Role of Technology and Innovation for Identifying and Growing Economic Resources

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Overview

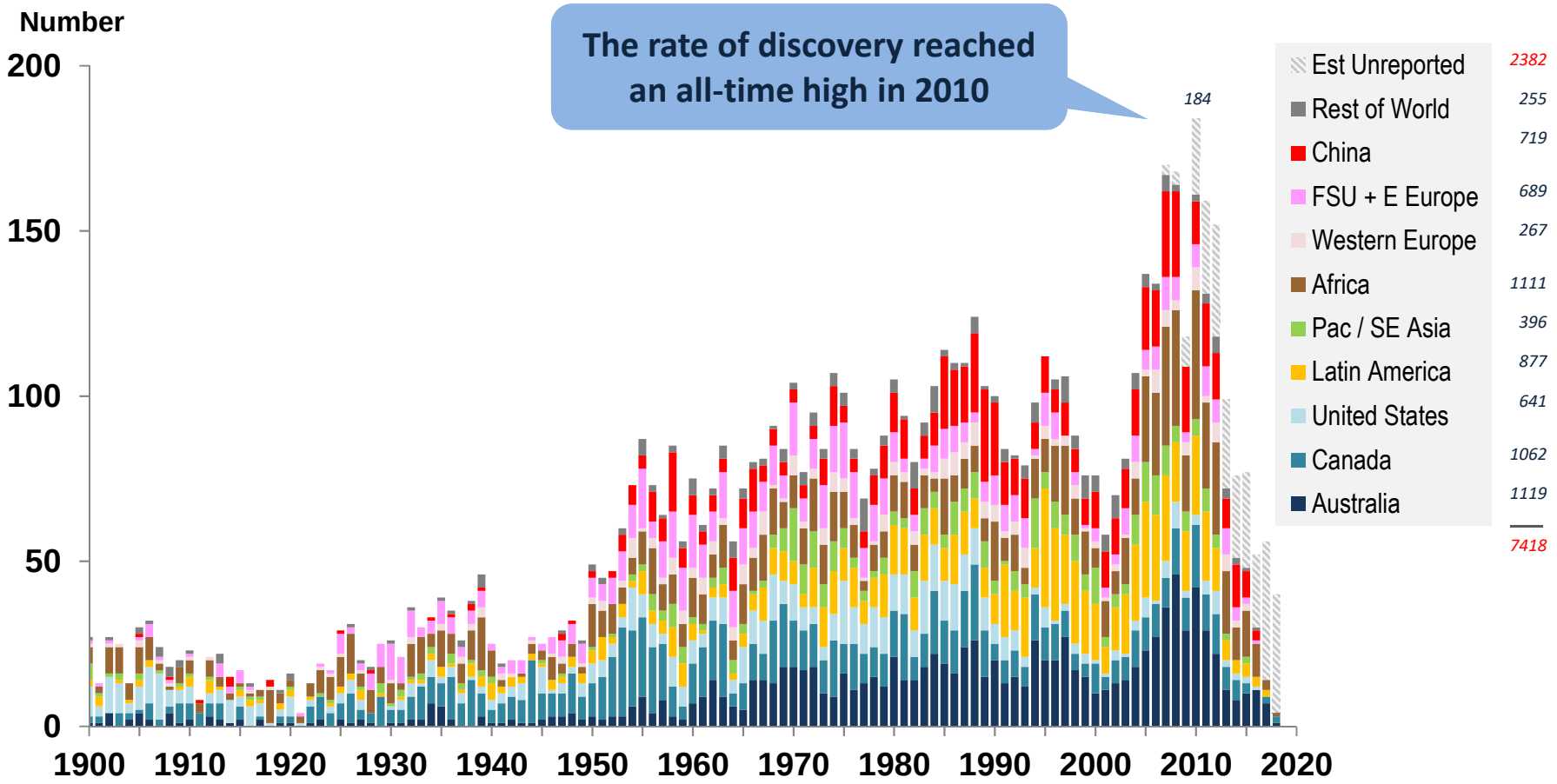
1. Long term trends in the number of discoveries
2. Location of recent discoveries
   … and where are the “hot spots” ?
3. Long term trends in discovery methods
   … and the difficulties in encouraging adoption
4. Declining discovery performance
5. Other factors driving resource growth
   … impact of engineering and process technology
6. Conclusions

Over the last century more than 7000 significant mineral deposits have been found in the World.

1. LONG TERM TREND IN THE NUMBER OF DISCOVERIES

Number of discoveries by region

Significant mineral discoveries in the World: 1900-2018



Note: Based on deposits >="Moderate" in-size. i.e. >100koz Au, >10kt Ni, >100Kt Cu, 250kt Zn+Pb, >5kt U_3O_8 >5 Mt Heavy Minerals, >20 Mt Fe, >20 Mt Thermal Coal >10 Mt Met Coal, >3 Mt P_2O_5 and >3 Mt K_2O

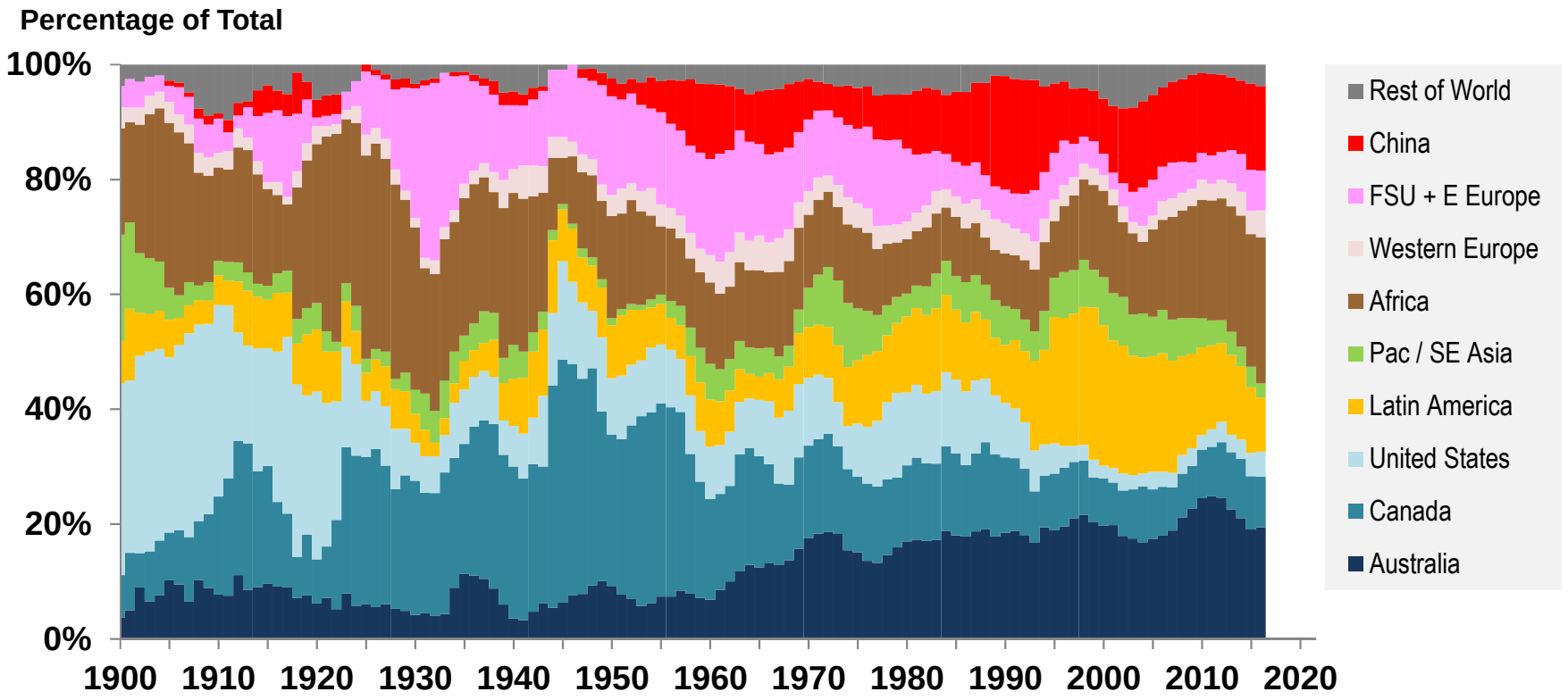
Source: MinEx Consulting © March 2019

Number of discoveries by region

Significant mineral discoveries in the World: 1900-2017

Smoothed Data
(5 year rolling average)

There has been a general movement to new regions & frontiers (Australia is the exception !)



The relative importance of each Region changes over time

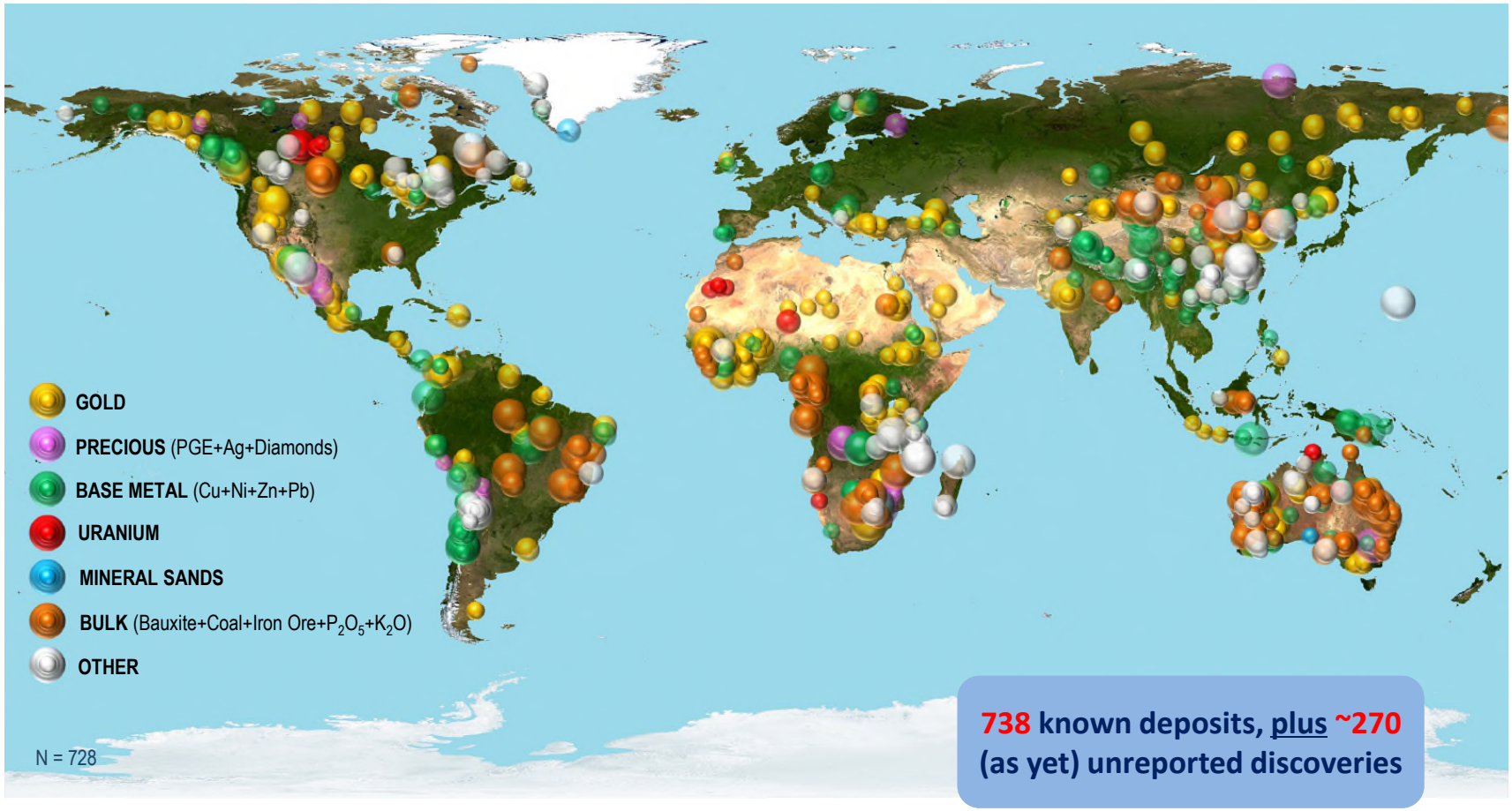
… is driven by geological maturity, technology, infrastructure and Country Risk

Source: MinEx Consulting © March 2019

Over the last decade more than 1000 significant discoveries were made in the World

2. LOCATION OF RECENT DISCOVERIES

Significant discoveries in the world by Size: 2009-2018

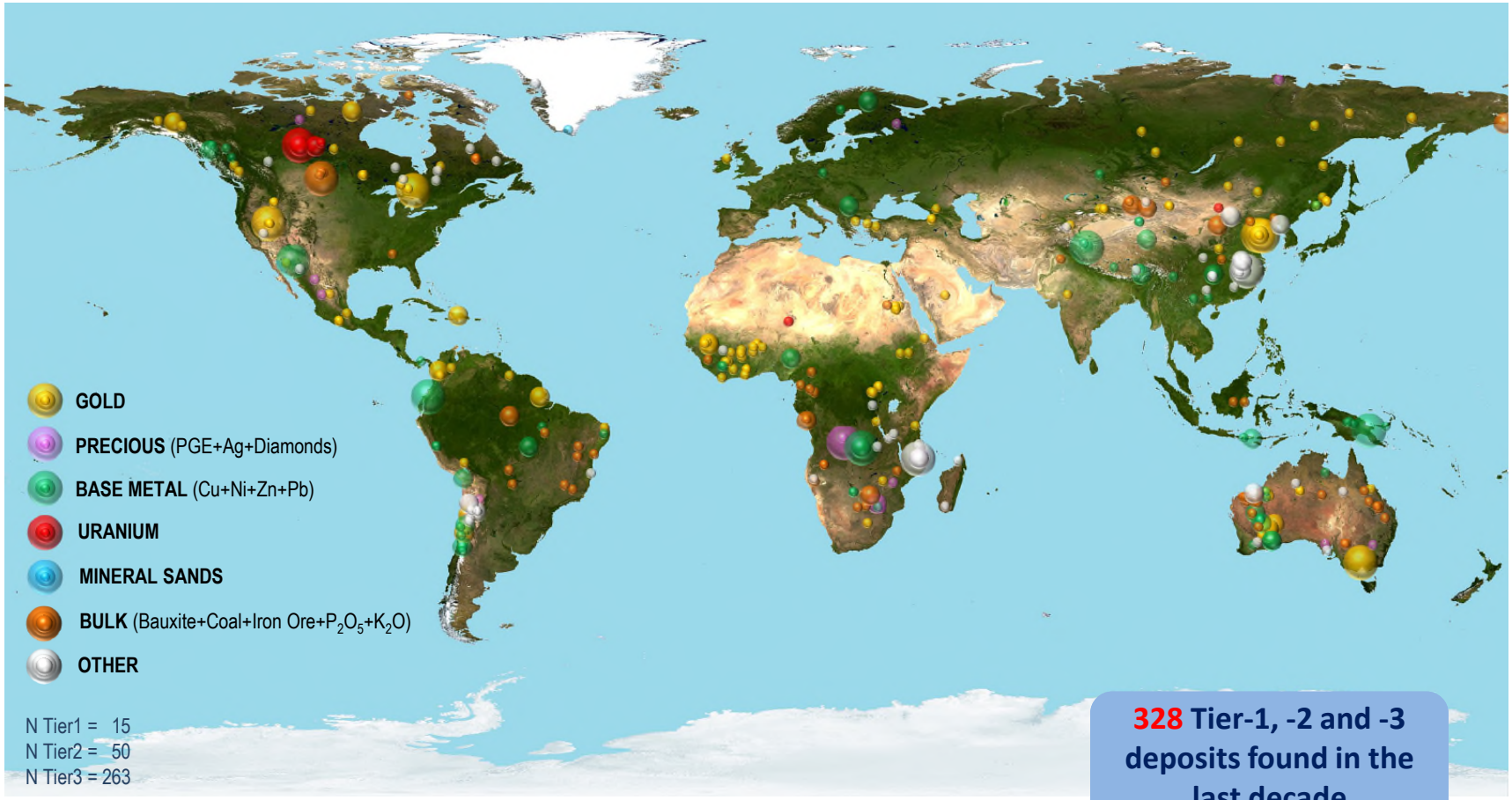


Note: Bubble Size refers to Moderate / Major / Giant deposits

Note: "Moderate" >100koz Au, >10kt Ni, >100Kt Cu, 250kt Zn+Pb, >5kt U_3O_8, >20 Mt Fe, >20 Mt Thermal Coal
"Major" >1Moz Au, >100kt Ni, >1Mt Cu, 2.5Mt Zn+Pb, >25kt U_3O_8 , >200 Mt Fe, >200 Mt Thermal Coal
"Giant" >6Moz Au, >1Mt Ni, >5Mt Cu, 12Mt Zn+Pb, >125kt U_3O_8 , >1000 Mt Fe, >1000 Mt Thermal Coal

Source: MinEx Consulting © March 2019

Significant discoveries in the World by Quality: 2009-2018

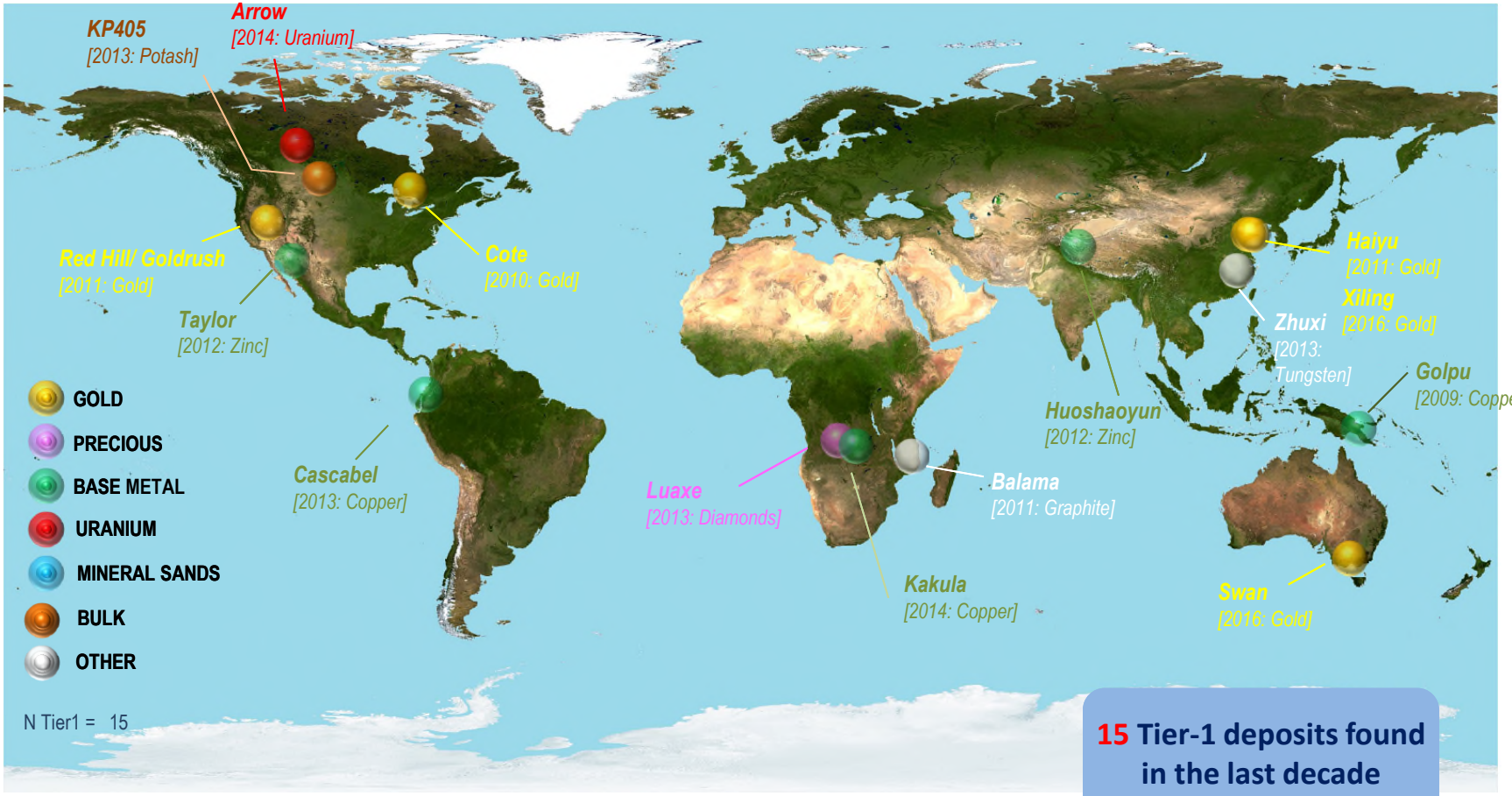


328 Tier-1, -2 and -3 deposits found in the last decade

Note: Bubble Size refers to Tier 1 / Tier 2 / Tier 3
"Tier 1" deposits are company-making mines and are large, long life and low cost with NPV at the Decision-to-Build stage of >$1000m (in 2013 US Dollars)
"Tier 2" deposits are "significant" and have some of the elements of a Tier 1 but have an NPV of $200 to $1000m
"Tier 3" deposits are modest or marginal deposits, with an NPV of $0 to $200m

Source: MinEx Consulting © March 2019

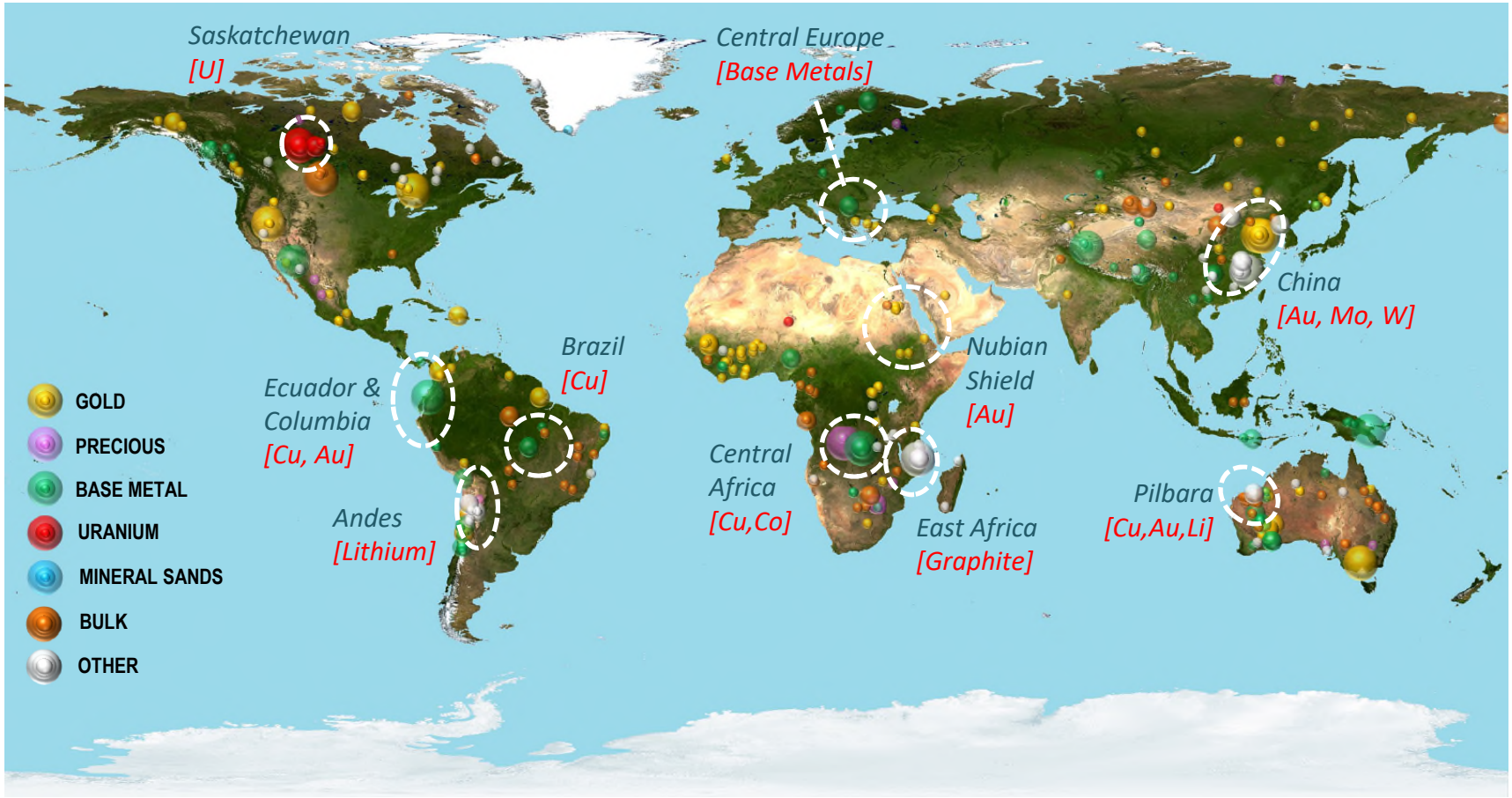
Tier-1 discoveries in the World: 2009-2018



Note: "Tier 1" deposits are company-making mines and are large, long life and low cost with NPV at the Decision-to-Build stage of >$1000m (in 2013 US Dollars)

Source: MinEx Consulting © March 2019

Current “Hot Spots” for exploration



Note: Bubble Size refers to Tier 1 / Tier 2 / Tier 3

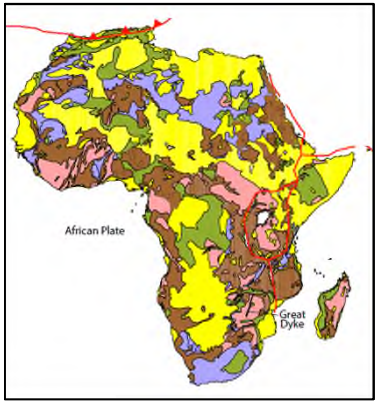
Source: MinEx Consulting © March 2019

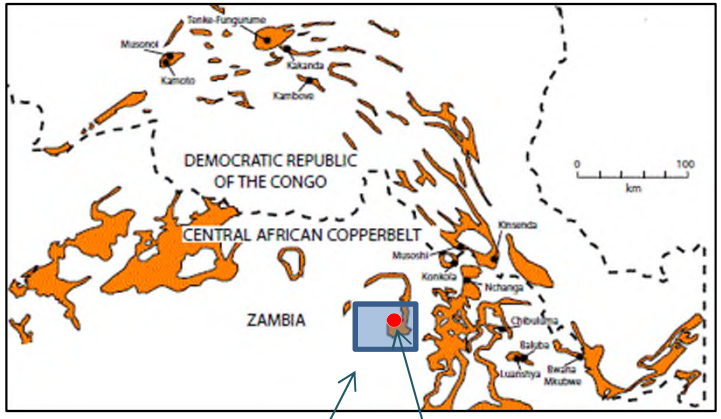
There have been several innovations in the exploration tools used to make discoveries

3. LONG TERM TRENDS IN DISCOVERY METHODS

Trends in exploration methods

The preferred search method used varies by commodity type, depth of cover and “scale”





Continental-Scale

Province-Scale

District-Scale

Project-Scale

Prospect-Scale

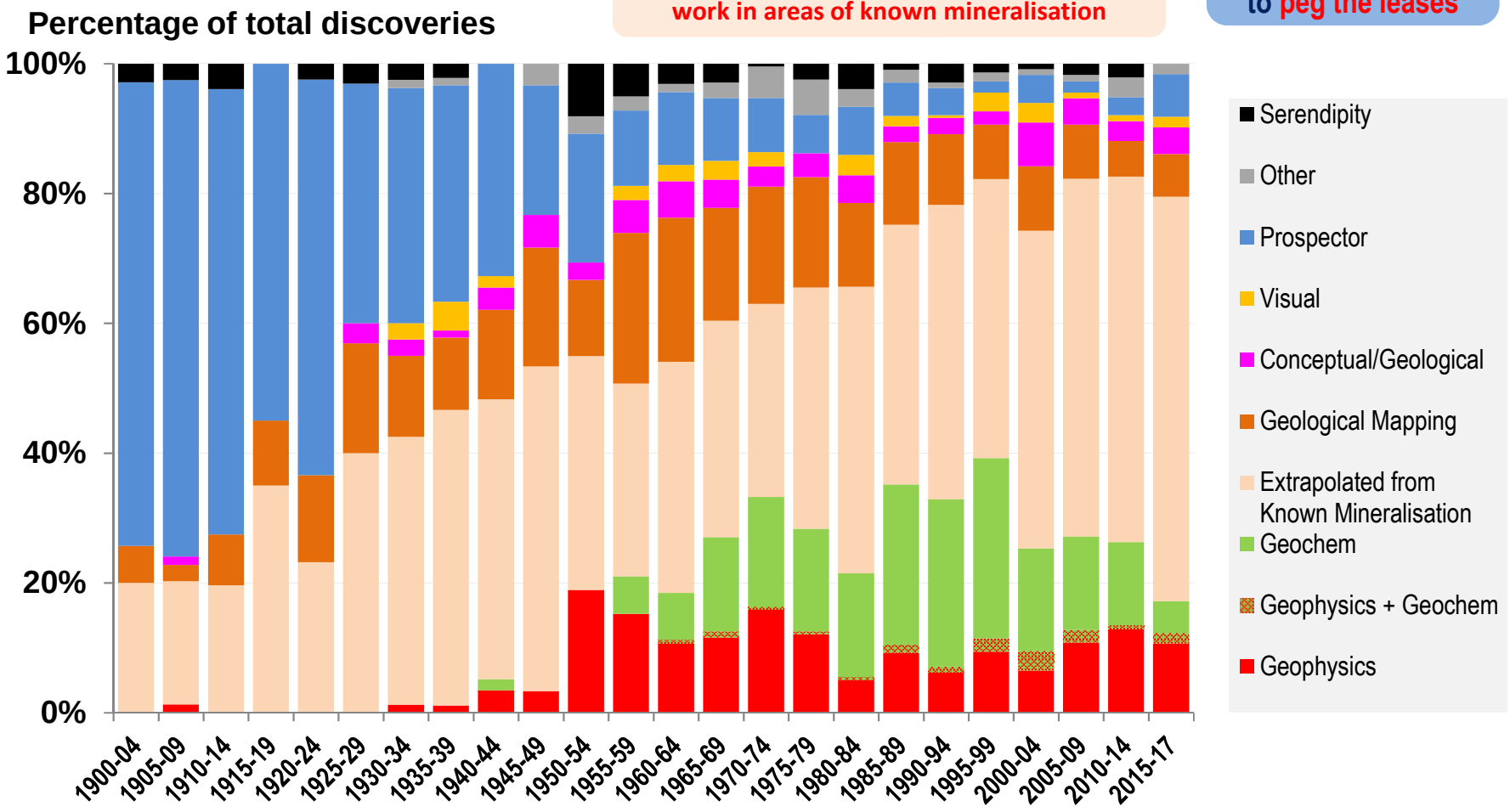
MinEx has carried out a detailed analysis of the discovery history of 3799 deposits at these two scales

Primary search method used at the project-scale

ALL discoveries in the World: 1900-2017

The most popular area selection method is to work in areas of known mineralisation

ie What method was used to decide where to peg the leases



Note: Analysis based on detailed analysis of 3799 projects (out of 7108 known discoveries)

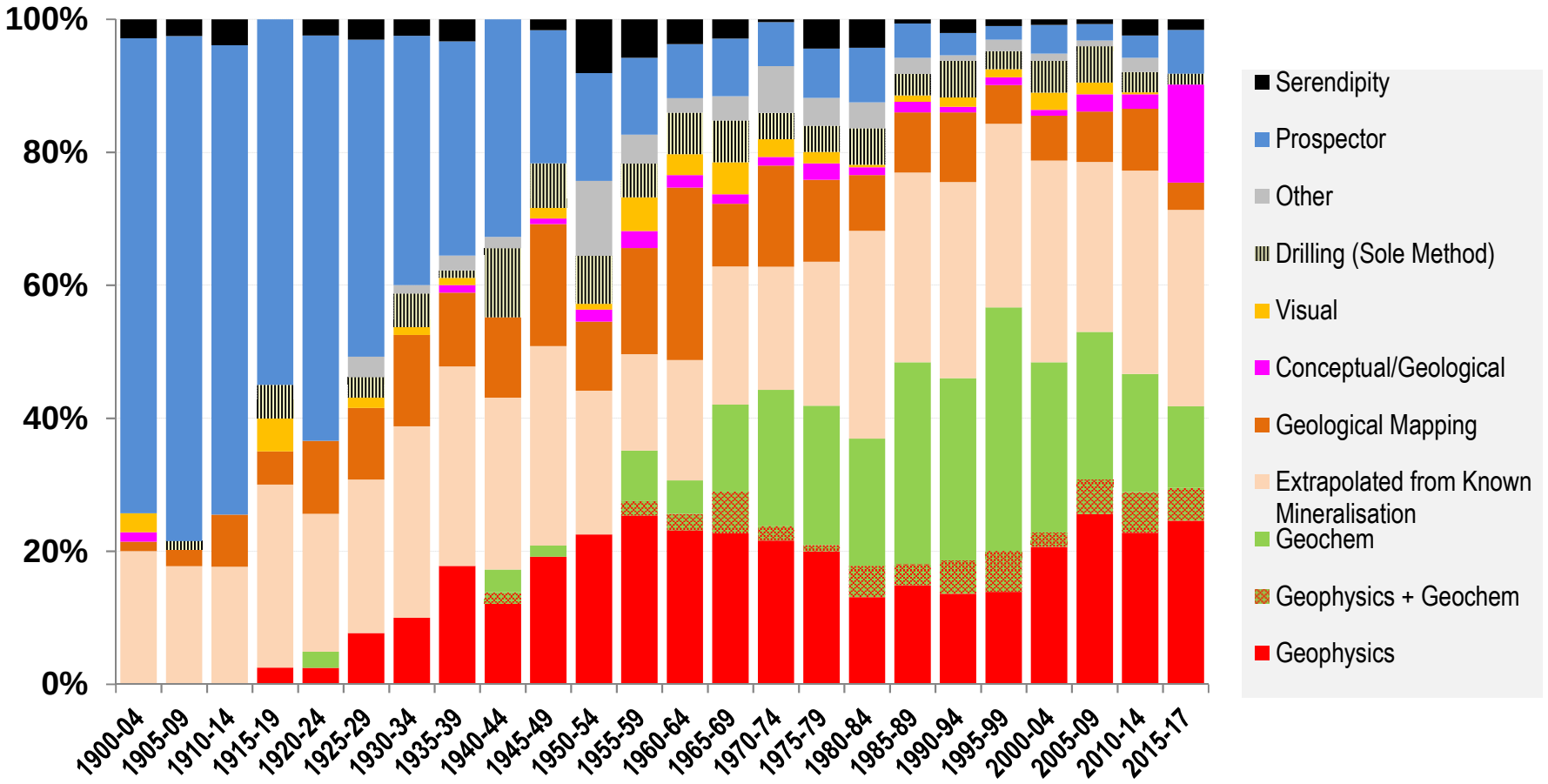
Source: MinEx Consulting © October 2018

Primary search method used at the prospect-scale

ALL discoveries in the World: 1900-2017

(Depending on the commodity & location) Geophysics and Geochemistry are the two main techniques used to site the drill rig

ie What method was used to decide where to drill the first hole



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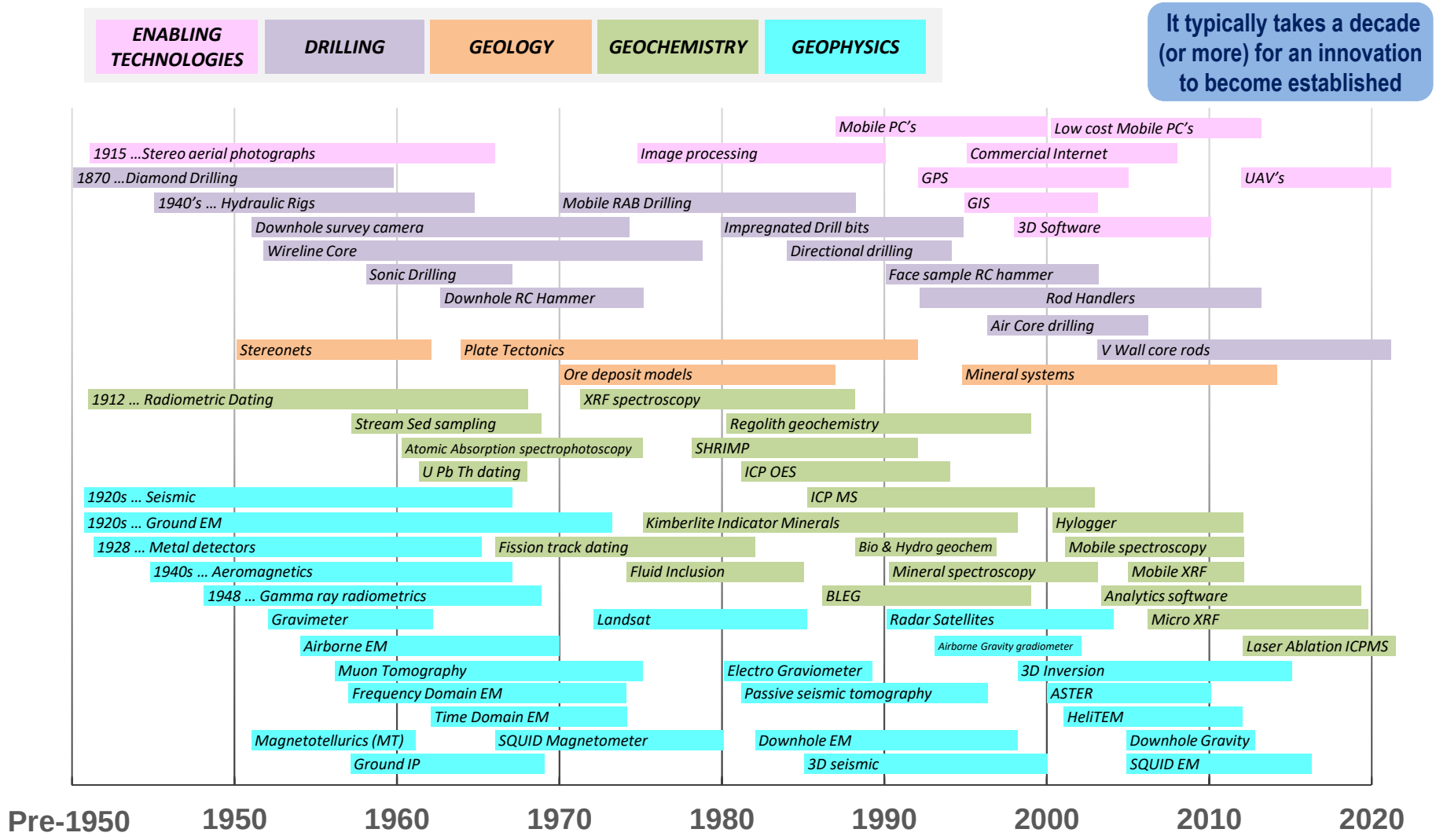
Source: MinEx Consulting © October 2018

Geologists have a wide range of tools to use …

Time line of 72 key innovations developed for mineral exploration



Note: The length of the box represents when the given technology was first introduced, and when it became mature.

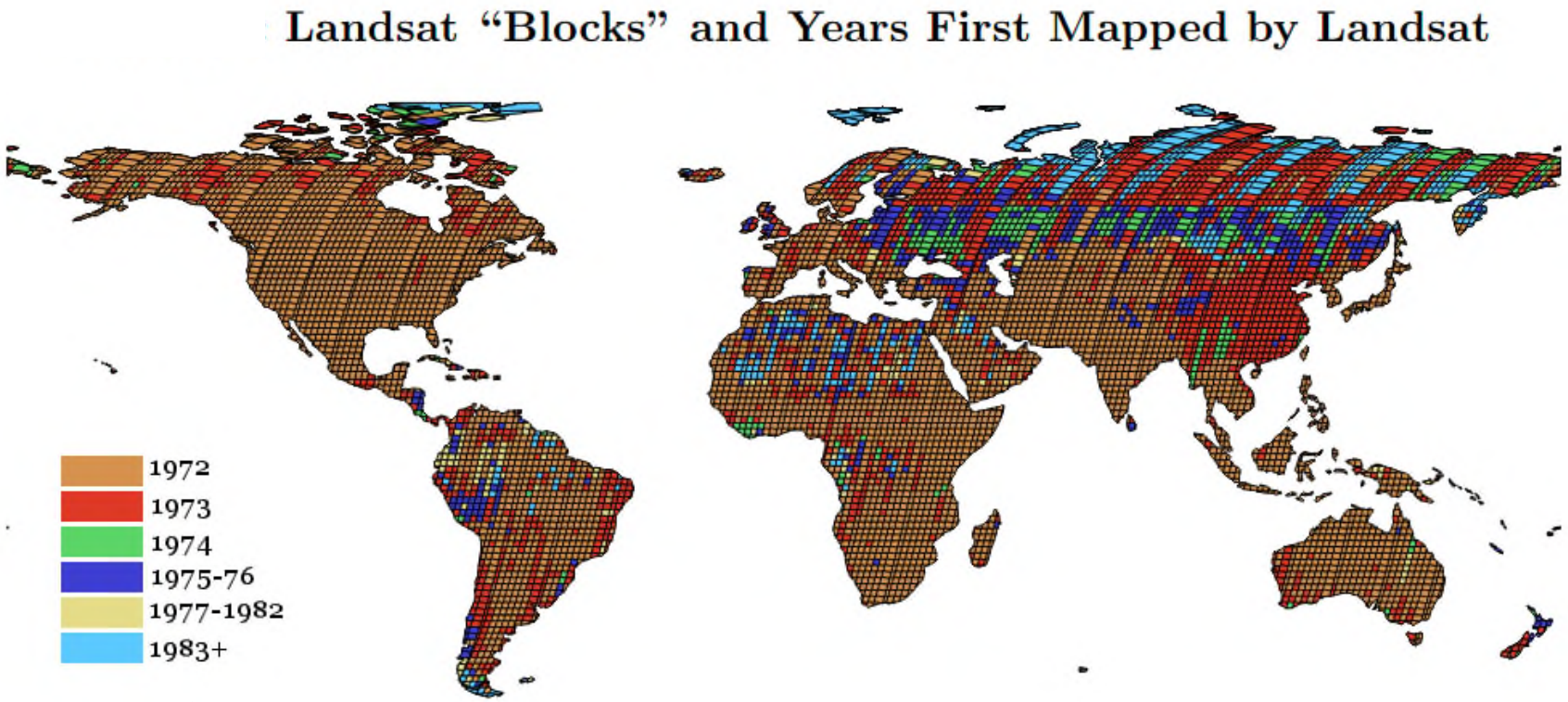
Source: Robbie Rowe (NextGen Geological), November 2018

However …

… The industry is relatively slow to adopt new ideas

CASE STUDY
Adoption of LandSat imaging

Impact of Landsat on exploration performance



However, in the early years many of the LandSat photos were obscured by clouds

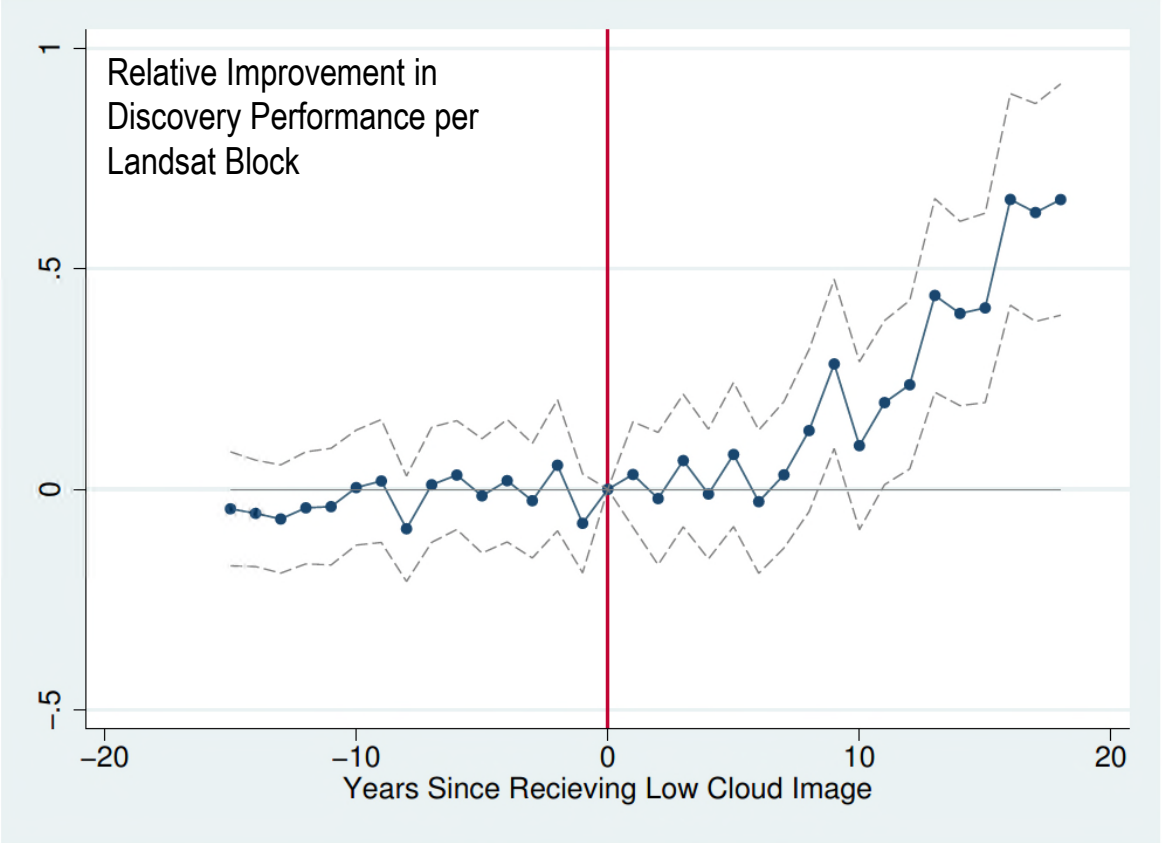
Source: Ahbishek Nagaraj, "The Private Impact of Public Maps LandSat Satellite Imagery and Gold Exploration", Masters Thesis, MIT, 2016

However it took a decade to convert the opportunity into success

By careful modelling of the statistical data Nagaraj found that when "cloud-free" images became available, the discovery rate per block went up by 50% (compared to equivalent other areas)

However, it took several years to capture the benefit.

[Surprisingly] he noted that Junior Explorers were twice as good at using the data than the Majors !



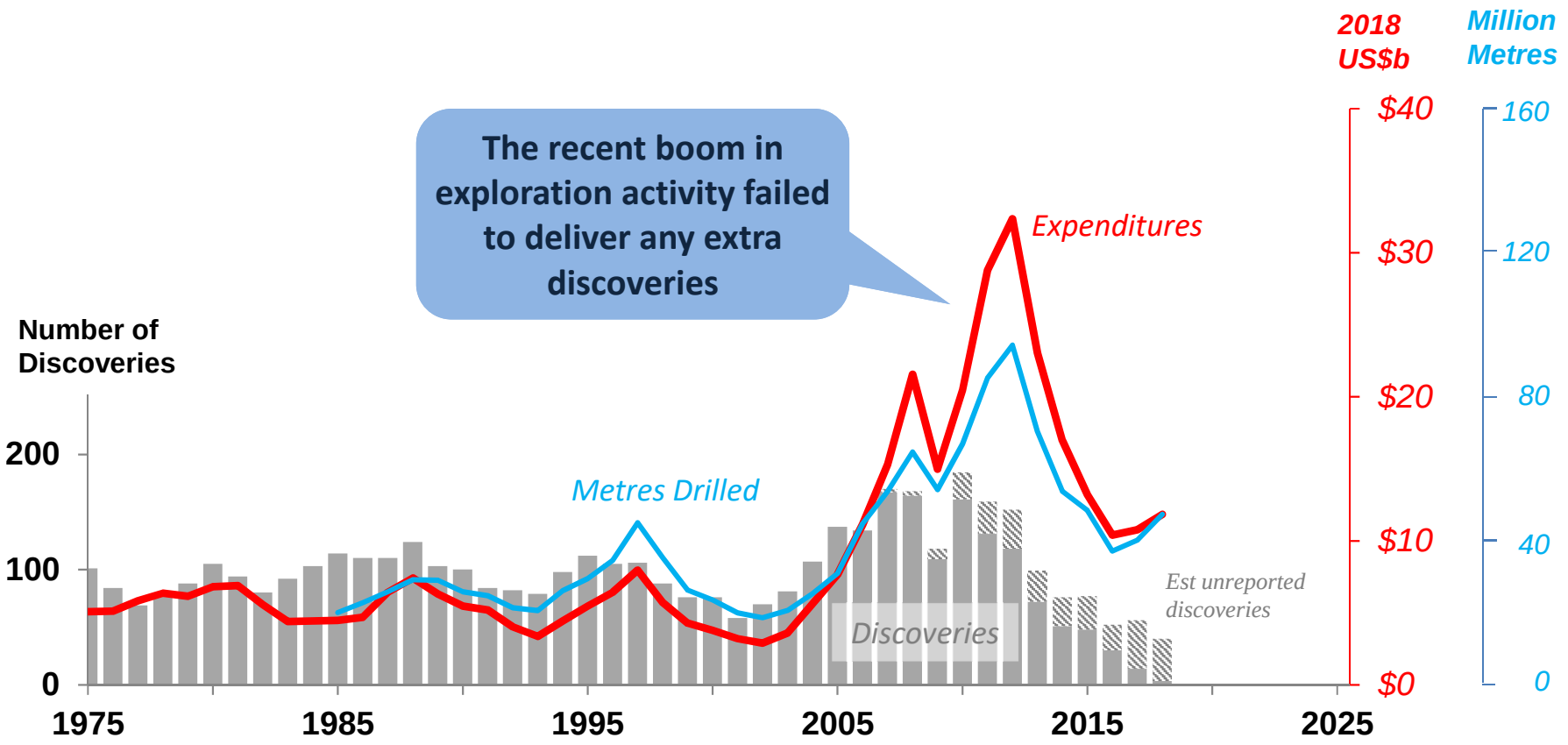
Source: Ahbishek Nagaraj, "The Private Impact of Public Maps LandSat Satellite Imagery and Gold Exploration", Masters Thesis, MIT, 2016

Over the last decade it has become much harder / more expensive to make a discovery

4. DECLINING EXPLORATION PERFORMANCE

Discovery Rate versus Exploration Drilling & Expenditures

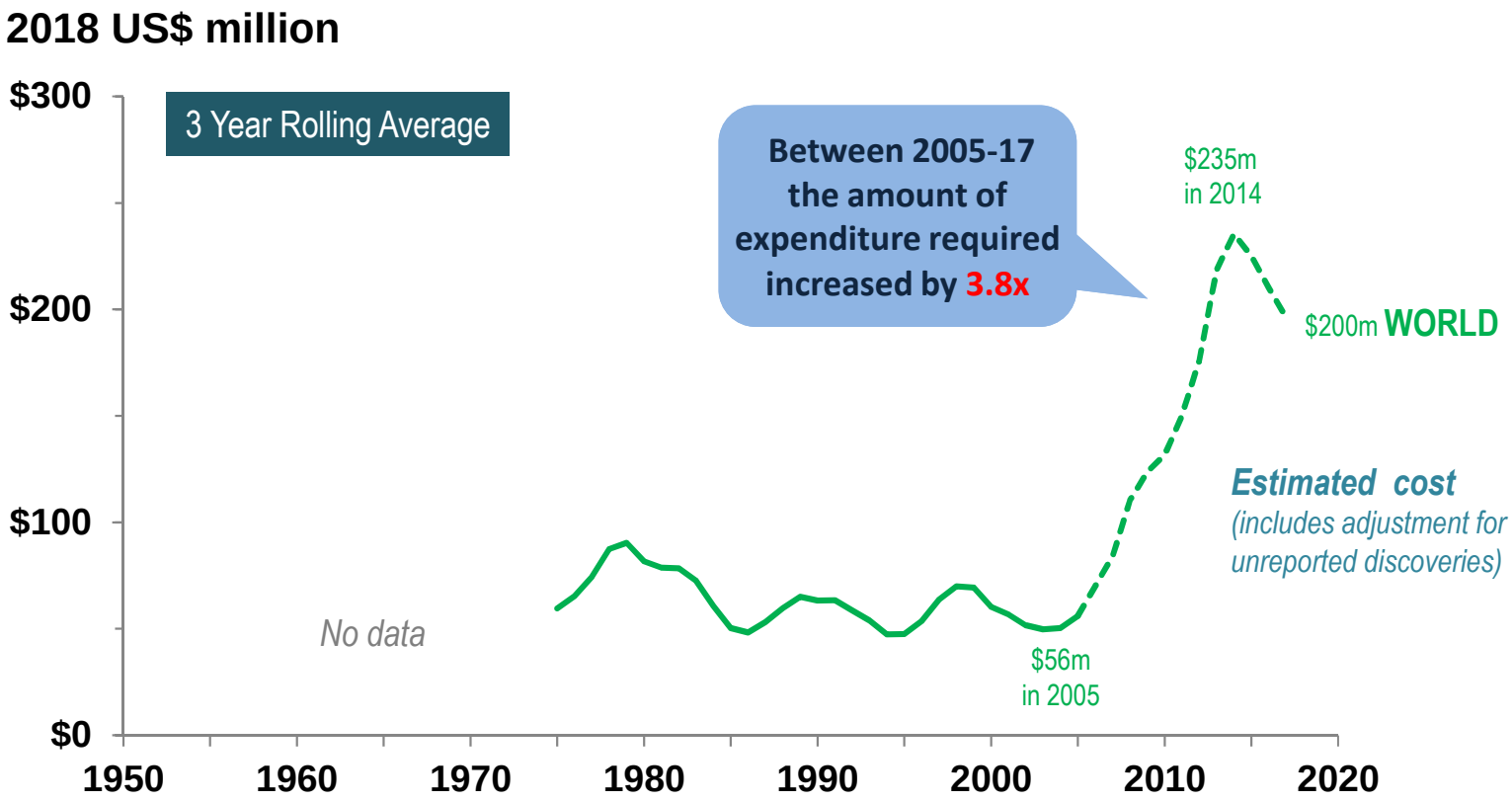
All Commodities World: 1975-2018



Source: MinEx Consulting © March 2019

Unit cost per discovery

Mineral discoveries in the World : All Commodities : 1975-2018



Note: Discoveries based on deposits >="Moderate" in size
i.e. >100koz Au, >10kt Ni, >100Kt Cu, 250kt Zn+Pb, >5kt U_3O_8 , > 10Mt Fe, >20Mt Thermal Coal

No exploration data available prior to 1975

Source: MinEx Consulting © March 2019

Unit cost per discovery

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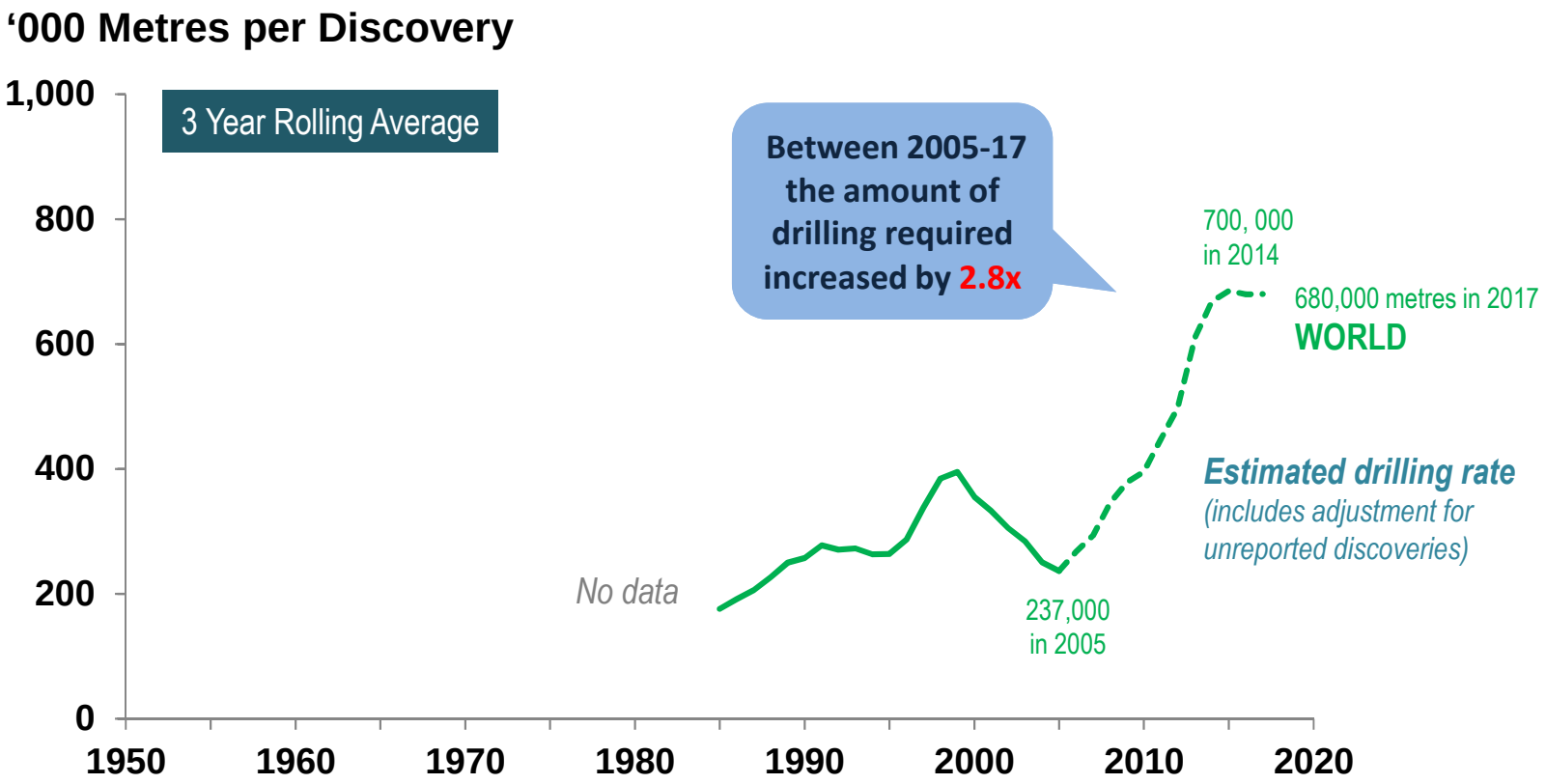

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i.e. >100koz Au, >10kt Ni, >100Kt Cu, 250kt Zn+Pb, >5kt U_3O_8 , > 10Mt Fe, >20Mt Thermal Coal

No drilling data available prior to 1985

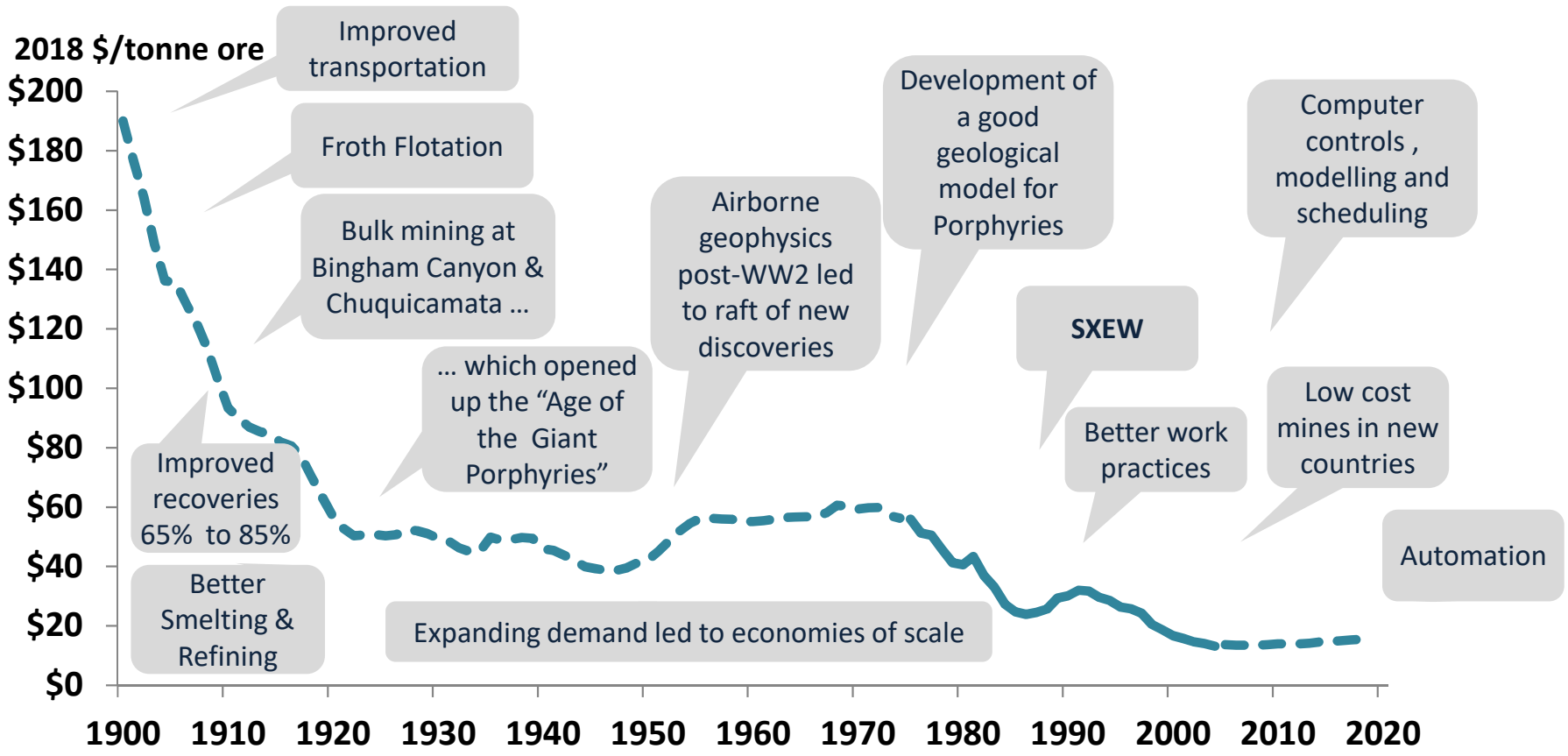
Source: MinEx Consulting © March 2019

Its more than just a game of “discovery”.
Engineers and technologists also have a key role to play

5. OTHER FACTORS DRIVING RESOURCE GROWTH

Key Technical Innovations

Estimated average operating costs for copper mines in Western World: 1900-2018

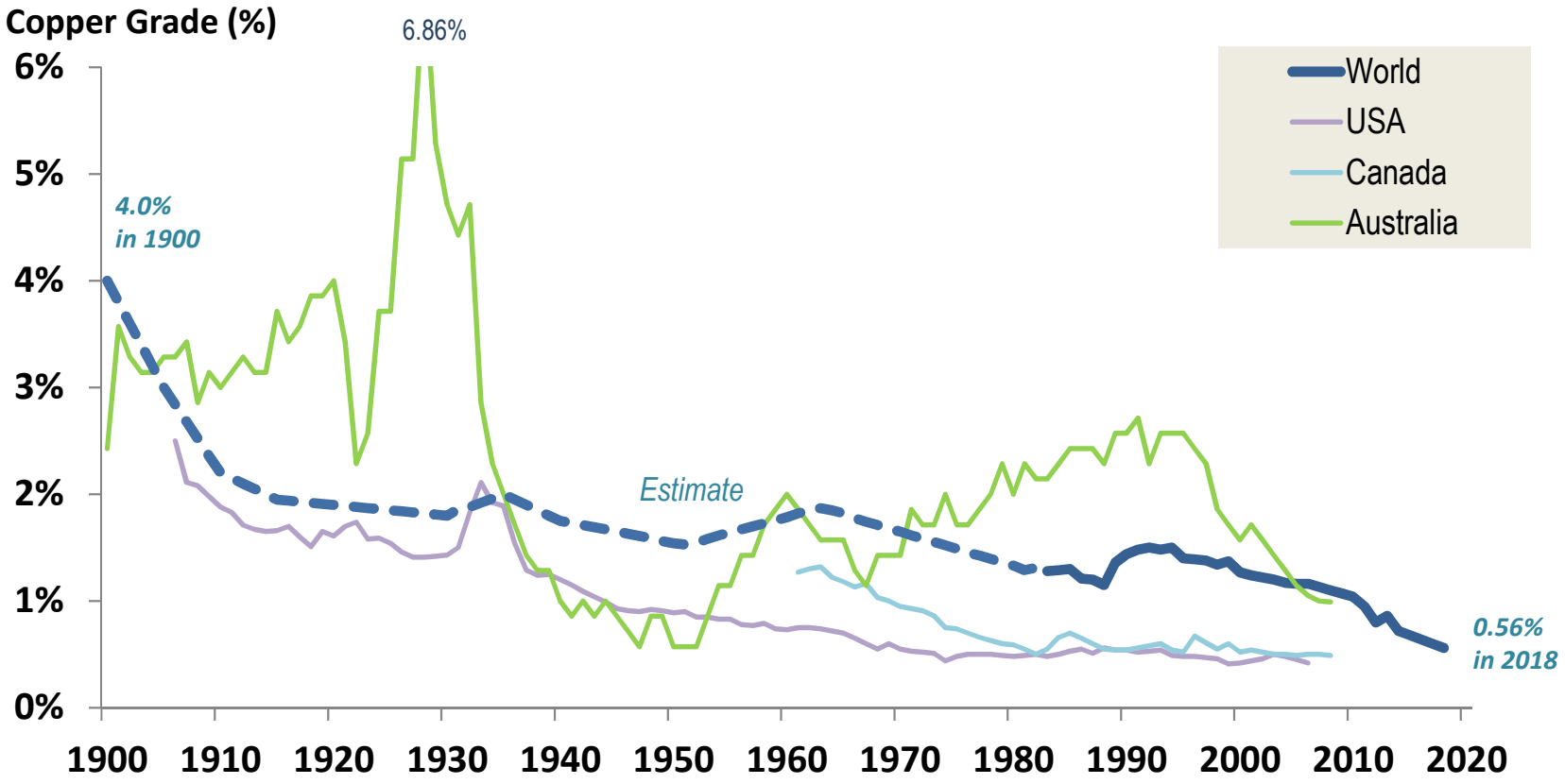


Includes, transportation, smelting & refining and marketing costs

Sources: Brook Hunt, CRU , SNL, Historical reports
MinEx Consulting estimates (for 1900-1974)

Ore grades mined have declined over time

Copper ore grade for World and selected countries: 1900-2018



Note: Rise in ore grade in Australia from 1972 onwards is due to startup of the high-grade Olympic Dam mine

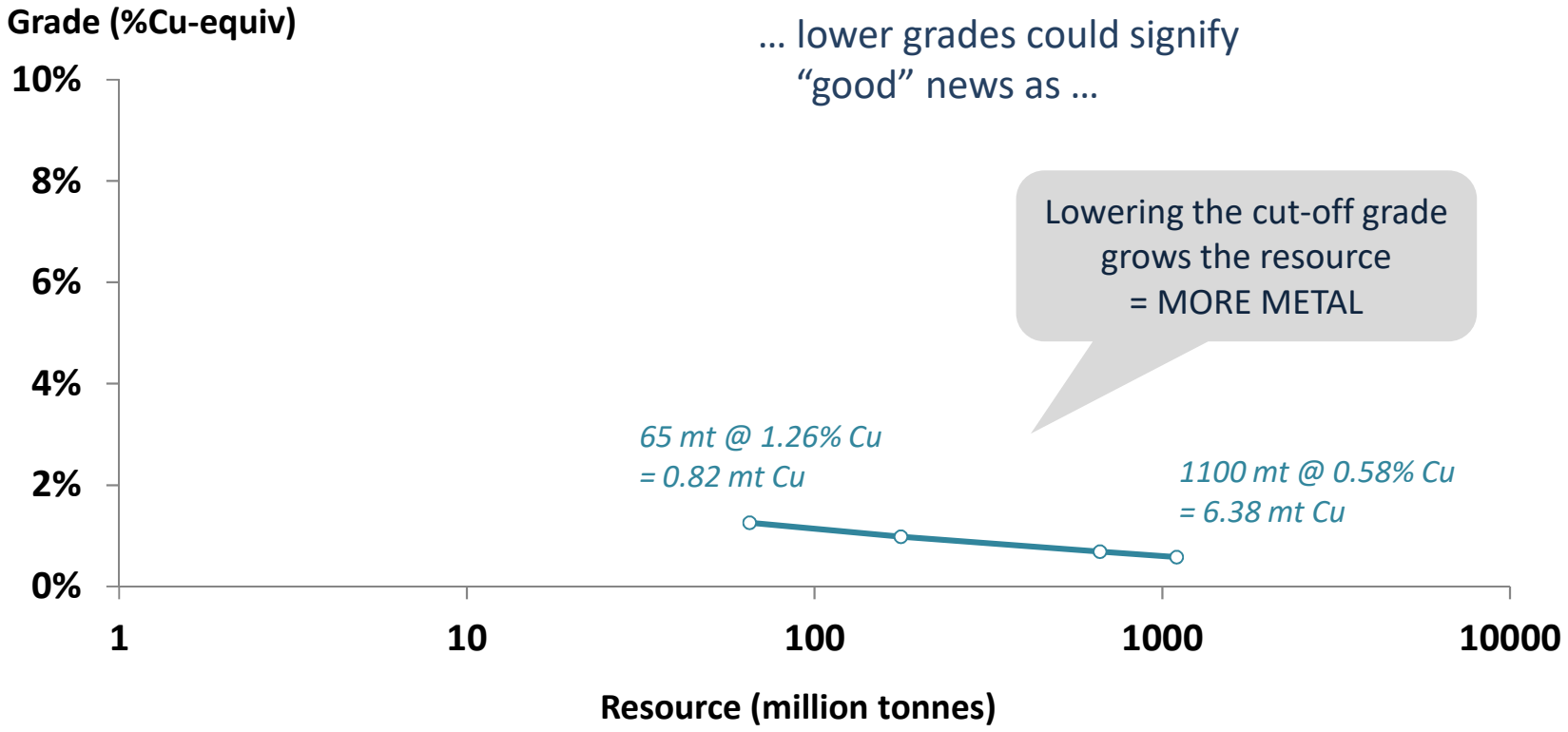
Sources: USGS, Mudd (2009), Brook Hunt, UBS
MinEx analysis of SNL data

QUESTION:

Is a declining ore grade bad news or good news ?

There is a trade-off between tonnes and grade

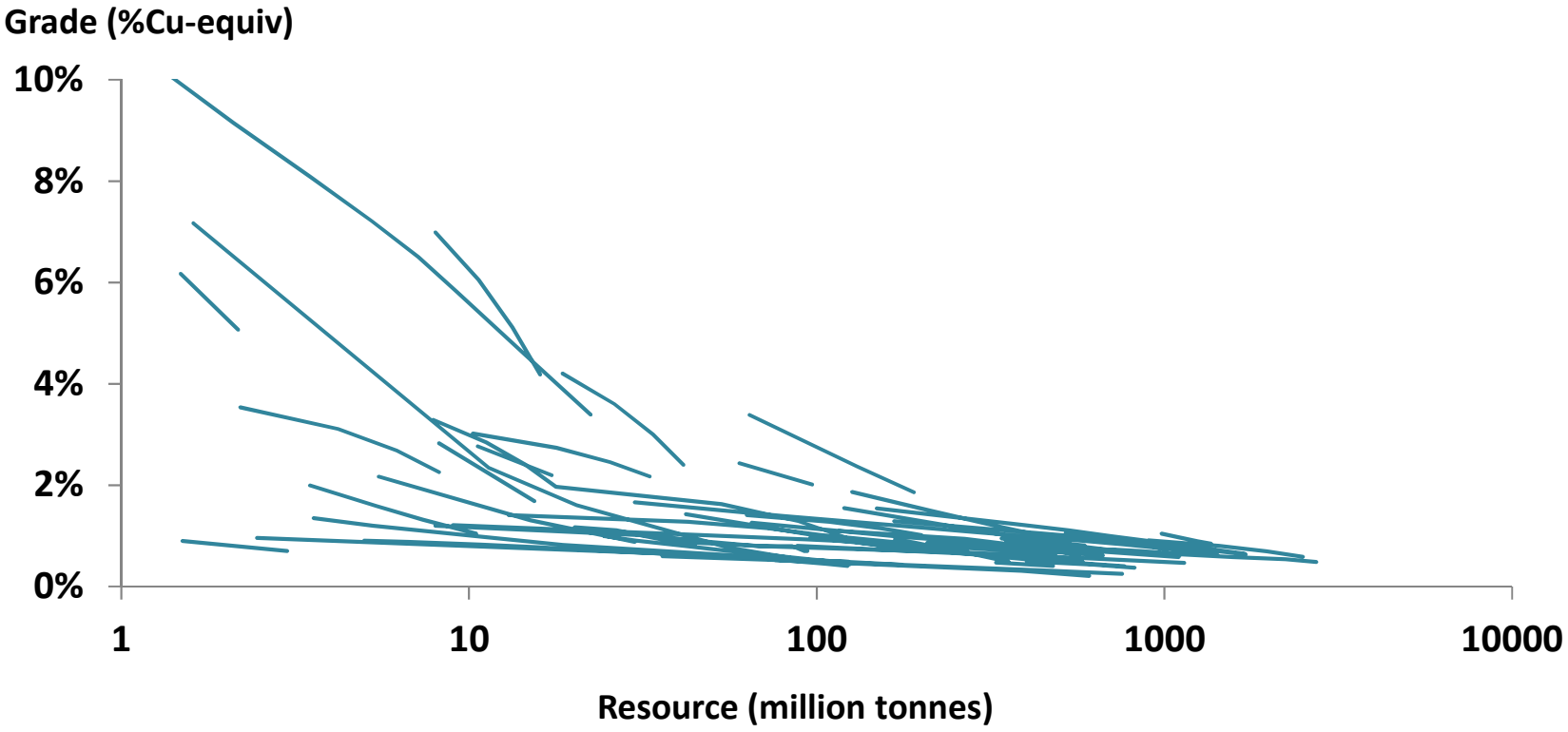
Rio Blanco copper deposit



Source: MinEx Consulting © March 2010

There is a trade-off between tonnes and grade

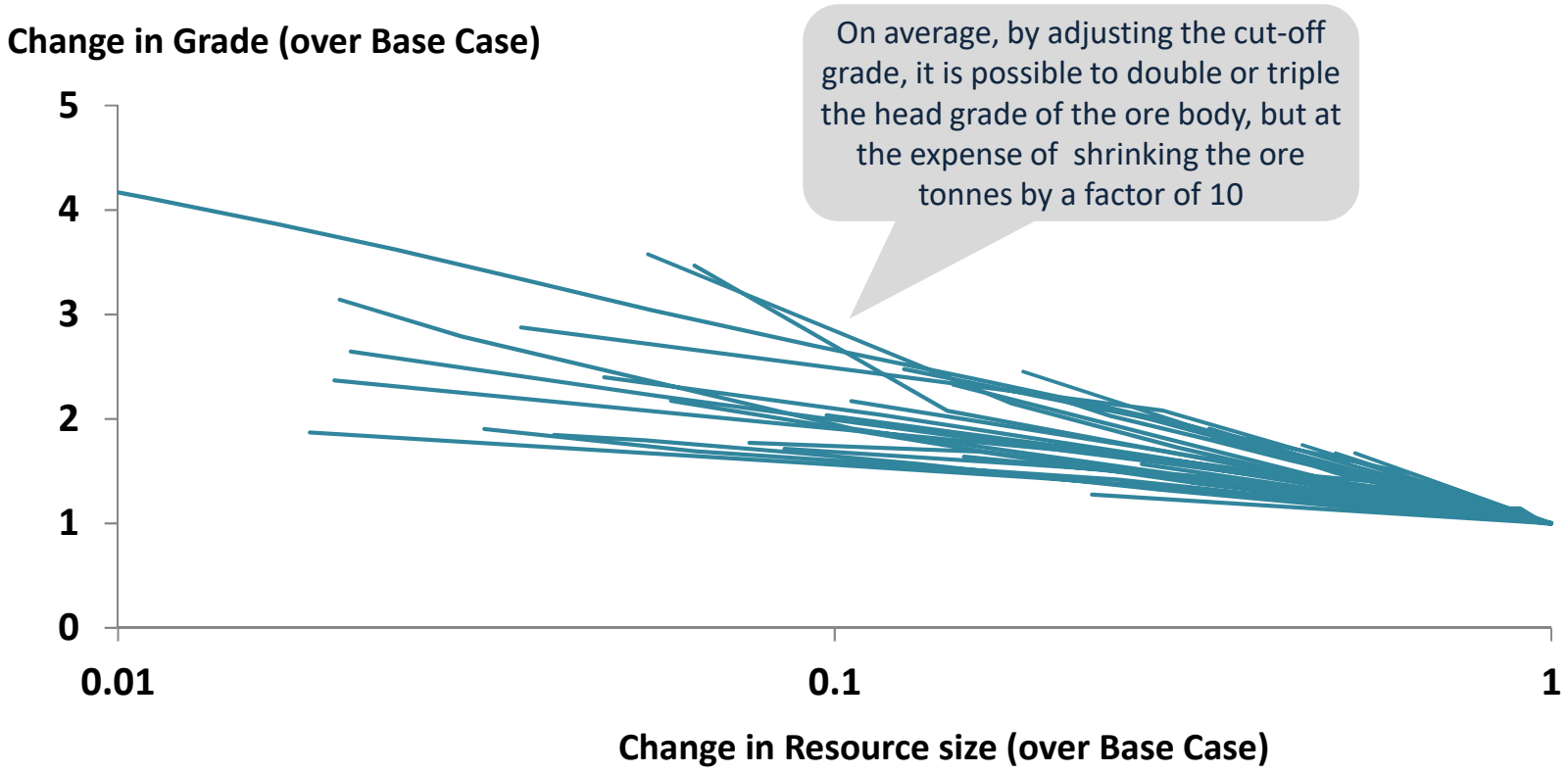
Tonnes-Grade data for 48 copper deposits



Source: MinEx Consulting © March 2010

There is a trade-off between tonnes and grade

NORMALISED Tonnes-Grade data for 48 copper deposits

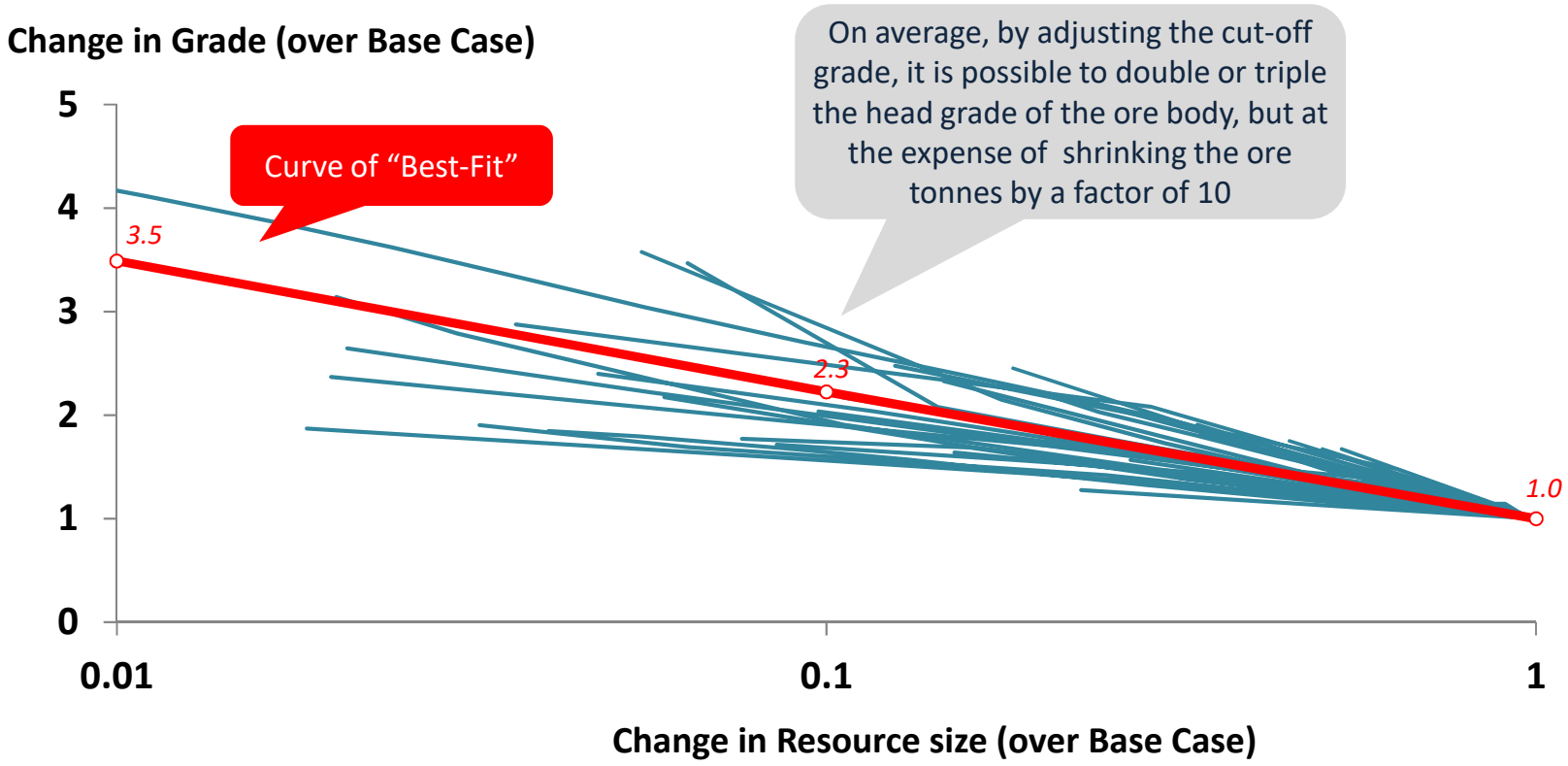


Base Case defined as the maximum reported resource size for a given deposit

Source: MinEx Consulting © March 2010

There is a trade-off between tonnes and grade

NORMALISED Tonnes-Grade data for 48 copper deposits



Base Case defined as the maximum reported resource size for a given deposit

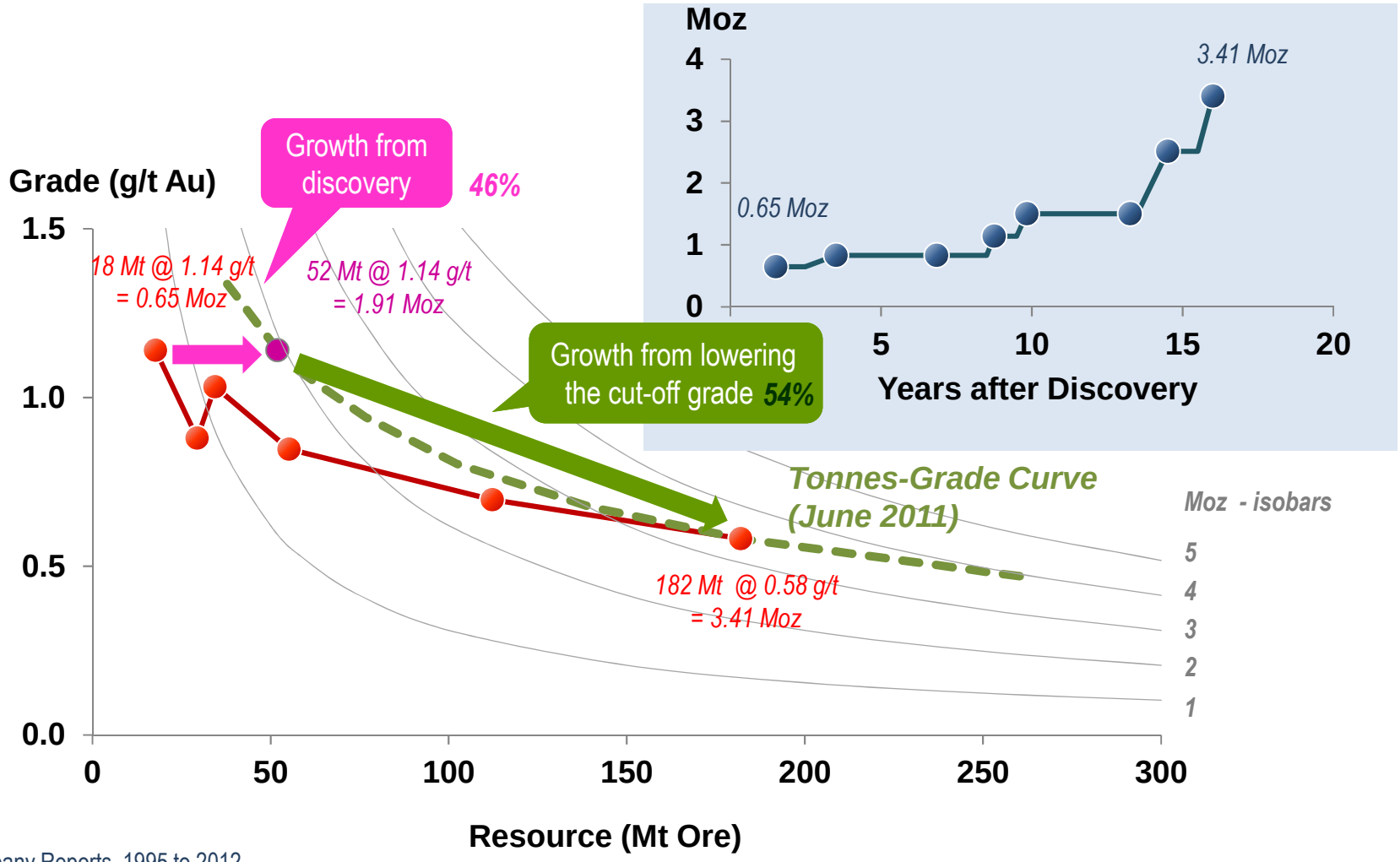
Source: MinEx Consulting © March 2010

CASE STUDY:

Resource growth for the Shahuindo Gold Deposit in Peru

In many cases, the contributions from the engineer are similar in impact to that delivered by the geologist

Shahuindo Gold Deposit: Discovered in 1995



Data: Company Reports 1995 to 2012

Changing the cut-off grade has a major impact on the size and quality of the resources available for mining

- Most deposits have a “halo” of low grade ore surrounding a high-grade core

- The reported size of the deposit will depend on the cut-off grade used
  - As a rule of thumb, lowering the cut-off grade by 50%, increases the ore tonnes by 4-8x and the contained metal by 2-4x

The ratio varies with the type of deposit

  - The cut-off grade is driven by economics .... which, in turn, are driven by commodity prices, costs and level of business risk

Costs are influenced, energy & labour-intensity, innovations in mining and processing methods and economies of scale

Other effects of mining-related innovation on exploration strategy

- New exploration targets
  - BiOx allowed the economic development of refractory gold deposits
  - SXEW process for oxide deposits fundamentally changed the economics of the copper industry
  - InSitu leaching now accounts for 48% World's uranium production
- Better infrastructure unlocks stranded projects
  - Geologists should "follow the road"

6. CONCLUSIONS

Conclusions [1/4]

- The number of significant minerals discoveries in the World peaked at 184 in 2010. We are now at less than half that rate
- Over several decades the industry has moved under deeper cover and to new jurisdictions
- 15 Tier-1 deposits were found in the last decade
- Have identified 10 current hot-spots for exploration around the World
  - Saskatechwan, Ecuador/Colombia, Andes, Brazil, Central Africa, East Africa, Nubian Shield, Central Europe, China and Pilbara
- In spite of the wealth of exploration tools available, our discovery performance has significantly declined in the last decade.
  - 72 key innovations identified since 1950 … but typically takes a decade (or more) for a new technology to become "mainstream"
- Between 2005 and 2017 ***3.8x higher***
  - the cost to make a discovery rose from $56 to $200m (in constant 2018 US Dollars)
  - The amount of drilling required rose from 237,000 metres to 680,000 metres ***2.8x higher***

Conclusions [2/2]

- From a Global Industry perspective the question should be reframed from *"how do we find new deposits?"* to *"how do we grow resources?"*
- Innovations in mining and processing make it economic to mine lower grade ore. This substantially increases the resource base
- As a rule of thumb, halving the cut-off grade will increase the ore tonnes by 4x and the contained metal by 2x
- Lower costs and better processing open up new opportunities to explore for (previously) unloved /unrecognised deposits.

Key learning
A good exploration manager should work together with the engineers and processing technologists to identify new business opportunities

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