Introduction to Mining Geology

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Acknowledgments:

I acknowledge gratefully the extent to which I have leant on the work contained in several good text books:

Introductory Mining Engineering, 2nd Edition, Howard Hartman and Jan Mutmansky, 2007. John Wiley & Sons, Inc. 584p.

Surface and underground excavations: methods, techniques & equipment, by Tatiya, R.R., 2005. A.A. Bakema, 579p.

Mining and the Environment: From Ore to Metal, by Karlheinz Spitz and John Trudinger, 2009. CRC Press, Leiden.

Mine Wastes: Characterization, Treatment and Environmental Impacts, 2nd Edition, by Bernd Lottermoser, 2007. Springer, Berlin Heidelberg.

OUTLINE OF LECTURES:

Topic 1: Ore mineralogy and orebodies
Topic 2: Topic 2: The Mining Cycle
Topic 3: Mineral Resource and Reserve
Topic 4: Mining Methods
Topic 5: Mining Methods- Part I-Surface mining
Topic 6: Mining Methods-Part II: Surface Mining-Planning and Design of Open Pit Mining
Topic 7: Mining Methods- Part III: Surface mining- Placer Mining
Topic 8: Mining Methods- Part IV: In-Situ Leaching (ISL)/ Solution Mining
Topic 9: Mining Methods- Part V- Underground Mining
Topic 10: Ore processing and metal recovery
Topic 11: Mine wastes
Topic 12: Environmental and social concerns

Introduction

- An Introduction to Mining and Mineral Processing is to geologists.
- This course provides a non-technical introduction to the basic concepts of:
  - Mineral exploration,
  - Ore extraction,
  - Mineral processing,
  - Mine waste management

  - With numerous examples, figures and images of mining.
  - Also included are some key aspects of the economics of a mining and mineral processing operation and some ideas about the future of mining.

Topic 1: Concepts of an Ore Deposit

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Outline of Topic 1:

- INTRODUCTION
- What is mining?
- Why do we need mines?
- What is a mineral ?
- What is an Ore Deposit?
- Concentrations of Metals
- Metals enrichment factors
- Types of Ore Deposit
- GEOLOGIC CONDITIONS AND CHARACTERISTIC OF ORE DEPOSITS:
    1) Shape of ore deposits
    2) Dip ore deposits
    3) Thickness ore deposits
    4) Depth of ore deposits
    5) Structure of ore deposits
    6) Ore value and profitability of mining
    7) Stability of ore rocks
    8) Chemical and mineral characteristics of ores
    9) Lessening of ore deposit
    10) Degree of breakability
- Life Cycle of a Metal Resource
- Mineral Supply and Demand
- Conservation
- Economic Impact on Mineral Supplies

We will explore all of the above in Topic 1.

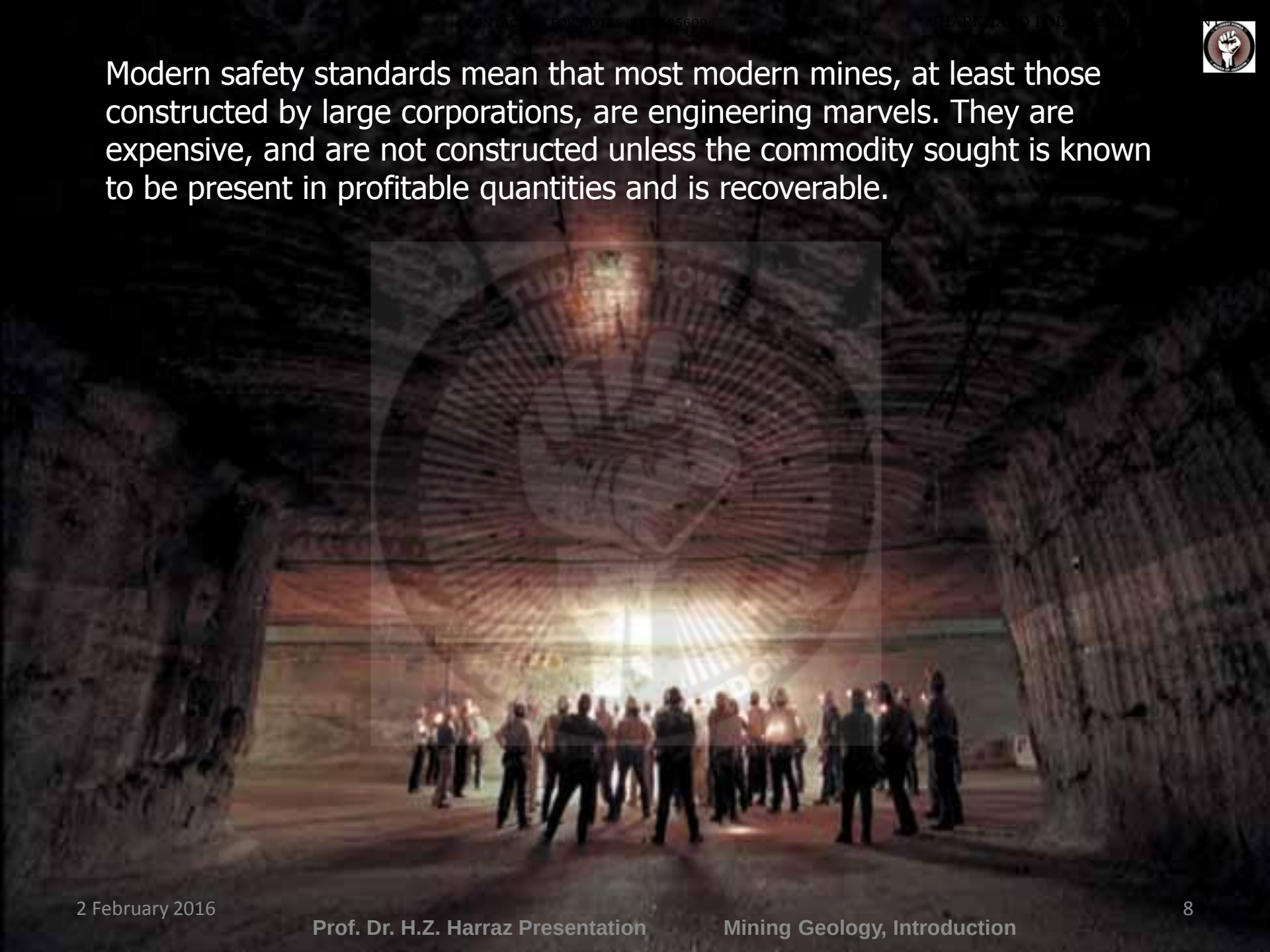
Mining Geology

- This is one of three employment centers for geologists, and it is presently enjoying a boom. The other boom employers are:

- The Petroleum Industry

- The Environmental Industry

Modern safety standards mean that most modern mines, at least those constructed by large corporations, are engineering marvels. They are expensive, and are not constructed unless the commodity sought is known to be present in profitable quantities and is recoverable.



What its all about!

Gold Bullion

What is mining?

Mining

The *activity* that removes from the earth's crust the abnormal concentration of metal found in the deposit

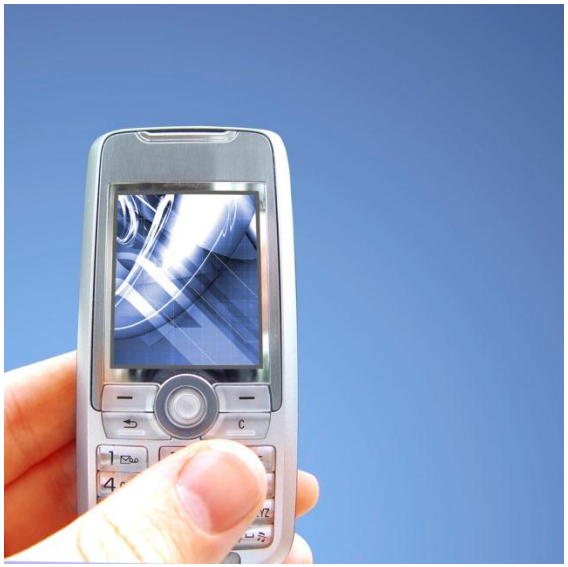
- Mining is extracting ore or minerals from the ground

Mine

An opening or excavation of the earth from which minerals are extracted

Why do we need mines?

- Houses
- Cars
- Toothpaste
- Plumbing
- Wiring
- Planes
- Electronics
- Jewelry
- Glass



If we can't grow it, it has to be mined!

What is a mineral ?

Mineral is a solid naturally-occurring compound having a definite chemical composition which under the present technological can be extracted.

Ore is a natural material with a high concentration of economically valuable minerals that can be mined for a profit

http://en.wikipedia.org/wiki/File:Pyrite_foolsgold.jpg

http://en.wikipedia.org/wiki/File:chalcopyrite.jpg

What is an Ore Deposit?

Ore deposit is an occurrence of minerals or metals in sufficiently high concentration to be profitable to mine and process **using current technology** and under **current economic conditions**.

Ore deposits may be considered as:

- Commercial mineral deposits (i.e., ***Ore:*** suitable for mining in the present times) or
- non-commercial ore deposits (i.e., ***Protore:*** problems in mining, transportation, prices....etc).

What is Ore Grade?

Ore grade is the concentration of economic mineral or metal in an ore deposit.

Grade units

Base metals	Weight percentage (wt.%)
Precious metals **(gold, silver, platinum)**	grams/tonne oz/ton ppm

Concentrations of Metals

Earth is a big planet

- The crust is the outer 20 km of earth.
- It is underlain by the mantle which is about 3000 km thick.
- The mantle is underlain by the earth's *core* which is about 3400 km thick.
- The radius of the Earth is about 6500 km.

We have mined as only as deep as 2 km !!!!

By comparison, the crustal concentration of silicon is 28% and that of oxygen is 46%.

1 ppm = 1 part per million.
1 ppm = 0.0001% = 1 gram/tonne

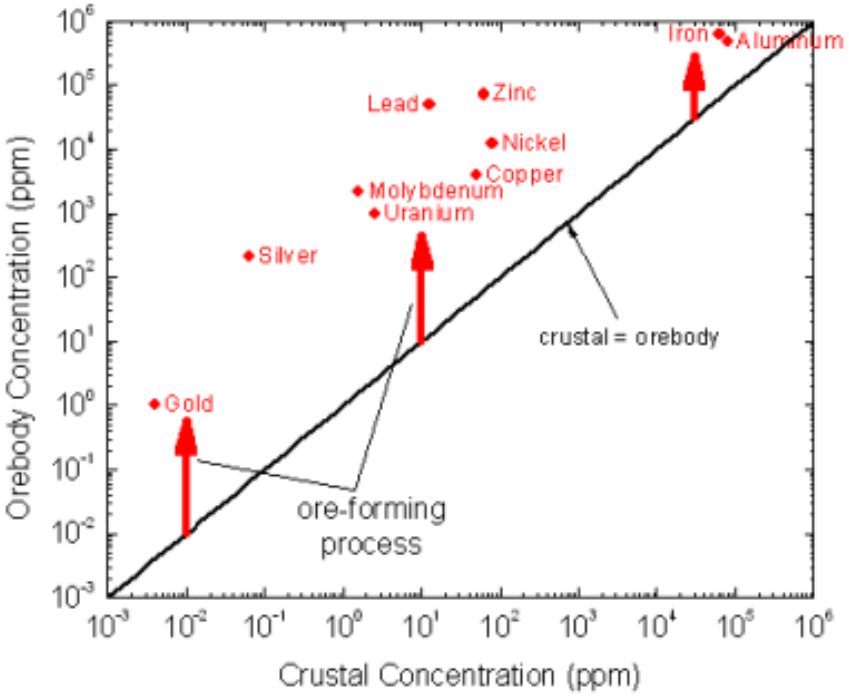
Metal	In Earth's crust concentration (Clarke)		In Ore Deposit Typical Grade	
	(wt.%)	(ppm)	(wt.%)	(ppm)
Aluminum	8.0	80,000	47	470,000
Iron	6.3	63,000	62	620,000
Copper	0.005	50	0.4 - 1	4,000 -10,000
Nickel	0.008	80	1.22	12,200
Zinc	0.0062	62	7.1	71,000
Uranium	0.00025	2.5	0.1 – 20	1,000- 200,000
Lead	0.00126	12.6	5	50,000
Silver	0.0000063	0.063	0.021	210
Gold	0.0000004	0.004	0.0001 - 0.0005	1 – 5
Molybdenum	0.000016	1.6	0.21	2,100

The grade of a typical gold deposit is of the order of thousands of times greater than the average concentration of gold in the earth's crust.
In contrast, the grade of an iron deposit is only 10 times greater.

These relationships are illustrated by a plot of the data in Figure 2 below.

What does it take to be an ore deposit?

Gold and silver are not abundant - lots of concentration is needed, more than one order of magnitude.



Iron and aluminum are abundant in crust - not much concentration is needed.

Figure 6. Orebody and crustal concentrations - if we were happy with average concentrations in the crust, all orebodies would line up along the y = x line.

(Note the logarithmic scale - one large division equals one order of magnitude, i.e multiply by 10)

Metals enrichment factors

Metals require significant enrichment above their normal background levels in the Earth's crust to form a mineable orebody.

Minerals are enriched to form orebodies through a wide range of different geological processes.

The enrichment factor required to make a mine viable *(i.e., profitable – within today's economic framework for minerals exploitation)* will vary from time to time, depending on commodity prices, and the ease of extraction of both the orebody from the ground and the target metal from the orebody.

- The concentrations of metals in ore deposits *depends on the current price of the metal since ore is what can be mined under current economic conditions.*

- Thus, as price goes up, the concentration of metal required to make rock an ore deposit, goes down.

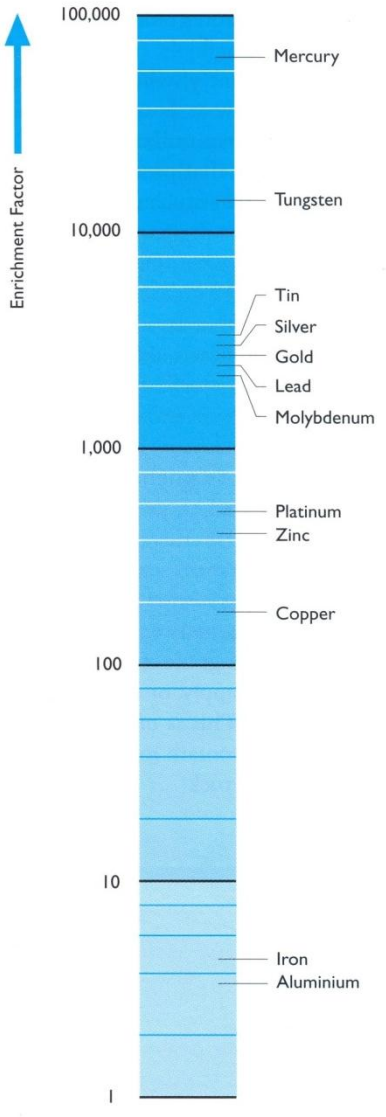
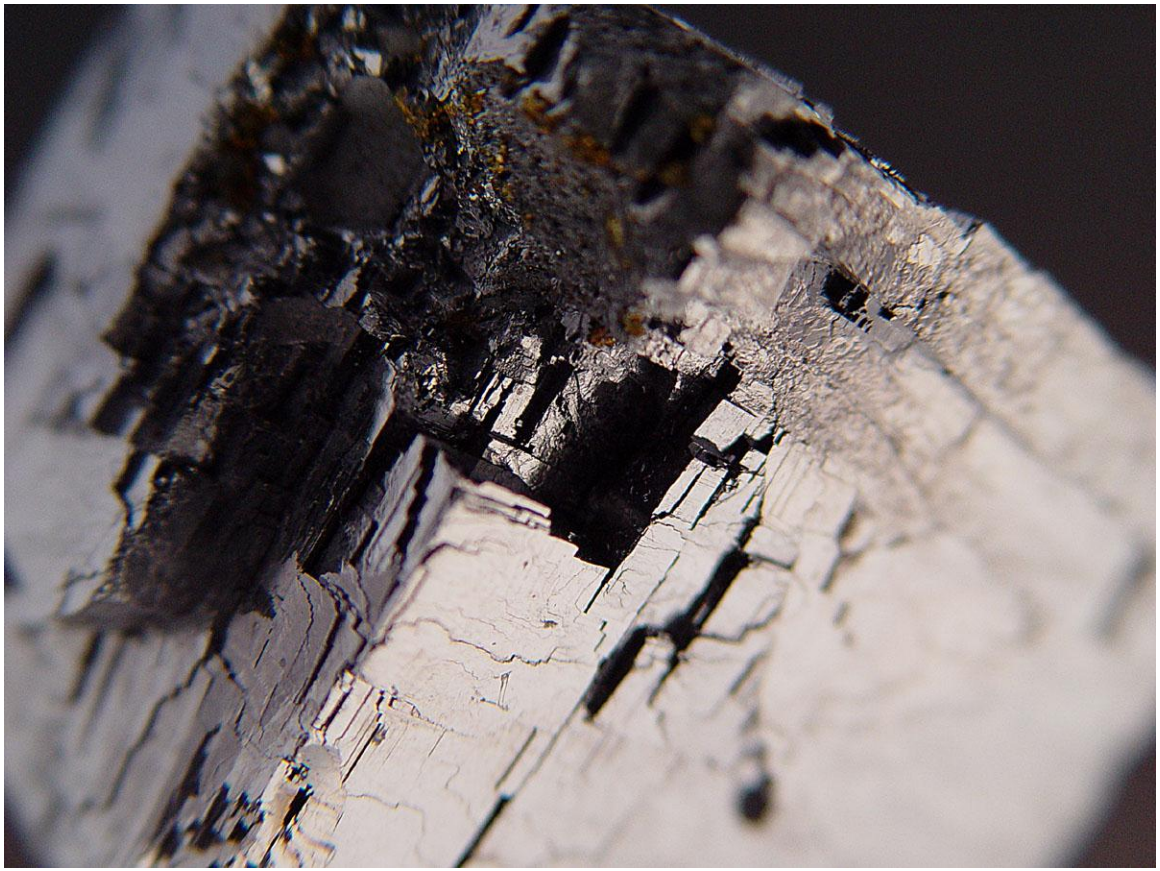


Figure from Spitz and Trudinger, 2009.

Useful metals come from rocks and minerals in the Earth's crust.



Galena sample – a main ore of lead. *Image: Stonetrust, Inc.*

Types of Ore Deposit

There are several types of ore deposits:

- **Magmatic:** crystallization of minerals within a body. of magma
- **Hydrothermal:** hot fluids released as magma cools, minerals precipitate from fluids.
- **Sedimentary:** precipitation of minerals from a lake or ocean water
- **Placer deposits:** deposition of metals in a river or stream (causing people to pan for them).
- **Residual:** concentrations of minerals produced by weathering and chemical reactions with oxygen and water.

This is a very broad classification. There are many sub-types and even more types - nature provides much complexity.

GEOLOGIC CONDITIONS AND CHARACTERISTIC OF ORE DEPOSITS

Parameters for dip, depth, thickness and geometry of deposits (***source SME Min. Eng. Handbook, 3ed., 2011) :***

1) Shape of ore deposits
2) Dip ore deposits
3) Thickness ore deposits
4) Depth of ore deposits
5) Structure of ore deposits
6) Ore value and profitability of mining
7) Stability of ore rocks
8) Chemical and mineral characteristics of ores
9) Lessening of ore deposit
10) Degree of breakability

1) Shape of ore deposits:-

According to shape features, ore deposits can be classified into three groups as follows:

i. Isometrical group: stock, nests, irregular shapes but their dimensions in space do not differ greatly,...etc.
ii. Tabular Groups
iii. Columnar group: extend in one direction, like; veins, layer, bed, seam, sheet, lenses,
iv. Impregnation or disseminated ore group

2) Dip ore deposits

Tabular deposits classified by dip and related to handling and rock strength as follows:

Class	Dip	Rock Strength	Bulk Handling Mode
Flat	≤ 20°	Weak rock (surficial)	Use mobile equipment (or conveyors)
Inclined	20 - 45°	Average rock	Use slashers (metal plate can also vibrate – as gravity slides)
Steep	≥45°	Strong rock (at depth)	Gravity flow of bulk solids

3) Thickness ore deposits

according to amounts of thickness of ore body, the deposits can be classified into:

Class	Deposit Thickness (m)		Comments
	Coal	Ore	
Tabular deposit			
Thin	≤0.9 - 1.2	≤0.9 - 1.8	Low profile or narrow mine equipment
Medium	1.2 – 2.4	1.8 – 4.6	Past and Stulls ≤3.1 m
Thick	2.4 – 4.6	4.6 – 5.3	Small surface equipment; crib problems
Massive (Very thick)	>4.6	>5.3	Pillar problems or poor recovery, benching necessary; caving considered

4) Depth of ore deposits:

Deposits classified by depth into:-

	Deposit Depth (m)		
	Underground (a measure of overburden pressure)		
Class	**Coal**	**Ore**	**Surface**
Shallow	≤61 Slope Entries possible	3≤05	≤61
Moderate	122 – 244 Pillar problems	305 - 457	61 -305
Deep	≥915 Bumps, Burst, Closure	≥1830	≥305 – 915 Open pit

5) Structure of ore deposits

according to structure of ore body, the deposits can be classified into:-

I. Massive ore.
II. Laminated ore.
III. Jointed ore.
IV. Loose ore.

Depend on Lumpiness of broken ore (i.e., size of lumps obtained on breaking parts), ore may be divided into:

a) Fine size ores	Dust to lumps (<100 mm)
b) Medium size ores	100 -300 mm
c) Large size ores	300 - 600 mm
d) Very large size ores	>600 mm

6) Ore value and profitability of mining

according to relative value of assay, the deposits can be classified into:

I. Rich ore

II. Medium ore.

III. Lean ore (Uneconomic): Only extracted by cheapest techniques like hand methods.

7) Stability of ore rocks

Stability is ability of massif to resist caving for a certain period of time.

The stability of ore rocks is usually depending on amounts of joints and laminations in the ore rocks as well as hardness of the ore rocks.

Therefore, the ore rocks may be divided into:-

I. Very unstable ore rock (like friable sandstones)
II. Unstable ore rock.
III. Medium ore rock.
IV. Stable ore rock.
V. Very stable ore rock.

8) Chemical and mineral characteristics of ores

I. Native ores
II. Noble metals.
III. Sulphide ores: chalcopyrite ($CuFeS_2$), Galena (PbS), pyrite (FeS), sphalerite (ZnS), stibnite (Sb_2S_3), and molybdnite (MoS_2).
IV. Oxidized ores: Hematite (Fe_2O_3), Magnetite (Fe_3O_4), Goethite ($Fe_2O_3.nH_2O$), (MnO_2), Cuprite (CuO_2), Cassiterite (SnO_2), and Chromite ($FeCrO_3$).
V. Silicate ores: Zircon ($ZrSiO_4$) and Beryl ($Al_2Be_3Si_6O_8$).

9) Lessening of ore deposit

I. **Oxidation** **(iron deposit, sulphide deposits)**

II. **Caking** **(Mn deposits)**

III. **Self ignition** **(Sulphur, coal)**

10) Degree of breakability

Breakability is the resistance of a rock parts to separation from the mass.

- According to its breakability, every rock falls into one of the following five groups:
  - Friable and flowing (ex. sand, peat, topsoil);
  - Soft (like. Clay);
  - Brittle (ex. Sandstone, limestone, shale, coal);
  - Strong (ex. granite, magnetite);
  - Very strong (ex. quartzite, diabase, porphyry).

The choice of the proper *method of breaking ground* depends first of all on the *degree of breakability* of the rock.

The following properties of rock must be distinguished:

i) Hardness: the resistance to penetration by a pointed tool;
ii) Strength,
iii) Toughness: the resistance of the mass to the separation of pieces from it;
iv) Elasticity or resilience: the resistance to impact.

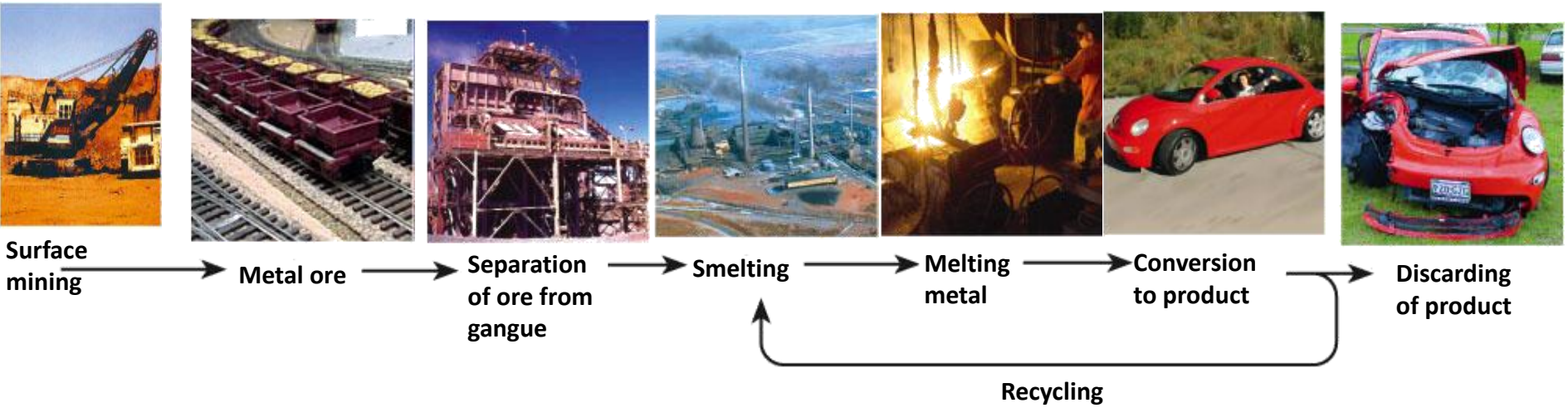
For classifying a rock in one of the last three groups, no strict criteria exist, therefore the classification suffers from a high degree of subjectivity, the more so as the properties of a rock can be vary with its structure (fissuring, foliation) and condition (weathering).

In this classification, a standard classification of rocks according to their amenability *to drilling and blasting*.

The reason for this classification is that drilling and blasting are very widely used in mining and yet many investigations have found no direct correlation between hardness or strength and the amenability of a rock to drilling and blasting.

In this classification, the amenability to drilling is evaluated by the speed of pure drilling in mm/minute and by the time of drilling 1 m of hole.

Life Cycle of a Metal Resource



Smelting : heating to release metals but creating air polluting by-products

Chemical removal processes such as using cyanide to remove gold can create Toxic holding ponds

Mining Ore

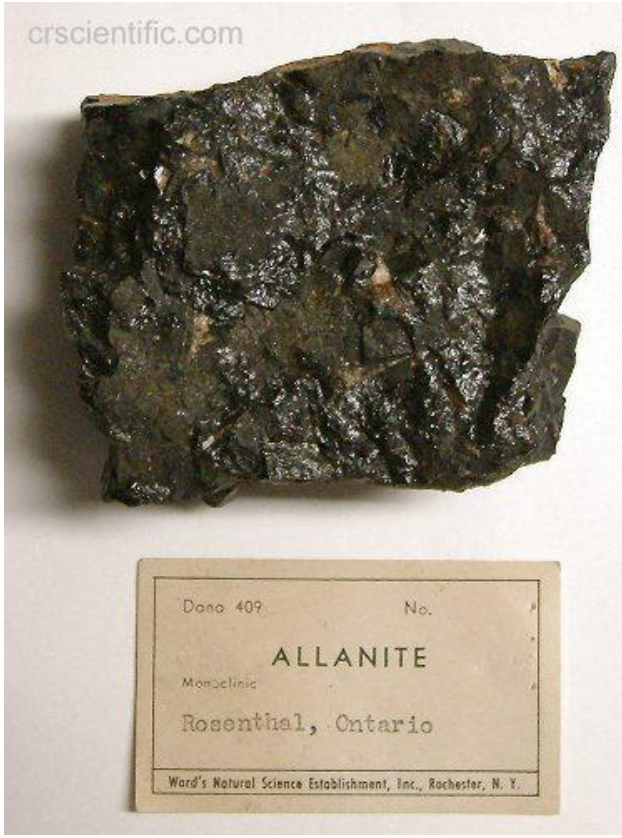
A) **Ore has two components:** gangue(waste) and desired metal.

B) **Separation** of ore and gangue which leaves tailings.

C) **Smelting** (air and water pollution and hazardous waste which contaminates the soil around the smelter for decades).

D) **Melting Metal.**

E) Conversion to product and discarding product.



Life Cycle of Metal Resources (fig. 14-8)

Mineral Supply and Demand

- World Scenario:
  - Assumptions:
    - ✓ Present demand = present production
    - ✓ Future projection is based on constant 1995 figures
    - ✓ Unrestricted distribution
  - Iron, Aluminum, Chromium, Cobalt and Platinum will last centuries
  - Copper, Lead, Zinc, Gold and Silver will last several decades only
  - Ditto for phosphates and sulfur
- Alleviating Factors:
  - More exploration
  - Better technology
  - Reclassification of sub-economic resources to reserve
- Reduce consumptions:
  - Smaller households, more leisure and travel, convenience, status etc. make it unlikely even in developed economies.
  - New technology adds to the existing needs e.g., cellular phones, computers, microwave oven.
  - In the US, population grew by 65% and consumption grew by 130% between 1950-1990.
  - Great demand for resources in the developing countries where there is a genuine need and where the great majority lives.
- If demand cannot be reduced, supplies must be increased or extended.

Conservation

- Substitution:
  - Increases consumption of the substituting metal or nonmetal (often petroleum) which itself might be limited in amount
- Recycling:
  - In USA 60% of lead, 40% of copper, 1/3rd of nickel and almost ¼ of Al, Cr, Co and Zn is recycled
  - Recycled Al requires 20 times less energy than new Al
  - Difficult to do with finished products like cars or fridges
  - Special problem with alloys
  - Road salt, fertilizers, lead in gasoline gets too disperse
  - Reduces waste disposal problem

Economic Impact on Mineral Supplies

A) Mineral prices are low because of subsidies: depletion allowances and deduct cost of finding more.

B) Mineral scarcity does not raise the market prices.

C) Mining Low Grade Ore: Some analysts say all we need to do is mine more low grade ores to meet our need:

1) We are able to mine low grade ore due to improved technology.

2) The problem is cost of mining and processing, availability of fresh water, environmental impact.

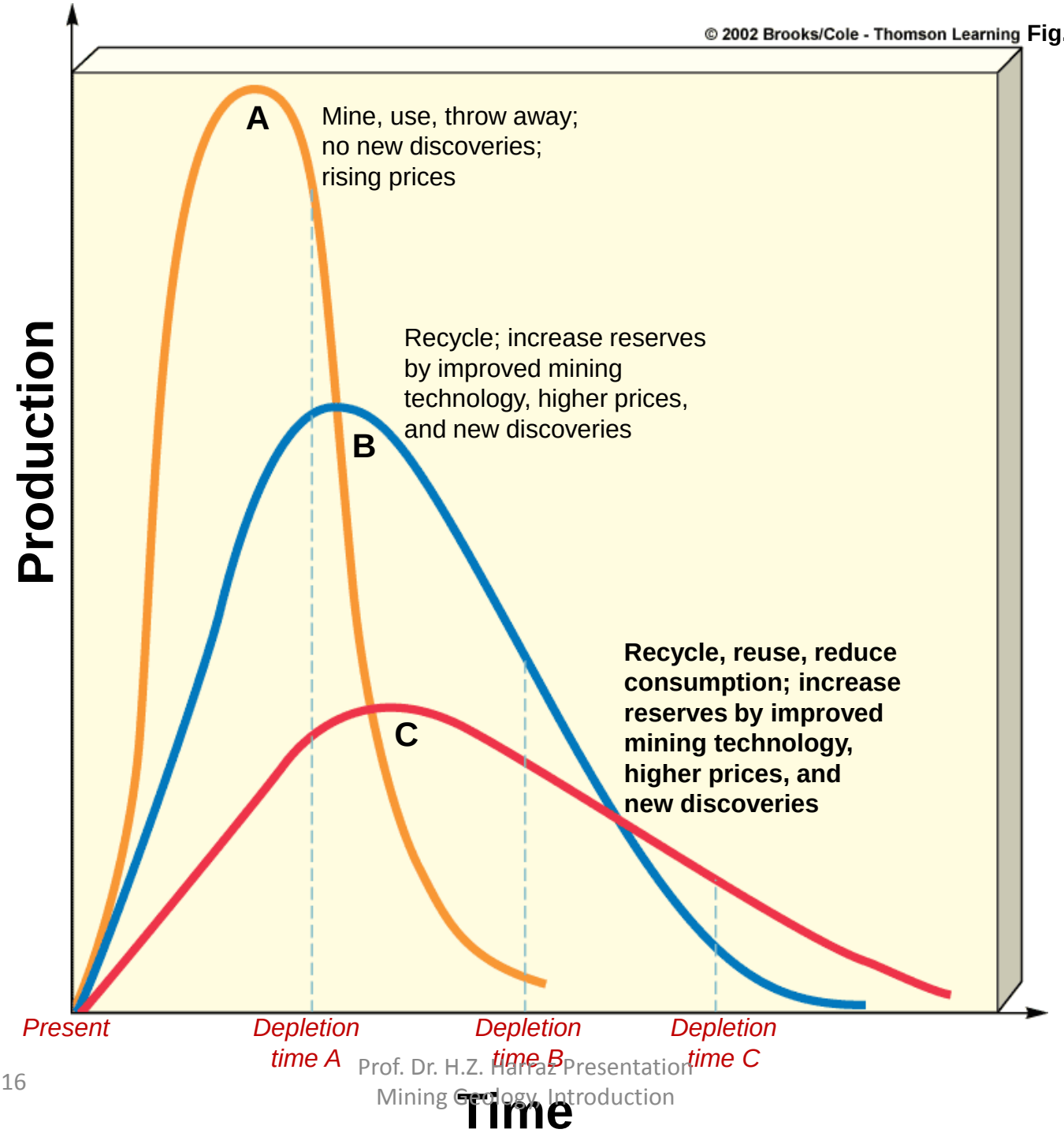

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Fig. 14.9, p. 329
A
Mine, use, throw away;
no new discoveries;
rising prices
Recycle; increase reserves
by improved mining
technology, higher prices,
and new discoveries
B
Recycle, reuse, reduce
consumption; increase
reserves by improved
mining technology,
higher prices, and
new discoveries
C
Production
Present
Depletion
time A
Depletion
time B
Depletion
time C
Time

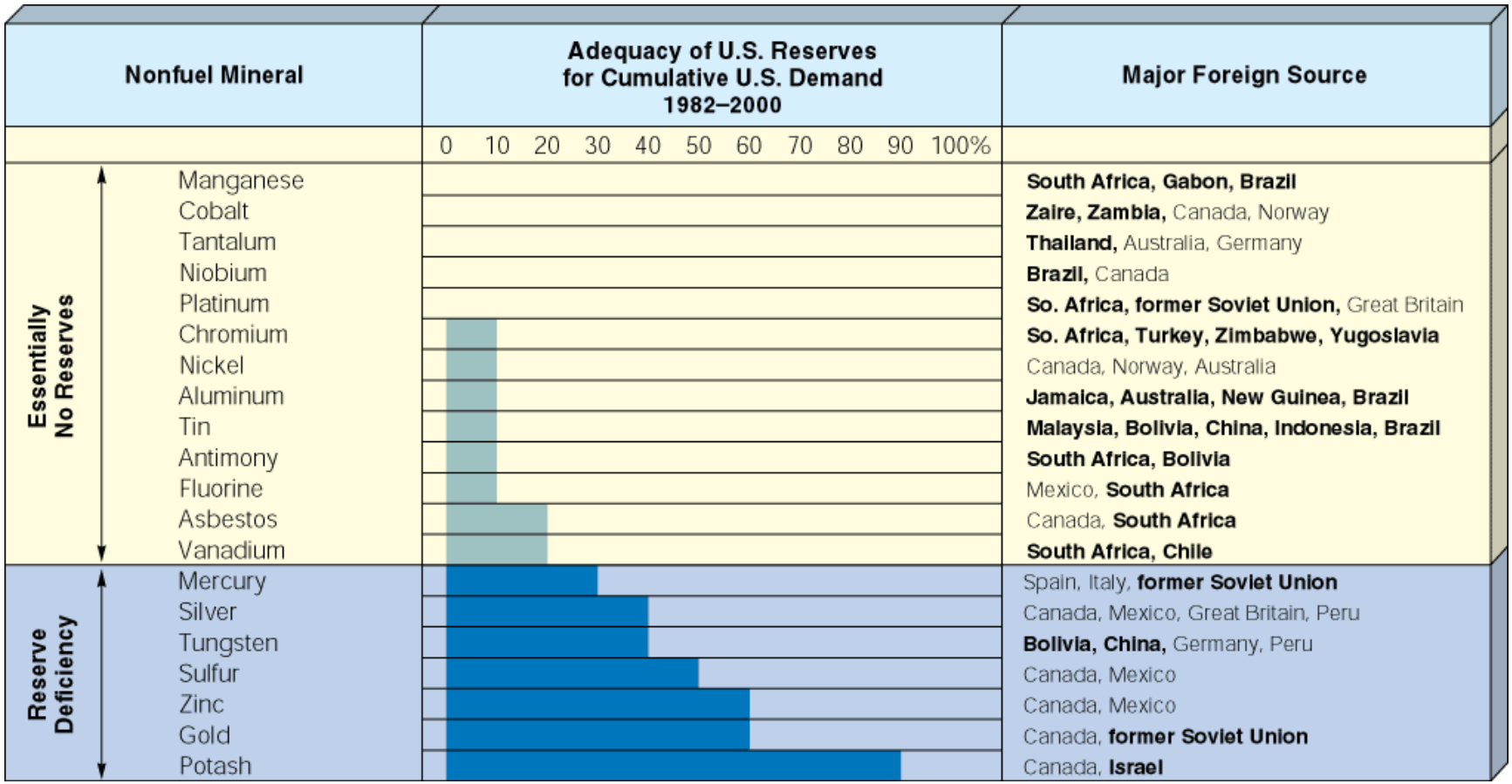

Fig. 14.10, p. 329