Resource Limitations on Earth

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Geologic Processes and the Formation of Mineral Deposits

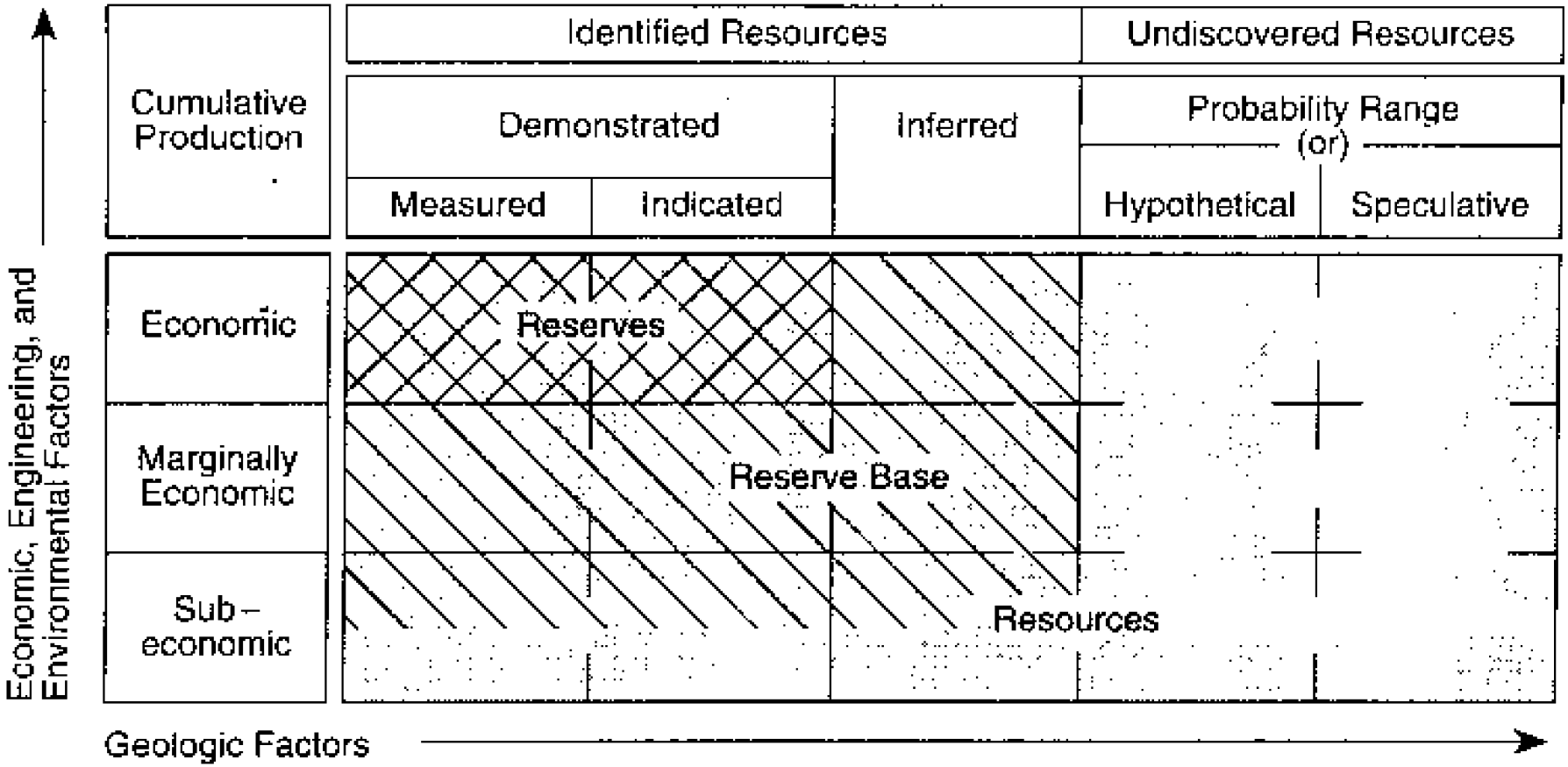
- On the Earth:
  - What is a Mineral Deposit?
  - Ore Forming Processes
  - Plate Tectonics and Ores
  - Geologic Time and Ores
- Surface, Interior, Plates, Rock Cycle, Hydrologic Cycle, Ores vs Temperature

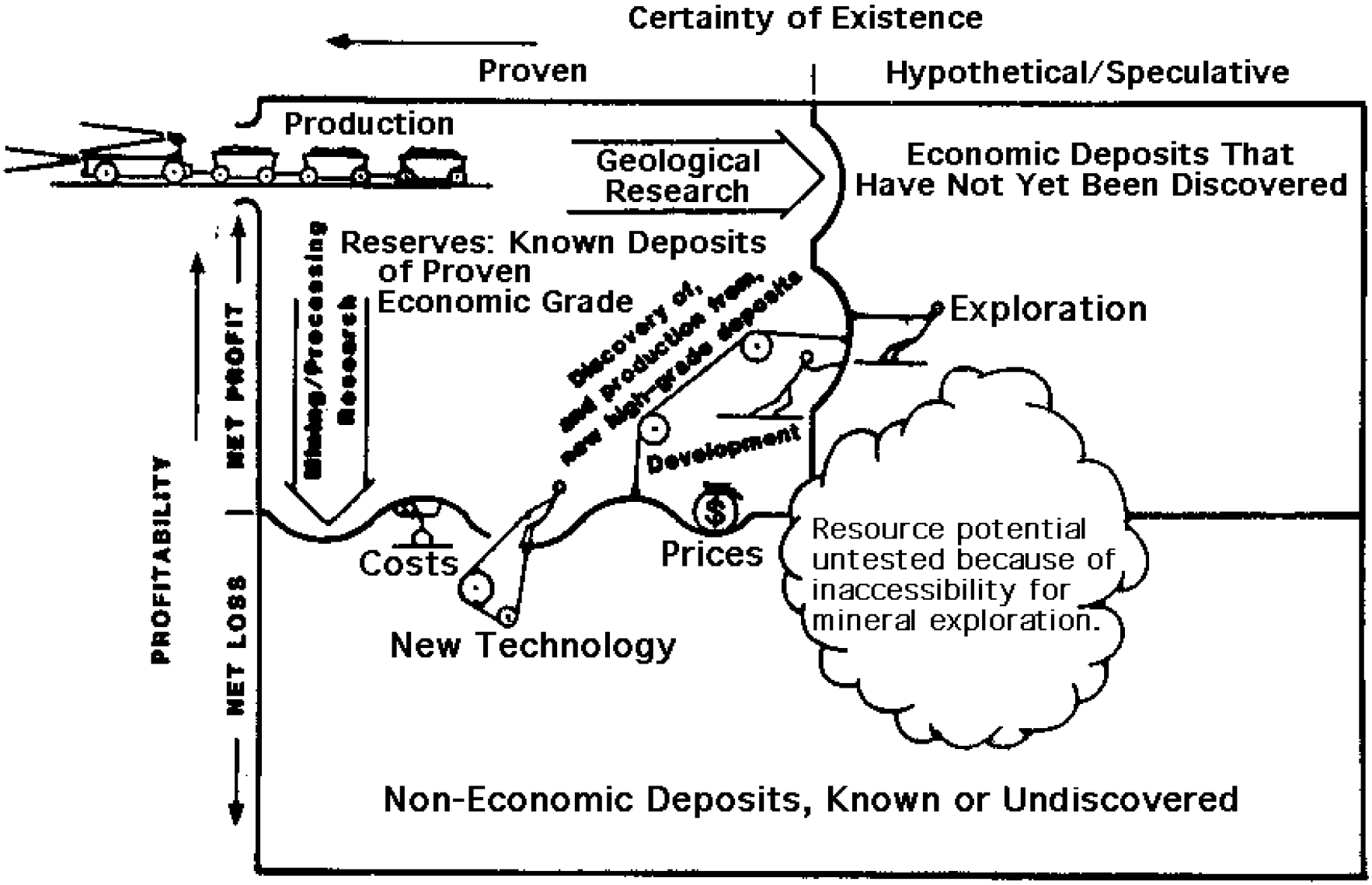
What is an Ore Deposit?

- Concentration of minerals
- Recoverable at a profit
- Dynamic function of economic, engineering, political, and environmental factors

USBM Box - Slides

- Reserves
  - identified geologically and are economic at present
- Reserve Base
  - reserves plus identified lower quality material
- Resources
  - reserve base plus any other concentration to be found in the future- educated guess


Cumulative Production
Identified Resources
Undiscovered Resources
Demonstrated
Inferred
Probability Range
(or)
Measured
Indicated
Hypothetical
Speculative
Economic
Marginally Economic
Sub – economic
Reserves
Reserve Base
Resources
Economic, Engineering, and Environmental Factors
Geologic Factors


Certainty of Existence
Proven
Hypothetical/Speculative
Production
Geological Research
Economic Deposits That Have Not Yet Been Discovered
Reserves: Known Deposits of Proven Economic Grade
Mining/Processing Research
Discovery of, and production from, new high-grade deposits
Exploration
Development
PROFITABILITY
NET PROFIT
NET LOSS
Costs
Prices
New Technology
Resource potential untested because of inaccessibility for mineral exploration.
Non-Economic Deposits, Known or Undiscovered

Ore Minerals and Ore Forming Processes - Terminology

- Ore mineral(s)
- Gangue minerals - waste
- Grade or concentration - geologic
- Cut-off Grade - economic
- Size of Deposit

Geologic Processes

- Surface Processes
  - Weathering, Sedimentation (clastic and chemical)
- Subsurface Processes
  - Actions of Fluids
    - Magmas, Brines, Groundwater
  - Chemical & Physical Processes

Ex: Surface Processes

- Chemical & Physical Weathering
- Regolith and Soils
- Removal of Soluble Constituents
  - Downward groundwater flow
  - Residual concentrations - Fe, Al, (Ni)
- Redistribution of Material
  - Secondary enrichments - Copper sulfides

Clastic Sedimentary Processes

- As simple as Beach Sands
- Placers - winnowed by flowing water
  - Gold, Titanium, Magnetite, Uraninite
- Paleoplacers = (old, fossil placers)
  - Ex: Gold in South Africa

Chemical Sedimentary Processes

- Precipitation from water
- Isolated Basins
- Evaporites
  - Marine: Gypsum, Halite (Salt)
  - Lakes: Trona (sodium salts - glass/ceramics)
- Banded Iron Formations - most important
- Metal-rich fluids injected into sed. basins

Reserve and Resource Estimation

- Earth's mineral endowment = Resource
- Fraction which has been identified and can be extracted at a profit = Reserve
- Estimates of these rely on Geology and Statistics

Geological Estimates

- Based on actual observation
- Individual deposit data is collected and compiled
- Such estimates only give us measured and perhaps indicated reserves
- How can we know resources?
- Categorize favorable geological environments - the educated ‘guessing’

Resource Estimation

- Particular commodities occur in only certain geological settings
- Searches can be focused after or during routine mapping
- Can identify probabilities of finding specific settings
- This may work with known deposit types but fails for those resources in deposit types not yet known or recognized

Statistical Estimates

- Usually hinge on the assumption that the mineral reserve can be treated as a single homogenous population
- This allows estimates of the whole to be made from partial information
- NO information on the where; only the how much
- Several empirical observations have been made:

Crustal Abundance Relation

- Reserves for some elements exhibit a constant ratio to their average crustal abundance
- Reserves for less explored commodities can be estimated from well explored ones
- See Fig 13-1 A. for such a plot

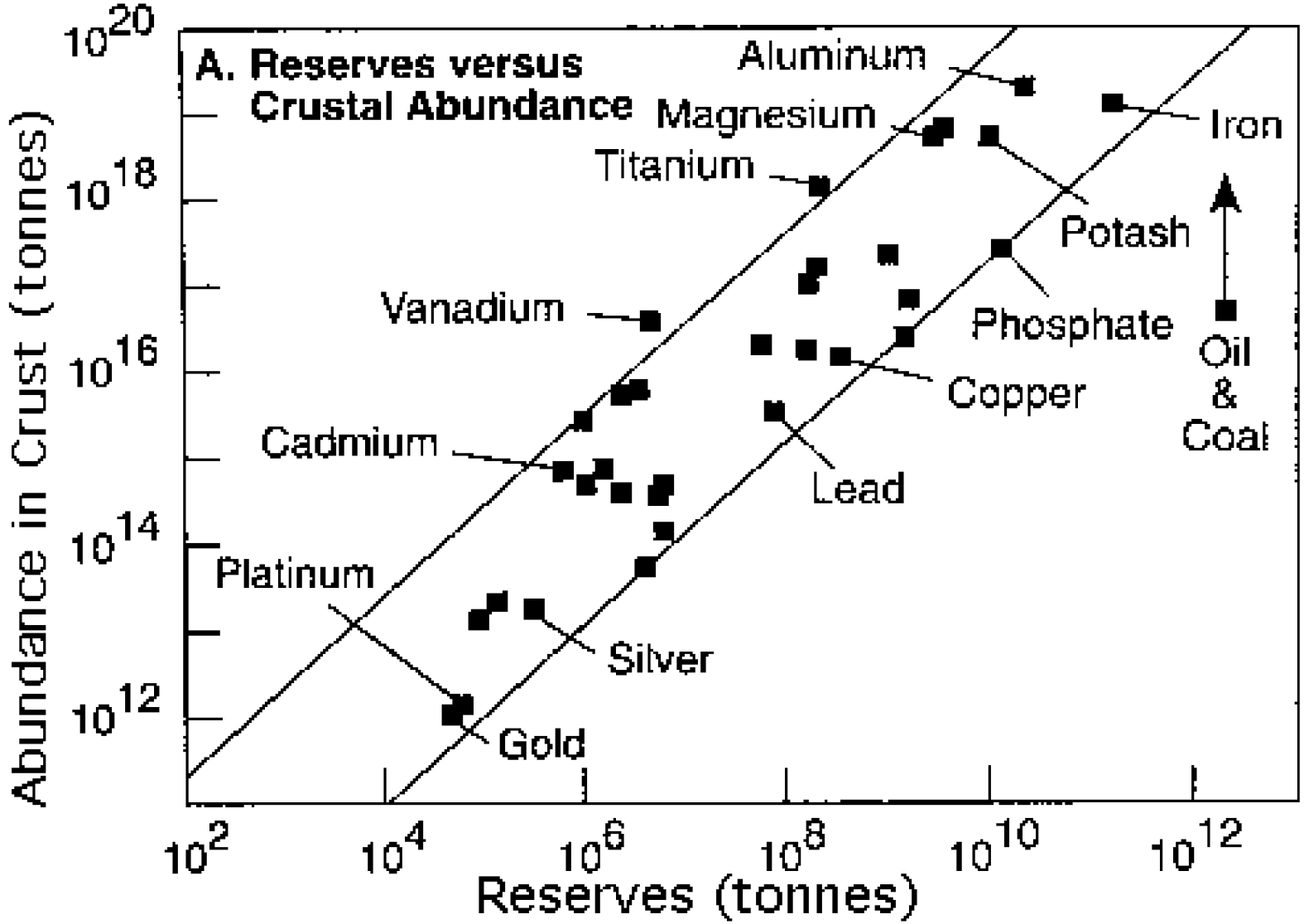


Figure 13-1 A, Mineral Resources, Economics and the Environment, S.E. Kesler, Macmillan

Lasky Relation

- Logarithmic increase in volume with an arithmetic decrease in grade
- Exact ratio varies with deposit type
- See Fig 13-1 B for example of Cu

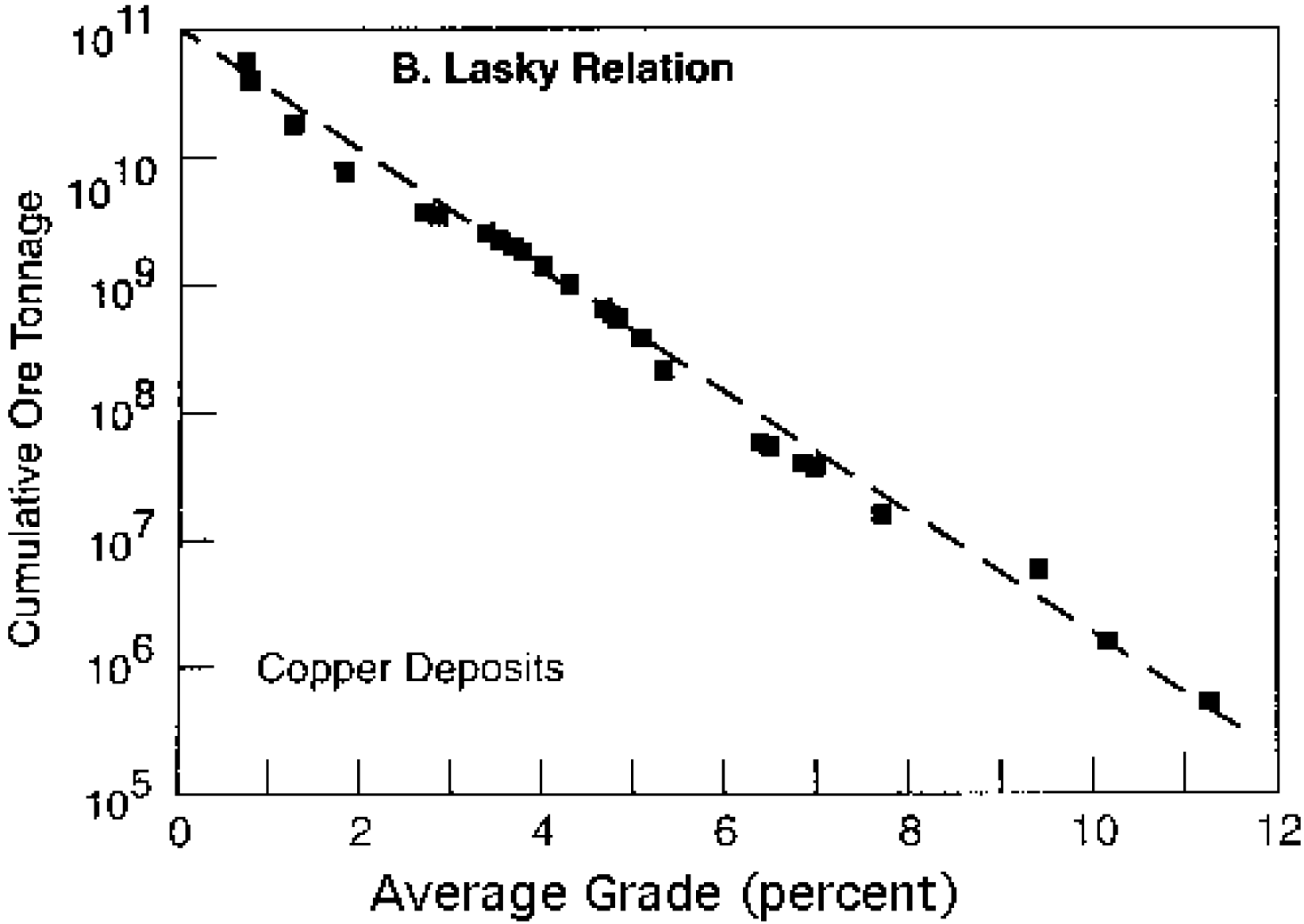


Figure 13-1 B, Mineral Resources, Economics and the Environment, S.E. Kesler, Macmillan

Watch out for Extrapolation!

- Infinite resource with infinitely low grade
  - Nonsense of course
- Neglects energy costs
- Assumes that the element/deposit remains the same in different rock types
  - Forms own mineral at “high” concentrations
  - Substitutes in crystal structure at “low” concs.

Combined Estimates are BEST

- Ex: Oil and Gas in the U.S. - Friday Class
- Similar data hard to acquire for most metals
- Where present, a single country's data is often masked by world wide production

Additional Factors

- Stockpiles - perhaps short term but…
  - Strategic minerals; definition changes
  - Abnormal factor in nominally "free market"
- Recycling
  - Most perfect form of mineral use
  - Not possible with many things however
  - (Will be KEY in space)

World Reserves and the Future

- Divide reserve figures by present consumption = RB/P
- 1992 data shown in Figure 13-5
- Some things are in very short supply

Use Reserve Base Instead of Reserves?

- Provides a longer term perspective
- 1 to 5 times more material available than in reserve calculation
- However what is the fallacy with this logic?

Population and Standard of Living will Increase Significantly

- Therefore present consumption is a minimum for the future
- 2 to 3 times greater consumption as an average for the next 10-50 years is likely
- Maybe twice the time shown in the Table before we run out of certain materials

Additional Problems with this Summary

- Source of the numbers: compare 1964 to early 1980's consumption - Fig. 6-2
- RB/P does not tell us the rate at which a commodity can be produced
- Doesn't tell us what price is needed to make the reserve base available

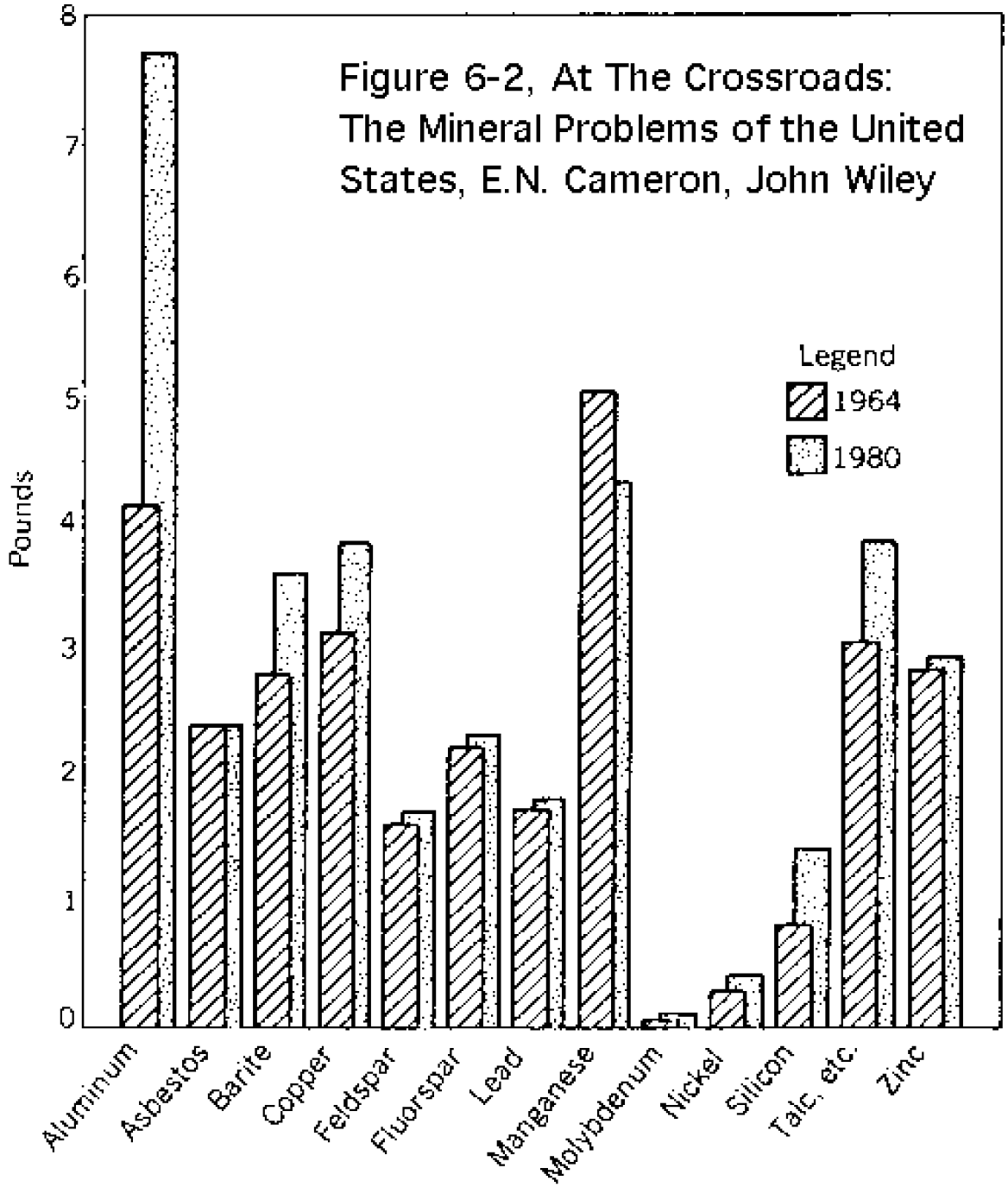


Figure 6-2, At The Crossroads: The Mineral Problems of the United States, E.N. Cameron, John Wiley
Pounds
0
1
2
3
4
5
6
7
8
Legend
1964
1980
Aluminum
Asbestos
Barite
Copper
Feldspar
Fluorspar
Lead
Manganese
Molybdenum
Nickel
Silicon
Talc, etc.
Zinc

Price vs Consumption

- Availability can be markedly influenced by price
- Fig. 6-1 shows 1980 U.S. consumption vs Price
- Cut the price by factor of 10 = consumption will increase 20-50 times

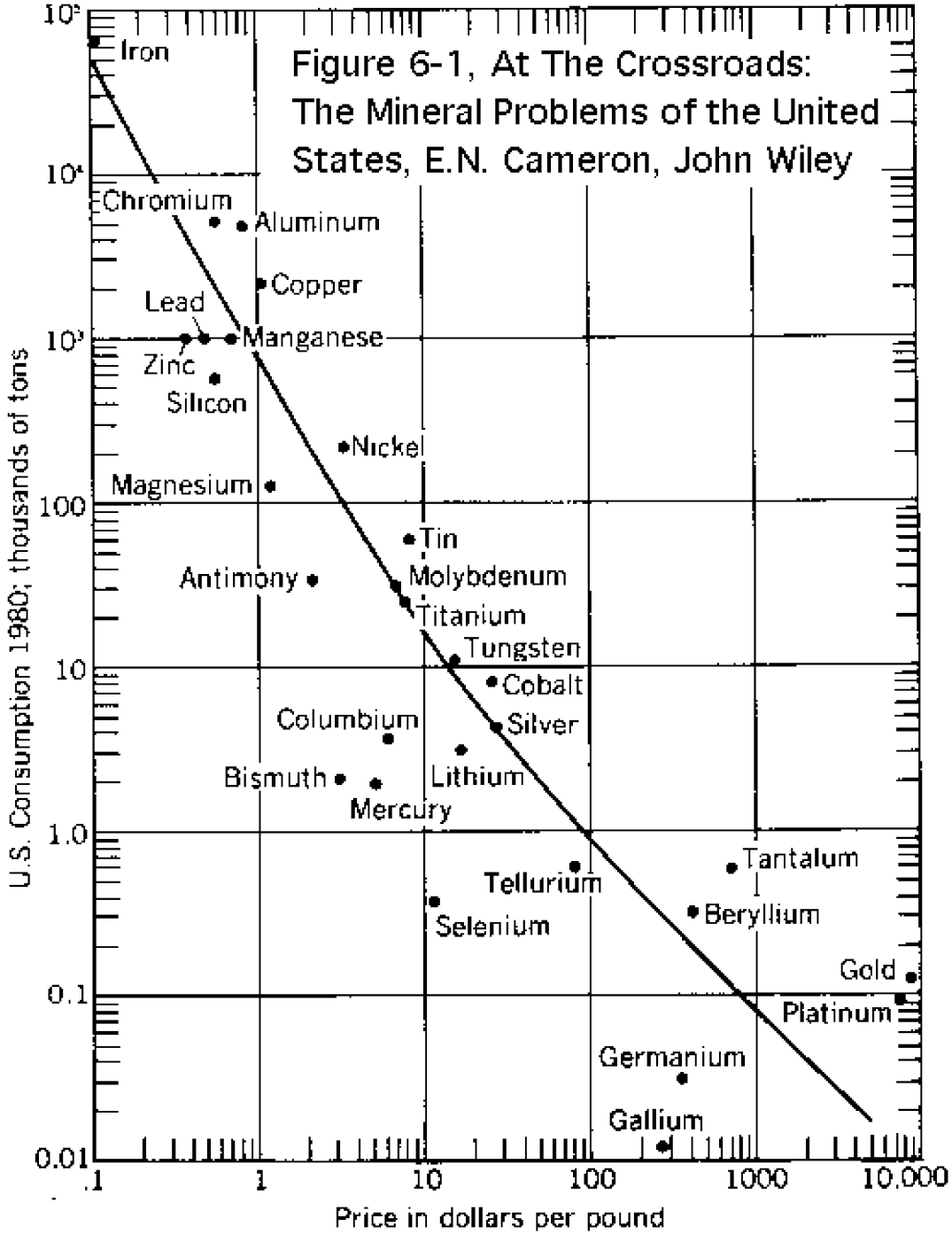
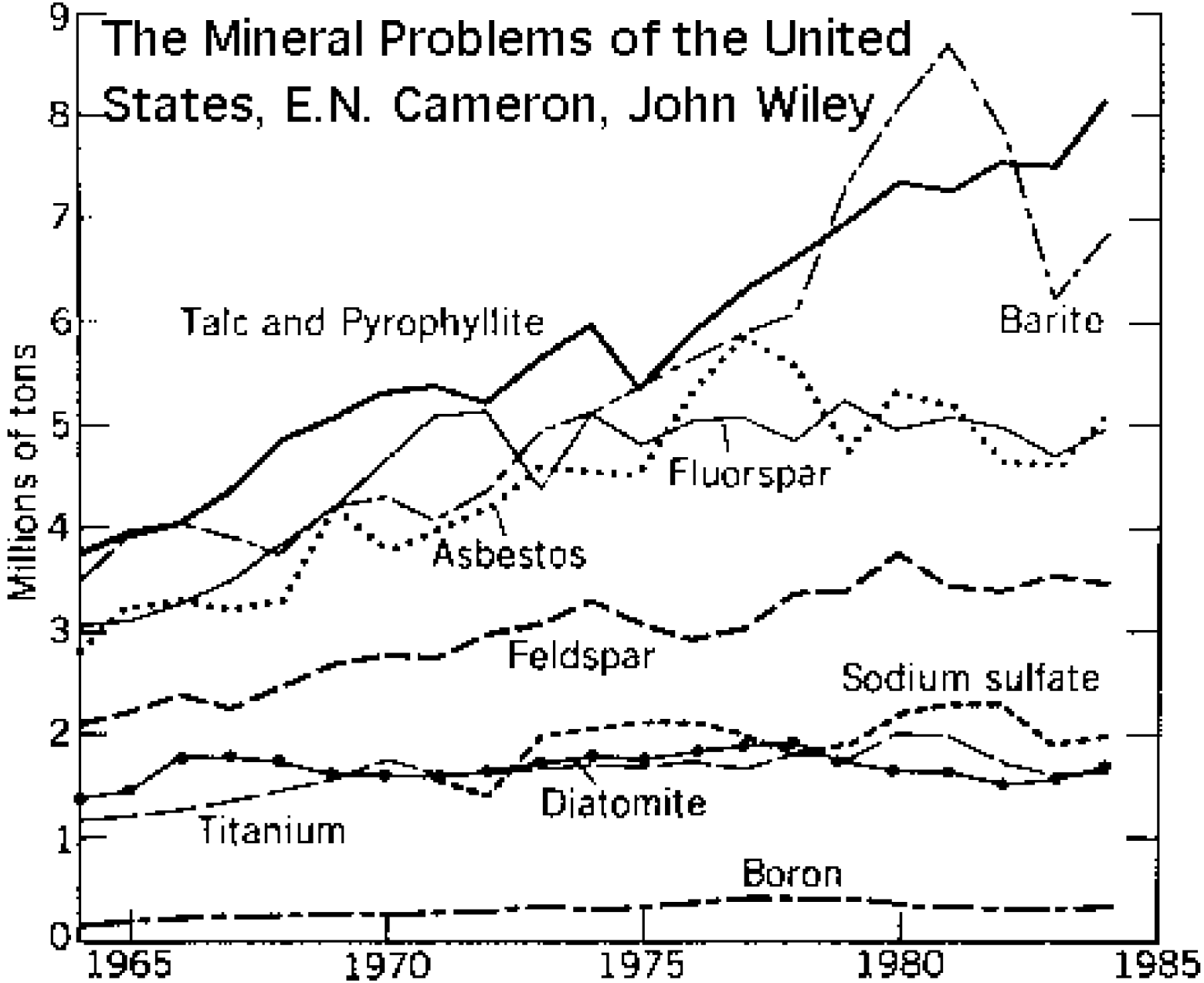


Figure 6-1, At The Crossroads: The Mineral Problems of the United States, E.N. Cameron, John Wiley
U.S. Consumption 1980; thousands of tons
Price in dollars per pound
10⁵
10⁴
10³
100
10
1.0
0.1
0.01
.1
1
10
100
1000
10,000
Iron
Chromium
Aluminum
Copper
Lead
Manganese
Zinc
Silicon
Nickel
Magnesium
Tin
Antimony
Molybdenum
Titanium
Tungsten
Cobalt
Columbium
Silver
Bismuth
Lithium
Mercury
Tantalum
Tellurium
Beryllium
Selenium
Gold
Platinum
Germanium
Gallium

How to Forecast Future Production?

- Look at past 20-30 years for guidance - see Fig. 6-8
- Examine and anticipate technological changes
- How can we anticipate events like the oil embargo?

Figure 6-8, At The Crossroads:
The Mineral Problems of the United States, E.N. Cameron, John Wiley



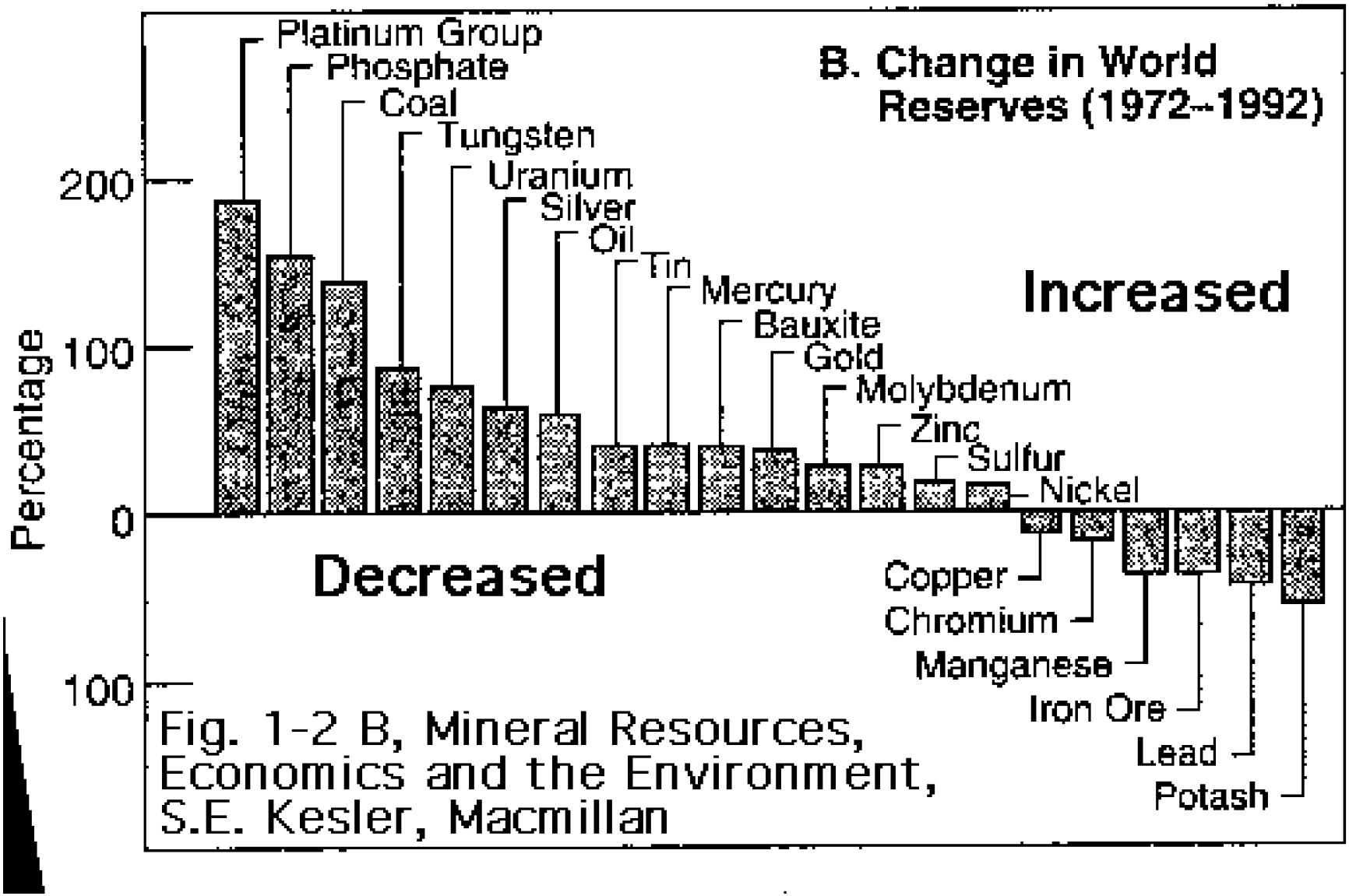


Fig. 1-2 B, Mineral Resources, Economics and the Environment, S.E. Kesler, Macmillan

The Real Significance of these Numbers:

- How long to find reserves and put them into production?
- Reserves are of no use if left in the ground
- Exploration takes a long time
- Development can take a long time
- Time is Money

How does this apply to Space

- Some rules the same, some different
  - "crustal abundances" vary from body to body
  - economies of scale may be missing
  - substitution possible?
  - role of recycling
- Technological constraints
  - Travel, extraction, processing, …