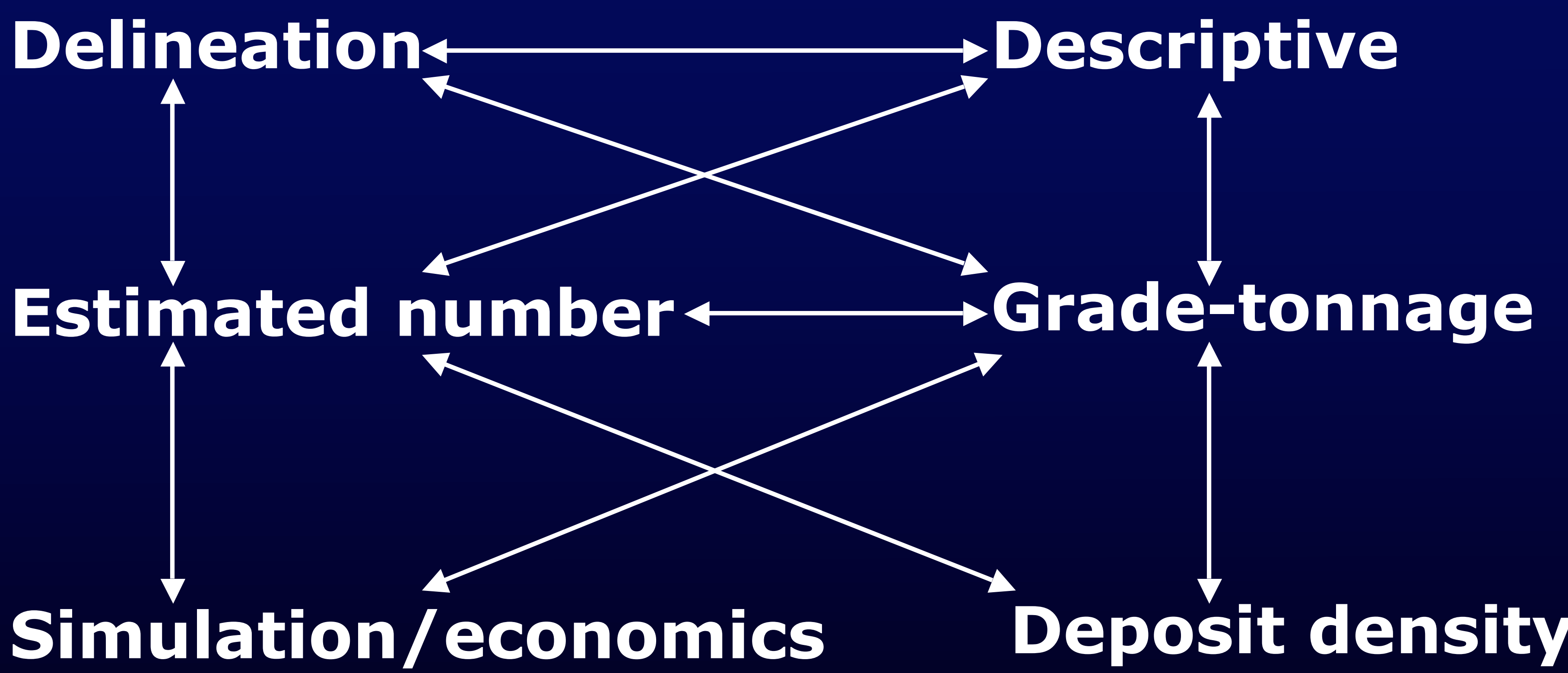
Preventing Biased Quantitative Resource Assessments Requires Consistency



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Research Opportunities—Delineation

- Because much of undiscovered mineral resources are under cover, it is critical to make better maps of geology under cover
- Improve methods of delineation under cover (better links of geology and structure as observed by geophysics to deposit types/sizes)
- Automate delineation (unbiased probabilities)

Selection of Methods to Integrate Information

- Rank of methods that minimize economic loss of misclassification (from best to worst)[1]:
    - Probabilistic neural network
    - Discriminate analysis
    - Logistic regression
    - Weights of evidence

[1] Harris, Zucher, Stanley, Marlow, and Pan, 2003, A comparative analysis of favorability mapping by weights of evidence, probabilistic neural networks, discriminate analysis and logistic regression, Natural Resources Research, v. 12, no. 4, p. 241-255.

Estimating the Number of Undiscovered Mineral Deposits

Estimating Number of Deposits

- The third part of an assessment is estimation of some fixed, but unknown number of deposits of each type that exist in the delineated tracts
- Estimates of number of deposits explicitly represent the probability (or degree of belief) that some fixed but unknown number of undiscovered deposits exist in the delineated tracts
- As such, these estimates reflect both the uncertainty of what may exist and a measure of the favorability of the existence of the deposit type

Estimation

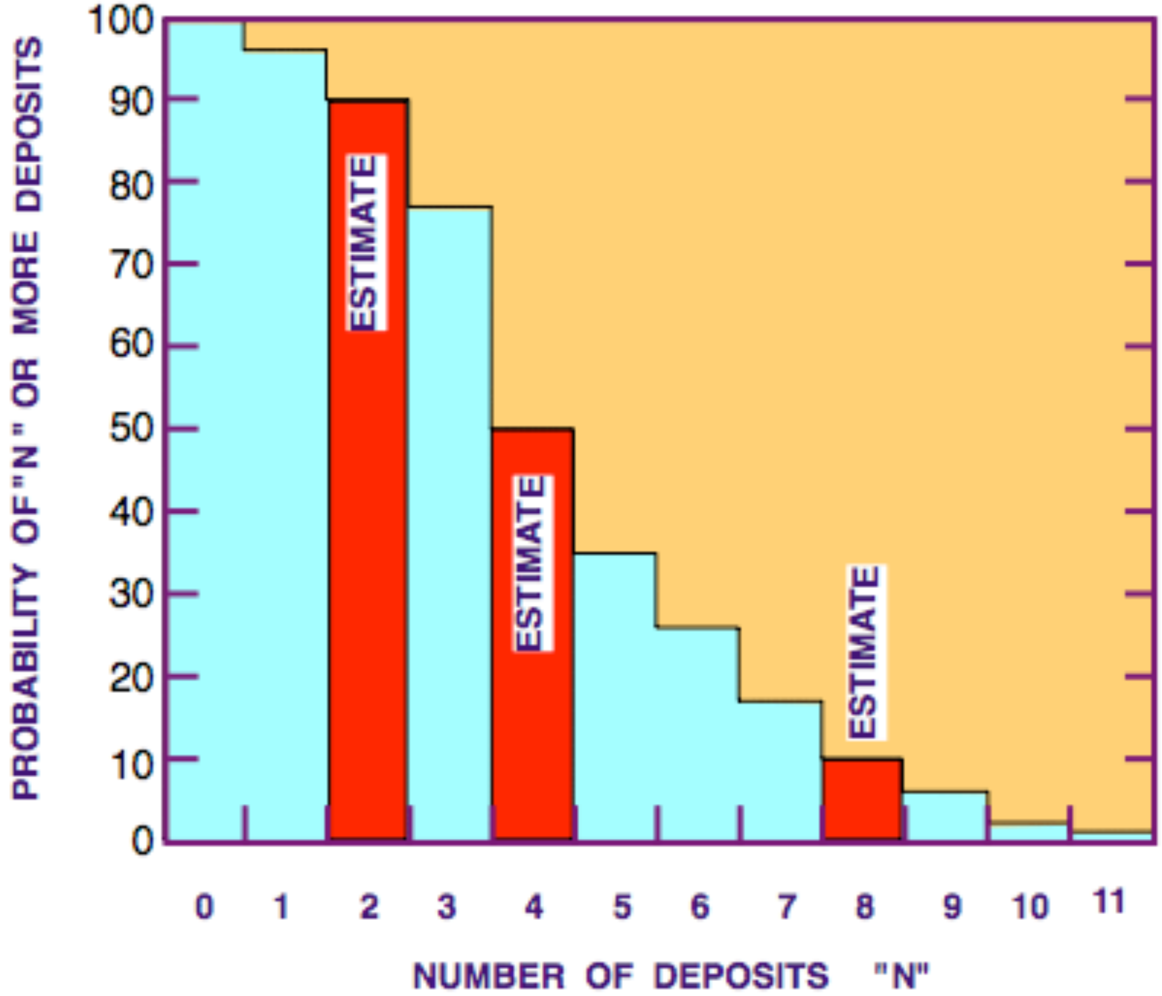
- In practice, a small group of scientists who are knowledgeable about the deposit type (and advised by regional experts) typically make consensus estimates
- Two general strategies tend to be used:

1) Individual occurrences, prospects, and indicators are assigned probabilities and the results combined

2) Estimator uses models of deposit densities in well-explored areas or recalls from experience many other areas that are geologically similar to the area being assessed and are well explored, and uses the proportions of deposits in these other areas to make the estimates for the new area

Estimating Undiscovered Deposits—
the form of the estimates

The relation of number of deposits estimates for probabilities of 0.9, 0.5, and 0.1 to the underlying probability distribution



Three estimates of number of undiscovered deposits with interpolated values.

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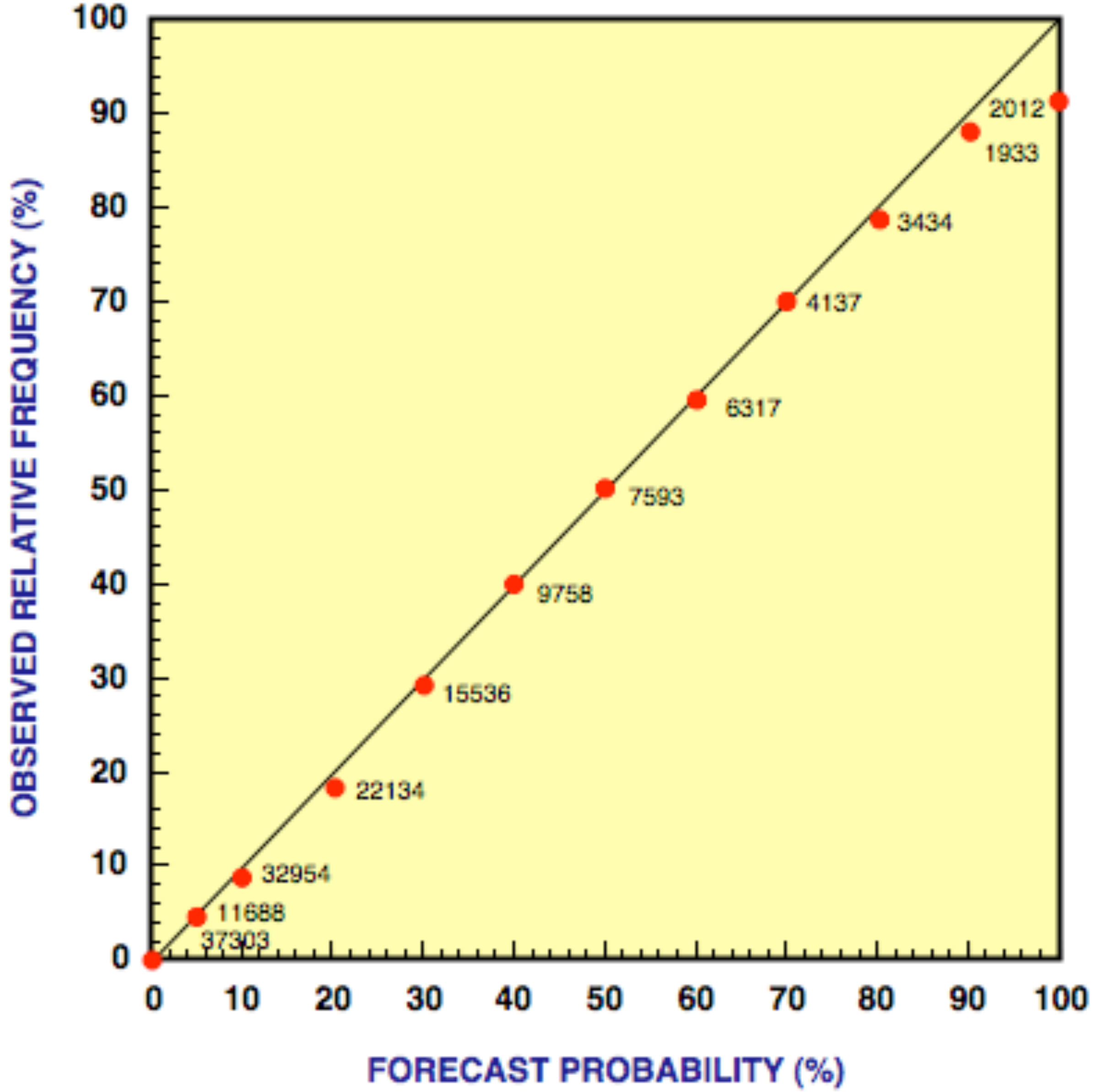
Guides for Estimating Number of Deposits

Goal:

Provide some statistical tools that can act as guides to low variance, unbiased estimates of the number of undiscovered deposits



Comparison of subjectively estimated chance of precipation and observed frequency. Numbers near symbols represent number of estimates. After Murphy and Winkler, 1984.

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Guidelines For Number Of Deposits Estimates

- Grade and tonnage model
- Deposit density models
- Statistical guides–coefficient of variation
- Counting and assigning probabilities to anomalies
- Process constraints
- Relative frequencies of related deposit types
- Area spatial limits
- Total known metal
- Exploration extent and efficiency

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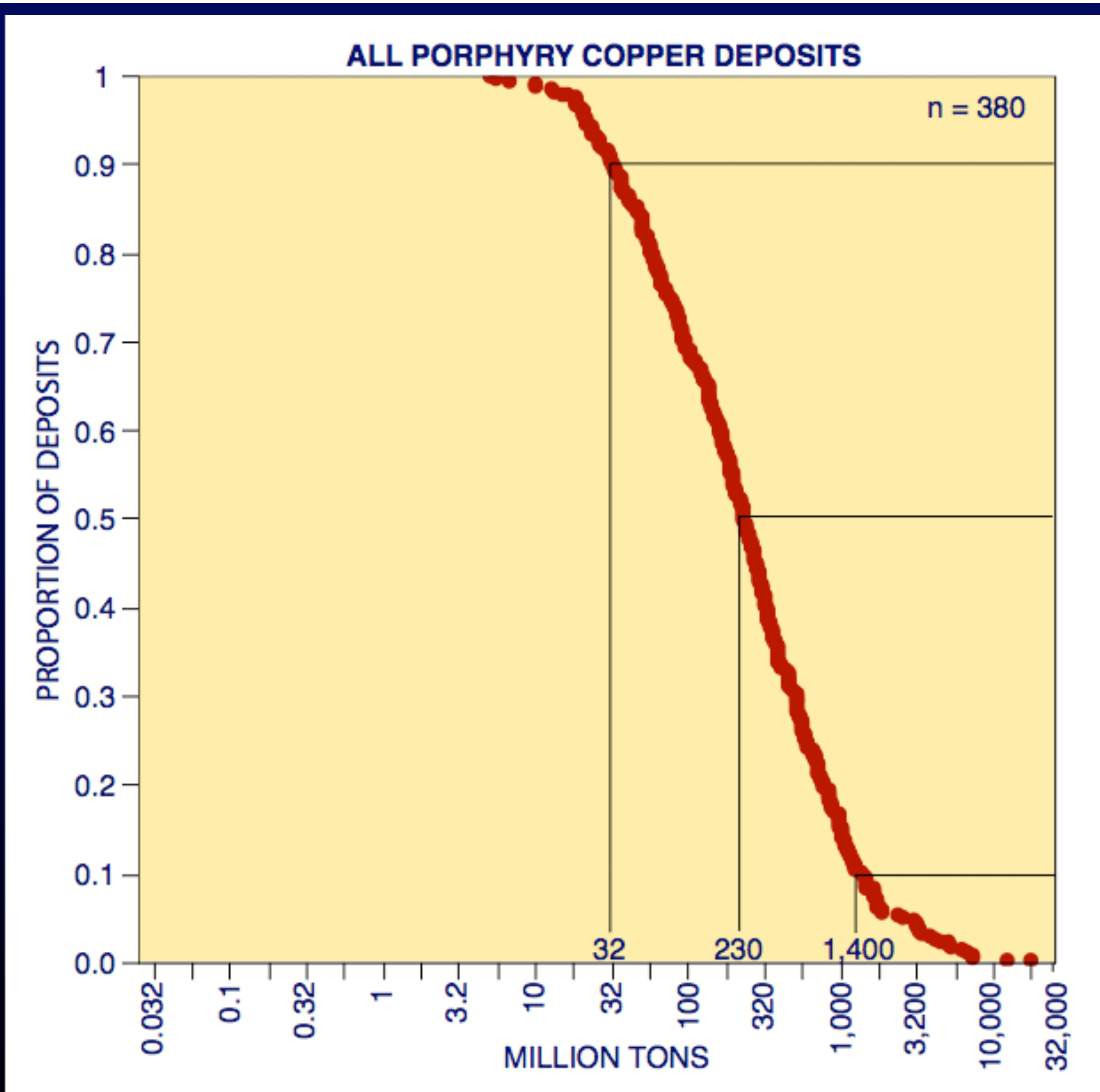
Guideline

Porphyry Copper G-T Model



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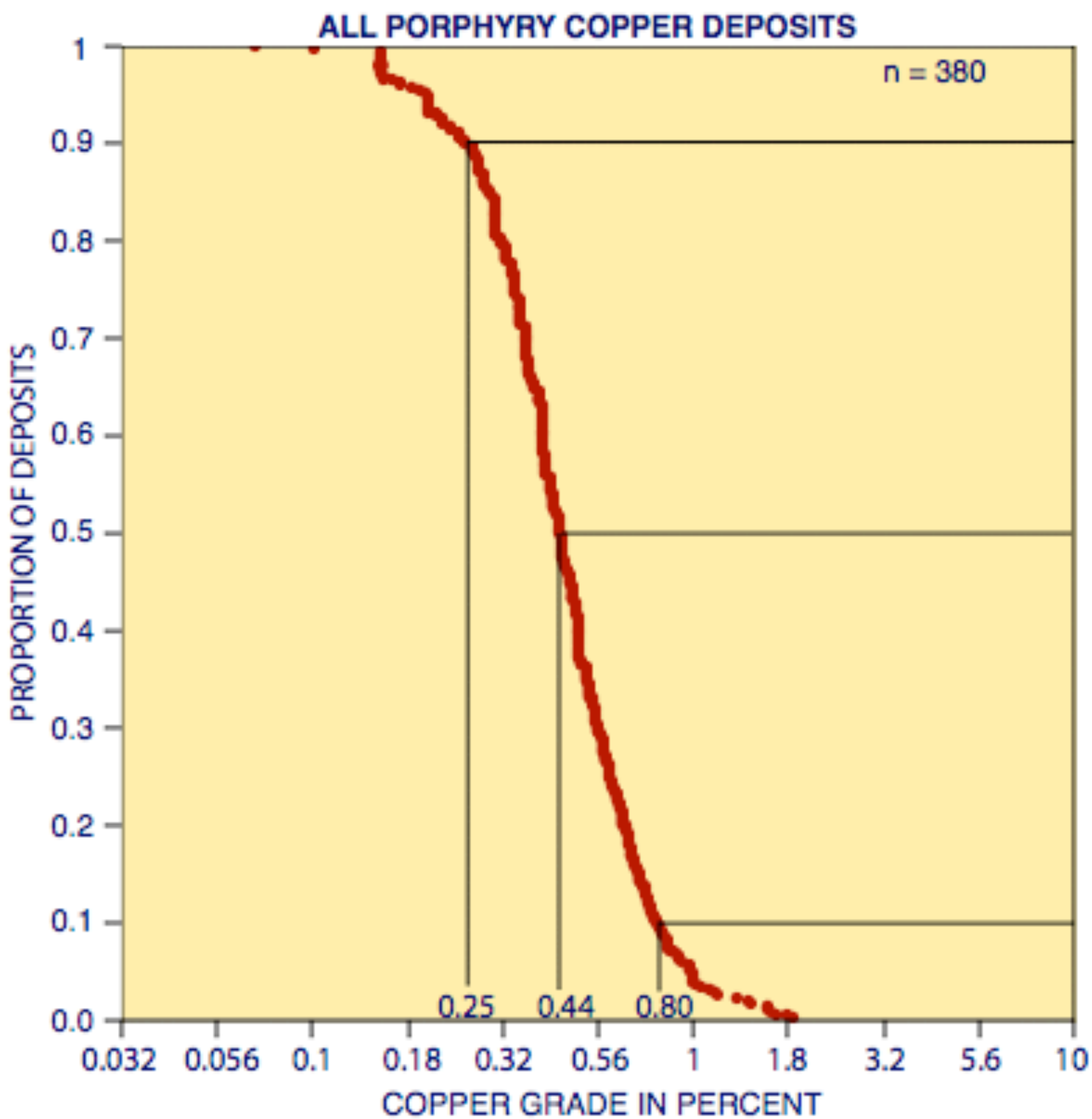
ALL PORPHYRY COPPER DEPOSITS
n = 380
PROPORTION OF DEPOSITS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.25
0.44
0.80
0.032
0.056
0.1
0.18
0.32
0.56
1
1.8
3.2
5.6
10
COPPER GRADE IN PERCENT

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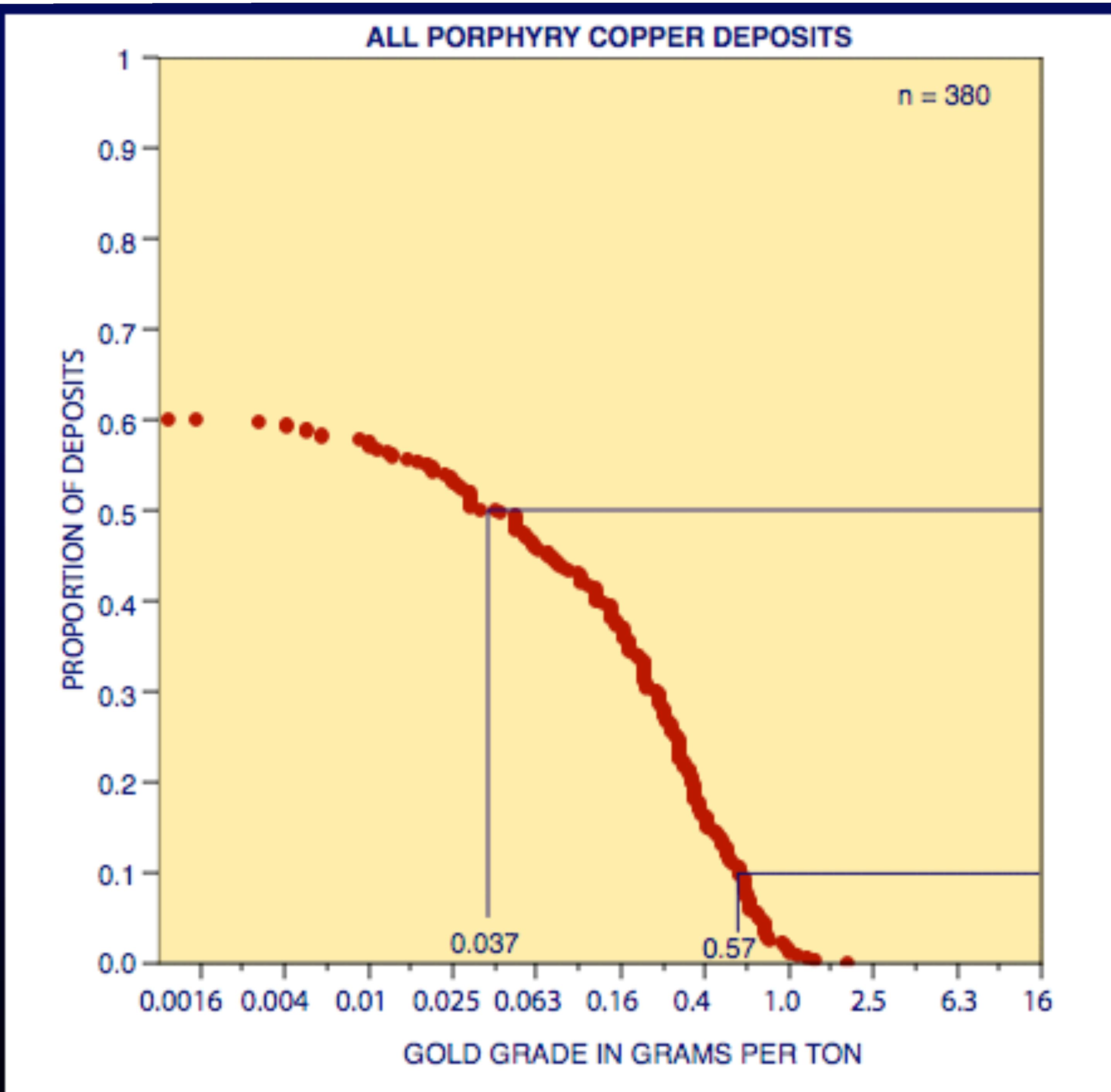

ALL PORPHYRY COPPER DEPOSITS
n = 380
PROPORTION OF DEPOSITS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.037
0.57
0.0016
0.004
0.01
0.025
0.063
0.16
0.4
1.0
2.5
6.3
16
GOLD GRADE IN GRAMS PER TON

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Guideline: Expected Number of Deposits and CV Estimator Based on MARK3

Probabilities of at least

90	50	10	5	1	*Expected (mean) number of deposits, λ	**Standard deviation, Sx	Coefficient of Variation, C_{ν} = $(Sx/\lambda)x100$
0	0	1	1	1	**0.30**	**0.50**	**167**
1	3	7	7	7	**3.53**	**2.26**	**64**
0	0	9	9	9	**2.70**	**3.53**	**131**
10	13	24	24	24	**14.73**	**5.64**	**38**

*λ = 0.233 N90 + 0.4 N50 + 0.225 N10 + 0.045 N05 + 0.03 N01

**Sx = 0.121 - 0.237 N90 - 0.093 N50 + 0.183 N10 + 0.073 N05 + 0.123 N01

Singer and Menzie, 2005

Guideline
Deposit Density Models

Numbers of deposits per unit area from well-explored regions are counted & used as a model

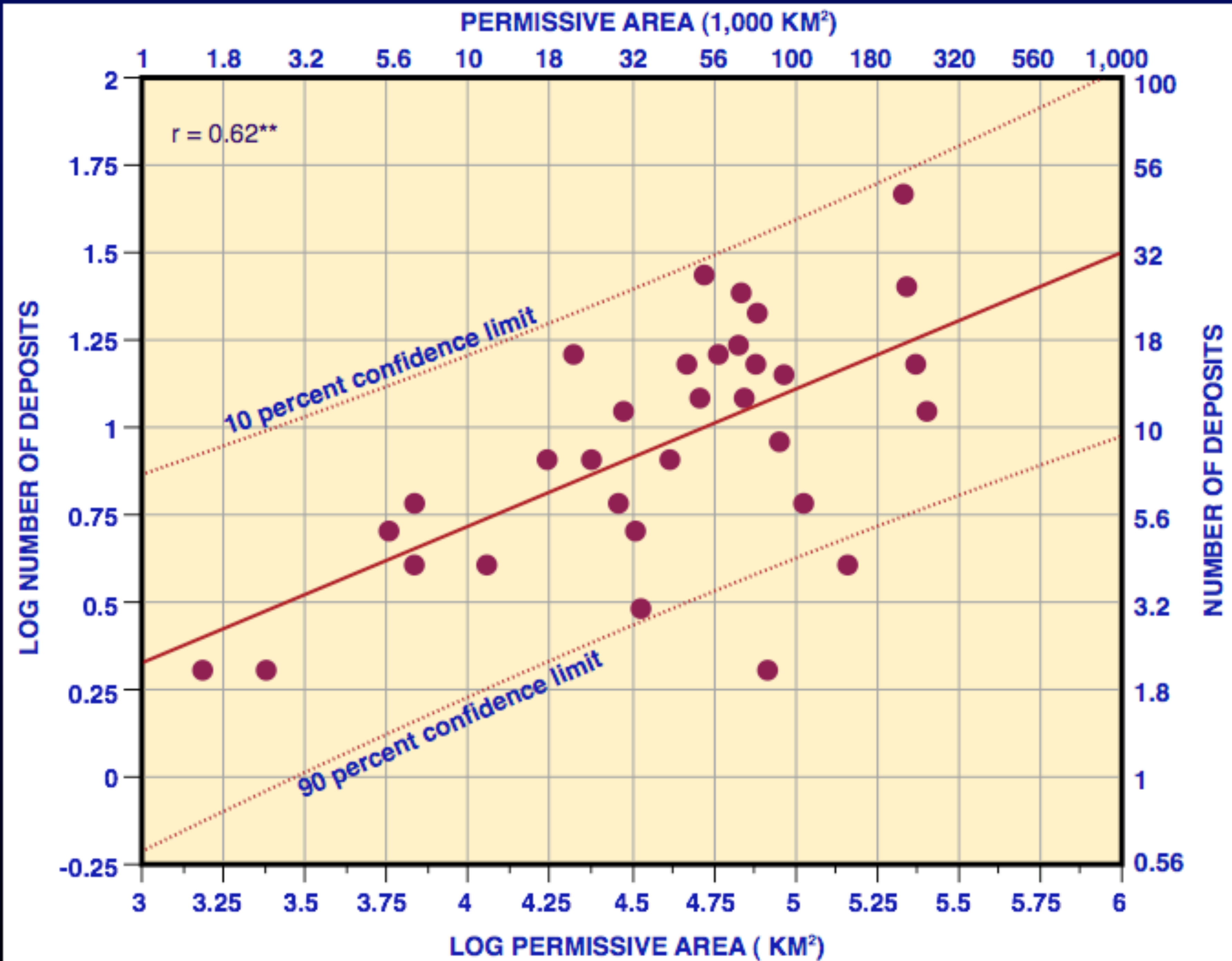
Resulting frequency distribution is either used directly for an estimate or indirectly as a guideline in some other method

The Density–Area Relationship

- Studies of the number of podiform chromite deposits, porphyry copper, and volcanic-hosted massive sulfide deposits show that deposit density (D/A) is related to the size of permissive tracts (A)

- The relationships can be used to make probabilistic estimates of number of deposits

Porphyry Copper



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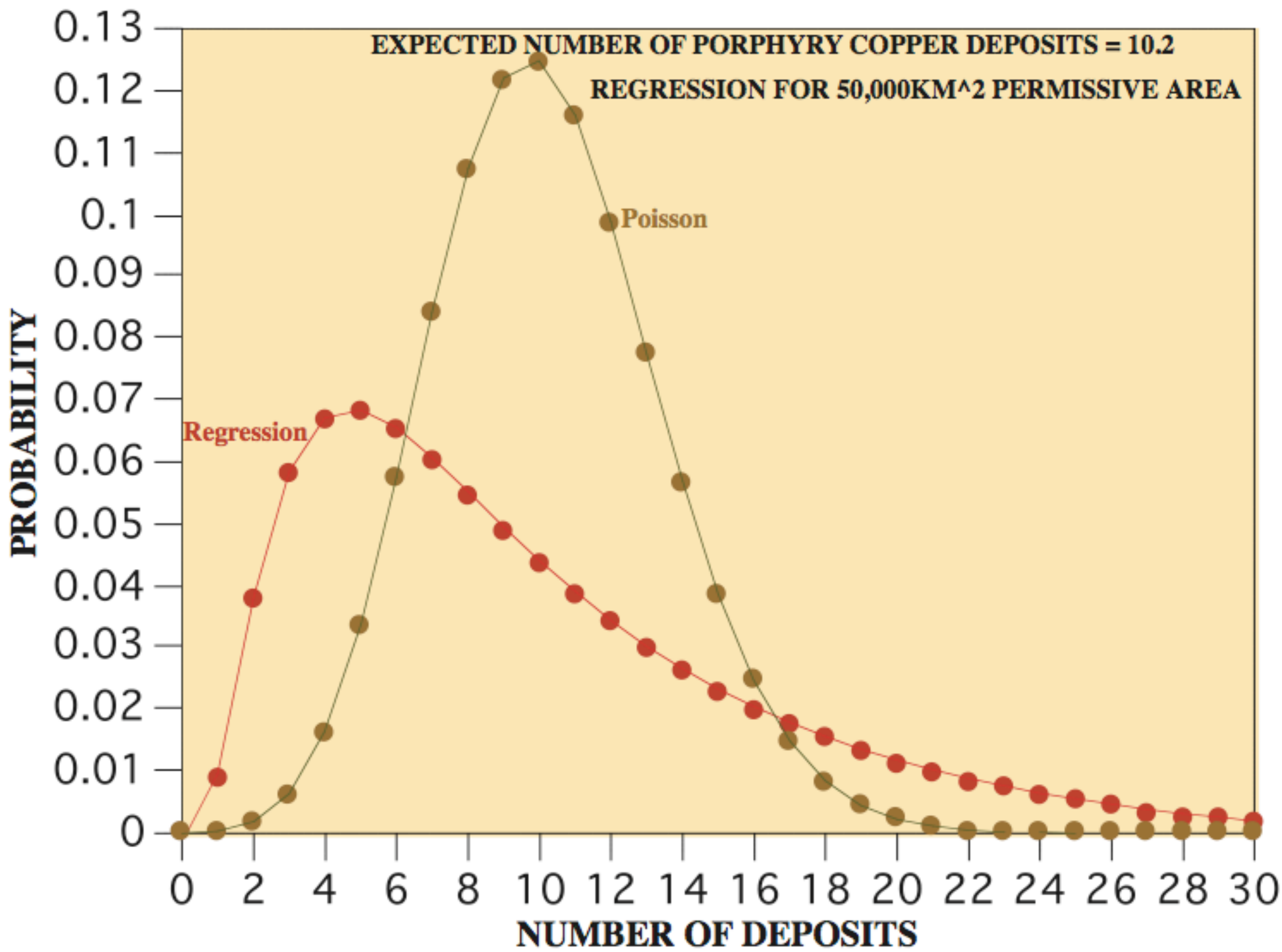
Expected Number (λ) Derived From Regression Equation Is Used Here As Estimate of Expected Number in Alternative Guides

For example:

In a Poisson distribution, the probability of a number of deposits (x) can be estimated by:

$$P(x, \lambda) = \lambda^{x} \exp\{ \lambda \} / x!$$

Where λ is the expected number of deposits. The standard deviation is $\sqrt{\lambda}$


EXPECTED NUMBER OF PORPHYRY COPPER DEPOSITS = 10.2
REGRESSION FOR 50,000KM^2 PERMISSIVE AREA
PROBABILITY
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Regression
Poisson
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
NUMBER OF DEPOSITS

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Two Alternative Estimators

If a **negative binomial distribution** is appropriate, the probability of a particular number of deposits (x) is estimated by:

$Nb(x,p,k) = \{(x+k-1)!/(k-1)!\ x!\}\ p^k(1-p)^x$

Where p = probability, k=parameter. Expected number of deposits (λ) is k(1-p)/p, standard deviation is $\sqrt{(k(1-p)/p^2)}$.

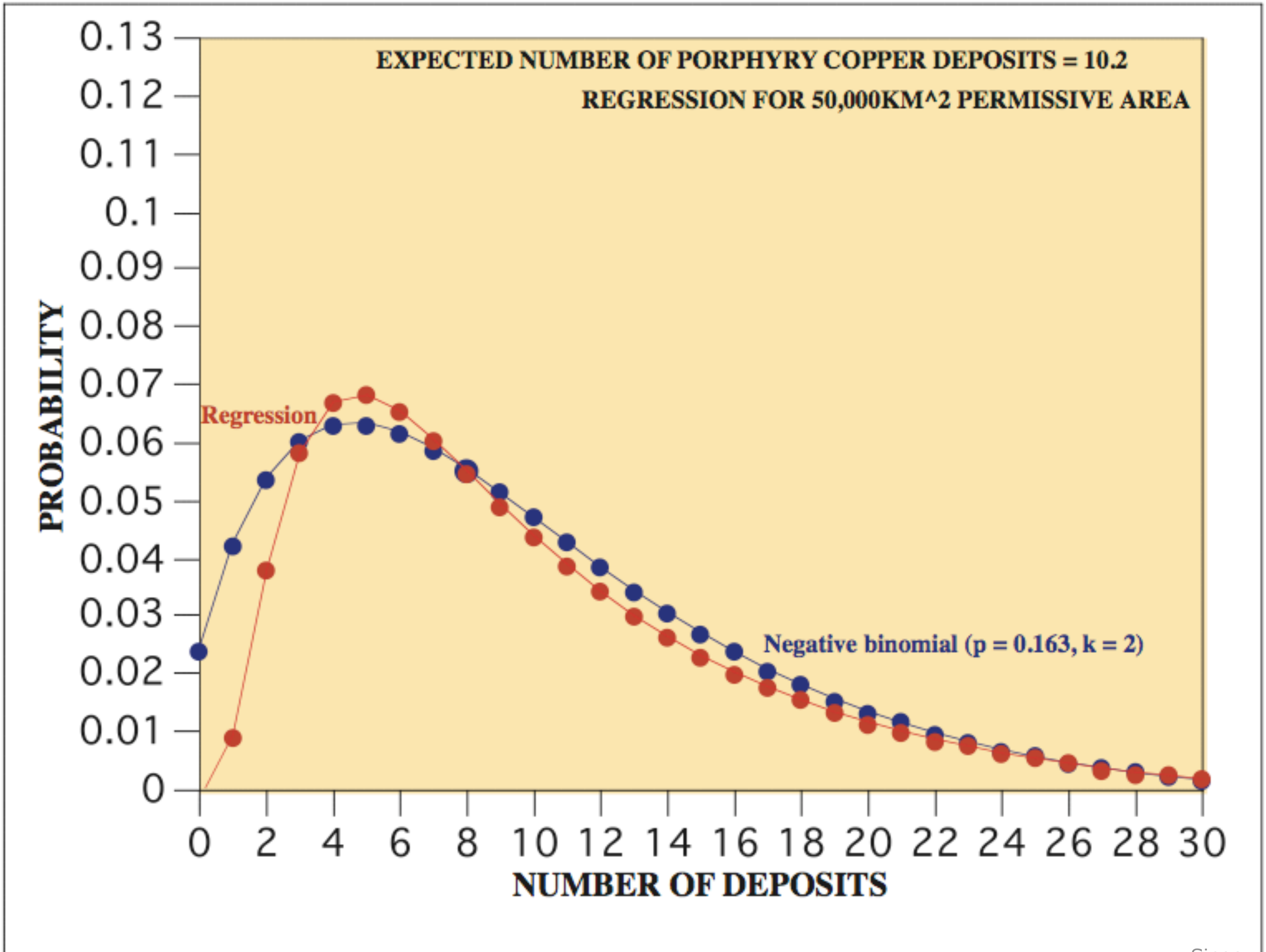
A distribution free method, **MARK3**, where expected number of deposits (λ) and standard deviation (s_x) for MARK3 generated distributions are:

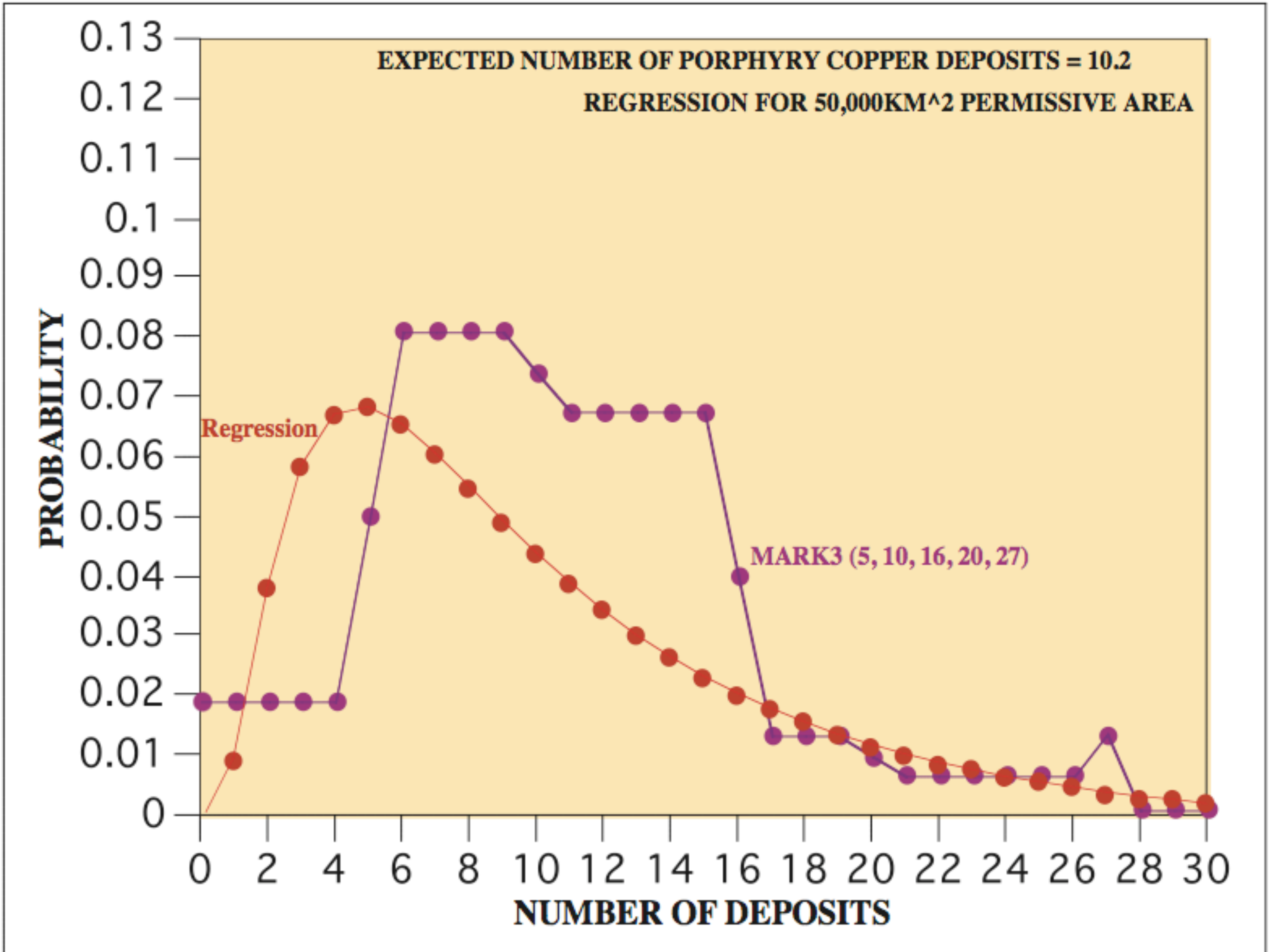
$$\lambda = 0.233N_{90}+0.4N_{50} + 0.225N_{10} +0.045N_{05} + 0.03N_{01}$$

$$s_x= 0.121-0.237N_{90}-0.093N_{50}+0.183N_{10}+0.073N_{05}+0.123N_{01}$$

and N_z is estimated number of deposits associated with z^{th} quantile.

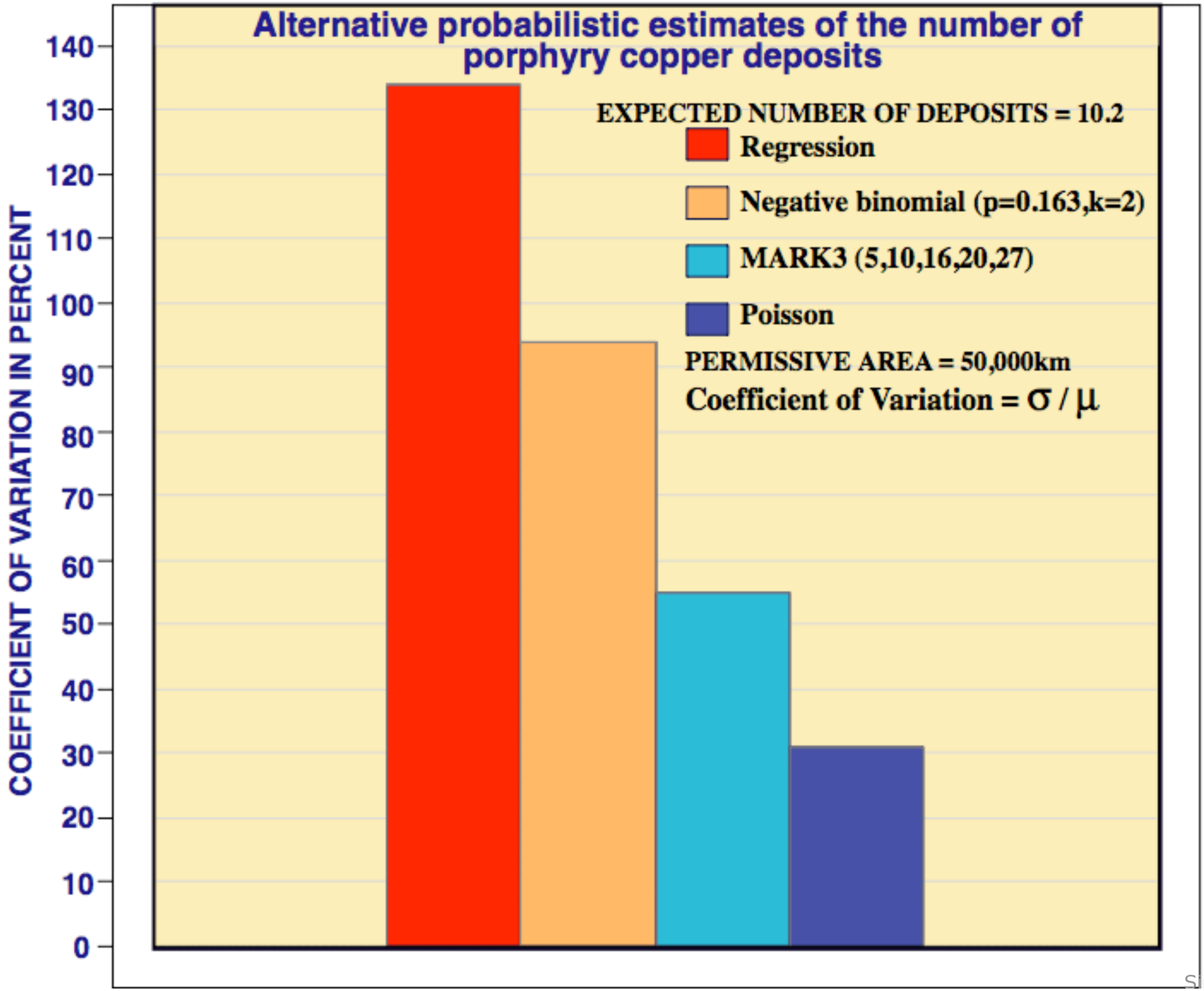
Singer and Menzie, 2005


EXPECTED NUMBER OF PORPHYRY COPPER DEPOSITS = 10.2
REGRESSION FOR 50,000KM^2 PERMISSIVE AREA
Regression
Negative binomial (p = 0.163, k = 2)
PROBABILITY
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
NUMBER OF DEPOSITS
Singer



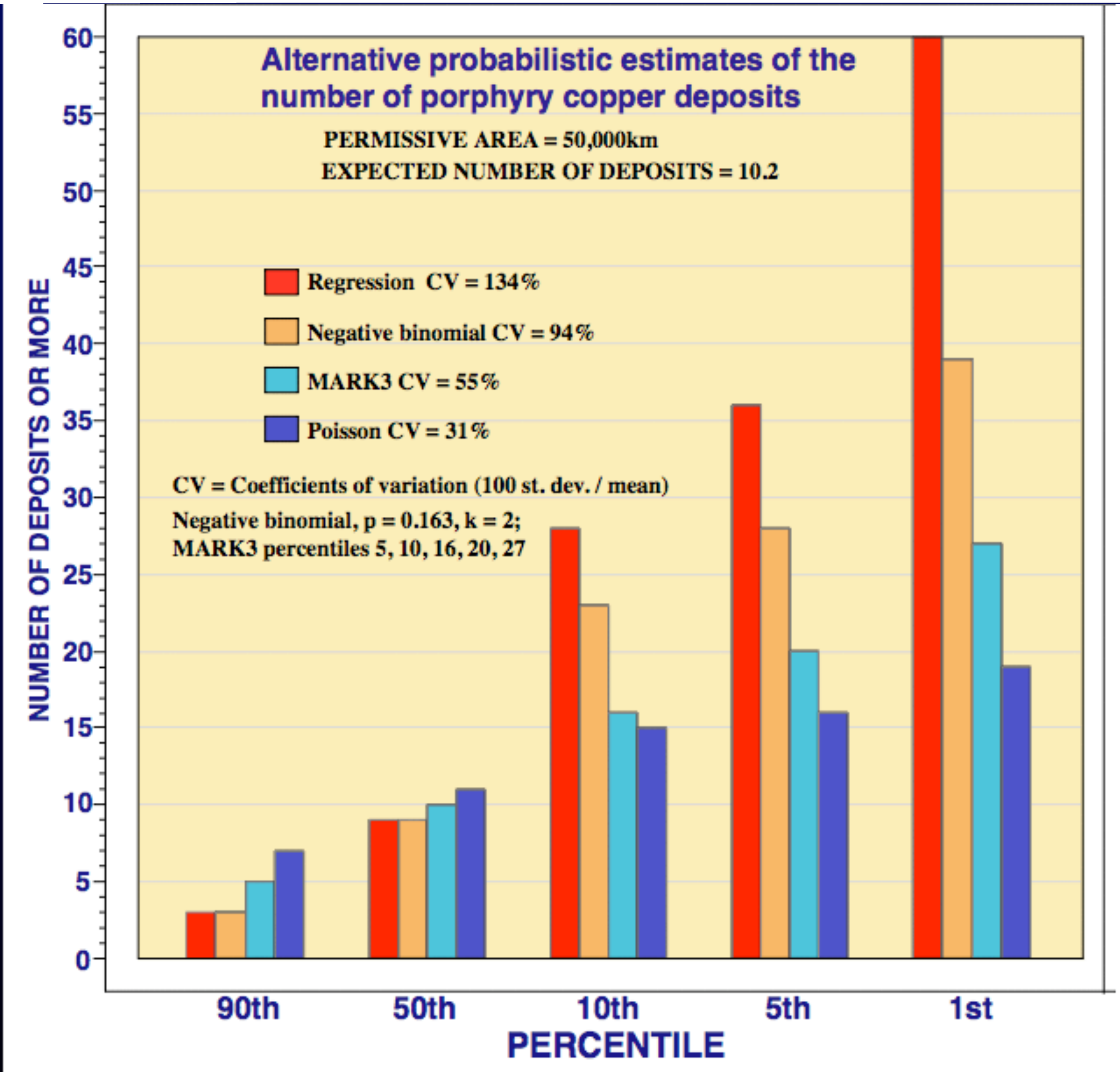
EXPECTED NUMBER OF PORPHYRY COPPER DEPOSITS = 10.2
REGRESSION FOR 50,000KM^2 PERMISSIVE AREA
PROBABILITY
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Regression
MARK3 (5, 10, 16, 20, 27)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
NUMBER OF DEPOSITS

Singer

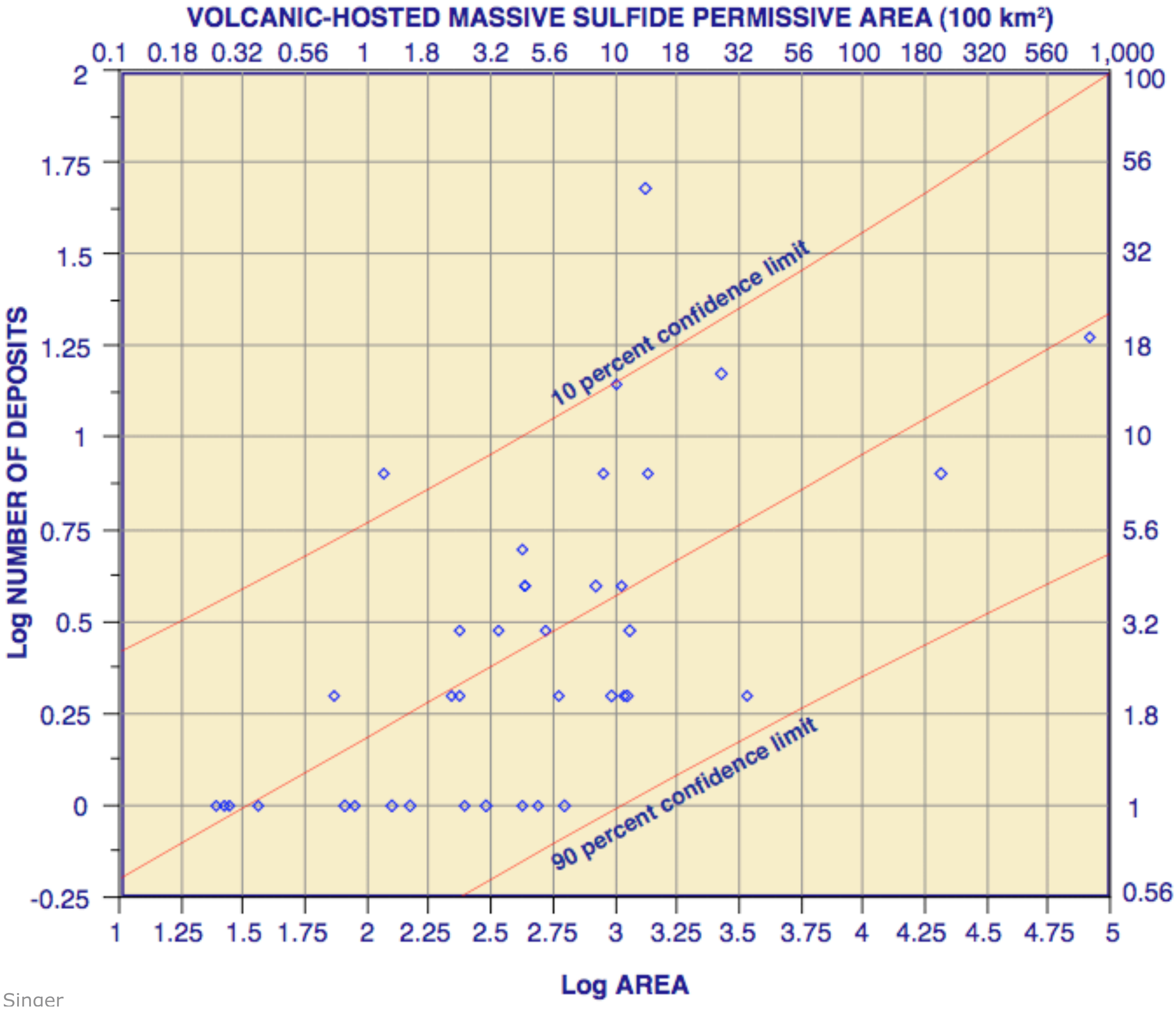


Alternative probabilistic estimates of the number of porphyry copper deposits
EXPECTED NUMBER OF DEPOSITS = 10.2
Regression
Negative binomial (p=0.163,k=2)
MARK3 (5,10,16,20,27)
Poisson
PERMISSIVE AREA = 50,000km
Coefficient of Variation = σ / μ
COEFFICIENT OF VARIATION IN PERCENT
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140

Singer


Alternative probabilistic estimates of the number of porphyry copper deposits
PERMISSIVE AREA = 50,000km
EXPECTED NUMBER OF DEPOSITS = 10.2
Regression CV = 134%
Negative binomial CV = 94%
MARK3 CV = 55%
Poisson CV = 31%
CV = Coefficients of variation (100 st. dev. / mean)
Negative binomial, p = 0.163, k = 2;
MARK3 percentiles 5, 10, 16, 20, 27
NUMBER OF DEPOSITS OR MORE
0
5
10
15
20
25
30
35
40
45
50
55
60
90th
50th
10th
5th
1st
PERCENTILE

Singer



Volcanic-hosted MS

Mosier et al., 2007

Singer

Example: Use of VMS Density Estimates

In USGS National Assessment (USGS, 1996) covered Tract LS04 (22,900 km^2)in Michigan was estimated at the 90th, 50th, and 10th percentiles, to have 30, 65, and 85, or more kuroko massive sulfide deposits for an expected number of 58 and a Coefficient of Variation (CV) of 33%

Using VMS deposit densities, the estimates would be 3, 12, and 48 for an expected number of 14 and a Coefficient of Variation of 134%

Poisson distribution estimates would be 10, 15, and 20 with a CV of 27%

Thus the National Assessment estimates are four times larger and the low CV suggests much more information about undiscovered deposits under cover than seems justified

Estimation

- Estimation of number of undiscovered deposits primarily guided by grade-tonnage model
- Another guide, deposit density, uses linear regression and associated confidence limits
- Poisson distribution with same mean leads to estimates having lower CV & implies no deposit clustering
- Coefficient of Variation used to explore estimates between these two extremes using either negative binomial or MARK3 emulator & imply deposit clustering
- These guides allow simple yet robust estimation of number of undiscovered deposits in exposed or covered permissive terranes

Number of Deposit Estimation

- Permissive areas frequently covered, need to make estimates not based only on prospects
- Estimates not main source of error, but source of concern by geologists
- Estimates typically made by expert judgment
- No evidence of bias in subjective estimates in meteorology, best estimates after machine guidance

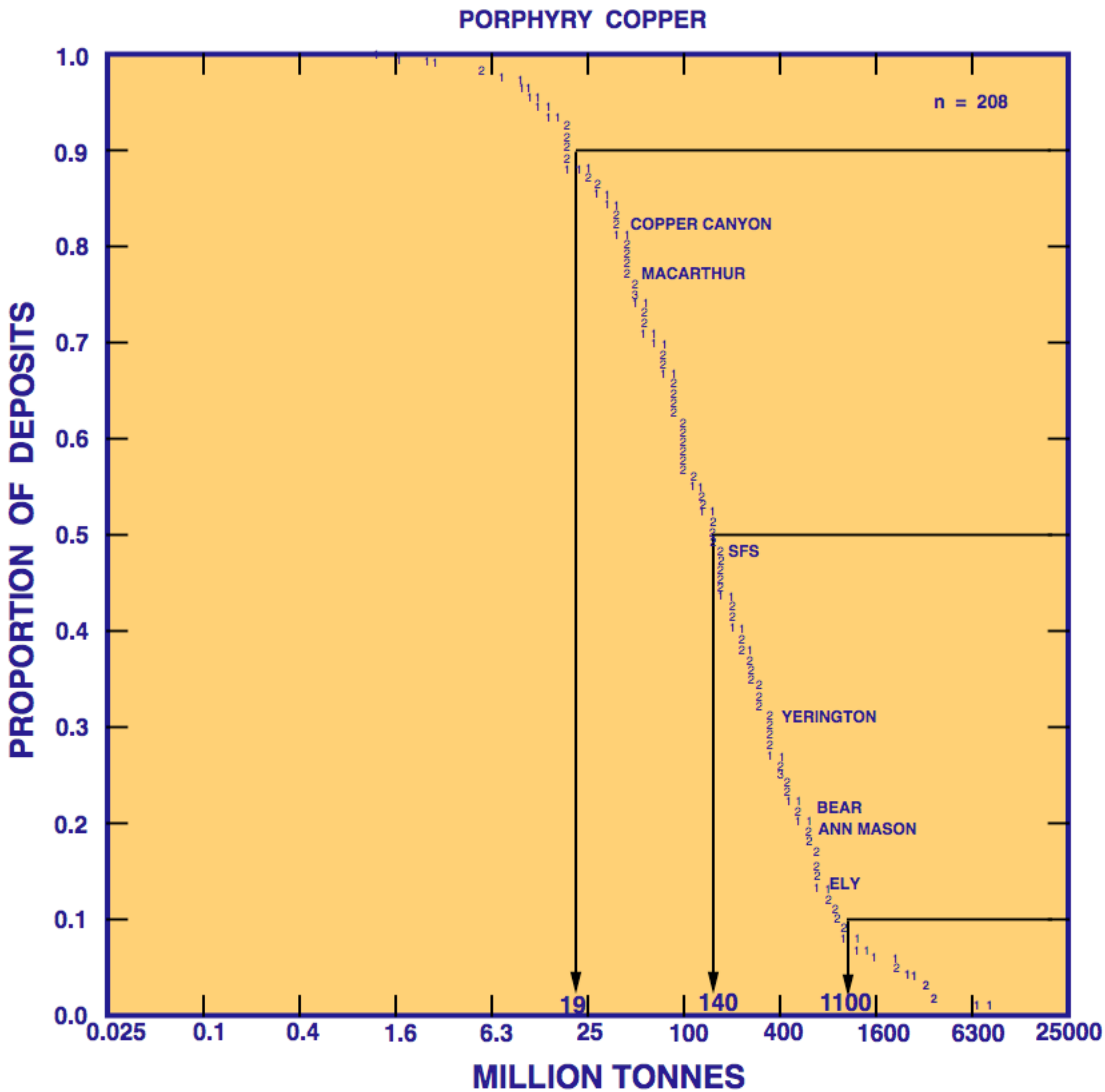
Appropriate Grade and Tonnage Model?

Is a Local Model Needed?

- It is sometimes believed that local deposits represent a special subtype or new type because they are almost never exactly the same as the "typical" deposit in every respect
- Sometimes the global model is accepted without considering whether it is appropriate
- There are two dangers in these two approaches:
  - Every deposit is considered to be unique and therefore prediction is not possible
  - A local model may be necessary to provide unbiased estimates of grades and tonnages of the undiscovered deposits
- To avoid both dangers, well-explored deposits in the local area should be tested to see if they are statistically different from the general model

Visually checking grade – tonnage model
(1992-96)

Singer

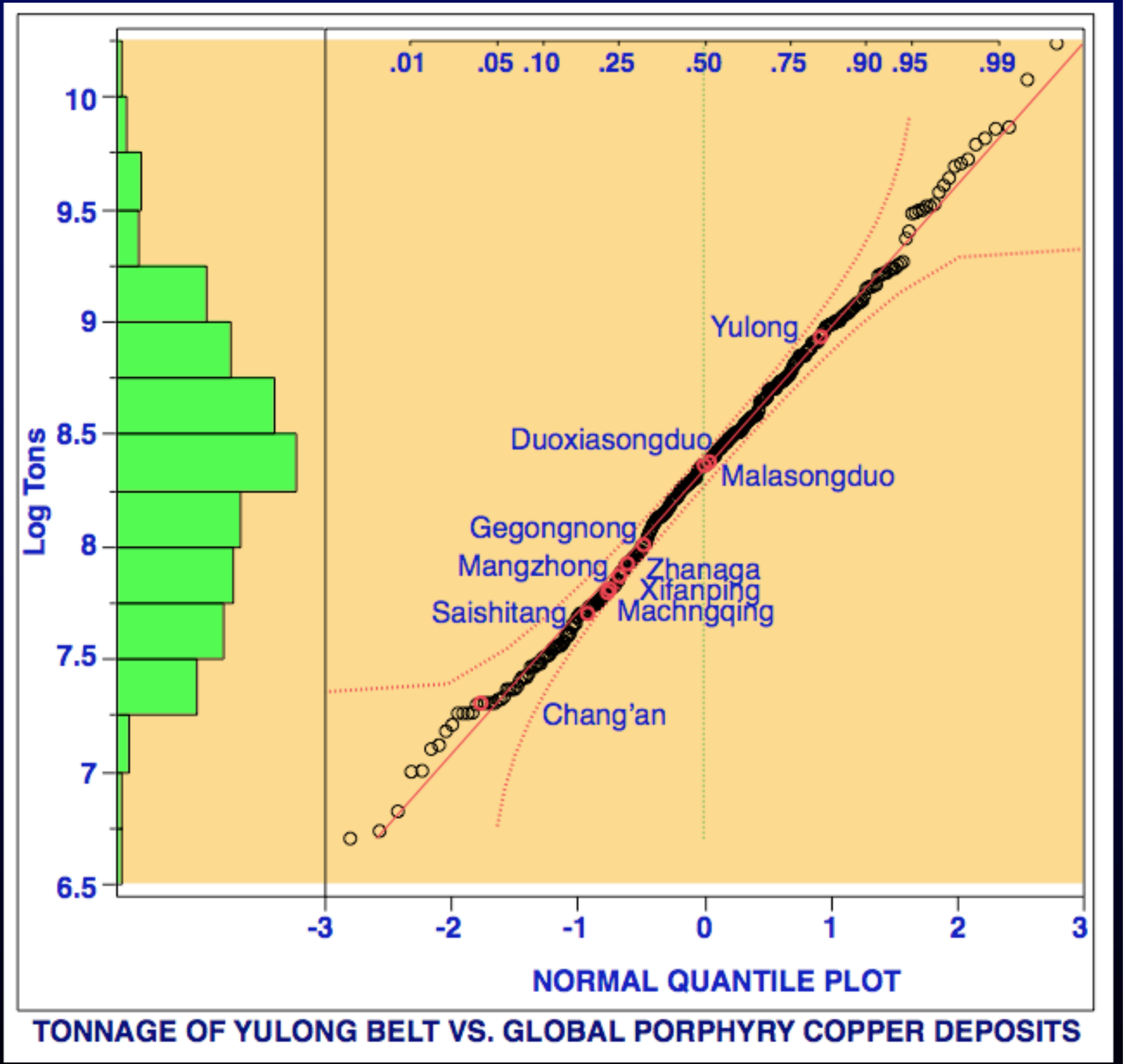


--Comparison of tonnages of known porphyry copper deposits in Nevada and poyphyry copper deposit model (1996).

Deposits for Testing

- Common mistake is using all mineral occurrence & deposit data for region
- Only well-explored (3-D) deposits that meet spatial combinations rules for the deposit type should be tested
- These deposits are typically small in number, but require careful documentation—an effort best done with data gathered as part of global mineral deposit model construction

Test of Tonnage of China's Known Yulong belt Porphyry Deposits Against Global Model



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Test of Appropriateness of Global Porphyry Copper Grade and Tonnage Model to China's Yulong Belt Deposits

$$t = (8.3436 - 8.0052) / 0.2021 = 1.67$$

381 degrees of freedom,

mean tonnage of Yulong deposits = 8.0052,

mean tonnage world = 8.3436, pooled standard error = 0.2021.

The probability of t = 1.67 with 381 df is 0.095.

We conclude that differences as large as seen here between tonnages of porphyry copper deposits in Yulong and world-wide porphyry copper deposits happen by chance alone about 10 percent of the time. Therefore we accept the global model as appropriate for undiscovered Yulong belt porphyry copper deposits of China. Similar results were observed for Cu grades, p = 0.33

For Mo grades, the p = 0.013 (Yulong higher).

Biased Estimates of Number of Deposits

Identifying Biases:

- There are estimation process issues that can point to bias such as the expert not following statistical or logical rules (Meyer and Booker, 2001)
- The most straightforward way to identify bias in estimates of number of deposits is to use the same tools that are available as guidelines for the estimates
- Number of deposit estimates that are inconsistent with the guidelines should at the least raise questions about possible bias

(Meyer, M.A., and Booker, J.M., 2001, Eliciting and analyzing expert judgment: A practical guide: American Statistical Association and Society for Industrial and Applied Mathematics)

Significant Biases Can Be Introduced By:

- **Flawed grade and tonnage models**
- **Lack of consistency of estimated number of deposits with grade and tonnage model**

Example of Biased Estimate:

- In an assessment[1] of epithermal gold vein deposits, 5 or more deposits were estimated at the 90 percent level, but no grade and tonnage model was provided, so these estimated deposits could be any size
- To provide critical information to decision–makers, the grade and tonnage model is key, and the estimated number of deposits that might exist must be from the grade and tonnage frequency distributions

[1]Wilson, F.H., White, W.H., Detterman, R.L., and Case, J.E., 1996, Maps showing the resource assessment of the Port Moller, Stepovak Bay, and Simeonof Island Quadrangles, Alaska Peninsula: U.S. Geological Survey MF 2155-F, 3 pieces, scale 1:250,000

Biased Grade and Tonnage Model

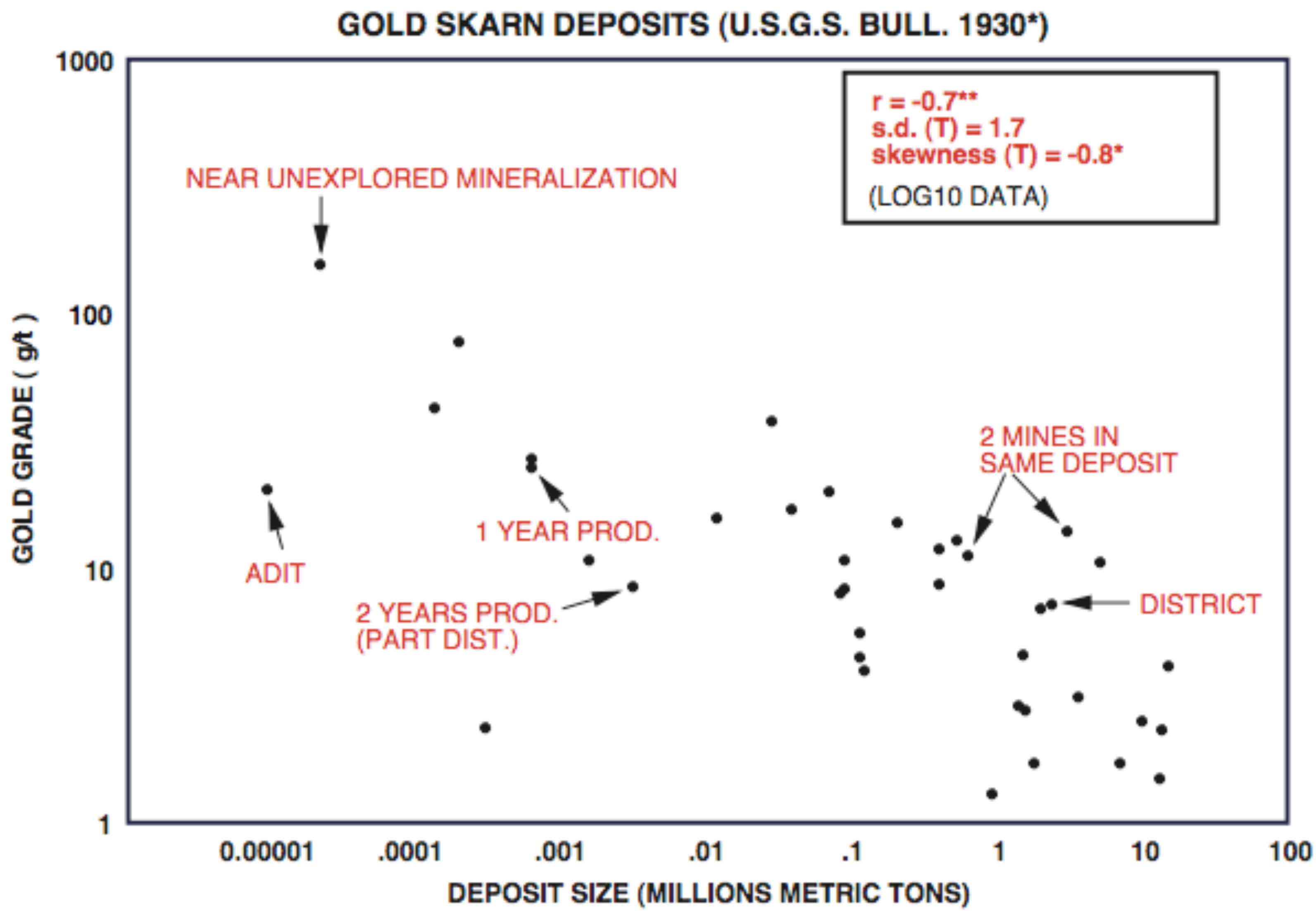

Fig. 4.9--Gold grades versus deposit tonnage for gold skarn deposits used in grade and tonnage model. Data from Theodore and others, 1991.

Singer

Undiscovered Deposits Are From the Same Probability Density Function As the Grade and Tonnage Model

Thus: Implicitly, 5% of gold skarns will be from 2 mines on the same deposit, 2.5% will be from adits, 2.5% from incompletely explored deposits, etc.--Forever!

Example: Not Introducing Biases

- In grade & tonnage models, deposits that are only partially drilled must be counted as prospects and not used
- Phrases such as “open on the west” or “more drilling planned” are used to classify as prospects
- In assessments, such prospects are considered as undiscovered (but with a high probability of being deposits) in order to be consistent with the grade and tonnage models and not introduce known biases

Estimates Of Number Of Undiscovered Kuroko Massive Sulfide Deposits In Medford, Oregon

PARTICIPANTS' ESTIMATES

	A	B	
90 % CHANCE OF AT LEAST	1	27	DEPOSITS
50 % CHANCE OF AT LEAST	2	50	DEPOSITS
10 % CHANCE OF AT LEAST	5	110	DEPOSITS

ESTIMATES BY B REFLECT THE 27 KNOWN KUROKO OCCURRENCES IN THIS 1:250,000 SCALE QUAD.

WHEN PARTICIPANT B WAS ASKED WHETHER HALF OF EACH OF HIS ESTIMATES WOULD BE LARGER THAN THE MEDIAN TONNAGE OF KUROKO DEPOSITS, HE SAID NO AND REVISED HIS ESTIMATE DOWNWARD

ESTIMATES OF THE NUMBER OF UNDISCOVERED HOT-SPRING HG DEPOSITS IN BETHEL, ALASKA

	PARTICIPANTS' ESTIMATES				
	A	B	C	D	
90 PERCENT CHANCE OF AT LEAST	1	1	2	9,000	DEPOSITS
50 PERCENT CHANCE OF AT LEAST	3	2	4	10,000	DEPOSITS
10 PERCENT CHANCE OF AT LEAST	6	6	7	11,000	DEPOSITS

ESTIMATES BY PARTICIPANT D WERE QUITE DIFFERENT THAN THOSE BY A, B, ANDC

ESTIMATES BY PARTICIPANT D ALSO SUGGEST THAT THERE IS MORE MERCURY IN THIS 1:250,000 SCALE QUADRANGLE THAN HAS EVER BEEN FOUND IN THE WORL D

PARTICIPANT D EXPLAINED THAT THE ESTIMATES WERE FOR GEOCHEMICAL ANOMALIES

Main Points About Number of Deposit Estimation

- Permissive areas frequently covered, need to be able to make estimates not based only on prospects
- Estimates not main source of error, but source of concern by geologists
- Estimates typically made by expert judgment
- No evidence of bias in subjective estimates in meteorology, best estimates after machine guidance
- Guides to making such estimates are available

Aids for Estimating Resources Under Cover:

- Geology from geophysics, drill holes, and extrapolation
- Structural controls from geophysics and extrapolation
- Metallogenic map interpolations
- Mineral deposit densities

Estimation Process

- Overview of purpose, goals, properties of statistics of quantiles
- Presentation of available geoscience data by regional experts
- Identify deposit types that might occur and delineate tracts
- Present guides such as deposit densities and grade and tonnage distributions
- Remind that half of each estimate should exceed deposit type's median tonnage
- Estimate the number of undiscovered deposits

Review Grade and Tonnage Models and Other Guidelines Appropriate to Porphyry Copper Deposits

- All "deposits" should be consistent with grade and tonnage distributions. Half of deposits in the grade and tonnage model have ore tonnages greater than 230 million tons
- Median of average copper grades is 0.44 percent Cu.
- About half of undiscovered porphyry copper deposits estimated should fall above median grade or tonnage of deposit model
- Known sites that appear to be small and incompletely explored are referred to as occurrences

Example of Estimation of Number of Deposits

Estimating Number of Undiscovered Porphyry Copper Deposits in Nevada

- Estimates were based on information in folio and on combined knowledge of each team member
- Each made an independent estimate based on personal beliefs about combinations of various criteria
- A number of guidelines for estimation were used

Estimating Number of Undiscovered Porphyry Copper Deposits in Nevada

- **Some estimators used the deposit density for Nevada**
- **Others based their estimates on number of deposits known in well studied areas of similar geology elsewhere in the world**
- **Because most undiscovered deposits were expected to be under cover, the following guides were less valuable here**
  - **Number of occurrences that might become deposits as a result of more complete exploration**
  - **Number of exploration "plays" that could be visualized for porphyry copper deposits**

Deposit Density Guide for Porphyry Copper Deposits of Nevada

- **Exposed part of Nevada permissive for porphyry copper deposits is well explored.**
- **There are 7 known deposits (Yerington, SFS {Luning}, Macarthur, Bear, Ely, Ann Mason, and Copper Canyon) defined in the same way as deposits in porphyry copper descriptive model (Cox, 1986) and grade & tonnage model (Singer, Mosier, and Cox, 1986)**
- **Two known porphyry copper deposits (Bear and Ann Mason) are completely covered by younger materials thus cannot be considered to belong to population of deposits that are well explored and exposed.**

Deposit Density Guide for Porphyry Copper Deposits of Nevada

- Exposed permissive rocks in Nevada cover an area of about 32,800 km^2
- Concealed permissive areas within one km of surface are about 84,500 km^2 in extent
- If there are no additional porphyry copper deposits to be discovered in exposed plutons in Nevada, then 5 deposits / 32,800 km^2 equals 15 porphyry copper deposits / 100,000km^2
- 15 porphyry copper deposits / 100,000km^2 times 84,500 km^2/100,000 km^2 of covered permissive area equals an expected 12.9 concealed deposits

Deposit Density Guide for Porphyry Copper Deposits of Nevada

- An expected 12.9 concealed deposits minus 2 discovered deposits leaves 11 undiscovered concealed deposits defined the same way as the porphyry copper grade & tonnage model
- On the negative side, assessors noted that during the intensive exploration for porphyry copper in 1960's and 70's, only a small number of deposits were found in Nevada, and that most of these were in the Yerington area
- Also, size of alteration around porphyry copper deposits is so large that porphyry copper deposits located under cover but near boundaries of exposed rocks have significant chance of having been discovered, thus reducing covered area that has not been explored

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Estimating Number of Undiscovered Porphyry Copper Deposits in Nevada

- The estimates were compared, and team members who made high or low estimates relative to the group were questioned about their reasons.
- In some cases a minority succeeded in influencing the team in raising or lowering their estimates.
- After several iterations, a consensus was reached that satisfied all team members.

Estimated number of undiscovered deposits in permissive tracts in Nevada. Estimates are presented as complementary percentiles. The 50th percentile, for example, is the number of deposits for which there is approximately a 50% chance of at least that number of deposits.

Deposit type	Number of deposits at different percentiles		
	90 th	50 th	10 th
Jur. porphyry Cu	1 or more	3 or more	6 or more
Cret. porphyry Cu	1 or more	2 or more	3 or more
Tert. porphyry Cu	1 or more	3 or more	4 or more

Expected number of deposits:

Jur. = 3.5

Cret. = 2.1

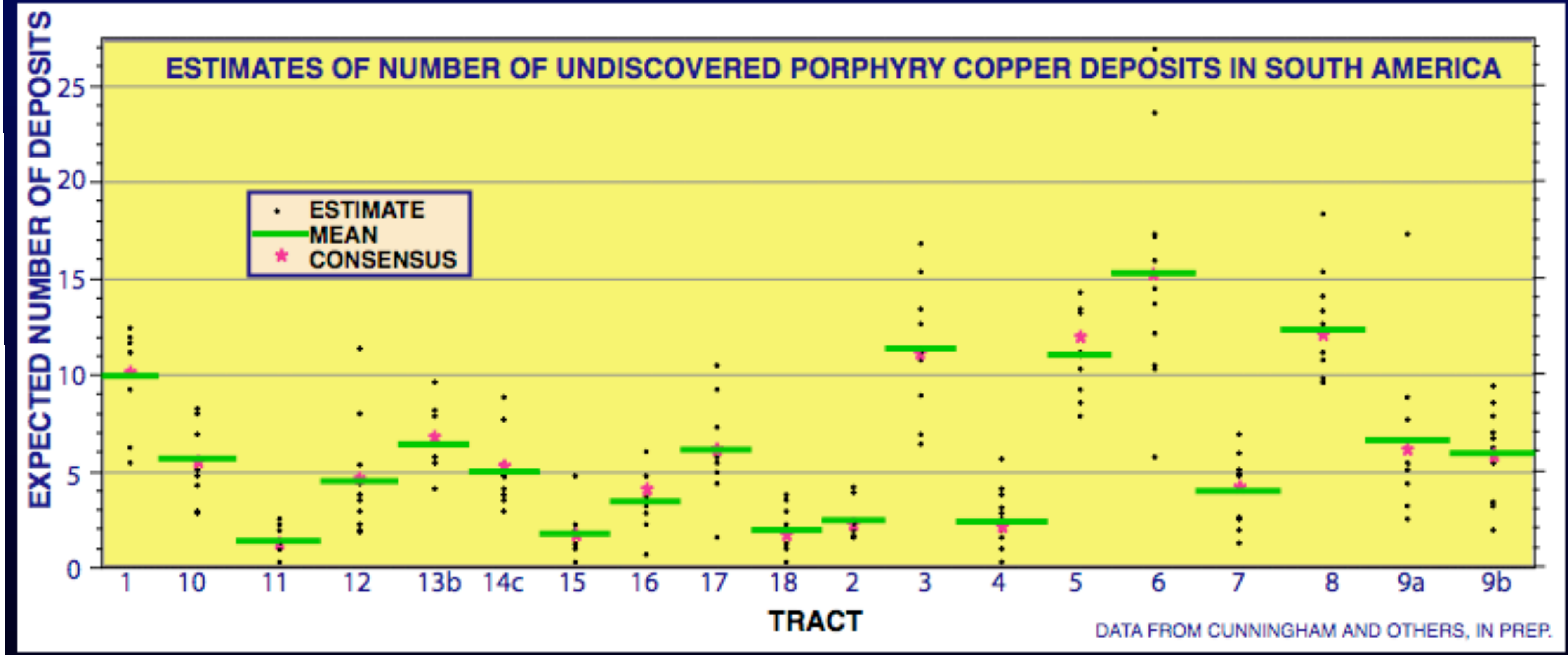
Tert. = 3.0

Cox et al 1996

Review of Estimated Number of Undiscovered Porphyry Copper Deposits in Nevada

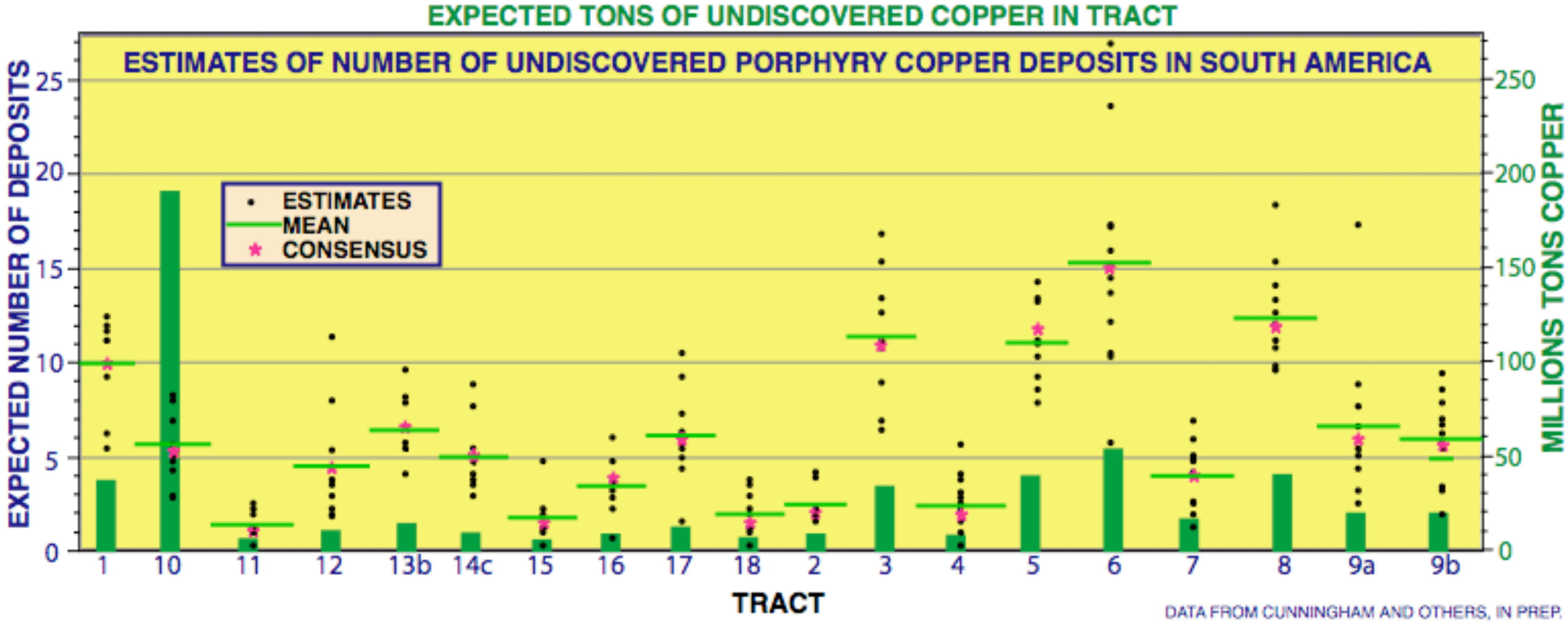
- Expected number of undiscovered porphyry copper deposits of all ages estimated in Nevada by Cox and others (1996) is 8.7 deposits.
- Deposit density in Nevada would suggest 11 undiscovered deposits.

Individual Estimated Number of Deposits Compared to Consensus and Mean



Singer

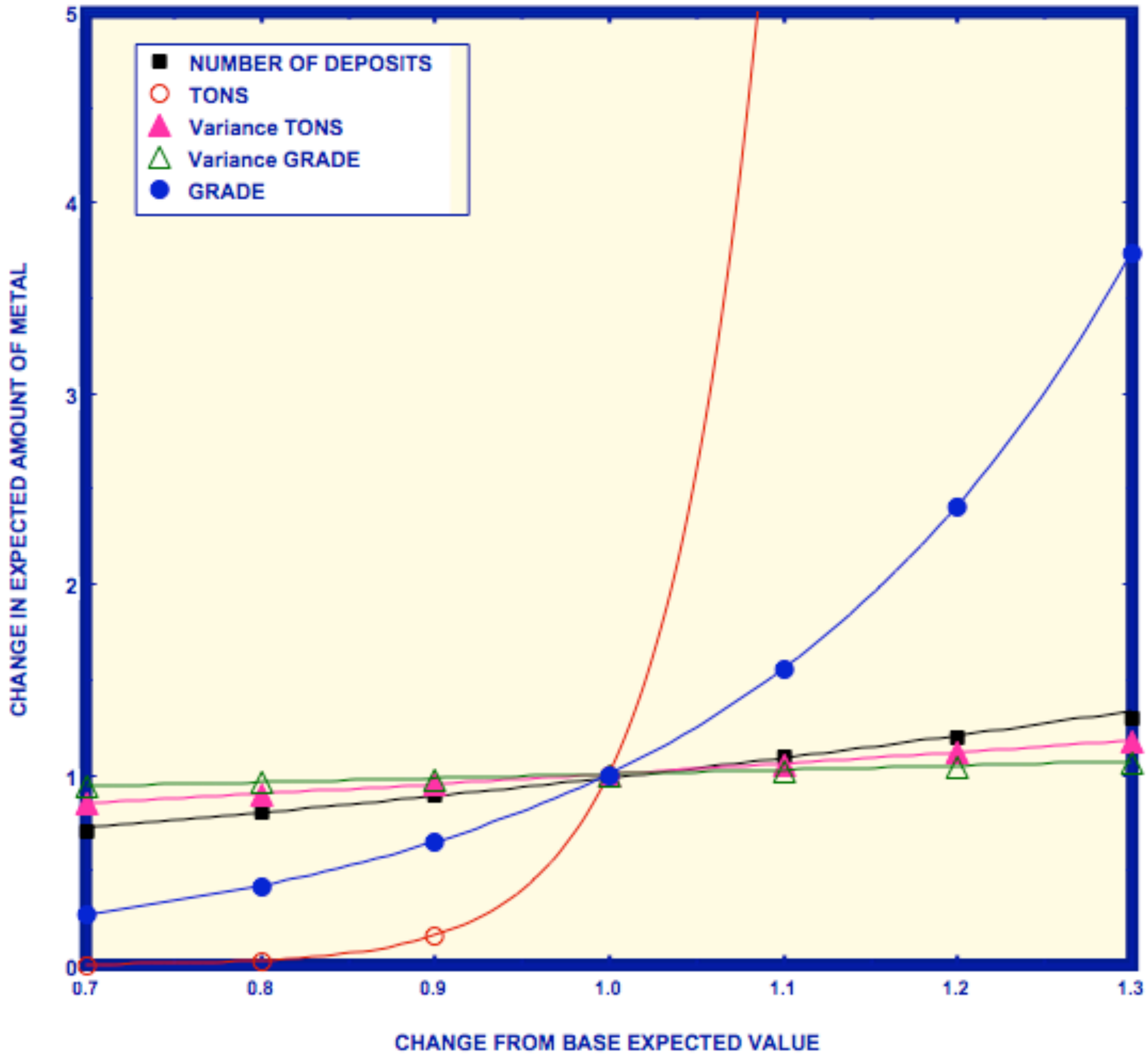
Effects on Estimated Metal of Number of Deposits Vs. Grade and Tonnage Model (Tract 10 Has Different G-T Model)



Uncertainty in Exploration and Resource Assessment

- Preliminary sensitivity analysis of metal content shows that the greatest opportunity to lower the uncertainty in assessments lies with tonnage estimates

- This means that selection of the proper grade and tonnage model is probably more critical to the final assessment than small errors in the number of deposits estimates



Sensitivity of expected amount of copper in porphyry copper deposits with respect to possible changes in expected number of deposits and means and variances of log tonnage and log copper grade

Singer and Kouda. 1999

Making Unbiased Estimates:

- There are estimation process issues that can point to bias such as the expert not following normative statistical or logical rules (Meyer and Booker, 2001)

- The most straightforward way to identify bias in estimates of number of deposits is to use the same tools that are available as guidelines for the estimates

- Number of deposit estimates that are inconsistent with the guidelines should at the least raise questions about possible bias

(Meyer, M.A., and Booker, J.M., 2001, Eliciting and analyzing expert judgment: A practical guide: American Statistical Association and Society for Industrial and Applied Mathematics)

Summary

- Estimation of number of undiscovered deposits primarily guided by grade-tonnage model
- Another guide, deposit density, uses linear regression and associated confidence limits
- Poisson distribution with same mean leads to estimates having lower Coefficient of variation & implies no deposit clustering
- Coefficient of variation used to explore estimates between these two extremes using either negative binomial or MARK3 emulator & imply deposit clustering
- These guides allow simple yet robust estimation of number of undiscovered deposits in exposed or covered permissive terranes
- To identify bias in estimates of number of deposits, use the same tools that are available as guidelines for estimates
- Calibration of operators very important