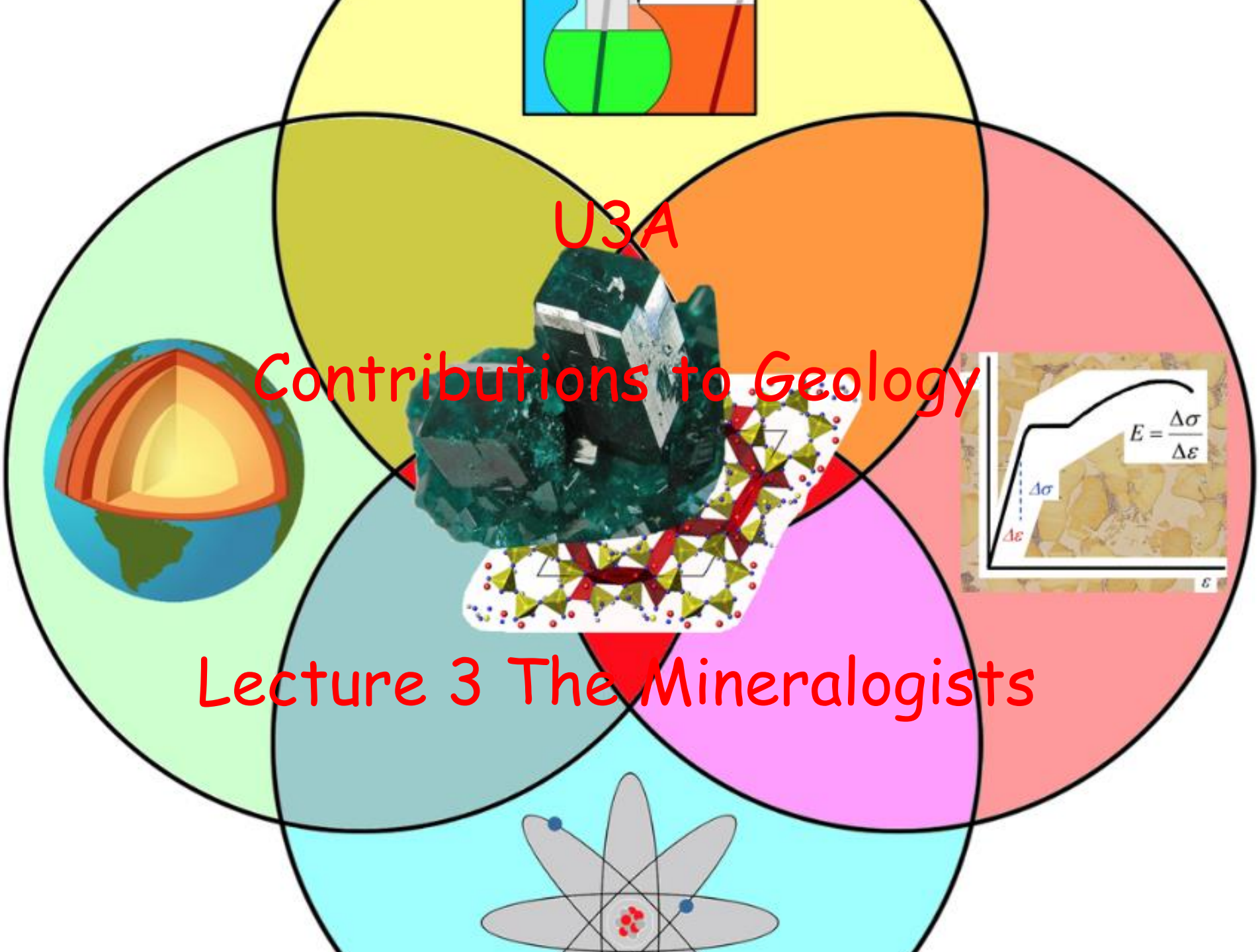

U3A
Contributions to Geology
$E = \frac{\Delta\sigma}{\Delta\varepsilon}$
$\Delta\sigma$
$\Delta\varepsilon$
ε
Lecture 3 The Mineralogists

Introduction

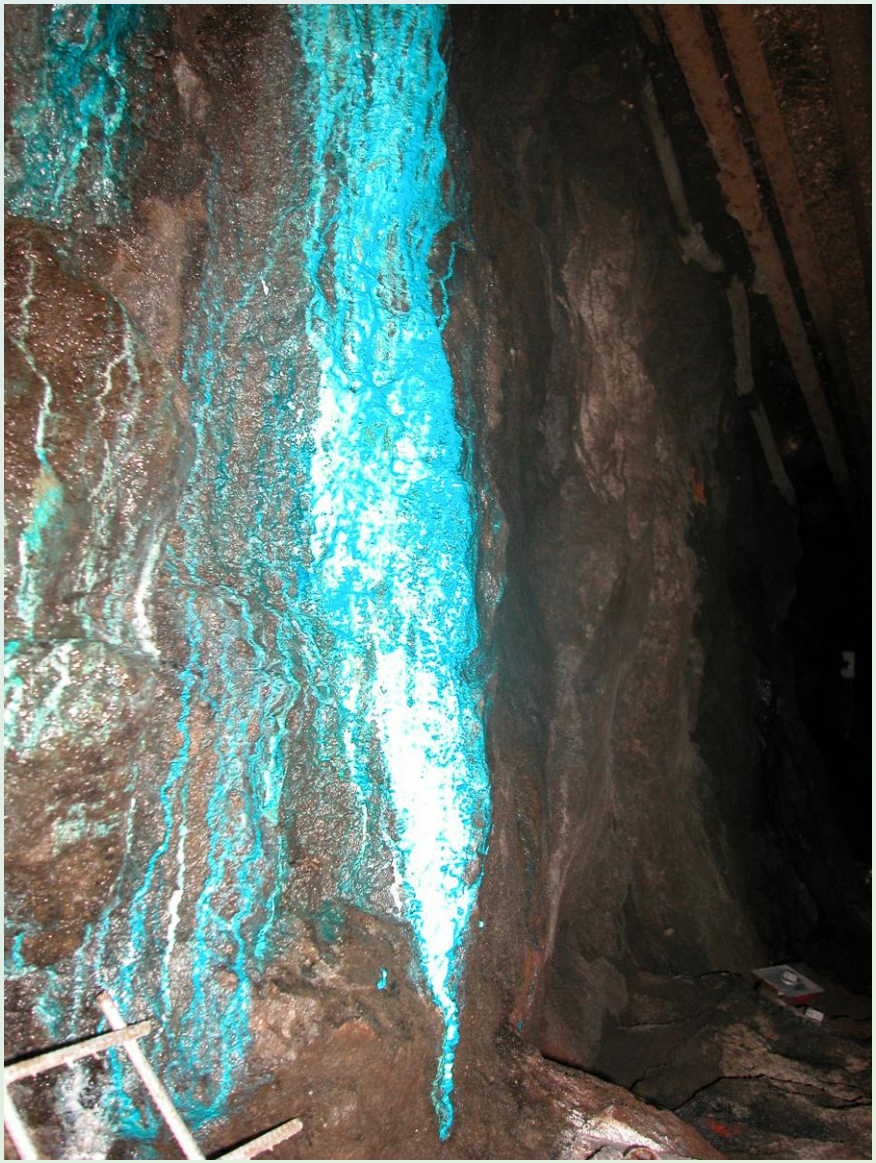
- Mineralogy → component of geology that involves the scientific study of the chemistry, crystal structure and optical and physical properties of minerals
- mineral use → as old as human history → natural pigments such as hematite, limonite and manganese oxide were used by early humans → cave paintings
- artifacts dating back 5000years from tombs in the Nile Valley were made using malachite, lapis lazuli, emerald and precious metals
- the Greek philosopher Theophrastus (372-287BC) produced the first written treatise on minerals titled "On Stones"
- Pliny the Elder 400years later in his work "Naturalis Historia" described minerals and their properties

Roman exploitation of minerals

- Romans applied knowledge of geology and mineralogy to locate, identify and process minerals

- Romans knew which minerals they needed to extract Cu and Sn → produce bronze; argentiferous galena → silver; iron ore

- Cu can occur in native form, but most Sn and Cu obtained from Cu and Sn compounds



Chrysacolla vein, Rocca San Silvestro mine, Tuscany

Georgius Agricola (Georg Bauer) (1494 - 1555)

- German physician, mineralogist and metallurgist born in Saxony in 1494

- regarded as "the father of mineralogy"

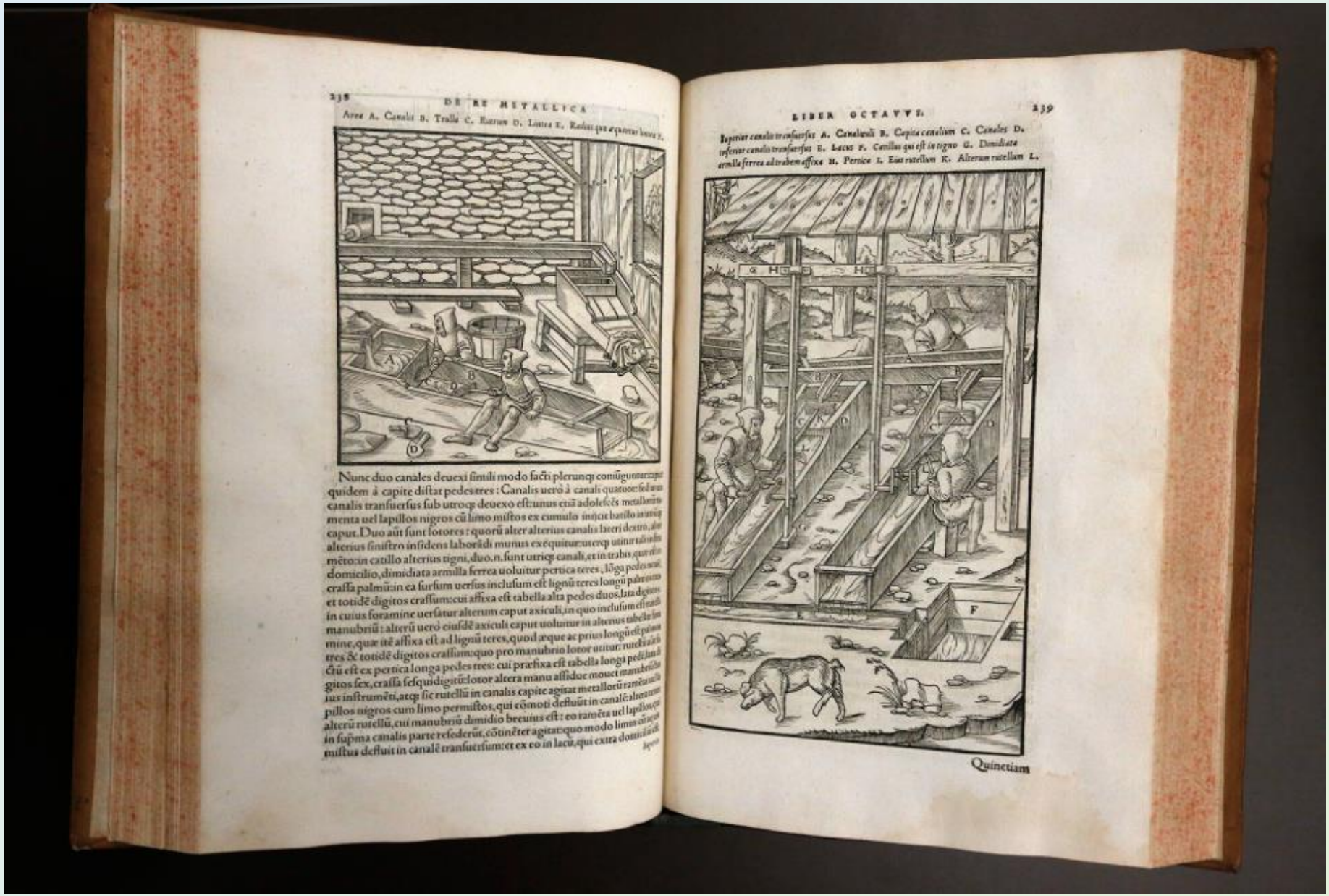
Georgius Agricola

- Studied the classics at Leipzig University intending to become a priest
- in 1522 commenced studying medicine at Leipzig and continuing at Bologna and Padua universities
- practised medicine in the mining town of Joachimsthal, Bohemia in 1527
- lost interest in medicine → moved to Chemnitz, Saxony → pursued passion for geology, mineralogy and mining
- published journal on physical geology
- in 1546 published "De natura fossilium" considered the first textbook on mineralogy
- described fossils exposed during mining → failed to recognise significance

Georgius Agricola

- named and classified minerals on basis of their physical properties and listed their locations
- developed interest in environmental issues → recognised consequences of de-forestation and stream pollution (through mining practices)
- identified potential occupational health and safety problems in mining
- his famous work "De Re Metallica" was published in 1556 → treatise on mining and extractive metallurgy → well illustrated
- in 1912 Herbert Hoover and his wife translated De Re Metallica into English

De Re Metallica



238 DE RE METALLICA

Area A. Canalis B. Tralla C. Rastrum D. Limus E. Radius qui æquatur huic F.

Nunc duo canales deuexi simili modo facti plerunq; coniugunturq; quidem à capite distat pedes tres: Canalis uerò à canali quatuor: sed unus canalis transuersus sub utroq; deuexo est: unus cui adolescēs metallorum menta uel lapillos nigros cū limo mistos ex cumulo iniicit batillo in unum caput. Duo aūt sunt fotores: quorū alter alterius canalis lateri dextro, alter alterius sinistro insistens laborādi munus exequitur: uteruq; utitur rutello mētorum catillo alterius tigni, duo.n. sunt utriq; canali, et in trabis, quæ ei domicilio, dimidiata armilla ferrea uoluitur pertica teres, lōga pedes nouē crassā palmū: in ea sursum uersus inclusum est lignū teres longū pālmos et totidē digitos crassum: cui affixa est tabella alta pedes duos, lata digitos in cuius foramine uersatur alterum caput axiculi, in quo inclusum est rotulæ manubriū: alterū uerò eiusdē axiculi caput uoluitur in alterius tabellæ foramine, quæ itē affixa est ad lignū teres, quod æque ac prius longū est palmos tres & totidē digitos crassum: quo pro manubrio fotor utitur: rutellū autē cū est ex pertica longa pedes tres: cui præfixa est tabella longa pedem, lata digitos sex, crassa sesquidigitū: fotor altera manu assidue mouet manubrium, instrumēti, atq; sic rutellū in canalis capite agitat metallorū ramēta cum lapillos nigros cum limo permistos, qui cōmoti defluūt in canalē: alterum alterū rutellū, cui manubriū dimidio brecius est: eo ramēta uel lapillos qui in fuprema canalis parte resederūt, cōtinēter agitat: quo modo limus cū aqua mistus defluit in canalē transuersum: et ex eo in lacū, qui extra domicilū est.

LIBER OCTAVVS. 239

Superior canalis transuersus A. Canaliculi B. Capita canalium C. Canales D. inferior canalis transuersus E. Lacus F. Camillus qui est in tigno G. Dimidiata armilla ferrea ad trabem affixa H. Pertica I. Eius rutellum K. Alterum rutellum L.

Quinetiam

Nicolaus Steno (Niels Stensen) (1638 – 1686)

Danish theologian and scientist, pioneer in both anatomy and geology

Nicolaus Steno

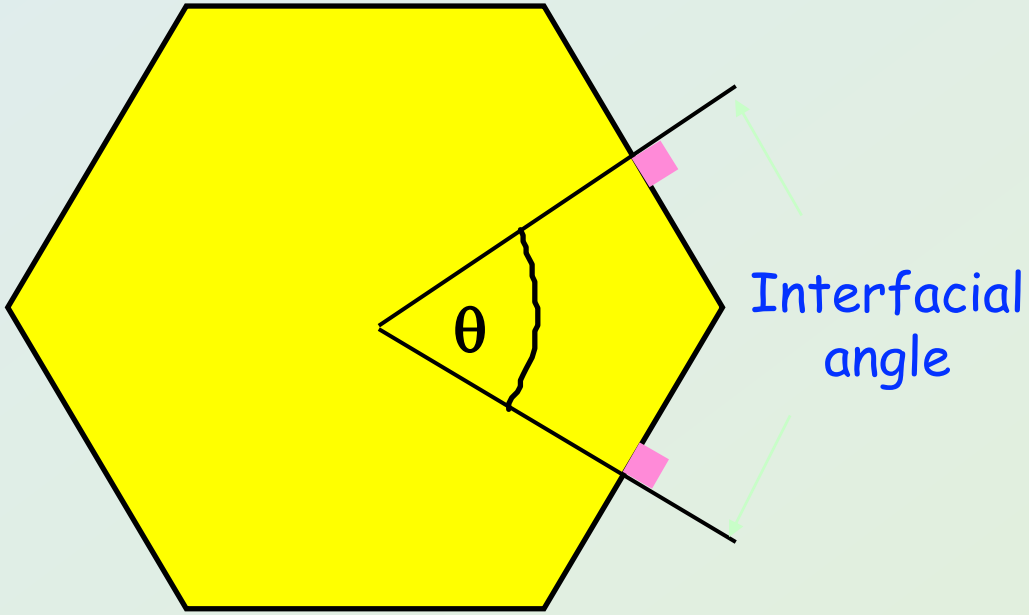
- Attended University of Copenhagen and studied medicine
- travelled extensively over Europe → settled in Italy
- appointed first professor of anatomy at Padua University
- contributed to geology in the fields of stratigraphy, palaeontology (identified *glossopterae*) and crystallography
- formulated "Law of constancy of interfacial angles"
- proposed "Principles of horizontality and superposition"
- abandoned science in 1667, converted to Roman Catholicism and became a bishop

Nature of crystals

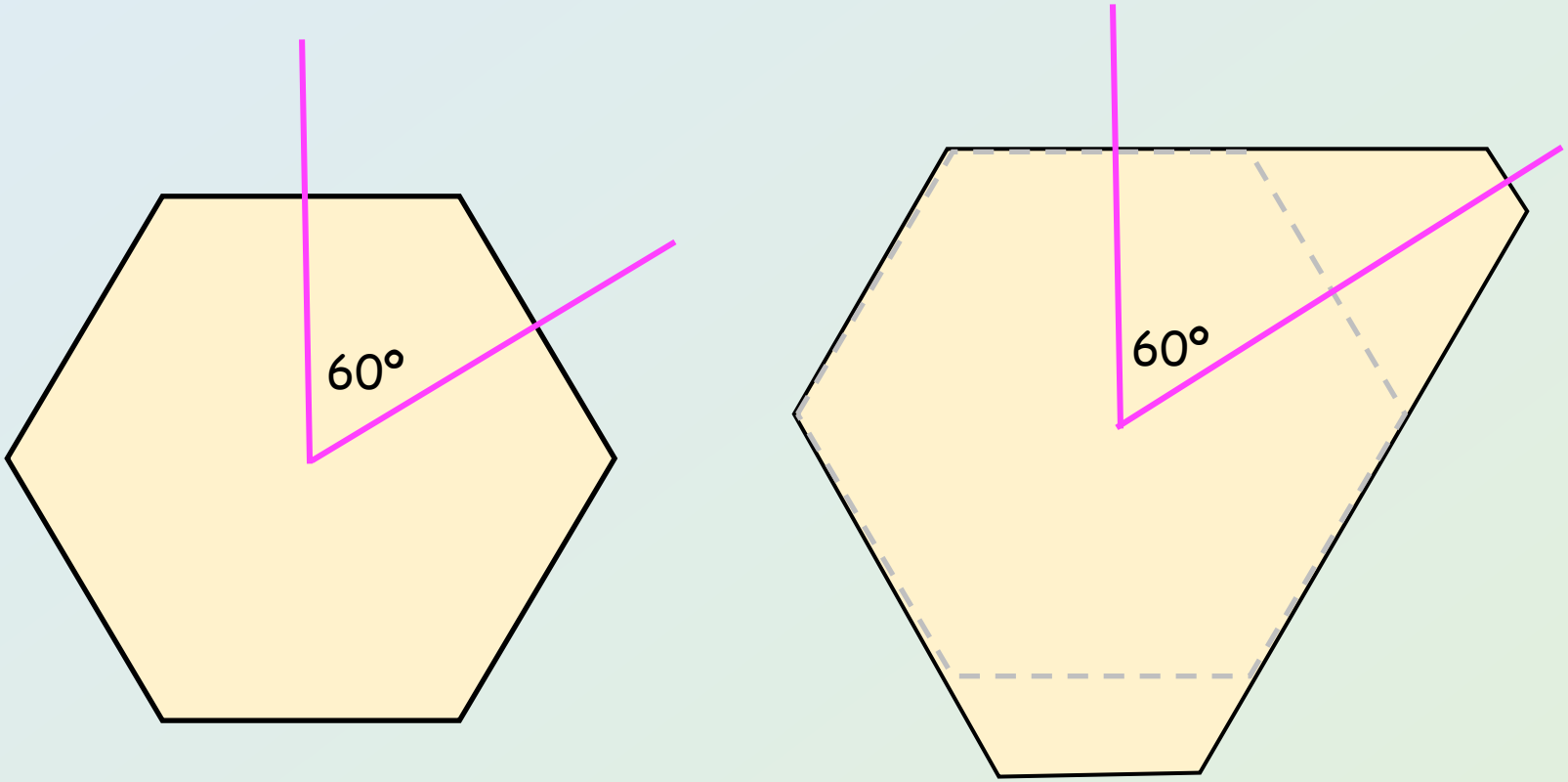
- Nicolaus Steno's best known contribution to the science of geology was in the field of crystallography

- Law of constancy of interfacial angles

  "in all crystals of the same substance, the angles between corresponding faces are constant"

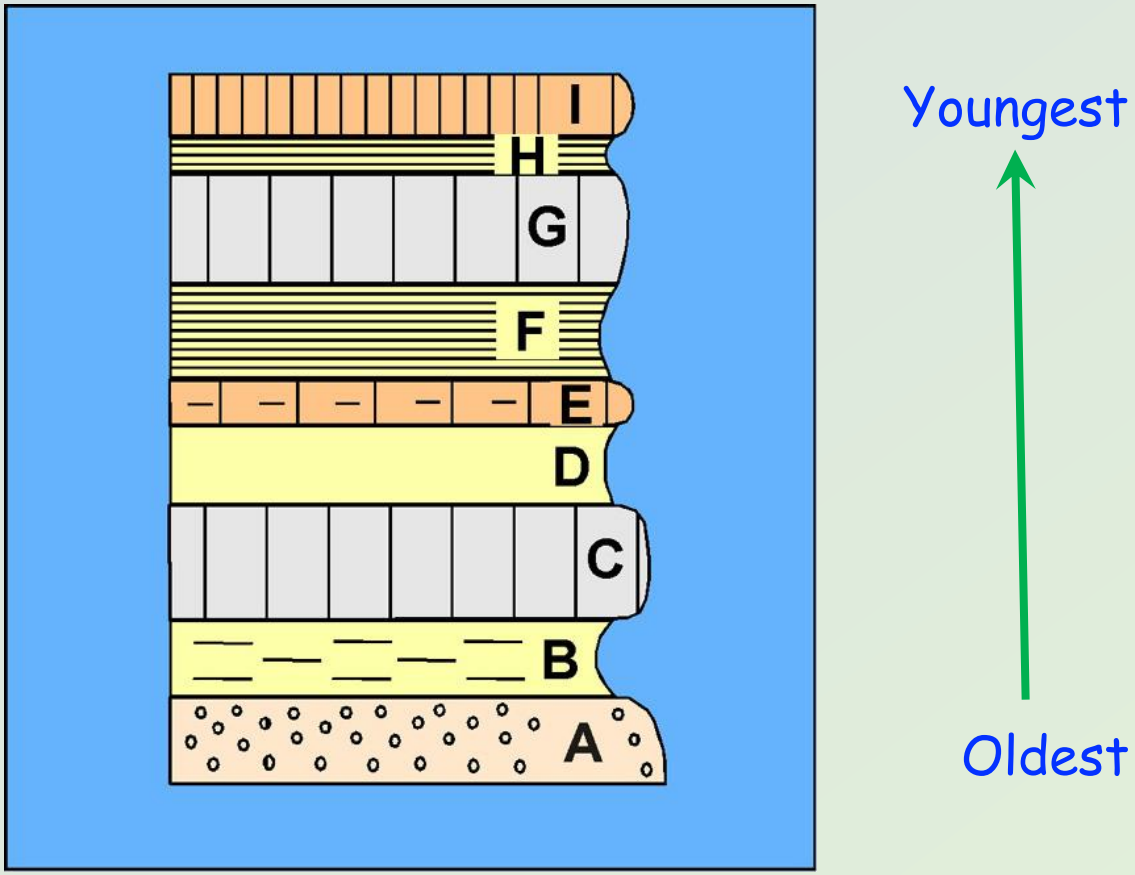


Constancy of interfacial angles



Laws of horizontality and Superposition

- Law of horizontality: "layers of sediment were originally deposited horizontally under the influence of gravity"
- Principle of superposition: "In a sequence of undeformed rocks any layer that is superimposed on another is younger than it"



Rene Hauy (1743 – 1822)

French theologian and mineralogist → important founder in the field of crystallography

Rene Hauy

- Studied theology at the colleges of Navarre and Lemoine → entered Catholic priesthood → developed keen interest in natural history

- imprisoned during French Revolution

- under Napoleon → professor of mineralogy at Museum of Natural History

- formulated important laws on crystallography

- deduced that crystals form from fundamental building blocks he called unit cells → implied some type of internal structure

- no fewer than 20 Nobel prizes have been awarded for research in whole or in part on principles stated by him e.g. William and Lawrence Bragg, Watson and Crick

Extracts from Hauy's journals

ESSAI

D'UNE THÉORIE

SUR LA STRUCTURE

DES CRYSTAUX,

APPLIQUÉE

A PLUSIEURS GENRES DE SUBSTANCES CRYSTALLISÉES;

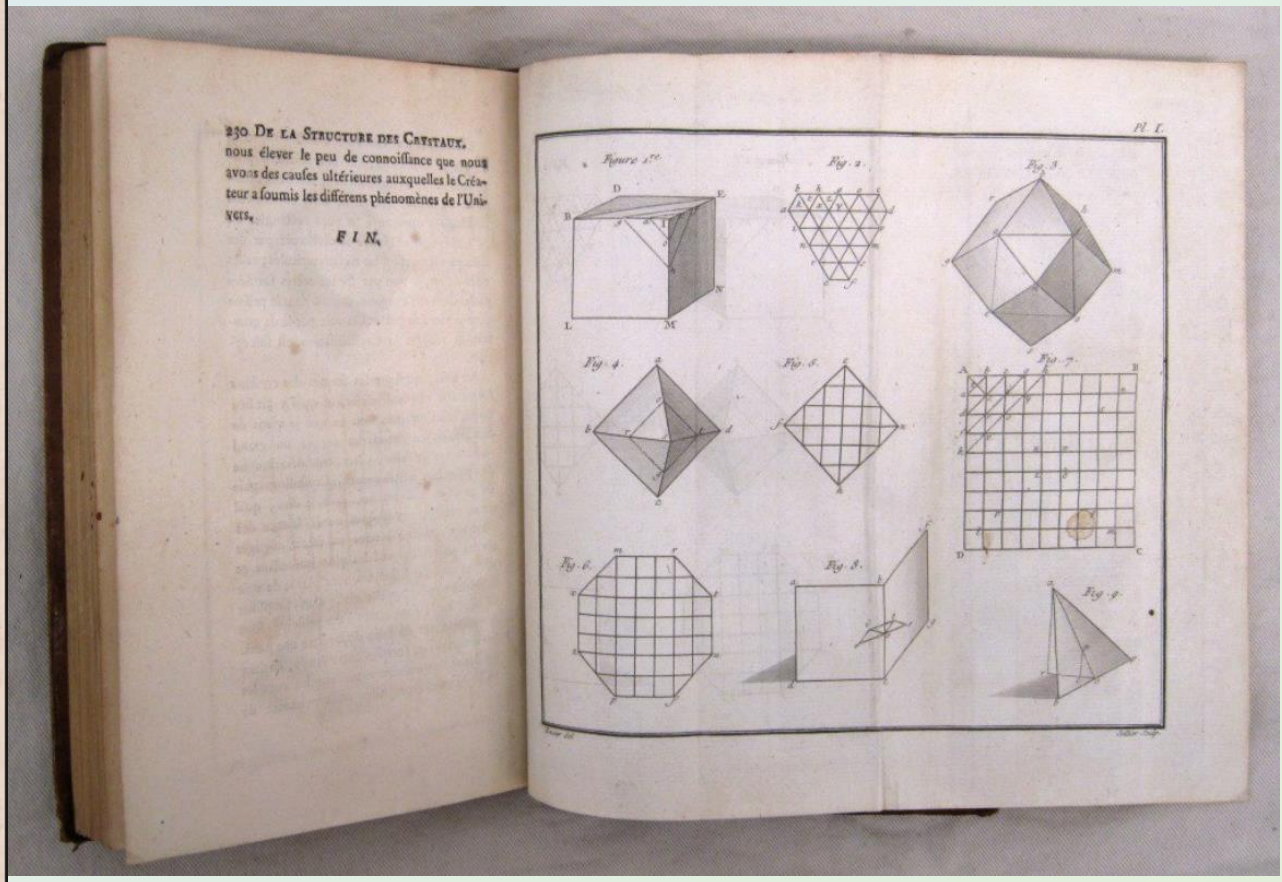
Par M. l'Abbé HAÜY, de l'Académie Royale des Sciences, Professeur d'Humanités dans l'Université de Paris.

A PARIS,

Chez Gogué & Née de la Rochelle, Libraires, Quai des Augustins, près le Pont Saint-Michel.

M. DCC. LXXXIV.

AVEC APPROBATION ET PRIVILÉGE DE L'ACADÉMIE.



230 DE LA STRUCTURE DES CRYSTAUX.

nous élever le peu de connoissance que nous avons des causes ultérieures auxquelles le Créateur a soumis les différens phénomènes de l'Univers.

FIN.

Unit cell

- Hauy proposed that all crystals are composed of fundamental building blocks that he called unit cells

- a unit cell is the smallest atomic arrangement that can on replication build up an entire crystal (6 arrangements exist)

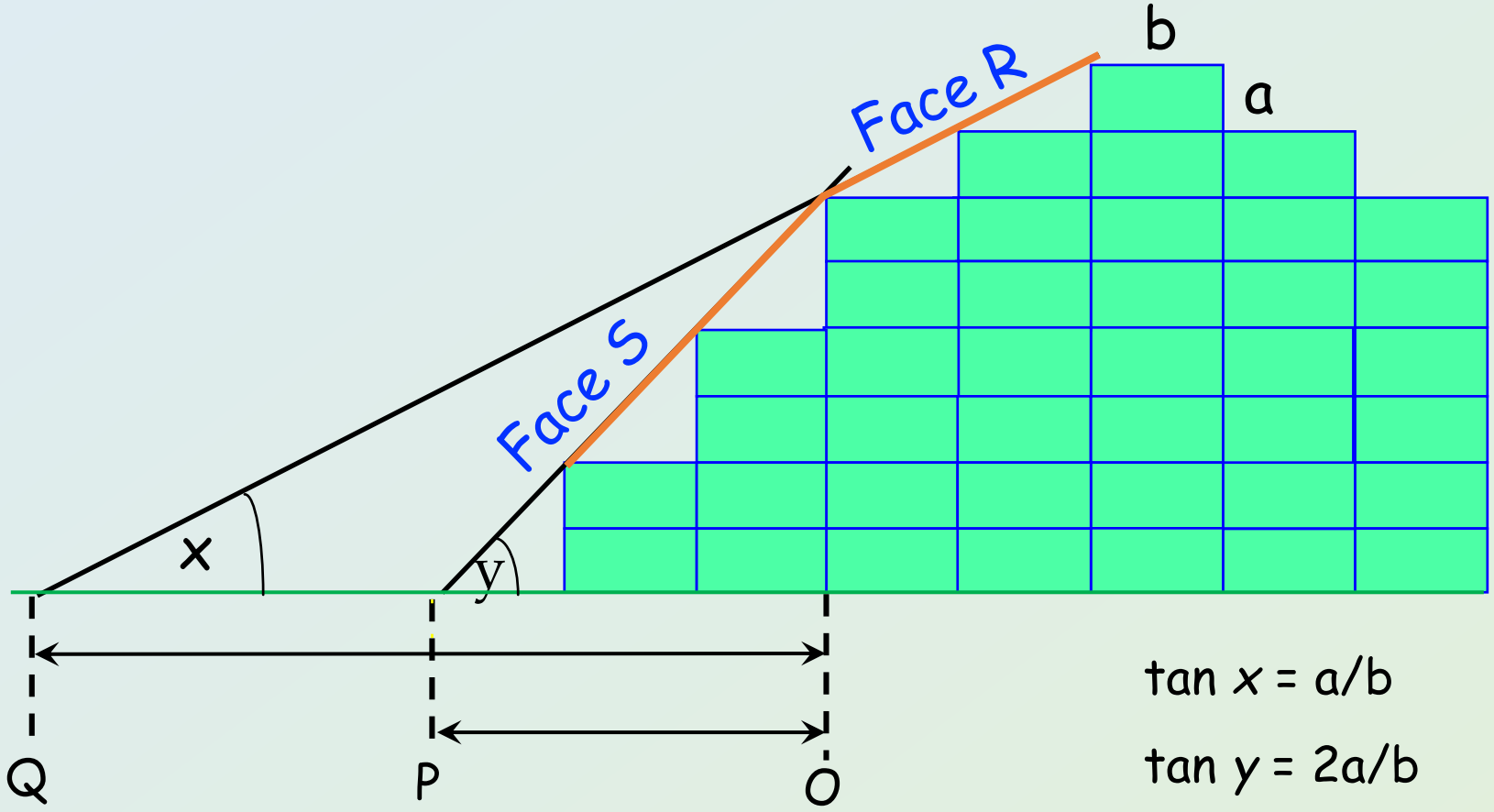
- e.g. the unit cell for halite is cubic
  the unit cell for calcite is rhombohedral

- a regular change in the packing arrangement could account for the constancy of interfacial angles.

- basis for his theory of "Rational ratios of intercepts"

Law of rational ratios of intercepts

"Where two or more crystal faces intersect a crystallographic axis → ratio of the intercepts → simple rational number"



$\tan x = a/b$

$\tan y = 2a/b$

$\tan y = 2\tan x$

NB. Intercept length OQ = 2OP

James Smithson (1764 – 1829)

English chemist and mineralogist best remembered for founding the Smithsonian Institute, Washington DC

James Smithson

- Born (illegitimately) into highly dysfunctional upper class family
- studied chemistry at Oxford University
- studied geological features in Scotland and the Hebrides
- collected mineral and ore samples from all over Europe
- credited with being the first geologist to use the term silicates
- renowned for study of calamine → proved that it was actually two minerals, $ZnCO_3$, and $Zn_4Si_2O_7(OH)_6.H_2O$
- donated his fortune and a very large number of geological samples to found the Smithsonian Institute in the USA

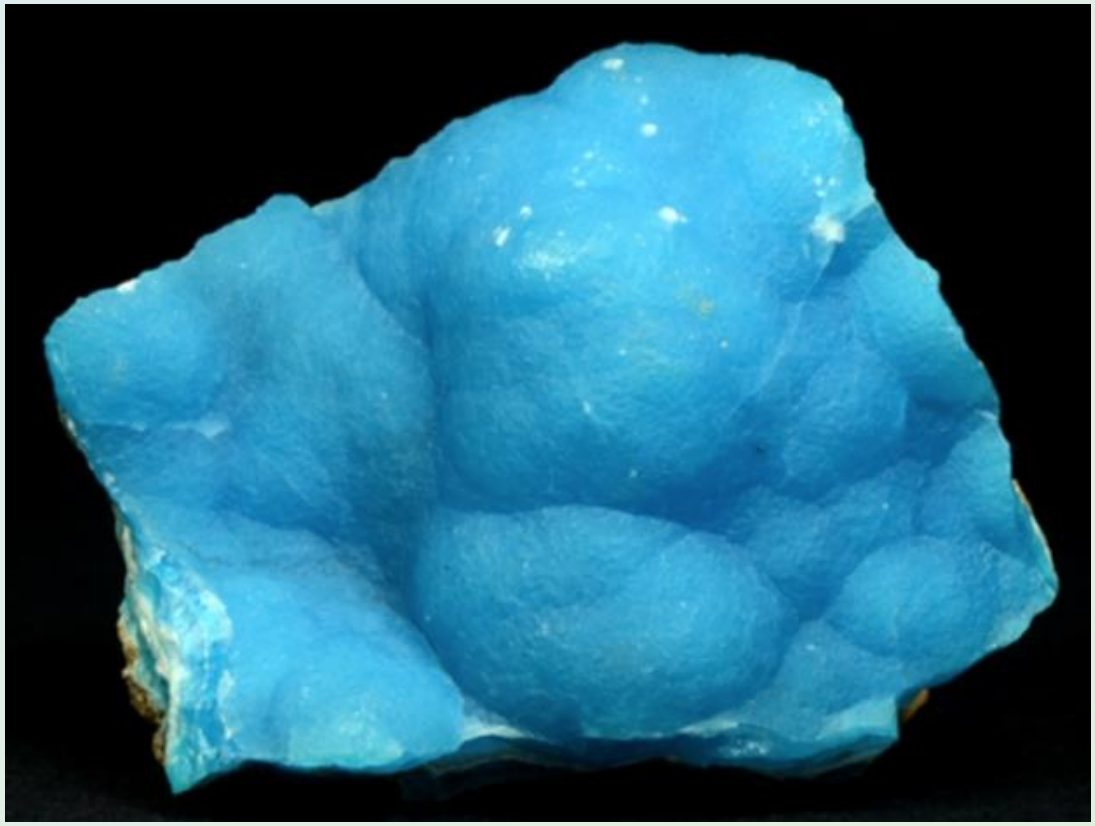
Smithsonian Institute

- Group of 21 museums, 21 libraries and educational and research centres and a zoo mostly located in Washington DC, USA
- established in 1846 from money and specimens donated by James Smithton
- contains 157million artworks, artifacts and specimens
- 145million specimens and artifacts are located in the Museum of Natural History

Beryl display Smithsonian Institute Natural History Museum

Calamine

Calamine is an historic name for an ore of zinc. James Smithson discovered that it was composed of two minerals, Smithsonite and hemimorphite



Calamine

Calamine components

Smithsonite and hemimorphite are superficially similar but chemically and structurally distinct

Smithsonite $ZnCO_3$

Hemimorphite $Zn_4Si_2O_7(OH)_6.H_2O$

Freidrich Mohs (1773 – 1839)

German geologist and mineralogist, born in Saxony

Friedrich Mohs

- Studied physics, chemistry and mathematics at the University of Halle, Saxony (taught by Abraham Gottlob Werner)
- later studied geology at the Mining Academy at Freiberg, Saxony
- moved to Austria in 1802 → employed at Gratz University of Technology
- explored the geology and mineralogy of Ireland and Scotland
- devised a classification scheme for minerals based on their hardness still in use today
- developed a scheme for the classification of minerals into crystal systems based on external symmetry

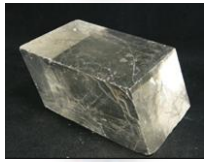
Mohs' hardness scale

1 - TALC - 1

2 - GYPSUM - 2

fingernail - - - - -

3 - CALCITE - 9



Copper coin - - - - -

4 - FLUORITE - 21

5 - APATITE - 48

knife blade - - - - -

6 - FELDSPAR - 72

7 - QUARTZ - 100

8 - TOPAZ - 200

9 - CORUNDUM - 400

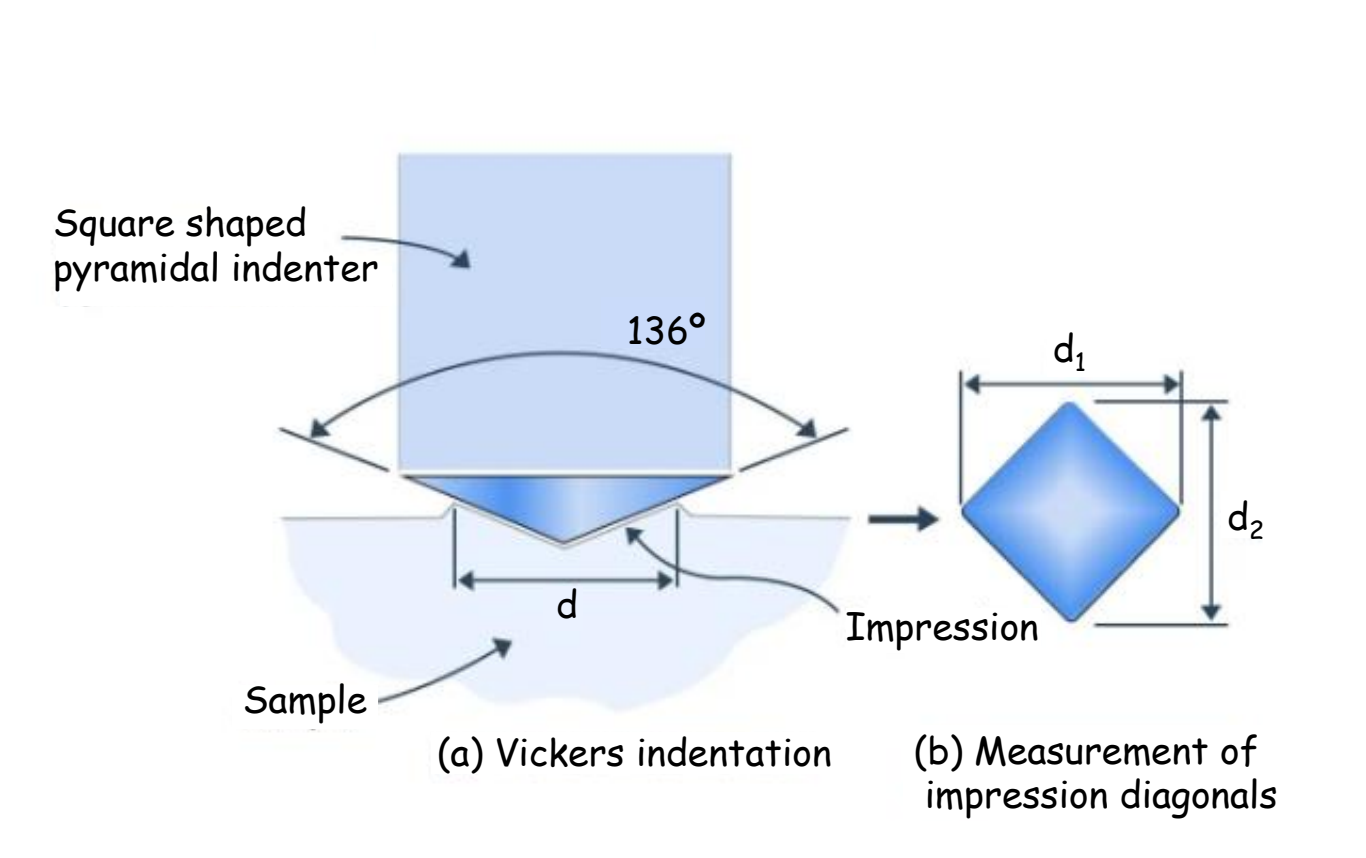
10 - DIAMOND - 1600

Blue = Vickers hardness

* Note that the scale is not linear

Vickers hardness test

Vickers hardness measures the hardness of a material by determining the size of a square indentation made by a pyramid indenter under a specific load



Mohs' crystal systems

Based on external symmetry of crystals

Mohs	Modern
rhombohedral	hexagonal
pyramidal	tetragonal
prismatic	orthorhombic
tessular	cubic

James Dwight Dana (1813 – 1895)

American geologist, mineralogist and zoologist, interested in music playing piano and guitar also artistic

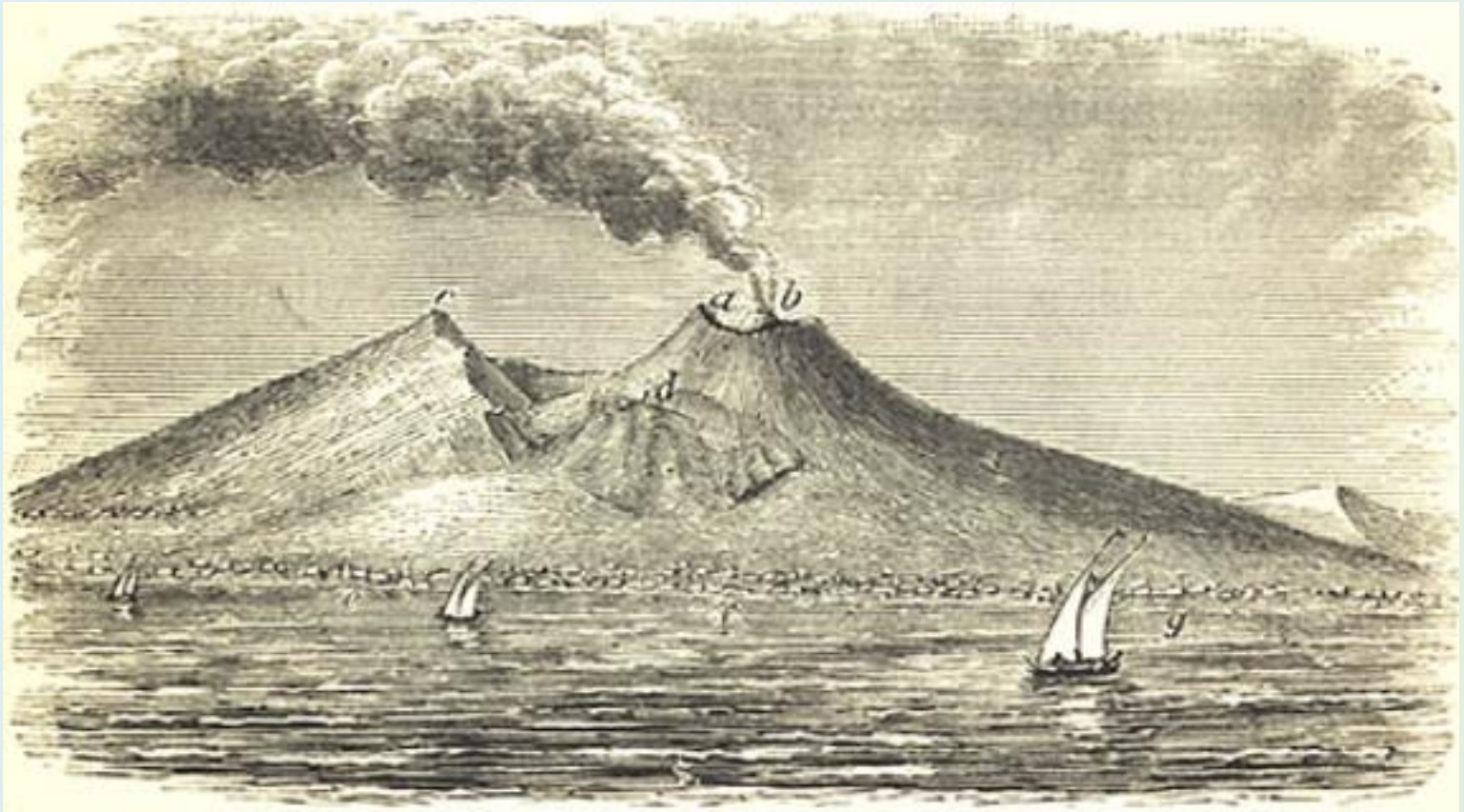
James Dwight Dana

- Studied chemistry and mineralogy at Yale University
- started career teaching navy midshipman mathematics
- appointed assistant to Prof. Silliman at Yale University in 1834
- in 1834 developed a new mineral classification scheme based on chemistry and crystallography of available samples
- published "System of Mineralogy" at age 24 → forerunner to "Dana's Manual of Mineralogy" → still a standard geology text
- mineralogist, geologist and zoologist on US 1839-40 Pacific expedition → visited Andes, atolls and reefed volcanic islands

James Dwight Dana

- spent three months in Australia → examining coal at Illawarra and collected fossils with the Rev. William Branwhite Clarke
- made pioneering studies on mountain building, volcanism and ocean basins
- supported the theory of a contracting Earth cooling from melt
- considered the physiographic features of Pacific Basin to be young
- formed hypothesis of hot spots creating island chains before knowledge of plate tectonics
- strain of his self-imposed overwork caused a physical breakdown in 1859 → never fully recovered withdrew from public until he died

Sketch by James Dana of Mt Vesuvius erupting



MOUNT VESUVIUS: from a sketch by the author in June, 1834. — *a*, the cone; *b*, summit cinder-cone; *c*, Somma, part of former outline of crater; *d*, Hermitage (now Observatory); *e*, Portici; *f*, Herculaneum; *g*, Torre del Greco. For Map, see p. 398.

Dana's Manual of Mineralogy

MANUAL

OF

MINERALOGY,

INCLUDING

OBSERVATIONS ON MINES, ROCKS,

REDUCTION OF ORES,

AND THE

APPLICATIONS OF THE SCIENCE TO THE ARTS.

WITH 260 ILLUSTRATIONS.

DESIGNED FOR THE USE OF SCHOOLS AND COLLEGES.

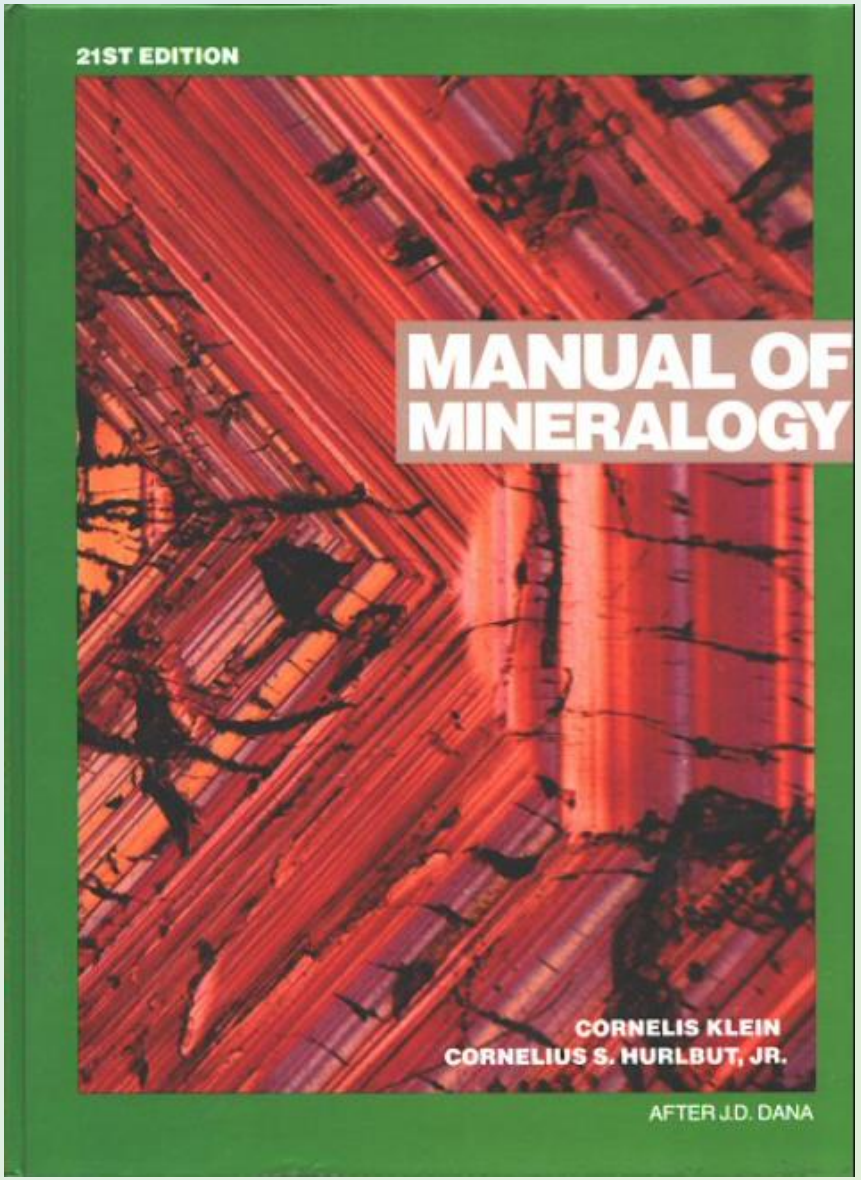
BY JAMES D. DANA, A. M.,

Member of the Soc. Ces. Nat. Cur. of Moscow, the Soc. Philomathique of Paris, the American Academy of Arts and Sciences at Boston, etc.; Author of "A System of Mineralogy."

NEW HAVEN:

PUBLISHED BY DURRIE & PECK.

1848.



Henry Clifton Sorby (1826-1908)

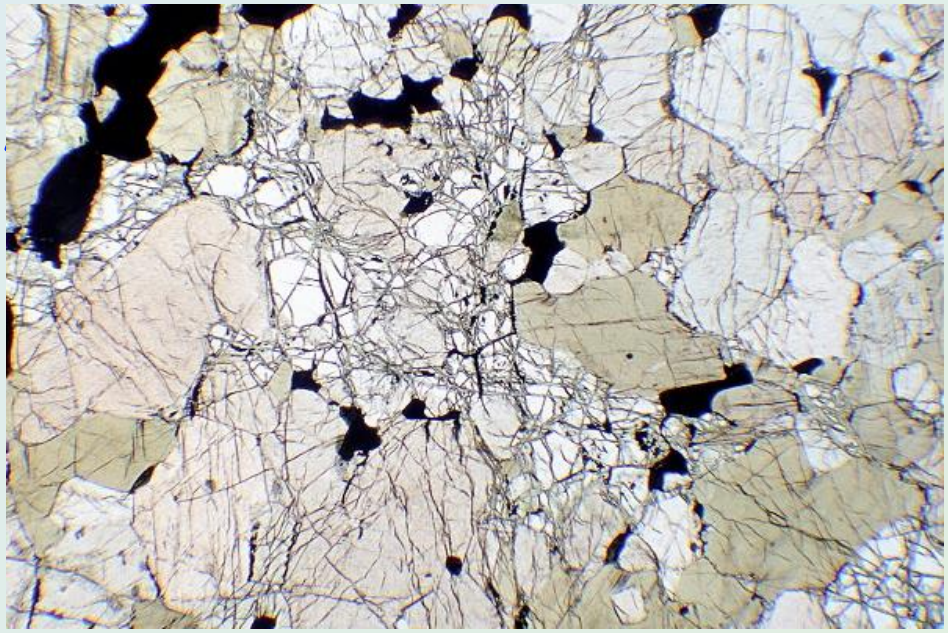
English microscopist and geologist who pioneered the science of optical mineralogy using polarised light

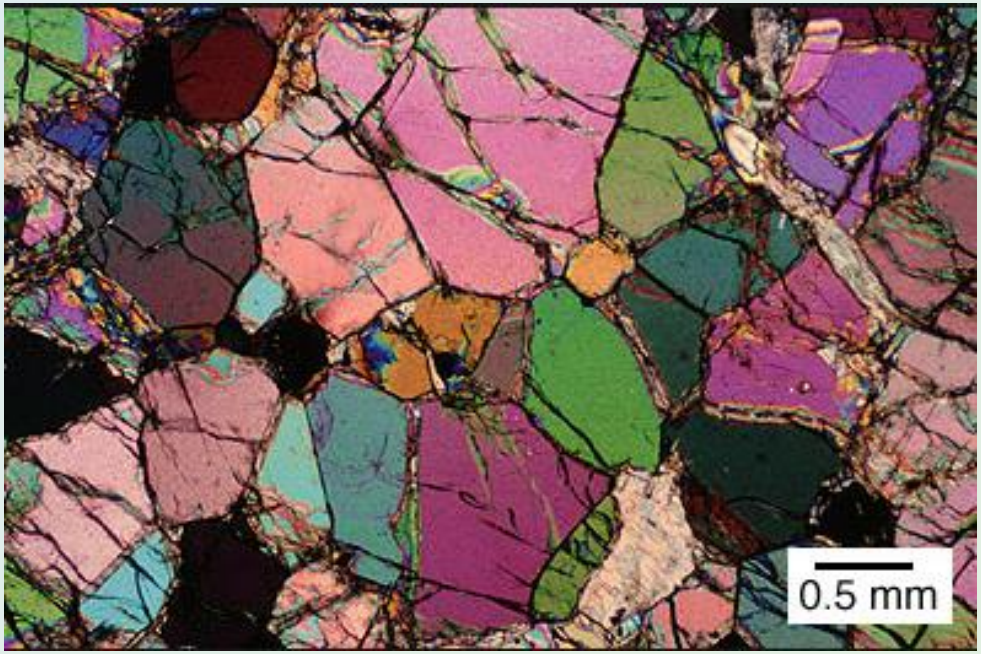
Henry Clifton Sorby

- In 1847 established private laboratory to study physical geology
- turned to studying rocks and minerals under the microscope → prepared sections of rocks 0.025mm thick
- showed that in thin sections minerals could be identified by their optical properties using a polarising microscope
- in 1858 published an important memoir " On the microscopical structure of crystals"
- studied the microscopical structure of iron and steel → recognised that carbon was necessary → give steel strength → led to development of Bessemer process

Olivine and pyroxenes

plane-polarised light





Olivine, crossed polars

Norman Bowen (1887-1956)

- Canadian mineralogist and geologist who revolutionised experimental petrology considered the greatest petrologist of 20th century
- studied chemistry, mineralogy and geology at Kingston University, Ontario
- completed PhD in geology at MIT in 1912
- conducted research at the Geophysical lab at Carnegie Institute (1912-1937), (1947-1952) University of Chicago (1937-1947)

Norman Bowen

- published "The later stages of the evolution of igneous rocks" in 1915
- paper offered a physicochemical explanation of the origin of igneous rocks via crystal fractionation
- Fractional crystallisation → process where crystals separate from a cooling magma as they grow forming different igneous rocks
- proposed Bowen's reaction series in 1922 → showing different igneous rocks could form from a single magma via fractional crystallisation
- demonstrated that minerals formed in crystallising magmas continuously change depending on variables → heat and time
- wrote his famous book " The Evolution of Igneous rocks" in 1928

Bowen's Reaction Series

- Bowen's reaction series is based on experiments and observations of natural rocks
- Bowen explained why certain types of minerals occur together while others are almost never associated with one another
- demonstrated order of mineral formation in crystallising melt
- as magmas cool→ crystallise certain minerals first at successively lower temperatures other minerals crystallise melt changes in composition
- crystallisation from a basalt magma can produce a range of rock compositions → explains mineral associations
- discontinuous series → ferromagnesian minerals
  continuous series → plagioclase feldspar series

Bowen's Reaction Series

- after plagioclase and ferromagnesian minerals have crystallised → only 10% of magma remains → depleted in Fe, Mg and Ca → enriched in Si, K, Na and Al
- Bowen showed that if a mineral remained in the melt after crystallisation → can react with remaining melt → form next mineral in series

$$\underset{\text{olivine}}{(Fe,Mg)_2SiO_4} + SiO_2 \rightarrow \underset{\text{pyroxene}}{(Fe,Mg)_2Si_2O_6}$$

- if mineral effectively removed from melt (crystal fractionation) → different igneous phases may form e.g. Bushveldt Complex (S.Africa), Palisades (USA)

Typical basalt magma composition

	Wt.%
SiO_2	50.30
Al_2O_3	15.19
Fe_2O_3	1.88
FeO	9.65
MgO	6.85
CaO	8.24
Na_2O	3.35
K_2O	0.72
TiO_2	1.76
P_2O_5	0.32
MnO	0.14

Bowen's reaction series

Fractional crystallisation of basalt magma

Olivine
$(Fe,Mg)_2SiO_4$
orthosilicate

Pyroxene
$(Ca,Mg,)Si_2O_6$
inosilicate

Amphibole
$Ca_2Na(Mg,Fe)_4(Al,Fe)_3Si_8O_{22}(OH)_2$

Biotite
$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$
Phyllosilicate

Decreasing temperature

Discontinuous Series

Continuous Series

Anorthite
$CaAl_2Si_2O_8$

Oligoclase
$(CaAl_2Si_2O_8) - (NaAlSi_3O_8)$

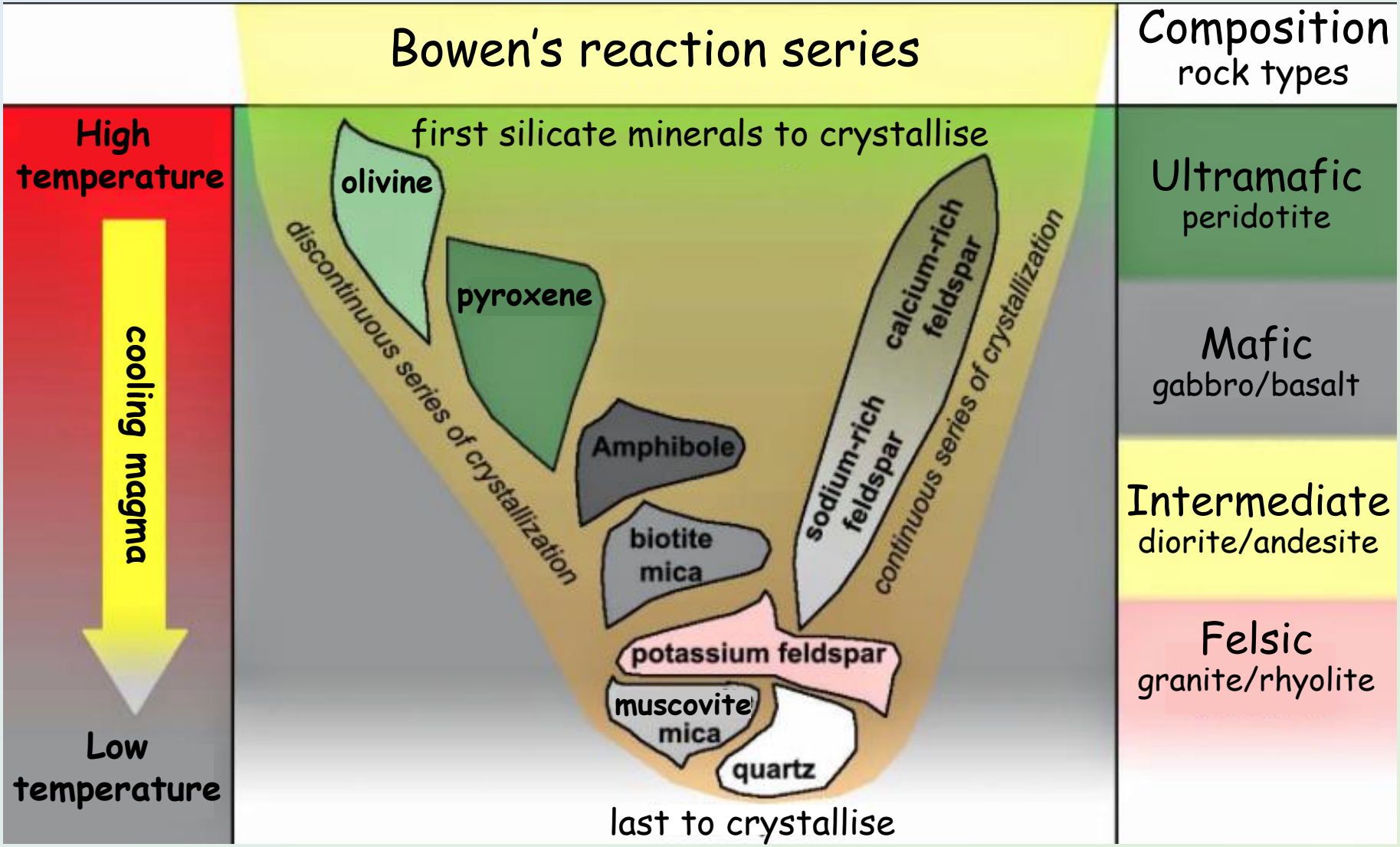
Increasing silica, Na, Al, K

Increasing Fe, Mg, Ca

Residual (last to crystallise) { K-feldspar $KAlSi_3O_8$

muscovite $KAl_2(AlSi_3O_{10})(OH)_2$

quartz SiO_2


Bowen's reaction series
Composition
rock types
High temperature
cooling magma
Low temperature
first silicate minerals to crystallise
olivine
pyroxene
Amphibole
biotite mica
potassium feldspar
muscovite mica
quartz
last to crystallise
discontinuous series of crystallization
continuous series of crystallization
calcium-rich feldspar
sodium-rich feldspar
Ultramafic
peridotite
Mafic
gabbro/basalt
Intermediate
diorite/andesite
Felsic
granite/rhyolite

Zoned plagioclase phenocryst