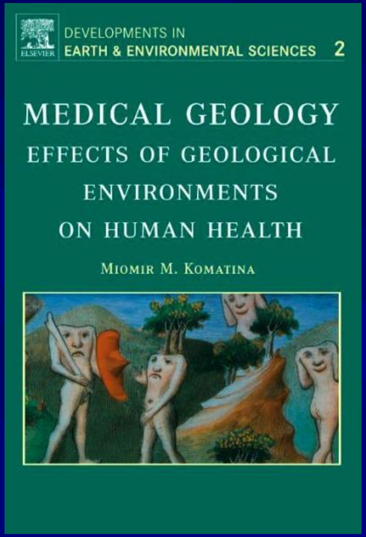
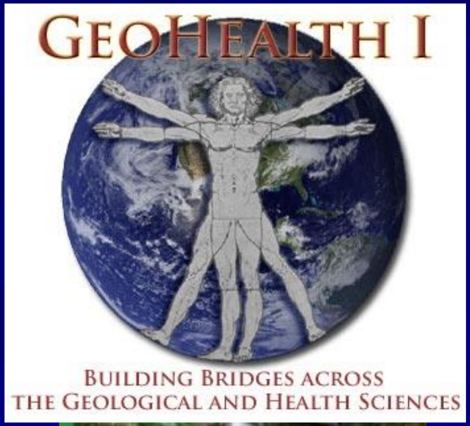
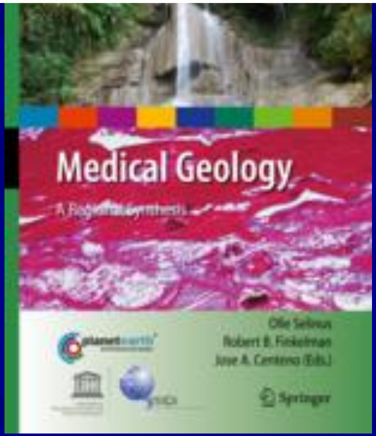
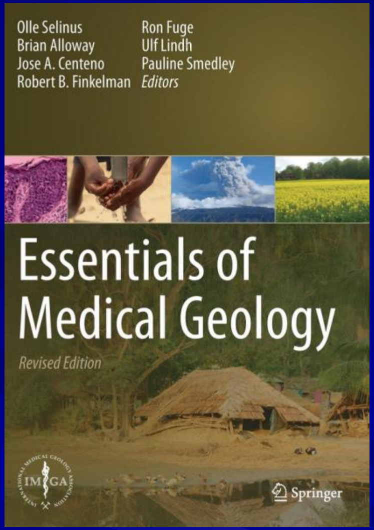
What is Medical Geology ?

“The science that deals with the relationships between natural geological factors and human and animal health” (*Selinus, 2005*)







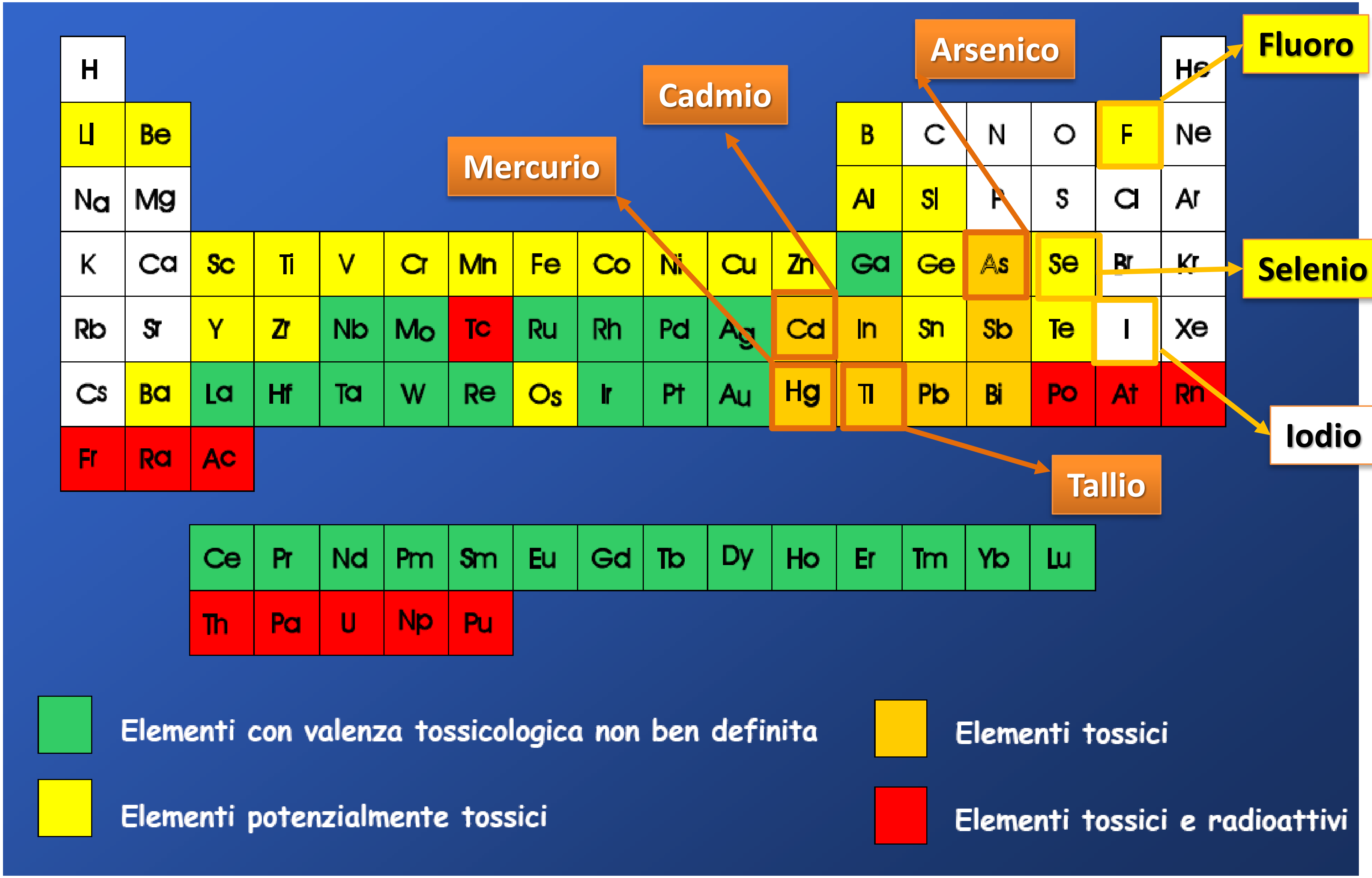


It is a dynamic re-emerging discipline bringing together geoscientists and biomedical/public health researchers to solve a wide range of environmental health problems.

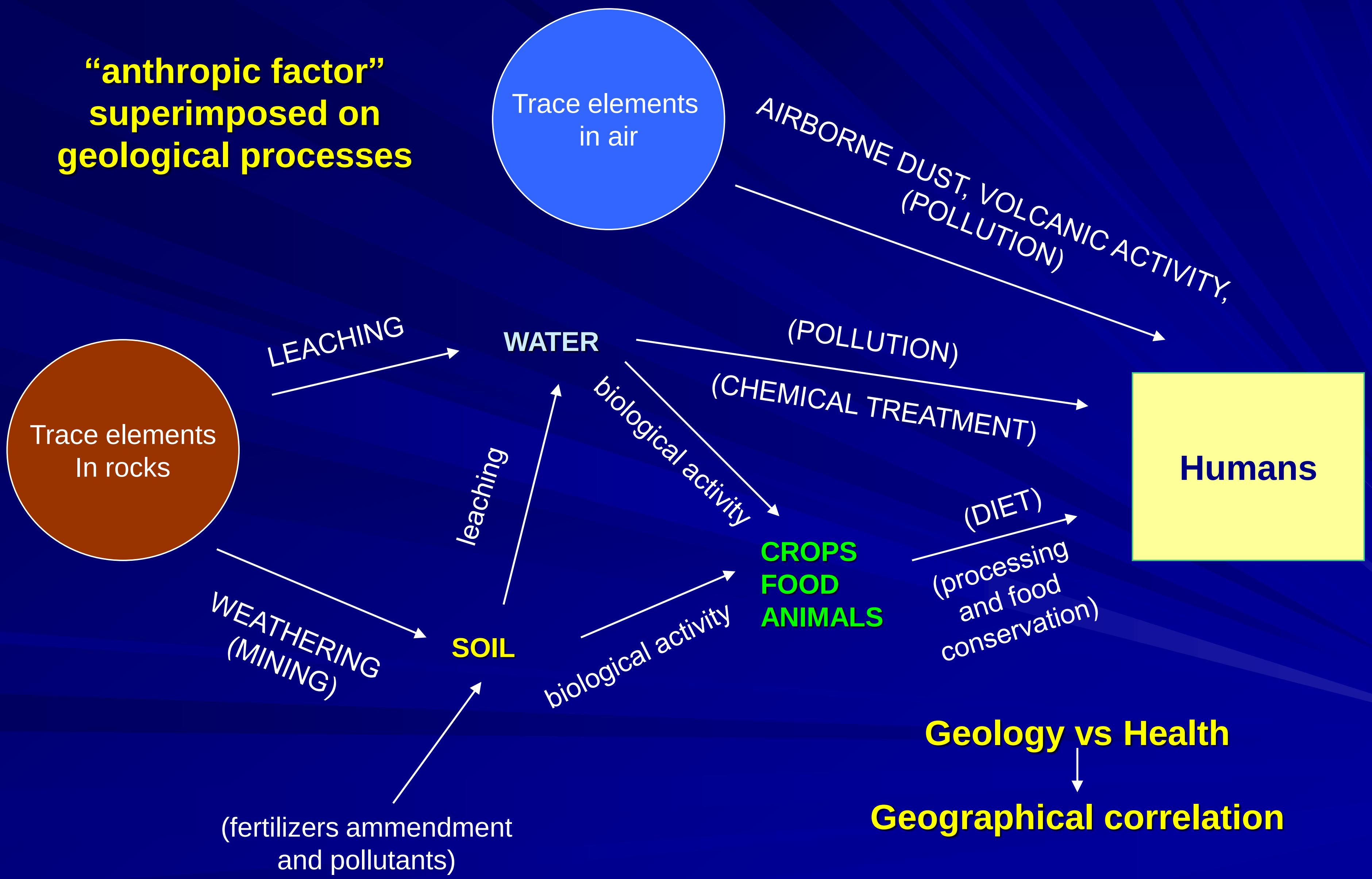
Environmental health problems

- Exposure to toxic levels of trace essential and non-essential elements
- Nutrient trace element deficiencies
- Naturally occurring toxic organic and inorganic compounds in drinking water
- Exposure to natural dust and to radioactivity
- Identification and effects of volcanic emissions

Aspetti ambientali della tavola periodica degli elementi



Pathways through which trace elements enter the body



TRACE ELEMENT EXPOSURE: DEFICIENCY AND TOXICITY

Trace elements play an essential role in the normal metabolism and physiological functions of animals and humans.

Macronutrients (C H N O P S) and **micronutrients**

16 elements are established as being essential for good health!

Ca, P, Mg and **F** are required for structural functions in bone and membranes.
Na, K and **Cl** are required for the maintenance of water and electrolyte balance in cells.
Zn, Cu, Se, Mn and **Mo** are essential constituents of enzymes or serve as carriers (iron) for ligands essential in metabolism.
I is an essential component of the thyroid hormone thyroxine.
Cr is the central atom of the hormone-like glucose tolerance factor.

Diseases Due to Trace Elements

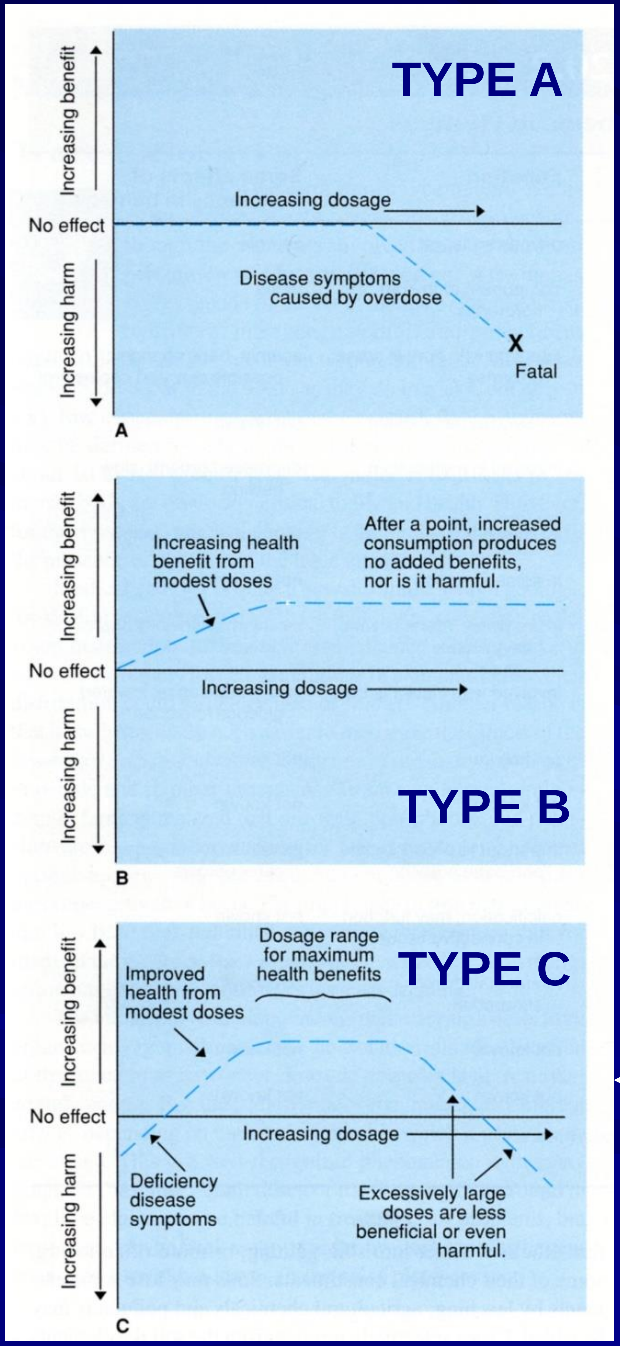
Endemic diseases due to trace element deficiency

- Iodine
- Selenium

Cronical exposure to essential and non-essential elements

- Fluorine
- Cadmium
- Arsenic
- Thallium
- Mercury

The effects of short-term dietary deficiencies or excess of trace elements



No essential elements: no effects at low concentrations, letal at high levels (ex. Cd, Pb, Hg, As)

Beneficial effects at the beggining and lower than a limit concentration; no effects at high level (ex. Ca)

Diseases due to trace element deficiency as well as excess (ex. Cu, Mo, Mn)

Iodine (curve type C)

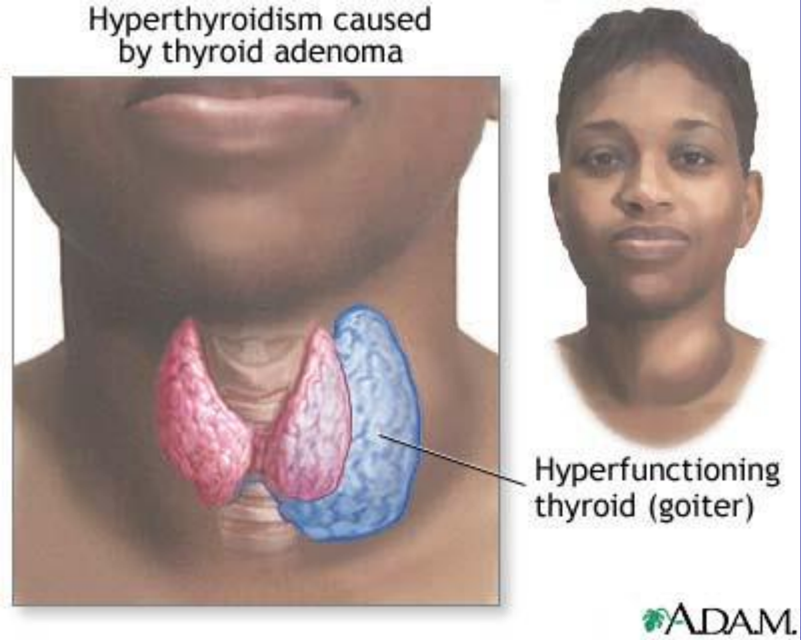
First element recognized as being essential to humans

Discovered accidentally in 1811 by *Bernard Courtois*

Necessary for thyroid gland → Iodine Deficiency Disorders (IDD) → goiter, cretinism, reduced IQ, mental retardation and birth defects

Goitrogens (Sulfur-containing compounds) inhibit Iodine uptake by thyroid and formation of hormones

The endemic disease was the first to be related to environmental geochemistry



At risk: 30 % worldwide population and 50-100 million people in Europe

Iodine (curve type C)

Geochemistry

Hydrophile, biophile, atmophile and chalcophile element

Abundance in the lithosphere: 0.25 mg/kg

Enriched in volcanic glasses but low concentrations in igneous rocks

Sedimentary rocks show a greater range of Iodine content

The highest concentrations in organic-rich shales

Rock type	*Mean iodine content* ($mg\,kg^{-1}$)
Igneous rocks	
Granite	0.25
All other intrusives	0.22
Basalts	0.22
All other volcanics	0.24
Volcanic glasses	0.52
Sedimentary rocks	
Shales	2.3
Sandstones	0.80
Limestones	2.3
Organic-rich shales	16.7

(Fuge, 2005)

Iodine (curve type C)

Geochemistry

Seawater is the biggest reservoir (avg. 60 µg/l)

Iodine is depleted in surface waters due to uptake from the organisms

Two inorganic forms:

- Iodide anion I^- → surface and shallow shelf waters → biological activity
- Iodate anion IO_3^- → stable in oxygenated, alkaline seawater

Iodine as seawater spray is the major mechanism of transfer from the sea to the atmosphere

Iodide ion can be converted to elemental iodine (I_2) by photochemical oxidation

Iodine (curve type C)

Geochemistry of Iodine in soils (<0.1-150 mg/kg)

Higher content in soils than parent material

The majority of the Iodine in soils is derived from atmosphere and marine environment.

Two main factors:

1) The proximity of the soil to the sea

2) The element can be strongly absorbed by soil component (water soluble content generally < 10 % of the total)

N.B! the only exception ^{129}I from nuclear reprocessing plant (22-49%)

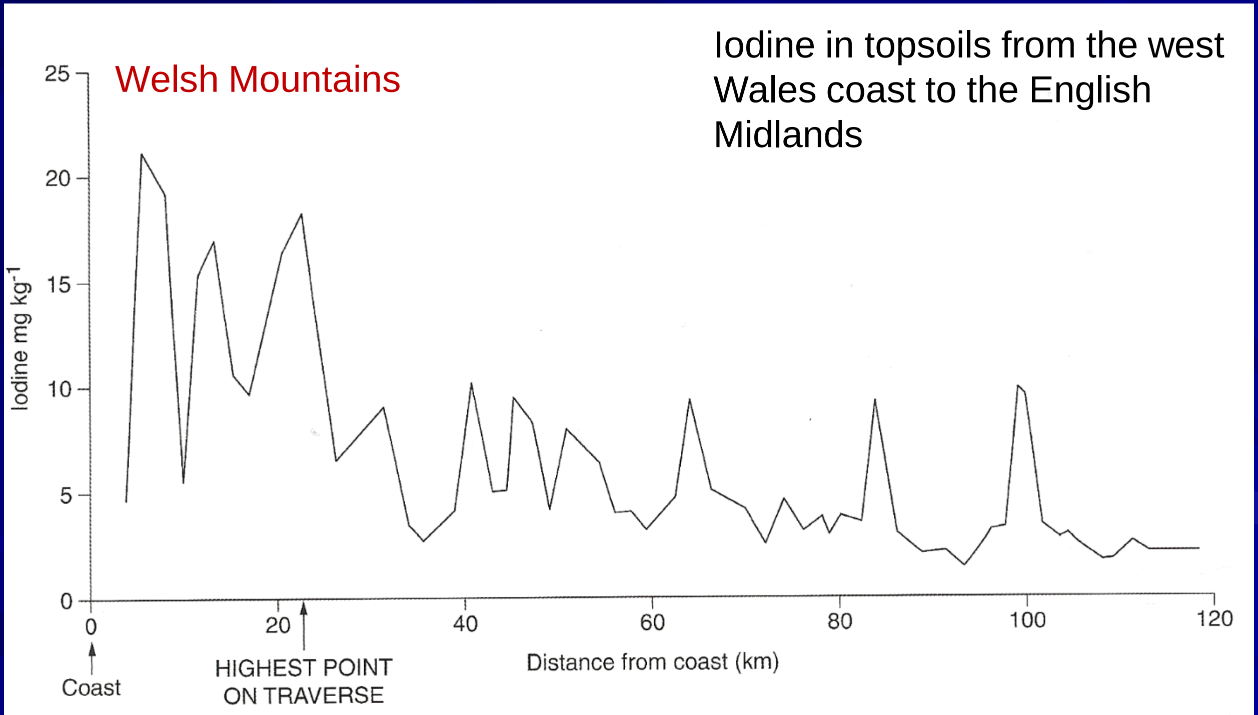
↓

High incidence of childhood thyroid cancer following the nuclear accident in Chernobyl (UKR)

Iodine (curve type C)

The relationship soil enriched in Iodine vs distance from the coast is not obvious !

Influence of topography; washout of atmospheric Iodine due to greater precipitation; upland soils are rich in organic matter



(Fuge, 1996)

Fe and Al oxides also play an important role in soil Iodine retention strongly dependent on soil pH: high sorption in acidic conditions

Iodine (curve type C)

Where Iodine is solubilized in soils at greatest rates?

It is strongly desorbed in waterlogged soils, in reducing conditions typical of rice paddies.

Acid soils: predominance of anion I^-

Alkaline soils: anion IO_3^- is dominant

↓

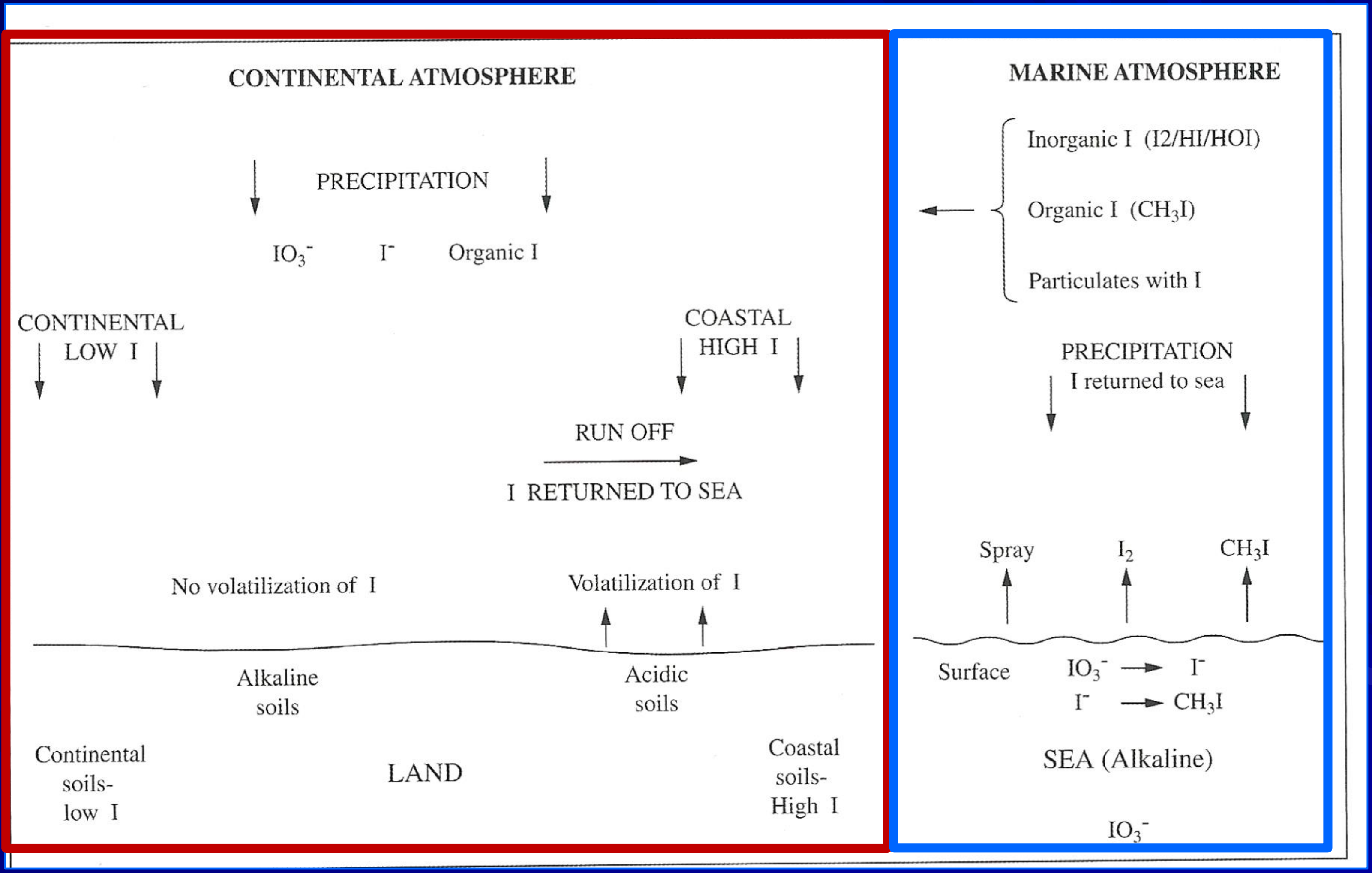
Bioavailability ?

Volatility ?

In the case of soils derived from sand-rich parent material, sandy soils have little ability to trap Iodine which is found in low concentrations

Iodine (curve type C)

Geochemical cycling



(Fuge, 2005)

Iodine (curve type C)

Transfer from soil to plant

No direct correlation between Iodine in soil and plants on it.

Iodide ion more than Iodate ion can be easily uptaken by the root system

Little translocation from the root to the aerial parts of the plant

↓

The most important pathway for the uptake is from atmosphere through leaves

Iodine (curve type C)

The traditional view: humans derive Iodine from consumption of crops and vegetables.

Seafood is also a rich source of Iodine (excess of the element in the diet in Japan and Iceland) → decrease of thyroid hormone production

In the developed countries, the major source is from dairy products (addition of Iodine to cattle feed, Iodine disinfectants in the dairy industry)

Possible uptake of Iodine by inhalation and by drinking water (not more than 10 % of the daily requirement)

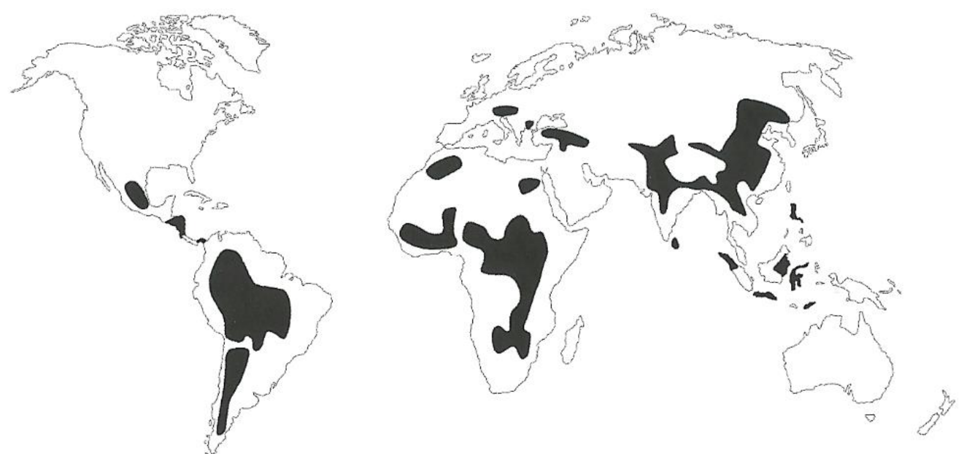
Iodine Deficiency Disorders (IDD)

Before 1950 in every country in the world….solution to IDD?

Addition of Iodine to the diet (iodized salt, bread, oil, irrigation waters) in many countries.

From 1970s: endemic goiter in poor countries!

In the 1990s, Iodine deficiency seems to go back to western Europe: as a result of dietary changes?



Dunn & van der Haar (1990)

Remote areas: Himalaya, Alps, the Andean Chain, continental Africa and China

Iodine Deficiency Disorders (IDD)

Endemias are not always esplicable with vicinity of the countries to the sea

Involvement of sulfur-containing goitrogens from geological sources and incorporated into drinking water and food or naturally occurring in vegetables.

Causes of IDD problems are due to the geochemistry of Iodine and its bioavailabilty

Ex. Atmosperic Iodine added to sandy soils in coastal areas of China are leached very rapidly → little Iodine available for plants and crops → no Iodine for livestock and humans

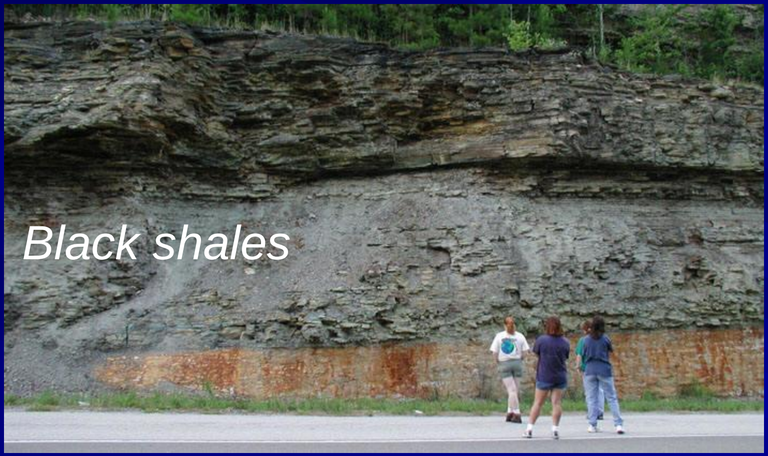
Selenium (curve type C)

Essential at low concentrations (antioxidant protective functions) but harmful in excess !

Dietary deficiency (<40 µg/day) and toxic levels (>400 µg/day)

Geology controls on concentration of Se in soils and the food chain

Phosphatic rocks



The assessment of Se-related health risks may be achieved by understanding the biogeochemical controls on the distribution and mobility of Se in the environment.

Health outcomes are not only dependent of total Se content in rocks!

Selenium (curve type C)

1817: it was identified by the Swedish chemist J.J. *Berzelius*

A consistent daily intake of elevated Selenium levels will lead to a chronic condition known as "alkali disease" or "Se poisoning".

- **13th century: Marco Polo noticed hoof disease in horses travelling to China**

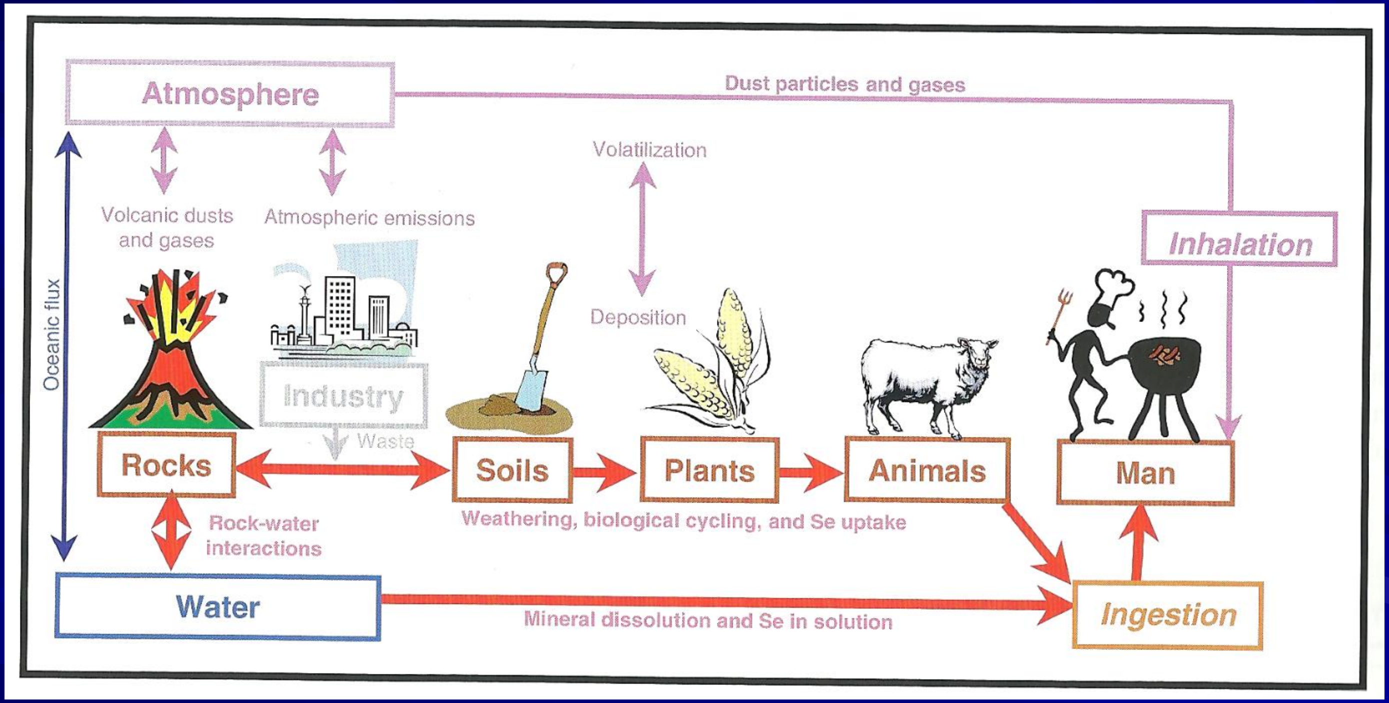
- **1931: Selenosis (Se toxicosis) was Identified (hair and nail loss in humans and hoof loss in animals)**

- Se deficiency in crops and livestock have been reported all over the world

Se supplementation has become a common practice in agriculture

Selenium (curve type C)

Se is dispersed from the **rocks (primary source)** through the **food chain** via complex **biogeochemical cycling processes** including **weathering** to form soils, **rock-water interactions** and **biological activity.**



(Fordyce, 2005)

Significant is also Se **cycling through the atmosphere** because of rapid transport

Selenium (curve type C)

Rocks

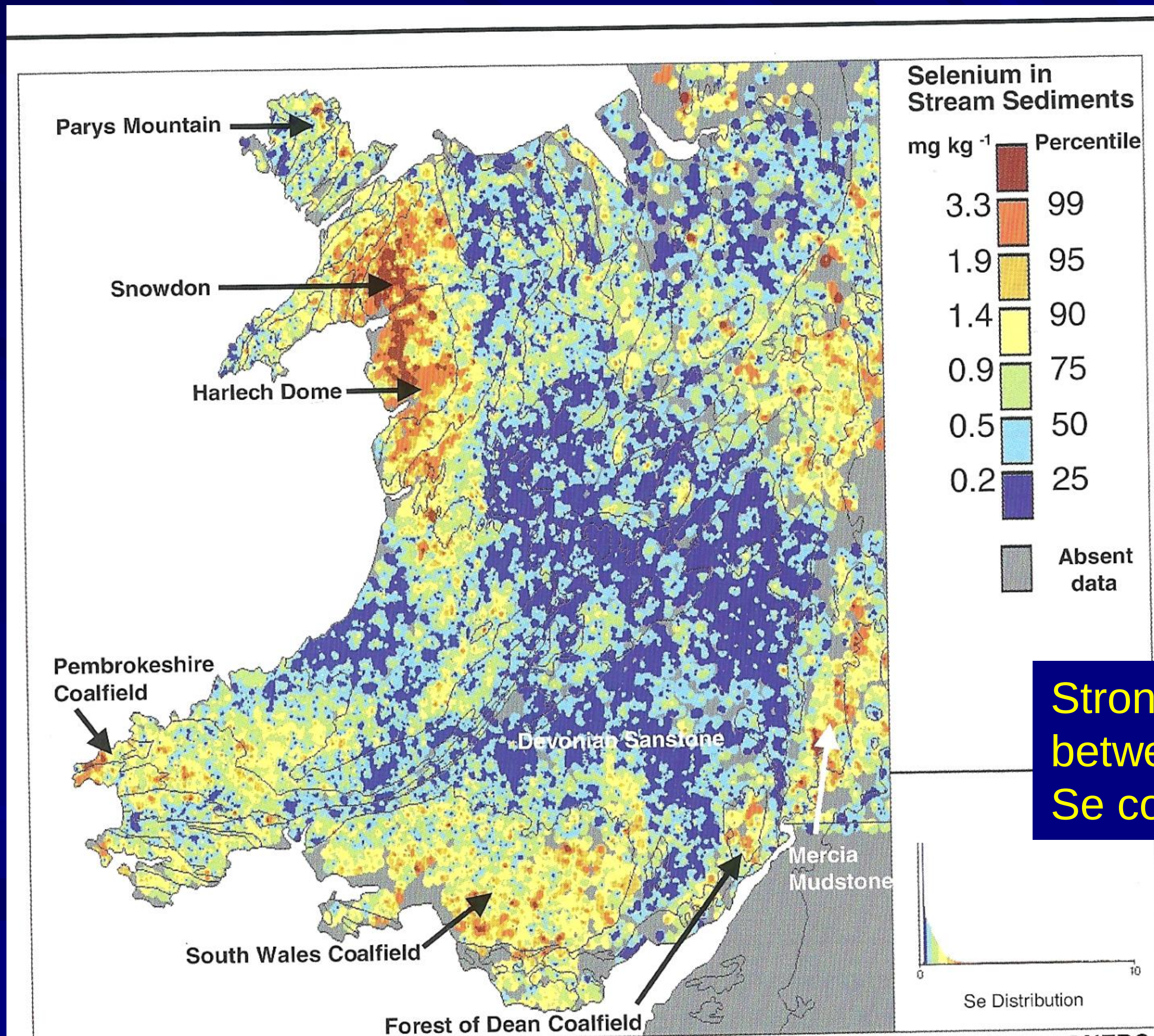
Crustal abundances very low (0.05 – 0.09 mg/kg)

Ash and gas from volcanoes can contain significant amount of Se (6-15 mg/kg) but volcanic rocks (basalts and rhyolites) are usually poor in Se.

Sedimentary rocks contain greater Se concentrations (0.1 mg/kg) than igneous rocks.

Very high concentrations (≤ 300 mg/kg) in phosphatic rocks due to similarity between phosphate and selenite anions; high concentrations (1-20 mg/kg) also in coal and organic-rich deposits.

Selenium (curve type C)

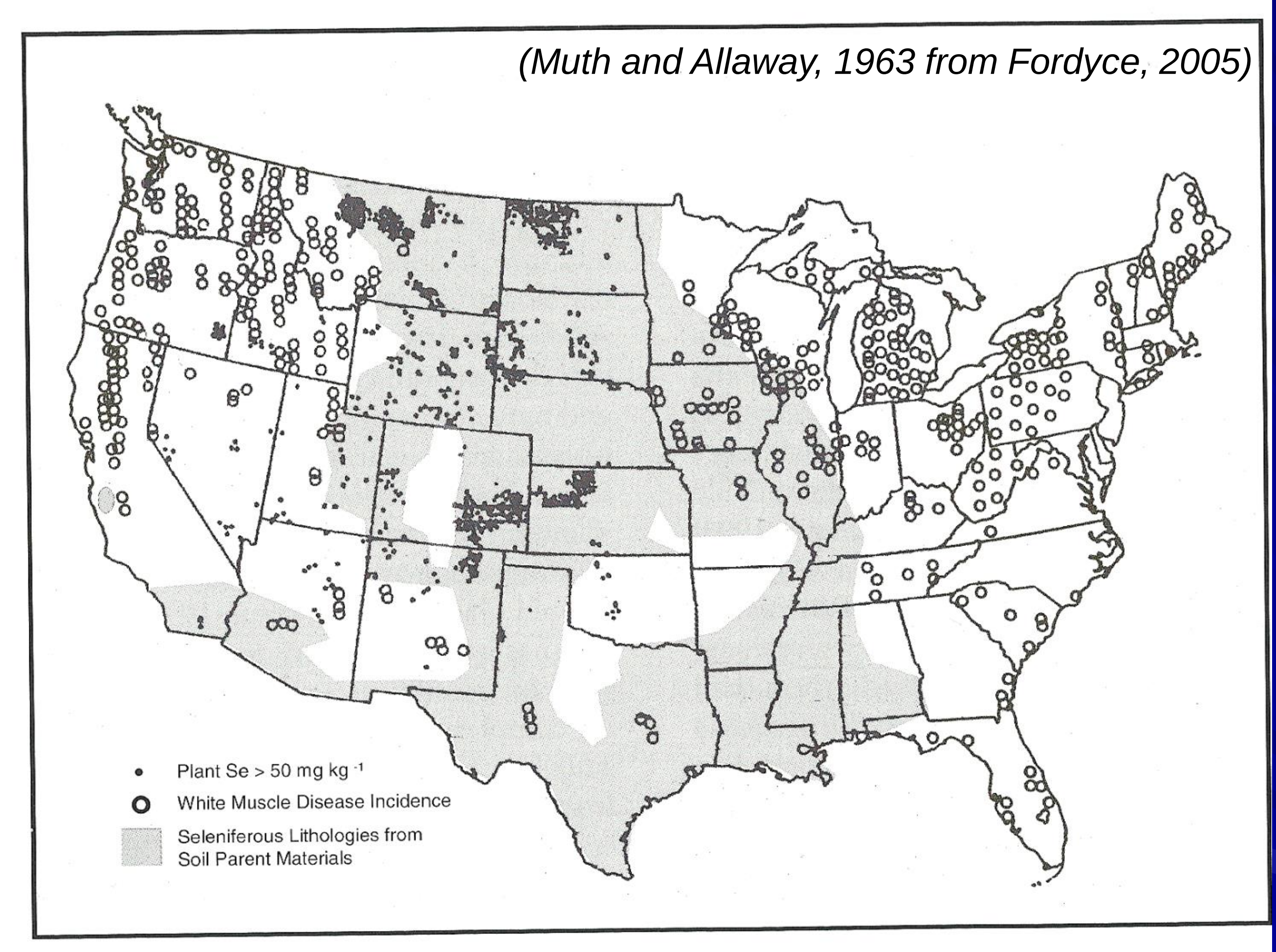


Strong relationship between geology and Se concentrations

(BGS, 2000 from Fordyce, 2005)

Selenium (curve type C)

Soil



Soils capable of producing **Se-rich vegetation toxic to livestock** were reported over black shale and sandstone deposits of the Great Plain (USA)

Selenium (curve type C)

Soil geochemsitry

Factors affecting bioavailability:

pH,

redox,

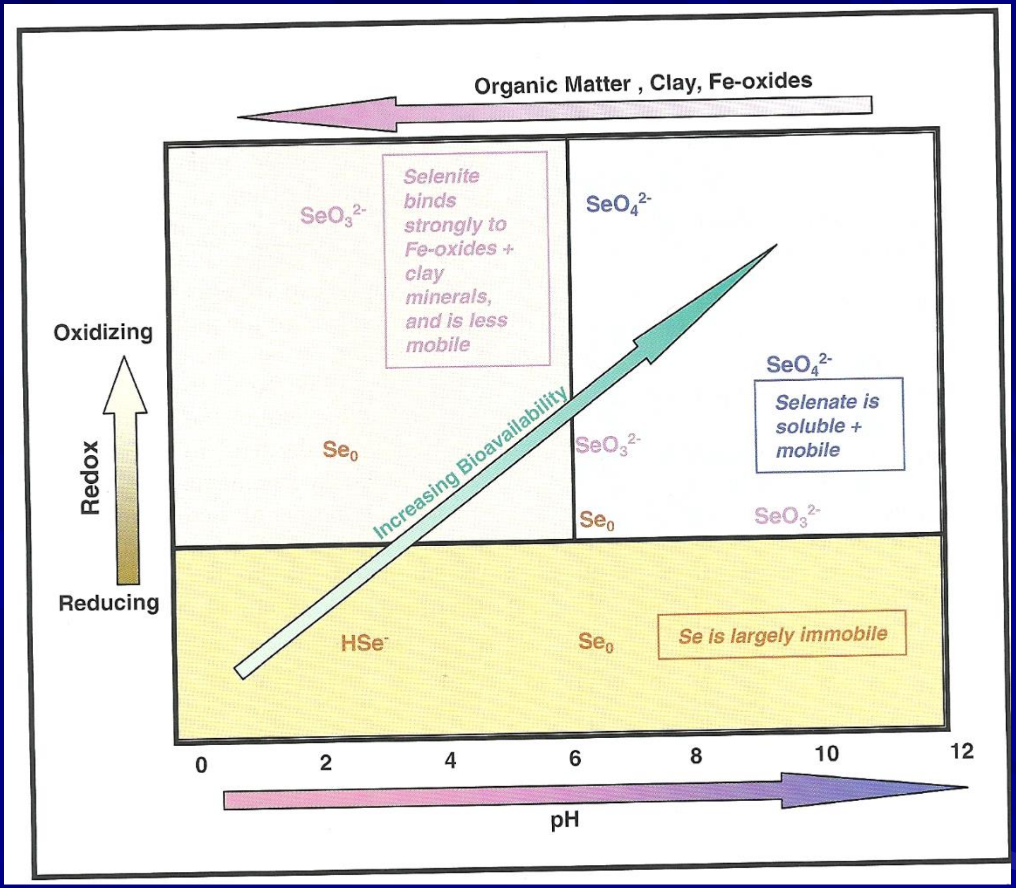
speciation,

texture,

mineralogy,

organic matter,

competitive ions



(Fordyce, 2005)

Selenate (Se^{6+}) is more mobile, soluble and less well absorbed by Selinite (Se^{4+}), thus, Selenium is much more bioavailable under oxydizing alkaline conditions and much less bioavailable in reducing acid conditions

Selenium (curve type C)

Plants

Food crops tend to have relatively low tolerance to Selenium toxicity, and most crops have the potential to accumulate the element in quantities that are toxic to animal and humans.

In general, root crops contain higher Se than plant leaves

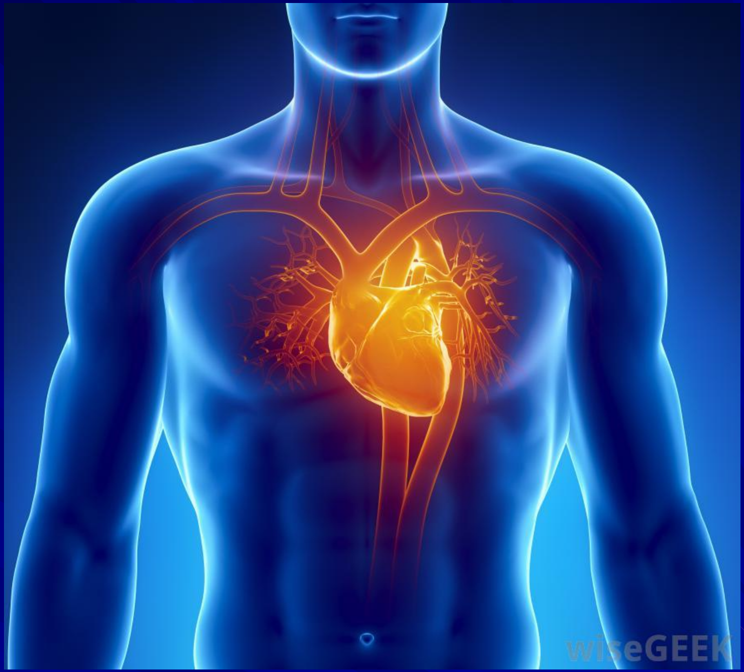
Selenium accumulation	*Plant species*
Better accumulators	Cruciferae (broccoli, radish, cress, cabbage, turnip, rape, and mustard)
	Liliaceae (onion)
	Leguminosae (red and white clover, peas)
	Helianthus (sunflower)
	Beta (Swiss chard)
Poorer Accumulators	Compositae (lettuce, daisy, artichoke)
	Gramineae (cocksfoot, ryegrass, wheat, oats, barely)
	Umbelliferae (parsnip, carrot)

Average selenium $mg\,kg^{-1}$ dry weight	*U. S. crop type*
0.407	Roots and bulbs
0.297	Grains
0.110	Leafy vegetables
0.066	Seed vegetables
0.054	Vegetable fruits
0.015	Tree fruits

Jacobs (1989).

(Fordyce, 2005)

Selenium deficiency (curve type C)

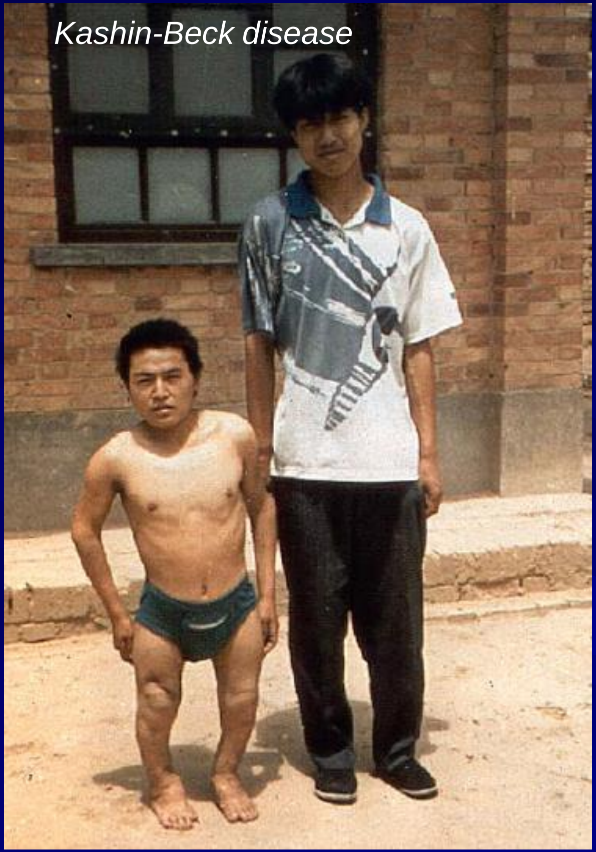


(Tan, 1989 from Fordyce, 2005)

Keshan disease juvenile cardiomyopathy affecting women and children: acute insufficiency of the heart function or as a chronic moderate-to-severe enlargement of the heart.

Remote areas in China where Se in soils and crops (<0.04 mg/kg) was very low

Selenium deficiency (curve type C)



In Siberia, China, South Korea and Africa

Kashin-Beck* disease endemic osteoartopathy causing deformity of the affected joints

Impairment of movement in the extremities is commonly followed by bone development disturbances such as shortened fingers and toe and, in more extremes cases, dwarfism

Se deficiency also adversely affects thyroid hormone metabolism

* The Russian scientists who first described it (1861-1899)

Selenium toxicity (curve type C)

Hydrogen Selenide (HSe^-) is the most toxic compound by inhalation.
Sodium selenite (Na_2SeO_3) is the most toxic via ingestion
Elemental Se in the diet has low toxicity as it is insoluble

Figure 2: Clubbing, onychomadesis, onycholysis, nail bed erythema, and granulation

Hair and nail loss were the prime symptoms of the disease in China in the 1960s, but disorders of the nervous system, skin, poor dental health, garlic breath and paralysis were also reported.