Bharathidasan University

Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. **M.Tech. Geological Technology & Geoinformatics** programme

Course Code: MTIGT0306

CRYSTALLOGRAPHY AND MINERALOGY

UNIT – 1 ELEMENTS OF CRYSTALLOGRAPHY

…..continued…..

Georgius Agricola, 'Father of Mineralogy'

German scientist '**Georg Bauer**' - named by birth;
his *First book on Mineralogy was published during* 1530
entitled : ***'Bermannus, sive de re metallica dialogus'***
(A description of the ore mountain-Ergebrge, Silver mining district)

René Just Haüy (1743 –1822)

"Father of Modern Crystallography"

French (Paris) Mineralogist generally known as **Abbé Haüy**

Prepared by
Dr. K.Palanivel
Professor, Department of Remote Sensing

MTIGT0306: THEORY – CRYSTALLOGRAPHY AND MINERALOGY 4 credits

1. **Elements of Crystallography**: Crystalline and Amorphous forms - Symmetry and Classification of Crystals - System of Crystal Notation - (Weiss and Millerian) - Forms and Habits. Crystal Systems (Isometric, Tetragonal, Hexagonal, Orthorhombic, Monoclinic, Triclinic, Twinning - Crystalline Aggregates – Columnar, Fibrous, Lamellar, Granular - Imitative shapes and Psudomorphism. **12 Hrs.**
2. **Crystal Properties:** Space Symmetry Elements- Translation – Rotation- Reflection - Inversion Screw and Glide-point groups and Crystal classes - Derivation of 32 Crystal classes based on Schoenflies notation - Bravais lattices and their Derivation - An outline of Space Groups. X-ray Crystallography. **12 Hrs.**
3. **Physical Mineralogy**: Physical Properties: (Colour – Structure – Form – Luster - Transparency – Streak – Hardness – Specific Gravity – Tenacity – Feel – Taste – Odour) - Electrical, Magnetic and Thermal properties-Determination of Specific Gravity (Jolly's spring balance, Walker's steel yard, Pycnometer methods) - Empirical and Structural formula of minerals – Isomorphism, Polymorphism and Psudomorphism - Atomic substitution and Solid solution in minerals - Non Crystalline minerals - Fluorescence in minerals - Metamict state. **16 Hrs.**
4. **Optical Mineralogy:** Optical Properties (Colour – Form – Cleavage - Refractive Index - Relief – Alteration – Inclusions – Zoning – Pleochroism – Extinction - Polarization colours – Birefringence) – Twinning - Optic sign (Uniaxial and biaxial)- Interference figures - Primary and Secondary Optic axes - Optic axial angle measurements – Optic Orientation – Dispersion in Crystals - Optic anomalies. **12 Hrs.**
5. **Mineral Groups:** Ortho and Ring Silicates (Olivine group - Garnet group). Alumino silicates (Epidote group - Zircon – Staurolite – Beryl - Cordierite and Tourmaline). Sheet Silicates (Mica group - Chlorite group and Clay minerals) - Chain Silicates (Pyroxene group - Amphibole group and Wollastonite). Frame work Silicates (Quartz -Feldspar - Feldspathoid - Zeolite and Scapolite groups) - Non-silicate (Spinel group, Carbonates and Phosphates). **12 Hrs.**

6. **Current Contours: (Not for Exam, only for Discussion):** Preparation of Field Kit for testing and identifying minerals during field survey; preparation of mineral and crystal samples for making thin sections, x-ray crystallographic studies. Learn how minerals together form different types of rocks.

Text Books:

1. Dana, E.S, A Text Book of Mineralogy, Wiley Eastern, 1955.
2. Flint, Y, Basic Crystallography, Mid Publishers, 1970.
3. Phillips, F.C. Longman, An Introduction to Crystallography, 1956.
4. Bloss.F.B., Crystallography and crystal New york 1971
5. Read, H.H, Rutley's Elements of Mineralogy, CBS Publishers & Distributors, Delhi,1984.

Reference Books:

1. Berry Mason, L.G,Mineralogy, W.H. Freeman & co - 1961.
2. D. Perkins, (2002), Mineralogy, 2nd Edition, Pearson Education (Singapore) Pte. Ltd, Delhi, 483pp, ISBN 81-7808-831-2
3. W. D. Nesse, (2000), Introduction to Mineralogy, Oxford University Press, ISBN 0-19- 510691-1
4. Naidu, P.R.J,. Optical Crystallography.
5. Wahlstrom, E.F, Optical Crystallography, John wiley, 1960.
6. Azaroff, L.V,Elements of X-ray Crystallography, 1968.
7. Deer, W.A, Howie, R.A and J.Zussman, LongmansAn Introduction to the Rock Forming Minerals, 1966.
8. Alexander N.Winchell,Elements of Optical Mineralogy, Part I and II,Wiley Eastern (p) Ltd, 1968
9. Ernest, E.Walhstrom, Optical Crystallography, John Wiley & Sons.1960.
10. Kerr B.F,Optical Mineralogy. Mc Graw Hill, 5 th Edition, New York-1995.
11. Mitra, S,Fundamentals of Optical Spectroscopic and X-ray Mineralogy.

Course outcomes:

After the successful completion of this course, the students are able to:

- **Gain knowledge about the source minerals as raw materials for anything on the Earth and for the survival of life**
- **Independently able to classify the crystals based on symmertical elements and face indices**
- **Understand various physical, chemical and optical properties of minerals so as to discriminate them**
- **Provide ideas about the major existence of rock forming silicates at the surface of the Earth**
- **Understand the various properties of mineral groups**
- **Know the crystal and mineral forms and their habits**

HEXAGONAL SYSTEM

A. Hexagonal Division

B. Rhombohedral Division

Crystal Classes in HEXAGONAL System

A. Hexagonal Division

1. Normal Class / Beryl Type
2. Hemimorphic Class / Zincite type
3. Tripyramidal Class / Apatite type
4. Pyramidal Hemimorphic Class / Nephelite type
5. Trapezohedral Class / β-Quartz type
6. Trigonal class / Benitonite type
7. Trigonal Tetartohedral class / Disilverortho-phosphate type

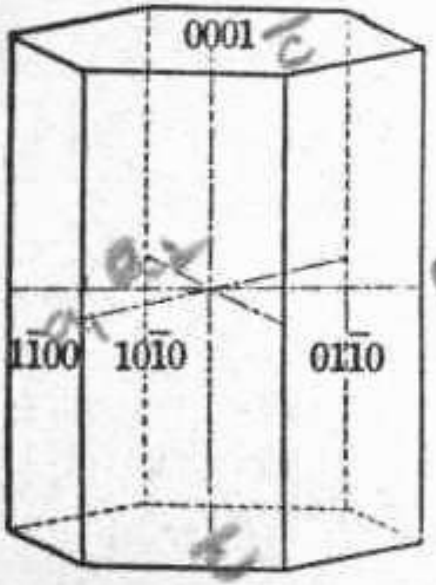
HEXAGONAL SYSTEM

A. Hexagonal Division

1. NORMAL CLASS - FORMS

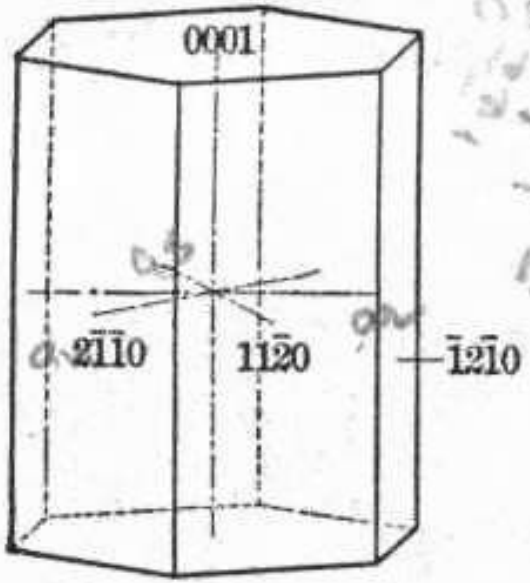
i. Base ..... (0001)
ii. Prism of the first order .....(10$\bar{1}$0)
iii. Prism of the second order .....(10$\bar{2}$0)
iv. Dihexagonal prism....(*hk-l0*) as 10-11)
v. Pyramid of the first order..... (h0-hl)
vi. Pyramid of the second order... (hh-2hl)
vii. Dihexagonal pyramid .....(hk-ll)

238



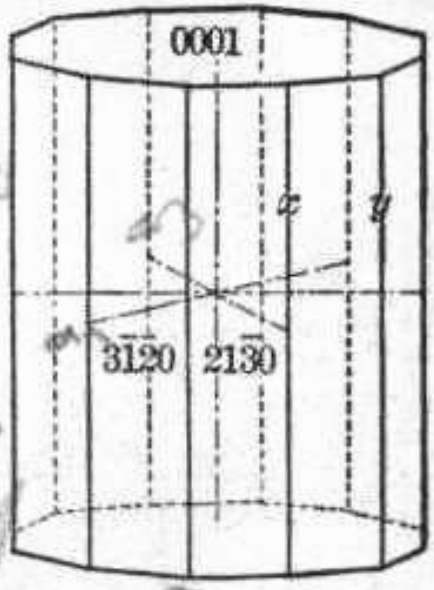
First Order Prism

239



Second Order Prism

240

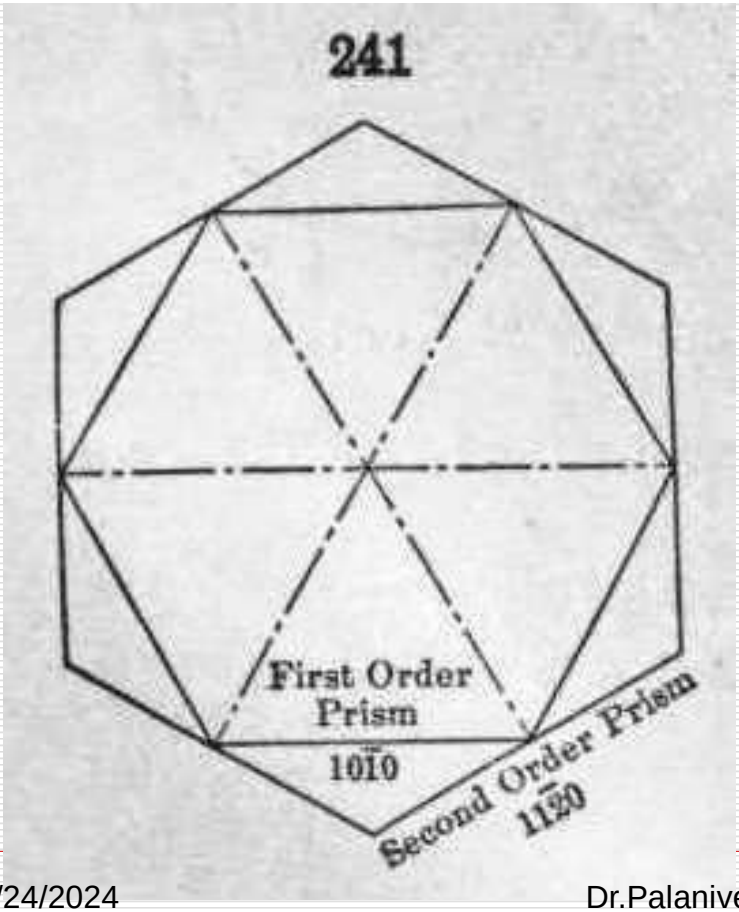


Dihexagonal Prism

Back…2..HS

1. Normal Class / Beryl Type

Hexagonal System



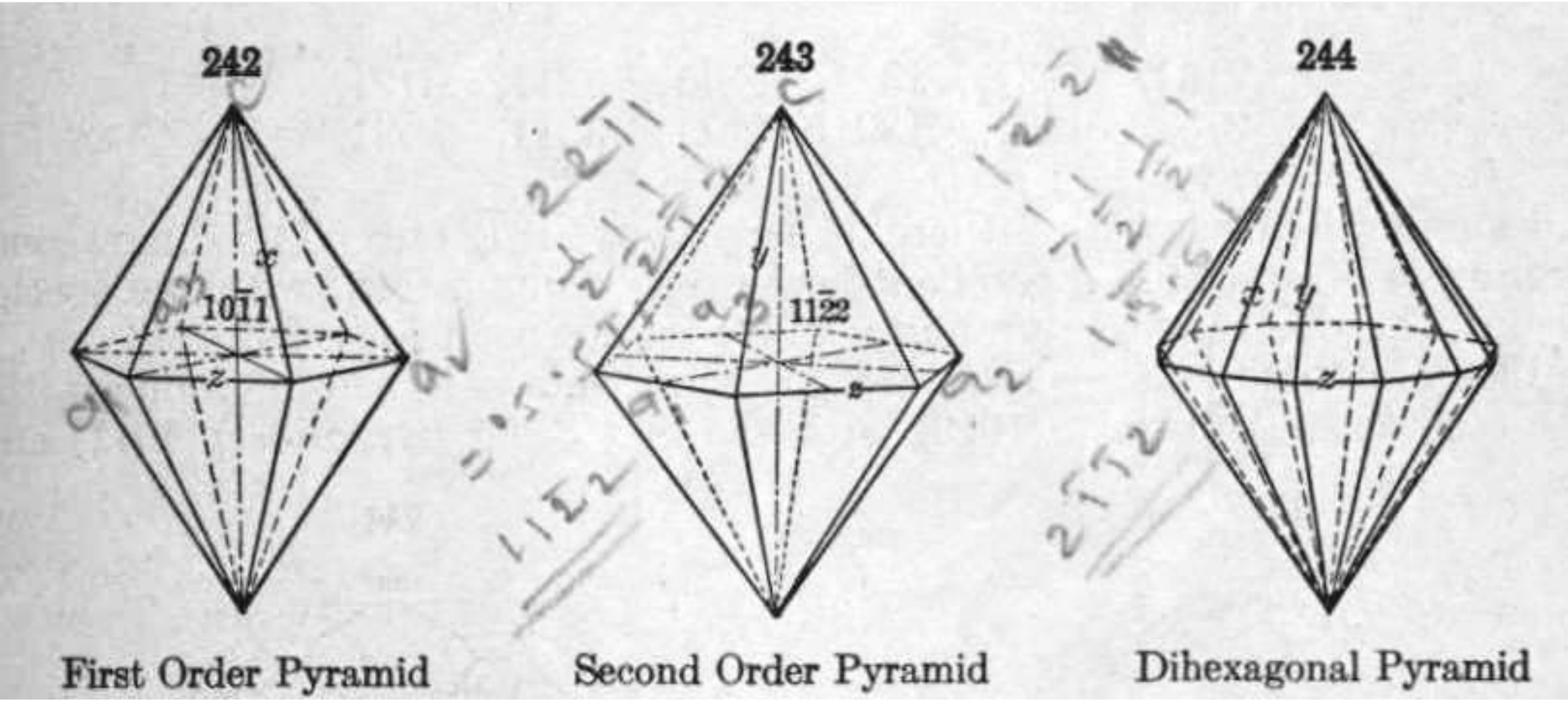
Symmetry

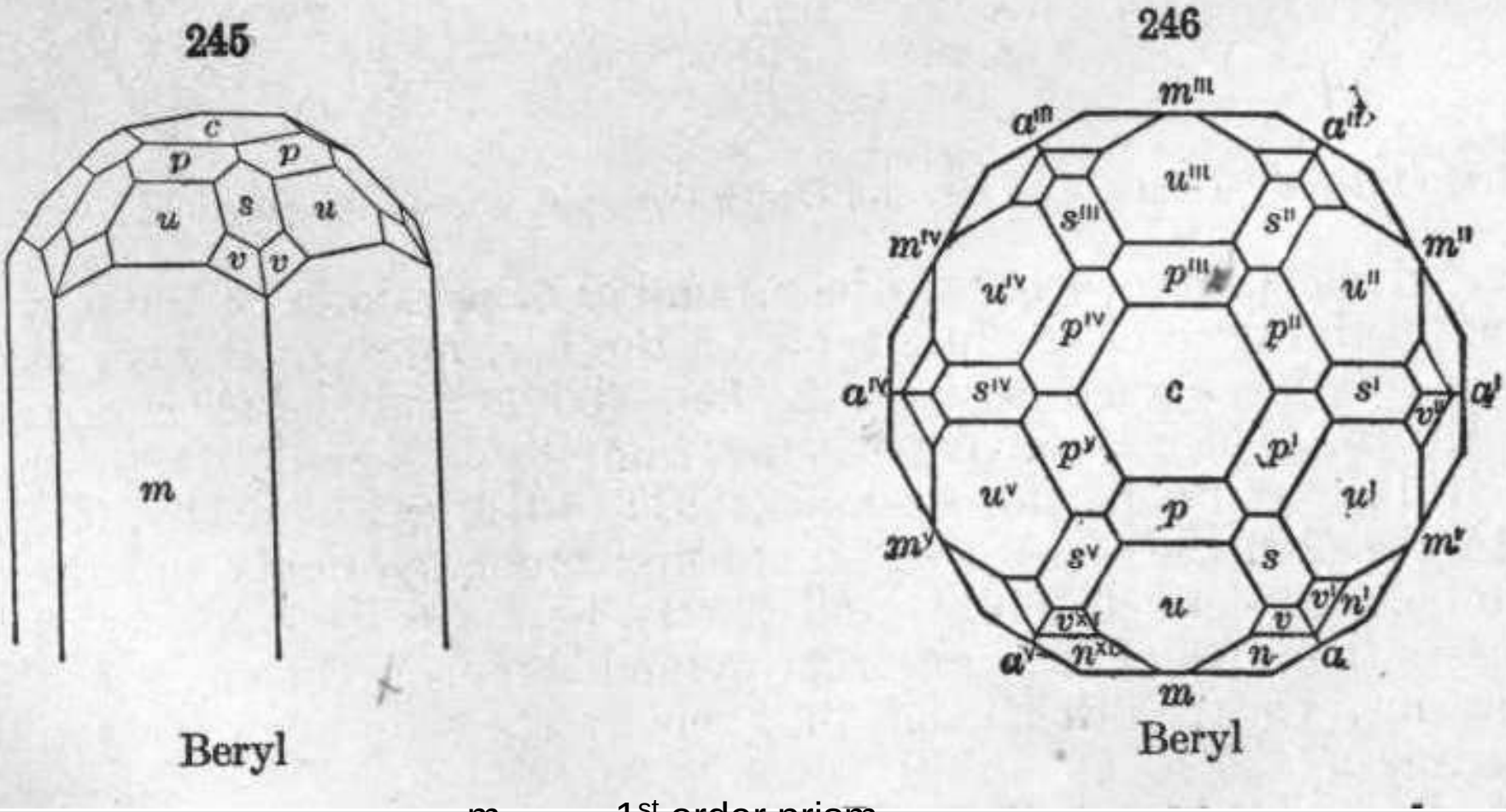
1 Vertical axis of 6 fold

6 Horizontal axes of 2 fold

6 Vertical Planes, 1 Hor. Pl.

Center of symmetry - Present


242
243
244
$10\bar{1}1$
$11\bar{2}2$
First Order Pyramid
Second Order Pyramid
Dihexagonal Pyramid



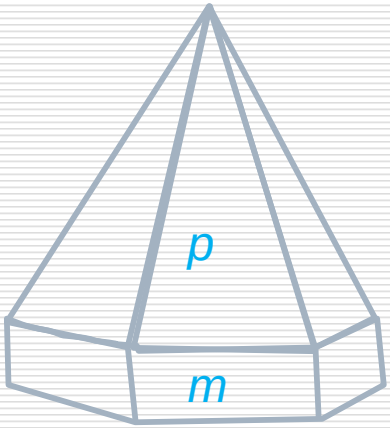
m – 1st order prism
p & u – 1st order pyramids
a – 2nd order prism
s – 2nd order pyramid
v & n – dihexagonal pyramids
c – base.

Back…2..HS-H

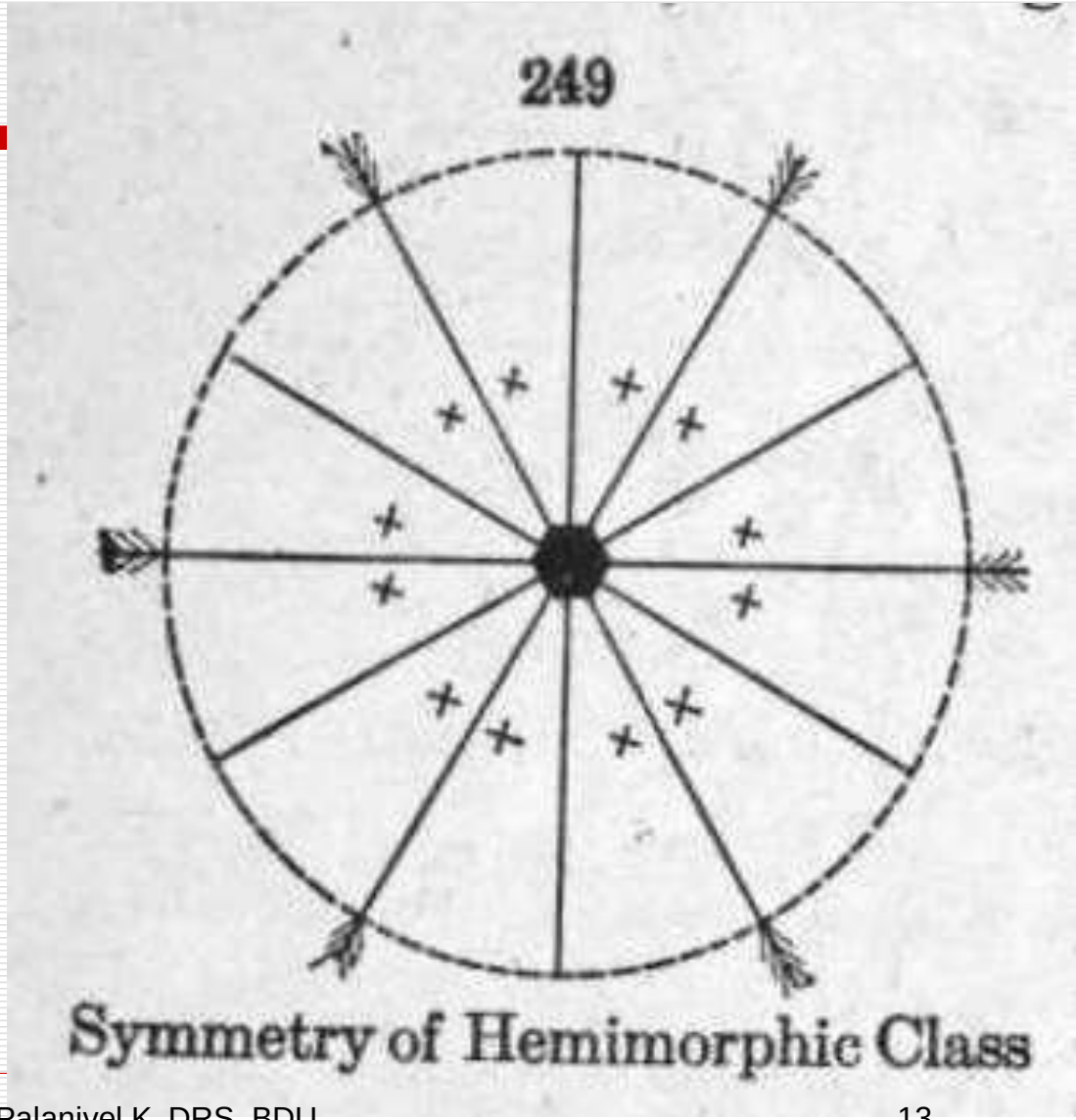
2. Hemimorphic class / Zincite type

Symmetry Elements of Hemimorphic Class :

Vert. Ax. 6;
6 Vert. P.



Zincite

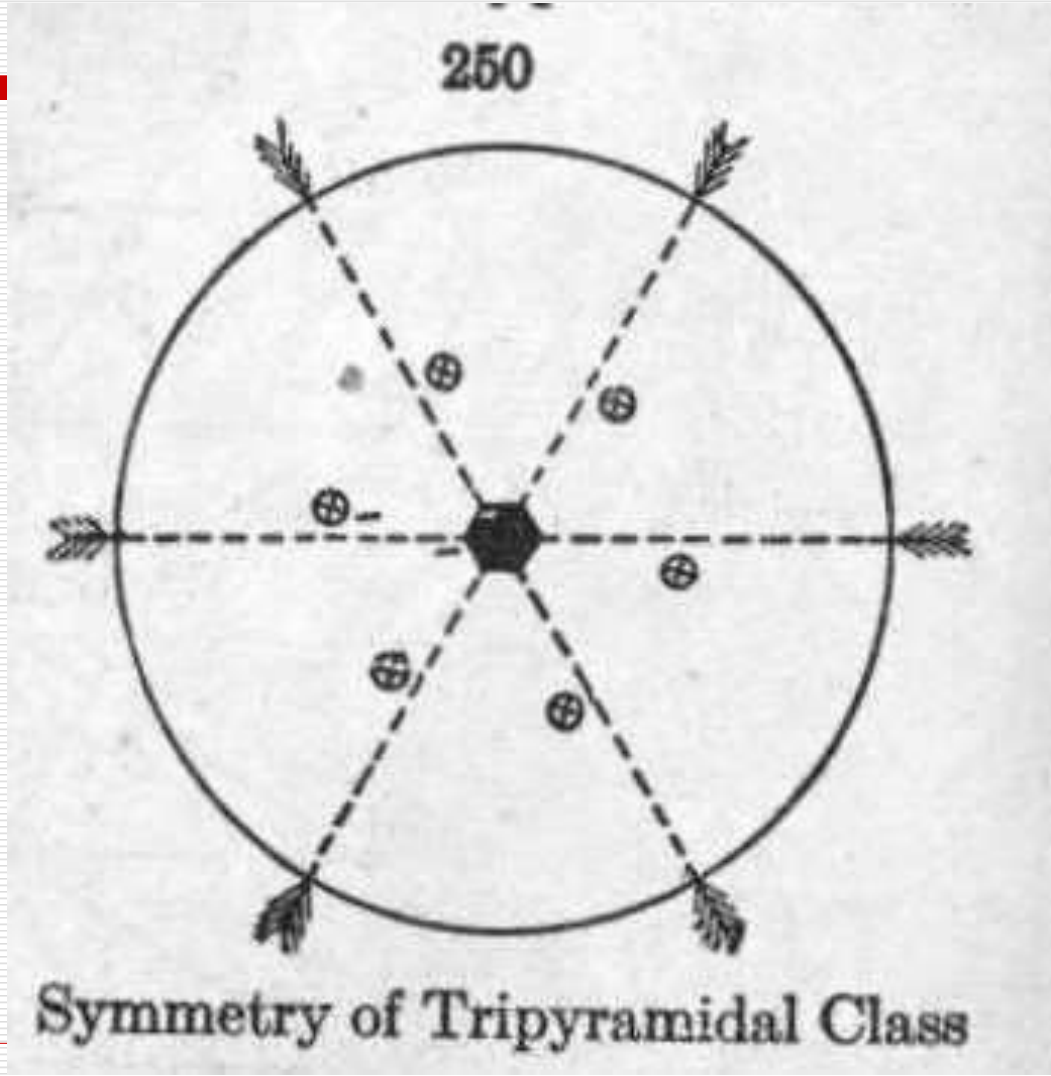


Back…2..HS-H

3. Tripyramidal class / Apatite type

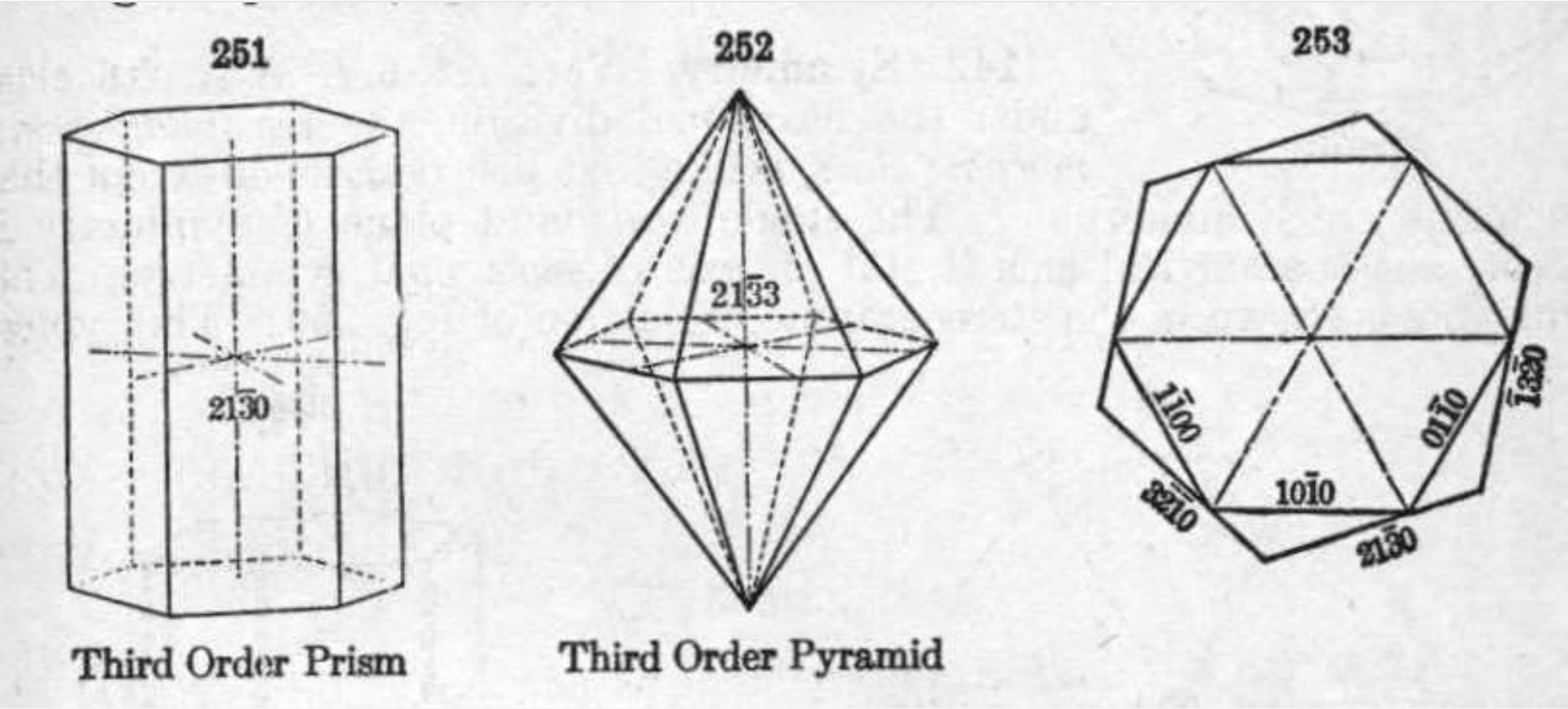
Symmetry Elements of Tripyramidal Class:

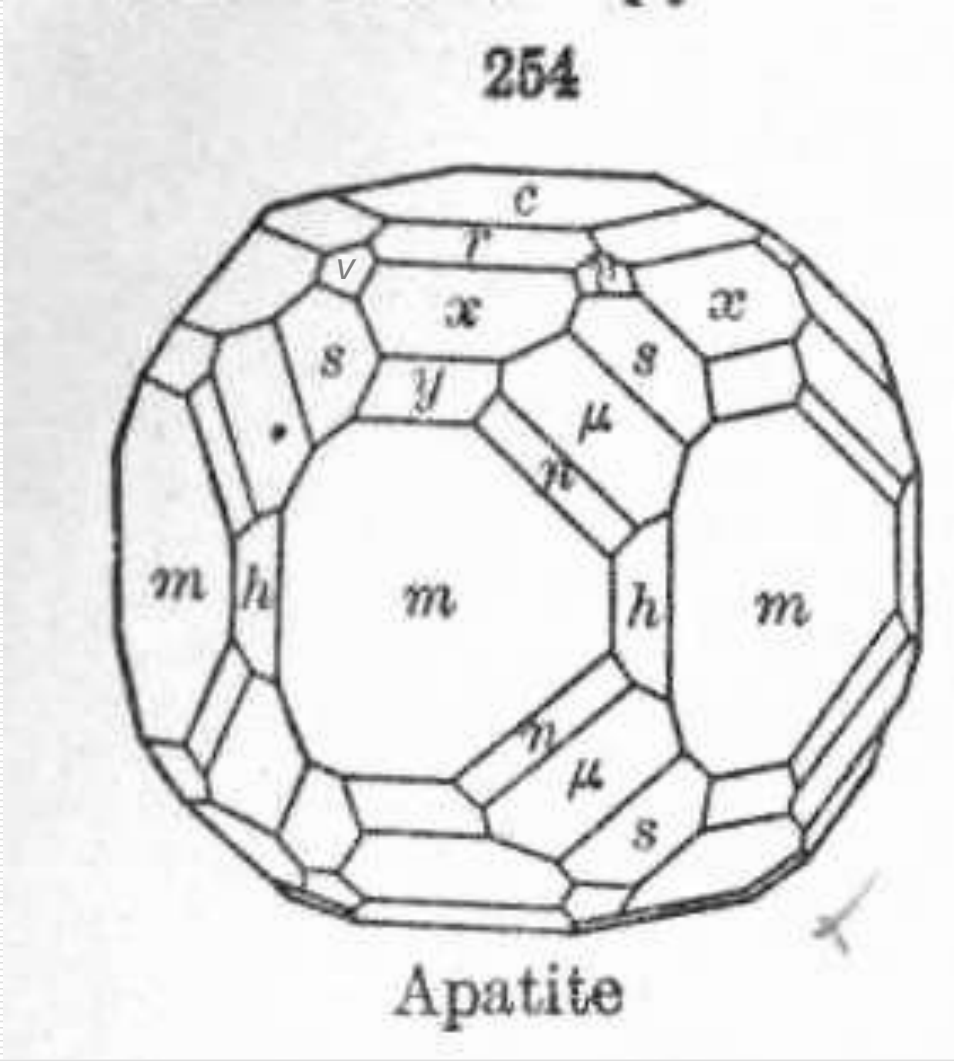
Vert. Ax. 6;
Hor. P
C.



Symmetry of Tripyramidal Class

Back…2..HS-H


251
2130
252
2133
253
1100
0110
1010
2130
Third Order Prism
Third Order Pyramid



m – 1st order prism
r, x & y – 1st order pyramids
s & v – 2nd order pyramids
h – 3rd order prism
μ & n – 3rd order pyramids
c – base.

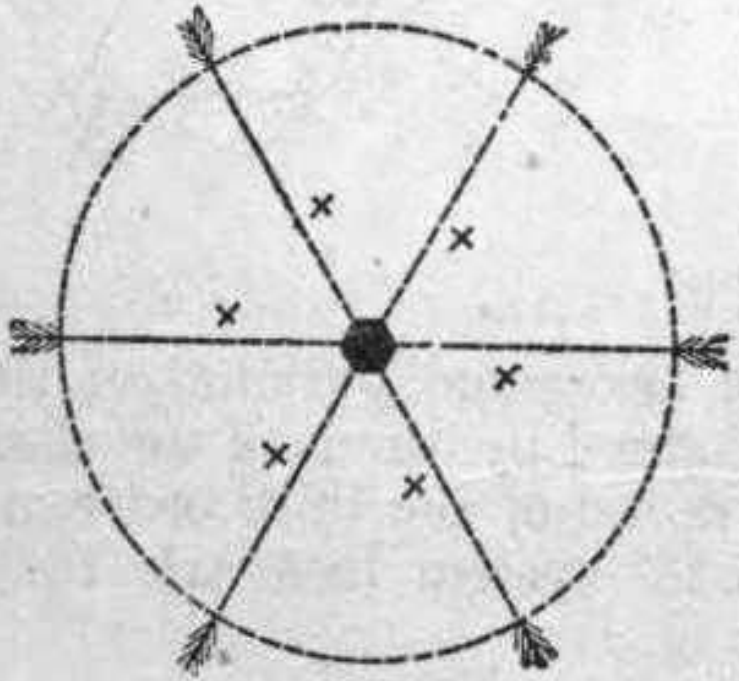
Back…2..HS-H

4. Pyramidal –Hemimorphic class / Nephelite type

Symmetry :

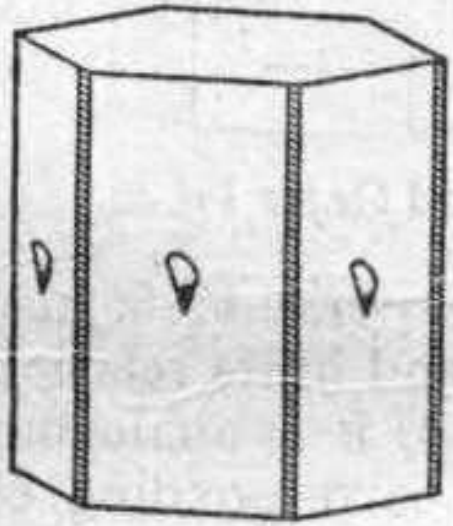
Vert. Ax. 6;

255



Symmetry of Pyramidal-Hemimorphic Class

256



Nephelite

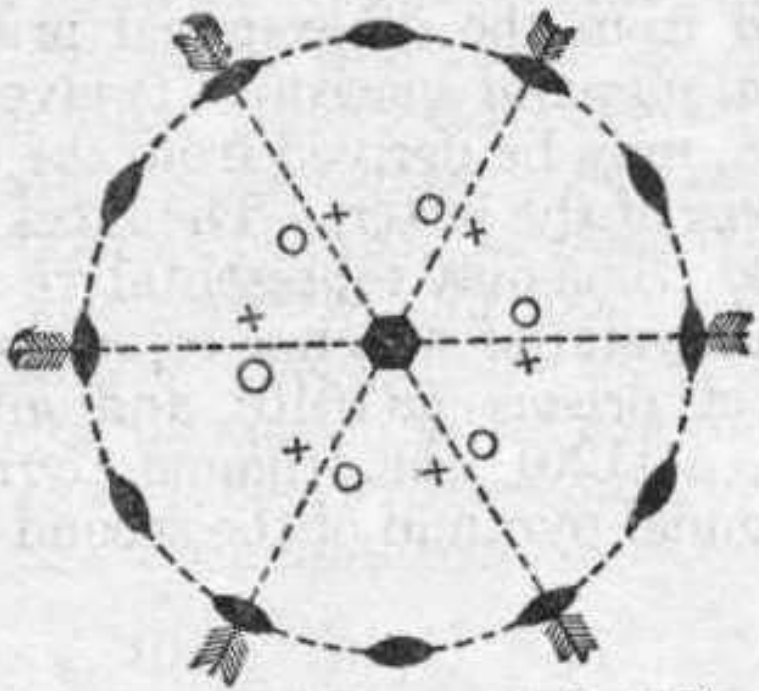
Back…2..HS-H

5. Trapezohedral class / β-Quartz type

Symmetry Elements of Trapezohedral Class:

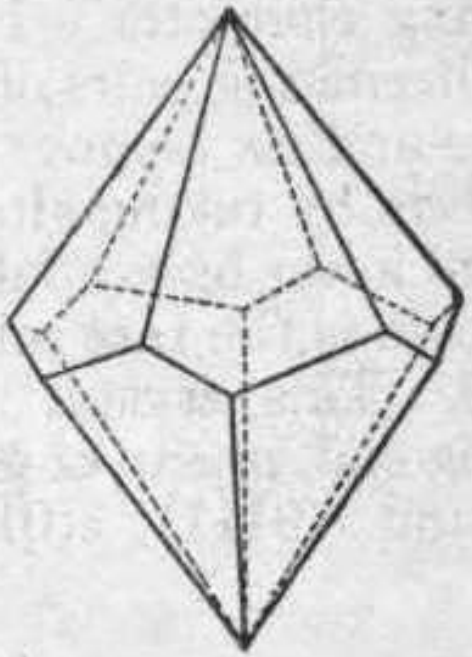
Vert. Ax. 6;
6 Hor. Ax. -2.

257



Symmetry of Trapezohedral Class

258



Hexagonal Trapezohedron

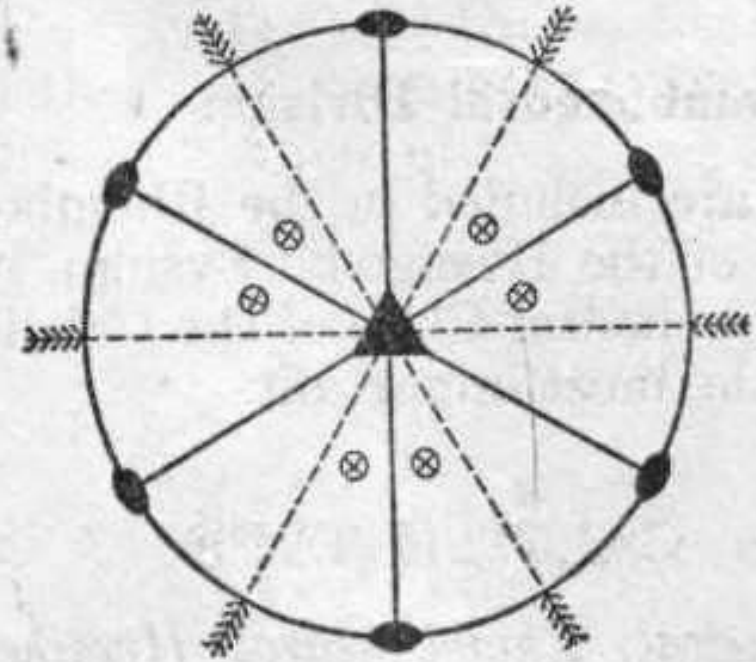
Back…2..HS-H

6. Trigonal class / Benitonite type

Symmetry Elements of Trigonal Class:

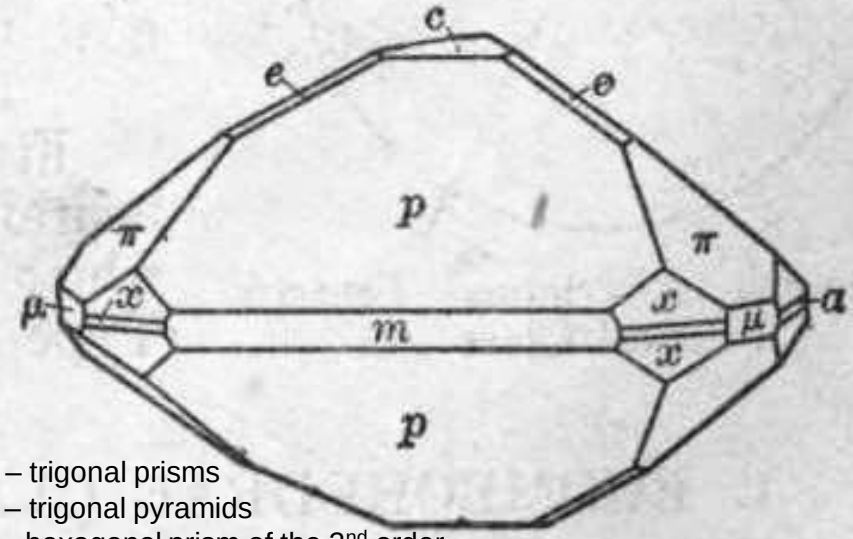
Vert. Ax. 3; 3 Hor. Ax. 2; 3 vert. P; Hor. P.

259



Symmetry of Trigonal Class

260



m & μ – trigonal prisms
p, π & e – trigonal pyramids
a – hexagonal prism of the 2nd order
x – hexagonal pyramid of the 2nd order
c – base.

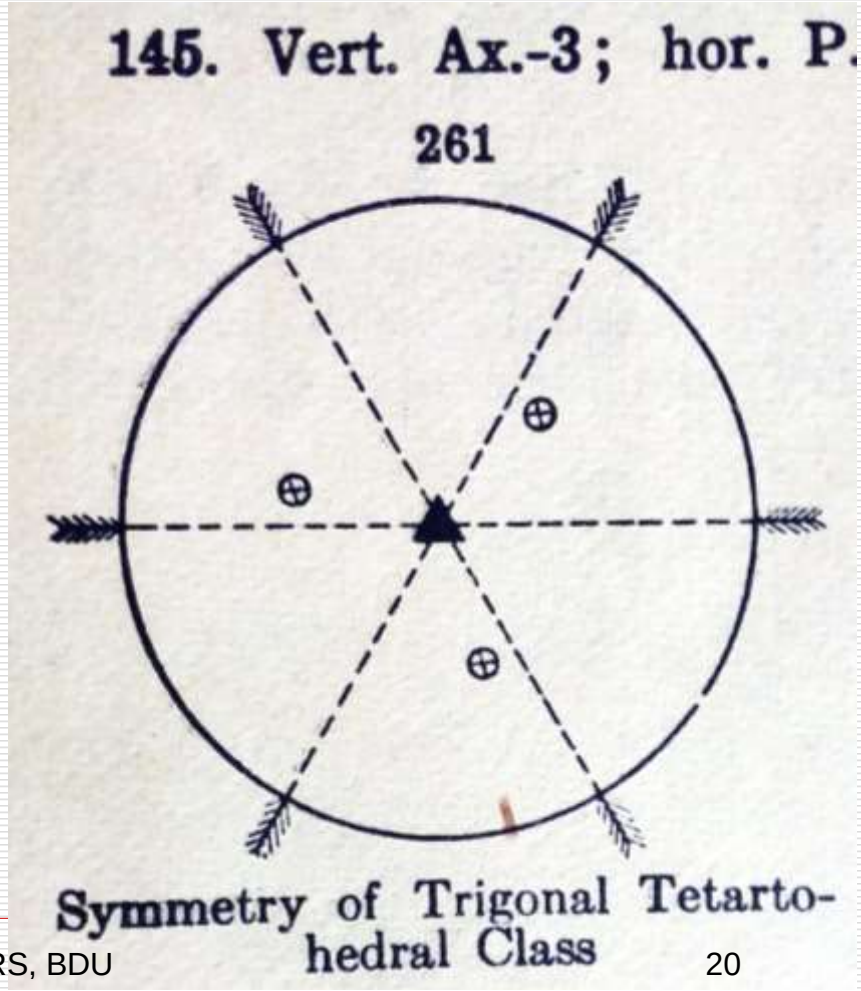
Benitoite (Palache)

Back…2..HS-H

7. Trigonal Tetartohedral class / Disilverortho-phosphate type

Symmetry Elements of Trigonal Tetartohedral Class:

Vert. Ax. 3;
Hor. P.



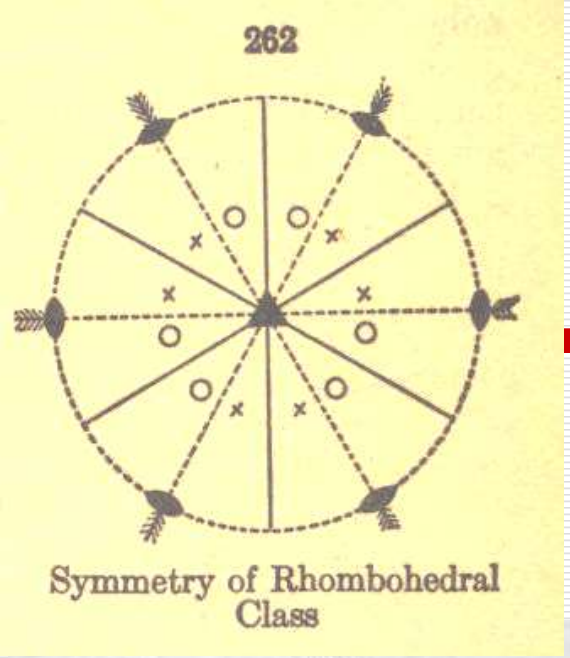
Back…2..HS-H

HEXAGONAL SYSTEM

B. RHOMBOHEDRAL DIVISION

CLASSES IN RHOBOHEDRAL DIVISION

1. RHOMBOHEDRAL CLASS / CALCITE TYPE (Trigonal Dipyramidal / Trigonal Equatorial class)
2. RHOMBOHEDRAL-HEMIMORPHIC CLASS – TOURMALINE TYPE (Ditrigonal Pyramidal / Trigonal Hemihedral Hemimorphic / Ditrigonal Polar Class)
3. TRI-RHOMBOHEDRAL CLASS – PHENACITE TYPE (Rhombohedral / Trigonal Rhombohedral / Rhombohedral Tetartohedral / Hexagonal Alternating class)
4. TRAPEZOHEDRAL CLASS – α-QUARTZ TYPE (Trigonal Trapezohedral / Trapezohedral Tetartohedral / Trigonal Holoaxial class)
5. TRIGONAL TETARTOHEDRAL HEMIMORPHIC CLASS – SODIUM PERIODATE TYPE (Trigonal Pyramidal / Trigonal Polar class)



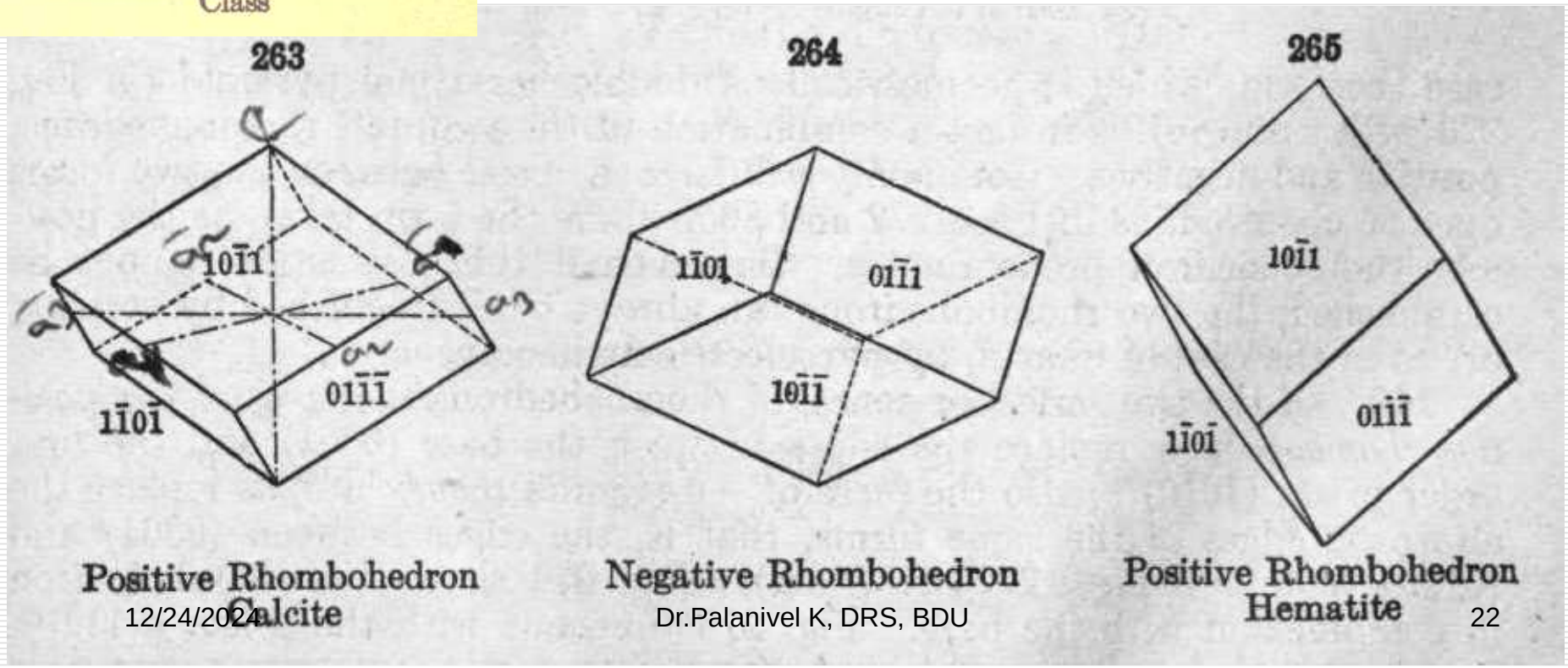
1. RHOMBOHEDRAL CLASS / CALCITE TYPE

Forms:

a. Rhombohedron
b. Scalenohedron &

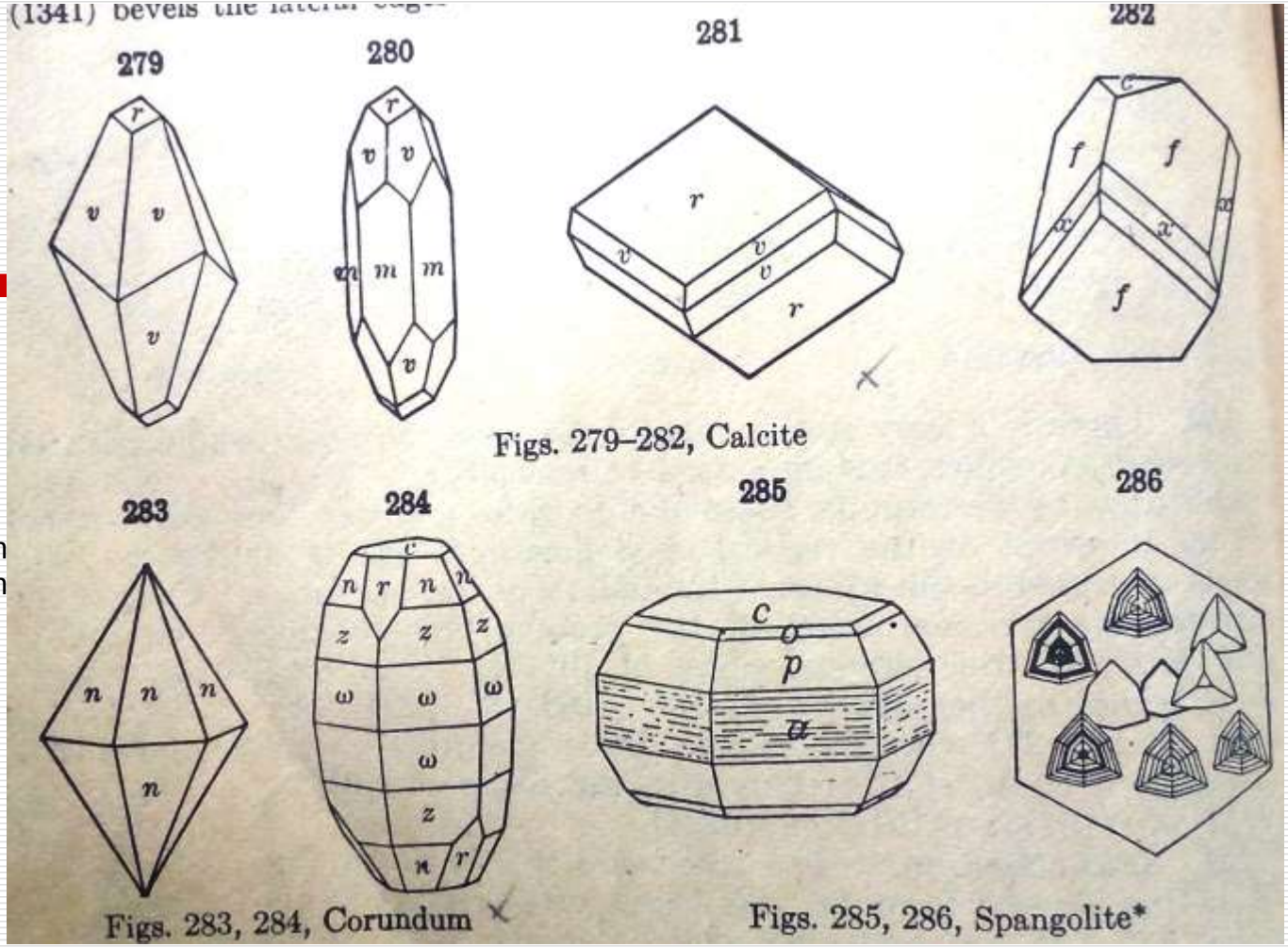
Vert. ax. 3

combination forms with prisms and pyramids.



Rhombohedron and Scalenohedron

v – scalenohedron
r, z & ω – rhombohedrons
x – negative scalenohedron
f – negative rhombohedron
c – base
m & a – prisms
n – 2nd order pyramid

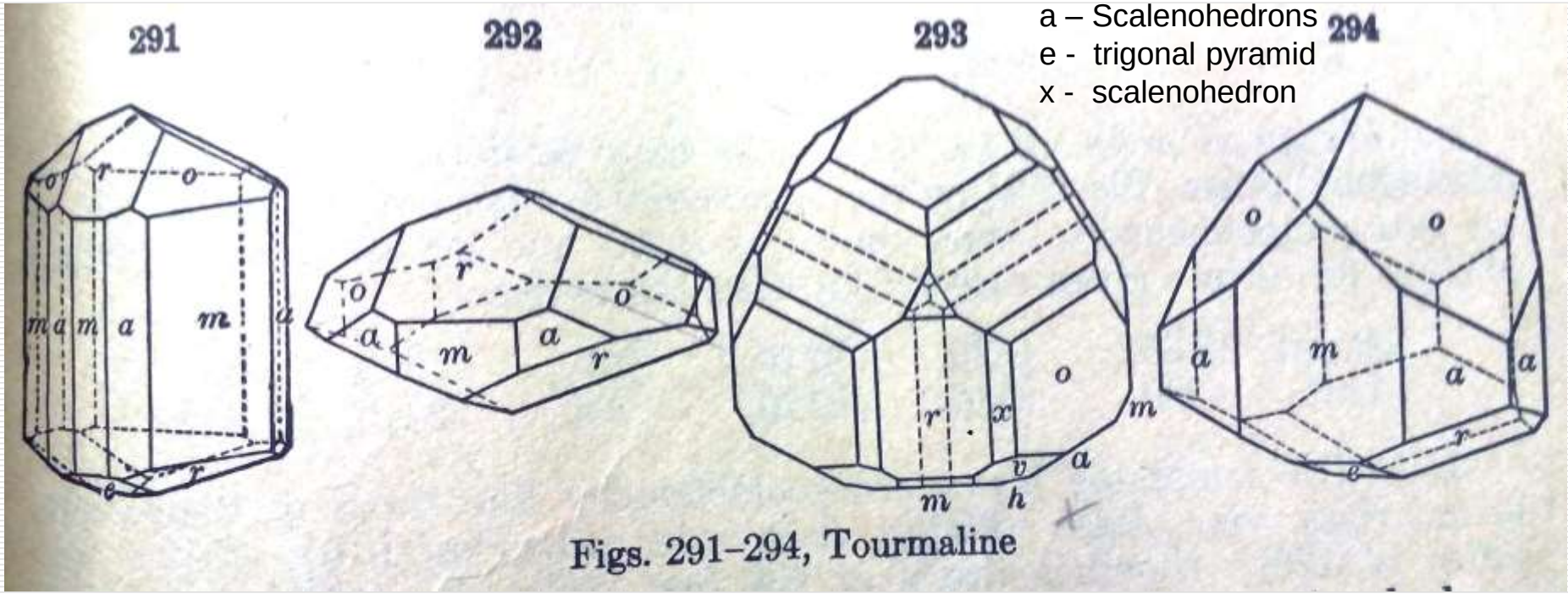


Back…2..HS-R

2. RHOMBOHEDRAL-HEMIMORPHIC CLASS – TOURMALINE TYPE (Ditrigonal Pyramidal / Trigonal Hemihedral Hemimorphic / Ditrigonal Polar Class)

Vert. ax. 3;
3 vert. diag. P.

Forms:
c - Basal planes or pedions
m - 1st order Trigonal prisms
o - 1st order Trigonal pyramids
r - +ve & -ve Rhombohedrons
a – Scalenohedrons
e - trigonal pyramid
x - scalenohedron



Back…2..HS-R

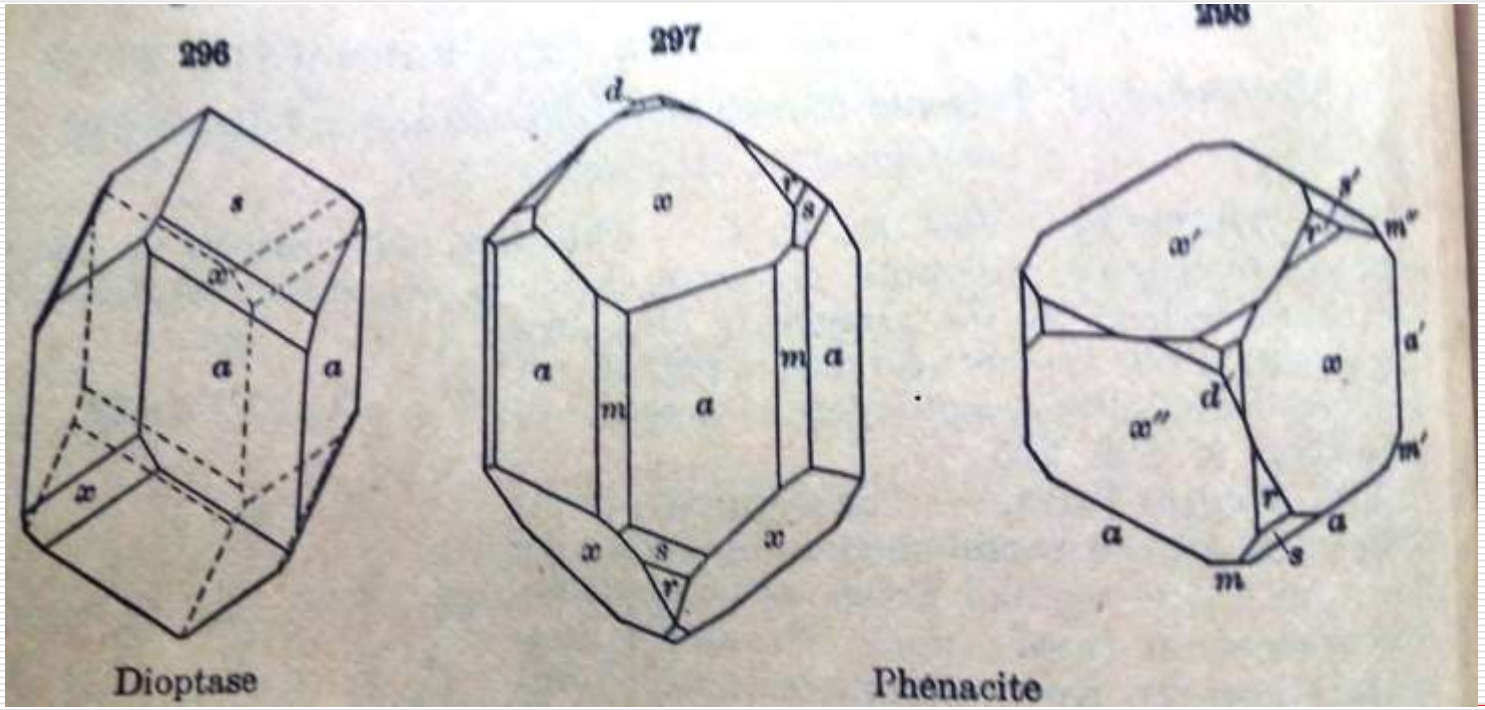
3. TRI-RHOMBOHEDRAL CLASS – PHENACITE TYPE

(Rhombohedral / Trigonal Rhombohedral / Rhombohedral Tetartohedral / Hexagonal Alternating class)

Forms:
r & d – 2nd order Rhombohedron
a - 2nd order Hexagonal Prism
x - 3rd order Rhombohedron

m - 1st order hexagonal prism
s – 1st order rhombohedron

Vert. ax. 3;
C

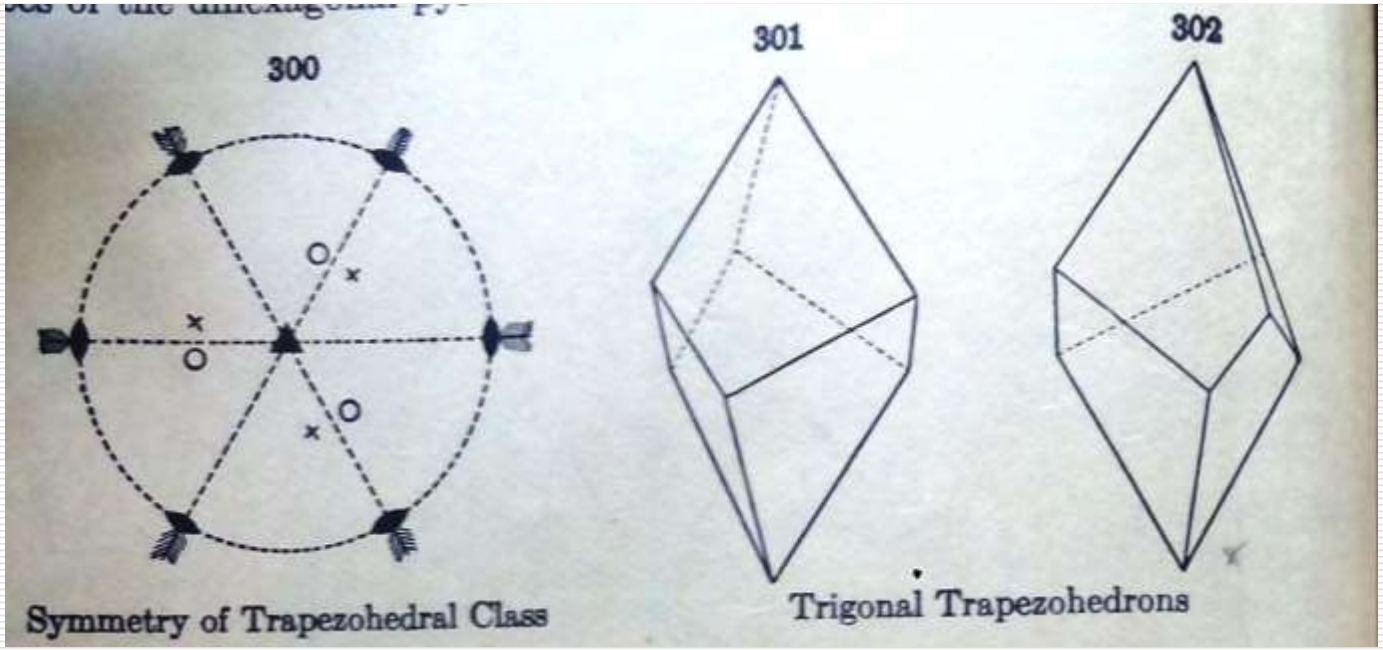


Back…2..HS-R

4. TRAPEZOHEDRAL CLASS – α-QUARTZ TYPE (Trigonal Trapezohedral/ Trapezohedral Tetartohedral/ Trigonal Holoaxial class)

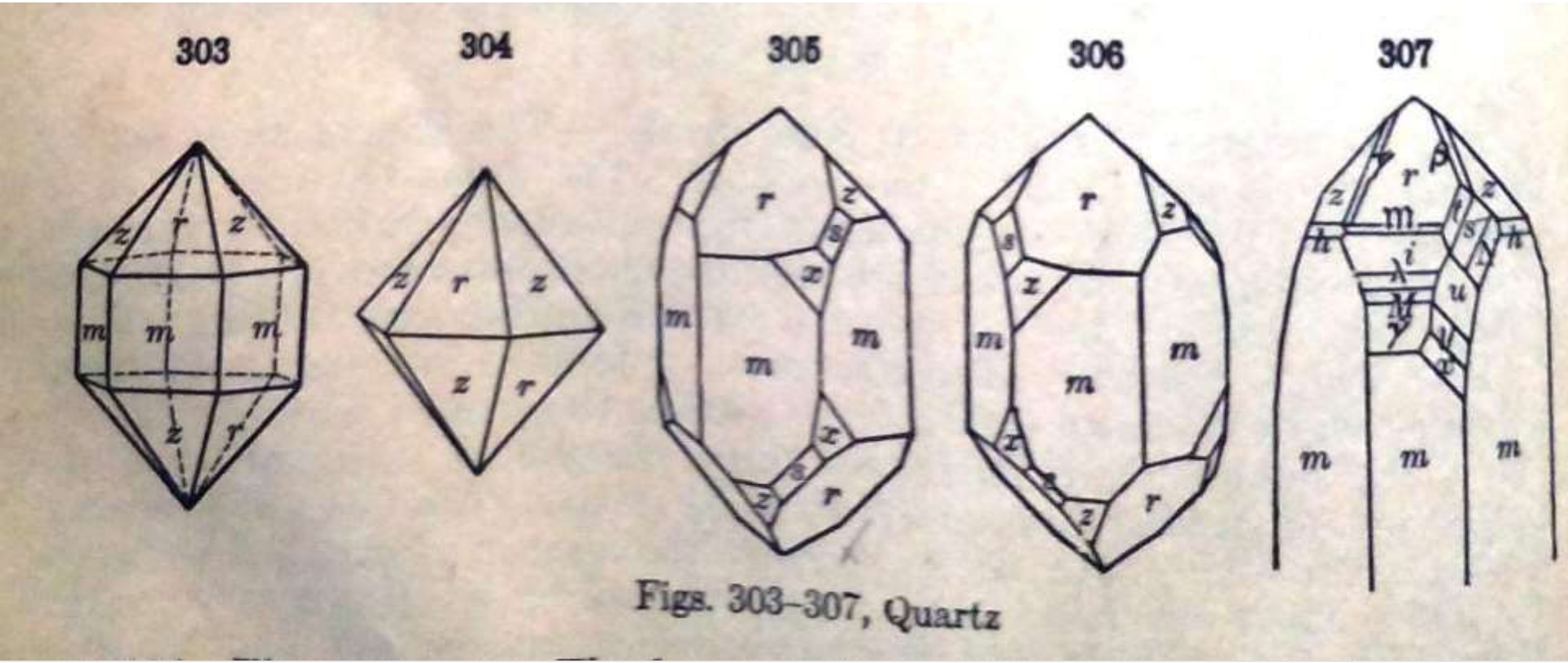
Vert. ax. 3;
3 hor. Ax.-2.

Forms:
Trigonal trapezohedrons +ve & -ve &
Ditrigonal prisms



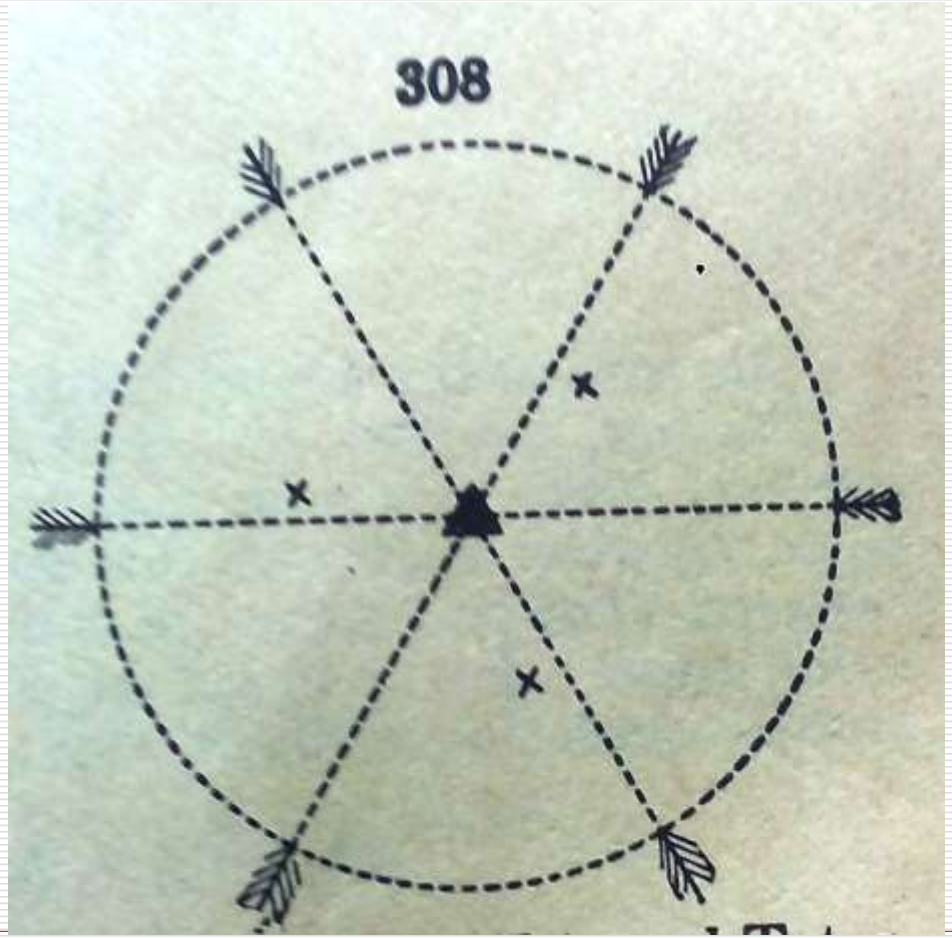
Back…2..HS-R

Combinations with other forms:
r & z – Rhombohedrons
s – right trigonal pyramid
x, N, i, γ, λ, y, u, h, β, M, l - right +ve & left -ve trapezohedrons
m - 1st order hexagonal prism



Figs. 303–307, Quartz

5. TRIGONAL TETARTOHEDRAL HEMIMORPHIC CLASS – SODIUM PERIODATE TYPE (Trigonal Pyramidal / Trigonal Polar class)



Vert. ax. 3

Back…2..HS-R

ORTHORHOMBIC SYSTEM

1. NORMAL CLASS / BARITE TYPE
2. HEMIMORPHIC CLASS / CALAMINE TYPE
3. SPHENOIDAL CLASS / EPSOMITE TYPE

ORTHORHOMBIC SYSTEM

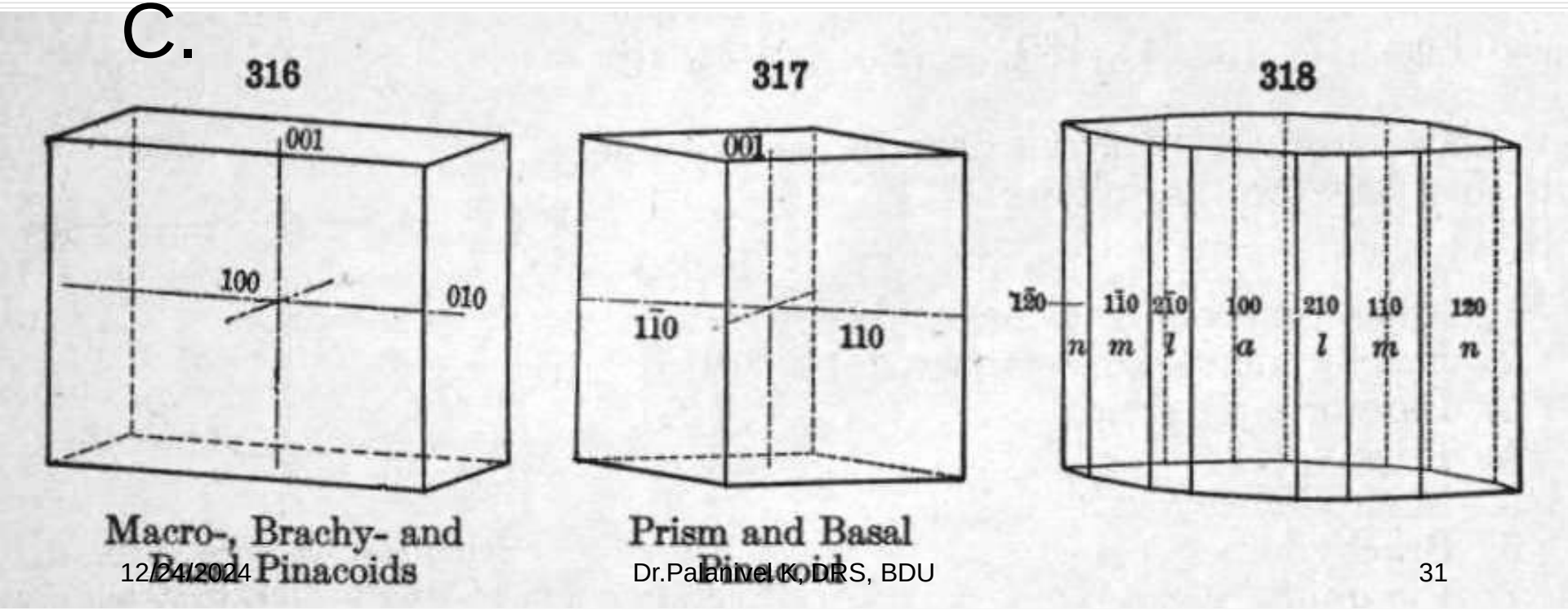
NORMAL CLASS / BARITE TYPE

- FORMS

1. Macropinacoid or a-pinacoid (100)
2. Brachypinacoid or b-pinacoid (010)
3. Base or c-pinacoid (001)
4. Prisms (hk0)
5. Macrodomes (h0l)
6. Brachydomes (0kl)
7. Pyramids (hkl).

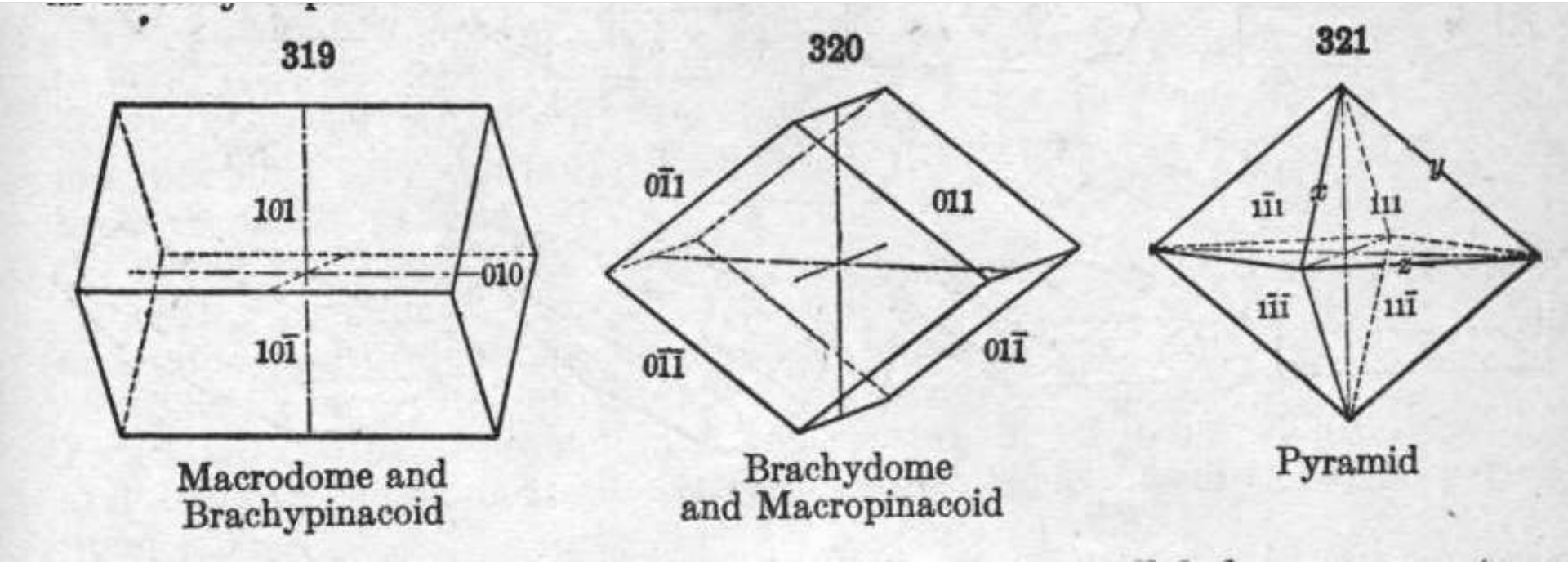
Symmetry Elements of Orthorhombic System – Normal class:

3 Xl. Ax.-2;
3 Xl. P &
C.



Macro-, Brachy- and Basal Pinacoids

Prism and Basal Pinacoid



Macrodome and Brachypinacoid

Brachydome and Macropinacoid

Pyramid

Figs. 322-333

a - macropinacoid

b – brachypinacoid

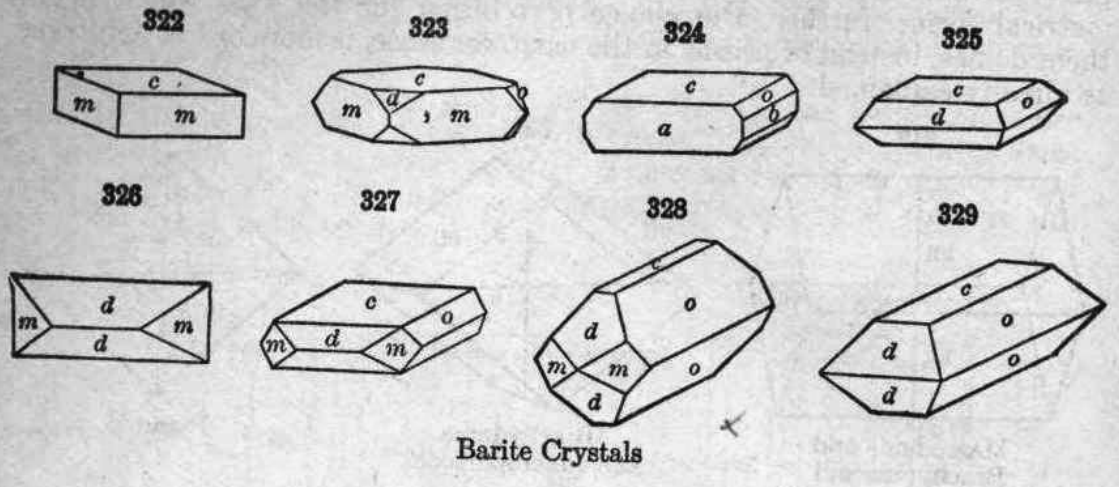
d, r – macrodome

o, n - brachydome

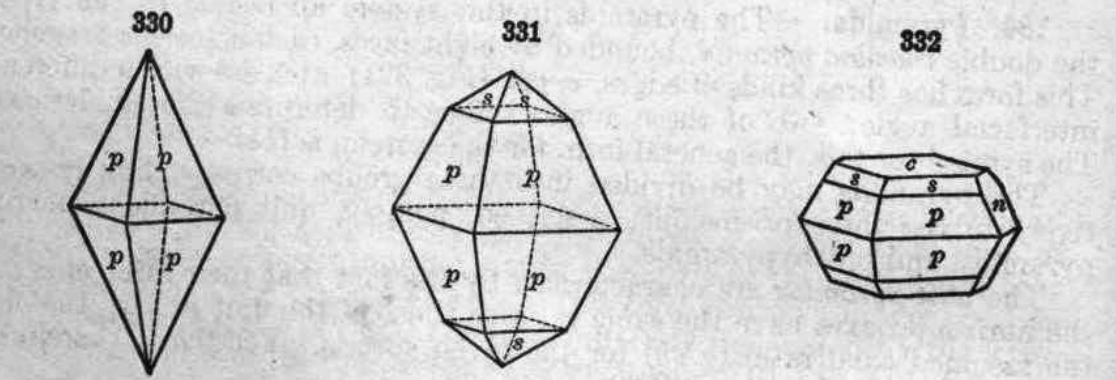
m - prism

p, s - pyramids

c – base or basal pinacoid



Barite Crystals



Sulphur Crystals

Figs. 334-336

b - brachypinacoid

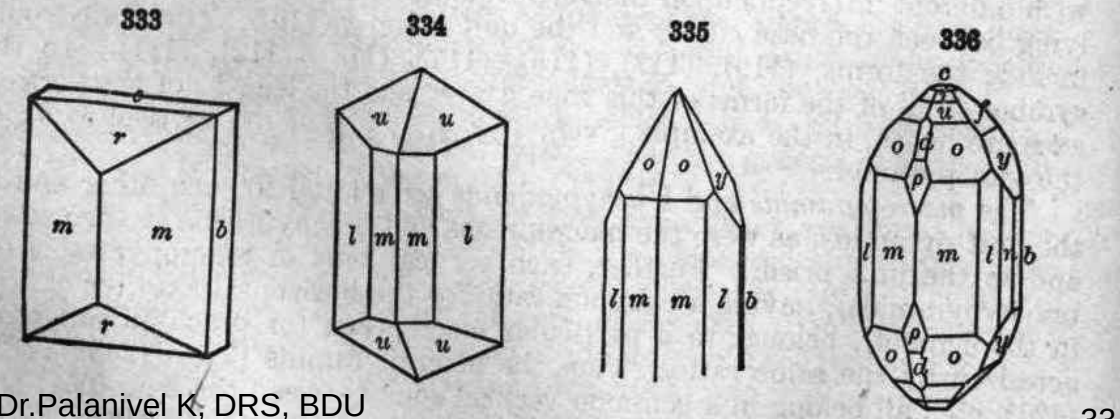
f, y - brachydome

d, ρ – macrodome

m, l, n - prism

i, u, o - pyramids

c – base or basal pinacoid



Staurolite

Figs. 334–336, Topaz

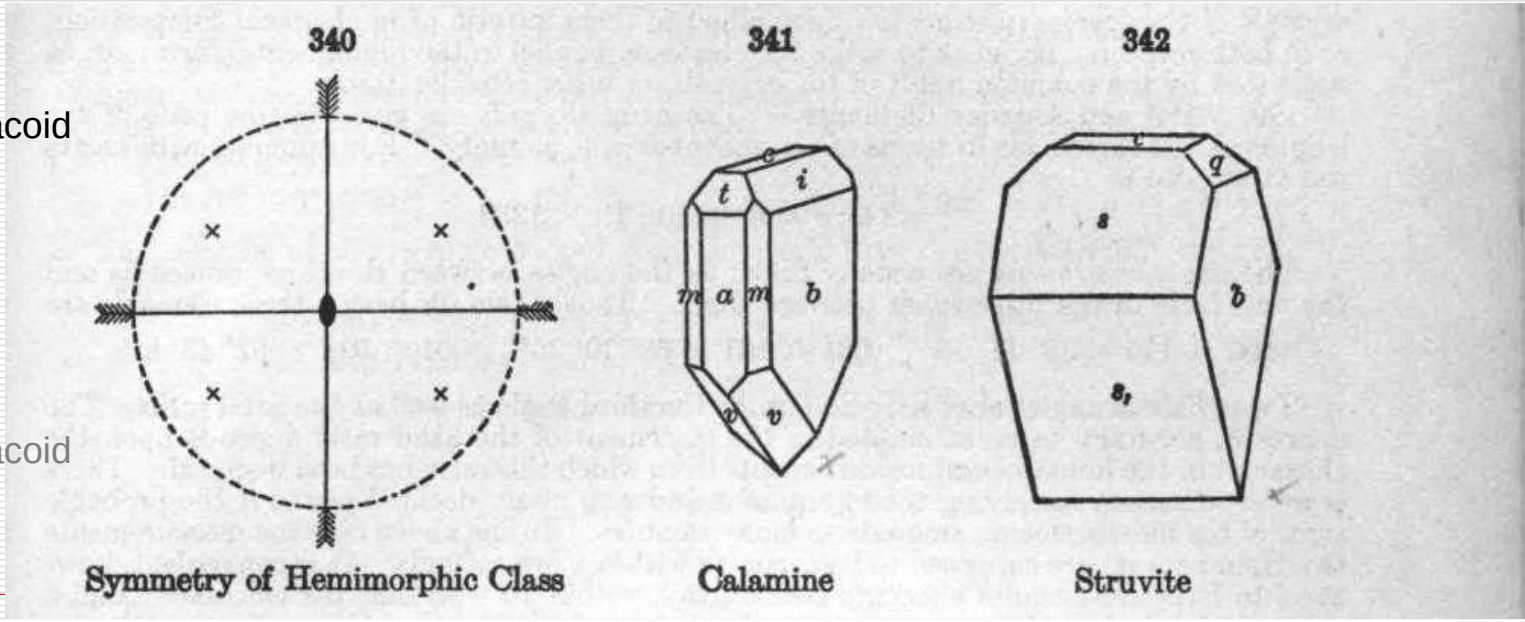
2. Hemimorphic class / Calamine type

Symmetry elements of Hemimorphic class:

Vert. Ax. -2; 2 Vert. Xl. P.

Fig. 341
a - macropinacoids
b – brachypinacoids
m – prisms
v - pyramids
t – macrodomes
i - brachydomes
c – base or basal pinacoid

Fig. 342
b – brachypinacoids
s – macrodomes
q - brachydomes
c – base or basal pinacoid

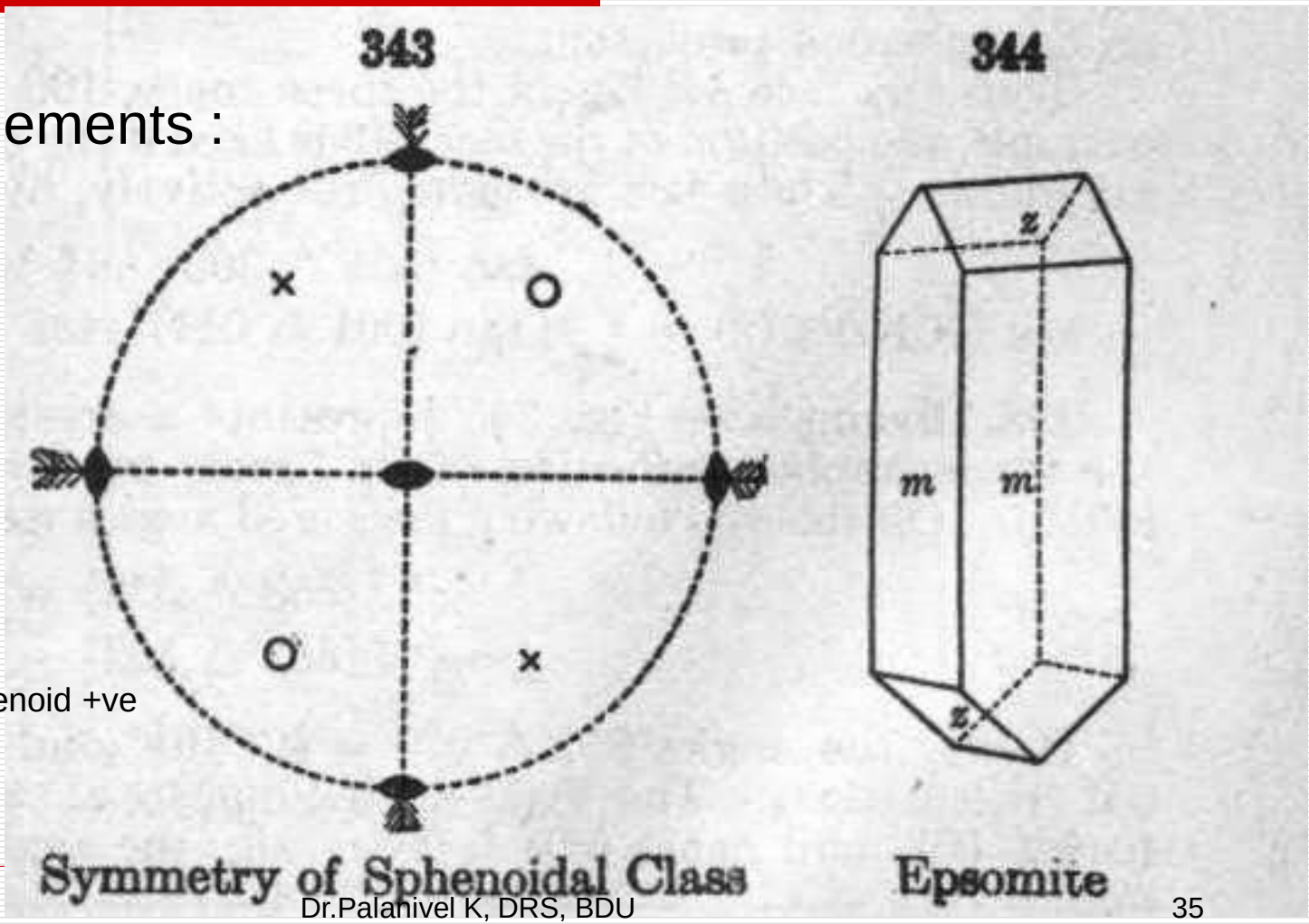


Back…2..OS

3. Sphenoidal Class / Epsomite type (Orthorhombic Disphenoidal or digonal Holoaxial class)

Symmetry Elements :

3 Xl. Ax.-2.



Symmetry of Sphenoidal Class

Epsomite

Form

m – prism
z - orthorhombic sphenoid +ve

Back…2..OS

MONOCLINIC SYSTEM

Classes

1. Normal Class
2. Hemimorphic Class / Tartaric Acid Type
3. Clinohedral Class / Clinohedrite Type

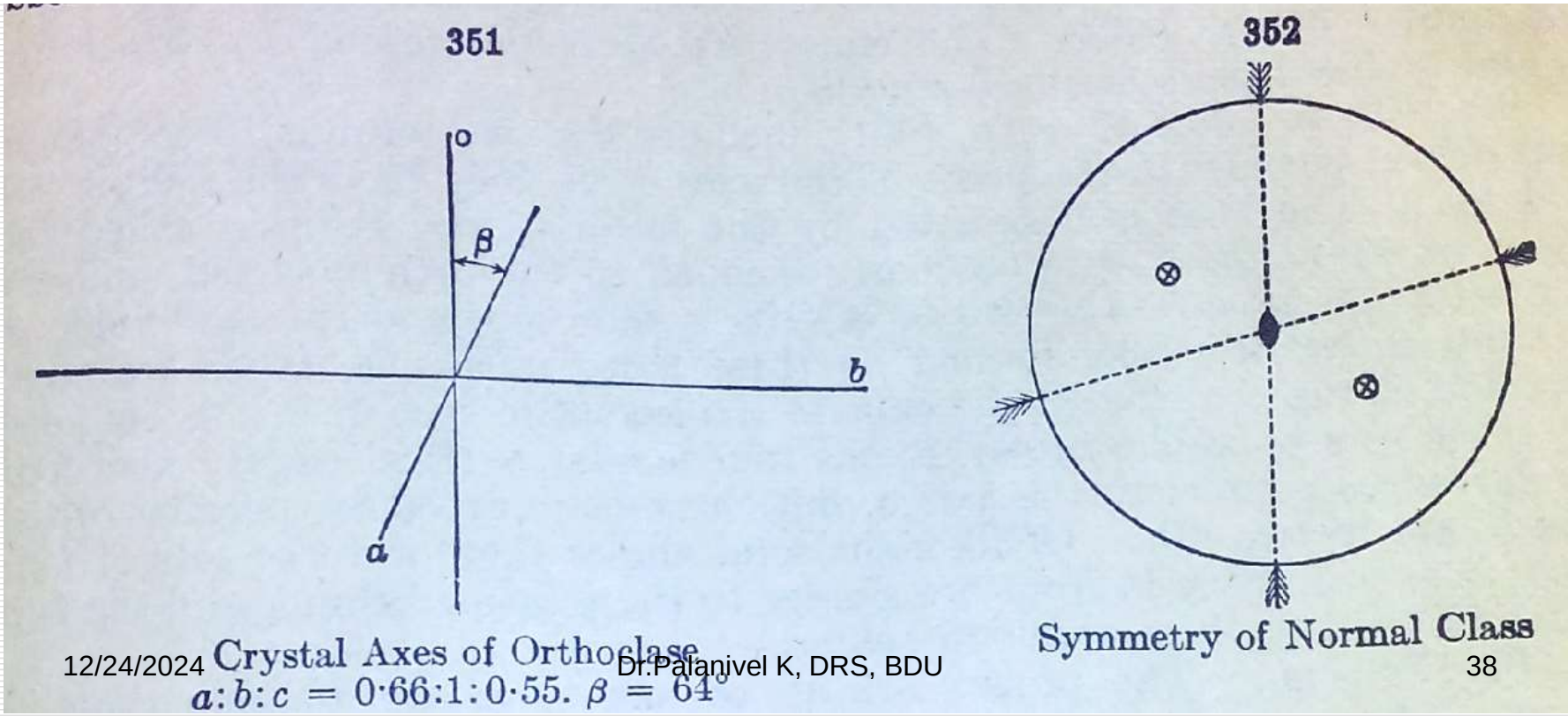
MONOCLINIC SYSTEM

1. NORMAL CLASS - FORMS

i. Orthopinacoid or a-pinacoid… (100)
ii. Clinopinacoid or b-pinacoid…. (010)
iii. Base or c-pinacoid ……(001)
iv. Prisms ……(hk0)
v. Orthodomes ……(h0l), (-h0l)
vi. Clinodomes ……(0kl)
vii. Pyramids ……(hkl), (-hkl).

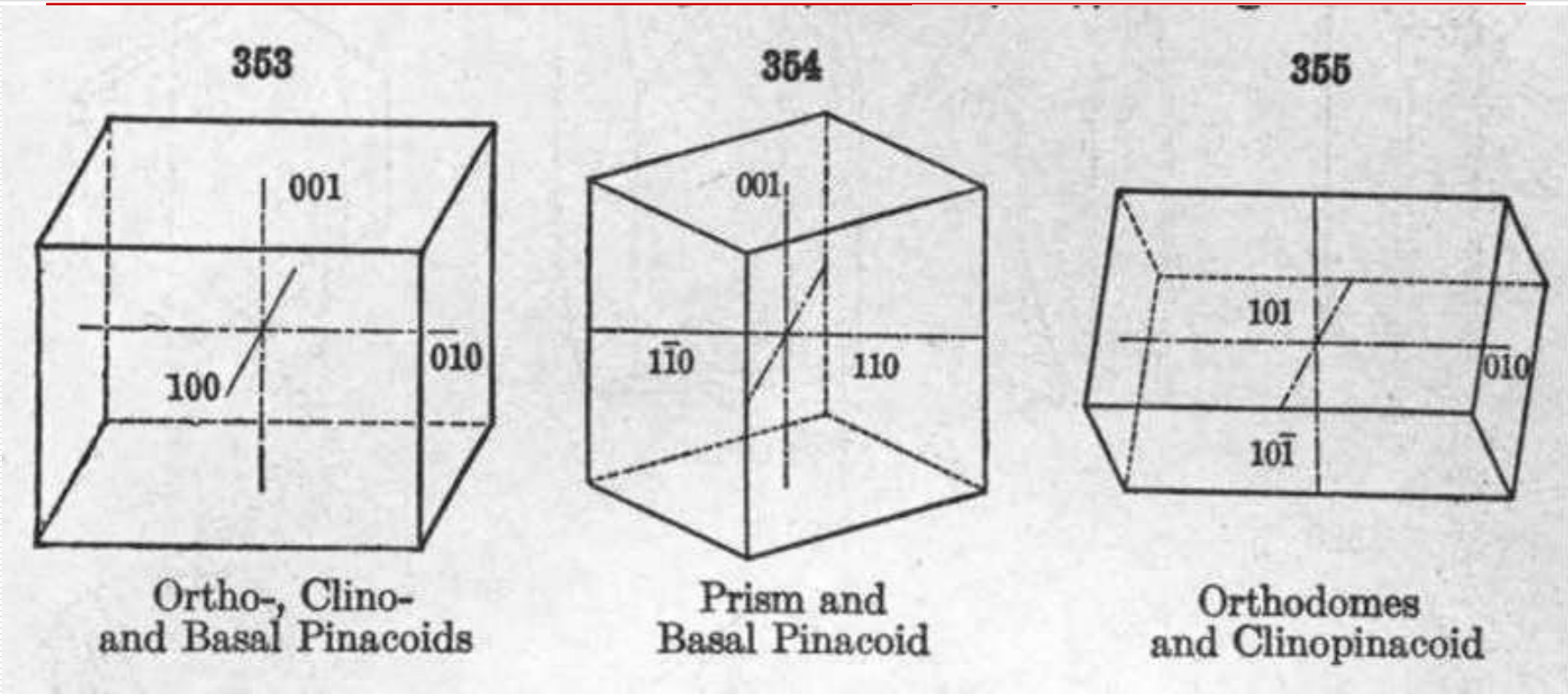
Symmetry Elements of Normal Class of Monoclinic System:

B xl. Ax.-2; a-c xl. P. & C.



Crystal Axes of Orthoclase
$a:b:c = 0{\cdot}66:1:0{\cdot}55.\ \beta = 64°$

Symmetry of Normal Class



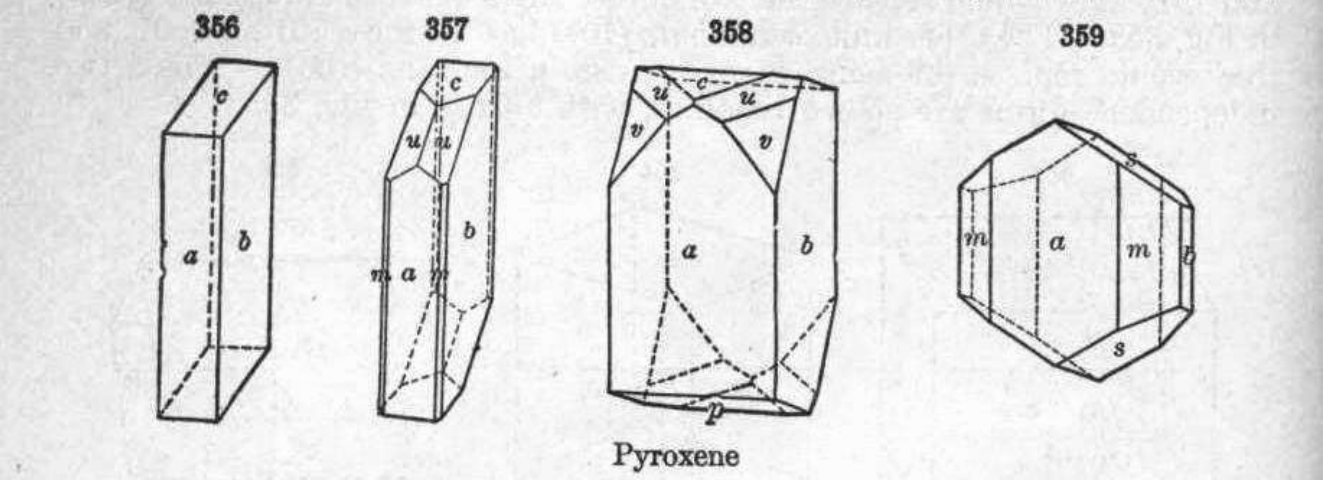
Ortho-, Clino- and Basal Pinacoids

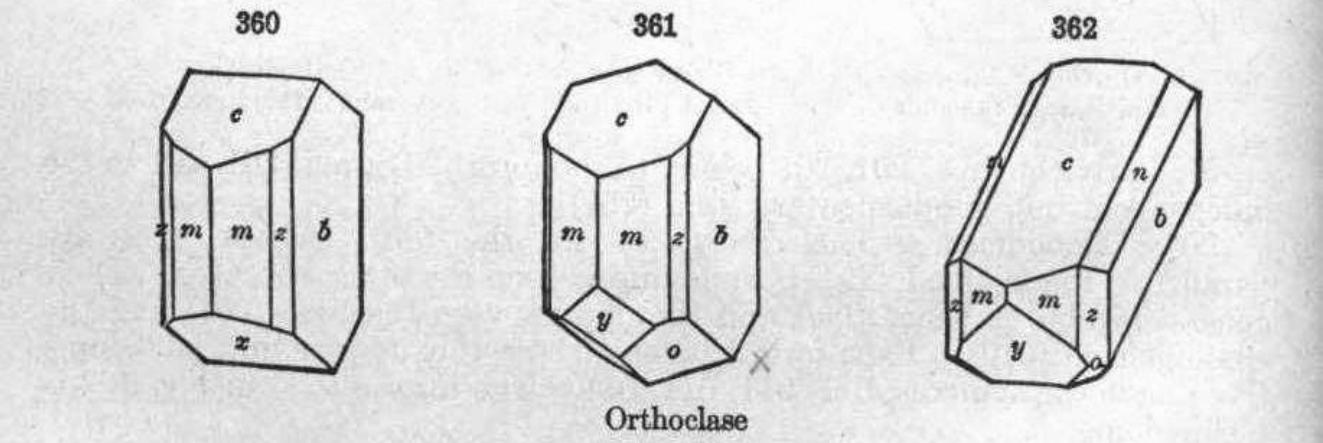
Prism and Basal Pinacoid

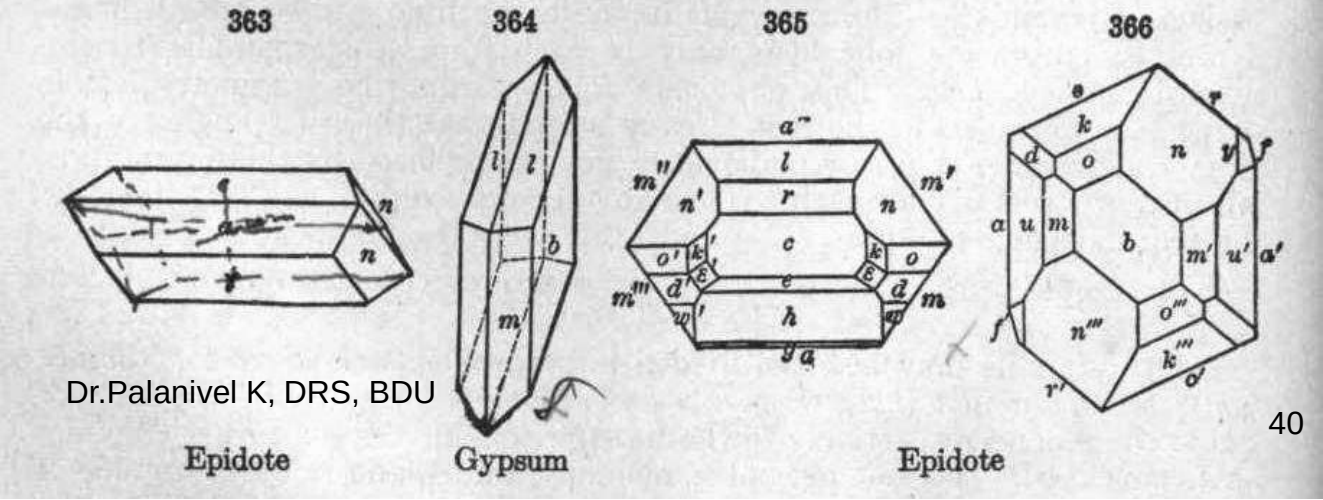
Orthodomes and Clinopinacoid

Figs. 356-366

a - orthopinacoids
b – clinopinacoids
m, h, z, f – prisms
v, u, s, o, ω, ε, l - pyramids
p, x, y, i, r – orthodomes
k, n – clinodomes
c – base or c-pinacoid





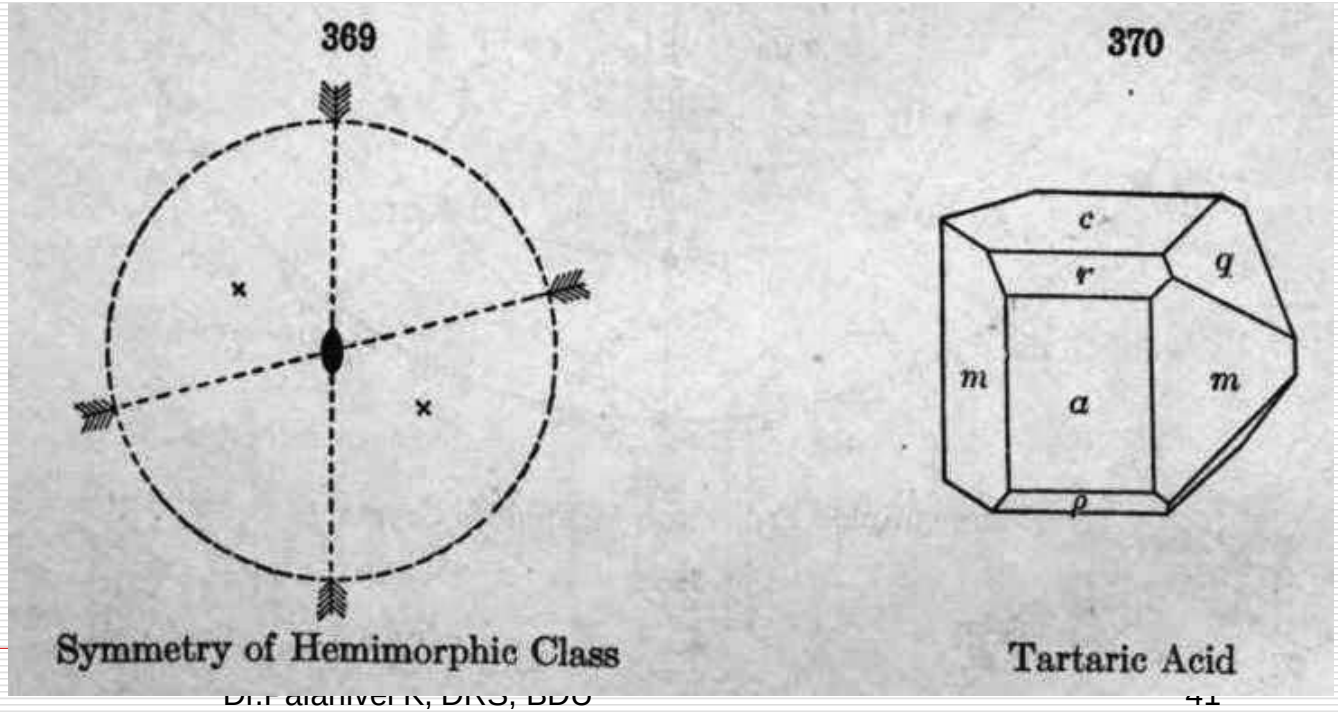


2. Hemimorphic Class / Tartaric Acid Type

Sym.: b Xl. Ax. 2.

Fig. 370

a - orthopinacoids
m – prisms
r, ρ – orthodomes
q- clinodomes
c – base or c-pinacoid



Back…2..MS

3. Clinohedral Class / Clinohedrite Type

Sym.: a-c xl. P.

Back…2..MS

TRICLINIC SYSTEM

CLASSES

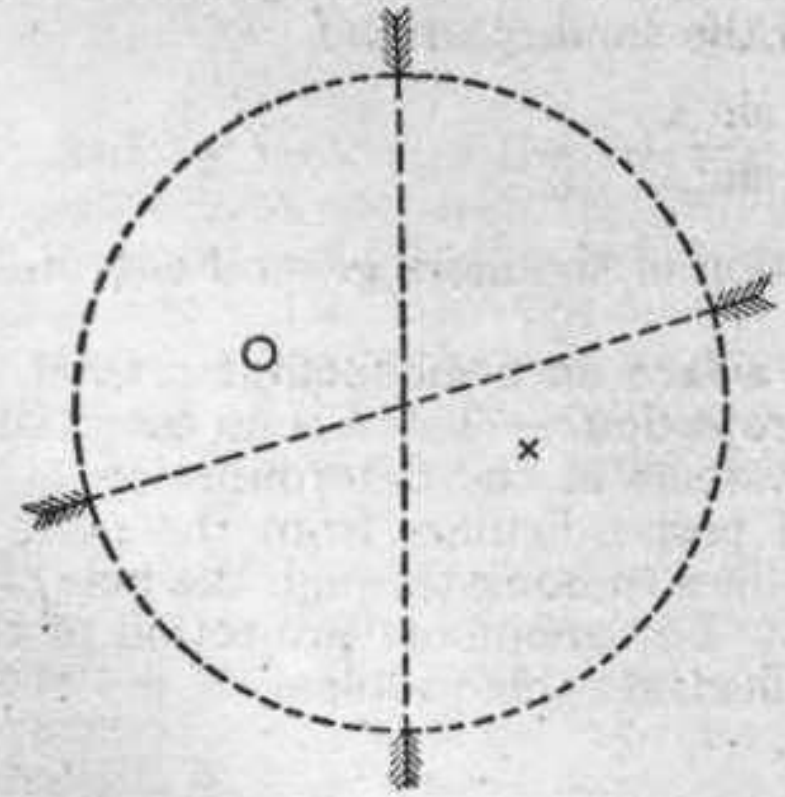
1. Normal Class
2. Assymmetric class / Calcium Thiosulphate type

TRICLINIC SYSTEM

NORMAL CLASS - FORMS

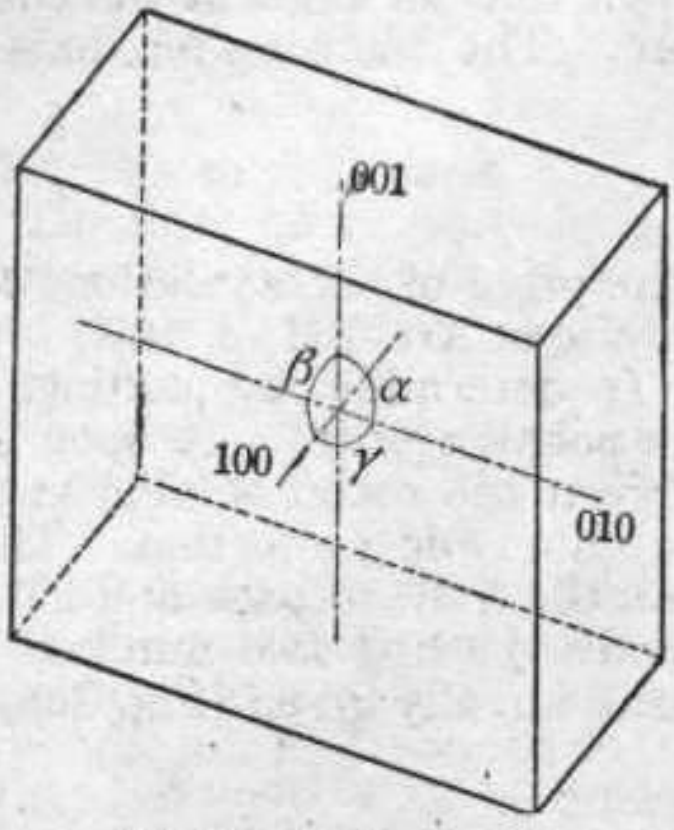
i. Macropinacoid or a-pinacoid..... (100)
ii. Brachypinacoid or b-pinacoid.... (010)
iii. Base or c-pinacoid .....(001)
iv. Prisms .....(hk0), (h-k0)
v. Macrodomes .....(h0l), (-h0l)
vi. Brachydomes .....(0kl), (0-kl)
vii. Pyramids.(hkl), (-hkl), (-h-kl), (h-kl).

378



Symmetry of Normal Class

379

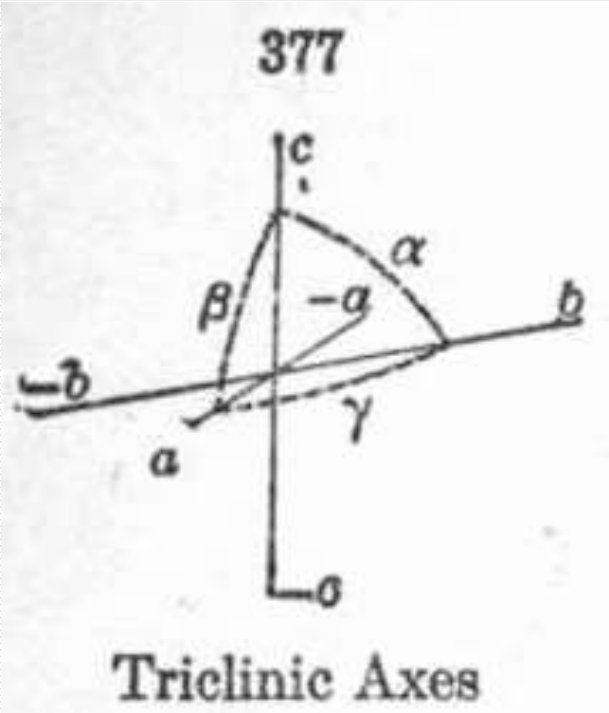


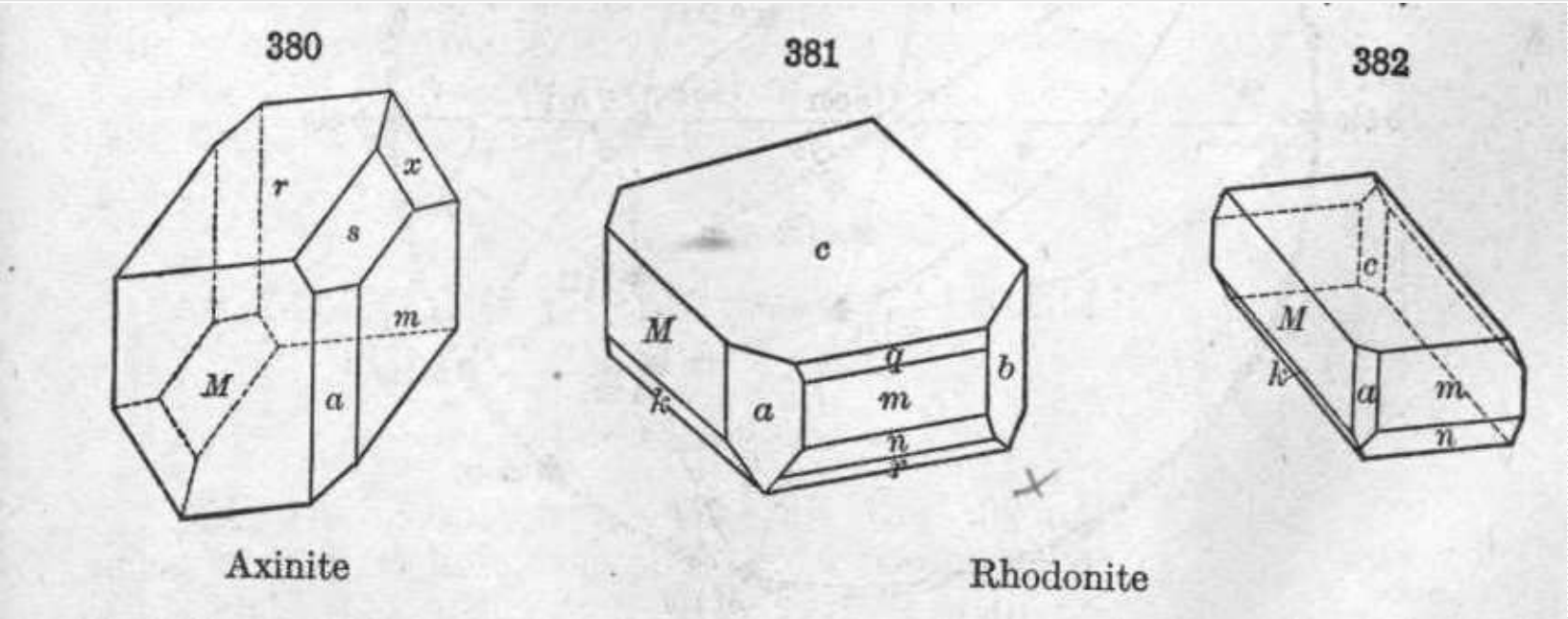
Triclinic Pinacoids

Back…2..TS

Symmetry Elements of Normal class of Triclinic System:

C. – Center of Symmetry present





Figs. 380-382

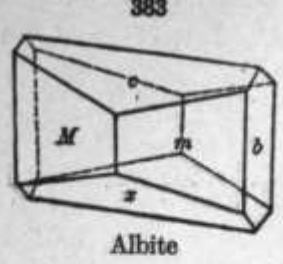
a - macropinacoid
b – clinopinacoid
m, M – prisms
x, r, k, q - pyramids
s– macrodome
i, n - clinodomes
c – base or c-pinacoid

Figs. 384-385

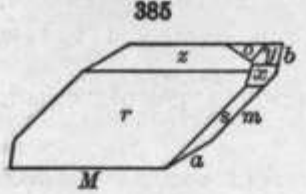
a - macropinacoid
b – brachypinacoid
m, M, x, f, z – prisms
m, o, α, p - pyramids
s, t, y – macrodomes
e, r, n - brachydomes
c – base or c-pinacoid

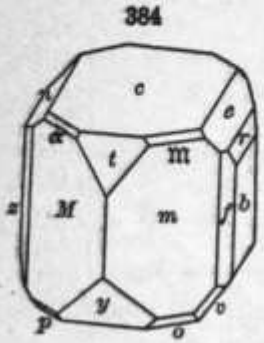
Fig. 386

a - macropinacoid
b – brachypinacoid
m, M – prisms
o, r, x, y, z - pyramids
s – macrodome

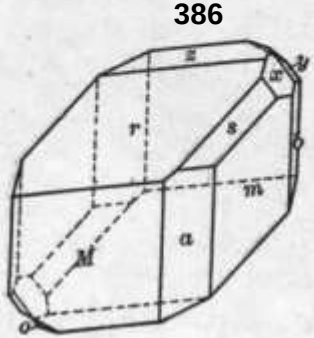


Albite

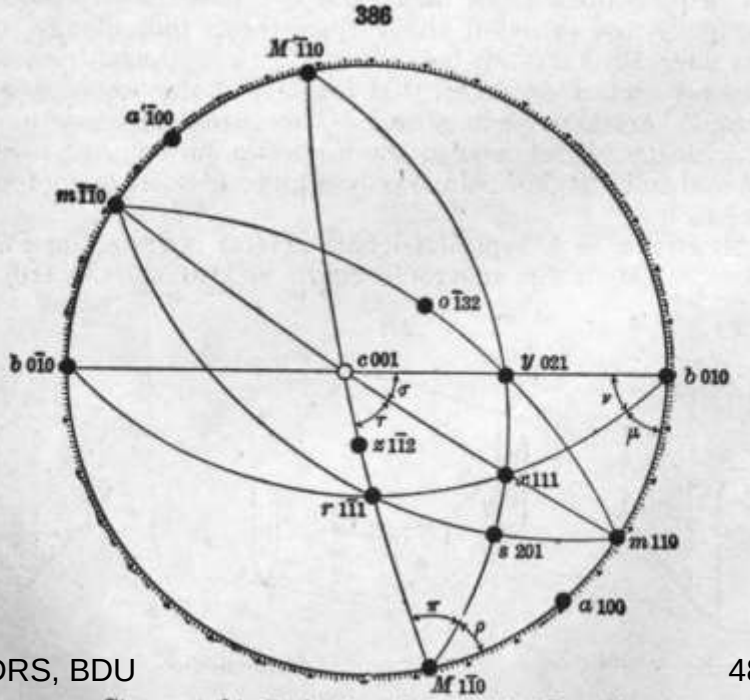




Anorthite



Axinite



Stereographic Projection of an Axinite Crystal

Back…2..TS

2. Assymmetric class / Calcium Thiosulphate type (Hemihedral or Pedial class)

No symmetry.

One face only.

E.g. $CaS_2O_3.6H_2O$

Calcium Thiosulphate

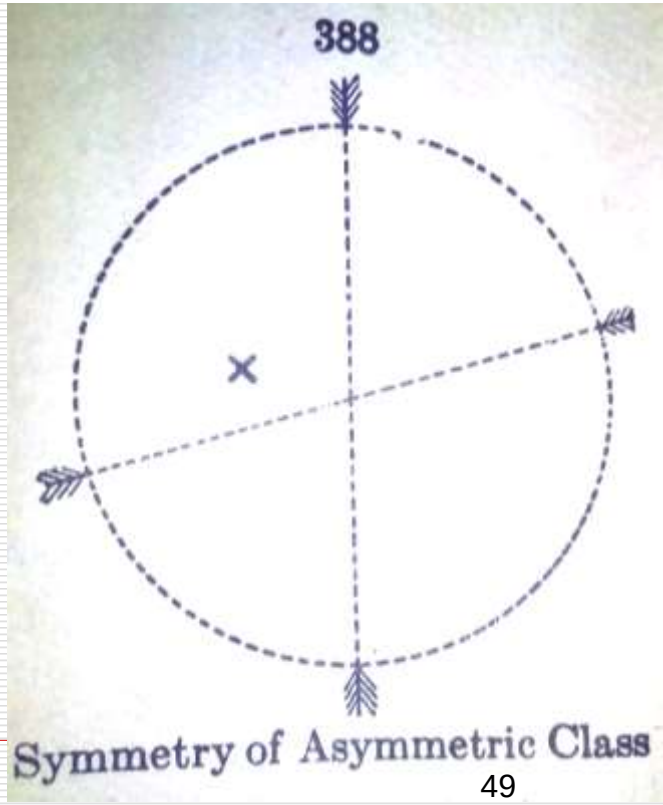
Macropinacoid or a-pinacoid (100)

or

Brachypinacoid or b-pinacoid (010)

or

Base or c-pinacoid (001)



Symmetry of Asymmetric Class

Back…2..TS

STATE OF AGGREGATION:

Crystal habits and forms

- The Shape and size of crystals give rise to certain descriptive terms applied to the typical appearance are known as **habit of crystals.**
- Factors influencing a crystal's habit include:
  - Combination of two or more crystal forms;
  - Trace impurities present during growth;
  - Crystal twinning and
  - Growth conditions (i.e., heat, pressure, space).

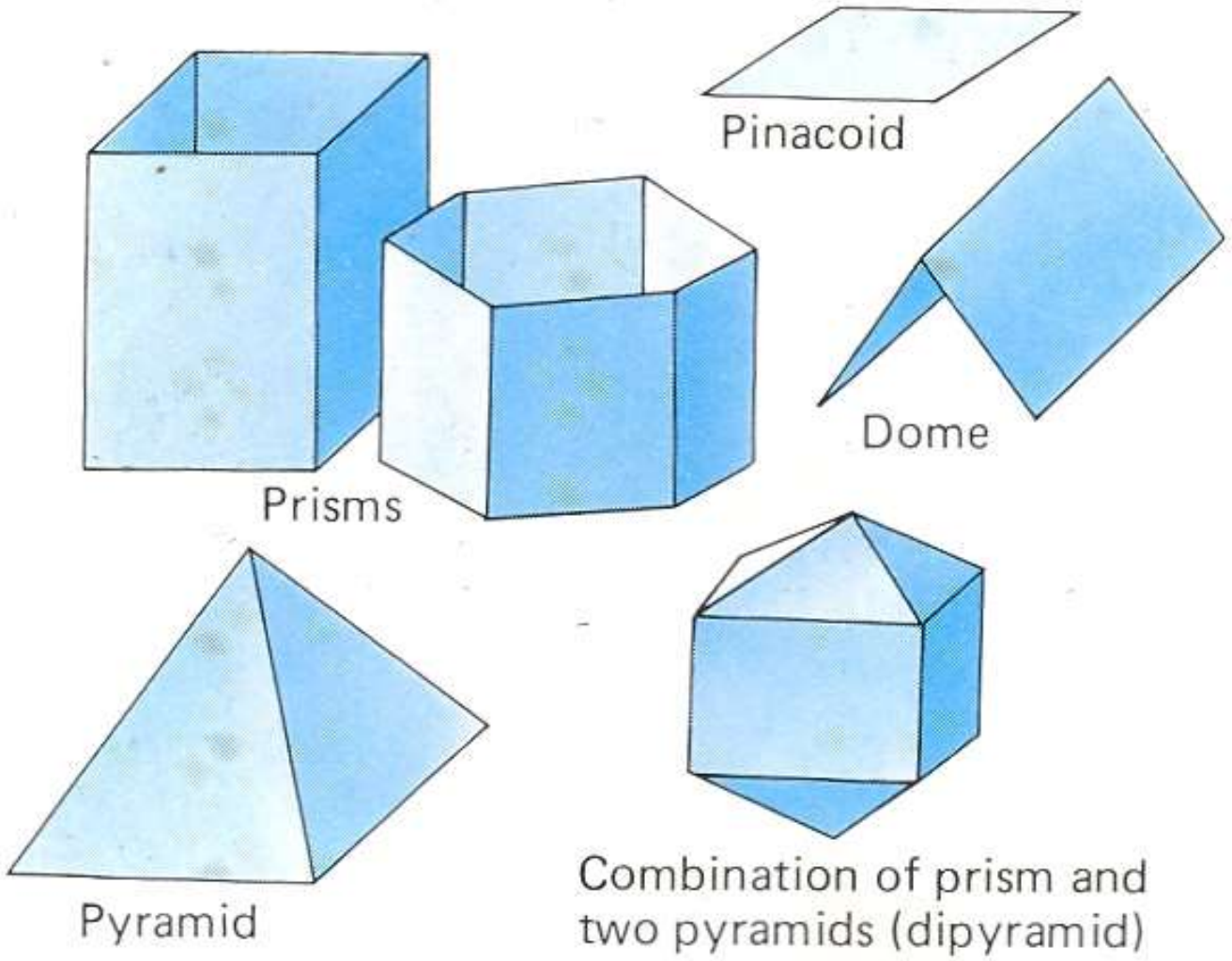


Figure 2–13 Some common crystal forms.

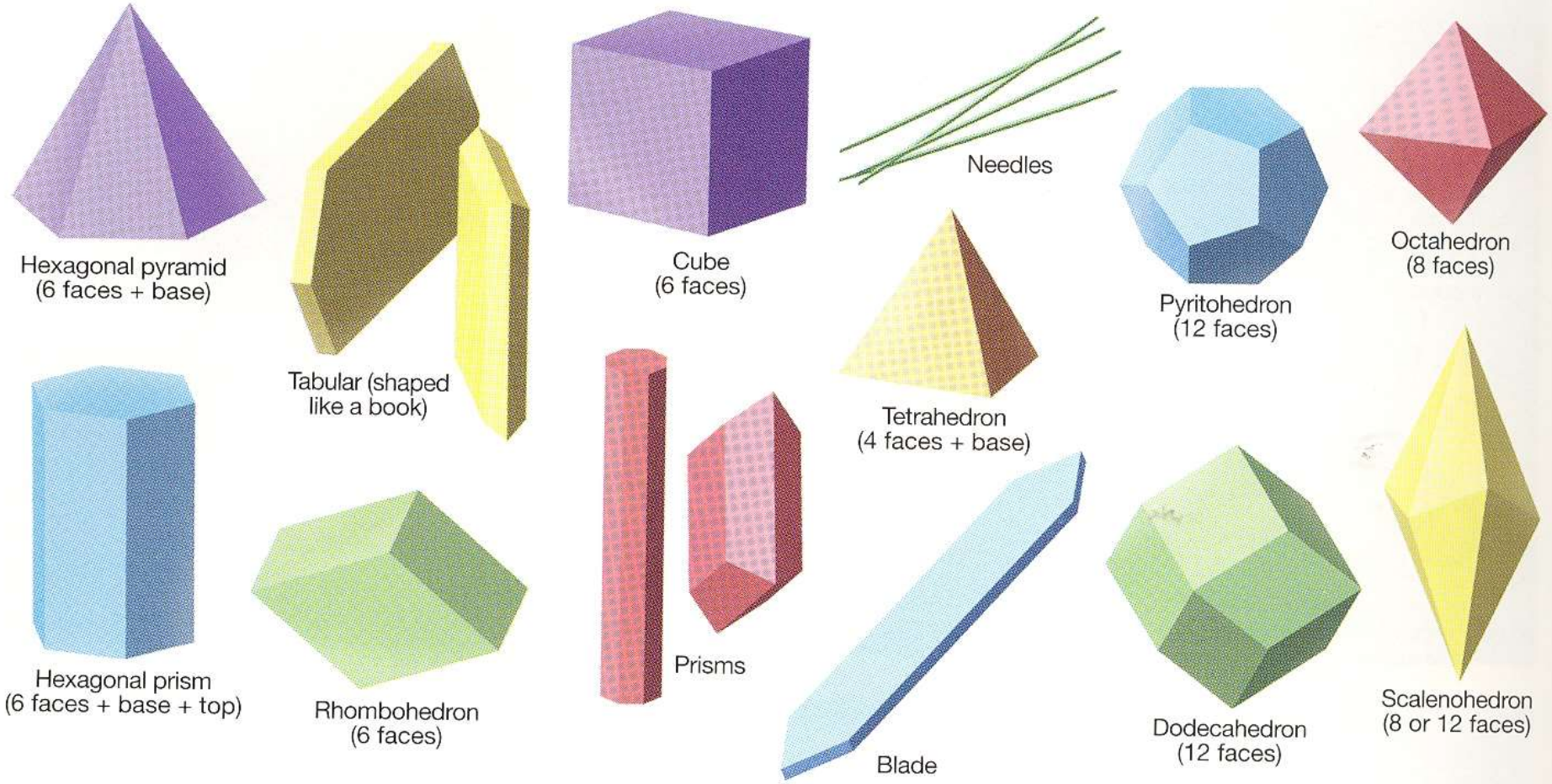


FIGURE 2.3 Some *crystal forms* (geometric shapes). The flat surfaces of these forms are called *crystal faces*.

List of crystal Forms, Habits and Crystalline Aggregates

Habit:	Description:	Example:
Crystallized	having fully developed faces	Quartz, Calcite, etc.
Crystalline	aggregate of imperfectly formed crystals that are interfered with one another during their growth	NaCl crystals
Cryptocrystalline	only very little traces of crystalline structures	Obsidian
Amorphous	complete absence of crystalline structure	Opal
Acicular	Needle-like, slender and/or tapered	Rutile in quartz
Amygdaloidal	Almond-shaped	Heulandite
Anhedral	Poorly formed, external crystal faces not developed	Olivine

Bladed	Blade-like, slender and flattened	Kyanite
Botryoidal or globular	Bunch of Grapes-like, hemispherical masses	Chalcedony, Smithsonite, Hemimorphite, Adamite and Variscite
Capillary	Fine hair like	Millerite, Nickel sulphide, Hair Pyrites
Columnar	Similar to fibrous: Long, slender prisms often with parallel growth	Calcite
Coxcomb	Aggregated flaky or tabular crystals closely spaced.	Barite
Dendritic or arborescent	Tree-like, moss-like branching in one or more direction from central point	Magnesite in opal, Mn Oxides
Dodecahedral	Dodecahedron, 12-sided	Garnet
Drusy or encrustation	Aggregate of minute crystals coating a surface	Uvarovite

Enantiomorphic	Mirror-image habit and optical characteristics; right- and left-handed crystals	Quartz
Equant, stout, stubby or blocky	Length, width, and breadth roughly equal	Zircon
Euhedral	Well-formed, external crystal faces developed	Spinel
Fibrous	Extremely slender prisms	Tremolite, Satinspar, Asbestos
Filiform or wiry	Thin wires, extremely fine twisted like the strands of a rope	Natrolite, Native silver and copper
Foliated or micaceous	Layered structure, parting into thin sheets	Mica
Granular	Aggregates of anhedral crystals in matrix	Scheelite
Hemimorphic	Doubly terminated crystal with two differently shaped ends.	Hemimorphite

Lamellar		Wollastonite
Lenticular	Flattened balls or pellets as in nodular/concretionary mnls.	
Mamilliated	Breast-like: surface formed by intersecting partial spherical shapes	Malachite
Massive or compact	Shapeless, no distinctive external crystal shape	Serpentine
Nodular, Concretionary or tuberose	Deposit of roughly spherical form with irregular protuberances	Geodes, Nodules of , Chalk and Phosphates
Octahedral	Octahedron, eight-sided (two pyramids base to base)	Diamond
Plumose	Fine, feather-like scales	Mottramite
Prismatic	Elongate, prism-like: crystal faces parallel to c-axis well-developed	Tourmaline
Pseudo-hexagonal	hexagonal appearance due to cyclic twinning	Aragonite
Pseudomorphous	Occurring in the shape of another mineral through pseudomorphous replacement	Tiger's eye

Radiating or divergent	Fibres radiating outward from a central point	Stibnite, Pyrite suns
Reniform or colloform	Similar to mamillary: intersecting kidney-shaped masses	Hematite
Reticulated	Cross-meshes like (net-like) acicular crystals forming intergrowths	Cerussite, Rutile needles in Mica
Rosette	Platy, radiating rose-like aggregate	Gypsum
Scaly	Small plates	Tridymite
Sphenoid	Wedge-shaped	Sphene
Stalactitic	Forming as stalactites or stalagmites; cylindrical or cone-shaped	Rhodochrosite
Stellate	Star-like, radiating	Pyrophyllite
Striated/striations	Surface growth lines parallel or perpendicular to a crystallographic axis	Chrysoberyl
Subhedral	External crystal faces only partially developed	
Tabular or lamellar	Flat, tablet-shaped, prominent pinnacoid	Ruby
Tuberose	Very irregular rounded surfaces-gnarled, root like shapes	Aragonite variety Flos-ferri
Wheat sheaf	Aggregates resembling hand-reaped wheat sheaves / straws	Zeolites

Pseudomorphism & Polymorphism

- **Pseudomorphism** – the assumption by a mineral of a form other than that which really belongs to it, by incrustation, infiltration, replacement or by alteration. E.g. Pyrite takes the shape of Goethite.

- **Polymorphism** – Two minerals of markedly different physical properties, but may have identical chemical compositions.
  - **Dimorphism** - Calcite – Aragonite, Graphite – Diamond.
  - **Trimorphous** – Titanium Dioxide-Anatase-Brookite-Rutile.

Twinning or Crystal Intergrowth

- Intergrowth of two or more individual crystals in such a way as to yield parallelism in the case of certain parts of different individuals and at the same time other parts of the different individuals are in reverse positions in respects to each other.
- They often appear externally to consist of two or more crystals symmetrically united.
- There are several types of twinning identified.

Types of twinning

- **Simple twin**: The twin of calcite consisting of two halves symmetrical with respect to the twin-plane is simple twin is also known as **contact-twin**. (Dana 445 – 452)

- **Penetration twin**: The two halves of the twin have grown so mixed together that the twin cannot be divided in to two separate halves is known as penetration twin. Eg.: Iron cross twins of Pyrite, interpenetrated twins of Fluorite and cross-shaped twins of Staurolite. (D433-435, 464-466)

- **Repeated twin**: The repetition of twinning along the twin-plane. If it is composed of three parts it is called as '**trilling**', if 4 parts – '**fourling**'. If the twin-plane is parallel in all parts and there so many repetitions, is described as '**polysynthetic**'. Eg.: Plagioclase feldspars. If the twin-plane does not remain parallel, the resulting twin approaches a curved form called '**cyclic**'. Eg.: Aragonite. (D456, 484), Rutile, Chrysoberyl.

- **Compound or complex twin**: Twinning has taken place on two or more laws is called as compound or complex twin.

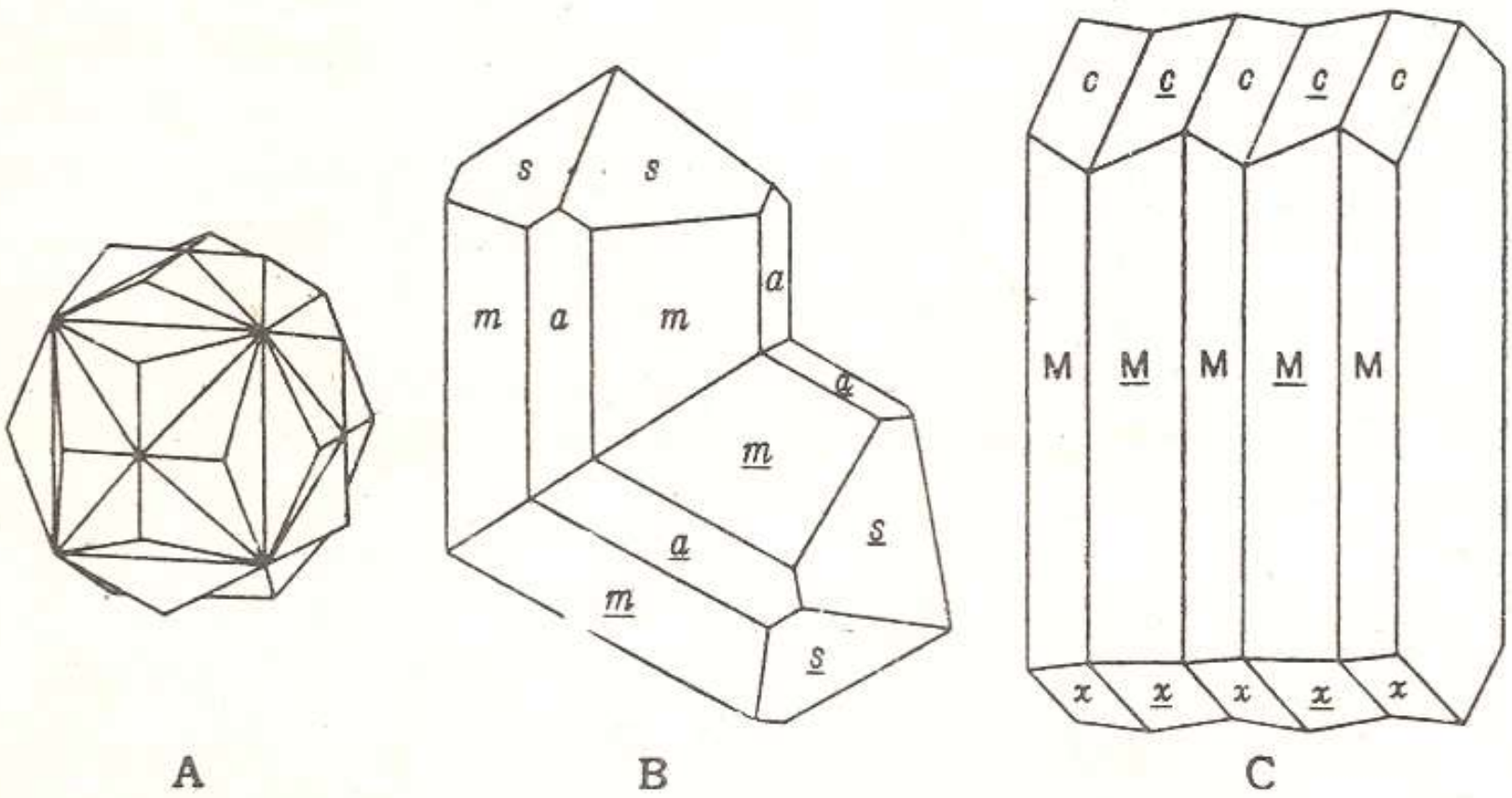


FIG. 87. Examples of Twins. A. Pyrite: Interpenetration Twin. B. Rutile: Geniculate Twin: twin-plane 101. C. Plagioclase: Repeated Twin: twin-plane 010.

Laws of Twinning:

- In Cubic system: ***Spinel law*** is the common twin in Galena type, in which the twin-plane is the octahedral face and the twin-axis is at right angles to this. Interpenetrated twins of Fluorspar in the octahedral face, Iron-cross of pyrite in the rhombo-dodecahedral face of pyritohedrons, normal Galena type are some of the other forms. D409, 410

- In Tetragonal system: ***Rutile law*** is the commenest type of twinning in which the pyramidal face of second order(101) or (301) is the twin-plane and composition-plane. It produced a **knee-shaped** or **geniculate twin** with 101 face or a sharper knee twins with 301 face. D420

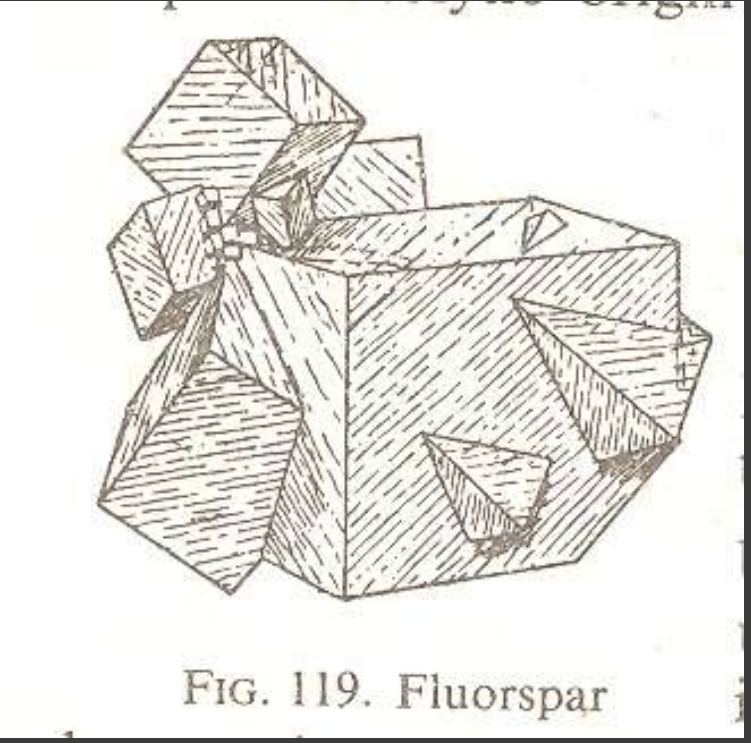
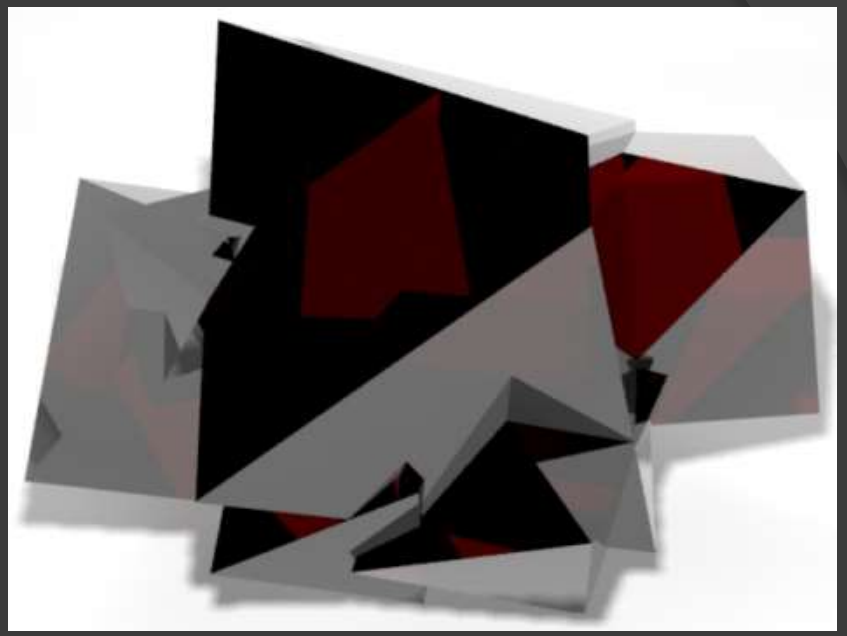
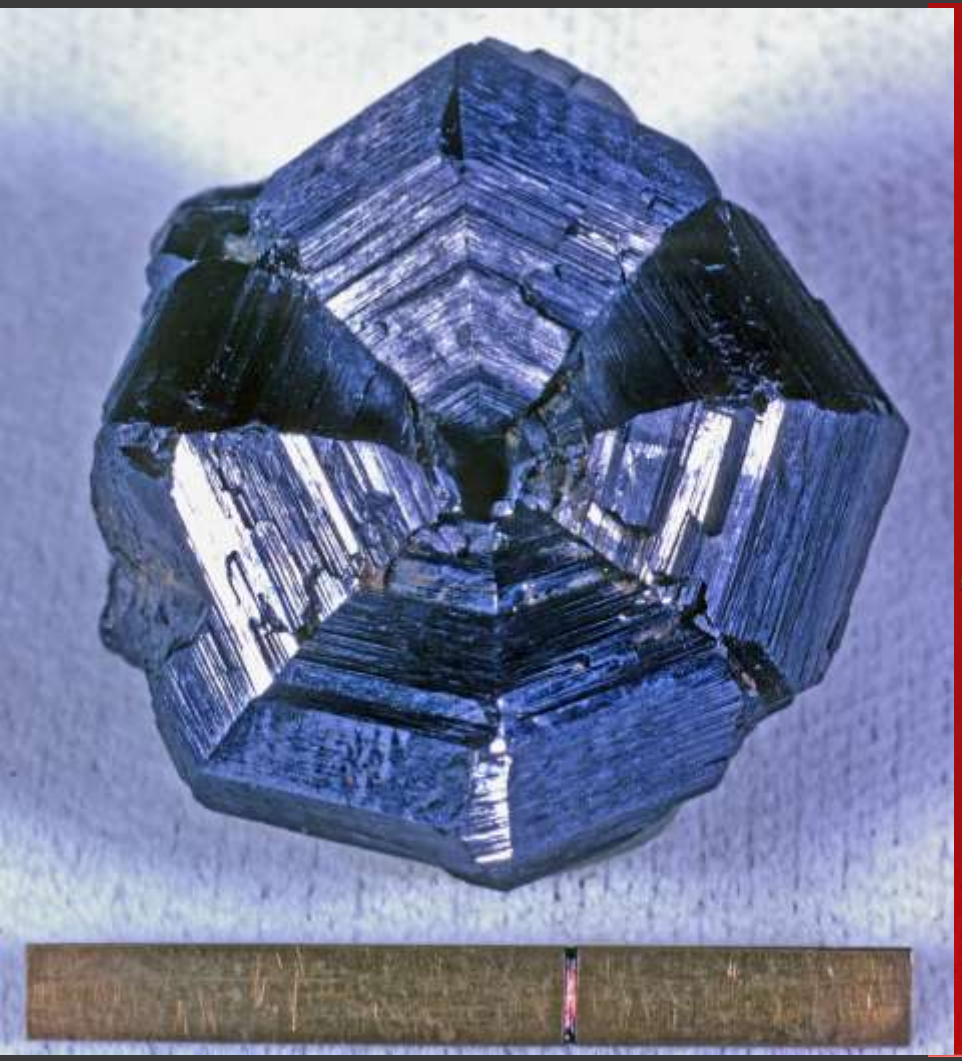


FIG. 119. Fluorspar



If the twin axes or twin planes not parallel, commonly resulting in threefold, fourfold, fivefold, sixfold, or eightfold twins, which, if equally developed, display geometrical symmetry not found in single crystals,



Eightling Rutile, Arkansas

Chrysoberyl, Brazil

Laws of Twinning:...contd...

- In Hexagonal system: ***Calcite twins*** (0001-base or the gliding planes such as 011-2, 10-11 & 02-21 rhombohedraons are the twin-planes), ***Quartz twins*** – interpenetration twin, vertical xallographic axis is the twin axis, with right and left handed crystals along 11-20 prism plane as twin-plane.

- In Orthorhombic system: ***Cyclic twins*** of Aragonite (110 prism is the twin-plane). The prism angle is nearly 60o so that twinning repeated five times to produce a pseudo-hexagonal crystal. ***Maltese cross*** (032-dome) and ***skew twin*** (232-bipyramid) in staurolite

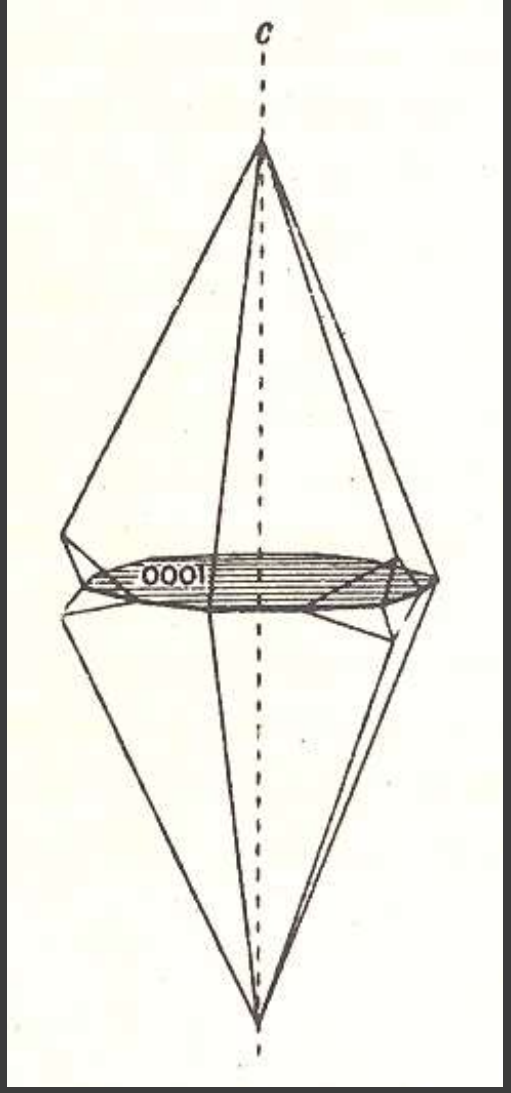


FIG. 86. Calcite Twin: Scalenohedron, twin-plane basal pinacoid 0001, twin-axis *c*.

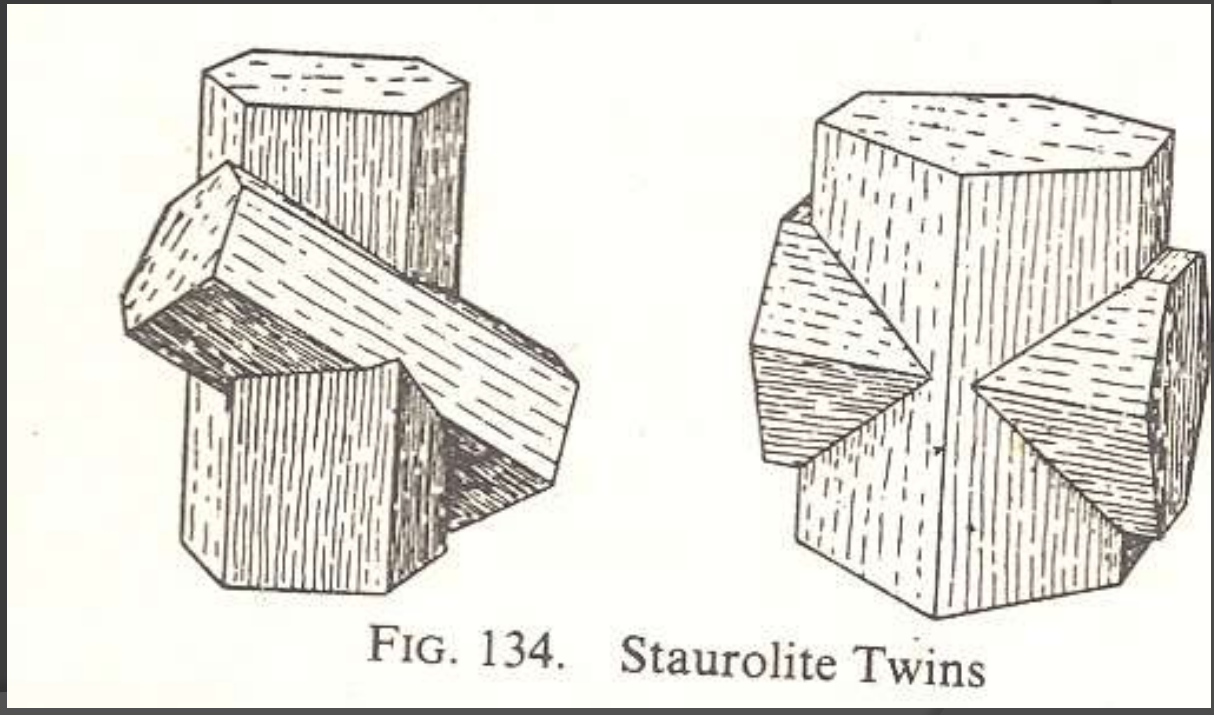


FIG. 134. Staurolite Twins

Laws of Twinning:...contd...

- In Monoclinic system: ***Swallow-tails twins*** in Gypsum, Hornblende and Augite twins, ***Carlspad twin*** and interpenetration Carlspad twin (vertical crystallographic axis is twin axis and the clinopinacoid (010) is the composition-plane), ***Baveno twin*** (clinodome-021 is the twin-plane and composition-plane), and ***Manebach twin*** (basal pinacoid-001).

- In Triclinic system: ***Albite law*** (010 the side pinacoid is the twin-plane), which is also repeated and polysynthetic twin. This repeated twin produces striations on the basal planes of the crystal and is also excellently seen in thin section of plagioclase.

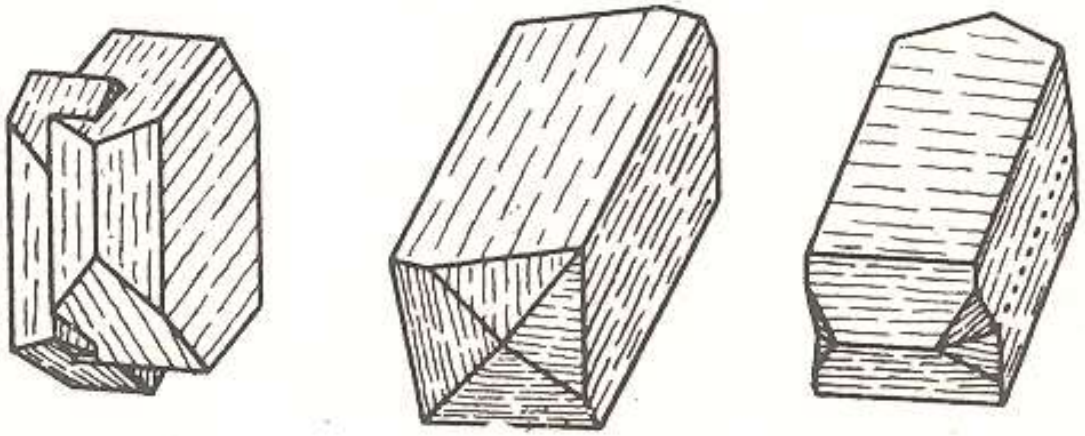


FIG. 88. Orthoclase Twins.

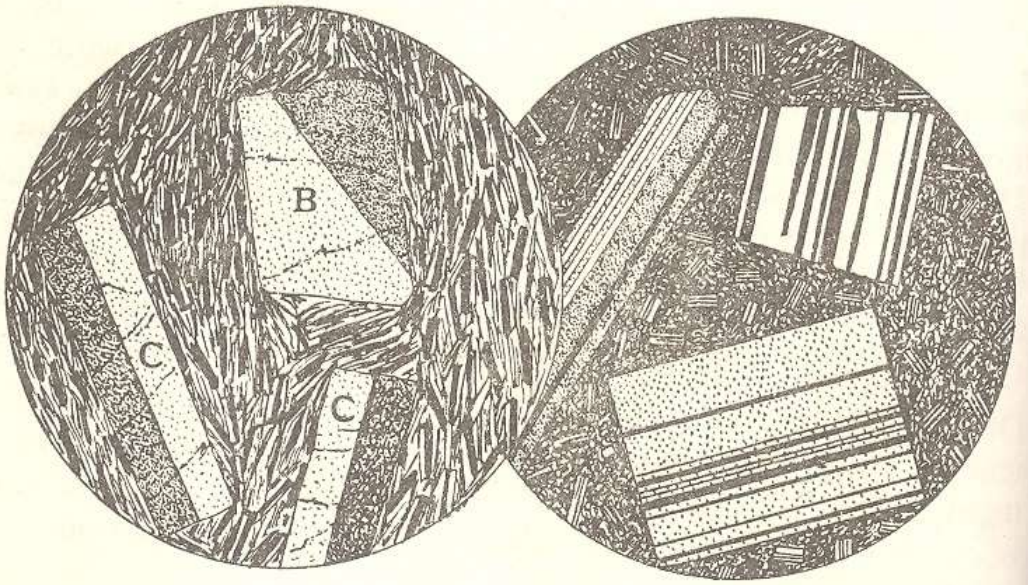


FIG. 144. Feldspars in thin section: Left, *orthoclase* showing Carlsbad twinning (C) and Baveno twinning (B); right, *plagioclase* showing Albite twinning—both figures between crossed nicols.

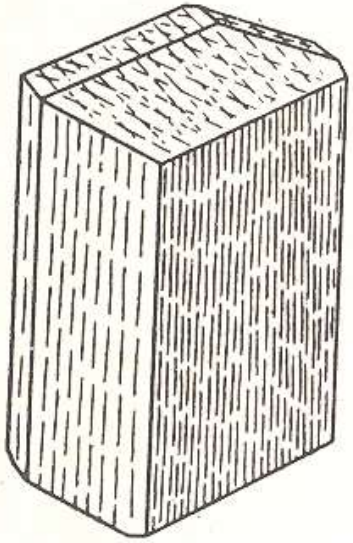


FIG. 139. Hornblende

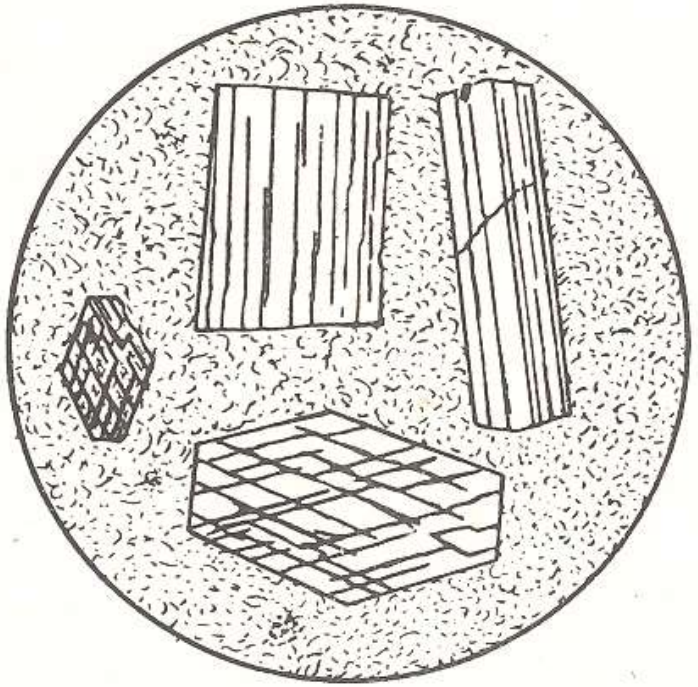
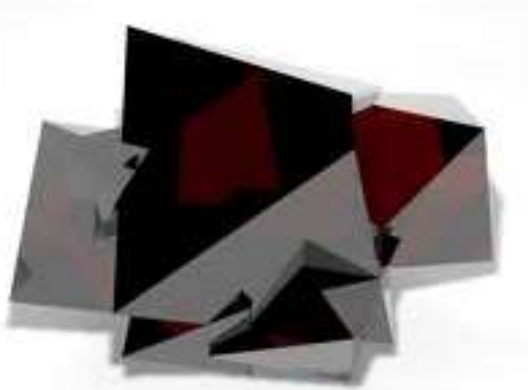


FIG. 140. Sections of hornblende, showing cleavages: above prismatic sections, below transverse section.

Imitative Shapes in Crystals

- Accidental imitative shapes – Presuppose an empty space, which has been filled up by the individuals of compound minerals to which is transferred the form of the pre-existing space. E.g. Implanted globular, reniform, botryoidal.
- Regular Accidental imitative shapes are also known as **Psudomorphoses** or **Supposititious**.
- Irregular Accidental imitative shapes – **Petrifaction**, **Tuberose**, …


Garnets



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H. Ph.: 94433 78145

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