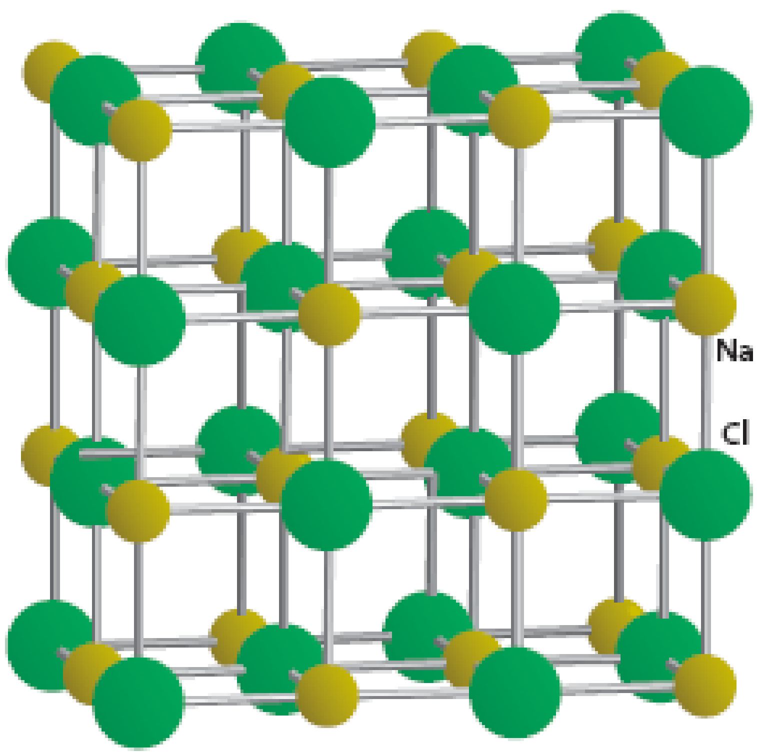
3. Basic concept of mineralogy I: Elements, Sulphides, Oxides, Carbonates etc.

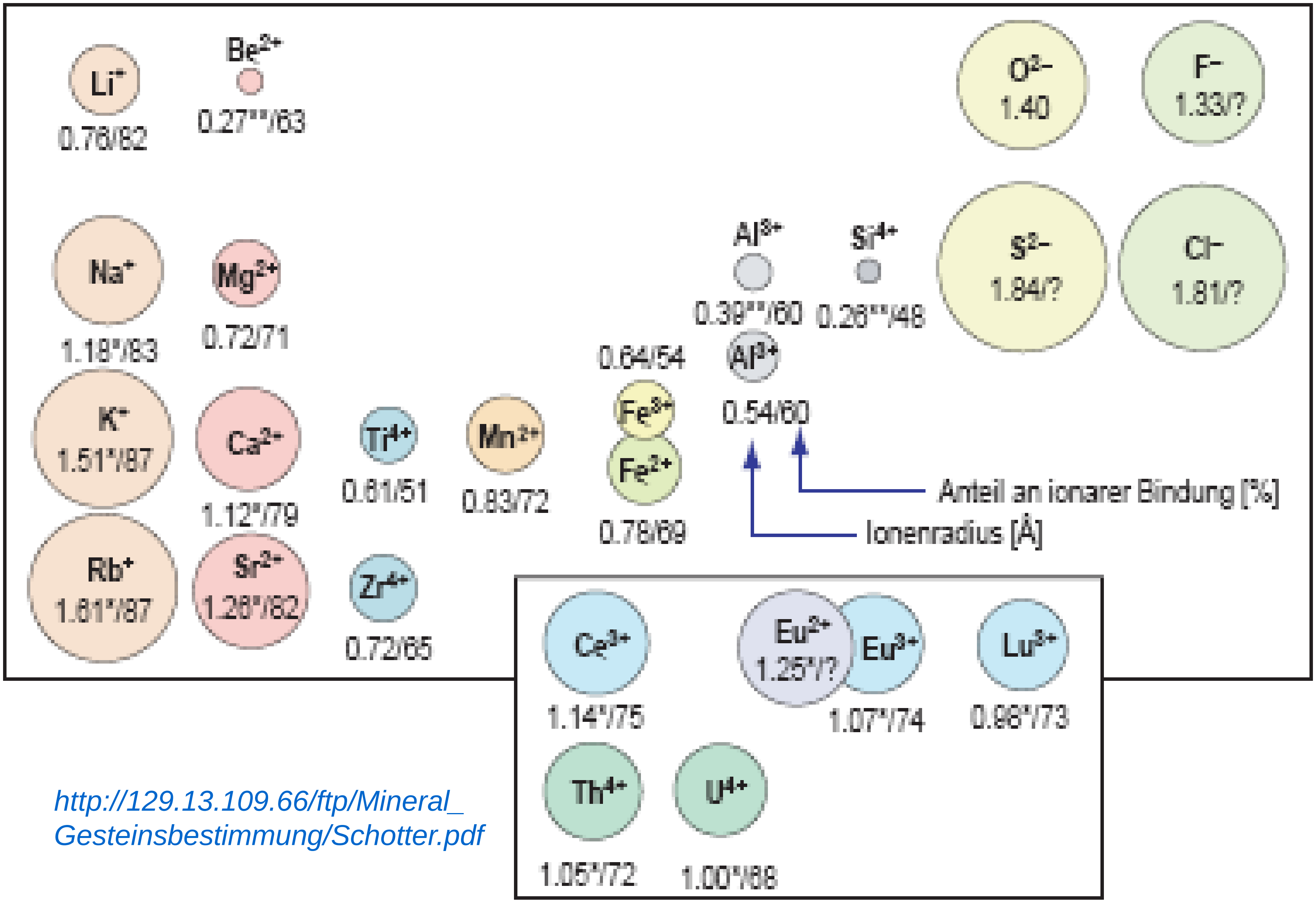
Why minerals are formed?

Elements have different tendencies to gain or emit electrons (➔Electronegativity), in order to obtain a noble gas configuration of the electrons. This produces cations or anions. Mineral formation (mineralization) is determined by the elements availability (material stock), their charge and ionic radius as well as the pressure and temperature conditions.



http://129.13.109.66/ftp/Mineral_Gesteinsbestimmung/Schotter.pdf

Important elements of the Earth's crust:



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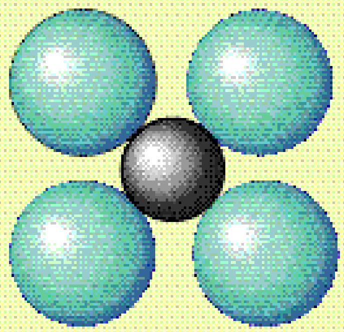
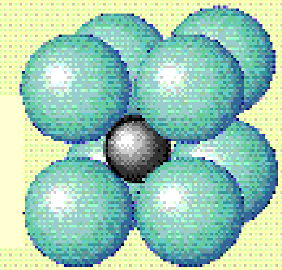
Gesteinsbestimmung/Schotter.pdf

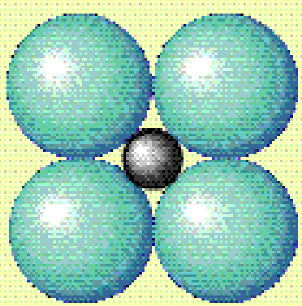
The arrangement of the elements in the cristal structure



Unstable

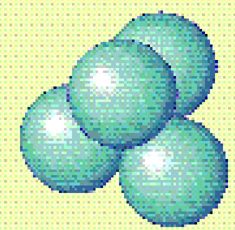
Cubic coordination

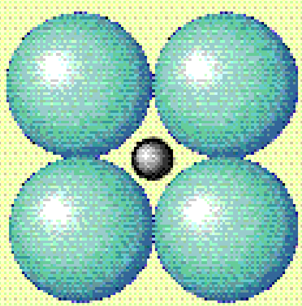




Optimal

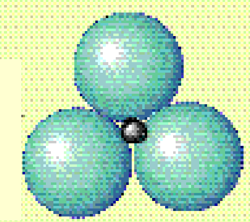
Tetrahedron coordination





Stable

Planar triple coordination



A mineral has:

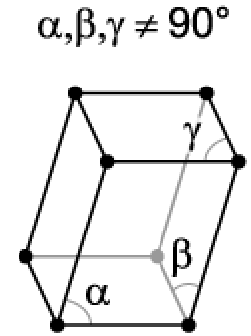
- A identical chemical composition
- A particular crystal structure

➔ordered internal structure of the ions or atoms

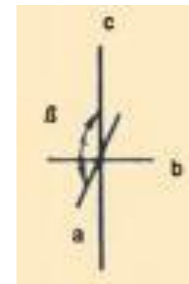
All crystalline minerals are classified into one of the seven crystal systems.

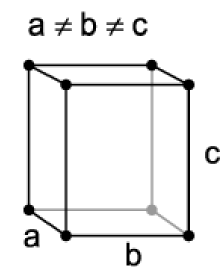
- Cubic
- tetragonal
- trigonal
- hexagonal
- orthorhombic
- monoclinic
- triclinic

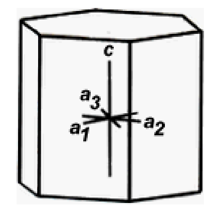
Crystal systems

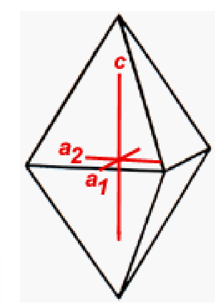


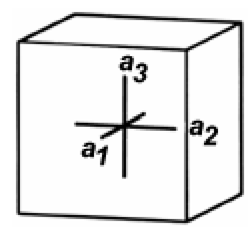
System:	Axes:	Angle:
1. Triclinc	$a \neq b \neq c \neq a$	$\alpha \neq \beta \neq \gamma \neq \alpha; \alpha, \beta, \gamma, \neq 90°$
2. Monoclinc	$a \neq b \neq c \neq a$	$\alpha = \gamma = 90°, \beta \neq 90°$
3. Orthorhombic	$a \neq b \neq c \neq a$	$\alpha = \beta = \gamma = 90°$
4. Hexagonal (trigonal)	$a = b \neq c$	$\alpha = \beta = 90°, \gamma = 120°$
5. Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90°$
6. Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90°$











- Crystals are solids with a regular arrangement of the ions or atoms according to the basic structure of the seven crystal systems.

- Crystals can form limited growth bodies by planar surfaces.

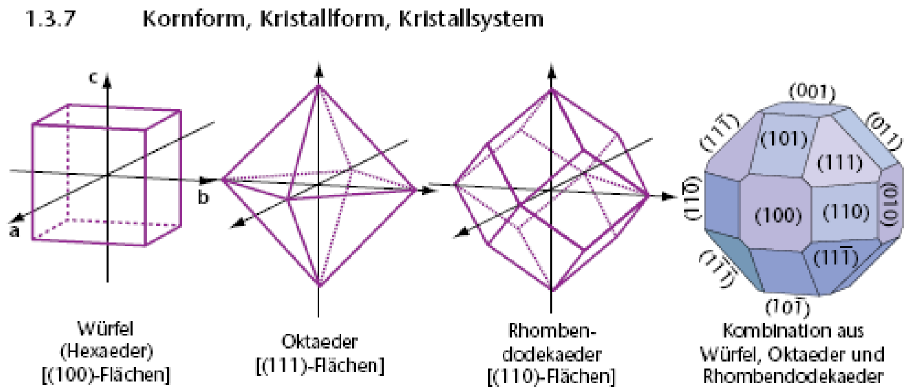
- The shape of the growth body (crystal form) is determined by the crystalline structure.

Characteristics of minerals

- Crystal form
- Hardness
- Fracture behavior
- Optical properties (color, line color, brightness)
- Density

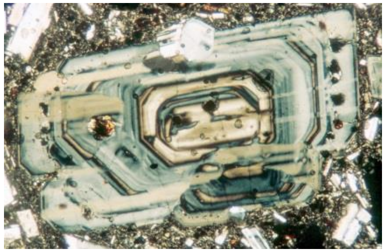
Grain form, crystal form

- **Crystal form**: external shape of a mineral grain which has grown without interfering with other solids (mineral granules)➔



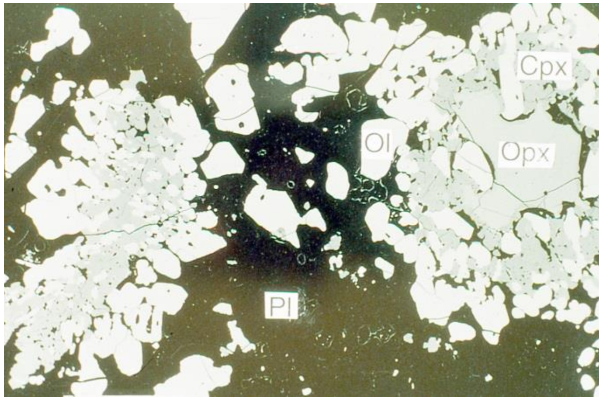
- **Idiomorphe grain form**

Idiomorphic
Plagioclas



- **xenomorphe grain form**

xenomorph
recrystallization

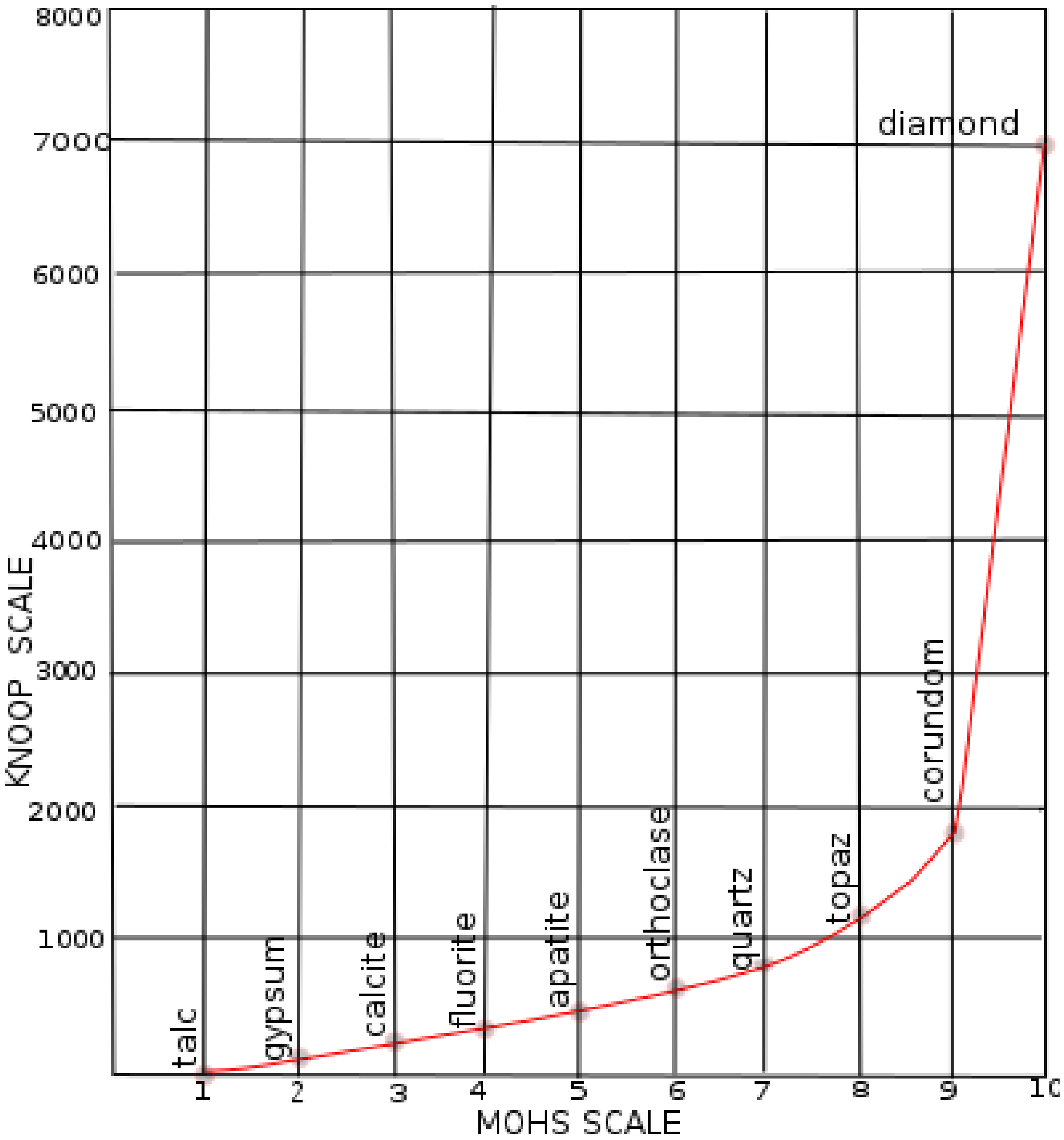


Friedrich Mohs (1773-1839)
German geologist/mineralogist.

Hardness

Resistance which a mineral opposes to scratching or grinding.

MOHS SCALE OF MINERAL HARDNESS		
Hardness	**Mineral**	**Everyday equivalent**
10	Diamond	synthetic diamond
9	Corundum	ruby
8	Topaz	sandpaper
7	Quartz	steel knife
6	Orthoclase / Feldspar	penknife blade
5	Apatite	glass
4	Fluorite	iron nail
3	Calcite	bronze coin
2	Gypsum	fingernail
1	Talc	baby powder


8000
7000
6000
5000
4000
3000
2000
1000
KNOOP SCALE
diamond
corundum
topaz
quartz
orthoclase
apatite
fluorite
calcite
gypsum
talc
1
2
3
4
5
6
7
8
9
10
MOHS SCALE

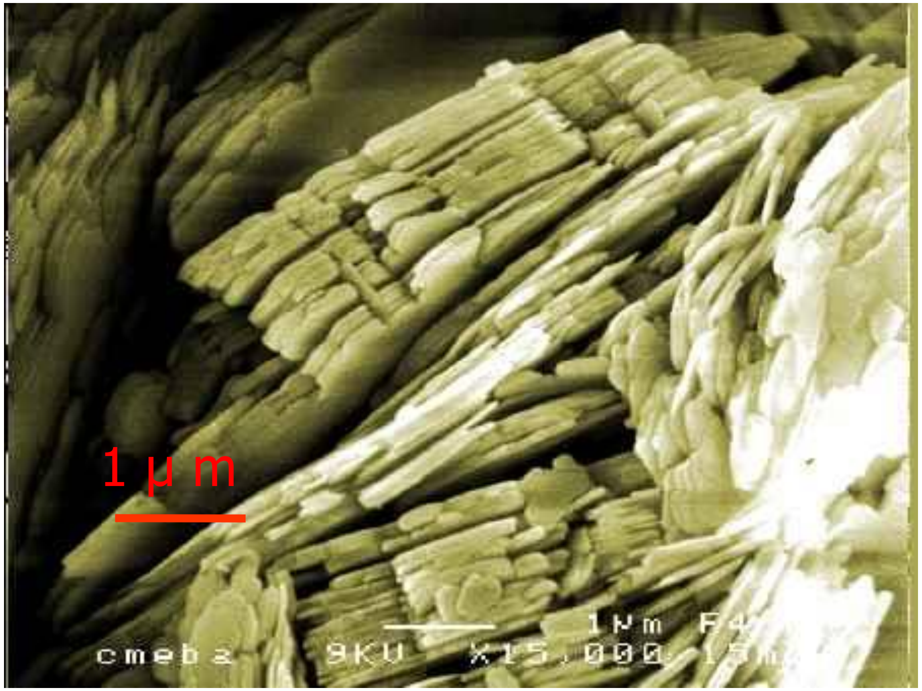
Fracture behavior and cleavage

- **Fracture:** The way a mineral breaks

>> rough, smooth, plintery**,** conchoidal

- **Cleavage:**

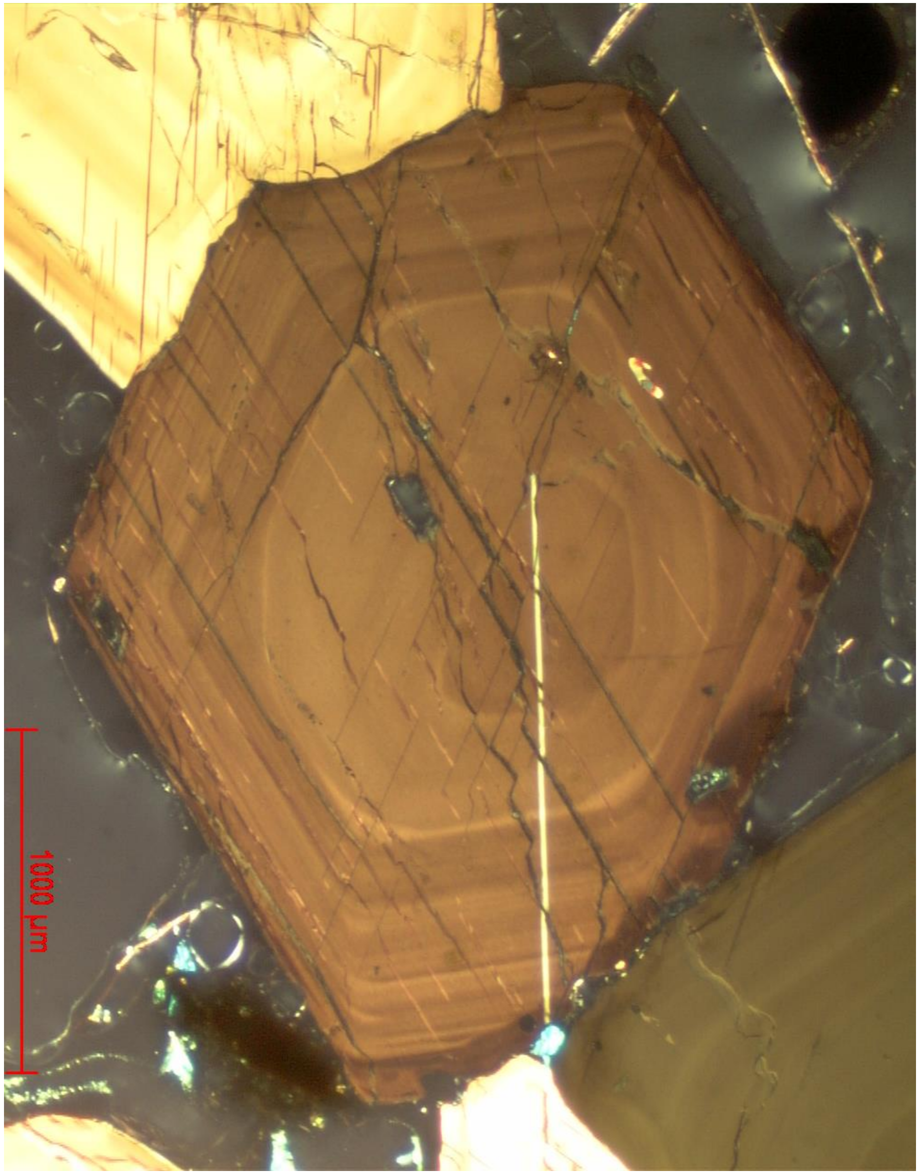
  Tendency of a mineral to break into certain parallel planes.



- **Plane of cleavage:**

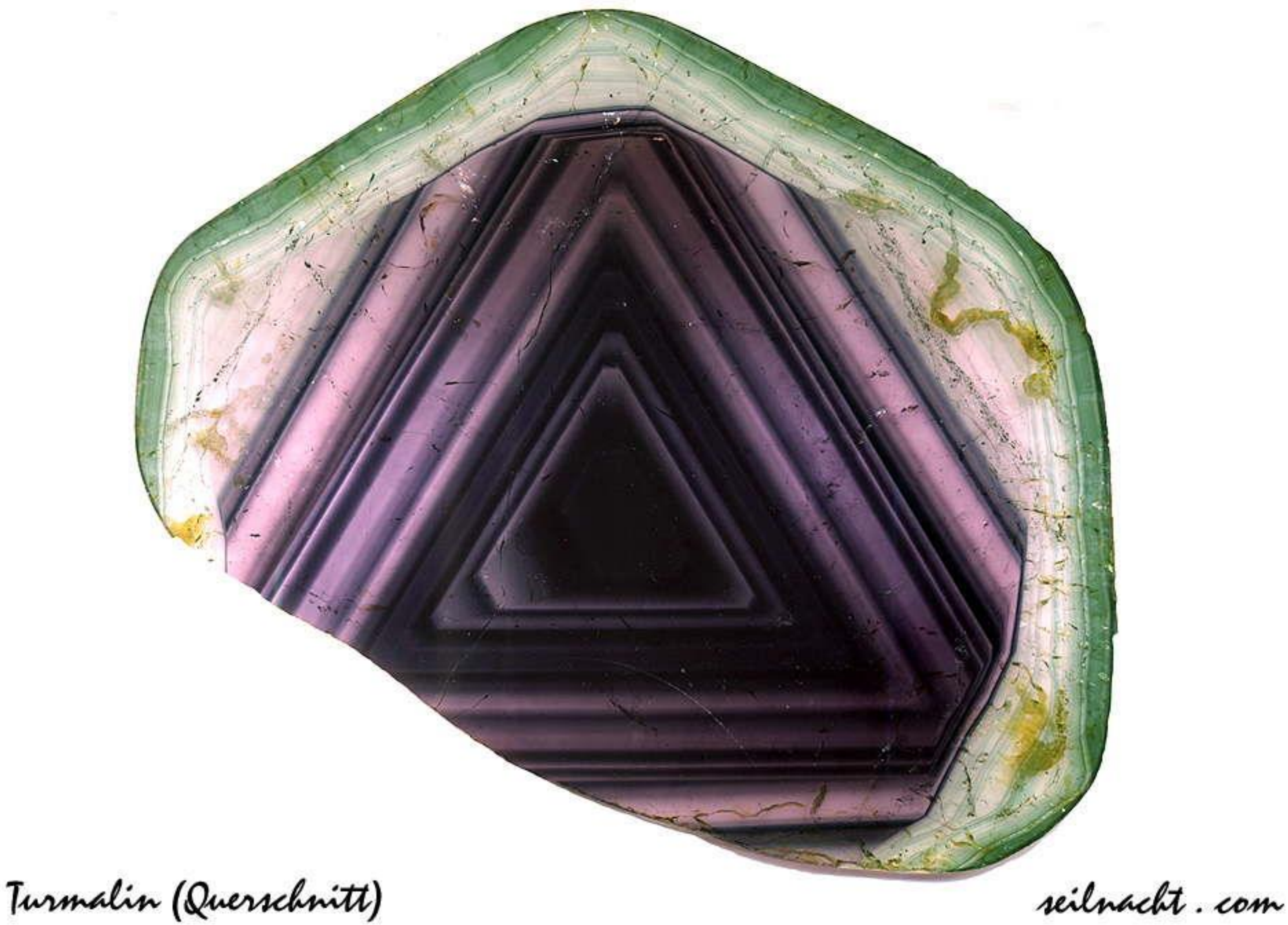
  Smooth surface that reflects the light and is oriented parallel to certain crystal structure planes.

- Many minerals have several good cleavages in different directions



Hornblende with two cleavege systems. They intersect at angles of 120 and 60 °

Colour

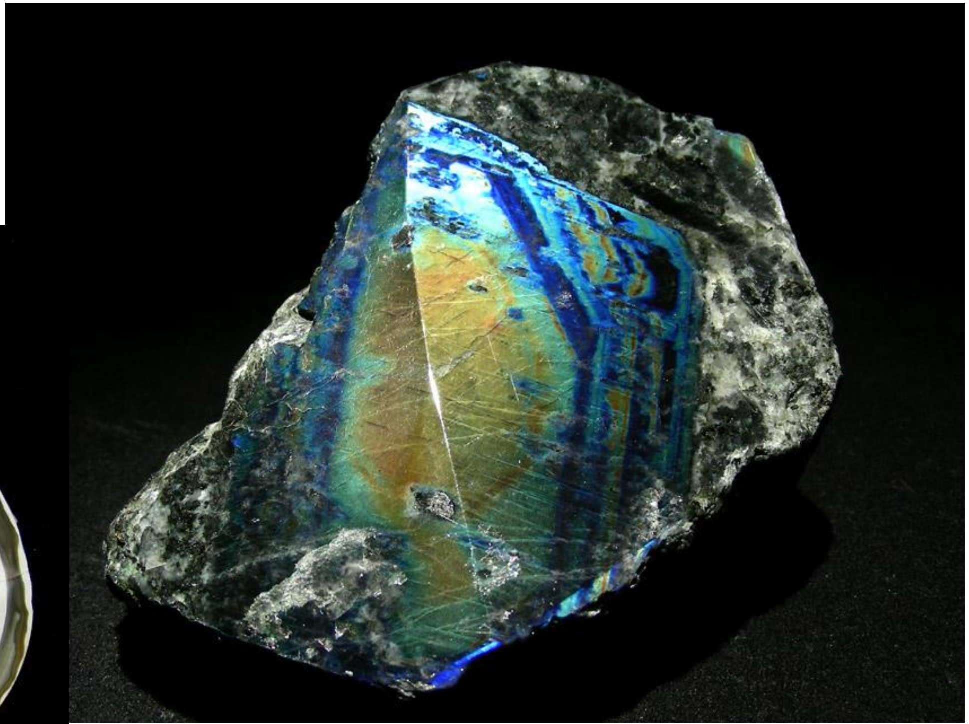


Color

- Incorporation of extremely fine inclusions of another type of mineral or liquid
- Integration of trace elements in the crystal structure
- Different chemical composition in mixed crystals
- Superficial reactions (initial colors - patina)
- Grain size
- Morphology of the grain surface

Minerals with different color varieties:

- Quartz: colorless, white pink, gray, yellow, violet
- Alkaline feldspar: white, flesh colored (salmon), gray, green



Only a few minerals have a constant color.

e.g: Galena: silver-gray

Sulfur: yellow

Thereforehe, color is not a clear diagnostic property!

Line and line color

➔Color of a mineral in the powdered state

➔Often it does not correspond to the color of the original larger mineral grain

➔ The line color is a relatively constant property of the minerals and therefore often of high diagnostic value.

- Hematite: red brownish line color
- Limonite: yellow brownish
- Magnetite: dark gray

Brigthness or luster

The luster is the appearance of a mineral surface in the reflected light.

- Minerals with **metallic luster**:
  Opaque and highly reflective, like polished metals
  Caution: many sulphides show initial colors or are covered by an oxide layer (patina)

- Minerals with **non-metallic luster**: it is further distinguished in glassy, waxy, greasy, silky, earthy, etc.

Specific density

- Quartz, Feldspar: ~2.6 g/cm^3 und
- Olivine, Amphibole: ~3.5 g/cm^3
- Gold: ~19 g/cm^3
- In the case of mixed crystals, the density depends on the respective chemical composition.

Other physical and chemical properties:

- Radioactivity
- Magnetic behavior
- Taste
- Smell
- Water soluble (some halides)
- Effervescence reaction to the hydrochloric acid (e.g., many carbonates)

Mineral classification

- The minerals are classified according to chemical composition and atomic structure (crystal structure).
-

  e.g.:

  Sulphide (S^{2-}), **Oxide** (O^{2-}), **Halide** (Cl^{-}), **Sulfate** (SO_4^{2-}), **Silicate** (SiO_4^{4-}), **Phosphate** (PO_4^{3-})

- About 4500 known minerals
- Only about 200 occur frequently in nature
- Classification according to H. Strunz
- Classified on the basis of chemical and crystal structure-typical properties

Classification into 9 classes according to Strunz:

I Group	Native elements
II Group	Sulphides (S^-)
III Group	Halides (F^-, Cl^-)
IV Group	Oxides und Hydroxides (O^{2-})
V Group	Nitrates, Carbonates, Borates
VI Group	Sulfates, Chromates, Molybdates, Wolframates
VII Group	Phosphates, Arsenates, Vanadates
VIII Group	Silicates ($[SiO_4^{-4}]$)
IX Group	Organic Minerals

I. Group: Native elements

Overview of minerals occurring in elemental form:

Metals		Metaloids (semimetals)		Non-metals	
Gold-Group		**Arsenic-Group**			
Gold	Au	Arsenic	As	Sulfur	S
Silver	Ag	Antimon	Sb	Diamond	C
Cupper	Cu	Bismuth	Bi	Graphite	C

Platinum-Group:

Platinum Pt

Iron-Group:		**Mercury –Group:**	
Iron	α-Fe	Mercury	Hg
Kamacite	α-Fe, Ni (Ni-ärmer)	Amalgam	Hg, Ag
Taenite	δ-Fe, Ni (Ni-rich)		

The gold-group:

Copper (Cu), Silver (Ag) and Gold (Au)

Copper

- cubic
- Hardness 2.5 - 3
- Density 9 - 19 g/cm^3
- Can be replaced by lead (Pb).
- For electro-technical devices and mechanical engineering
- As a base metal a very limited bond range
  ➔ Usually as oxide, sulfide or carbonate

Copper (Cu: bronze color)
Dendritically formed with green coating of copper oxide (Corocono, Bolivia).

Silver

Silber gediegen, Schlema/Erzgebirge, Foto und Copyright: Thomas Seilnacht

- Under hydrothermal conditions
- Very rare occurrence as native element

Gold

Biggest ever found gold nugget
294 ounces (almost 1 kg)

- In hydrothermal mineralization and impregnation in the area of highly differentiated granite intrusions
- Mostly derived from secondary enriched placers (concentrate minerals from diluvial processes)

Gold (Au)
Gold nuggets from South Australia

Conglomerate with gold placer

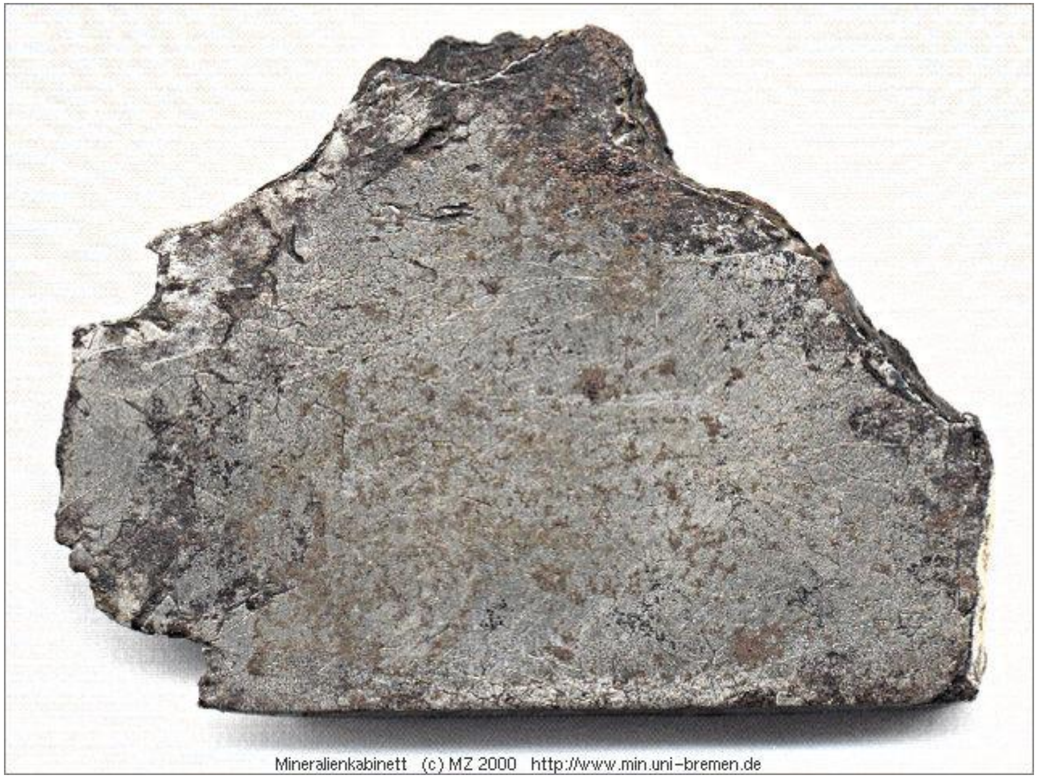
In 1886, gold ore was found in a fossil placer in the Witwatersrand Basin in South Africa. Gold-rich layers were found at the base of the conglomerates in a finer granular sandstone.

Platine group: Platine (Pt)

Würfelförmiger Platinkristall, Konder/Sibirien; Foto: Thomas Seilnacht

Iron

- Fe
- Density 7.9 g/cm^3
- Hardness of 4.5
- Very rare occurrence as element, since rapid reaction with electronically inert elements such as oxygen, sulfur



Meteor (Octaedrite) from the Joluca-Tal, Mexico.

Mercury

- Hg
- Crystallizes at -39 ° C
- Rhombohedral crystals
- As an alloy with gold or other precious metals (Amalgan). In dental technology and in the electrotechnical industry.

Mercury (Hg) with cinnabar from Idria, Carniola, Slovenia.

Metaloides (semi-metals)

Arsenic-Group:

▪ Arsenic	As
▪ Antimony	Sb
▪ Wismute	Bi

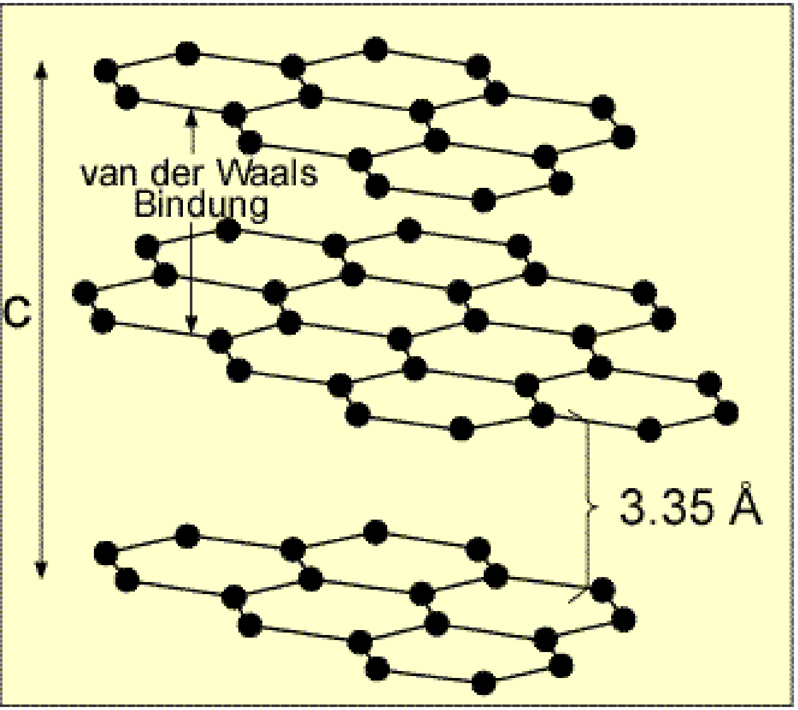
- Much more brittle than most metals
- Better cleavage
- Lower density than most metals
- For alloys and thermocouples
- Arsenic and antimony extremely rare in nature
- Bismuth in hydrothermal silver-tin deposits of the Erzgebirge and Bolivia.

Non-metals

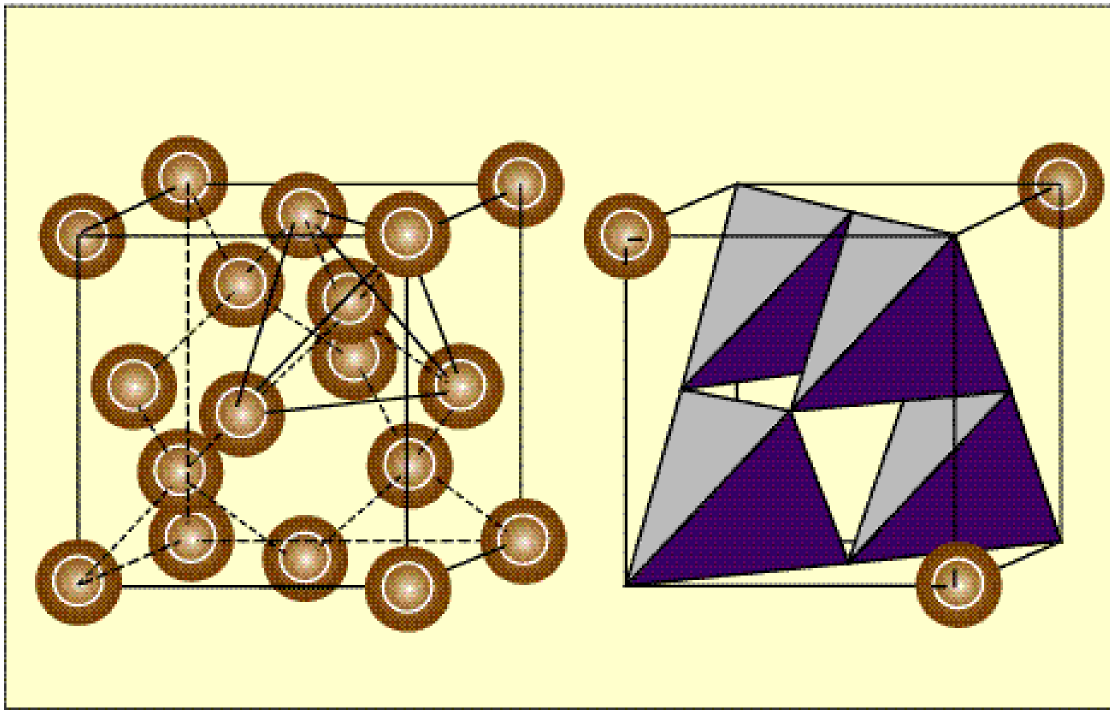
Graphite	C
Diamond	C
Sulfur	S

- Carbon occurs in nature modifications as graphite and diamond.

Graphit Struktur



Diamant-Struktur



- C hexagonal
- low hardness (1)
- low density (2.2 g/cm^3)

- C cubic
- Very high hardness (10)
- Very high density (3.5 g/cm^3)

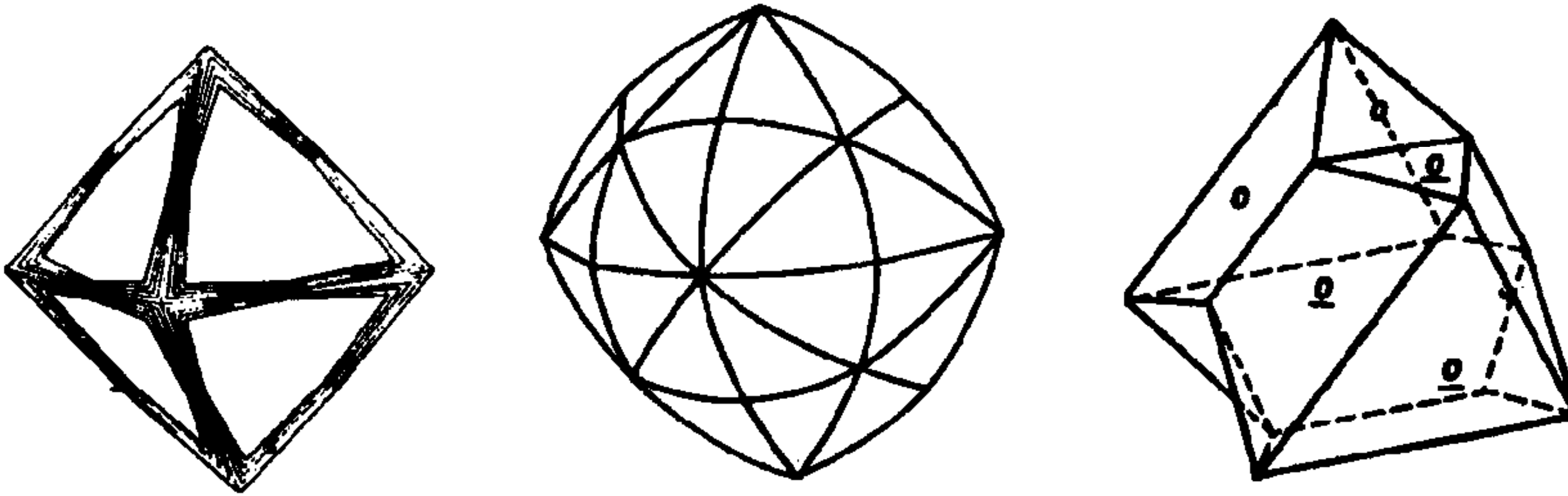
Graphite

Foto: Daggi

- C hexagonal
- Gray, flaky-scaly, metallic-shining crystals

Where does the graphite come from?

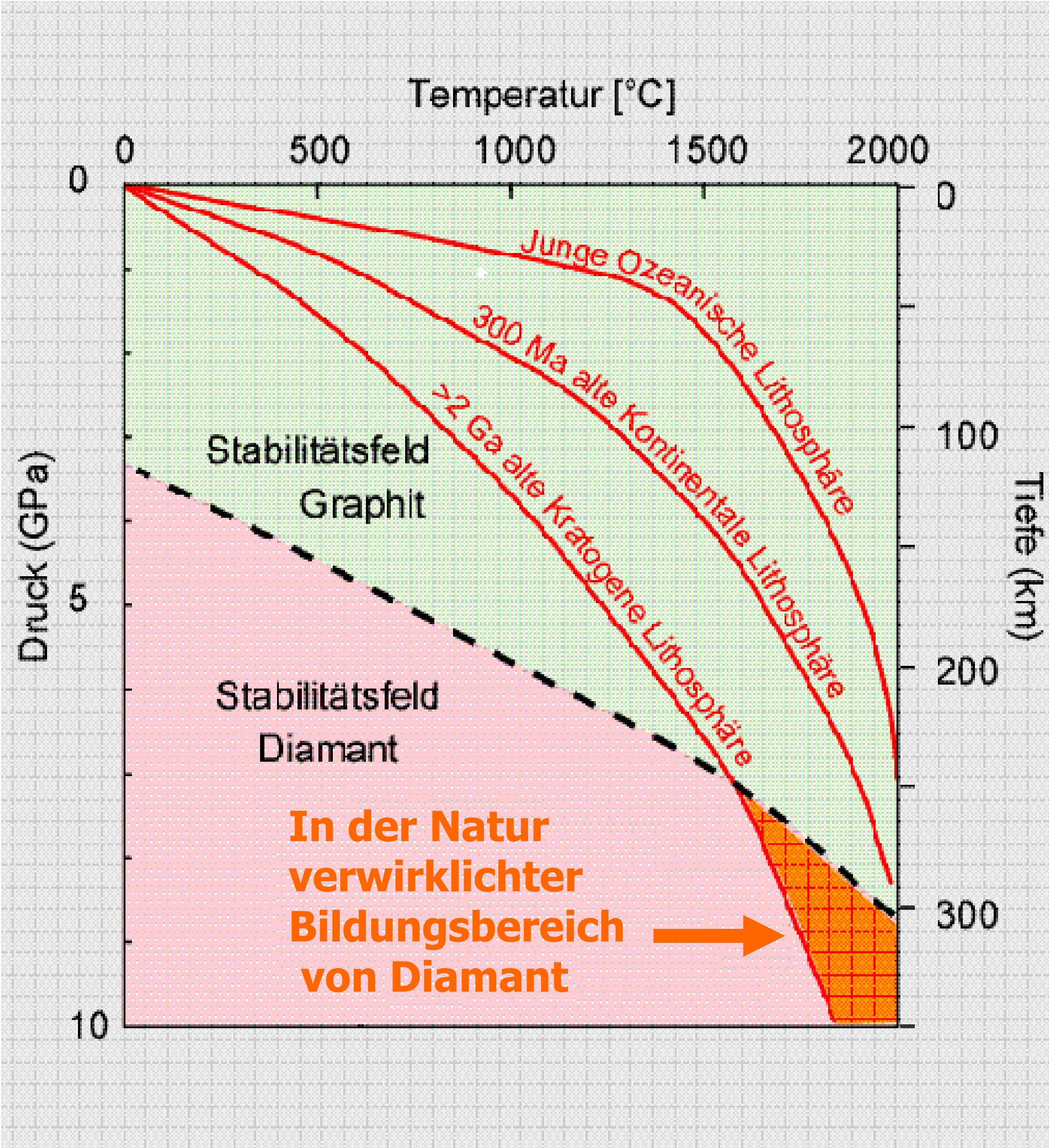
- From carboniferous substances of sedimentary rocks
- As a deposition from fluid phases
- Formed on metamorphic mounds and funnels
- Rarely magmatic



Diamantkristalle

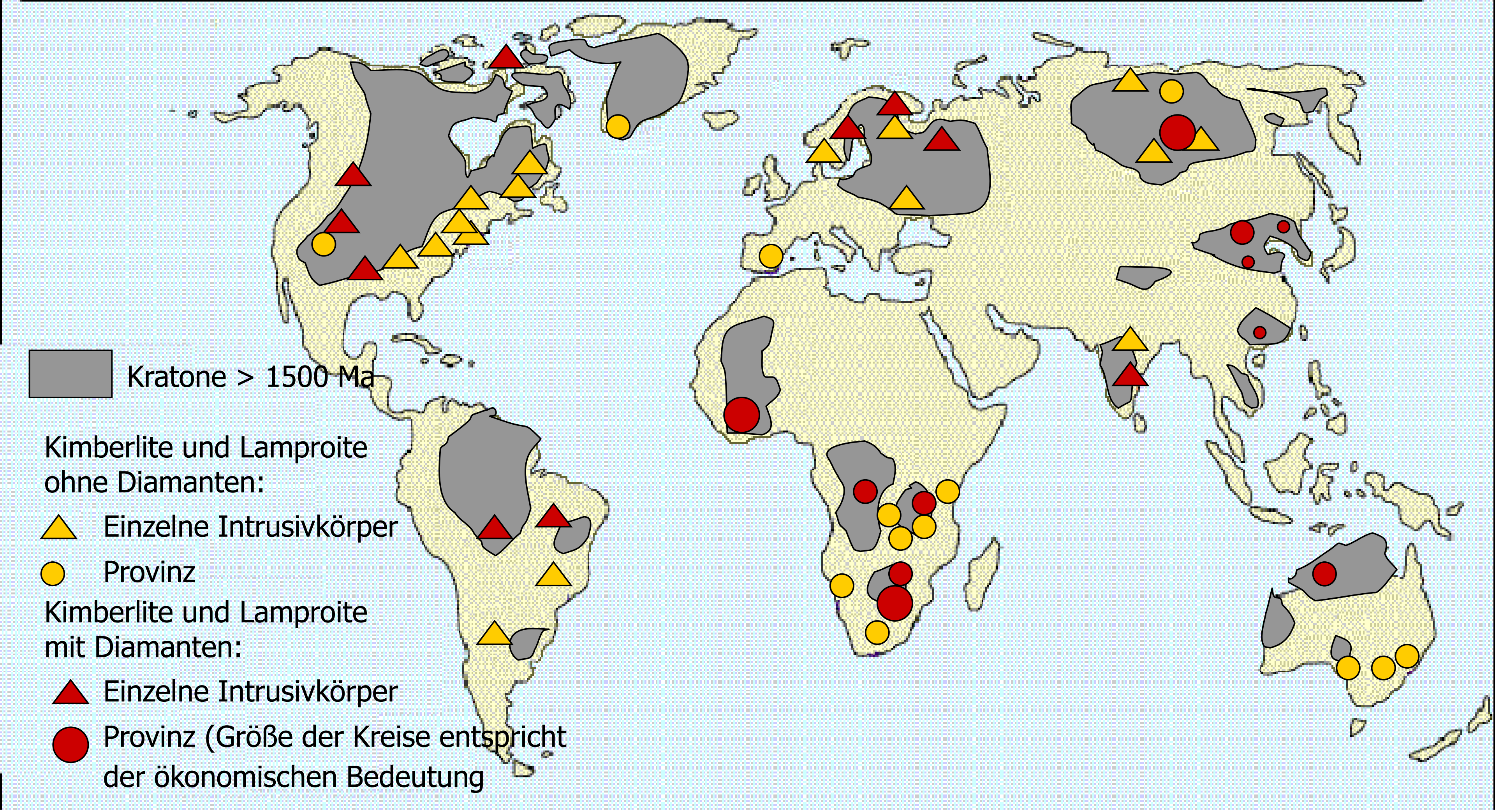
How are diamonds formed?

- In the Earth's mantle (200 -> 400 km depth) with relatively low geothermal gradient.
- Carbon recycling in the area of subduction zones
- In kimberlitic eruption vents



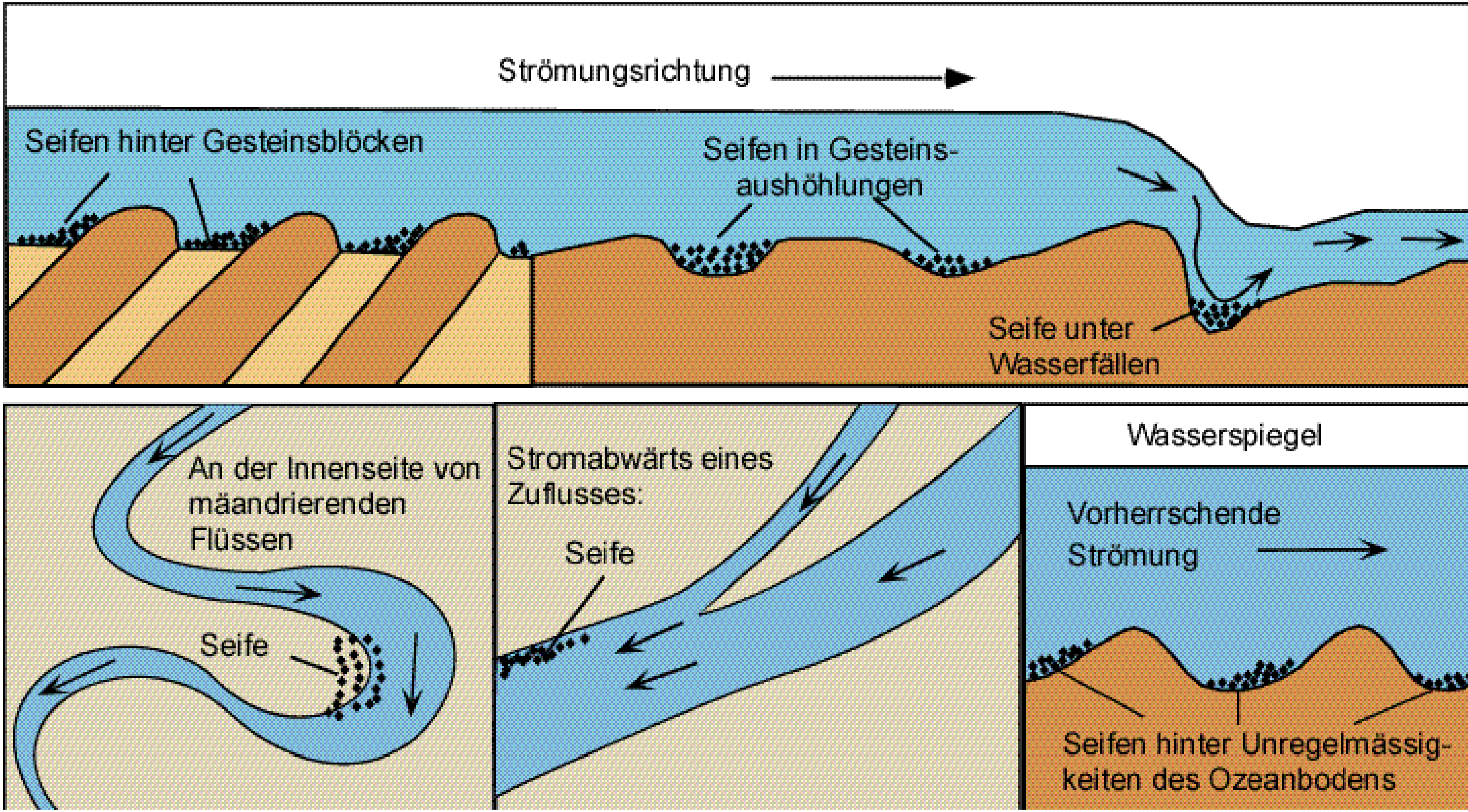
Temperatur [°C]
0
500
1000
1500
2000
Druck (GPa)
0
5
10
Tiefe (km)
0
100
200
300
Junge Ozeanische Lithosphäre
300 Ma alte Kontinentale Lithosphäre
>2 Ga alte Kratogene Lithosphäre
Stabilitätsfeld Graphit
Stabilitätsfeld Diamant
In der Natur verwirklichter Bildungsbereich von Diamant

Globale Verteilung diamantführender und diamantfreier Kimberlite und Lamproite



Placer deposits

Weather-resistant heavy minerals accumulate in placers: e.g. Gold, diamond, corundum (saffir, ruby)



Diamond octahedron (4 carats) in Kimberlite, Jagersfontein Mine, South Africa

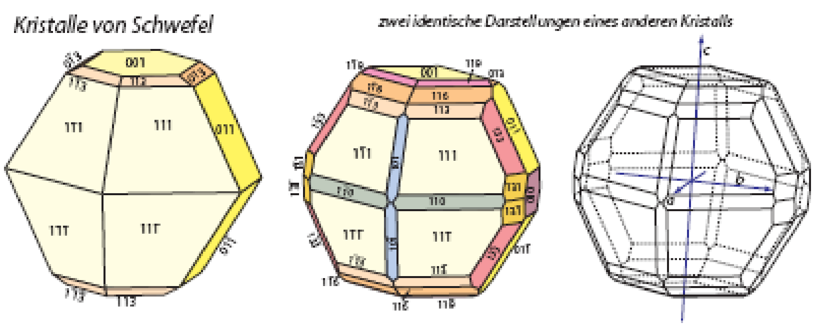
T. Stachel

Eclogite xenolith with diamond. Height of the image 2.5 cm

T. Stachel

Sulfur (S)

- orthorhombic (α-Sulfur)
- low hardness ($1^1/_2$ - 2) and density (2.1 g/cm^3)



Vulcanic formed sulfur

Elementary sulfur

How is sulfur produced?

- Gypsum ($CaSO_4 \times 2 H_2O$) and anhydrite ($CaSO_4$) are reduced to calcium sulfide in the presence of carbonaceous substances (action of anaerobic bacteria).
- Calcium carbonate and elemental sulfur are produced by the further action of carbonated water.

- Volcanic origen by sublimation of sulfur vapor on the crater walls and by partial oxidation of H_2S-containing solfarates

Where is sulfur used?

- Cellulose industry
- Pharmaceutical and cosmetic industries
- Explosive industry
- Sulfuric acid recovery
- Fertilization?

II. Group: Sulphides

- Covers most of the ore minerals (minerals with economic value).

- Magmatic fluids, hydrothermal and sedimentary (in the presence of H2S in the form of clay)

Division by H. Strunz based on the decreasing ratio of metal and non-metal (Me: S)

- 1. Sulphides and arsenides with Me:S> 1:1 (E.g., Cu2S, Ag2S)
- 2. Sulphides and arsenides with Me:S = 1:1 (E.g., CuS, FeS, ZnS)
- 3. Sulphides and arsenides with Me S <1:1 (E.g., FeS2, MoS2, Fe5S6)
- 4. Complex sulphides (sulphos salts)
- 5. Sulphides with non-metallic character

- Lead, zinc and iron in cubic sulphide modifications:
  - Specific gravity 3.9-7.5 g/cm3
  - Different line color, color and hardness (21/2, 4, 61/2).

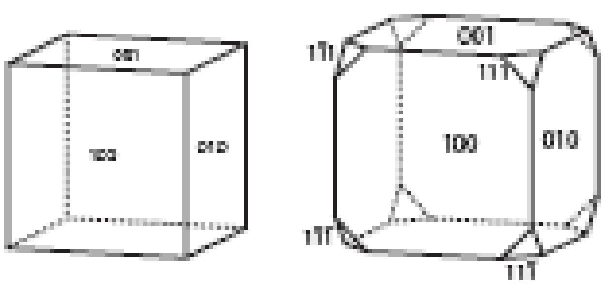
Examples: Galena PbS

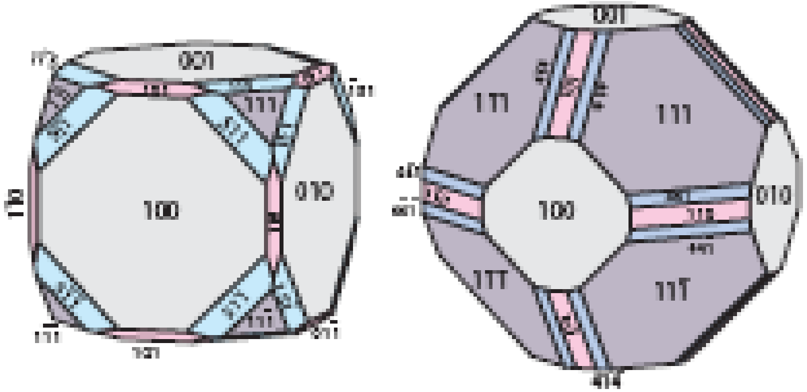
Blende (Sphalerite) ZnS

Pyrite FeS2

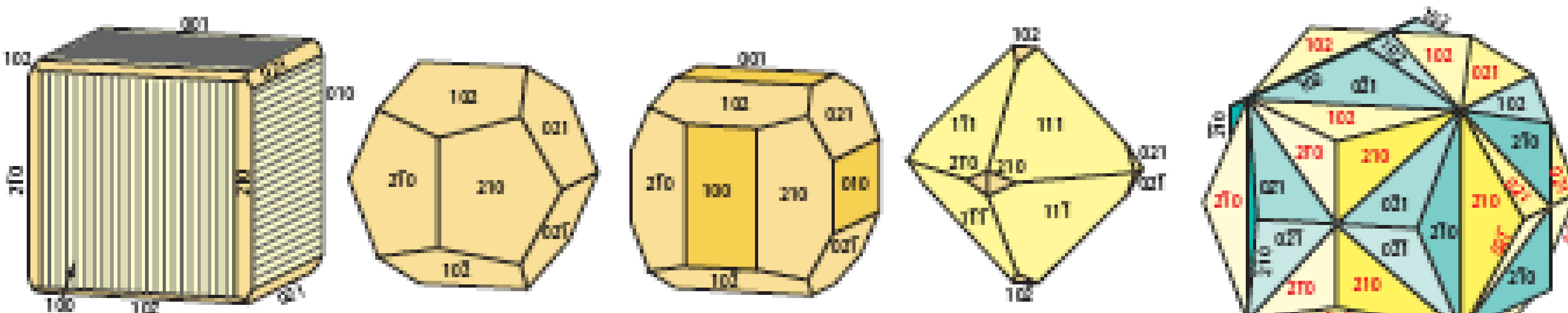
Pyrite (FeS_2)
from Elba, Italien.

Galenia from Pribram, Böhmen, Czech Repubilc.





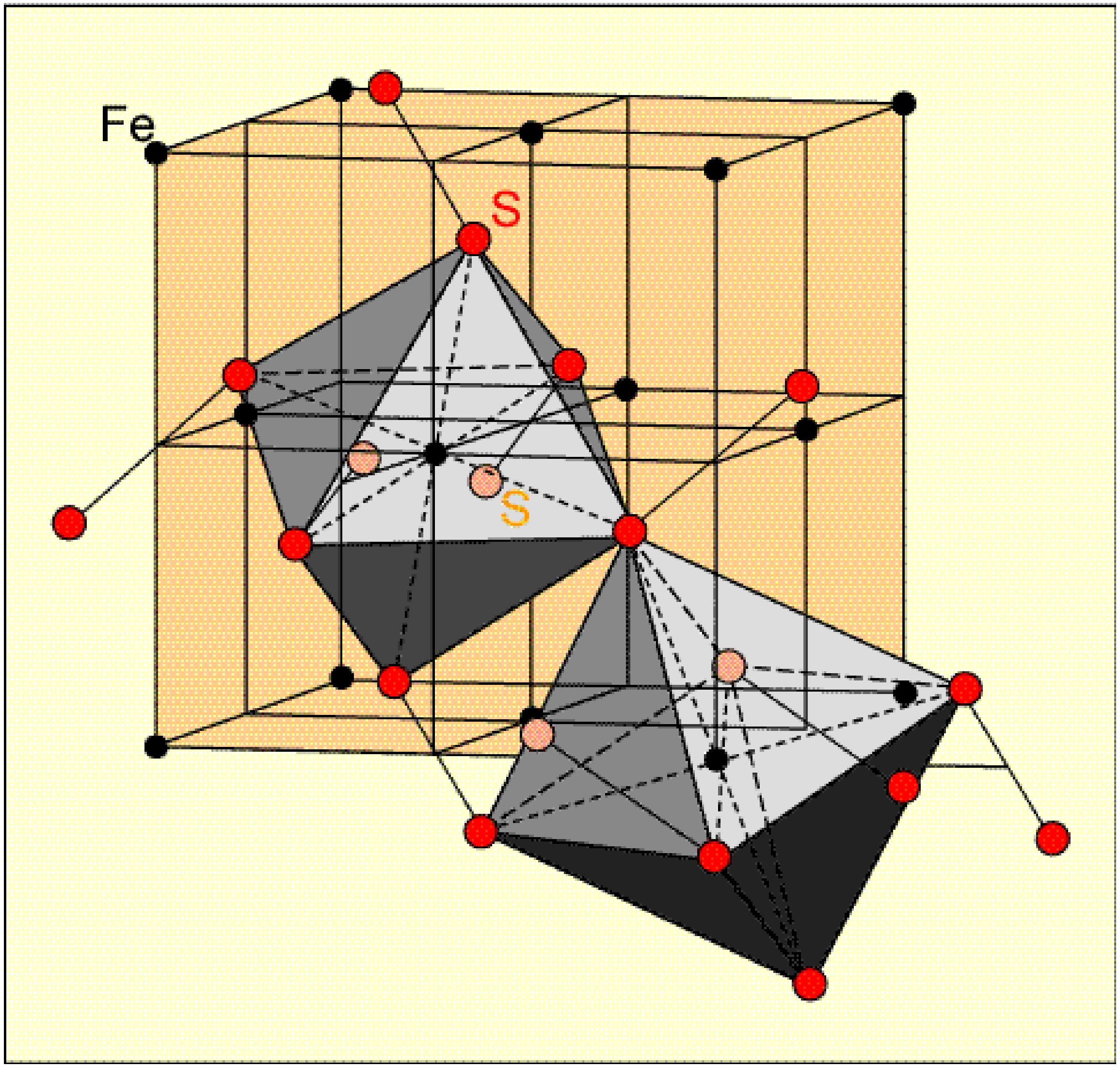
Kristalle von Bleiglanz



(a) *(b)* *(c)* *(d)* *(e)*

Ausbildung von Pyrit

Koordination des Fe-Atoms in der Pyrit-Struktur



Blende (sphalerite) and galena in calcite (white) from Raibl, Alpen, Italy