MEDICAL GEOLOGY/GEOCHEMISTRY: An Exposure

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IAP 2006: 12.091 Credit Course: January 9 - 25, 2006

Session 1, January 9, 2006

Detailed course work

The course work involves the following:

1. January 9, 11, 16, 18, 23 10 AM to 12 PM
   5 sessions each of 2 hours
   25%
2. Review Quiz– 5 Questions
   20%
3 Project
   Literature Survey – Writing a report
   30%
4. Project Presentation
   25%

Required percentage to pass this course is 85%
Grading: P/F

Session 1 January 9, 2006

Objective

Introduction:

- **Definitions and terminology of Medical Geology/Geochemistry**

Classification of elements:

- **Periodic table of elements**
- **Major, minor and trace Elements: Geological and biological materials**
- **Geochemical classification**

Elemental link between geosphere and biosphere:

- **An attempt to understanding**

Essential and non-essential elements with

- **reference to human health**

Selection of Elements for Report and Presentation

Introduction

Definitions &Terminology Of Medical Geology/Geochemistry

Definitions – Terminology

Geology definition

- **Scientific study of the origin, history, and structure of the earth.**
- **Structure of a specific region of the earth's crust.**
- **Scientific study of the origin, history, and structure of the solid matter of a celestial body.**

What is geology?

"Geology, the study of the earth, employs the methods of other sciences, as well as those unique to geology, to investigate the nature, processes, and history of the earth."

http://www.udel.edu/geology/define.html

Definitions – Terminology …

Geochemistry

- **The scientific study of the composition and alterations of the solid matter of the earth or a celestial body.**

- Scientific study of chemical processes and reactions forming the rocks and soils, and the cyclic processes that transport the Earth's chemical components in time and space.

Some important fields of geochemistry are:

- **Isotope geochemistry**: Scientific determination of the relative and absolute concentrations of the elements and their isotopes inside the earth and on the surface, examining the distribution and movements of elements in different parts of the earth such as crust, mantle etc., and also determining the distribution and movement of minerals.
- **Cosmogeochemistry**: Chemistry of the composition of elements and their isotopes in the **cosmos**.
- **Organic geochemistry**: Scientific study of processes and compounds that are derived from living or once-living organisms.

Definitions – Terminology …

Environmental Geochemistry

is the study of the geologic processes that interact strongly with the materials present in the Earth's crust.

The geologic processes:

- weathering of rocks,
- soil formation,
- solutes in surface and ground water,
- global atmospheric transport of particulate matter,
- global cycling of contaminant products.

Definitions – Terminology …

"geomedicine" or
"geographic medicine"
In 1930s , was the science using the geographical and cartographical methods to explain the results of medical research.

The term was redefined in 1990 as "the science dealing with the influence of ordinary environmental factors on the geographic distribution of health Problems in man and animals".
- J. Lag

Reference: General Survey of Geomedicine in Geomedicine, pp 1-24, J. Lag CRC Press, Boca Raton, Fl, 1990.

Definitions – Terminology …

Medical Geology /Geochemistry

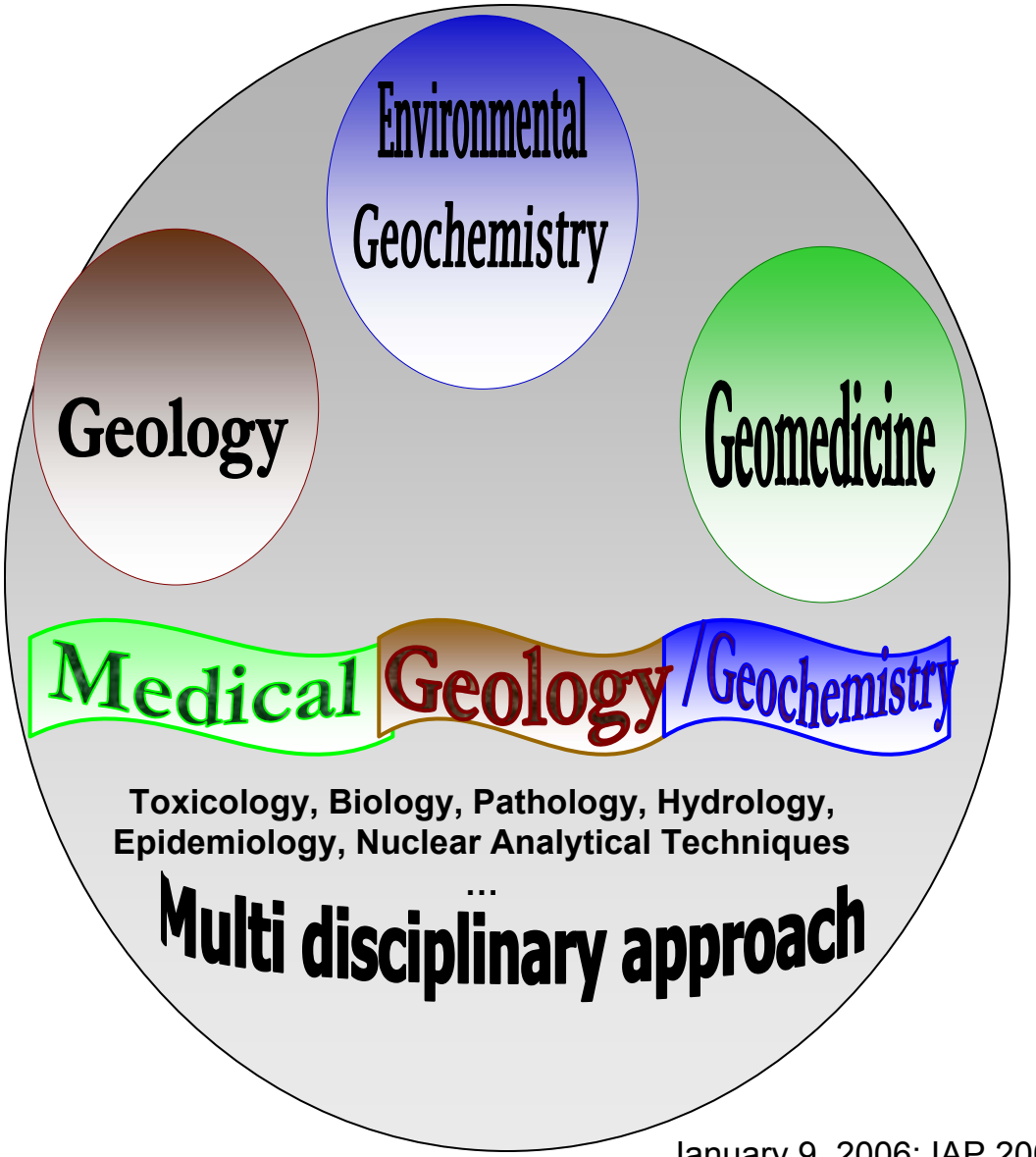
Medical geochemistry looks at the effects of geochemical processes and geological factors on the health of humans and plants.

Geomedicine /Geographic Medicine

"**Medical geography** looks at the geographical distribution of disease while **not focusing** on the underlying geology. It examines the causal associations between specific diseases and the physical and social environments."

References:Selinus 2002, Finkelman et al 2001 ; Lag 1990; Medical Geology: new relevance in the earth sciences.
C. A. Bowman, P. T. Bobrowsky, O. Selinus Episodes Vol. 26(4) 270-278, 2003

Definitions – Terminology …



Medical Geology/Geochemistry

is the study of interaction between abundances of elements and isotopes and the health of humans and plants.

Classification of Elements

- Periodic Table of Elements
- Major-Minor-Trace Elements
- Geochemical Classification
- Essential and Non-Essential

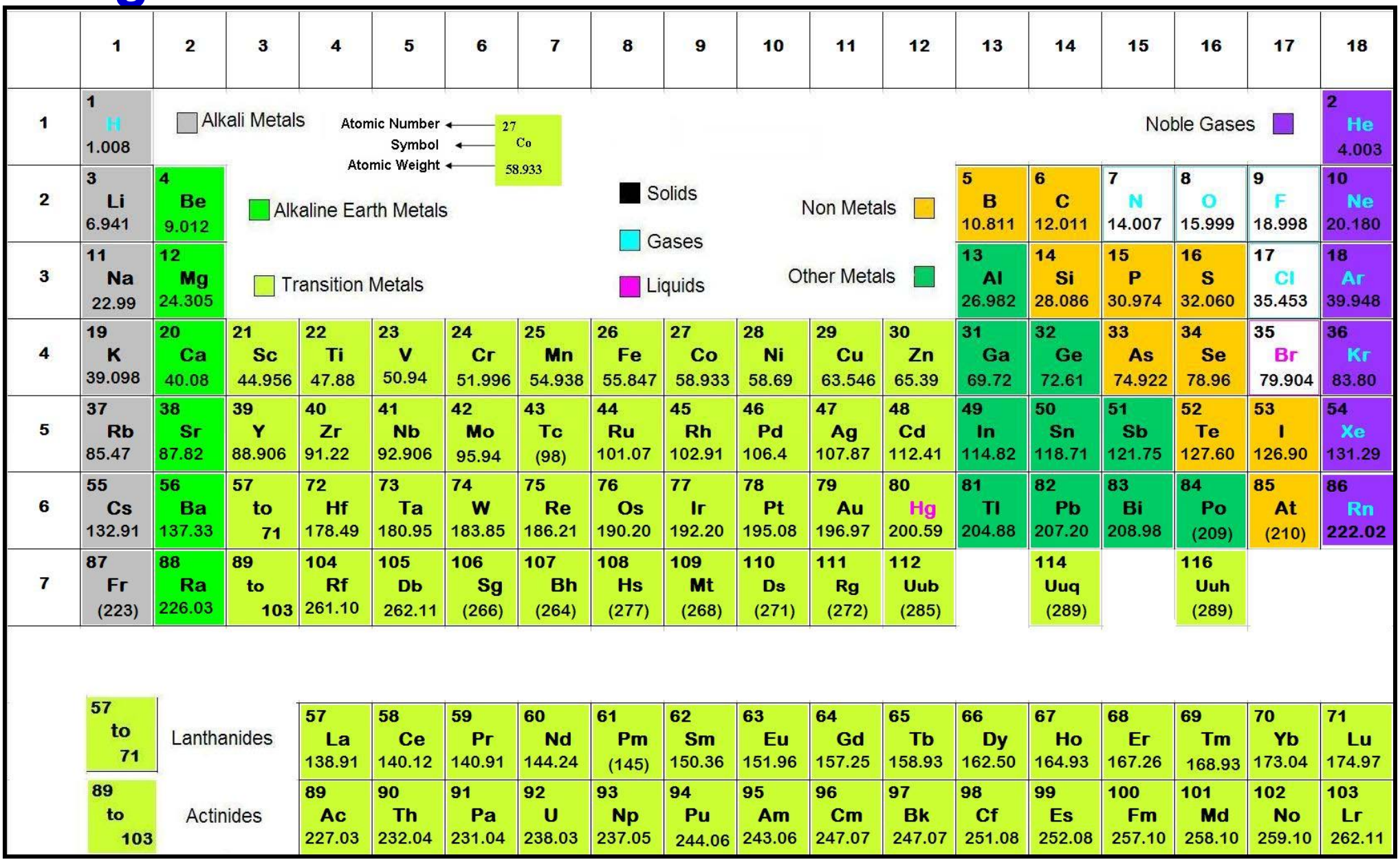
Classification of elements

Before I proceed to explain the relationship between the concentration of elements and human nutrition, first I like to review the classification of elements.

Different studies classified the elements differently.

The well known Periodic Table of Elements shows the grouping of elements based on their chemical characteristics.

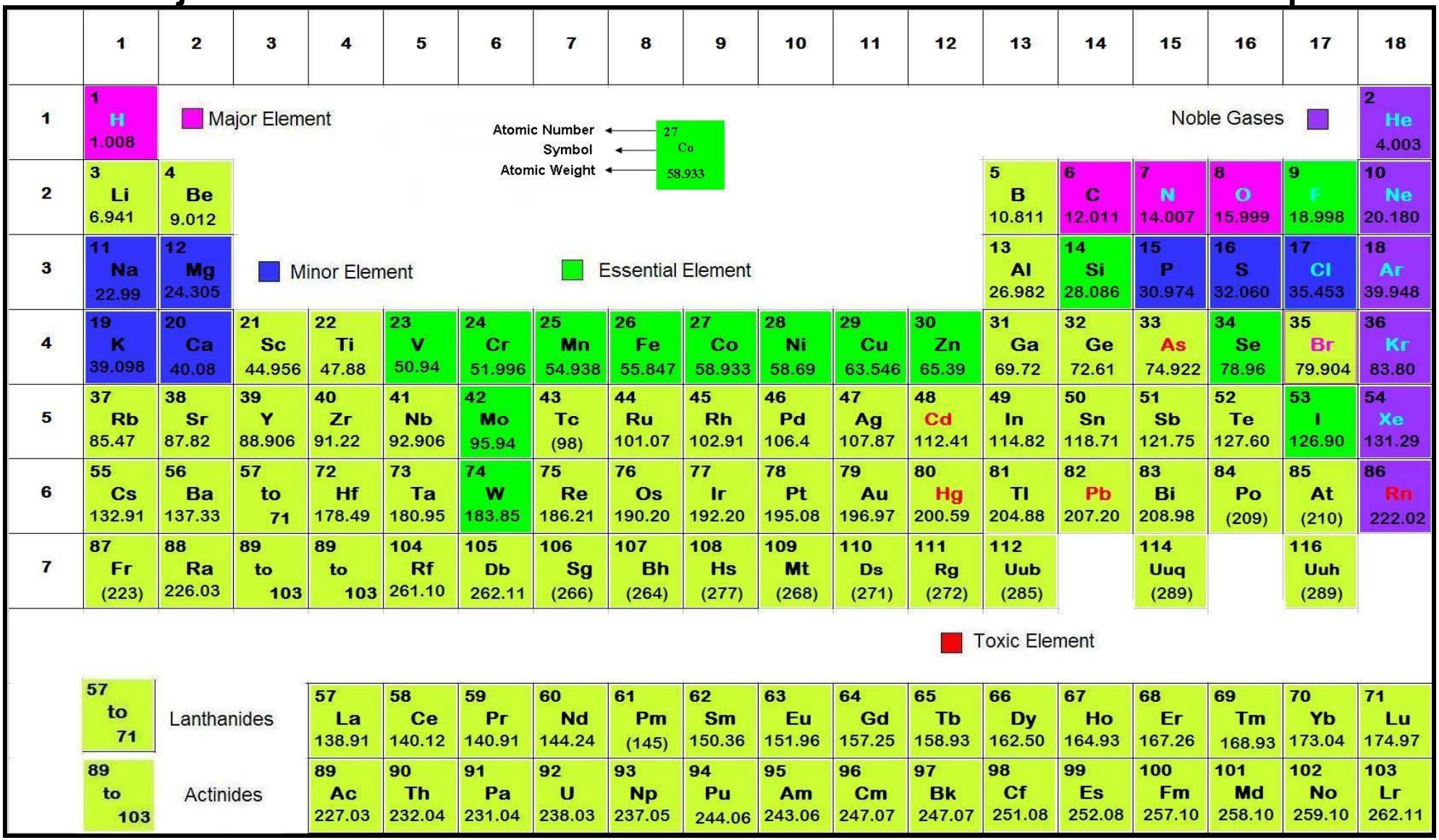
Figure 1. Periodic Table of Elements



Note: The symbol for element 105 is Db [Ref. CRC Handbook of Chemistry and Physics, 86th Edition, 2005-2006].
The symbol Ha, also, is in use for element 105 . [Ref. http://periodic.lanl.gov]

Figure 2. Periodic Table of Elements

Major – Minor and Trace elements classification with reference to biosphere



Note: Based on Figure 1. pp XI, Essentials of Medical Geology. The symbol for element 105 is Db [Ref. CRC Handbook of Chemistry and Physics, 86th Edition, 2005-2006]. The symbol Ha, also, is in use for element 105 [Ref. http://periodic.lanl.gov].

Classification of elements : Major – Minor – Trace

Major, Minor and Trace element concentrations:

- **Major: Concentrations exceeding 1% by mass; 1% = 1g / 100g**
- **Minor: Concentrations in the range 0.1% to 1.0% by mass**
- **Trace : Concentrations less than 0.1% by mass**

ppm μg/g (micro gram/gram) 10^{-6} g/g
ppb ng/g (nano gram/gram) 10^{-9} g/g
ppt pg/g (pico gram/gram) 10^{-12} g/g
ppf fg/g (femto gram/gram)10^{-15} g/g
ppa ag/g (atto gram/ gram) 10^{-18} g/g

Classification of elements

- Major – Minor – Trace and Toxic concepts are context dependent.
- Major – Minor – Trace abundances of elements are different for different category of materials.

  For example they are different for geological and biological materials.

Table 1.
Major-Minor abundances of different elements in two different categories of materials

Element	Earth's Crust	Human Body
	Abundance	Abundance
Oxygen	46.6%	65.4%
Silicon	27.7%	60 ppm
Iron	5.0%	260 ppm
Calcium	3.6%	1.4%
Sodium	2.8%	0.14%
Potassium	2.6%	0.34%
Magnesium	2.1%	0.5%

Based on Figure 1.3, pp 6, An Introduction to Environmental Chemistry; Table 1, pp 116, Essentials of Medical Geology.

Classification of elements- Geochemical

Grouping the elements according to their geochemical associations:

-phile means ‘forming’ or ‘loving’.

Atmophile related to atmosphere.

Chalcophile - chalco means copper.

Lithophile – litho means stone – crustal.

Siderophile – sidero means iron.

Classification of elements Geochemical

Table 2 . Geochemical Empirical Classification of Elements

Classification	Brief Characteristics	Main Elements
Atmophile	Predominant in air	H, He, Hg, N, O and other noble gases and C (as CO_2)
Chalcophile	'Form sulfides, arsenides, selenides, tellurides; Sources of ore minerals for nonferrous metals'	Ag, As, Cd, Cu, Hg, Pb, S, Te, Zn
Lithophile	'Form silicates, aluminosilicates, oxides, carbonates, sulfates, halides, phosphates and vandates among other mineral forms in the natural environment'	Al, Ba, Ca, Cs, Li, K, Mg, Na, Rb, Sr, REE REE: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu
Siderophile	'Form alloys with iron and these are important sources of platinum group metals and gold'.	Au, C, Co, Fe, Ge, Mo, Ni, P, Pt, Sn

Empirical means based on observation, valid information, not from theory

Based on Table 1, pp 26, Essentials of Medical Geology.

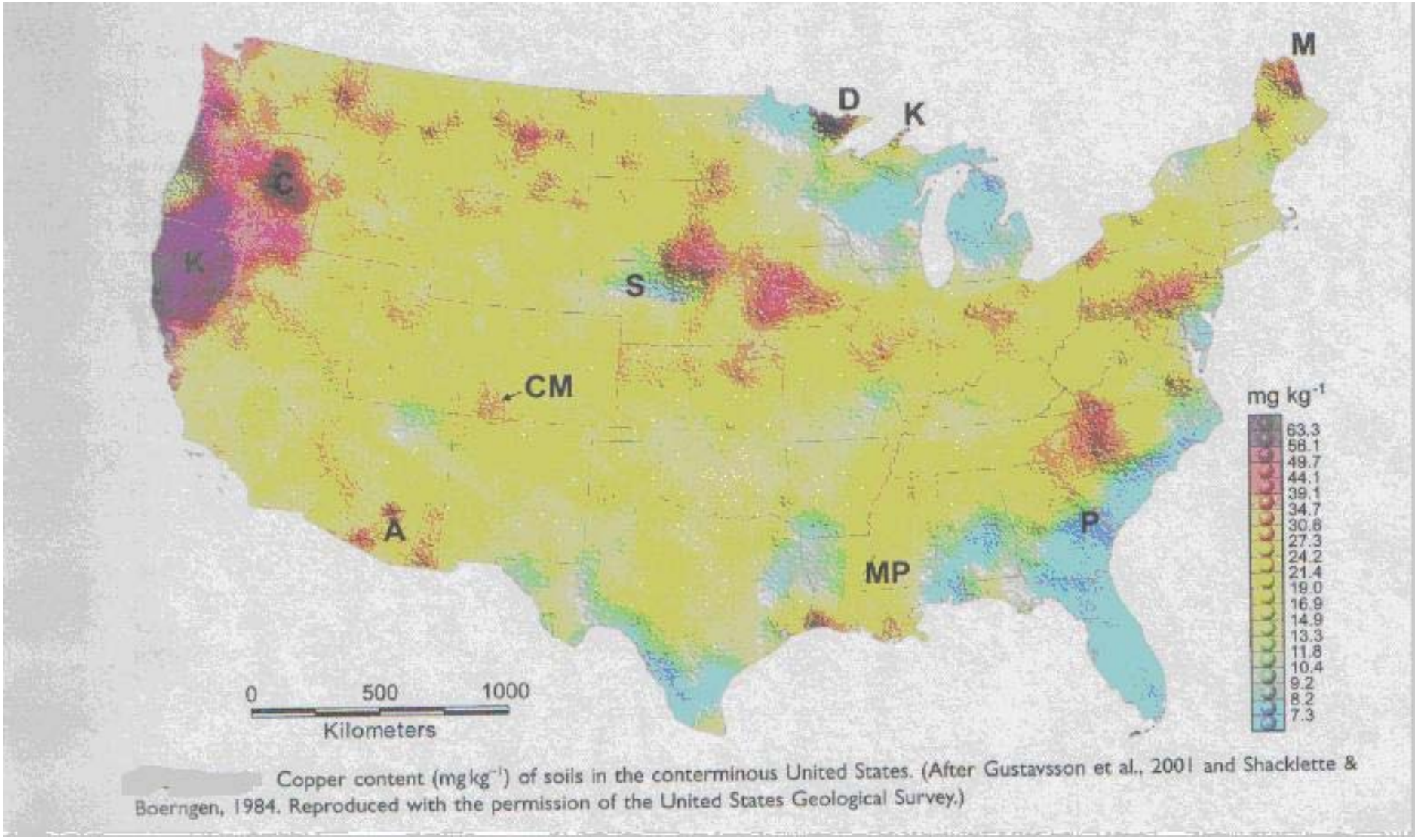
What is the purpose of all theses classifications?

The purpose is

- They provide the basis for the understanding of chemical diversity of the geological and biological materials.
- This understanding leads to further understanding of the interlink between the geosphere and biosphere and ultimately the influences on the human health.

Chemical Variability of the Earth …

Figure 3. Concentration variation of a single element in different regions.



Copper content (mg kg^{-1}) of soils in the conterminous United States. (After Gustavsson et al., 2001 and Shacklette & Boerngen, 1984. Reproduced with the permission of the United States Geological Survey.)

Courtesy of USGS.

Reference: Geochemical land scapes of the conterminous United States – New map presentations for 22 elements, N. Gustavsson, B. Bolviken, D. B. Smith, and R. C. Sverson, U. S. Geol. Surv. Bull. 1645 (2001) 38.

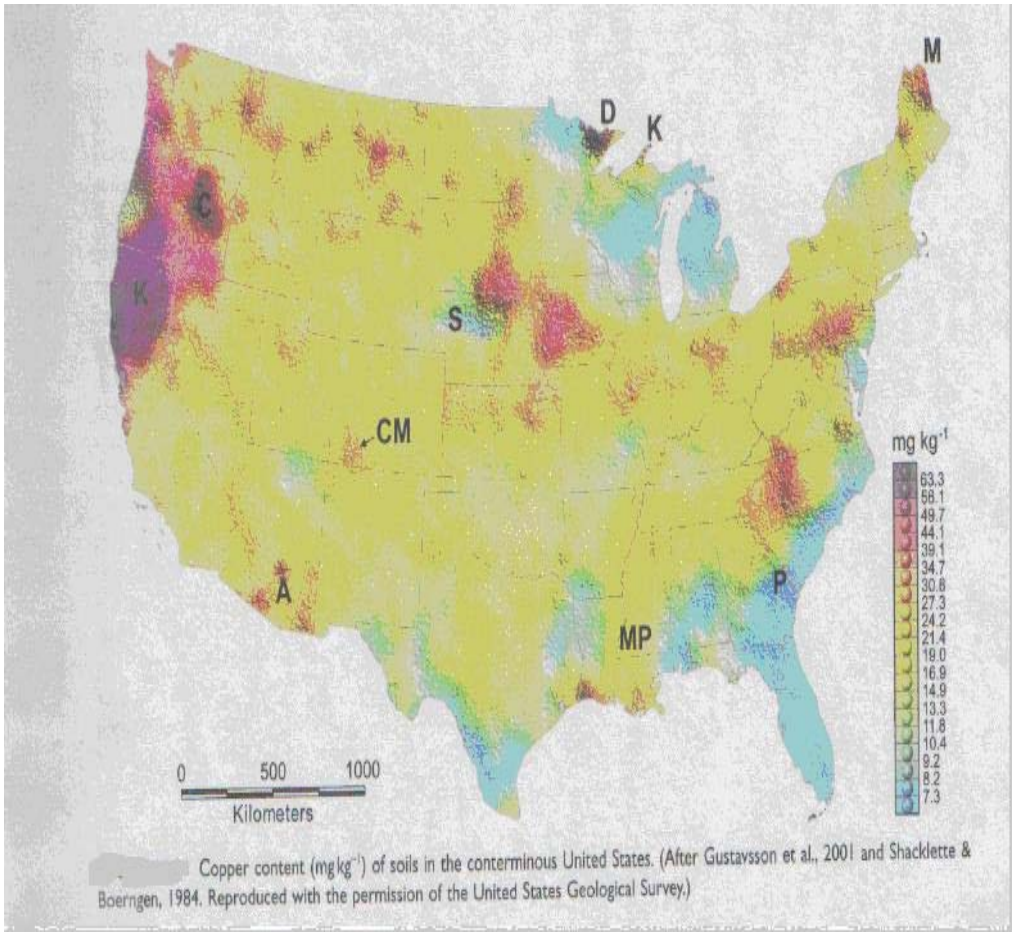
Classification of elements : Major – Minor -Trace
Chemical Variability of the Earth

Table 3. Concentration variation of a single element in different regions.

Important aspects

1) High levels in the Northwest vs. Low levels in the Southeast
2) High levels in Minnesota – associated with Duluth Gabbro
3) High levels in Arizona where copper is mined
4) There is no one average background level.
5) Background values are for contiguous regional areas
6)Background levels are ranges reflecting the natural heterogeneity

Variation of Cu concentration	
	Cu (mg/kg)
Earth's Crust	55-63
Continental Crust	25-50
Igneous	
Ultramafic	10
Mafic	87
Sedimentary rocks	
Sandstone	15
Limestone	4
Shale	45
Black shale	50-200



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Classification of elements : Major – Minor -Trace
Chemical Variability of the Earth

There are two ideas about igneous rocks that are geologically important.

1. Evolution of igneous rocks - change from one kind of rock into another.
2. Rocks are not randomly distributed across the earth. Specific kinds of rocks are found in specific places due to specific reasons, all connected to plate tectonic processes.

Chemical Variability of the Earth

Why is the abundance of different elements varying?

What are the effects on human health?

Natural & Geological Environment

Natural environment consists of innumerable components, stated simply, consists of

- Atmosphere
- Hydrosphere
- Lithosphere
- Animal life
- Plant life

The components of the natural environment are inter-related closely and interact constantly.

Interferences will cause negative or positive effects on the environment.

Reference: pp 39, Medical geology - Effects of geological environments on human health.

Basic Components of the Earth

Earth basically consists of Crust, Mantle and Core.

Crust:
outer most; thinner than the mantle and core; brittle and breakable.
Mantle: below crust;

- **lithosphere - crust and uppermost solid mantle; broken up into the moving plates containing continents and oceans**
- **asthenosphere is below the upper mantle**
  asthenes – weak
  is hot semi-solid material subjected to high temperature and pressure
- **lithosphere is thought to be floating on the asthenosphere**

Core :

- **Liquid Outer core**
- **Solid Inner core (Fe-Ni alloy)**

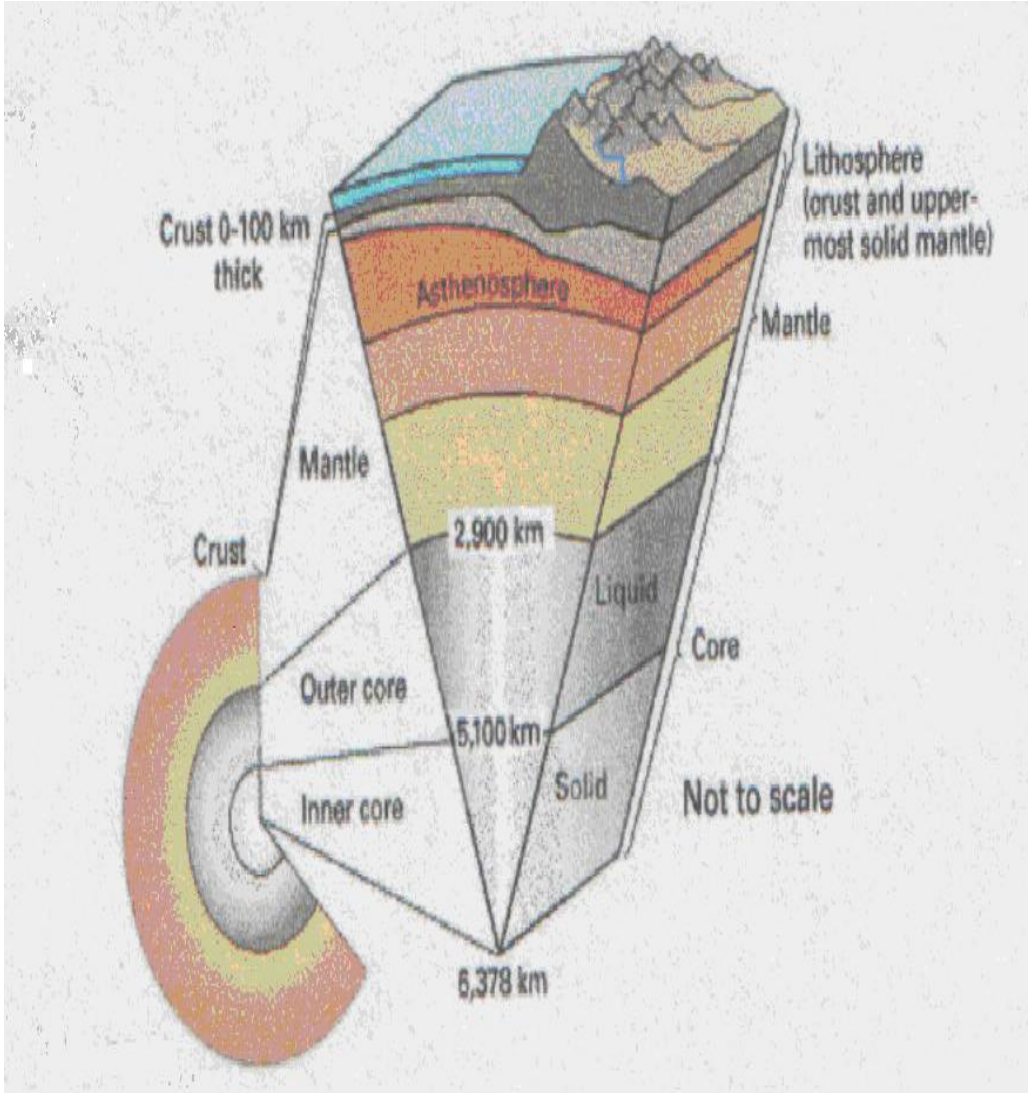


Figure 4. Cross-sectional view of the Earth

Courtesy of USGS.
Reference: http://pubs.usgs.gov/publications/text/inside.html.

Natural & Geological Environment

- For a long time, the understanding was that the relationship between the inner parts of the lithosphere and the biosphere is only mono-directional, i.e., one –way. But the reverse is also true is the current understanding.
- Magmatism and metamorphism:

  Formations of rocks, volcanic exhalations, rock folding, mountain formation and such processes influence the processes like weathering, sediment formation, ground water activity.

Page 45 Komatina.

Natural & Geological Environment …

- A quarter century worth research effort clearly indicates that the reverse influence, namely, the external processes effect the internal processes. For example, processes happening in the biosphere effect the composition of hydrothermal solutions, sedimentary formation of sulphur.
- “Thus, there is unity of the lithosphere as a complex dynamic system with feed back from the biosphere.” – M. Komatina

Reference: pp 45, Medical geology - Effects of geological environments on human health.

Geological Environment

- **Igneous rocks**:

  Rocks formed by the cooling and solidification of hot molten magma. Magma is a material formed by localized melting within the Earth.
- **Intrusive igneous rocks** are formed by If the magma solidification beneath the Earth's surface. Example: Granite.
- **Extrusive igneous or volcanic rocks** are formed by the solidification of magma above Earth's surface in the form of lava. Example: Basalt.

Geological Environment …

Sedimentary rocks are formed at the Earth's surface:

- **Clastic sedimentary rocks** from the weathered and eroded fragments of pre-existing rocks –

  example: quartz sandstone;
- **Organic sedimentary rocks** from the hard parts of animals or plants – example: shelly limestone, coal;
- **Chemical sedimentary rocks** from the precipitation out of solution of dissolved minerals – example: rock salt, gypsum.

Geological Environment …

The color/composition of the rock is, at its simplest, divided into

- Mafic: dark colored rocks
- Intermediate colored rocks.
- Felsic: light colored rocks.
- Ultramafic: Some characteristics of mafic, but lack some others. Example: Dunite, Peridotite

Geological Environment

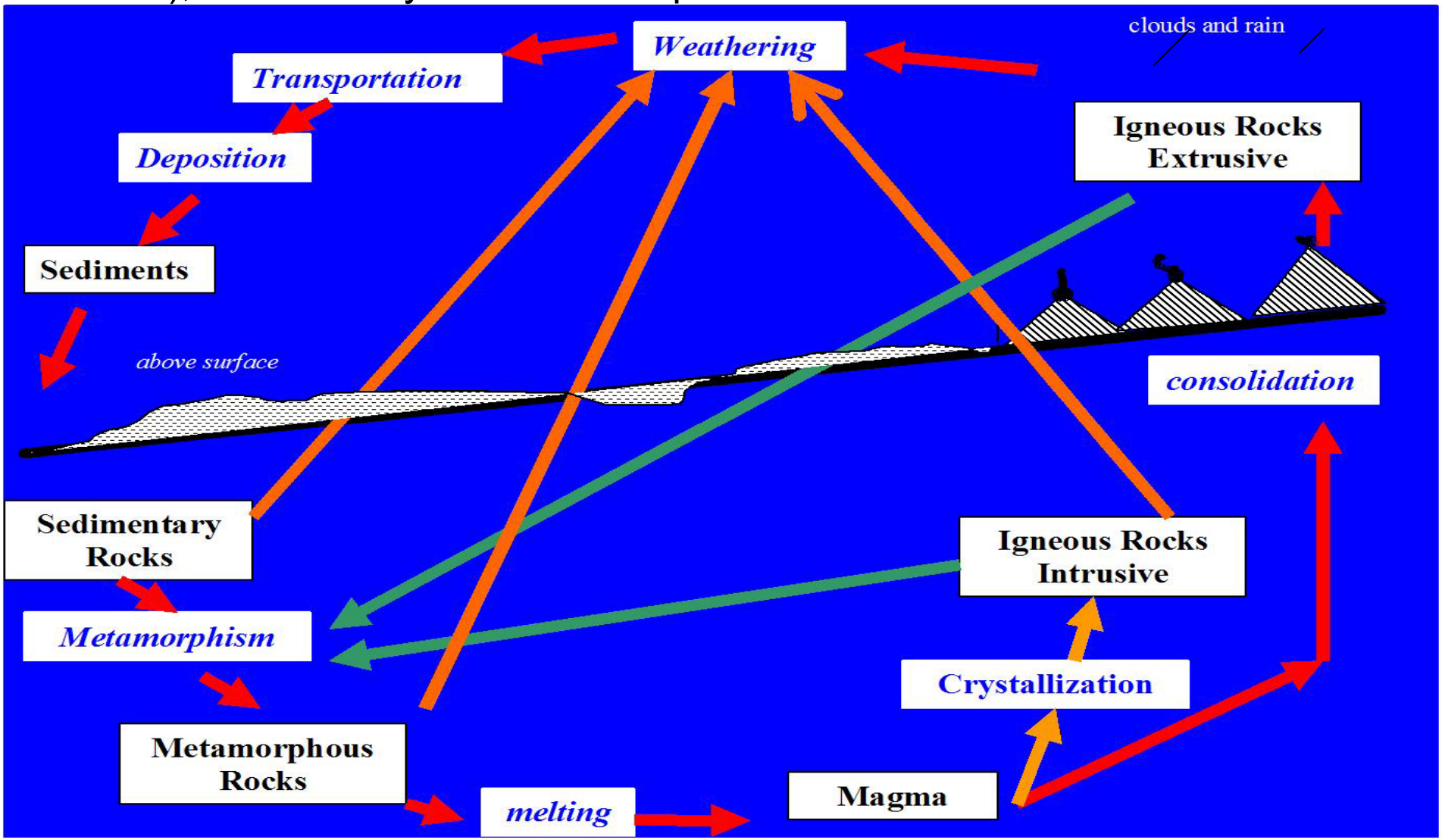
- Metamorphic rocks are formed from the mineralogical and/or textural transformation, in the solid state, of pre-existing rocks due to the action of temperature and/or pressure.
- Metamorphic rocks that have been subjected

  (1) to deep burial typically display a foliated texture due to the parallel alignment of some constituent minerals – example:schist;

  (2) to the segregation of minerals into separate bands of different composition, example: gneiss

Figure 5. Rock Cycle

Earth processes involving the atmosphere, lithosphere, crust and upper mantle and the cycle of three types of rocks, namely, igneous (intrusive and extrusive), sedimentary and metamorphous rocks are all inter-related.



Natural & Geological Environment …

- The geochemical associations of different elements are responsible for the formation of different minerals which become Earth's major natural sources.
- Some geochemical associations are listed.
- Geochemists observed consistent patterns in the distribution of many elements.

Table 4.
Observation of geochemical associations of elements in some Igneous and Sedimentary rock types

Description	Association
Igneous rocks:	
Mafic	Mg-Fe-Ti-V
Ultramafic	Mg-Fe-Cr-Ni-Co
Sedimentary rocks	
Fe-oxide enhanced	Fe-As-Co-Ni-Se
Mn-oxide enhanced	Mn-As-Ba-Co-Mo-Ni-V-Zn
Phosphate enhanced	P-F-U-Cd-Ag-Pb-Mo

Based on Table II, pp 27, Essentials of Medical Geology.

Natural & Geological Environment …

Simple Explanation:

- **The composition of the individual minerals that form the rock influences the elemental diversity.**
- **The properties are carried forward to other materials through processes of**
  - **erosion**
  - **weathering**
  - **soil formation**
- **And to water that passes through the solid phase materials**

Natural & Geological Environment …

What is the link between the elements of the Earth and its environment to the humans and plants?

Elemental link between geosphere and biosphere

An attempt to understand

Link between the geosphere and the biosphere …

Earth basically consists of Crust, Mantle and Core.

Crust: outer most; thinner than the mantle and core; brittle and breakable

Mantle: below crust;

- **lithosphere - crust and uppermost solid mantle; broken up into the moving plates containing continents and oceans**
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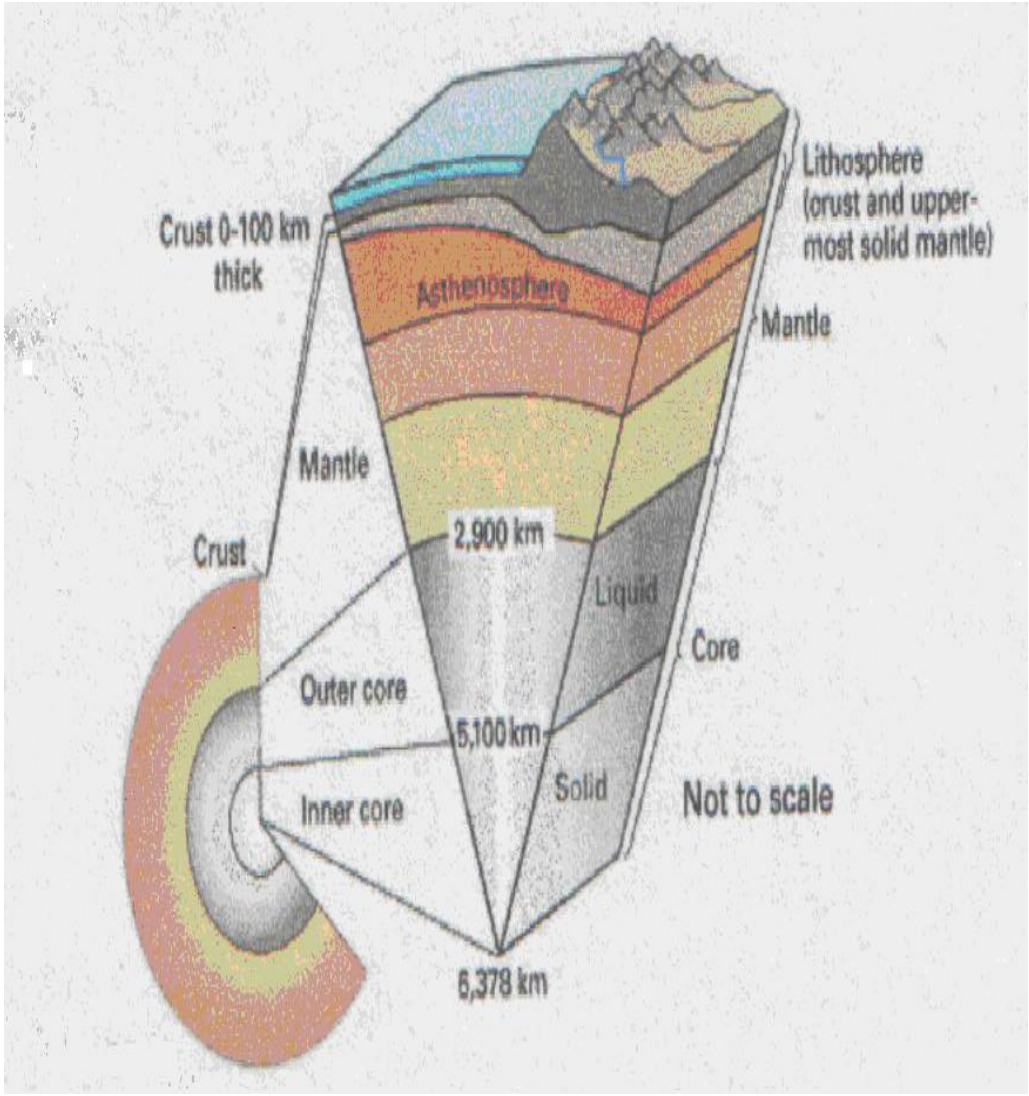


Figure 4. Cross-sectional view of the Earth

Courtesy of USGS.
Reference: http://pubs.usgs.gov/publications/text/inside.html.

Link between the geosphere and the biosphere

In order to visualize the very first link between the biosphere and the geosphere, 4 billion years ago, one has to focus on the essential characteristics of the primitive earth and the primitive cell of the living organism [Reference. R. J. P. Williams].

Based on Chapter 4: Uptake of elements from a chemical point of view, R. J. P. Williams, pp 61- 85, Essentials of Medical Geology.

Link between the geosphere and the biosphere …

Change of oxidation states of elements with increased oxygen with time

Prof. R. J. P. Williams explained excellently, in his article “Uptake of elements form a chemical point of view”:

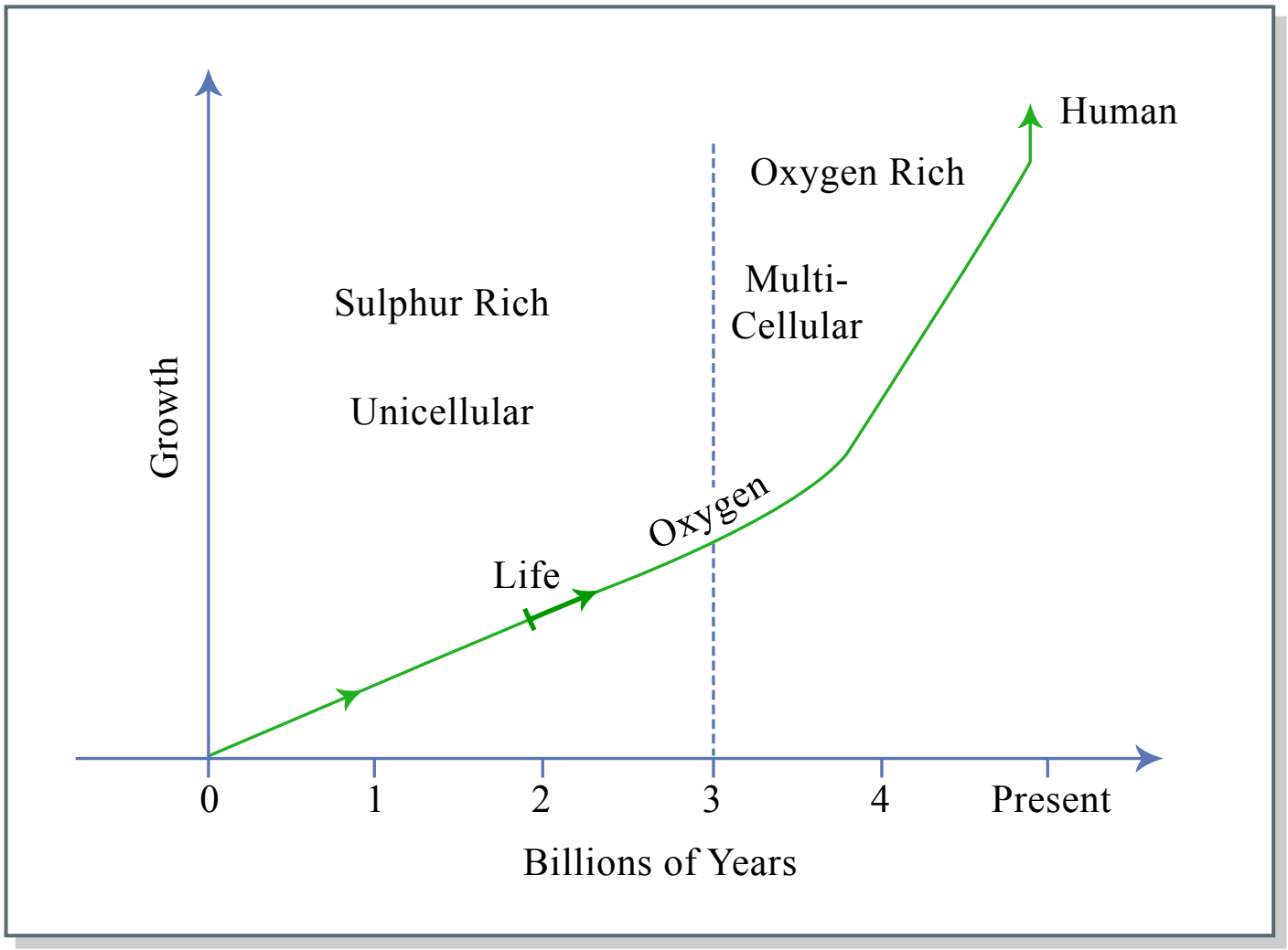
- the influence of primitive sea on the chemical elements of chemical system, which in turn effected the primitive life,
- the free elements of the primitive sea self generated a chemical system of interactions that could be seen in cytoplasm of all cells even in today,
- the evolution of the free and bound the metallomes and metabollomes was largely due to the formation of large compartments, and in oxidative possibilities

Note: Metallome, coined by R.J.P. Williams, means distribution of free metal ions in every one of cellular compartments. Metabollome (or metabolome) means the entire set of metabolic entities and small network pathways in a cell, tissue, organ, organisms, and species.

Ref. Chemical selection of elements by cells, R.J.P. Williams, Coordination Chemistry Reviews 216–217: 583–595;2001
Chapter 4: Uptake of elements from a chemical point of view, R. J. P. Williams, pp 61- 85, Essentials of Medical Geology.

Link between the geosphere and the biosphere …

Figure 6. Oxygen and Cellular changes with time



Based on Figure 11, pp 77, Essentials of Medical Geology.

Figure by MIT OCW.

Table 5. Time sequence of geological and biological changes

Time	Biological	Interpretation	Oxygen	Elements	Elements	Elements
Million years ago	Evidence		%	Loss	Gain	Little change
400	Large fishes, first land plants		100	(1)	(2)	
550	Cambrian fauna	Shelly metazoans Absorption through external shell	10			
670	Ediacarian fauna	Metazoans, collagen	1			
1400	Cells larger	Eukaryotic cells	>1			(3)
2000	Enlarged thick walled cells	Oxygen tolerating blue green algae	1			
2800	Filamentous Chains, Stromatolites	Resemble blue green algae	0.1			
> 3500	Stromatolites , depletion of ^{13}C	Precursors of blue green algae	<0.01			
3800	Rhythmically banded rocks, depletion of ^{13}C	Microbial organisms (?)	<0.01			

(1) Fe^{2+}, S^{2-}, Se^{2-}, H_2, MoS^{2-}_4, NH_3, Co_2
(2) Cu^{2+}, Zn^{2+}, Cd^{2+}, Fe^{3+}, MoO^{2-}, NO^{3-}, SO^{2-}_4, SeO^{2-}_4, I_2
(3) Mn^{2+}, Ca^{2+}, Mg^{2+},$Si(OH)_4$, HPO^{2-}_4, Cl^-, Na^+, K^+

Based on Figure 11, pp 77, Essentials of Medical Geology.

Chemical Variability of the Earth

Why is the abundance of different elements varying?

Essential and Non-essential Elements With Reference to Human Health

- Introduction
  - Essential vs Non-essential
- Sources of Exposure
- Health Effects
- Metal Induced Changes
  - Toxicity
    - Carcinogenesis
- Summary

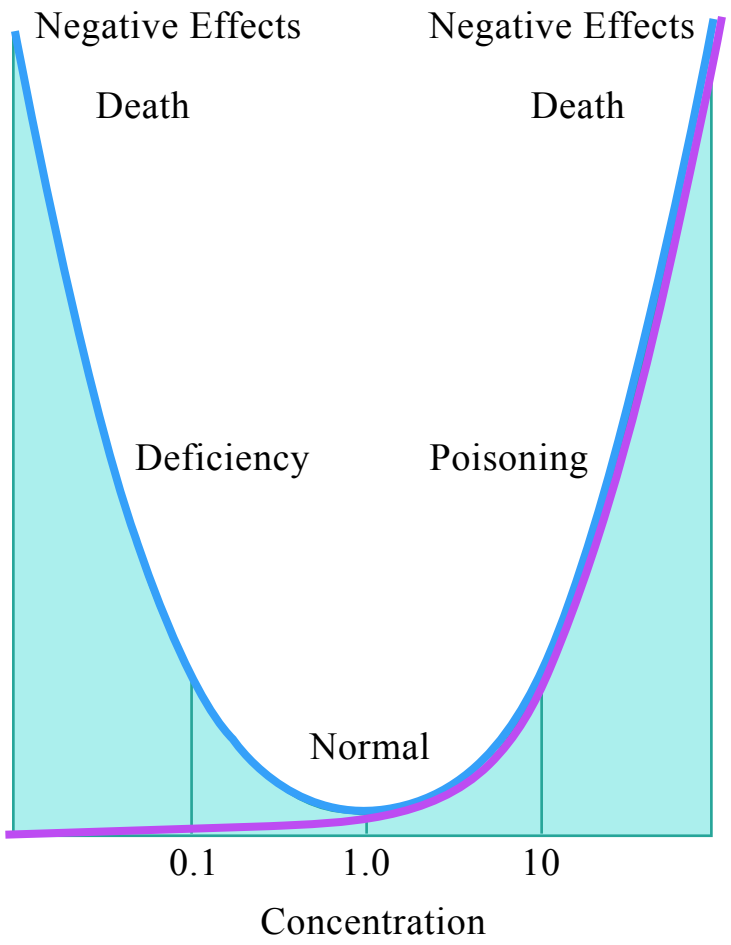
Essential and Non-Essential Elements with reference to human health Introduction:

Essential element considerations in human health:

- Presence in healthy tissues
- Constant concentrations
- Withdrawal from the system causes reproducible physiological symptoms (abnormalities)
- Addition should reverse the conditions
- Physiological changes, due to excess or deficient concentrations of element (or elements), should be preventable or even be cured when the excess or deficient condition of the element(s) is prevented or cured.

Based on pp 88, Essentials of Medical Geology.

Figure 7. Dose Response – Health Effects



Dose-effect curve showing the relationship between concentrations and biological effects of essential (blue) and of non-essential (purple) elements.

Figure by MIT OCW.

Table 6.

Major - Minor – Trace elements of human body

Concentration	Element	Classification
3 - 65 %	C, H, N, O	Major elements
0.1 - 1%	Ca, Cl, K, Mg, Na, P, S (Electrolytes)	Minor elements
<100mg/kg	As, Br, Co, Cr, Cu, F, Fe, I, Li	Trace elements
	(All are not listed)	

Table 7.
Major-Minor Elements of Human Body

Concentration	Element	Classification
65%	O	Major
18%	C	Major
10%	H	Major
3.00%	N	Major
1.40%	Ca	Minor
0.50%	Mg	Minor
0.34%	K	Minor
0.26%	S	Minor
0.14%	Na	Minor
0.14%	Cl	Minor

Based on Table 1, pp 116, Essentials of Medical Geology.

Table 8. Trace Elements of Human Body

Concentration	Element	Classification
0.26 mg/kg	As	Trace
2.9 mg/kg	Br	Trace
0.021 mg/kg	Co	Trace
0.094mg/kg	Cr	Trace
1 mg/kg	Cu	Trace
37 mg/kg	F	Trace
60 mg/kg	Fe	Trace
0.019 mg/kg	I	Trace
0.009 mg/kg	Li	Trace
0.17 mg/kg	Mn	Trace
0.08 mg/kg	Mo	Trace
0.14 mg/kg	Ni	Trace
0.11 mg/kg	Se	Trace
260 mg/kg	Si	Trace
0.24 mg/kg	Sn	Trace
0.11 mg/kg	V	Trace
0.008 mg/kg	W	Trace
33 mg/kg	Zn	Trace

Based on Table II, pp116, Essentials of Medical Geology.

Pathways of Metals in Environment Effects on Health

- Pathways:
  - Air (inhalation)
  - Absorption
  - Drinking water
  - Food cycles
- Metal induced effects
  - Carcinogenic, Teratogenic, Mutagenic

Teratogenic: mis-shapen animal or plant.

Trace Element Deficiency & Toxicity Health Effects

- Established Toxic Elements are
  - Arsenic
  - Cadmium
  - Lead
  - Mercury
  - Radon

Table 9.
Toxicity: Cancer Effects

Elements	Target organ/site
As	Bladder, liver, lung, skin, Vascular and neurological changes
Cd	Bladder, kidney, lung, Hypertension, vascular and neurological changes
Cr	Kidney, liver, lung
Hg	Brain, kidney, lung, neurological changes
Pb	Neurological, IQ (children), Anemia
Radon	Lung
Others	Be (skin, lung), Co (liver,lung), U (skin)

Table 10.
Toxicity: Pigmentation disorders

Elements	Effect
Arsenic	Hyper and hypo pigmentation
Gold	Chrysias
Mercury	Hyper pigmentation
Silver	Argyria

Based on: Trace elements in environmental health and human diseases, Josè- Diversity of Trace Elements.pdf

Table 11.
Toxicity: Arsenic induced effects

Pigmentation (hyper and hypo)
Keratosis
Bowen's disease
Squamous cell carcinoma
Basal cell carcinoma

Based on: Trace elements in environmental health and human diseases, Josè- Diversity of Trace Elements.pdf

Table 12.
Toxicity: Cardiovascular diseases

Elements ❖ From epidemiological studies	Effect
❖ Co, Hg, Se, Al, As, Au, Cr	Cardiomyopathy
❖ Fe, Se, Ca, Cu, Mg	Atherosclerosis
Al, As, Hg, ❖ Pb	Hypertension

Based on: Trace elements in environmental health and human diseases, Josè- Diversity of Trace Elements.pdf

Atherosclerosis: Hardening and thickening of walls of arteries with fatty degeneration

Armed forces

Table 13.
Toxicity: Lung diseases

Elements	Effect
Asbestos fibers	Amphipbole types are more pathogenic than serpentine type
Beryllium	Presence of granulomas
Iron; Iron mixed with free silica	Siderosis; silicosiderosis

Based on: Trace elements in environmental health and human diseases, Josè- Diversity of Trace Elements.pdf

Table 14.
Toxicity: Liver diseases *(Hepatotoxicity)*

Element
Aluminium
❖ Arsenic
Barium
Beryllium
Cadmium
Chromium
❖ Copper
Gold
❖ Iron
Lead

❖ From epidemiological studies

Based on: Trace elements in environmental health and human diseases, Josè- Diversity of Trace Elements.pdf

Table 15.
Toxicity: Kidney diseases *(Nephrototoxicity)*

Element
❖ Arsenic
Bismuth
❖ Cadmium
❖ Chromium
Gold
❖ Lead
Lithium
Platinum

❖ From epidemiological studies

Table 16: Significant Endemic Diseases

Element	Effect
Arsenic	Skin lesions, Cancer
Fluoride	Dental and Skeletal
Iodine	Goiter and Cretinism
Selenium	Kaschin-Beck disease: *Degenarative osteoarthropathic disease* Keshan disease: *Chronic heart disease (cardiomyopathy)*

Based on: Trace elements in environmental health and human diseases, Josè- Diversity of Trace Elements.pdf

Table 17.
Diseases due to deficiency and toxicity of some elements

Element	Deficiency	Toxicity
Chromium	Disturbances in the glucose metabolism	Kidney damage (Nephritis)
Cobalt	Anemia , “White Liver disease”	Heart failure
Copper	Anemia, poor growth, bone decreased in WBC	Idiopathic Cu toxicosis
Iron	Anemia	Hemochromatosis
Magnesium	Convulsions, malfunctions of the skeleton	
Selenium	Liver necrosis	Muscular dystrophy
Zinc	Dwarf growth, retarded development of gonads	“Metallic” fever

Based on: Trace elements in environmental health and human diseases, Josè- Diversity of Trace Elements.pdf

Summary

- Trace element deficiency or excess (toxicity) cause a wide range of environmentally related health problems.
- Toxicity may effect more than one organ in the system.
- Toxicity may vary with chemical or physical form of the metals.
- Deficiency related effects may be treatable (by providing dietary supplements etc.)

Selection of Elements for Report and Presentation

Format:

Introduction

Experimental Method

Facts

Results and Conclusion

References

Summary

I talked about

- Different Terminologies of Medical Geography, Geomedicine, Medical Geology/Geochemistry
- Classification of Elements
  - Periodic Table of Elements
  - Major-Minor-Trace Elements
  - Geochemical Empirical Classifications
  - Essential and Non-essential Elements
- Link between the geosphere and biosphere

Summary …

I talked about

- Essentiality and non-essentiality of elements with reference to human health.
- Sources of exposure of toxic elements.
- Health effects induced by deficiency and excess of metals.

Internet Keywords

- medical geology, medical geochemistry
- major, minor, trace elements
- essential and nonessential elements
- periodic table of elements
- toxic elements
- Primitive earth, primitive sea

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