Hugo Strunz
Ernest H. Nickel

Strunz Mineralogical Tables

Chemical Structural Mineral Classification System
9th Edition

E. Schweizerbart'sche Verlagsbuchhandlung
(Nägele u. Obermiller) Stuttgart

STRUNZ MINERALOGICAL TABLES

Chemical-Structural Mineral Classification System

Ninth Edition

by

Hugo Strunz and Ernest H. Nickel

with 226 figures

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Cover Diagram: A fragment of the crystal structure of sillénite – a framework composed of corner-sharing BiO_4 tetrahedra and flat BiO_5 pyramids.

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Preface to the First Edition

The chemical classification of minerals, begun by Berzelius and Rose, was developed into a comprehensive crystallographic-chemical classification over a period of about 100 years, especially by Naumann, Dana, Groth and Hintze, and has been published in well-known manuals and tables. The latest tabular summary, published by P. v. Groth and K. Mieleitner, appeared in 1921. The enormous progress in chemical crystallography since Laue's discovery (1912) requires that a fundamental revision of the current systematics should be undertaken.

It would be desirable to individually name all the authors who have provided the basics for constructing the new classification by their time-consuming X-ray and chemical investigations. However, their numbers are too large to permit this to be done in the available space; I can only point to the *Strukturbericht* of the *Zeitschrift für Kristallographie* with its numerous references and continuing editions. Special mention must be made of the authors Aminoff, W. L. Bragg, V. M. Goldschmidt, Gossner, Machatschki, Niggli, Palache, Pauling, Rinne and W. H. Taylor who, together with their co-workers, conducted outstanding mineralogical-chemical and structural studies. The names Ramdohr and Schneiderhöhn are notable for their contributions to ore microscopy.

In the course of time, incompletely investigated minerals may require reallocation in the system. Similarly, the occasional discredited mineral name may have to be revalidated. Such changes, however, will generally be restricted to the less common minerals, and those that can easily be shifted in collections. Because of the large volume of material in this volume, the occasional literature reference may be overlooked. The author would therefore appreciate all contributions from his professional colleagues and friends of mineralogy.

The development of the classification system grew from several early papers, at the invitation of the German Mineralogical Society.

Berlin, spring, 1941
H. Strunz

Translated, 1999
E. H. Nickel

Preface to the Fifth Edition

Exactly 300 years ago (1669), Nicolaus Steno discovered the law of constant interfacial angles in quartz, and Erasmus Bartholinus discovered the double refraction of light in calcite; about the same time, Robert Boyle (1661) defined the concept of chemical elements by qualitative mineral analyses.

Exactly 150 years ago (1819), Eilhard Mitcherlich discovered isomorphism, and at about the same time, Jakob Berzelius (1824) was the first to propose a chemical system of minerals. In the following years this system was extended by Gustav Rose, Dana, Groth and Hintze.

About 50 years ago (1912), Max von Laue discovered X-ray diffraction by crystals; with the application of the X-ray method to the determination of crystal structures, especially by William Henry Bragg and Sir Lawrence Bragg (since 1913), the development of crystallography took a new direction, thereby making an enormous impact on science and technology.

For the “Classification of Minerals”, crystal-structure determinations improved the definitions of mineral species and varieties, assisted in the development of the concept of crystal structure types, helped to establish isotypic series and homeotypic and heterotypic groups, and pointed to the recognition of much broader crystallochemical relationships. The X-ray method appreciably simplified the generally unique characterization of a mineral species and led to a reduction in varieties and the discreditation of many “minerals” accepted up to that time, thereby eliminating countless superfluous “mineral names”.

The idea of developing a “classification of minerals based on crystal chemistry” evolved between 1930 and 1940. The basic concepts of this classification, established in the first edition of *Mineralogische Tabellen* (1941) are still valid today, and have been progressively refined and adapted to conform to the latest revelations of structural research. In this 5th edition, 1745 minerals have been classified in tabular form, including the international name (with original author and year of publication), chemical formula, symmetry, lattice constants and cell content, with a brief explanation of the structure type, relationships, etc. In comparison with the fourth edition, 119 new mineral species have been added to the classification, and 55 additional mineral names have been temporarily incorporated into the text. It has not been necessary to make substantial revisions, although some sections of the oxides and silicates have been thoroughly reworked. The main part of the book, namely the actual classification with footnotes citing the original publications, is based on a critical documentation of all the mineral data of structural interest from 1912 to mid-1969.

About 400 varietal names that have been in use for centuries and are still current today (e. g. amethyst, ruby, sapphire, emerald) have been included in the text. Unfortunately it was felt necessary to retain about 300 names of poorly defined or inadequately characterized minerals; it is hoped that my professional colleagues will assist in cleansing the classification by providing more complete data or by completely discrediting such minerals.

To prevent the continuing proliferation of superfluous mineral names by uncritical publication, the *International Mineralogical Association* (IMA) has created a *Commission on New Minerals and Mineral Names* which undertakes regular voting; the chairman of this Commission, Dr. Michael Fleischer, deserves our heartfelt gratitude for his admirable work.

The introduction to the classification comprises an introduction to crystal chemistry, with definitions, rules, tables of crystallochemical importance, a summary of the classification principles, and a description of structure types that are regarded as essential to an understanding of the structural principles and systematics of minerals and of structural relationships between related minerals.

Following the main part of the book is a general index which lists the recognized names of species and varieties, as well as synonyms (more than 4000 in all), and which includes some brief explanations; this is followed by a formula index.

The author is pleased to express his appreciation and gratitude to the publisher and the printing establishment for the careful manner in which five editions of a complicated book have been typeset.

Berlin, 1 January, 1970
Hugo Strunz

Translated, 1999
Ernest H. Nickel

Preface to the 9th Edition

The chemical-structural mineral classification system developed since the first edition of *Mineralogische Tabellen* (1941) evolved from the chemical mineral system of Haüy (1801), which was based on cations, and of Berzelius (1814, 1824), based on anions, followed by the chemical-morphological system of Gustav Rose (1838, 1852), the periodic system of the chemical elements (cf. Introduction), and finally by the developing knowledge of atomic crystal structures (since Laue, 1912, Bragg, 1913).

The classification system used in the first, and subsequent editions of *Mineralogische Tabellen*, combines chemical features with structural principles, such as structure types, cation size and coordination numbers; minerals are generally arranged according to increasing cation size. A characteristic scheme of chemical formulae was introduced, as well as internationalized names, such as *neso*- to *tektosilicates*. International priority principles have always been acknowledged.

Since the last edition (1978), technological developments, such as improved electron microscopy (since Ernst Ruska, 1931), chemical analysis by microprobe (since Raymond Castaing, 1951), scanning electron microscopy (since Oatley & McMullan, 1952), automatic computer-controlled instrumentation and software for structure determination, have made it possible to carry out the chemical, structural, morphological and physical characterization of tiny particles of new minerals (on the scale of micrograms) within a few days or weeks; computerized structural and morphological drawings can be produced within minutes.

As a result, the number of minerals approved by the Commission on New Minerals & Mineral Names of the IMA (International Mineralogical Association) has grown from about 2500 in 1978 to about 4000 at present, with about 60 to 80 new minerals added each year.

In this edition, the world of minerals is divided by chemical features into ten classes, each of which is subdivided, on chemical-structural principles, into divisions, subdivisions, groups of isotypic and homeotypic minerals, or individual minerals with unique structure types; groups with two or more mineral names comprise minerals with similar structure or composition. The classification system and alphanumeric coding scheme used in this 9th edition of the *Strunz Mineralogical Tables* were presented at the 1994 IMA meeting in Pisa. They permit the insertion of thousands of new minerals in the future without changing the basic classification framework.

The authors gratefully acknowledge the contributions to this volume made by a number of mineralogical colleagues, particularly Emil Makovicky for helpful suggestions relating to the sulfide and sulfosalt classification, and Friedrich Liebau for constructive critical reading of the cyclo- and inosilicate portions of the manuscript. We also acknowledge the contribution made by Irmgard Stolle, Berlin, who provided assistance in the preparation of the manuscript.

This contribution to mineralogy is indebted to about seven generations of diligent and active researchers over a period of two hundred years. The authors welcome suggestions for improvements.

February 24th, 2001

Hugo Strunz
Berlin

Ernest H. Nickel
Perth (Wembley)

Contents

Introduction

1. ELEMENTS (Metals and intermetallic alloys; metalloids and nonmetals; carbides, silicides, nitrides, phosphides)

2. SULFIDES and SULFOSALTS (sulfides, selenides, tellurides; arsenides, antimonides, bismuthides; sulfarsenites, sulfantimonites, sulfbismuthites, etc.)

Sulfides, etc.

Sulfosalts

3. HALIDES

4. OXIDES (Hydroxides, $V^{[5,6]}$ vanadates, arsenites, antimonites, bismuthites, sulfites, selenites, tellurites, iodates)

5. CARBONATES (+ NITRATES)

6. BORATES

7. SULFATES (selenates, tellurates, chromates, molybdates, wolframates)

8. PHOSPHATES, ARSENATES, VANADATES

9. SILICATES (Germanates)

10. ORGANIC COMPOUNDS

INTRODUCTION

Historical Development

René Just Haüy (1743–1822), in his well-known four-volume work *Traité de Minéralogie* (Paris, 1801), classified minerals on the type of metals they contain, or, as he would say now, on the type of cations, or the electropositive principle.

Jöns Jacob Berzelius (1779–1848), the famous Swedish chemist who introduced chemical formulae into chemistry and mineralogy, classified minerals by the type of anion, *i. e.* the electronegative principle (1814, 1824).

With this background, together with the knowledge about the seven crystal systems (Christian Samuel Weiss, 1815), the recognition of isomorphy and polymorphy (Mitscherlich, 1819, 1824), and the triad rule of chemical elements (Döbereiner, 1829), Gustav Rose (1798–1873) developed a chemical-morphological mineral system (Berlin, 1838, 1852), which looks quite modern, even today:

Class I. ELEMENTS. A. Metals. Cubic: copper, silver, gold, iron, platinum, iridium. – Tetragonal: tin. – Rhombohedral and Hexagonal: arsenic, antimony, bismuth, tellurium, (Os, Ir). – B. Metalloids. Cubic: diamond. – Hexagonal: graphite. – Orthorhombic: sulfur, iodine. – Monoclinic: sulfur, selenium. – **Class II. SULFIDES. – Class III. HALIDES. – Class IV. OXIDES**, divided into **SIMPLE OXIDES** and **COMPLEX OXIDES**, such as **CARBONATES, PHOSPHATES, SILICATES, BORATES** and **SULFATES**.

This mineral system was a precursor to the important discovery of the Periodic System of the chemical elements developed independently by Dmitry Mendeleev and Lothar Meyer (1869). It influenced the further development of Rose's system, especially in the famous 6th edition of the System of Mineralogy by Dana (1892).

Differing from Rose, Paul Groth (1843–1927), Munich, 1912, "the world's most famous authority on crystallography" (Bragg, 1933), inserted the halides between the simple and complex oxides. This was followed by three important works: Hintze *et al.*: *Handbuch der Mineralogie* (1897–1971); Palache *et al.*: *The System of Mineralogy of Dana* (7th ed., 1944, 1951); Hey: *An Index of Mineral Species and Varieties, Arranged Chemically* (2 eds., 1950, 1975), followed by Clark: *Hey's Mineral Index* (3rd ed., 1993). More about this, with full references, has been given in recent publications.*

The discovery of the diffraction of X-rays by the space lattices of crystals (Max von Laue, 1912), and the resulting determination of crystal structures (W. H. and W. L. Bragg, since1913), enabled many more structures to be determined within the next decade and, by about 1933, the general rules governing atomic crystal structures were recognized.

By 1941 it was therefore possible to develop, in *Mineralogische Tabellen*, an extension of the Rose classification scheme, a comprehensive mineral system based on chemistry and structure, applied systematically to the entire mineral domain. Since then, *Min-*

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* H. Strunz, Lapis, 1994 (1), 56–60: Klassifikation der Sulfide (in German); Lapis-Extraedition, 1993: Classification of elements, sulfides, halides (in English), distributed by mail and at the IMA General Meeting in Pisa (1994). – N. Jahrb. Min. Mh., 1996, 435–445 (general historical survey, with references). – Eur. Journ. Min., 1997, 225–232 (borates). – H. Strunz & E. H. Nickel, Zap. Vses. Min. Ob. 1997 (5), 1–14 (tektosilicates).

eralogische Tabellen have gone through many editions, reprints and translations, some with co-author Christel Tennyson.

As this 9th edition was in preparation, two important works comprising all known mineral species were published: **Dana's New Mineralogy** (Gaines *et al.*, 1997) in which the classification is the same as that used in the seventh edition of Dana's System of Mineralogy, vols. 1 and 2 (1944, 1951) by Palache *et al.*, and vol. 3 (silica minerals) by Frondel (1960), except for the silicates which follow the well-known enlarged Bragg classification. The multi-volume **Handbook of Mineralogy** by Anthony *et al.*, vol. I, Elements, Sulfides, Sulfosalts (1990); vol. II, Silica, Silicates (1995), vol. III, Halides, Hydroxides, Oxides (1997); vol. IV, Phosphates, Arsenates, Vanadates (2000); the arrangement in this series is alphabetical by mineral name, and crystal structures are not considered. Also useful is the **Glossary of Mineral Species** (founded by Fleischer, 1971 and continued by Mandarino to 8th edition, 1999).

Chemical Bonding and Crystal Structures

Atoms are the smallest chemical entities of relevance to the crystal structures of minerals. They consist of a nucleus of **protons** and **neutrons** surrounded by a cloud of **electrons** that are constrained within energy levels or "shells". Within each shell, the electrons occupy particular **orbitals** designated by the symbols *s, p, d* and *f*. The *s* orbitals are the outermost ones for all elements, and have the highest energy. They have spherical symmetry and can accommodate two electrons. The *p* orbitals consist of three mutually perpendicular dumbbell-shaped clouds that can accommodate six electrons. The *d* and *f* orbitals have more complex configurations and can accommodate ten and fourteen electrons, respectively. Only the outer orbitals are involved in bonding between atoms, and the electron configurations of these orbitals are shown in the **Periodic System of the Elements** (Table, inside cover). The symbols *s, p,* etc. represent the orbitals, and the *n* on s^n, p^n gives the number of electrons in that orbital. [He], [Ne], etc. represent the stable shells according to the noble gases He, Ne, etc.

Also shown in this version of the Periodic Table is the atomic number of each element, which corresponds to the total number of electrons, and the atomic weight relative to the mass of C^{12} which has been assigned a mass of 12.000 (the atomic weight of carbon shown in the Periodic Table is slightly higher than this because of the additional presence of a small amount of the C^{13} isotope in natural carbon). The atomic weight represents the sum of the numbers of protons and neutrons in the nucleus of the atom. It has long been known that the elements in a vertical column have similar chemical properties because they have the same number of valence electrons. However, the lanthanides and actinides (except for thorium) shown at the bottom of the Table do not fit readily into this scheme because of the effect of *f* orbitals in the outer electron shells.

The electrons of adjoining atoms in a crystal structure interact in several different ways to form chemical bonds, generally classified into ionic, covalent and metallic types, although combinations of these idealized types commonly occur.

In **ionic bonding**, the outer electron(s) are transferred from an electropositive atom (resulting in a positively charged ion) to an electronegative atom (resulting in a negatively charged ion). The resulting ions, respectively termed cations and anions, are attracted to each other by electrostatic forces. The size of an ion depends to a first approximation on the atomic number, and secondarily on the number of electrons in the outer shell. The ionic radii of all the chemical elements is illustrated in the diagram on the inside back cover. In the classification scheme used in this book, the minerals within a group are arranged primarily according to increasing atomic number of the principal cations in the mineral, but those containing Mg^{2+}, Fe^{2+} and Mn^{2+} are arranged according to increasing ionic size, 0.72, 0.78, 0.83Å.

In **covalent bonding**, the orbitals of adjoining atoms interact. During this process, the orbitals are hybridized, and the immediate neighbourhood of the ion is strongly influenced by the electron configuration of this hybridization, resulting in strongly directional bonding. For example, one *s* and three *p* orbitals are commonly hybridized (sp^3) into the shape of a tetrahedron, as in $Si^{[4]}$. Another common polyhedral configuration in mineral structures is the octahedron, formed by the hybridization of one *s*, three *p* and two *d* orbitals, generally written as d^2sp^3. Examples of the main polyhedral configurations found in minerals are shown in Figure 3.

In **metallic bonding**, the outermost electrons of the atoms are delocalized, and can move about freely within the array of cations. Metals are characterized by their metallic luster, caused by the interaction of light with the electrons, and by good electrical conductivity because of the mobility of electrons within the structure.

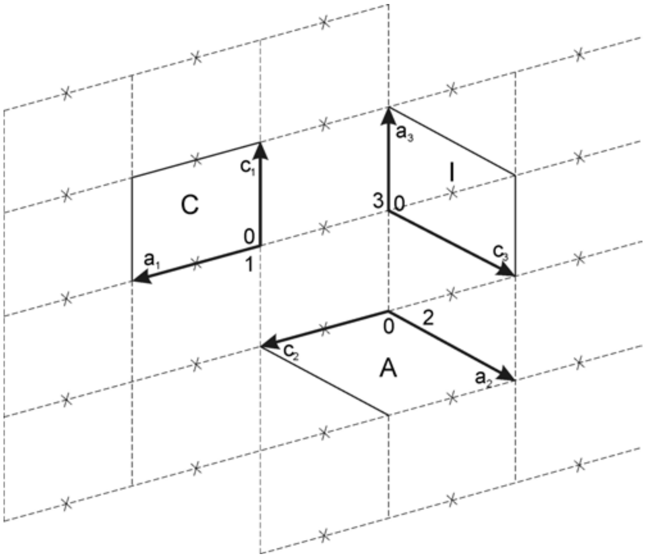


***Fig 1. Unit cell settings of a monoclinic crystal with centered Bravais lattice**: Setting 1 = C-centred; setting 2 = A-centred; setting 3 = I-centred. Projection on (010), the b-axis is normal to the plane of the drawing; the cell edges and full lines are at height b = 0; the stars are at height b = ½.*

The bonding between atoms creates three-dimensional crystal structures. These structures can be categorized by their inherent symmetry elements which have been formalized into 230 crystallographic **space groups** (Table 1). The relationship between the different settings of a monoclinic unit cell is illustrated in Fig. 1. The space groups can be derived by combining the 14 **translation types** (Fig. 2) of Bravais (1850) with all possible symmetry operations (Table 2). The relationship between space groups and **crystal classes** is shown in Table 3.

Table 1. Crystal Systems (names), Crystal Classes (symbols), Space Groups (numbers; short symbols for standard and other settings)

Triclinic		
Class	**No.**	**Symbol**
1	1	P1
$\bar{1}$	2	P$\bar{1}$

Normal setting of triclinic minerals: 1) Three shortest lattice parameters; 2) *c*[001] = axis of the main morphological zone; 3) α and β obtuse, γ acute; and 4) $a < b$.

Monoclinic		**Setting**		
Class	**No.**	$\mathbf{a_1\ b\ c_1}$ $\mathbf{c_1\ -b\ a_1}$	$\mathbf{a_2\ b\ c_2}$ $\mathbf{c_2\ -b\ a_2}$	$\mathbf{a_3\ b\ c_3}$ $\mathbf{c_3\ -b\ a_3}$
2	3	P2		
	4	$P2_1$		
	5	C2	A2	I2
m	6	Pm		
	7	Pc	Pn	Pa
	8	Cm	Am	Im
	9	Cc	An	Ia
		Aa	Cn	Ic
2/m	10	P2/m		
	11	$P2_1/m$		
	12	C2/m	A2/m	I2/m
	13	P2/c	P2/n	P2/a
	14	$P2_1/c$	$P2_1/n$	$P2_1/a$
	15	C2/c	A2/n	I2/a
		A2/a	C2/n	I2/c

Setting of monoclinic crystals: 1) a:b:c always with b as unique axis, β obtuse, in structure and morphology; 2) three shortest lattice parameters; 3) three choices of settings $\mathbf{a_1\ b\ c_1}$, $\mathbf{a_2\ b\ c_2}$ and $\mathbf{a_3\ b\ c_3}$ apply to both P and C Bravais lattices (P = uncentred unit cell; C = C-centred unit cell, demonstrated in Fig. 1 for a centred unit cell); $\mathbf{a_1}$ and $\mathbf{c_1}$, etc. can be exchanged, with -**b**; 4) the symmetry elements and their orientation in the chosen unit cell are derived from the "extinction conditions", and are expressed by the space group symbol. For further details see *International Tables for Crystallography* (Theo Hahn, ed.) Vol. A, 4th ed., 1996, and *Brief Teaching Edition of Vol. A* (Theo Hahn, ed.), 4th revised and enlarged edition, 1996, both published by The International Union of Crystallography. In the monoclinic system, for five space groups (nos. 3, 4, 6, 10 and 11), each setting choice gives the same space group symbol; for two space groups (nos. 9 and 15), six symbols; and for the others, three. The symbol in the first lines and first columns of the tabulations are the "standard short symbols", with the "standard settings", *e.g.* , for no. 5: C2, for no. 7: Pc, etc.

Orthorhombic				
Class	**No.**	**a b c** **a -c b**	**c a b** **b a -c**	**b c a** **-c b a**
222	16	P222		
	17	$P222_1$	$P2_122$	$P22_12$
	18	$P2_12_12$	$P22_12_1$	$P2_122_1$
	19	$P2_12_12_1$		
	20	$C222_1$	$A2_122$	$B22_12$
	21	C222	A222	B222
	22	F222		
	23	I222		
	24	$I2_12_12_1$		
mm2	25	Pmm2	P2mm	Pm2m
	26	$Pmc2_1$	$P2_1ma$	$Pb2_1m$
		$Pm2_1b$	$Pcm2_1$	$P2_1am$
	27	Pcc2	P2aa	Pb2b
	28	Pma2	P2mb	Pc2m
		Pm2a	Pbm2	P2cm
	29	$Pca2_1$	$P2_1ab$	$Pc2_1b$
		$Pb2_1a$	$Pbc2_1$	$P2_1ca$
	30	Pnc2	P2na	Pb2n
		Pn2b	Pcn2	P2an
	31	$Pmn2_1$	$P2_1mn$	$Pn2_1m$
		$Pm2_1n$	$Pnm2_1$	$P2_1nm$
	32	Pba2	P2cb	Pc2a
	33	$Pna2_1$	$P2_1nb$	$Pc2_1n$
		$Pn2_1a$	$Pbn2_1$	$P2_1cn$
	34	Pnn2	P2nn	Pn2n
	35	Cmm2	A2mm	Bm2m
	36	$Cmc2_1$	$A2_1ma$	$Bb2_1m$
		$Bm2_1b$	$Ccm2_1$	$A2_1am$
	37	Ccc2	A2aa	Bb2b
	38	Amm2	B2mm	Cm2m
		Am2m	Bmm2	C2mm
	39	Abm2	B2cm	Cm2a
		Ac2m	Bma2	C2mb
	40	Ama2	B2mb	Cc2m
		Am2a	Bbm2	C2cm
	41	Aba2	B2cb	Cc2a
		Ac2a	Bba2	C2cb
	42	Fmm2	F2mm	Fm2m
	43	Fdd2	F2dd	Fd2d
	44	Imm2	I2mm	Im2m
	45	Iba2	I2cb	Ic2a
	46	Ima2	I2mb	Ic2m
		Im2a	Ibm2	I2cm

Setting of orthorhombic crystals: 1) three shortest lattice parameters, with $a:b:c$ in agreement with morphology; 2) six choices of settings, **a b c** (first line, first column, standard setting), **c a b** (first line, second column), etc.; transformation **a b c** → **c a b** means that the new **a**-axis corresponds to the old **c**, the new **b** is the old **a**, and the new **c** is the old **b**, etc., and *vice versa*; 4) if, for example, for a chosen unit cell, the "extinction conditions" give a space group symbol C2mm, the transformation **-c b a** → **a b c** gives the standard space group symbol *Amm*2 (no. 38). Further details are given in the *International Tables for Crystallography*, Vol. A (1983, 1996).

In the orthorhombic system, for ten space groups (Nos. 16, 19, 22, etc.), each setting gives the same space group symbol; for two space groups, (Nos. 61, 73) two symbols, for the others three or six.

Setting of orthorhombic crystals: continued

Orthorhombic (continued)

Class	No.	a b c a -c b	c a b b a -c	b c a -c b a
mmm	47	Pmmm		
	48	Pnnn		
	49	Pccm	Pmaa	Pbmb
	50	Pban	Pncb	Pcna
	51	Pmma	Pbmm	Pmcm
		Pmam	Pmmb	Pcmm
	52	Pnna	Pbnn	Pncn
		Pnan	Pnnb	Pcnn
	53	Pmna	Pbmn	Pncm
		Pman	Pnmb	Pcnm
	54	Pcca	Pbaa	Pbcb
		Pbab	Pccb	Pcaa
	55	Pbam	Pmcb	Pcma
	56	Pccn	Pnaa	Pbnb
	57	Pbcm	Pmca	Pbma
		Pcmb	Pcam	Pmab
	58	Pnnm	Pmnn	Pnmn
	59	Pmmn	Pnmm	Pmnm
	60	Pbcn	Pnca	Pbna
		Pcnb	Pcan	Pnab
	61	Pbca		
		Pcab		
	62	Pnma	Pbnm	Pmcn
		Pnam	Pmnb	Pcmn
	63	Cmcm	Amma	Bbmm
		Bmmb	Ccmm	Amam
	64	Cmca	Abma	Bbcm
		Bmab	Ccmb	Acam
	65	Cmmm	Ammm	Bmmm
	66	Cccm	Amaa	Bbmb
	67	Cmma	Abmm	Bmcm
		Bmam	Cmmb	Acmm
	68	Ccca	Abaa	Bbcb
		Bbab	Cccb	Acaa
	69	Fmmm		
	70	Fddd		
	71	Immm		
	72	Ibam	Imcb	Icma
	73	Ibca		
		Icab		
	74	Imma	Ibmm	Imcm
		Imam	Immb	Icmm

Tetragonal

Class	**No.**	**Symbol**
4	75	P4
	76	$P4_1$
	77	$P4_2$
	78	$P4_3$
	79	I4
	80	$I4_1$
$\bar{4}$	81	$P\bar{4}$
	82	$I\bar{4}$
4/m	83	P4/m
	84	$P4_2/m$
	85	P4/n
	86	$P4_2/n$
	87	I4/m
	88	$I4_1/a$
422	89	P422
	90	$P42_12$
	91	$P4_122$
	92	$P4_12_12$
	93	$P4_222$
	94	$P4_22_12$
	95	$P4_322$
	96	$P4_32_12$
	97	I422
	98	$I4_122$
4mm	99	P4mm
	100	P4bm
	101	$P4_2cm$
	102	$P4_2nm$
	103	P4cc
	104	P4nc
	105	$P4_2mc$
	106	$P4_2bc$
	107	I4mm
	108	I4cm
	109	$I4_1md$
	110	$I4_1cd$

Tetragonal (continued)

Class	**No.**	**Symbol**
$\bar{4}2m$	111	$P\bar{4}2m$
	112	$P\bar{4}2c$
	113	$P\bar{4}2_1m$
	114	$P\bar{4}2_1c$
	115	$P\bar{4}m2$
	116	$P\bar{4}c2$
	117	$P\bar{4}b2$
	118	$P\bar{4}n2$
	119	$I\bar{4}m2$
	120	$I\bar{4}c2$
	121	$I\bar{4}2m$
	122	$I\bar{4}2d$
4/mmm	123	P4/mmm
	124	P4/mcc
	125	P4/nbm
	126	P4/nnc
	127	P4/mbm
	128	P4/mnc
	129	P4/nmm
	130	P4/ncc
	131	$P4_2/mmc$
	132	$P4_2/mcm$
	133	$P4_2/nbc$
	134	$P4_2/nnm$
	135	$P4_2/mbc$
	136	$P4_2/mnm$
	137	$P4_2/nmc$
	138	$P4_2/ncm$
	139	I4/mmm
	140	I4/mcm
	141	$I4_1/amd$
	142	$I4_1/acd$

Trigonal		
Class	**No.**	**Symbol**
3	143	P3
	144	$P3_1$
	145	$P3_2$
	146	R3
$\bar{3}$	147	$P\bar{3}$
	148	$R\bar{3}$
32	149	P312
	150	P321
	151	$P3_112$
	152	$P3_121$
	153	$P3_212$
	154	$P3_221$
	155	R32
3m	156	P3m1
	157	P31m
	158	P3c1
	159	P31c
	160	R3m
	161	R3c
$\bar{3}$m	162	$P\bar{3}1m$
	163	$P\bar{3}1c$
	164	$P\bar{3}m1$
	165	$P\bar{3}c1$
	166	$R\bar{3}m$
	167	$R\bar{3}c$

Hexagonal		
Class	**No.**	**Symbol**
6	168	P6
	169	$P6_1$
	170	$P6_5$
	171	$P6_2$
	172	$P6_4$
	173	$P6_3$
$\bar{6}$	174	$P\bar{6}$
6/m	175	P6/m
	176	$P6_3/m$
622	177	P622
	178	$P6_122$
	179	$P6_522$
	180	$P6_222$
	181	$P6_422$
	182	$P6_322$
6mm	183	P6mm
	184	P6cc
	185	$P6_3cm$
	186	$P6_3mc$
$\bar{6}$m2	187	$P\bar{6}m2$
	188	$P\bar{6}c2$
	189	$P\bar{6}2m$
	190	$P\bar{6}2c$
6/mmm	191	P6/mmm
	192	P6/mcc
	193	$P6_3/mcm$
	194	$P6_3/mmc$

Cubic

Class	**No.**	**Symbol**
23	195	P23
	196	F23
	197	I23
	198	$P2_13$
	199	$I2_13$
$m\bar{3}$	200	$Pm\bar{3}$
	201	$Pn\bar{3}$
	202	$Fm\bar{3}$
	203	$Fd\bar{3}$
	204	$Im\bar{3}$
	205	$Pa\bar{3}$
	206	$Ia\bar{3}$
432	207	P432
	208	$P4_232$
	209	F432
	210	$F4_132$
	211	I432
	212	$P4_332$
	213	$P4_132$
	214	$I4_132$
$\bar{4}3m$	215	$P\bar{4}3m$
	216	$F\bar{4}3m$
	217	$I\bar{4}3m$
	218	$P\bar{4}3n$
	219	$F\bar{4}3c$
	220	$I\bar{4}3d$
$m\bar{3}m$	221	$Pm\bar{3}m$
	222	$Pn\bar{3}n$
	223	$Pm\bar{3}n$
	224	$Pn\bar{3}m$
	225	$Fm\bar{3}m$
	226	$Fm\bar{3}c$
	227	$Fd\bar{3}m$
	228	$Fd\bar{3}c$
	229	$Im\bar{3}m$
	230	$Ia\bar{3}d$

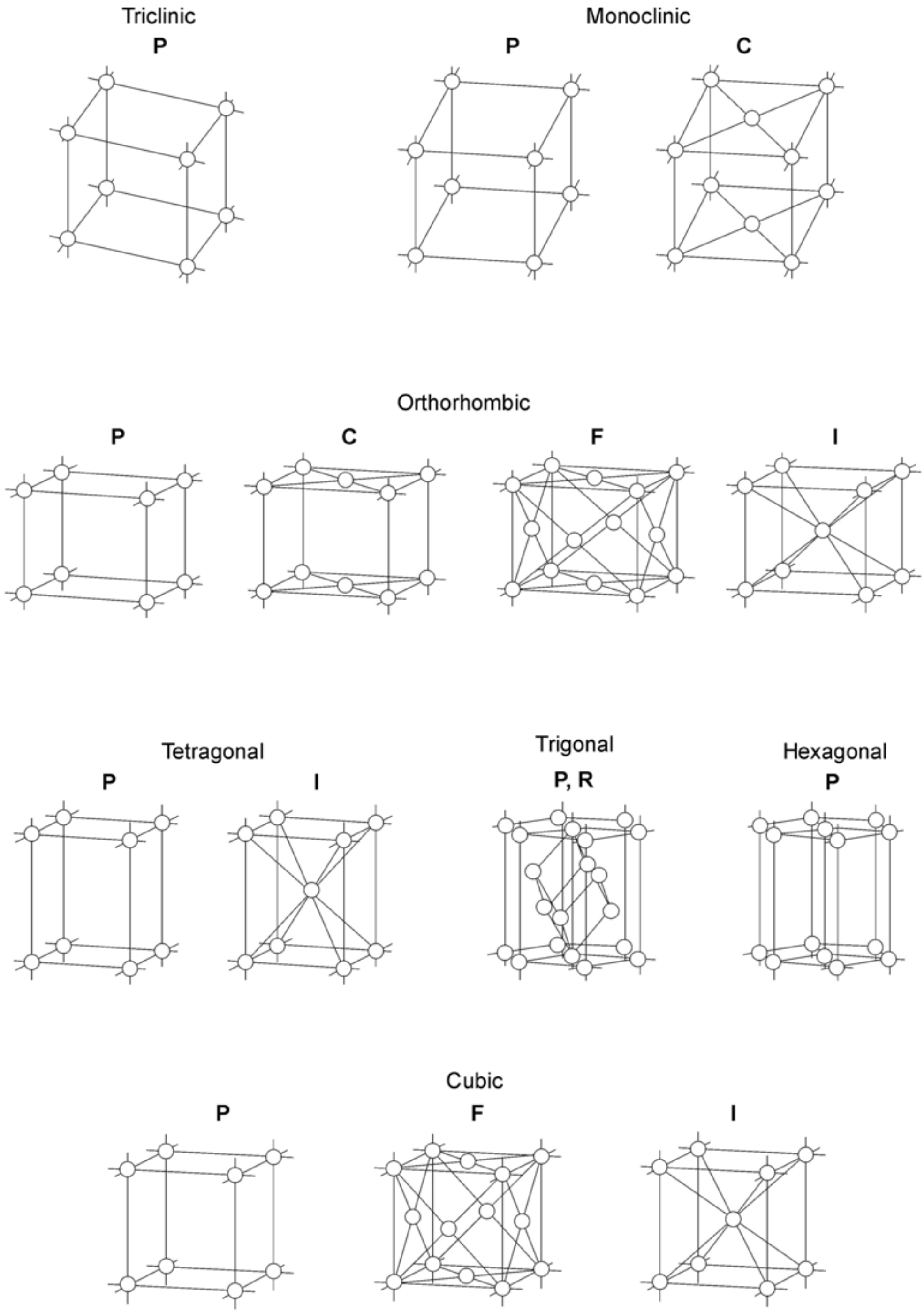


Fig 2. The 14 three-dimensional translation lattice types (Bravais, 1850). *P = primitive; C = c-face centred, F = all face centred, R = rhombohedral (crystals in the 7 rhombohedral space groups are described in relation to hexagonal axes).*

Table 2. Symmetry Operations
Possible symmetry operations which, in combination with the 14 translation lattices, give the 230 space groups. For example, space group no. 62: Pbnm means P = primitive translation lattice; b = axial glide plane // (100) with glide vector b/2; n = diagonal glide plane // (010) with diagonal glide vector a/2 + c/2; m = mirror plane // (001) (see chrysoberyl, triphylite, olivine).

Rotation Axes	Screw Axes	Inversion Axes
1	–	$\bar{1} \equiv i$
2	2_1	$\bar{2} \equiv m$
3	3_1, 3_2	$\bar{3} \equiv 3 + i$
4	4_1, 4_2, 4_3	$\bar{4}$
6	6_1, 6_2, 6_3, 6_4, 6_5	$\bar{6} \equiv 3/m$

Symmetry Planes	Symbol	Glide Vector
Mirror Plane	m	0
Axial Glide Planes	a b c	a/2 b/2 c/2
Diagonal Glide Planes	n	a/2 + b/2 or a/2 + c/2 or b/2 + c/2
Diamond Glide Plane	d	a/4 + b/4 + c/4

Table 3. Crystal Systems, Classes, Space Groups

Crystal System	**Crystal Class**		**Laue Class****	**Range of Space Groups**	
	Names	**Sym-bols***		**Nos.**	**Symbols**
Triclinic	Triclinic-pedial (asymmetric)	1	–	1	P1
	Triclinic-pinacoidal	$\bar{1}$	+	2	P$\bar{1}$
Monoclinic	Monoclinic-sphenoidal	2	–	3–5	P2 – C2
	Monoclinic-domatic	m	–	6–9	Pm – Cc
	Monoclinic-prismatic	2/m	+	10–15	P2/m – C2/c
Orthorhombic	Orthorhombic-disphenoidal	222	–	16–24	P222 – $I2_12_12_1$
	Orthorhombic-pyramidal	mm2	–	25–46	Pmm2 – Ima2
	Orthorhombic-dipyramidal	mmm	+	47–74	Pmmm – Imma

Table 3. Continued

Crystal System	Crystal Class		Laue Class**	Range of Space Groups	
	Names	Symbols*		Nos.	Symbols
Tetragonal	Tetragonal-pyramidal	4	–	75–80	P4 – $I4_1$
	Tetragonal-disphenoidal	$\bar{4}$	–	81–82	$P\bar{4}$ – $I\bar{4}$
	Tetragonal-dipyramidal	4/m	+	83–88	P4/m – $I4_1/a$
	Tetragonal-trapezohedral	422	–	89–98	P422 – $I4_122$
	Ditetragonal-pyramidal	4mm	–	99–110	P4mm – $I4_1cd$
	Tetragonal-scalenohedral	$\bar{4}2m$	–	111–122	$P\bar{4}2m$ – $I\bar{4}2d$
	Ditetragonal-dipyramidal	4/mmm	+	123–142	P4/mmm – $I4_1/acd$
Trigonal	Trigonal-pyramidal	3	–	143–146	P3 – R3
	Trigonal-rhombohedral	$\bar{3}$	+	147–148	$P\bar{3}$ – $R\bar{3}$
	Trigonal-trapezohedral	32	–	149–155	P312 – R32
	Ditrigonal-pyramidal	3m	–	156–161	P3m1 – R3c
	Trigonal-scalenohedral	$\bar{3}m$	+	162–167	$P\bar{3}1m$ – $R\bar{3}c$
Hexagonal	Hexagonal-pyramidal	6	–	168–173	P6 – $P6_3$
	Trigonal-dipyramidal	$\bar{6}$	–	174	$P\bar{6}$
	Hexagonal-dipyramidal	6/m	+	175–176	P6/m – $P6_3/m$
	Hexagonal-trapezohedral	622	–	177–182	P622 – $P6_322$
	Dihexagonal-pyramidal	6mm	–	183–186	P6mm – $P6_3mc$
	Ditrigonal-dipyramidal	$\bar{6}m2$	–	187–190	$P\bar{6}m2$ – $P\bar{6}2c$
	Dihexagonal-dipyramidal	6/mmm	+	191–194	P6/mmm – $P6_3/mmc$
Cubic	Cubic-tetartoidal	23	–	195–199	P23 – $I2_13$
	Cubic-disdodecahedral	$m\bar{3}$	+	200–206	$Pm\bar{3}$ – $Ia\bar{3}$
	Cubic-gyroidal	432	–	207–214	P432 – $I4_132$
	Cubic-hex'tetrahedral	$\bar{4}3m$	–	215–220	$P\bar{4}3m$ – $I\bar{4}3d$
	Cubic-hex'octahedral	$m\bar{3}m$	+	221–230	$Pm\bar{3}m$ – $Ia\bar{3}d$

* The class symbols can be derived from the space group symbols by deleting the Bravais symbols (P, C, etc.), dropping all subscripts from screw axes ($2_1, 3_1, 4_1$, etc. → 2, 3, 4, etc.) and replacing all glide plane symbols by the mirror plane symbol, m. Thus $I4_1/acd$ becomes 4/mmm. A slash means perpendicularity of a rotational element and a reflection element.

** The 11 Laue Classes, indicated by +, summarize the preceding classes by introducing an inversion center. Inversion center: – no, + yes.

Crystal systems and crystal axes: C. S. Weiss (1815).
Crystal classes: J. F. C. Hessel (1830); Class names: P. v. Groth (1905), modified in *Min. Tab.* (1941).
Space groups: E. S. v. Fedorov (1891); A. M. Schoenflies (1891).
Laue classes: M. v. Laue (1912); Friedel's Law (1913).
Class and space groups (short) symbols: C. Hermann & C. Mauguin (1935), standard settings. Symbols according to *International Tables for Crystallography* (1996).

Definitions

Crystals. Crystals are solids with a three-dimensional lattice arrangement of atoms, ions or molecules. Ideas about this were independently expressed by Johannes Kepler (1611) in a paper on hexagonal snow crystals, by Christiaan Huygens (1690) in his fundamental work on the wave theory of optics, wherein he ascribed to calcite a structure made up of ellipsoidal particles, by Torbern Olof Bergman (1773), and especially by René Just Haüy (1782) who suggested that all crystals consist of a three-dimensional masonry of equal parallelepipedal building bricks, the “molécules intégrantes” which have the form of tiny cleavage rhombohedra in calcite, and which express the laws governing the symmetry of crystals.

Ludwig August Seeber, a physicist in Freiburg, in his “Erklärung des Baues fester Körper” (1824), in an attempt to find an explanation for the thermal expansion and elasticity of crystals, arrived at a parallelepipedal arrangement, formed by the balance of temperature-dependent attractive and repulsive forces of indivisible parts of matter, thus forming a theory of stable equilibrium in crystals. Max von Laue said that such an arrangement implies a primitive translation lattice (Historical Introduction: *International Tables for X-ray Crystallography*, 1952).

Minerals. A mineral substance is generally regarded as a naturally occurring solid that has been formed by geochemical or geophysical processes, either on earth or in extraterrestrial bodies. Most minerals occur as crystals, and frequently have an external morphology that is a function of the internal arrangement of atoms comprising the crystal.

A mineral species is a mineral substance with well-defined chemical composition and crystallographic properties, and which merits a unique name.

Isotypy. Isotypic substances are those that have the same crystallographic space group and analogous chemical formulae and crystal structures. The terms “isostructural” and “isomorphic” are essentially synonymous with “isotypic”.

Homeotypy. Homeotypic substances are those that have similar crystal structures, but with different crystallographic space groups and/or chemical compositions.

Heterotypy. Heterotypic substances are chemically related, but have different chemical compositions and structures.

Polymorphism. Polymorphs are substances with essentially identical compositions, but with different crystal structures.

Polytypism. Polytypes are substances that occur in different structural modifications, each of which can be regarded as being built up by the stacking of layers of (nearly) identical structure and composition, and with the modifications differing only in their stacking sequence.

Diadochy. This refers to the substitution of a chemical element by another one in a crystal lattice, leaving the basic structure unchanged, except for relatively minor variations in the unit-cell parameters. If the substitution occurs over a wide compositional range, such a range is commonly referred to as an isomorphous series or a solid-solution series.

Coupled Replacement. This occurs when two or more chemical elements with different valencies are replaced by other chemical elements that maintain electrostatic neutrality in the crystal.

Coordination. The number of anions surrounding the specified cation in a crystal structure is referred to as the coordination number, and is shown as a numerical digit in square brackets, e. g. [6]; in a chemical formula this symbol is shown as a superscript immediately following the element symbol. The configuration of the coordinating ions is commonly referred to in terms of a polyhedral form; the more common of which are shown in Fig. 3.

The Data in the Tabulations

Each mineral group (or sometimes single mineral) is given an alphanumeric coding, which is explained below in "The Classification System". When the crystal structure is known, a brief description is given, sometimes accompanied by an illustration. Within a group, each mineral is listed by name, chemical formula, space group designation (and number), the author(s) of the original description, crystallographic parameters and unit-cell contents (Z). One or more references relating to the data are given, with the structural reference(s) indicated by a following "(str)".

The chemical formulae are generally end-member formulae, but major substitutions are commonly indicated within round brackets, in decreasing order of abundance. In the first edition of *Mineralogische Tabellen* (1941), a method of writing chemical formulae was introduced whereby subsidiary anions (F,O,OH) were positioned before the complex anions, with both enclosed in square brackets, e. g. *fluorapatite* $Ca_5[F|(PO_4)_3]$, *euchroite* $Cu_2[OH|AsO_4] \cdot 3H_2O$. This procedure was adopted for reasons of specified bonding strength, as all valence electrons of the subsidiary anions are used in bonding to the cations, whereas only a fraction of the valency electrons of the oxygens of the complex ions are involved in bonding to the cations.

Space groups and unit-cell parameters are generally as taken from the published literature, but some have been transformed into alternative settings to maintain consistency within a group or to conform with traditional morphological descriptions.

The Classification System

In this first English edition of *Mineralogical Tables*, the world of minerals is divided by chemical features into 10 Classes which are subdivided on chemical-structural principles, into Divisions, Subdivisions and Groups of isotypic or homeotypic species, or individual minerals of a unique structure type. Groups with a heading containing more than one mineral name include two or more heterotypes of usually unknown structures. Related groups may be designated a Family.

Because of the great diversity of bonding types exhibited by minerals, a variety of criteria has been used to classify minerals within a Class. Some minerals, like the borates and silicates, can be classified mainly on the basis of crystal structure, *ie* the degree of polymerization of the anionic polyhedra. Other minerals, such as the sulfides and oxides,

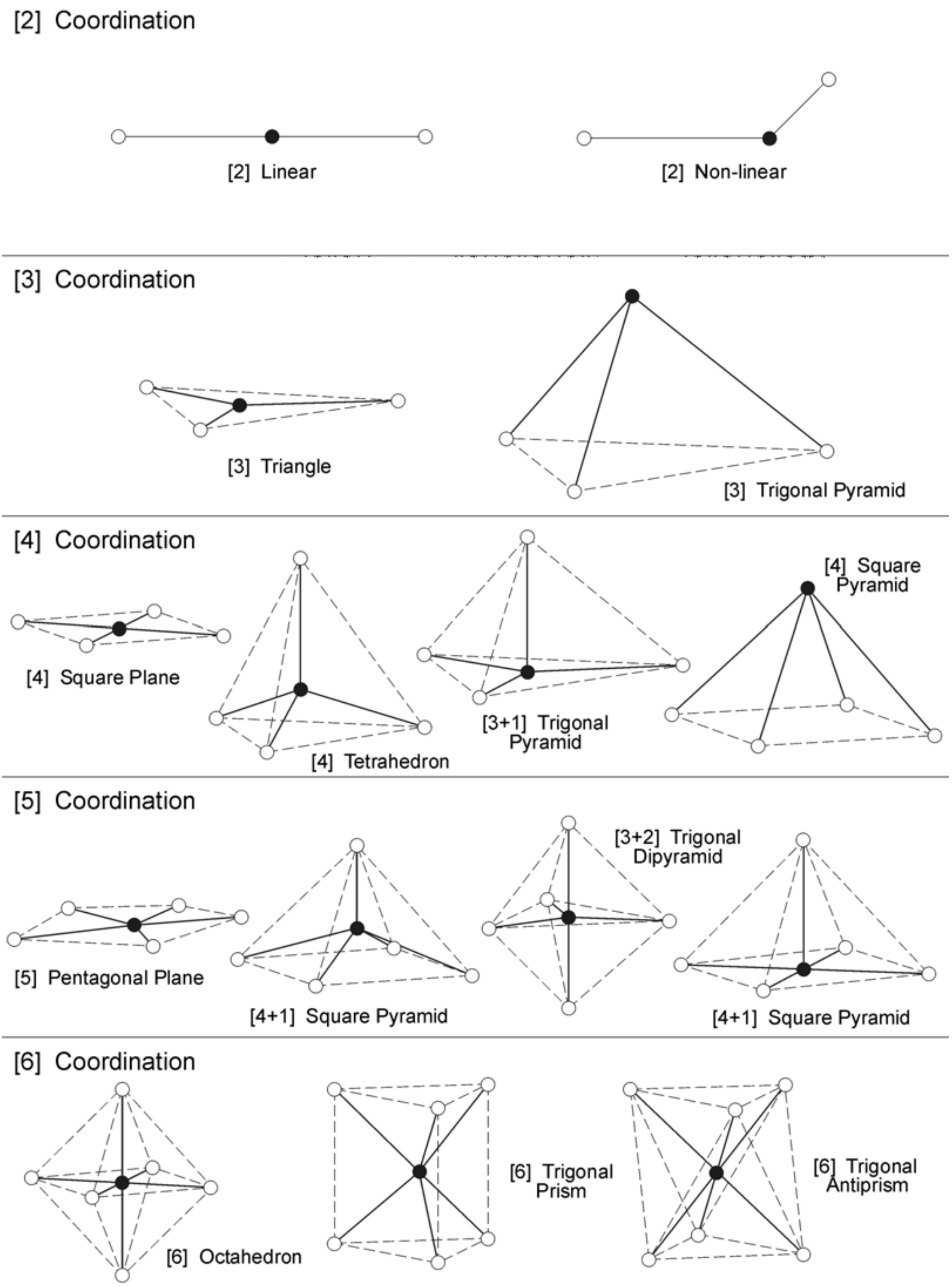
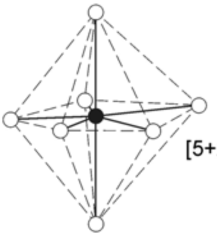
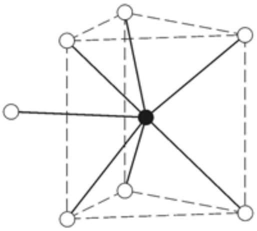


***Fig 3. The more common coordination polyhedra**. The black circle represents the central cation; the white circles represent the coordinating anions; cation-anion bonds are shown as solid lines, and polyhedral forms as dashed lines.*

[7] Coordination

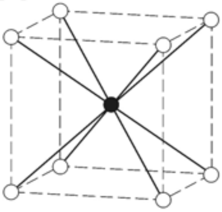


[5+2] Pentagonal Dipyramid

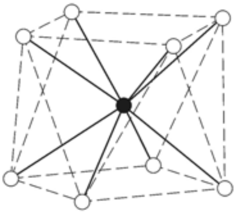


[3+3+1] Monocapped Trigonal Prism

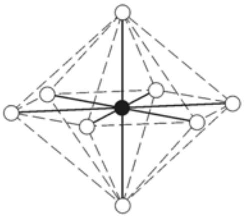
[8] Coordination



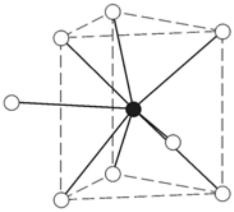
[8] Cube (Hexahedron)



[8] Square Antiprism

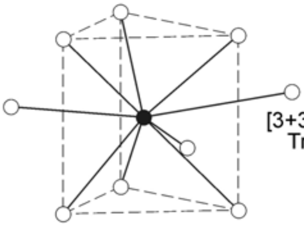


[6+2] Hexagonal Dipyramid

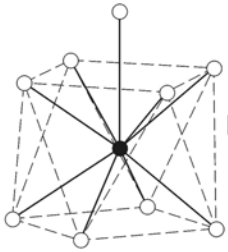


[3+3+2] Bicapped Trigonal Prism

[9] Coordination

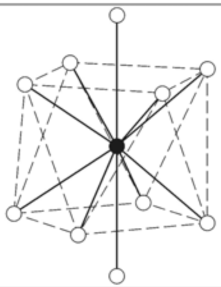


[3+3+3] Tricapped Trigonal Prism



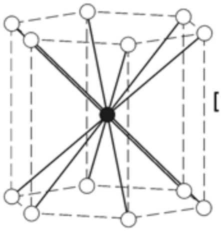
[4+4+1] Monocapped Square Antiprism

[10] Coordination

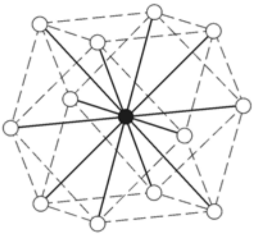


[4+4+2] Bicapped Square Antiprism

[12] Coordination



[12] Hexagonal Prism



[12] Cubooctahedron

can be conveniently grouped according to cation:anion ratio. Still others, such as halides, carbonates, sulfates and phosphates, are classified primarily on the presence or absence of OH and H_2O. The principal motive underlying the classification scheme is to provide a convenient framework to which all minerals can be readily allocated.

An alphanumeric coding scheme, from 1.AA.05 to 1.AA.10 …, etc., encompasses groups rather than individual minerals (as done by Hölzel, 1989). In this scheme, the first numeric digit represents a Class, the first alphabetic character represents a Division, and the second alphabetic character represents a Subdivision. The final two numeric digits represent a Group or individual mineral. In future, new minerals, isotypic or homeotypic with those of known structures can be inserted into an existing group; new minerals with a new structure type can be inserted into the gaps between existing group numbers.

It is hoped that the small number of classes, the logical classification principles, the specific rendition of chemical formulae, and the alphanumeric coding scheme make it relatively easy for scientists and friends of mineralogy to keep the entire system in mind.

Summary of System

1. ELEMENTS (Metals and intermetallic alloys; metalloids and nonmetals; carbides, silicides, nitrides, phosphides)

1.A: Metals and Intermetallic Alloys
    1.AA. Copper-cupalite family
    1.AB. Zinc-brass family
    1.AC. Indium-tin family
    1.AD. Mercury-amalgam family
    1.AE. Iron-chromium family
    1.AF. Platinum group elements
    1.AG. PGE-metal alloys
1.B: Metallic Carbides, Silicides, Nitrides and Phosphides
    1.BA. Carbides
    1.BB. Silicides
    1.BC. Nitrides
    1.BD. Phosphides
1.C: Metalloids and Nonmetals
    1.CA. Arsenic group elements
    1.CB. Carbon-silicon family
    1.CC. Sulfur-selenium-iodine
1.D: Nonmetallic Carbides and Nitrides
    1.DA. Nonmetallic carbides
    1.DB. Nonmetallic nitrides

2. SULFIDES and SULFOSALTS (sulfides, selenides, tellurides; arsenides, antimonides, bismuthides; sulfarsenites, sulfantimonites, sulfbismuthites, etc.)

Sulfides, etc.

2.A: Metal/metalloid alloys

- 2.AA. Alloys of metalloids with Cu, Ag, Au
- 2.AB. Ni-metalloid alloys
- 2.AC. Alloys of metalloids with PGE

2.B: Metal Sulfides, M:S $>$ 1:1 (mainly 2:1)
- 2.BA. With Cu, Ag, Au
- 2.BB. With Ni
- 2.BC. With Rh, Pd, Pt, etc.
- 2.BD. With Hg, Tl
- 2.BE. With Pb (Bi)

2.C: Metal Sulfides, M:S = 1:1 (and similar)
- 2.CA. With Cu
- 2.CB. With Zn, Fe, Cu, Ag, etc.
- 2.CC. With Ni, Fe, Co, etc.
- 2.CD. With Sn, Pb, Hg, etc.

2.D: Metal Sulfides, M:S = 3:4 and 2:3
- 2.DA. M:S = 3:4
- 2.DB. M:S = 2:3
- 2.DC. Variable M:S

2.E: Metal Sulfides, M:S $\leq$ 1:2
- 2.EA. M:S = 1:2, with Cu, Ag, Au; Ni, Sn, PGE; Mo, W
- 2.EB. M:S = 1:2, with Fe, Co, Ni, PGE, etc.
- 2.EC. M:S = 1: $>$2

2.F: Sulfides of arsenic, alkalies; sulfides with halide, oxide, hydroxide, H_2O.
- 2.FA. With As, (Sb), S
- 2.FB. With alkalies (without Cl, etc.)
- 2.FC. With Cl, Br, I (halide-sulfides)
- 2.FD. With O, OH, H_2O

Sulfosalts

2.G: Sulfarsenites, sulfantimonites, sulfbismuthites
- 2.GA. Neso-sulfarsenites, etc. without additional S
- 2.GB. Neso-sulfarsenites, etc. with additional S
- 2.GC. Poly-sulfarsenites
- 2.GD. Unclassified sulfosalts

2.H: Sulfosalts of SnS archetype
- 2.HA. With Cu, Ag, Fe (without Pb)
- 2.HB. With Cu, Ag, Fe, Sn and Pb
- 2.HC. With only Pb
- 2.HD. With Tl
- 2.HE. With alkalies, H_2O
- 2.HF. With SnS and PbS archetype structure units

2.J: Sulfosalts of PbS archetype
- 2.JA. Chains, combined into sheets
- 2.JB. Galena derivatives, with Pb
- 2.JC. Galena derivatives, with Tl

2.K: Sulfarsenates

3. HALIDES

- 3.A: Simple halides, without H_2O
  - 3.AA. M:X = 1:1 and 2:3
  - 3.AB. M:X = 1:2
  - 3.AC. M:X = 1:3
- 3.B: Simple halides, with H_2O
  - 3.BA. M:X = 1:1 and 2:3
  - 3.BB. M:X = 1:2
  - 3.BC. M:X = 1:3
  - 3.BD. Simple halides with H_2O and additional OH
- 3.C: Complex halides
  - 3.CA. Borofluorides
  - 3.CB. Neso-aluminofluorides
  - 3.CC. Soro-aluminofluorides
  - 3.CD. Ino-aluminofluorides
  - 3.CE. Phyllo-aluminofluorides
  - 3.CF. Tekto-aluminofluorides
  - 3.CG. Aluminofluorides with CO_3, SO_4, PO_4
  - 3.CH. Silicofluorides
  - 3.CJ. With MX_6 complexes; M = Fe, Mn, Cu
- 3.D: Oxyhalides, hydroxyhalides and related double halides
  - 3.DA. With Cu, etc., without Pb
  - 3.DB. With Pb, Cu, etc.
  - 3.DC. With Pb (As, Sb, Bi), without Cu
  - 3.DD. With Hg

4. OXIDES (Hydroxides, $V^{[5,6]}$ vanadates, arsenites, antimonites, bismuthites, sulfites, selenites, tellurites, iodates)

- 4.A: Metal:Oxygen = 2:1 and 1:1
  - 4.AA. Cation:Anion (M:O) = 2:1 (and 1.8:1)
  - 4.AB. M:O = 1:1 (and up to 1:1.25); with small to medium-sized cations only
  - 4.AC. M:O = 1:1 (and up to 1:1.25); with large cations (± smaller ones)
- 4.B: Metal:Oxygen = 3:4 and similar
  - 4.BA. With small and medium-sized cations
  - 4.BB. With only medium-sized cations
  - 4.BC. With medium-sized and large cations
  - 4.BD. With only large cations
- 4.C: Metal:Oxygen = 2:3, 3:5, and similar
  - 4.CA. With small cations
  - 4.CB. With medium-sized cations
  - 4.CC. With large and medium-sized cations
- 4.D: Metal:Oxygen = 1:2 and similar
  - 4.DA. With small cations: Silica family
  - 4.DB. With medium-sized cations; chains of edge-sharing octahedra
  - 4.DC. With medium-sized cations; sheets of edge-sharing octahedra

- 4.DD. With medium-sized cations; frameworks of edge-sharing octahedra
- 4.DE. With medium-sized cations; with various polyhedra
- 4.DF. With large (± medium-sized) cations; dimers and trimers of edge-sharing octahedra
- 4.DG. With large (± medium-sized) cations; chains of edge-sharing octahedra
- 4.DH. With large (± medium-sized) cations; sheets of edge-sharing octahedra
- 4.DJ. With large (± medium-sized) cations; polyhedral frameworks
- 4.DK. With large (± medium-sized) cations; tunnel structures
- 4.DL. With large (± medium-sized) cations; fluorite-type structures
- 4.DM. With large (± medium-sized) cations; unclassified

4.E: Metal:Oxygen = $<$ 1:2

4.F: Hydroxides (without V or U)

- 4.FA. Hydroxides with OH, without H_2O; corner-sharing tetrahedra
- 4.FB. Hydroxides with OH, without H_2O; insular octahedra
- 4.FC. Hydroxides with OH, without H_2O; corner-sharing octahedra
- 4.FD. Hydroxides with OH, without H_2O; chains of edge-sharing octahedra
- 4.FE. Hydroxides with OH, without H_2O; sheets of edge-sharing octahedra
- 4.FF. Hydroxides with OH, without H_2O; various polyhedra
- 4.FG. Hydroxides with OH, without H_2O; unclassified
- 4.FH. Hydroxides with H_2O ± (OH); insular octahedra
- 4.FJ. Hydroxides with H_2O ± (OH); corner-sharing octahedra
- 4.FK. Hydroxides with H_2O ± (OH); chains of edge-sharing octahedra
- 4.FL. Hydroxides with H_2O ± (OH); sheets of edge-sharing octahedra
- 4.FM. Hydroxides with H_2O ± (OH); unclassified

4.G: Uranyl Hydroxides

- 4.GA. Without additional cations
- 4.GB. With additional cations (K, Ca, Ba, Pb, etc.); with mainly $UO_2(O,OH)_5$ pentagonal polyhedra
- 4.GC. With additional cations; with mainly $UO_2(O,OH)_6$ hexagonal polyhedra

4.H: $V^{[5,6]}$ Vanadates

- 4.HA. Nesovanadates
- 4.HB. Uranyl Sorovanodates
- 4.HC. [6]-Sorovanadates
- 4.HD. Inovanadates
- 4.HE. Phyllovanadates
- 4.HF. Tektovanadates
- 4.HG. Unclassified V oxides

4.J: Arsenites, antimonites, bismuthites, sulfites, selenites, tellurites; iodates.

- 4.JA: Arsenites, antimonites, bismuthites; without additional anions, without H_2O
- 4.JB. Arsenites, antimonites, bismuthites; with additional anions, without H_2O
- 4.JC. Arsenites, antimonites, bismuthites; without additional anions, with H_2O
- 4.JD. Arsenites, antimonites, bismuthites; with additional anions, with H_2O
- 4.JE. Sulfites
- 4.JF. Selenites without additional anions, without H_2O

- 4.JG. Selenites with additional anions, without H_2O
- 4.JH. Selenites without additional anions, with H_2O
- 4.JJ. Selenites with additional anions, with H_2O
- 4.JK. Tellurites without additional anions, without H_2O
- 4.JL. Tellurites with additional anions, without H_2O
- 4.JM. Tellurites without additional anions, with H_2O
- 4.JN. Tellurites with additional anions, with H_2O

4.K: Iodates
- 4.KA. Iodates without additional anions, without H_2O
- 4.KB. Iodates with additional anions, without H_2O
- 4.KC. Iodates without additional anions, with H_2O
- 4.KD. Iodates with additional anions, with H_2O

5. CARBONATES (+ NITRATES)

5.A: Carbonates without additional anions, without H_2O
- 5.AA. Alkali carbonates
- 5.AB. Alkali-earth (and other M^{2+}) carbonates
- 5.AC. Alkali and alkali-earth carbonates
- 5.AD. With rare-earth elements (REE)

5.B: Carbonates with additional anions, without H_2O
- 5.BA. With Cu, Co, Ni, Zn, Mg, Mn
- 5.BB. With alkalies, etc.
- 5.BC. With alkali-earth cations
- 5.BD. With rare earth elements (REE)
- 5.BE. With Pb, Bi
- 5.BF. With (Cl), SO_4, PO_4

5.C: Carbonates without additional anions, with H_2O
- 5.CA. With medium-sized cations
- 5.CB. With large cations (alkali and alkali-earth carbonates)
- 5.CC. With rare earth elements (REE)

5.D: Carbonates with additional anions, with H_2O
- 5.DA. With medium-sized cations
- 5.DB. With large and medium-sized cations
- 5.DC. With large cations

5.E: Uranyl Carbonates
- 5.EA. $UO_2:CO_3 = 1:1$
- 5.EB. $UO_2:CO_3 = < 1:1$ to $1:2$
- 5.EC. $UO_2:CO_3 = 1:3$
- 5.ED. $UO_2:CO_3 = 1:4$
- 5.EE. $UO_2:CO_3 = 1:5$
- 5.EF. $UO_2:CO_3 > 1:1$
- 5.EG. With SO_4 or SiO_4

5.N: NITRATES
- 5.NA. Without OH or H_2O
- 5.NB. With OH

- 5.NC. With H_2O
- 5.ND. With OH (etc.) and H_2O

6. BORATES

- 6.A: Monoborates
  - 6.AA. BO_3, without additional anions; 1(Δ).
  - 6.AB. BO_3, with additional anions; 1(Δ) + OH, etc.
  - 6.AC. $B(O,OH)_4$, without and with additional anions; 1(T), 1(T)+OH, etc.
- 6.B: Diborates
  - 6.BA. Neso-diborates with double triangles $B_2(O,OH)_5$; 2(2Δ); 2(2Δ) + OH, etc.
  - 6.BB. Neso-diborates with double tetrahedra $B_2O(OH)_6$; 2(2T)
  - 6.BC. Ino-diborates with triangles and/or tetrahedra
- 6.C: Triborates
  - 6.CA. Neso-triborates
  - 6.CB. Ino-triborates
  - 6.CC. Phyllo-triborates
- 6.D: Tetraborates
  - 6.DA. Neso-tetraborates
  - 6.DB. Ino-tetraborates
  - 6.DC. Phyllo-tetraborates
  - 6.DD. Tekto-tetraborates
- 6.E: Pentaborates
  - 6.EA. Neso-pentaborates
  - 6.EB. Ino-pentaborates
  - 6.EC. Phyllo-pentaborates
  - 6.ED. Tekto-pentaborates
- 6.F: Hexaborates
  - 6.FA. Neso-hexaborates
  - 6.FB. Ino-hexaborates
  - 6.FC. Phyllo-hexaborates
- 6.G: Heptaborates and other megaborates
- 6.H: Unclassified borates

7. SULFATES (selenates, tellurates; chromates, molybdates, wolframates)

- 7.A: Sulfates (selenates, etc.) without additional anions, without H_2O
  - 7.AA. With small cations
  - 7.AB. With medium-sized cations
  - 7.AC. With medium-sized and large cations
  - 7.AD. With only large cations
- 7.B: Sulfates (selenates, etc.) with additional anions, without H_2O
  - 7.BA. With small cations
  - 7.BB. With medium-sized cations
  - 7.BC. With medium-sized and large cations
  - 7.BD. With only large cations
- 7.C: Sulfates (selenates, etc.) without additional anions, with H_2O

- 7.CA. With small cations
- 7.CB. With only medium-sized cations
- 7.CC. With medium-sized and large cations
- 7.CD. With only large cations

7.D: Sulfates (selenates, etc.) with additional anions, with H_2O
- 7.DA. With small cations
- 7.DB. With only medium-sized cations; insular octahedra and finite groups
- 7.DC. With only medium-sized cations; chains of edge-sharing octahedra
- 7.DD. With only medium-sized cations; sheets of edge-sharing octahedra
- 7.DE. With only medium-sized cations; unclassified
- 7.DF. With large and medium-sized cations
- 7.DG. With large and medium-sized cations; with NO_3, CO_3, $B(OH)_4$, SiO_4 or IO_3

7.E: Uranyl sulfates
- 7.EA. Without cations
- 7.EB. With medium-sized cations
- 7.EC. With medium-sized and large cations

7.F: Chromates
- 7.FA. Without additional anions
- 7.FB. With additional O, V, S, Cl
- 7.FC. With PO_4, AsO_4, SiO_4
- 7.FD. Dichromates

7.G: Molybdates and wolframates
- 7.GA. Without additional anions or H_2O
- 7.GB. With additional anions and/or H_2O

7.H: Uranium and uranyl molybdates and wolframates
- 7.HA. With U^{4+}
- 7.HB. With U^{6+}

8. PHOSPHATES, ARSENATES, VANADATES

8.A: Phosphates, etc. without additional anions, without H_2O
- 8.AA. With small cations (some also with larger ones)
- 8.AB. With medium-sized cations
- 8.AC. With medium-sized and large cations
- 8.AD. With only large cations

8.B: Phosphates, etc., with additional anions, without H_2O
- 8.BA. With small and medium-sized cations
- 8.BB. With only medium-sized cations, (OH, etc.):$RO_4 \leq 1:1$
- 8.BC. With only medium-sized cations, (OH, etc.):$RO_4 > 1:1$ and $< 2:1$
- 8.BD. With only medium-sized cations, (OH, etc.):$RO_4 = 2:1$
- 8.BE. With only medium-sized cations, (OH, etc.):$RO_4 > 2:1$
- 8.BF. With medium-sized and large cations, (OH, etc.):$RO_4 < 0.5:1$
- 8.BG. With medium-sized and large cations, (OH, etc.):$RO_4 = 0.5:1$
- 8.BH. With medium-sized and large cations, (OH,etc.):$RO_4 = 1:1$
- 8.BJ. With medium-sized and large cations, (OH, etc.):$RO_4 = 1.5:1$
- 8.BK. With medium-sized and large cations, (OH, etc.):$RO_4 = 2:1, 2.5:1$

- 8.BL. With medium-sized and large cations, (OH, etc.):$RO_4 = 3:1$
- 8.BM. With medium-sized and large cations, (OH, etc.):$RO_4 = 4:1$
- 8.BN. With only large cations, (OH, etc.):$RO_4 = 0.33:1$
- 8.BO. With only large cations, (OH, etc.):$RO_4 \geq 1:1$

8.C: Phosphates without additional anions, with H_2O

- 8.CA. With small and large/medium cations
- 8.CB. With only medium-sized cations, $RO_4:H_2O = 1:1$
- 8.CC. With only medium-sized cations, $RO_4:H_2O = 1:1.5$
- 8.CD. With only medium-sized cations, $RO_4:H_2O = 1:2$
- 8.CE. With only medium-sized cations, $RO_4:H_2O \leq 1:2.5$
- 8.CF. With large and medium-sized cations, $RO_4:H_2O > 1:1$
- 8.CG. With large and medium-sized cations, $RO_4:H_2O = 1:1$
- 8.CH. With large and medium-sized cations, $RO_4:H_2O < 1:1$
- 8.CJ. With only large cations

8.D: Phosphates, etc. with additional anions, with H_2O

- 8.DA. With small (and occasionally larger) cations
- 8.DB. With only medium-sized cations, (OH, etc.):$RO_4 < 1:1$
- 8.DC. With only medium-sized cations, (OH, etc.):$RO_4 = 1:1$ and $< 2:1$
- 8.DD. With only medium-sized cations, (OH, etc.):$RO_4 = 2:1$
- 8.DE. With only medium-sized cations, (OH, etc.):$RO_4 = 3:1$
- 8.DF. With only medium-sized cations, (OH, etc.):$RO_4 > 3:1$
- 8.DG. With large and medium-sized cations, (OH, etc.):$RO_4 < 0.5:1$
- 8. DH. With large and medium-sized cations, (OH, etc.):$RO_4 < 1:1$
- 8.DJ. With large and medium-sized cations, (OH, etc.):$RO_4 = 1:1$
- 8.DK. With large and medium-sized cations, (OH, etc.):$RO_4 > 1:1$ and $< 2:1$
- 8.DL. With large and medium-sized cations, (OH, etc.):$RO_4 = 2:1$
- 8.DM. With large and medium-sized cations, (OH, etc.):$RO_4 > 2:1$
- 8.DN. With only large cations
- 8.DO. With CO_3, SO_4, SiO_4

8.E: Uranyl phosphates and arsenates

- 8.EA. $UO_2:RO_4 = 1:2$
- 8.EB. $UO_2:RO_4 = 1:1$
- 8.EC. $UO_2:RO_4 = 3:2$
- 8.ED. Unclassified

8.F: Polyphosphates, polyarsenates, [4]-polyvanadates

- 8.FA. Diphosphates, etc., without OH and H_2O; dimers of corner-sharing RO_4 tetrahedra
- 8.FB. Diphosphates, etc., with OH only
- 8.FC. Diphosphates, etc., with H_2O only
- 8.FD. Diphosphates, etc., with OH and H_2O
- 8.FE. Ino-[4]-vanadates

9. SILICATES (Germanates)

9.A: Nesosilicates

- 9.AA. Nesosilicates without additional anions; cations in tetrahedral [4] coordination

9.AB. Nesosilicates without additional anions; cations in [4] and greater coordination

9.AC. Nesosilicates without additional anions; cations in octahedral [6] coordination

9.AD. Nesosilicates without additional anions; cations in [6] and/or generally greater coordination

9.AE. Nesosilicates with additional anions (O, OH, F, H_2O); cations in tetrahedral [4] and mostly greater coordination

9.AF. Nesosilicates with additional anions; cations in [4], [5] and/or only [6] coordination

9.AG. Nesosilicates with additional anions; cations in mostly [6] and > [6] coordination

9.AH. Nesosilicates with CO_3, SO_4, PO_4, etc.

9.AJ. Nesosilicates with BO_3 triangles and/or $B^{[4]}$, $Be^{[4]}$ tetrahedra, corner-sharing with SiO_4 tetrahedra

9.AK. Uranyl neso- and polysilicates

9.B: Sorosilicates

9.BA. Si_2O_7 groups, without non-tetrahedral anions; cations in tetrahedral [4] coordination

9.BB. Si_2O_7 groups, without non-tetrahedral anions; cations in tetrahedral [4] and greater coordination

9.BC. Si_2O_7 groups, without non-tetrahedral anions; cations in octahedral [6] and greater coordination

9.BD. Si_2O_7 groups, with additional anions; cations in tetrahedral [4] and greater coordination

9.BE. Si_2O_7 groups, with additional anions; cations in octahedral [6] and/or other coordination

9.BF. Sorosilicates with mixed SiO_4 and Si_2O_7 anions; cations in tetrahedral [4] and greater coordination

9.BG. Sorosilicates with mixed SiO_4 and Si_2O_7 groups; cations in octahedral [6] and greater coordination

9.BH. Sorosilicates with Si_3O_{10},or larger anions; cations in tetrahedral [4] and greater coordination

9.BJ. Sorosilicates with Si_3O_{10}, Si_4O_{11}, etc. anions; cations in octahedral [6] and/or greater coordination

9.BK. Unclassified sorosilicates

9.C: Cyclosilicates

9.CA. $[Si_3O_9]^{6-}$ 3-membered single rings (*dreier-Einfachringe*), without insular complex anions

9.CB. $[Si_3O_9]^{6-}$ 3-membered single rings, with insular complex anions

9.CC. $[Si_3O_9]^{6-}$ branched 3-membered single rings

9.CD. $[Si_3O_9]^{6-}$ 3-membered double rings

9.CE. $[Si_4O_{12}]^{8-}$ 4-membered single rings (*vierer-Einfachringe*), without insular complex anions

9.CF. $[Si_4O_{12}]^{8-}$ 4-membered single rings, with insular complex anions

- 9.CG. $[Si_4O_{12}]^{8-}$ branched 4-membered single rings
- 9.CH. $[Si_4O_{12}]^{8-}$ 4-membered double rings
- 9.CJ. $[Si_6O_{18}]^{12-}$ 6-membered single rings (*sechser-Einfachringe*), without insular complex anions
- 9.CK. $[Si_6O_{18}]^{12-}$ 6-membered single rings, with insular complex anions
- 9.CL. $[Si_6O_{18}]^{12-}$ branched 6-membered single rings
- 9.CM. $[Si_6O_{18}]^{12-}$ 6-membered double rings (*sechser-Doppelringe*)
- 9.CN. $[Si_8O_{24}]^{16-}$ 8-membered rings
- 9.CO. $[Si_9O_{27}]^{18-}$ 9-membered rings
- 9.CP. 12-membered and larger rings

9.D: Inosilicates.

- 9.DA. Inosilicates with 2-periodic single chains, Si_2O_6; pyroxene family
- 9.DB. Inosilicates with 2-periodic single chains, Si_2O_6; with additional O, OH, H_2O. Pyroxene-related minerals
- 9.DC. Inosilicates with branched 2-periodic single chains
- 9.DD. – 9.DE. Inosilicates with 2-periodic double chains; amphibole family
- 9.DD. Orthoamphiboles
- 9.DE. Clinoamphiboles
- 9.DF. Inosilicates with 2-periodic multiple chains
- 9.DG. Inosilicates with 3-periodic single and multiple chains
- 9.DH. Inosilicates with 4-periodic single chains
- 9.DJ. Inosilicates with 4-periodic double and triple chains
- 9.DK. Inosilicates with 5-periodic single chains
- 9.DL. Inosilicates with 5-periodic double chains
- 9.DM. Inosilicates with 6-periodic single chains
- 9.DN. Inosilicates with 6-periodic double chains
- 9.DO. Inosilicates with 7-, 8-, 10-, 12- and 14-periodic chains
- 9.DP. Transitional ino-phyllosilicate structures
- 9.DQ. Unclassified inosilicates

9.E: Phyllosilicates

- 9.EA. Single nets of tetrahedra with 4-, 5-, (6-), and 8-membered rings
- 9.EB. Double nets with 4- and 6-membered rings
- 9.EC. Phyllosilicates with mica sheets, composed of tetrahedral and octahedral nets
- 9.ED. Phyllosilicates with kaolinite layers composed of tetrahedral and octahedral nets
- 9.EE. Single tetrahedral nets of 6-membered rings connected by octahedral nets or octahedral bands
- 9.EF. Single nets with 6-membered rings, connected by $M^{[4]}$, $M^{[8]}$, etc.
- 9.EG. Double nets with 6-membered rings
- 9.EH. Transitional structures between phyllosilicate and other silicate units

9.F: Tektosilicates without zeolitic H_2O

- 9.FA. Tektosilicates without additional non-tetrahedral anions
- 9.FB. Tektosilicates with additional anions

9.G: Tektosilicates with zeolitic H_2O: zeolite family

- 9.GA. Zeolites with chains of 4-membered rings connected by a fifth Si
- 9.GB. Zeolites with chains of single connected 4-membered rings

- 9.GC. Zeolites with chains of doubly-connected 4-membered rings
- 9.GD. Zeolites with chains of 5-membered rings
- 9.GE. Zeolites with sheets with 4-4-1-1 structural units
- 9.GF. Zeolites with Leucite-type frameworks
- 9.GG. Zeolites with Cages and double cages of 4-, 6-, and 8-membered rings
- 9.GH. Unclassified zeolites

9.H: Unclassified silicates
- 9.HA. With Alkali and Alkali-earth Elements
- 9.HB. With Ti, V, Cr
- 9.HC. With Mn, Fe
- 9.HD. With Co, Ni
- 9.HE. With Cu, Zn
- 9.HF. With Nb, Ta, Zr
- 9.HG. With REE, Th
- 9.HH. With Pb

9.J: Germanates

10. ORGANIC COMPOUNDS

10.A: Salts of organic acids
- 10.AA. Acetates
- 10.AB. Oxalates
- 10.AC. Benzine Salts
- 10.AD. Cyanates

10.B: Hydrocarbons

10.C: Miscellaneous Organic Minerals

In the preparation of the tabulation, which comprises the main portion of this book, we used information from a large number of sources. Most of the data came from primary published sources, but much useful information was also obtained from secondary sources such as the *Mineral Database* produced by Aleph Enterprises, Livermore, California, and various textbooks, notably *Structural Chemistry of Silicates* by F. Liebau (1985), *Natural Zeolites* by G. Gottardi and E. Galli (1985), *Crystallography and Crystal Chemistry* by F. D. Bloss (1994), and *Crystal Structure, I. Patterns and Symmetry* by M. O'Keeffe and B. G. Hyde (1996), Authoritative crystallographic information is provided by *International Tables for Crystallography*, Volume A, fourth, revised and enlarged edition by Theo Hahn (1996), and *Brief Teaching Edition of International Tables for Crystallography*, Volume A, by Theo Hahn, editor (1996), both published by Kluwer Academic, Dordrecht. The structure diagrams were produced by means of the *Atoms* computer program developed by Eric Dowty of Shape Software, Kingsport, Tennessee, USA.

References to published data cited in the tabulations are given in an abbreviated form in the interest of saving space. In general, only the year of publication and the page number are cited, but when several volumes are published within the same year, the volume number is added after the year, e. g. ZK 1987/181. The abbreviations used are as follows:

PERIODICALS

AC	Acta Crystallographica
Accad. Naz. Lincei	Accademia Nazionale dei Lincei
Acta Chem. Scand.	Acta Chemica Scandinavica
Acta Geol. Sinica	Acta Geologica Sinica
Acta Min. Sinica	Acta Mineralogica Sinica
Acta Petr. Min.	Acta Petrologica Mineralogica (Chinese)
Acta Phys. Sinica	Acta Physica Sinica
Ah	Neues Jahrbuch für Mineralogie, Abhandlungen
AM	American Mineralogist
Am. J. Sci.	American Journal of Science
Ann. Phys.	Annalen der Physik
Ark. Kem.	Arkiv för Kemi
Ark. Kem. Min. Geol.	Arkiv för Kemi, Mineralogi och Geologi
Ark. Min. Geol.	Arkiv för Mineralogi och Geologi
Austral. J. Chem.	Australian Journal of Chemistry
Austral. J. Min.	Australian Journal of Mineralogy
Austral. J. Phys.	Australian Journal of Physics
Austral. Min.	Australian Mineralogist
BM	Bulletin Société française de Minéralogie et Crystallographie; Bulletin de Minéralogie
Bull. Geol. Soc. Denmark	Bulletin of the Geological Society of Denmark
Bull. Geol. Soc. Finland	Bulletin of the Geological Society of Finland
Bull. Geol. Soc. Turkey	Bulletin of the Geological Society of Turkey
BYU	Brigham Young University
Can. J. Chem.	Canadian Journal of Chemistry
CA	Chemical Abstracts
Chem. Comm.	Chemical Communications
Chem. Erde	Chemie der Erde
Chem. Lett.	Chemistry Letters
Chem. Mater.	Chemistry of Materials
Chinese Sci. Bull.	Chinese Science Bulletin
CIM Spec. Vol.	Canadian Institute of Mining and Metallurgy, Special Volume
Clay Mins.	Clay Minerals
Clays Cl. Mins.	Clays and Clay Minerals
CM	Canadian Mineralogist
Contr. Min. Pet.	Contributions to Mineralogy and Petrology
CR	Comptes Rendus de l'Academie des Sciences, Paris
Cryst. Struct. Comm.	Crystal Structure Communications
Czech. J. Phys.	Czechoslovak Journal of Physics
Dok. Akad. Nauk	Doklady Akademiy Nauk
Dok. Akad. Nauk SSSR	Doklady Akademiy Nauk SSSR
Dok. Earth Sci.	Transactions (Doklady) of the USSR Academy of Sciences, Earth Science Sections

Ec. Geol.	Economic Geology
EJM	European Journal of Mineralogy
Eur. J. Sol. St. Inorg. Chem.	European Journal of Solid State Inorganic Chemistry
Fortsch. Min.	Fortschritte der Mineralogie
GAC-MAC	Geological Association of Canada – Mineralogical Association of Canada (Annual Meeting)
Geochim. Cosmochim. Acta	Geochimica et Cosmochimica Acta
Geol. För. Förh.	Geologiska Föreningens i Stockholm, Förhandlingar
Grønl. Geol. Undersøg.	Grønlands Geologiske Undersøgelse
Handb. Min.	Handbook of Mineralogy (Anthony *et al.*)
Helv. Chim. Acta	Helvetica Chimica Acta
IGC	International Geological Congress
IMA	International Mineralogical Association
Inorg. Chem.	Inorganic Chemistry
J. Alloys Comp.	Journal of Alloys and Compounds
J. Am. Chem. Soc.	Journal of the American Chemical Society
J. Appl. Chem.	Journal of Applied Chemistry
J. Appl. Cryst.	Journal of Applied Crystallography
J. Appl. Phys.	Journal of Applied Physics
J. Chem. Soc. Dalt.	Journal of the Chemical Society, Dalton Transactions
J. Chem. Phys.	Journal of Chemical Physics
J. Geol. Soc. Japan	Journal of the Geological Society of Japan
J. Inorg. Nucl. Chem.	Journal of Inorganic and Nuclear Chemistry
JLCM	Journal of Less-Common Metals
J. Min. Soc. Jap.	Journal of the Mineralogical Society of Japan
J. Mol. Struct.	Journal of Molecular Structure
J. Phys.	Journal of Physics
J. Phys. Chem.	Journal of Physical Chemistry
J. Phys. Chem. Sol.	Journal of the Physics and Chemistry of Solids
J. Phys. Soc. Japan	Journal of the Physical Society of Japan
J. Res. NBS	Journal of Research, National Bureau of Standards
J. Sol. St. Chem.	Journal of Solid State Chemistry
Struct. Chem.	Journal of Structural Chemistry
J. Wash. Acad. Sci.	Journal of the Washington Academy of Science
Kali u. Steinsalz	Kali und Steinsalz
Lunar Planet. Sc.	Lunar and Planetary Sciences
MA	Mineralogical Abstracts
Mater. Res. Bull.	Materials Research Bulletin
Medd. Grønland	Meddelelser om Grønland
Mh	Neues Jahrbuch für Mineralogie, Monatshefte
Mh. Chem.	Monatshefte für Chemie
Min. Deposita	Mineralium Deposita
Min. Jour.	Mineralogical Journal (Japan)
Min. Pet.	Mineralogy and Petrology
Min. Polonica	Mineralogica Polonica

Min. Tab.	Mineralogische Tabellen
Min. Zhur.	Mineralogicheskiy Zhurnal (Ukraine)
Mitt. Österr. Min. Ges.	Mitteilungen der Österreichischen Mineralogischen Gesellschaft
MM	Mineralogical Magazine
MR	Mineralogical Record
MSA	Mineralogical Society of America (Annual Meeting)
MSA Spec. Pap.	Mineralogical Society of America Special Paper
Nature, Phys. Sci.	Nature, Physical Sciences
Naturw.	Naturwissenschaften
NBS Circ.	National Bureau of Standards, Circular
NBS Monogr.	National Bureau of Standards, Monograph
New Zeal. J. Geol. Geoph.	New Zealand Journal of Geology and Geophysics
Norsk. Geol. Tid.	Norske Geologisk Tidsskrift
Norske Vid.	Norske Videnskapsakademi
PDF	Powder Diffraction File of the International Centre for Diffraction Data (JCPDS)
Per. Min.	Periodico di Mineralogia
Phil. Mag.	Philosophical Magazine
Physik. Z.	Physikalische Zeitschrift
Phys. Chem. Min.	Journal of the Physics and Chemistry of Minerals
Phys. Rev.	Physical Review
Powd. Diff.	Powder Diffraction
Proc. Austral. I.M.M.	Proceedings of the Australasian Institute of Mining and Metallurgy
Proc. Lun. Sci. Conf.	Proceedings of the Lunar Science Conference
Proc. Roy. Soc.	Proceedings of the Royal Society, London
Rend. Accad. Lincei	Rendiconti, Accademia dei Lincei
Rend. Soc. Ital. Min. Pet.	Rendiconti, Societa Italiana di Mineralogia e Petrologia
Rend. Soc. Min. Ital.	Rendiconti, Societa Mineralogica Italiana
Rev. Min.	Reviews in Mineralogy (Mineralogical Society of America)
Rom. J. Min.	Romanian Journal of Mineralogy
Sc. Geol. Sinica	Scientia Geologica Sinica
SB	Strukturberichte
SMPM	Schweitzerische Mineralogische und Petrographische Mitteilungen
Sov. Phys. Cryst.	Soviet Physics, Crystallography
Sov. Phys. Dok.	Soviet Physics, Doklady
SR	Structure Reports
Svensk Kem. Tid.	Svensk Kemisk Tidskrift
TMPM	Tschermak's Mineralogische und Petrographische Mitteilungen
Tr. Min. Muz. AN SSSR	Trudy Mineralogicheskogo Muzeya Akademiya Nauk SSSR
USGS Prof. Pap.	United States Geological Survey, Professional Paper

Vest. Mosk. Univ.	Vestnik Moskovskogo Universiteta
Anorg. Allg. Chem.	Zeitschrift für Anorganische und Allgemeine Chemie
Z. Anorg. Chem.	Zeitschrift für Anorganische Chemie
Z. Elektrochem.	Zeitschrift für Elektrochemie
ZK	Zeitschrift für Kristallographie
Z. Metallk.	Zeitschrift für Metallkunde
Z. Naturf.	Zeitschrift für Naturforschung
Z. Phys. Chem.	Zeitschrift für Physikalische Chemie
ZVMO	Zapiski Vsesoyuznogo Mineralogicheskogo Obshchvestva; Zapiski Vserossiyskogo Mineralogischeskogo Obshchestva

CLASS 1. ELEMENTS

(Metals and Intermetallic Alloys; Metalloids and Nonmetals;
Carbides, Silicides, Nitrides, Phosphides)

The minerals in this Class are separated into four Divisions. **– 1.A: Metals and Intermetallic alloys. – 1.B: Metal Carbides, Silicides, Nitrides and Phosphides. – 1.C: Metalloids and Nonmetals**; and **1.D: Nonmetal Carbides and Nitrides**. The Divisions are further broken down into Subdivisions (or families), based on composition and structure, periodic system and structure types. Within the Subdivisions, the minerals are separated into structural groups; a single group name indicates isotypy or homeotypy of species within the group, and a multiple name indicates compositional or structural similarity.

1.A: Metals and Intermetallic Alloys

In metals and intermetallic alloys, the atoms have lost their valence electrons, resulting in cations in a "sea" of freemoving electrons, constituting metallic bonding. Dense packing of the cations is responsible for high density and thermal conductivity; the free valence electrons are responsible for metallic luster and high electrical conductivity. The metals have typically high coordination numbers [CN], mostly [12] or [8].

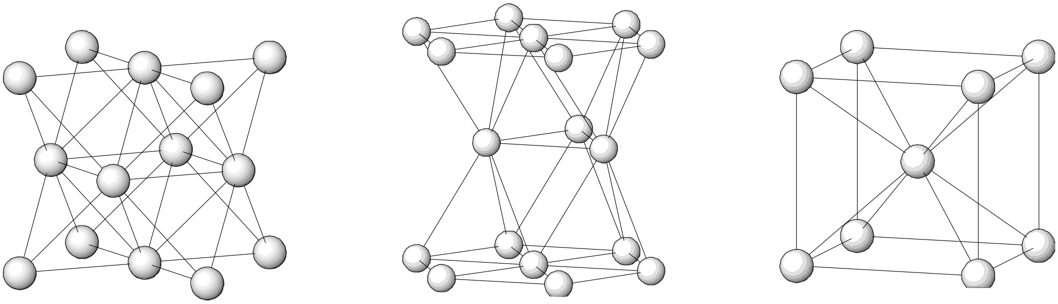


Fig 1.AA.00: *The structures of copper (left), zinc (middle) and iron (right).*

Subdivisions 1.AA – 1.AG

- 1.AA. Copper-cupalite family
  - 1.AA.05. Copper group
  - 1.AA.10. Nickel group
  - 1.AA.15. Cupalite-khatyrkite group
  - 1.AA.20. Anyuiite-hunchunite group
- 1.AB. Zinc-brass family
  - 1.AB.05. Zinc group
  - 1.AB.10. Brass group
- 1.AC. Indium-tin family
  - 1.AC.05. Indium

- 1.AC.10. Tin
- 1.AC.15. Bronze group

1.AD. Mercury-amalgam family
- 1.AD.05. Mercury
- 1.AD.10. Copper amalgam group
- 1.AD.15. Silver amalgam group
- 1.AD.20. Gold amalgam group
- 1.AD.25. Palladium amalgam
- 1.AD.30. Leadamalgam

1.AE. Iron-chromium family
- 1.AE.05. Iron-kamacite group
- 1.AE.10. Chromium group
- 1.AE.15. Chromferide group
- 1.AE.20. Wairauite-awaruite group
- 1.AE.25. Jedwabite

1.AF. Platinum-group elements
- 1.AF.05. Ruthenium group
- 1.AF.10. Rhodium group

1.AG. PGE-metal alloys
- 1.AG.05. Hexaferrum
- 1.AG.10. Zvyagintsevite group
- 1.AG.15. Taimyrite group
- 1.AG.20. Paolovite-cabriite group
- 1.AG.25. Stannopalladinite group
- 1.AG.30. Reserved
- 1.AG.35. Isoferroplatinum group
- 1.AG.40. Tetraferroplatinum group
- 1.AG.45. Hongshiite
- 1.AG.50. Yixunite-damiaoite group
- 1.AG.55. Niggliite

1.AA. Copper-Cupalite Family

1.AA.05. **Copper Group**. $M^{[12]}$ in cubic closest packing; Cu structure type and derivatives.

Copper	Cu	Cubic, Fm$\bar{3}$m (225)	
(*Cuprum*[1])		a = 3.615Å	Z = 4
Silver	Ag	Cubic, Fm$\bar{3}$m (225)	
(*Argentum*[2])		a = 4.086Å	Z = 4
Gold	Au	Cubic, Fm$\bar{3}$m (225)	
(*Aurum*[3])		a = 4.078Å	Z = 4
"Electrum"	Au-Ag	Cubic, Fm$\bar{3}$m (225)	
(*Plinius,* AD 77[4])	(disordered)	a = 4.08Å	Z = 4

Related Minerals

Silver-2*H*	Ag	Hexagonal, P6_3/mmc (194) (Zn type)	
(Novgorodova *et al.*, 1979[5])		a = 2.93, c = 4.78Å	Z = 2
Silver-4*H*	Ag	Hexagonal, P6_3/mmc (194) (Am type)	
(Novgorodova *et al.*, 1979[6])		a = 2.91, c = 9.46Å	Z = 4

Cu-Au Alloys. Native gold with some Cu in solid solution in plutonic rocks forms ordered phases during slow cooling below ~ 385 °C. In **auricupride**, the Cu coordination is $Cu[Cu_8Au_4]$, and that of Au is $Au[Cu_{12}]$. In **cuproauride**, these coordinations are reversed. In **tetraauricupride**, the Cu coordination is $Cu[Cu_4Au_8]$ and that of Au is $Au[Cu_8Au_4]$; alternating (001) planes of Cu and Au atoms.

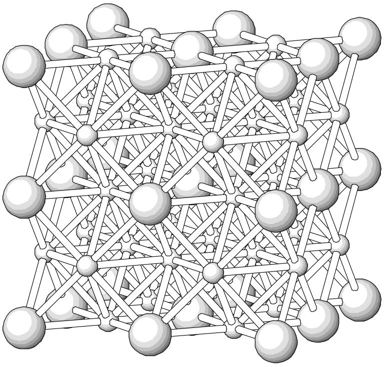


Fig 1.AA.05a. *The crystal structure of auricupride. Large spheres = Au; small spheres = Cu.*

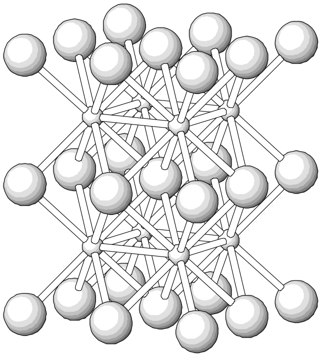


Fig 1.AA.05b. *The crystal structure of tetra-auricupride. Large spheres = Au; small spheres = Cu.*

Auricupride	Cu_3Au	Cubic, $Pm\bar{3}m$ (221)	
(Ramdohr, 1950[7])		a = 3.75Å	Z = 1
Cuproauride	$CuAu_3$	Cubic, $Pm\bar{3}m$ (221)	
(Lozhechkin, 1939[8])		a = 3.98Å	Z = 1
Tetraauricupride	CuAu	Tetragonal, P4/mmm (123)	
(Chen *et al.* 1982[9])		a = 2.81, c = 3.72Å	Z = 1

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[1] *Latin name*. Plinius: AD 77, *Aes Cyprium*; W. L. Bragg: 1914, SB 1, 35 (str); Batchelder & Simmons: J. Appl. Phys. 1965, 2864 (str)

[2] *Latin name.* Vegard: 1916, SB 1, 36 (str)

[3] *Latin name.* Vegard: 1916, SB 1, 38 (str); Batchelder & Simmons: J. Appl. Phys. 1965, 2864 (str)

[4] A solid-solution of Au and Ag, in nature usually with ~25–30 at. % Ag

[5] ZVMO 1979, 552; AM 1980, 1069 (Abst.)

[6] *idem* (Americium type)

[7] Fortsch. Min. 1950, 69; Borelius *et al.*: Ann. Phys. 1928, 291; SB 1, 506 (strs. in the Cu-Au system)

[8] Dokl. Akad. Nauk SSSR 1939/24, 454; Kubiak & Janczak: J. Alloys Compounds 1991/176, 133 (str); Stumpfl & Clark: Trans. Inst. Mining Metall. 1965/74, B933; Oen & Kieft: Mh 1974, 1; Verryn *et al.*: EJM 1991, 451; Knipe & Fleet: CM 1997, 573, with the Cu-Au phase diagram after Okamoto *et al.*, 1987. The name was originally used for Cu_3Au_2, which is not found in the Cu-Au phase diagram.

[9] Sc. Geol. Sinica 1982, 111; AM 1983, 1250 (Abst.); Borelius *et al.*: *idem* (str)

1.AA.10. **Nickel Group.** Cu structure type.

Nickel	Ni	Cubic, $Fm\bar{3}m$ (225)	
(Ramdohr, 1967[1])		a = 3.52Å	Z = 4
Aluminium	Al	Cubic, $Fm\bar{3}m$ (225)	
(Oleinikov *et al.*, 1978[2])		a = 4.05Å	Z = 4
Lead	Pb	Cubic, $Fm\bar{3}m$ (225)	
(*Plumbum*[3])		a = 4.95Å	Z = 4

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[1] AM 1968, 348 (Abst.); Hull: 1917, SB 1, 68 (str)
[2] Dok. Akad. Nauk SSSR 1978/243, 191; AM 1980, 205 (Abst.); Hull: 1917, SB 1, 45 (str); Straumanis & Ejima: Z. Phys. Chem., 1960, 440 (str)
[3] *Latin name.* Vegard: 1916, SB 1, 55 (str); Owen & Yates: Phil. Mag. 1933, 472 (str)

1.AA.15. **Cupalite-Khatyrkite Group**. In **khatyrkite**, columns // [001] of face-sharing $AlCu_8$ polyhedra are connected into a framework by sharing edges of the polyhedra; copper forms $CuAl_4$ square planes.

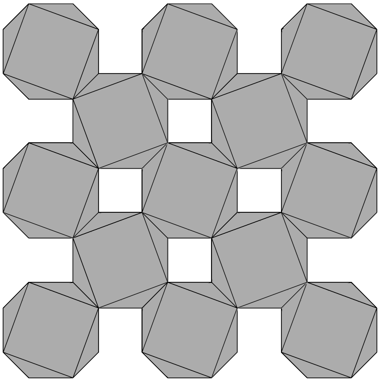

__Fig 1.AA.15.__ A slice // (001) through the khatyrkite structure, showing the $AlCu_8$ polyhedra.

Cupalite	CuAl	Orthorhombic	
(Razin *et al.*, 1985[1])		a = 6.94, b = 4.16, c = 10.04Å	Z = 10
Khatyrkite	$CuAl_2$	Tetragonal, I4/mcm (140)	
(Razin *et al.*, 1985[2])		a = 6.07, c = 4.89Å	Z = 4

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[1] ZVMO 1985, 90; AM 1986, 1278 (Abst.)
[2] *idem*; Friauf: J. Am. Chem. Soc. 1927, 3107 (str)

1.AA.20. **Anyuiite-Hunchunite Group**. **Anyuiite** is isostructural with khatyrkite. **Hunchunite** is a Laves phase in which Pb $[Pb_4]$ tetrahedra form a framework like that of C in diamond, with Au in the interstices; isostructural with maldonite.

Anyuiite	$AuPb_2$	Tetragonal, I4/mcm (140)	
(Razin & Sidorenko, 1989[1])		a = 7.39, c = 5.61Å	Z = 4
Hunchunite	Au_2Pb	Cubic, $Fd\bar{3}m$ (227)	
(Wu *et al.*, 1992[2])		a = 7.93Å	Z = 8

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[1] Min. Zhur. 1989(4), 88; AM 1991, 299 (Abst.); Wallbaum: Z. Metallk. 1943, 200 (str)
[2] Acta Min. Sinica 1992, 319; AM 1994, 1210 (Abst.); Perlitz: 1934, SB 3, 612 (str)

1.AB. Zinc-Brass Family

1.AB.05. **Zinc Group**. $M^{[12]}$ in hexagonal closest packing; Zn structure type.

Zinc	Zn	Hexagonal, $P6_3/mmc$ (194)	
(*Anon.*[1])		a = 2.665, c = 4.947Å	Z = 2
Cadmium	Cd	Hexagonal, $P6_3/mmc$ (194)	
(Oleinikov *et al.*, 1979[2])		a = 2.98, c = 5.62Å	Z = 2
Titanium	Ti	Hexagonal, $P6_3/mmc$ (194)	
(Trumilina *et al.*, 1988[3])		a = 2.95, c = 4.69Å	Z = 2
Rhenium	Re	Hexagonal, $P6_3/mmc$ (194)	
(Rafal'son & Sorokin, 1976[4])		a = 2.76, c = 4.46Å	Z = 2

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[1] Clarke & Sillitoe: AM 1970, 1019; Hull & Davey: 1921, SB 1, 41 (str)

[2] Dok. Earth Sci. 1979/248, 182; AM 1980, 1065 (Abst.); Hull & Davey: 1921, SB 1, 42 (str)

[3] Dok. Akad. Nauk SSSR 1988/303, 948; AM 1991, 1435 (Abst.); Hull: 1921, SB 1, 53 (str)

[4] AM 1978, 1283 (Abst.); V. M. Goldschmidt: 1929, SB 1, 759 (str)

1.AB.10. **Brass Group** (Cu-Zn Alloys). In **Zhanghengite** (β-brass), the atoms are in body-centred arrangement, with atoms in 8-fold cubic coordination (Fe structure type). **β'-brass** has the CsCl-type structure, which also gives 8-fold coordination. In **γ-brass**, the atoms are in body-centred cubic close-packing, but with ordering of the Cu and Zn atoms.

α-Brass	α-(Cu,Zn)	(Zn up to 36 %,	Cubic, $Fm\bar{3}m$ (225) (Cu type)	
(Okrugin *et al.*, 1981[1])		disordered)	a = 3.65–3.69Å	Z = 4
Zhanghengite	(β-brass)	β-CuZn	Cubic, $Im\bar{3}m$ (229) (Fe type)	
(Wang, 1986[2])		(1:1, disordered)	a = 2.95Å	Z = 1
β'-Brass	β'-CuZn	(1:1, ordered)	Cubic, $Pm\bar{3}m$ (221) (CsCl type)	
(Rao & Anantharaman, 1969[3])			a = 2.93–2.95Å	Z = 1
γ-Brass	Cu_5Zn_8	(Hume-Rothery	Cubic, $I\bar{4}3m$ (217)	
(Bradley & Gregory, 1931[4])		phase)	a = 8.85–8.89Å	Z = 4
Danbaite	$CuZn_2$		Cubic	
(Yue *et al.*, 1983[5])			a = 7.76Å	Z = 12
ε-Brass	$CuZn_3$	(ordered)	Hexagonal	
(Westgren & Phragmén, 1925[6])			a = 2.74, c = 8.58Å (?)	Z = 1
η-Brass	η-(Cu,Zn)	(Zn 96–100 %,	Hexagonal, $P6_3/mmc$ (194) (Zn type)	
(Westgren & Phragmén, 1925[7])		disordered)	a = 2.67, c = 4.94Å	Z = 2

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[1] AM 1982, 416 (Abst.); Owen & Preston: 1923, SB 1, 523 (str)

[2] Acta Min. Sinica 1986, 220; AM 1990, 244 (Abst.); Owen & Preston: *idem* (str);

[3] Z. Metallk. 1969/60, 312

[4] Bradley & Gregory: 1931, SB 2, 693 (str); homeotype of α-Mn, SB 2, 2 (str)
[5] Kexue Tongbao 1983, 1383; AM 1984, 566 (Abst.)
[6] Westgren & Phragmén: 1925, SB 1, 535 (str)
[7] *idem*

1.AC. Indium-Tin Family

1.AC.05. **Indium**. Distorted cubic closest packing of $In^{[12]}$.

Indium	In	Tetragonal, I4/mmm (139)	
(Ivanov, 1967[1])		a = 3.25, c = 4.95Å	Z = 2

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[1] AM 1967, 299 (Abst.); Hull & Davey: 1921, SB 1, 44 (str); Smith & Schneider: JLCM, 1964, 17 (str)

1.AC.10. **Tin**. Distorted diamond structure type, with $Sn^{[4]}$ in tetrahedral coordination.

Tin	β-Sn	Tetragonal, $I4_1/amd$ (141)	
(*Stannum*[1])		a = 5.82, c = 3.18Å	Z = 4

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[1] *Latin name*; Ivanov: AM 1967, 299 (Abst.); Mark & Polanyi: 1923, SB 1, 54 (str)

1.AC.15. **Bronze Group**. Nickeline structure type. **η'-Bronze** has the nickeline structure type, but with additional Cu.

η'-Bronze	$Cu_{1.2}Sn$	Hexagonal, $P6_3/mmc$ (194)	
(Clark, 1972[1])		a = 4.23, c = 5.12Å	Z = 2
Sorosite	Cu(Sn,Sb)	Hexagonal, $P6_3/mmc$ (194) (?)	
(Barkov *et al.*, 1998[2])		a = 4.22, c = 5.12Å	Z = 2
Yuanjiangite	AuSn	Hexagonal, $P6_3/mmc$ (194)	
(Chen *et al.*, 1994[3])		a = 4.32, c = 5.51Å	Z = 2

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[1] Mh 1972, 108; Rose: Mh 1981, 117; Bernal: Nature 1928/122, 54 (str)
[2] AM 1998, 901
[3] Acta Petr. Min. 1994, 232; AM 1995, 1330 (Abst.); Preston & Owen: 1927, SB 1, 562 (str)

1.AD. Mercury-Amalgam Family

1.AD.05. **Mercury**. Hg has distorted cubic closest packing, with [3 + 3 + 6] coordination; its structure is related to that of zinc.

Mercury (*Hydrargyrium*[1])	Hg (below –38.9 °C)	Trigonal, $R\bar{3}m$ (166) a = 3.46, c = 6.71Å	Z = 3

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[1] *NewLatin name.* Barrett: AC 1957, 58 (str)

1.AD.10. **Copper Amalgam Group**. The **belendorffite** structure contains $Hg^{[11]}$ and $Cu^{[12]}$.

Kolymite (Markova *et al.*, 1980[1])	Cu_7Hg_6	Cubic, $Im\bar{3}m$ (229), $I\bar{4}3m$ (217), I432 (211) a = 9.42Å	Z = 4
Belendorffite (Bernhardt & Schmetzer, 1992[2])	Cu_7Hg_6	Trigonal, R3m (160) (pseudo-cubic) a = 9.41Å α = 90.5°	Z = 4

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[1] ZVMO 1980, 206; AM 1981, 218 (Abst.)

[2] Mh 1992, 21; AM 1992, 1305 (Abst.); Lindahl & Westman: Acta. Chem. Scand. 1969, 1181 (str)

1.AD.15. **Silver Amalgam Group**. **"Kongsbergite"** (α-amalgam) has Ag-type structure with Hg up to ~ 30 %. The **schachnerite** structure is a derivative of the zinc structure. In **moschellandsbergite**, the atoms are in body-centred close packing (CsCl structure type), but with two empty Hg sites per unit cell, which lowers the symmetry.

Schachnerite (Seeliger & Mücke, 1972[1])	$Ag_{1.1}Hg_{0.9}$ (β-amalgam, disordered)	Hexagonal, $P6_3/mmc$ (194) a = 2.98, c = 4.84Å	Z = 1
Paraschachnerite (Seeliger & Mücke, 1972[2])	$Ag_{1.2}Hg_{0.8}$ (β'-amalgam, ordered)	Orthorhombic, Cmcm (63), $Cmc2_1$ (36), C2cm (40) a = 2.96, b = 5.13, c = 4.83Å	Z = 2
Eugenite (Kucha, 1986[3])	$Ag_{11}Hg_2$	Cubic, $I\bar{4}3m$ (217) a = 10.02Å	Z = 4
Moschellandsbergite (Berman & Harcourt, 1938[4])	$Ag_5Hg_{7.5}$	Cubic, I23 (197) a = 10.05Å	Z = 4
Luanheite (Shao *et al.*, 1984[5])	Ag_3Hg	Hexagonal a = 6.61, c = 10.98Å	Z = 6

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[1] Ah 1972/177, 1; AM 1973, 347 (Abst.)

[2] *idem*

[3] Min. Polonica 1986(2), 3; AM 1995, 845 (Abst.)

[4] AM 1938, 761; Fairhurst & Cohen: AC 1972.B, 371 (str); compare γ-brass

[5] Acta Min. Sinica 1984, 97; AM 1988, 192 (Abst.)

1.AD.20. **Gold Amalgam Group**. **Weishanite** appears to have the schachnerite structure. The structure of **goldamalgam** is related to that of moschellandsbergite.

Weishanite	$(Au,Ag)_{1.2}Hg_{0.8}$	Hexagonal, $P6_3/mmc$ (194)	
(Li *et al.*, 1984[1])		a = 2.93, c = 4.82Å	Z = 1
Goldamalgam	γ-$(Au,Ag)_2Hg_3$	Cubic, $Im\bar{3}m$ (229)	
(Chen *et al.*, 1981[2])		a = 10.01Å	Z = 10

---

[1] Acta Min. Sinica 1984, 102; AM 1988, 196 (Abst.)

[2] Dizhi Pinglun 1981, 107; AM 1985, 215 (Abst.)

1.AD.25. **Palladium Amalgam**. CuAu structure type.

Potarite	PdHg	Tetragonal, $P4/mmm$ (123)	
(Harrison, 1926[1])		a = 3.02, c = 3.71Å	Z = 1

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[1] Terada & Cagle: AM 1960, 1093 (str)

1.AD.30. **Leadamalgam**. Structure not known.

Leadamalgam	$Pb_{0.7}Hg_{0.3}$	Tetragonal, $I4/mmm$ (139)	
(Chen *et al.*, 1981[1])		a = 3.55, c = 4.53Å	Z = 2

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[1] Dizhi Pinglun 1981, 107; AM 1985, 215 (Abst.)

1.AE. Iron-Chromium Family

1.AE.05. **Iron-Kamacite Group**. In **iron** (α-Fe), the $Fe^{[8]}$ atoms are in a cubic body-centred packing (Fe structure type); it is magnetic up to 769 °C (Curie point). The β-Fe phase, stable above 769 °C, is non-magnetic. The γ-Fe phase is stable above 911 °C. In the high-pressure form, **ε-iron**, $Fe^{[12]}$ has the Zn structure type. **Kamacite** is α-(Fe,Ni), **taenite** is γ-(Fe,Ni) (Cu type), and **tetrataenite** is similar but with Ni-Fe ordering (CuAu structure type).

Iron	α-Fe	Cubic, $Im\bar{3}m$ (229)	
(*Ferrum*[1])		a = 2.87Å	Z = 2
γ-Iron	γ-Fe	Cubic, $Fm\bar{3}m$ (225)	
(artificial[2])		a = 3.65Å	Z = 4
ε-Iron	ε-Fe (stable at	Hexagonal, $P6_3/mmc$ (194)	
(Ramdohr, 1966[3])	$P > 131$ kbar)	a = 2.47, c = 3.96Å	Z = 2

Kamacite	α-(Fe,Ni)	Cubic, Im$\bar{3}$m (229)	
(Reichenbach, 1861[4])	with Fe:Ni ≥ 3:1	a = 2.87–2.88Å	Z = 2
Taenite	γ-(Fe,Ni)	Cubic, Fm$\bar{3}$m (225)	
(Reichenbach,1861[5])	with Fe:Ni < 3:1	a = 3.60Å	Z = 4
Tetrataenite	FeNi	Tetragonal, P4/mmm (123)	
(Clarke & Scott, 1980[6])	with Fe:Ni = 1:1	a = 2.53, c = 3.58Å	Z = 1
Taenite-1*M* (Tagai	FeNi	Monoclinic, Pm (6), pseudo-cubic	
& Takeda, 1995[7])	with Fe:Ni = 1:1	a = 3.58, b = 3.58, c = 3.59Å	
		β = 90.0°	Z = 2

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[1] *Latin name.* Nordenskiöld, 1870 – first reported natural occurrence; Hull: 1917, SB 1, 66 (str)

[2] Westgren & Lindh: 1921, SB 1, 66 (str); Basinski *et al.*, 1955 (str), from Donnay & Ondik *Crystal Data*, 1973

[3] Chem. Erde 1966/25, 259 ; Takahashi & Basset: Science 1964/145, 483 (str)

[4] Young: 1926, SB 1, 523 (str); Ramsden & Cameron: AM 1966, 37

[5] *idem* (str)

[6] AM 1980, 624; Rubin: MM 1994, 215

[7] ZK 1995/210, 14 (str)

1.AE.10. **Chromium Group**. The Cr$^{[8]}$ atoms are in cubic body-centred packing; α-Fe structure type.

Chromium	Cr	Cubic, Im$\bar{3}$m (229)	
(Yue *et al.*, 1981[1])		a = 2.88Å	Z = 2
Wolfram (Tungsten)	W	Cubic, Im$\bar{3}$m (229)	
(Novgorodova *et al.*, 1995[2])		a = 3.16Å	Z = 2
Tantalum	Ta	Cubic, Im$\bar{3}$m (229)	
(Seredin *et al.*, 1998[3])		a = 3.31Å	Z = 2

---

[1] Kexue Tongbao 1981, 959; AM 1982, 854 (Abst); Hull: 1921, SB 1, 61 (str)

[2] Dok. Akad. Nauk SSSR 1995/340, 681; AM 1996, 1284 (Abst.)

[3] Dok. Earth Sci. 1998/361, 642; Owen & Iball: 1932, SB 2, 163 (str)

1.AE.15. **Chromferide Group**. Probably ordered phases; CsCl structure type.

Chromferide	Fe(Fe$_{0.5}$Cr$_{0.2}\square_{0.3}$)	Cubic, Pm$\bar{3}$m (221)	
(Novgorodova *et al.*, 1986[1])		a = 2.86Å	Z = 1
Ferchromide	Cr(Cr$_{0.5}$Fe$_{0.2}\square_{0.3}$)	Cubic, Pm$\bar{3}$m (221)	
(Novgorodova *et al.*, 1986[2])		a = 2.88Å	Z = 1

---

[1] ZVMO 1986, 355; AM 1988, 190 (Abst.)

[2] *idem*

1.AE.20. **Wairauite-Awaruite Group**. The **wairauite** structure is of the CsCl structure type. The **awaruite** structure is of the auricupride (Cu_3Au) structure type.

Wairauite	FeCo (ordered)	Cubic, Pm$\bar{3}$m (221)	
(Challis & Long, 1964[1])		a = 2.86Å	Z = 1
Awaruite	$FeNi_3$	Cubic, Pm$\bar{3}$m (221)	
(Skey, 1885[2])		a = 3.59Å	Z = 1

---

[1] MM 1964, 942; Bayliss: CM 1990, 751
[2] Nickel: CM 1959, 307; Bayliss: *idem*

1.AE.25. **Jedwabite**. Structure not known.

Jedwabite	$Fe_7(Ta,Nb)_3$	Hexagonal, $P6_3/mmc$ (194), $P6_3mc$ (186), P$\bar{3}$2c (190)	
(Novgorodova *et al.*, 1997[1])		a = 4.81, c = 7.87Å	Z = 1

---

[1] ZVMO 1997 (2), 100; AM 1998, 654 (Abst.)

1.AF. Platinum-Group Elements (PGE)

1.AF.05. **Ruthenium Group**. Platinum-group elements with hexagonal close packing; Zn structure type.

Ruthenium	Ru	Hexagonal, $P6_3/mmc$ (194)	
(Urashima *et al.*, 1974[1])		a = 2.71, c = 4.28Å	Z = 2
Osmium	Os	Hexagonal, $P6_3/mmc$ (194)	
(Berzelius, 1819[2])		a = 2.73, c = 4.31Å	Z = 2
Rutheniridosmine	(Os,Ir,Ru)	Hexagonal, $P6_3/mmc$ (194)	
(Aoyama, 1936[3])		a = 2.73, c = 4.33Å	Z = 2

---

[1] Hull & Davey: 1921, SB 1, 69 (str); Min. Jour. 1974, 438; AM 1976, 177 (Abst.)
[2] Hull: 1921, SB 1, 70 (str); Harris & Cabri: CM 1973/12, 104
[3] Strunz: Min. Tab. 1966; Cabri: CIM Spec. Vol. 1981/23, 91

1.AF.10. **Rhodium Group**. Platinum-group elements with cubic close packing; Cu structure type.

Rhodium	(Rh,Pt)	Cubic, Fm$\bar{3}$m (225)	
(Cabri & Laflamme, 1974[1])		a = 3.84Å	Z = 4
Palladium	Pd	Cubic, Fm$\bar{3}$m (225)	
(Wollaston, 1803[2])		a = 3.89Å	Z = 4

Iridium	Ir	Cubic, $Fm\bar{3}m$ (225)	
(Hausmann, 1813[3])		a = 3.84Å	Z = 4
Platinum	Pt	Cubic, $Fm\bar{3}m$ (225)	
(Ulloa, 1748[4])		a = 3.92Å	Z = 4

---

[1] CM 1974, 399; Hull: 1920: SB 1, 69 (str)

[2] Hull & Davey: 1921, SB 1, 70 (str)

[3] Hull & Davey: *idem* (str); Singh: AC 1968, 469 (str)

[4] Hull & Davey: 1921, SB 1, 71 (str); Cabri & Feather: CM 1975, 117 (PGE nomenclature); Harris & Cabri: CM 1991, 231 (PGE nomenclature)

1.AG. PGE-Metal Alloys

Ru,Os-M Alloys

1.AG.05. **Hexaferrum**. Hexagonal close-packing; Zn structure type, *cf* ε-Fe.

Hexaferrum	(Fe,Os,Ru,Ir)	Hexagonal, $P6_3/mmc$ (194)	
(Mochalov *et al.*, 1998[1])		a = 2.59, c = 4.17Å	Z = 2

---

[1] ZVMO 1998 (5), 41; AM 1999, 1686 (Abst.)

Pd,Pt-M Alloys

1.AG.10. **Zvyagintsevite Group**. **Zvyagintsevite** has the auricupride (Cu_3Au) structure type. **Atokite** and **rustenburgite** may have the Cu structure type.

Zvyagintsevite	$Pd_3(Pb,Sn)$	Cubic, $Pm\bar{3}m$ (221)	
(Genkin *et al.*, 1966[1])	(ordered phase)	a = 4.03Å	Z = 1
Atokite	$(Pd,Pt)_3Sn$	Cubic, $Fm\bar{3}m$ (225)	
(Mihalik *et al.*, 1975[2])	(disordered phase)	a = 3.99Å	Z = 1
Rustenburgite	$(Pt,Pd)_3Sn$	Cubic, $Fm\bar{3}m$ (225) ?	
(Mihalik *et al.*, 1975[3])	(disordered phase?)	a = 3.99Å	Z = 1

---

[1] CM 1966, 541; Szymanski *et al.*: CM 1997, 773 (str)

[2] CM 1975, 146; AM 1976, 340 (Abst.)

[3] *idem*

1.AG.15. **Taimyrite Group**. Structures not known. Isotypes.

Taimyrite	$(Pd,Pt)_9Cu_3Sn_4$	Orthorhombic	
(Begizov *et al.*, 1982[1])		a = 7.88, b = 3.89, c = 7.88Å	Z = 1

Tatyanaite	$(Pt,Pd)_9Cu_3Sn_4$	Orthorhombic	
(Barkov *et al.*, 2000[2])		a = 7.89, b = 4.07, c = 7.73Å	Z = 1

---

[1] ZVMO 1982, 78; AM 1983, 1252 (Abst.) a, b, c = 16.11, 11.27, 8.64Å; 12.57, 13.40, 17.09Å; Barkov *et al.*: EJM 2000, 391 (data from Evstigneeva Nekrasov, 1984, for synthetic taimyrite)

[2] EJM 2000, 391; AM 2000, 1845 (Abst.)

1.AG.20. **Paolovite-Cabriite Group**. Structures not known.

Paolovite	Pd_2Sn	Orthorhombic, Pbnm (62)	
(Genkin *et al.*, 1974[1])		a = 8.11, b = 5.66, c = 4.32Å	Z = 4
Cabriite	Pd_2CuSn	Orthorhombic, Pmmm (47)	
(Evstigneeva & Genkin, 1983[2])		a = 7.88, b = 7.88, c = 3.94Å	Z = 4

---

[1] AM 1974, 1331 (Abst.)

[2] CM 1983, 481; AM 1984, 1190 (Abst.)

1.AG.25. **Stannopalladinite Group**. Structures related to that of nickeline.

Stannopalladinite	Pd_3Sn_2	Hexagonal, $P6_3/mmc$ (194)	
(Maslenitzki *et al.*, 1947[1])		a = 4.38, c = 5.66Å	Z = 1
Plumbopalladinite	Pd_3Pb_2	Hexagonal, $P6_3mc$ (186)	
(Genkin *et al.*, 1970[2])		a = 4.47, c = 5.72Å	Z = 1

---

[1] Shelton *et al.*: CM 1981, 599

[2] AM 1971, 1121 (Abst.); Shelton *et al.*: CM 1981, 599 (phase relations)

1.AG.30. **Reserved**. For future similar alloys.

1.AG.35. **Isoferroplatinum Group**. Probably auricupride (Cu_3Au) structure type.

Chengdeite	Ir_3Fe	Cubic, $Pm\bar{3}m$ (221)	
(Yu, 1995[2])		a = 3.79Å	Z = 1
Isoferroplatinum	Pt_3Fe	Cubic, $Pm\bar{3}m$ (221)	
(Cabri & Feather, 1975[1])		a = 3.86Å	Z = 1

---

[1] Acta Geol. Sinica 1995, 215; AM 1996, 516 (Abst.)

[2] CM 1975, 117; AM 1976, 338 (Abst.)

1.AG.40. **Tetraferroplatinum Group**. Isostructural with tetraauricupride; alternating (001) layers of Pt and (Fe,Cu) atoms.

Tulameenite	Pt_2FeCu	Tetragonal, P4/mmm (123)	
(Cabri *et al.*, 1973[1])		a = 3.89, c = 3.58Å	Z = 1
Tetraferroplatinum	PtFe	Tetragonal, P4/mmm (123)	
(Cabri & Feather, 1975[2])		a = 2.72, c = 3.69Å	Z = 1
Ferronickelplatinum	Pt(Ni,Fe)	Tetragonal, P4/mmm (123)	
(Rudashevskiy *et al.*, 1983[3])		a = 2.73, c = 3.64Å	Z = 1

---

[1] CM 1973, 21; AM 1974, 383 (Abst.); Shahmiri *et al.*: MM 1985, 547 (str)
[2] CM 1975, 117; AM 1976, 341 (Abst.); Tarkian: Min. Petrol. 1987/36, 169
[3] ZVMO 1983, 487; AM 1984, 1190 (Abst.); Bayliss: CM 1990, 751

1.AG.45. **Hongshiite**. Structure not known.

Hongshiite	PtCu	Trigonal, R$\bar{3}$m (166), R3m (160), R32 (155)	
(Yu *et al.*, 1974[1])		a = 10.71, c = 13.19Å	Z = 48

---

[1] AM 1984, 411 (Abst.)

1.AG.50. **Yixunite-Damiaoite Group**. **Yixunite** has the auricupride structure; **damiaoite** may be related.

Yixunite	Pt_3In	Cubic, Pm$\bar{3}$m (221)	
(Yu, 1997[1])		a = 3.99Å	Z = 1
Damiaoite	$PtIn_2$	Cubic, Fm$\bar{3}$m (225)	
(Yu, 1997[2])		a = 6.36Å	Z = 4

---

[1] AM 1998, 655 (Abst.)
[2] AM 1998, 653 (Abst.)

1.AG.55. **Niggliite**. Nickeline-type structure; cf. also yuanjiangite, AuSn.

Niggliite	PtSn	Hexagonal, P6_3/mmc (194)	
(Scholtz, 1936[1])		a = 4.10, c = 5.43Å	Z = 2

---

[1] Yushko-Zakharova & Chernaev: Dok. Earth Sci. 1966/170, 148 (str); Cabri & Harris: MM 1972, 794

1.B: Metal Carbides, Silicides, Nitrides and Phosphides

These can be regarded as interstitial alloys. The non-metal atoms (C, etc.) are located in small empty sites of the metal structures. High hardness, density and reflectivity. Metallic (and covalent) bonding. CN (of the non-metal atoms) is [4] or [6].

Subdivisions 1.BA. – 1.BD.

- 1.BA. Carbides
  - 1.BA.05. Martensite-“austenite”-cohenite group
  - 1.BA.10. Haxonite group
  - 1.BA.15. Tongbaite
  - 1.BA.20. Tantalcarbide group
  - 1.BA.25. Tungsten carbide
- 1.BB. Silicides
  - 1.BB.05. Suessite-gupeiite group
  - 1.BB.10. Perryite-xifengite group
  - 1.BB.15. Fersilicite-ferdisilicite group
- 1.BC. Nitrides
  - 1.BC.05. Roaldite-siderazot group
  - 1.BC.10. Osbornite-carlsbergite group
- 1.BD. Phosphides
  - 1.BD.05. Schreibersite group
  - 1.BD.10. Barringerite

1.BA. Carbides

1.BA.05. **Martensite-“Austenite”-Cohenite Group**. In **martensite** (magnetic steel) and **“austenite”** (non-magnetic steel), $C^{[6]}$ atoms are in octahedral coordination, interstitial in α’- and γ-Fe, whereas in **cohenite**, they are in triangular-prismatic coordination in pleated layers of hexagonal close-packed $Fe^{[11,12]}$ atoms. α’-Fe is tetragonally deformed α-Fe.

Martensite (Osmond, 1895, synthetic[1])	α’-Fe with ~ 0.3–1.5 % C	Tetragonal, I4/mmm (139) a ~ 2.85, c ~ 2.88–3.04Å	Z = 2
“Austenite” (Osmond, 1901, synthetic[2])	γ-Fe with ~ 2–7 % C	Cubic, Fm$\bar{3}$m (225) a = 3.63Å	Z = 4
Cohenite (Weinschenk, 1889[3])	Fe_3C (cementite in metallurgy)	Orthorhombic, Pnma (62) a = 5.09, b = 6.75, c = 4.52Å	Z = 4

---

[1] Calvert, 1993: PDF 44–1291; Roberts: J. Met. 1953, 203; Zhang *et al.*: Geochim. Cosmochim. Acta 1993, 3725 (in meteorites)

[2] Westgren & Phragmén: 1921, SB 1, 577 (str)

[3] Westgren & Phragmén: *idem* (str); Fasiska & Jeffrey: AC 1965/19, 463 (str)

1.BA.10. **Haxonite Group**. Isotypes. The structure may be related to γ-Fe and taenite.

Haxonite (Scott, 1971[1])	$(Fe,Ni)_{23}C_6$	Cubic, Fm$\bar{3}$m (225) a = 10.55Å	Z = 4
Isovite (Generalov *et al.*, 1998[2])	$(Cr,Fe)_{23}C_6$	Cubic, Fm$\bar{3}$m (225) a = 10.65Å	Z = 4

---

[1] Nature, Phys. Sci. 1971/229, 61; AM 1974, 209 (Abst.)

[2] ZVMO 1998 (5), 26; AM 1999, 1686 (Abst.)

1.BA.15. **Tongbaite**. The carbon atoms are at the centres of triangular prisms formed by six Cr atoms; these triangular prisms share faces to form columnes// [001] and edges // [001]; the Cr atoms are enclosed by five C atoms in the form of square pyramids.

Tongbaite (Tian *et al.*, 1983[1])	Cr_3C_2	Orthorhombic, Pnam (62) a = 5.57, b = 11.47, c = 2.82Å	Z = 4

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[1] Acta Min. Sinica 1983, 241; AM 1985, 218 (Abst.); Rundqvist & Runnsjö: 1969, SR 34A, 56 (str)

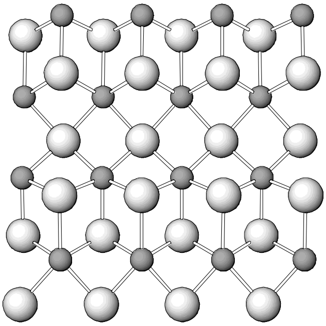

Fig 1.BA.15. A slice through the tongbaite structure approximately // (100), c-axis horizontal. Large spheres = Cr; small spheres = C.

1.BA.20. **Tantalcarbide Group**. Halite structure type.

Khamrabaevite (Novgorodova *et al.*, 1984[1])	TiC	Cubic, Fm$\bar{3}$m (225) a = 4.32Å	Z = 4
Niobocarbide (Novgorodova *et al.*, 1997[2])	(Nb,Ta)C	Cubic, Fm$\bar{3}$m (225) a = 4.45Å	Z = 4
Tantalcarbide (Frondel, 1962[3])	TaC	Cubic, Fm$\bar{3}$m (225) a = 4.45Å	Z = 4

---

[1] ZVMO 1984, 697; AM 1985, 1329 (Abst.)

[2] ZVMO 1997 (1), 76; AM 1998, 1117 (Abst.)

[3] AM 1962, 786; Schwarz & Summa: Metallwirtschaft 1933, 298 (str)

1.BA.25. **Tungsten Carbide**. A hexagonal array of W atoms, with $C^{[6]}$ in trigonal-prismatic interstices.

Tungsten Carbide (Zhang *et al.*, 1986[1])	WC	Hexagonal, P6_3/mmc (194) a = 2.90, c = 2.84Å	Z = 1

---

[1] AM 1989, 948 (Abst.); Glavatskikh *et al.*: AM 1998, 189 (Abst.); Westgren & Phragmén: 1926, SBI, 575 (str); Leciejewicz: AC 1961, 200 (str)

1.BB. Silicides

1.BB.05. **Suessite-Gupeiite Group**. The structure of **suessite** is similar to that of α-Fe; in **gupeite**, *a* is doubled.

Suessite	$Fe_{0.75}Si_{0.25}$	Cubic, $Im\bar{3}m$ (229)	
(Keil *et al.*, 1982[1])	(disordered α phase)	a = 2.84Å	Z = 2
Gupeiite	Fe_3Si (ordered phase)	Cubic, $Fm\bar{3}m$ (225)	
(Yu, 1984[2])		a = 5.67Å	Z = 4

---

[1] AM 1982, 126; Phragmén: 1926, SB 1, 589 (str); Weill: 1945, SR 10, 61 (str)

[2] AM 1986, 228 (Abst.)

1.BB.10. **Perryite-Xifengite Group**. In **perryite**, layers of $Ni^{[11-14]}$ atoms // (0001) alternate with layers of $Si^{[8-12]}$ atoms

Perryite	$(Ni,Fe)_8(Si,P)_3$	Trigonal, R3c (161)	
(Frederiksson & Henderson, 1965[1])		a = 6.64, c = 37.98Å	Z = 12
Xifengite	Fe_5Si_3 (η phase)	Hexagonal, $P6_3/mcm$ (193)	
(Yu, 1984[2])		a = 6.76, c = 4.72Å	Z = 2

---

[1] MM 1970, 905; Okada *et al.*: AC 1991.C, 1358 (str)

[2] AM 1986, 228 (Abst.); Weill, 1943, SR 10, 63 (str); Haughton, etc., 1930, 1937; SR 10,62 (Fe-Si phase diagram)

1.BB.15. **Fersilicite-Ferdisilicite Group**. **Fersilicite** has a distorted NaCl-type structure.

Fersilicite	FeSi (ε phase)	Cubic, $P2_13$ (198)	
(Gevorkyan *et al.*, 1969[1])		a = 4.46Å	Z = 4
Ferdisilicite	$FeSi_2$	Tetragonal, P4/mmm (123)	
(Gevorkyan *et al.*, 1969[2])		a = 2.69, c = 5.14Å	Z = 1

---

[1] Geol. Zhur. 1969 (2), 62; AM 1969, 1737 (Abst.); Wever & Möller: 1930, SB 2, 13 and 241 (str); Hanawalt *et al.*: Annal. Chem 1938/10, 475 (str)

[2] Geol. Zhur. 1969 (2), 62; AM 1969, 1737 (Abst.); Aronsson: Acta Chem. Scand. 1960, 1414 (str); PDF 35–822

1.BC. Nitrides

1.BC.05. **Roaldite-Siderazot Group**. In **roaldite**, the N atoms are ordered in tetrahedral sites, related to the γ-Fe phase. **Siderazot** is related to the ε-Fe phase.

Roaldite	Fe_4N	Cubic, $P\bar{4}3m$ (215)	
(Buchwald & Nielsen, 1981[1])		$a = 3.79Å$	$Z = 1$
Siderazot	Fe_3N	Hexagonal, $P6_322$ (182)	
(Silvestri, 1876[2])	(Fe:N ~3:1–3:1.5)	$a = 4.68$, $c = 4.37Å$	$Z = 2$

---

[1] Lunar Planet. Sc. 1981, 112; AM 1981, 1100 (Abst.); Jack: 1948, SR 11, 141 (str)

[2] Hendricks & Kosting: ZK 1930/74, 511; 1930, SB 2, 302 (str)

1.BC.10. **Osbornite Group**. Halite structure type.

Osbornite	TiN	Cubic, $Fm\bar{3}m$ (225)	
(Maskelyne, 1870[1])		$a = 4.24Å$	$Z = 4$
Carlsbergite	CrN	Cubic, $Fm\bar{3}m$ (225)	
(Buchwald & Scott, 1971[2])		$a = 4.16Å$	$Z = 4$

---

[1] Christensen: Acta Chem. Scand. A1975, 563 (str); Bashir *et al.*: J. Appl. Cryst. 1996, 471 (str)

[2] Nature, Phys. Sci. 1971/233, 113; AM 1972, 1311 (Abst.)

1.BD. Phosphides

1.BD.05. **Schreibersite Group**. An interstitial sheet structure // (001), with P coordinated by 9 (Fe,Ni) atoms, 8 within the sheets, 1 between the sheets.

Schreibersite	$(Fe,Ni)_3P$	Tetragonal, $I\bar{4}$ (82)	
(Patera, 1847[1])		$a = 9.04$, $c = 4.46Å$	$Z = 8$
Nickelphosphide	$(Ni,Fe)_3P$	Tetragonal, $I\bar{4}$ (82)	
(Britvin et al., 1999[2])		$a = 8.99$, $c = 4.40Å$	$Z = 8$

---

[1] Doenitz: ZK 1970/131, 222 (str)

[2] ZVMO 1999 (3), 64; AM 2000, 875 (Abst.)

1.BD.10. **Barringerite**. A close-packed arrangement of PFe_9, FeP_4 and FeP_5 polyhedra.

Barringerite	$(Fe,Ni)_2P$	Hexagonal, $P\bar{6}2m$ (189)	
(Buseck, 1969[1])		$a = 5.87$, $c = 3.46Å$	$Z = 3$

---

[1] Science1969/165, 169; AM 1970, 317 (Abst.); Rundqvist & Jellinek: Acta Chem. Scand. 1959, 425 (str)

1.C: Metalloids and Nonmetals

In the metalloids and nonmetals, the atomic orbitals can be hybridized in different ways to create a variety of structures that can have metalloid or nonmetallic character depending on the electronic interactions between neighbouring atoms. In the non-metals, there is covalent and van der Waals bonding.

Subdivisions 1.CA. – 1.CC.

- 1.CA. Arsenic group elements
  - 1.CA.05. Arsenic group
  - 1.CA.10. Arsenolamprite
  - 1.CA.15. Paradocrasite
- 1.CB. Carbon-silicon family
  - 1.CB.05. Graphite group
  - 1.CB.10. Diamond group
  - 1.CB.15. Silicon
- 1.CC. Sulfur-selenium-iodine
  - 1.CC.05. Sulfur group
  - 1.CC.10. Selenium group
  - 1.CC.15. Iodine

1.CA. Arsenic-Group Elements

1.CA.05. **Arsenic Group**. In **arsenic**, $As^{[3]}$ atoms form puckered sheets of trigonal 6-membered rings // (0001), with stacking as in graphite-3*R*. Covalent bonding within the sheets, metalloid bonding between the sheets. The a : c ratio decreases in the order **arsenic-stibarsen-antimony-bismuth**, resulting in increasing metallic character.

Arsenic* (*Anon.*[1])	As	Trigonal, $R\bar{3}m$ (166) a = 3.76, c = 10.55Å	Z = 6
Stibarsen (Wretblad, 1941[2])	AsSb	Trigonal, $R\bar{3}m$ (166) a = 4.02, c = 10.80Å	Z = 3
Antimony (*Anon.*[3])	Sb	Trigonal, $R\bar{3}m$ (166) a = 4.31, c = 11.27Å	Z = 6
Bismuth (Agricola, 1439[4])	Bi	Trigonal, $R\bar{3}m$ (166) a = 4.54, c = 11.86Å	Z = 6

---

* In German: As = Arsen, As_2O_3 = Arsenic (highly poisonous).

[1] Schiferl & Barrett: J. Appl. Cryst. 1969, 30 (str); Swanson & Fuyat, 1954: PDF 5–632

[2] AM 1941, 456 (Abst.); Ferguson: PDF 31–80

[3] Barrett *et al.*: AC 1963, 451 (str); Swanson & Fuyat, 1954: PDF 35–732

[4] Barrett: Austral. J. Phys. 1960, 200 (str); Swanson & Fuyat, 1954: PDF 5–519

1.CA.10. **Arsenolamprite**. The $As^{[3]}$ atoms are in widely separated double layers // (001). Dimorphs arsenic, arsenolamprite.

Arsenolamprite (Hintze, 1886[1])	As (orthorhombic)	Orthorhombic, Bmab (64) a = 3.63, b = 4.45, c = 10.96Å	Z = 8

---

[1] Johan: Chem. Erde 1959, 71; Clark: MM 1970, 732; Smith *et al.*: Phil. Mag. 1975, 57 (str)

1.CA.15. **Paradocrasite**. Structure not known.

Paradocrasite	$Sb_2(Sb,As)_2$	Monoclinic, C2 (5)	
(Leonard *et al.*, 1971[1])		a = 7.25, b = 4.17, c = 4.43Å	
		β = 123.1°	Z = 1

---

[1] AM 1971, 1127

1.CB. Carbon-Silicon Family

1.CB.05. **Graphite Group**. In **graphite**, $C^{[3]}$ atoms form planar sheets of hexagonal rings // (0001); covalent bonding within the sheets (three hybrid sp^2 electrons of each C atom overlap their orbitals with those of three neighbouring C atoms; C-C = 1.42Å), metalloid bonding between the sheets by “free” π electrons; (C-C = 3.35Å). **Fullerenes,** artificial C_{60} and C_{70}, from hollow spheres composed of 5- and 6-membered rings; the spheres may cristalize in cubic or hexagonal closest packing.

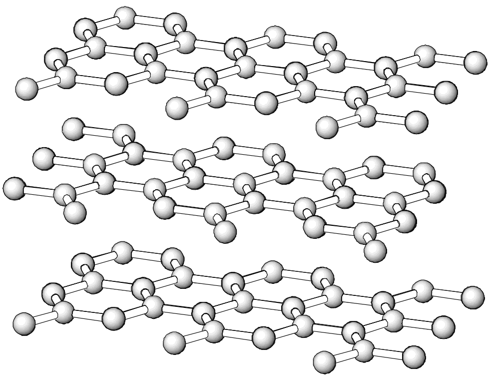

Fig 1.CB.05. The structure of graphite showing the sheets of 6-membered $C^{[3]}$ rings // (0001).

Graphite-2*H*	C	Hexagonal, $P6_3/mmc$ (194)	
(Werner, 1789[1])		a = 2.46, c = 6.71Å	Z = 4
Graphite-3*R*	C	Trigonal, $R\bar{3}m$ (166)	
(Lipson & Stokes, 1942[2])		a = 2.46, c = 10.06Å	Z = 6
“Chaoite”	C	Hexagonal, P6/mmm (191) ?	
(El Goresy, 1970[3])		a = 8.95, c = 14.08Å	Z = 168
“Fullerite”	C_{60}	Cubic (Cu-type structure)	
(Parthasarathy et al., 1998[4])		a = 14.20Å	Z = 4

---

[1] Hull: 1917, SB 1, 28 (str); Trucano & Chen: Nature 1975/258, 136 (str)
[2] Nature 1942/149, 328 (str); Holcombe 1974: PDF 26–1079 (R3)
[3] Smith & Buseck: Science 1982/216, 984 (a mixture); AM 1983, 1251 (Abst.)
[4] Parthasarathy et al., 1998; AM 1999, 1686 (Abst.); Novgorodova: 1999; AM 2000, 629 (Abst.; tetragonal, $\alpha = 14.22$, $c = 13.56$Å)

1.CB.10. **Diamond Group**. **Diamond** has a cubic tetrahedral framework structure. Four C atoms at the corners and the three face-centres of the unit cell correspond to cubic closest packing; four of the eight tetrahedral sites in this packing are occupied by C atoms, the remainder are empty. Corner-sharing CC_4 tetrahedra form a framework with channels along the six <110> directions. Extremely strong covalent bonding (4 hybridized sp^3 electrons of each C atom overlap their orbitals in <111> directions with those of four neighbouring C atoms; C-C = 1.54Å); This very strong bonding is responsible for the extreme properties exhibited by this mineral. **Lonsdaleite**, a dimorph of diamond, has a hexagonal tetrahedral framework structure. Members of the sphalerite-wurtzite family are homeotypes of diamond and lonsdaleite.

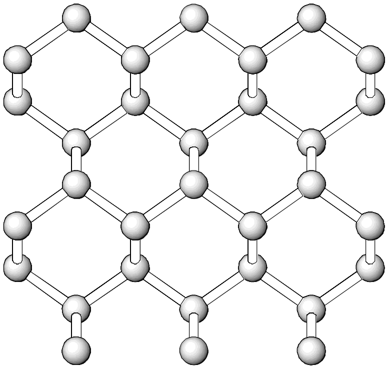

Fig 1.CB.10. *The structure of diamond projected on (110).*

Diamond (Pliny, A. D. 77[1])	C	Cubic, $Fd\bar{3}m$ (227) a = 3.567Å	Z = 8
Lonsdaleite (Frondel & Marvin, 1967[2])	C	Hexagonal, $P6_3/mmc$ (194) a = 2.51, c = 4.12Å	Z = 4
“Lonsdaleite-4*H*” (O’Keeffe & Hyde, 1996[3])	C	Hexagonal, $P6_3/mmc$ (194) a = 2.51, c = 8.12Å	Z = 8

---

[1] Hist. Nat. 37,15; W. H. Bragg & W. L. Bragg: Proc. Roy. Soc. 1913, 277 (str); Straumanis & Aka: J. Am. Chem. Soc. 1951, 5643 (str)
[2] Nature 1967/214, 587; AM 1967, 1579 (Abst.); Ownby *et al.*: J. Am. Ceram. Soc. 1992, 1876 (str)
[3] O’Keeffe & Hyde: Crystal Structures I, 1996, 301 (str, synth. product)

1.CB.15. **Silicon**. Diamond structure type.

Silicon	Si	Cubic, $Fd\bar{3}m$ (227)	
(Marshintsev *et al.*, 1982[1])		a = 5.43Å	Z = 8

---

[1] Dok. Earth Sci. 1982/262, 163; Novgorodova *et al.*: AM 1991, 668 (Abst.); Debye & Scherrer: 1916, SB 1, 52 (str)

1.CC. Sulfur-Selenium-Iodine

1.CC.05. **Sulfur Group**. Molecules of puckered 8-membered rings of S atoms, with covalent bonding within the molecules and van der Waals bonding between the molecules.

Sulfur	α-S	Orthorhombic Fddd (70)	
(*Anon.*[1])		a = 10.44, b = 12.84, c = 24.37Å	Z = 128
β-Sulfur	β-S	Monoclinic, $P2_1/a$ (14)	
(Panichi, 1912[2])		a = 10.85, b = 10.93, c = 10.95Å	
		β = 96.2°	Z = 48
Rosickyite	γ-S	Monoclinic, P2/c (13)	
(Sekanina, 1931[3])		a = 8.44, b = 13.02, c = 9.36Å	
		β = 125.0°	Z = 32

---

[1] Warren & Burwell: J. Chem. Phys. 1935, 6 (str); Rettig & Trotter: AC 1987.C, 2260 (str)

[2] Burwell: ZK 1937/97, 132; SB 5, 29 (str); Sands: J. Am. Chem. Soc. 1965, 1395 (str)

[3] Y. Watanabe: AC 1974.B, 1396 (str)

1.CC.10. **Selenium Group**. Helical chains // [001]; covalent bonding along the chains, metalloid bonding between the chains.

Selenium	γ-Se	Trigonal, $P3_121$ (152) and $P3_221$ (154)	
(Berzelius, 1818[1])		a = 4.37, c = 4.95Å	Z = 3
Tellurium	γ-Te	Trigonal, $P3_121$ (152) and $P3_221$ (154)	
(Klaproth, 1802[2])		a = 4.46, c = 5.92Å	Z = 3

---

[1] Bradley: 1924. SB1, 31 (str); Marsh *et al.*: AC 1953, 71 (str)

[2] Cherin & Unger: AC 1967/23, 670 (str)

1.CC.15. **Iodine**. I_2 molecules in sheets // (010).

Iodine	I_2	Orthorhombic Ccmb (64)	
(Matteucci, 1897[1])		a = 4.79, b = 7.27, c = 9.80Å	Z = 4

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[1] Harris *et al.*: J. Am. Chem. Soc. 1928, 1583 (str); SB1, 760

1.D: Nonmetal Carbides and Nitrides

Minerals in this Division have covalent bonding and nonmetallic character.

Subdivisions 1.DA. – 1.DB.

- 1.DA. Nonmetal Carbides
    - 1.DA.05. Moissanite group
- 1.DB. Nonmetal Nitrides
    - 1.DB.05. Nierite
    - 1.DB.10. Sinoite
    - 1.DB.15. “Borazon”

1.DA. Nonmetal Carbides

1.DA.05. **Moissanite Group**. Synthetic SiC (carborundum: Acheson, 1893), and the naturally-occurring mineral (Moissan, 1894), **moissanite** (Kunz, 1895), occur as a wide range of polytypes, which are differentiated by crystallographic suffixes (introduced by Ramsdell[2], 1947). **Moissanite-3*C*** (β-moissanite) has the sphalerite structure type (β-ZnS), and **moissanite-2*H*** (α-moissanite), the wurtzite (α-ZnS) structure type (α-moissanite includes all hexagonal and trigonal polytypes). Strong covalent bonding, hardness 9½, an important abrasive.

Moissanite-3*C* (Regis & Sand, 1958[1])	β-SiC	Cubic, F$\bar{4}$3m (216) a = 4.35Å	Z = 4
Moissanite-2*H* (Kunz, 1905[2])	α-SiC	Hexagonal, P6_3mc (186) a = 3.08, c = 5.05Å	Z = 2
Moissanite-4*H* (artificial[3])	SiC	Hexagonal, P6_3mc (186) a = 3.09, c = 10.09Å	Z = 4
Moissanite-5*H* (Gevorkyan *et al.*, 1974[4])	SiC	Hexagonal a = 3.06, c = 12.58Å	Z = 5
Moissanite-6*H* (Kunz, 1905[5])	SiC	Hexagonal, P6_3mc (186) a = 3.09, c = 15.17Å	Z = 6
Moissanite-15R (Marshintsev *et al.*, 1990[6])	SiC	Trigonal, R3m (160) a = 3.09, c = 37.95Å	Z = 15
Moissanite-33R (Marshintsev, 1990[7])	SiC	Trigonal a = 3.08, c = 83.0Å	Z = 33

---

[1] Bull. Geol. Soc. Am. 1958/69, 1633; Bräkken: ZK 1930/75, 573 (str)

[2] Am. J. Sci. 1905, ser. 4/19, 396 (unspecified polytype); Ott: ZK 1926/63, 1; SB 1, 145 (str); Ramsdell: AM 1947, 64; Shaffer: AC 1969.B, 477 (extended classification of the polytypes)

[3] Ott: *idem* (str)

[4] ZVMO 1974, 106; AM 1976, 1054 (Abst.)

[5] Am. J. Sci. 1905, ser. 4/19, 396; Ott: *idem* (str); Bauer *et al.*: AM 1963, 620. Strongly prevalent in synthetic products and in nature

[6] Min. Zhur. 1990 (3), 17; AM 1992, 208 (Abst.); Ott: *idem* (str)

[7] Min. Zhur. 1990 (3), 17; AM 1992, 208 (Abst.)

1.DB. Nonmetal Nitrides

1.DB.05. **Nierite**. A framework of corner-sharing SiN_4 tetrahedra; each N atom is surrounded by 3 Si atoms in a triangular configuration.

Nierite	α-Si_3N_4	Trigonal, P31c (159)	
(Lee *et al.*, 1995[1])		a = 7.74, c = 5.61Å	Z = 4

---

[1] Meteoritics 1995, 387; Marchand *et al.*: AC 1969.B, 2157 (str)

1.DB.10. **Sinoite**. A framework of corner-sharing SiN_3O tetrahedra.

Sinoite	Si_2N_2O	Orthorhombic, $Cmc2_1$ (36)	
(Anderson *et al.*, 1964[1])		a = 8.84, b = 5.47, c = 4.84Å	Z = 4

---

[1] Science, 1964/146, 256; AM 1965, 521 (Abst.); Brosset & Idrestedt: Nature 1964/201, 1211 (str)

1.DB.15. **"Borazon"**. Sphalerite structure type; a high-pressure product of hexaonal BN.

"Borazon"	BN	Cubic, $F\bar{4}3m$ (216)	
		a = 3.61Å	Z = 4

Wentorf: J. Chem. Phys. 1957/26, 956 (synthet.)

CLASS 2. SULFIDES and SULFOSALTS

(Sulfides, selenides, tellurides; arsenides, antimonides, bismuthides; sulfarsenites, sulfantimonites, sulfbismuthites, etc.)

The minerals in this class are compounds of metals with S, Se, Te (chalcogens) and As, Sb Bi (metalloids). A wide range of bonding types is represented, including metallic, covalent and ionic. The appearance is predominantly metallic, although the minerals in the 2.F division are mainly non-metallic. The classification begins with the **Metal/Metalloid Alloys (2.A)**, followed by the **Simple Sulfides, Selenides, etc. (2.B to 2.F)**, and the complex sulfides or **Sulfosalts (2.G to 2.K)**.

The **Simple Sulfides** are classified into **Divisions** on the basis of the metal:sulfur ratio, M:S = 2:1, 1:1, 3:4 and 2:3, 1:2, and higher. The **Subdivisions** are generally arranged according to the position of the metals in the Periodic System of the Elements, and increasing ionic size or coordination number [CN]. **Groups** combine mineral species with isotypic (or homeotypic) structures; groups with two or more mineral names include heterotypes.

The **Sulfosalts*** are characterized by the presence of trigonal pyramids that represent the fundamental building blocks in the structure. These trigonal pyramids include $[AsS_3]^{3-}$, $[SbS_3]^{3-}$ or $[BiS_3]^{3-}$, and consist of three sulfur atoms forming the base of the pyramid, and the metalloids As, Sb or Bi at the apex. This can be attributed to the lone-electron-pair effect of the metalloid ions. The classification of the sulfosalts is based partly on the chemical-structural scheme developed by Nowacki (*Schweiz. Min. Petr. Mitt.* 1969, 109–156) and Edenharter (*Schweiz. Min. Petr. Mitt.* 1976, 195–217), and partly on the concept of SnS and PbS archetypes and the incorporation of these structural elements into homologous series by Makovicky (*N. Jb. Min., Abh.*1989, 269–297, etc.).

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* Berzelius (1819).

2.A: Metal/Metalloid Alloys

Subdivisions 2.AA – 2.AC.

2.AA. Alloys of metalloids with Cu, Ag, Au
    2.AA.05. Algodonite-domeykite group
    2.AA.10. Koutekite
    2.AA.15. Novákite
    2.AA.20. Horsfordite-cuprostibite group
    2.AA.25. Kutinaite
    2.AA.30. Allargentum-dyscrasite group
    2.AA.35. Maldonite
2.AB. Ni-metalloid alloys
    2.AB.05. Dienerite
    2.AB.10. Orcelite
    2.AB.15. Maucherite
2.AC. Alloys of metalloids with PGE
    2.AC.05. Atheneite-vincentite group
    2.AC.10. Stillwaterite group
    2.AC.15. Isomertieite
    2.AC.20. Stibiopalladinite-palladoarsenide group
    2.AC.25. Polarite group
    2.AC.30. Rhodarsenide group
    2.AC.35. Polkanovite

2.AA. Alloys of Metalloids with Cu, Ag, Au

2.AA.05. **Algodonite-Domeykite Group**. **Algodonite** has hexagonal close-packing of Cu atoms, stabilized by disordered partial replacement of Cu by As; Zn-type derivative. In **domeykite**, the arsenic forms a body-centred cubic lattice with Cu in the interstices; Cu is coordinated by three As and six Cu; As is coordinated by nine Cu. In **β-domeykite**, the arsenic is in hexagonal close packing with Cu in tetrahedral interstices.

Algodonite	α-$Cu_{1.7}As_{0.3}$	Hexagonal, $P6_3/mmc$ (194)	
(Field, 1857[1])		a = 2.59, c = 4.23Å	Z = 1
Domeykite	α-Cu_3As	Cubic, $I\bar{4}3d$ (220)	
(Haidinger, 1845[2])		a = 9.62Å	Z = 16
β-Domeykite	β-Cu_3As to	Trigonal, $P\bar{3}c1$ (165)	
(Padera, 1952[3])	$Cu_{2.6}As$ (>225 °C)	a = 7.14, c = 7.32Å	Z = 6

---

[1] Naud & Priest: Mater. Res. Bull. 1972, 782 (str)
[2] Iglesia & Nowacki: ZK 1977/145, 334 (str)
[3] MA 1953/12, 201 (Abst.); Makovicky *et al.*: Ah 1979/135, 221; Mansmann: ZK 1965/122, 399 (str)

2.AA.10. **Koutekite**. The structure is a derivative of the fluorite structure.

Koutekite	Cu_5As_2	Orthorhombic, Ibam (72)	
(Johan, 1958[1])		a = 5.98, b = 11.58, c = 5.49Å	Z = 4

---

[1] Nature 1958/181, 1553; AM 1958, 794 (Abst.); Makovicky *et al.: idem.*; Liebisch & Shubert: J. Less-Comm. Metals 1971, 231 (str); Abulgazina *et al.*: AM 1993, 677 (Abst.)

2.AA.15. **Novákite**. Structure not known.

Novákite	$Cu_{20}AgAs_{10}$	Monoclinic, C2/m (12), C2 (5) or Cm (8)	
(Johan & Hak, 1961[1])		a = 16.27, b = 11.71, c = 10.01Å	
		β = 112.7°	Z = 4

---

[1] AM 1961, 885; Johan: TMPM 1985/34, 167

2.AA.20. **Horsfordite-Cuprostibite Group**. In **cuprostibite**, there is close-packing of Cu and Sb atoms, with each Cu atom coordinated by 8Cu and 4Sb, and each Sb coordinated by 9Cu.

Horsfordite	Cu_5Sb	No data known.
(Laist & Norton, 1888[1])		

Cuprostibite	Cu_2Sb	Tetragonal, P4/nmm (129)	
(Sörensen *et al.*, 1969[2])		a = 3.99, c = 6.09Å	Z = 2

---

[1] Possibly an unstable high-temperature phase.

[2] ZVMO 1969, 716; AM 1970, 1810 (Abst.); Elander *et al.*: Ark. Kem. Min. Geol. 1935/12B, 1 (str)

2.AA.25. **Kutinaite**. Structure not known.

Kutinaite	$Cu_7Ag_3As_{3.5}$	Cubic	
(Hak *et al.*, 1970[1])		a = 11.76Å	Z = 8

---

[1] AM 1970, 1083; Johan: TMPM 1985/34, 167

2.AA.30. **Allargentum-Dyscrasite Group**. Approximate hexagonal close-packing of Ag and Sb; Zn-type derivatives. In **allargentum**, the Ag and Sb are disordered. In **dyscrasite**, the Ag and Sb atoms are ordered into alternating pseudo-hexagonal close-packed layers SbAg and AgAg.

Allargentum	$Ag_{1-x}Sb_x$	Hexagonal, $P6_3/mmc$ (194)	
(Ramdohr, 1950[1])	(x = 0.09–0.16)	a = 2.95, c = 4.77Å	Z = 2
Dyscrasite	Ag_3Sb	Orthorhombic, Pm2m (25)	
(Beudant, 1832[2])		a = 3.01, b = 5.21, c = 4.83Å	Z = 1

---

[1] Petruk *et al.*: CM 1970, 163; Weibke & Efinger: Z. Elektrochem. 1940, 53 (str)

[2] Peacock: Univ. Toronto, Geol. Ser. 1940/44, 31 (str, setting); Scott: CM 1976, 139 (str)

2.AA.35. **Maldonite**. $Bi[Bi_4]$ tetrahedra form a framework like that of C in diamond, with Au in the interstices; a Laves phase.

Maldonite	Au_2Bi	Cubic, $Fd\bar{3}m$ (227)	
(Ulrich, 1869[1])		a = 7.98Å	Z = 8

---

[1] Prokuronov *et al.*: ZVMO 1976, 453; Jurriaanse: ZK 1935/90, 322 (str); SB3, 612

2.AB. Ni-Metalloid Alloys

2.AB.05. **Dienerite** (doubtful validity)

Dienerite	Ni_3As	Cubic
(Doelter, 1926[1])		

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[1] No crystallographic data available; original specimen lost.

2.AB.10. **Orcelite**. Structure not known.

Orcelite (Caillère *et al.*, 1959[1])	$Ni_{5-x}As_2$ (x = 0.23)	Hexagonal, $P6_3cm$ (185) a = 6.70, c = 12.39Å	 Z = 6

---

[1] CR 1959/249, 1771; AM 1960, 753 (Abst.); Oen *et al.*: BM 1980, 198

2.AB.15. **Maucherite**. $NiAs_5$ square pyramids (as in millerite) and $NiAs_6$ octahedra share edges and faces to form a framework with short Ni-Ni distances.

Maucherite (Grünling, 1913[1])	$Ni_{11}As_8$	Tetragonal, $P4_12_12$ (92) or $P4_32_12$ (96) a = 6.87, c = 21.82Å	 Z = 4

---

[1] Fleet: AM 1973, 203 (str)

2.AC. Alloys of Metalloids with Platinum-Group Elements

2.AC.05. **Atheneite-Vincentite Group**. M : (As,Sb,Bi) ≥ 3.0 : 1. Structures not known.

Atheneite (Clark *et al.*, 1974[1])	$(Pd,Hg)_3As$	Hexagonal, P6/mmm (191) a = 6.80, c = 3.48Å	 Z = 2
Vincentite (Stumpfl & Tarkian, 1974[2])	$(Pd,Pt)_3$ (As,Sb,Te)	Monoclinic, P2/m (10) a = 11.18, b = 10.31, c = 4.31Å β = 98.1°	 Z = 8

---

[1] MM 1974, 528; AM 1974, 1330 (Abst.)
[2] MM 1974, 525 (tetr.); AM 1974, 1332 (Abst.); Bayliss, 1991: PDF 44–1432

2.AC.10. **Stillwaterite Group**. M : (As,Sb,Sn) < 3.0 : 1, > 2.5 : 1. Structures not known; **Mertieite-I** is dimorphous with isomertieite.

Stillwaterite (Cabri *et al.*, 1975[1])	Pd_8As_3	Trigonal, $P\bar{3}$ (147) or P3 (143) a = 7.40, c = 10.31Å	 Z = 3
Palarstanide (Begizov *et al.*, 1981[2])	~ $Pd_8(Sn,As)_3$	Trigonal a = 7.50, c = 10.34Å	 Z = 3
Mertieite-I (Desborough *et al.*, 1973[3])	$Pd_{11}As_2Sb_2$	Pseudo-hexagonal a = 15.04, c = 22.41Å	 Z = 18
Mertieite-II (Desborough *et al.*, 1973[4])	$Pd_8(Sb,As)_3$	Hexagonal a = 7.55, c = 43.18Å	 Z = 12

Arsenopalladinite	$Pd_8(As_{2.5}Sb_{0.5})$	Triclinic, P1 (1) or P$\bar{1}$ (2)	
(Claringbull & Hey, 1956[5])		a = 7.43, b = 13.95, c = 7.35Å	
		α = 92.9, β = 119.5, γ = 87.8°	Z = 6

---

[1] CM 1975, 321; AM 1977, 1060 (Abst.)

[2] ZVMO 1981, 487; AM 1982, 858 (Abst.); Evstigneeva & Genkin: AM 1989, 1219 (Abst., new data)

[3] AM 1973, 1; PDF 25–698

[4] AM 1973, 1; Cabri *et al.*: CM 1975, 321

[5] MA 1957/13, 237 (Abst.); Clark *et al.*: MM 1974, 528; Cabri *et al.*: CIM Spec. Vol. 1981/23, 83

2.AC.15. **Isomertieite**. Structure not known.

Isomertieite	$Pd_{11}As_2Sb_2$	Cubic, Fd$\bar{3}$m (227)	
(Clark *et al.*, 1974[1])		a = 12.28Å	Z = 8

---

[1] MM 1974, 528; AM 1983, 851 (Abst.)

2.AC.20. **Stibiopalladinite-Palladoarsenide Group**. M:(As,Sb,Bi) ≤ 2.5:1, > 1:1. Structures not known. **Majakite** may be an isotype of barringerite $(Fe,Ni)_2P$.

Stibiopalladinite	Pd_5Sb_2	Hexagonal, P6_3cm (185)	
(Adam, 1927[1])		a = 7.61, c = 14.21Å	Z = 6
Palladoarsenide	Pd_2As	Monoclinic, P2/m (10)	
(Begizov *et al.*, 1974[2])		a = 9.25, b = 8.47, c = 10.44Å	
		β = 94°	Z = 18
Palladobis-mutharsenide	$Pd_2As_{0.8}Bi_{0.2}$	Orthorhombic, Pmcn (62) or P2_1cn (33)	
		a = 7.50, b = 18.88, c = 6.84Å	Z = 20
(Cabri *et al.*, 1976[3])			
Majakite	PdNiAs	Hexagonal, P$\bar{6}$2m (189) (?)	
(Genkin *et al.*, 1976[4])		a = 6.07, c = 7.20Å	Z = 6
Genkinite	$(Pt,Pd)_4Sb_3$	Tetragonal	
(Cabri *et al.*, 1977[5])		a = 7.74, c = 24.16Å	Z = 8

---

[1] El Boragy *et al.*: J. Less-Comm. Metals 1970/22, 445

[2] ZVMO 1974, 104; AM 1975, 162 (Abst.)

[3] CM 1976, 410

[4] ZVMO 1976, 698; AM 1977, 1260 (Abst.)

[5] CM 1977, 389; AM 1979, 654 (Abst.)

2.AC.25. **Polarite Group**. M:(As,Sb,Bi) ≤ 1:1. Structures not known.

Borishanskiite	$Pd(As,Pb)_2$	Orthorhombic, $Ccm2_1$ (36) ?	
(Razin *et al.*, 1975[1])		a = 7.18, b = 8.62, c = 10.66Å	Z = 16
Polarite	Pd(Bi,Pb)	Orthorhombic, $Ccm2_1$ (36)	
(Genkin *et al.*, 1969[2])		a = 7.19, b = 8.69, c = 10.68Å	Z = 16

---

[1] ZVMO 1975, 57; AM 1976, 502 (Abst.)
[2] ZVMO 1969, 708; AM 1970, 1810 (Abst.)

2.AC.30. **Rhodarsenide Group**. Structure not known.

Rhodarsenide	$(Rh,Pd)_2As$	Orthorhombic	
(Tarkian *et al.*, 1997[1])		a = 5.87, b = 3.89, c = 7.30Å	Z = 4
Palladodymite	$(Pd,Rh)_2As$	Orthorhombic, Pnma (62)	
(Britvin *et al.*, 1999[2])		a = 5.91, b = 3.90, c = 7.34Å	Z = 4

---

[1] EJM 1997, 1321; AM 1998, 909 (Abst.)
[2] ZVMO 1999 (2), 39; AM 2000, 876 (Abst.)

2.AC.35. **Polkanovite**. A framework of edge-sharing $RhAs_5$ square pyramids and $RhAs_4$ tetrahedra.

Polkanovite	$Rh_{12}As_7$	Trigonal, $P6_3/m$ (176)	
(Britvin *et al.*, 1998[1])		a = 9.31, c = 3.64Å	Z = 1

---

[1] ZVMO 1998 (2), 60; AM 1999, 195 (Abst.); Lambert-Andron *et al.*: J. Less-Comm. Metals 1985/108, 353 (str)

Simple Sulfides, Selenides, etc. (2.B to 2.F)

2.B: Metal Sulfides, M:S $>$ 1:1 (mainly 2:1)

Subdivisions 2.BA. – 2.BE.

- 2.BA. With Cu, Ag, Au
  - 2.BA.05. Chalcocite-digenite group
  - 2.BA.10. Bornite
  - 2.BA.15. Berzelianite-umangite group
  - 2.BA.20. Weissite-rickardite group
  - 2.BA.25. Acanthite group
  - 2.BA.30. Stromeyerite-jalpaite group
  - 2.BA.35. Eucairite-naumannite group
  - 2.BA.40. Henryite-hessite group
  - 2.BA.45. Argyrodite group
  - 2.BA.50. Petzite group
  - 2.BA.55. Bezsmertnovite group

- 2.BB. With Ni
    - 2.BB.05. Heazlewoodite group
    - 2.BB.10. Hauchecornite group
    - 2.BB.15. Pentlandite group
- 2.BC. With Rh, Pd, Pt, etc.
    - 2.BC.05. Prassoite group
    - 2.BC.10. Oosterboschite
    - 2.BC.15. Chrisstanleyite
    - 2.BC.20. Telargpalite-sopcheite group
    - 2.BC.25. Luberoite
- 2.BD. With Hg, Tl
    - 2.BD.05. Balkanite-imitérite group
    - 2.BD.10. Carlinite
    - 2.BD.15. Thalcusite-sabatierite group
- 2.BE. With Pb(Bi)
    - 2.BE.05. Betekhtinite-furotobeite group
    - 2.BE.10. Shandite group

2.BA. With Cu, Ag and/or Au

2.BA.05. **Chalcocite-Digenite Group**. Both **chalcocite** modifications have hexagonal close-packing of S atoms; in **high chalcocite**, the Cu atoms are disordered and statistically distributed between triangular, tetrahedral and 2-coordinated sites; in **low chalcocite**, the Cu atoms are ordered, with most in triangular coordination. The **djurleite** structure is similar. In **tetragonal chalcocite**, the Cu atoms have triangular coordination. Both **digenite** modifications have cubic close-packing of S atoms with Cu in octahedral, tetrahedral and triangular sites.

Chalcocite (Beudant, 1832[1])	α-Cu_2S (<103 °C)	Monoclinic, $P2_1/c$ (14) (pseudo-hexagonal) a = 15.25, b = 11.88, c = 13.49Å β = 116.3°	Z = 48
Chalcocite (high) (Buerger, 1941[2])	β-Cu_2S (>103 °C)	Hexagonal, $P6_3/mmc$ (194) a = 3.95, c = 6.75Å	Z = 2
Chalcocite (tetragonal) (Clark & Sillitoe, 1971[3])	$Cu_{1.96}S$	Tetragonal, $P4_12_12$ (92) a = 4.00, c = 11.29Å	Z = 4
Djurleite (Roseboom, 1962[4])	$Cu_{1.96}S$	Monoclinic, $P2_1/n$ (14) a = 26.90, b = 15.75, c = 13.47Å β ~ 90.1°	Z = 128
Roxbyite (Mumme *et al.*, 1988[5])	$Cu_{2-x}S$ (x = 0.18–0.26)	Monoclinic, C2/m (12), C2 (5) or Cm (8) a = 53.79, b = 30.90, c = 13.36Å β = 90.0°	Z = 4x128
Digenite (Breithaupt, 1844[6])	$Cu_{1.8}S$	Trigonal, $R\bar{3}m$ (166), pseudo-cubic a = 3.92, c = 48.00Å	Z = 15
Digenite (high) (Morimoto & Kullerud, 1963[7])	β-$Cu_{1.8}S$	Cubic, $Fm\bar{3}m$ (225) a = 5.57Å	Z = 4
Anilite (Morimoto *et al.*, 1969[8])	$Cu_{1.75}S$	Orthorhombic, Pnma (62) a = 7.89, b = 7.84, c = 11.01Å	Z = 16
Geerite (Goble & Robinson, 1980[9])	$Cu_{1.6}S$	Trigonal (pseudo-cubic, a' = 5.41) a = 3.86, c = 46.1Å	Z = 15

Structures related to covellite

Spionkopite	$Cu_{1.39}S$	Trigonal, P$\bar{3}$m1 (164), P321 (150), P3m1 (156)	
(Goble, 1980[10])		a = 22.96, c = 41.43Å	Z = 504
Yarrowite	$Cu_{1.12}S$	Trigonal, P$\bar{3}$m1 (164), P321 (150), P3m1 (156)	
(Goble, 1980[11])		a = 3.80, c = 67.26Å	Z = 24

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[1] Evans: ZK 1979/150, 299 (str)
[2] Buerger & Wuensch: Science 1963/141, 276 (str)
[3] Mh 1971, 418; Skinner: Ec. Geol. 1970, 724; Jánosi: AC 1964, 311 (str)
[4] AM 1962, 1181; Evans: ZK 1979/150, 299 (str)
[5] MM 1988, 323; AM 1989, 946 (Abst.)
[6] Donnay *et al.*: AM 1958, 228 (str)
[7] AM 1963, 110 (str)
[8] AM 1969, 1256; Koto & Morimoto: AC 1970.B, 915 (str)
[9] CM 1980, 519; Goble: CM 1985, 61 (may be rhombohedral)
[10] CM 1980, 511; AM 1981, 1279 (Abst.); Goble: CM 1985, 61 (str)
[11] *idem*

2.BA.10. **Bornite**. Face-centred cubic close-packing of S atoms, with an ordered distribution of Cu and Fe atoms in the tetrahedral interstices. The polyhedral configuration can be visualized as two types of cubes alternating along the three crystallographic axes: antifluorite-type, with eight MS_4 tetrahedra per cube, and sphalerite-type, with four MS_4 tetrahedra and MS_3 triangles per cube. In **bornite (high)**, the Cu and Fe atoms are disordered in the tetrahedral interstices.

Bornite	Cu_5FeS_4	Orthorhombic, Pbca (61)	
(Haidinger, 1845[1])	(<228 °C)	a = 10.95, b = 21.86, c = 10.95Å	Z = 16
Bornite (high)	β-Cu_5FeS_4	Cubic, Fm$\bar{3}$m (225)	
(Haidinger, 1845[2])	(>228 °C)	a = 5.50Å	Z = 1

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[1] Koto & Morimoto: AC 1975.B, 2268 (str)
[2] Morimoto & Kullerud: AM 1961, 1270 (str); Morimoto: AC 1964, 351 (str)

2.BA.15. **Berzelianite-Umangite Group**. **Berzelianite** has face-centred cubic close-packing of Se atoms, with Cu in tetragonal and trigonal sites. In **umangite**, Cu-Cu bonding creates sheets // (001).

Berzelianite	Cu_2Se	Cubic, Fm$\bar{3}$m (225)	
(Beudant, 1832[1])		a = 5.69Å	Z = 4
Bellidoite	β-Cu_2Se	Tetragonal, $P4_2/n$ (86)	
(De Montreuil, 1975[2])		a = 11.52, c = 11.74Å	Z = 32
Umangite	Cu_3Se_2	Tetragonal, P$\bar{4}2_1$m (113)	
(Klockmann, 1891[3])		a = 6.40, c = 4.28Å	Z = 2

Athabascaite	Cu_5Se_4	Orthorhombic	
(Harris *et al.*, 1970[4])		a = 8.23, b = 11.98, c = 6.44Å	Z = 4

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[1] Yamamoto & Kashida: J. Sol. St. Chem. 1991, 202 (str)

[2] Ec. Geol. 1975, 384; AM 1975, 736 (Abst.)

[3] Heyding & Murray: Can. J. Chem. 1976, 841 (str)

[4] CM 1970, 207; AM 1971, 632 (Abst.)

2.BA.20. **Weissite-Rickardite Group**. In **rickardite**, edge-sharing $CuTe_4$ tetrahedra form sheets // (001) linked by $CuTe_{4+1}$ pyramids.

Weissite	$Cu_{2-x}Te$	Hexagonal, P6/mmm (191)	
(Crawford, 1927[1])	($x \leq 0.33$)	a = 12.54, c = 21.71Å	Z = 45
Rickardite	$Cu_{3-x}Te_2$	Orthorhombic, Cmcm (63)	
(Ford, 1903[2])	($x \leq 0.26$)	a = 3.97, b = 4.00, c = 6.11Å	Z = 2

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[1] Thompson: AM 1949, 342; Patzak: Z. Metallk. 1956, 418; Bayliss: AM 1990, 751 (space group P3m1, a = 8.34, c = 21.69Å)

[2] Schutte & DeBoer: AC 1993.B, 398 (str)

With Ag

2.BA.25. **Acanthite Group**. A body-centred array of tetrahedrally coordinated S atoms with AgS_3 triangles in planes nearly // (010); the sheets are linked by $Ag^{[2]}$. The Ag atoms are ordered in **acanthite**, but disordered in **argentite**.

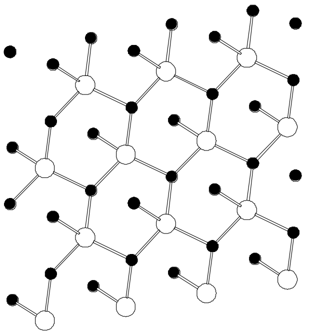

Fig 2.BA.25. *A slice // (010) through the acanthite structure. White circles = S; black dots = Ag.*

Acanthite	Ag_2S (<173 °C)	Monoclinic, $P2_1/n$ (14)	
(Kenngott, 1855[1])		a = 4.23, b = 6.93, c = 7.86Å	
		$\beta = 99.6°$	Z = 4
Argentite	β-Ag_2S (>173 °C)	Cubic, $Im\bar{3}m$ (229)	
(Haidinger, 1845[2])		a = 4.89Å	Z = 2

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[1] Frueh: ZK 1958/110, 136 (str)

[2] Sadanaga & Sueno: Min. Jour. 1967, 124

2.BA.30. **Stromeyerite-Jalpaite Group**. **Stromeyerite** has hexagonal close-packed S atoms with $Cu^{[3]}$ triangles in (001) layers that are bridged by $Ag^{[2]}$. In **jalpaite**, AgS_6 octahedra share edges to form an open 3-dimensional framework; $Cu^{[2]}$ atoms are accommodated in the cavities.

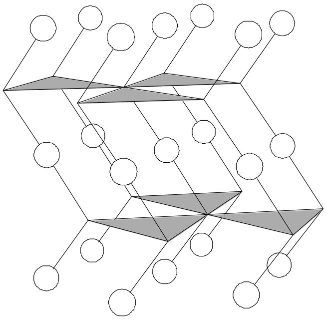

Fig 2.BA.30a. *The structure of stromeyerite projected approximately on (100); CuS_3 triangles linked by $Ag^{[2]}$ spheres.*

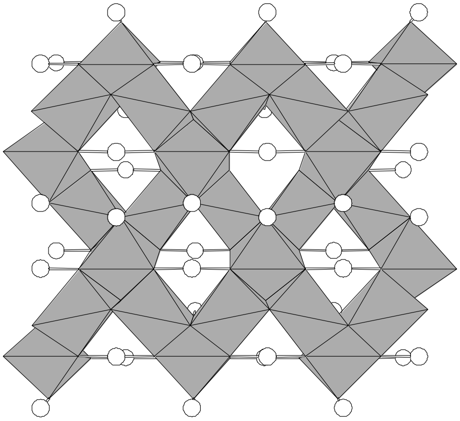

Fig 2.BA.30b. *A slice // (100) through the jalpaite structure; AgS_6 octahedra; $Cu^{[2]}$ spheres with bonds to nearest S atoms.*

Stromeyerite (Beudant, 1832[1])	CuAgS (<94 °C)	Orthorhombic, $Cmc2_1$ (36) a = 4.06, b = 6.62, c = 7.97Å	 Z = 4
Mckinstryite (Skinner *et al.*, 1966[2])	$Cu_{0.8}Ag_{1.2}S$	Orthorhombic, Pnam (62) or $Pna2_1$ (33) a = 14.04, b = 15.68, c = 7.80Å	 Z = 32
Jalpaite (Breithaupt, 1850[3])	$CuAg_3S_2$	Tetragonal, $I4_1/amd$ (141) a = 8.69, c = 11.76Å	 Z = 8

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[1] Baker *et al.*: AC 1991.B, 891 (str)

[2] Ec. Geol. 1966, 1383; AM 1967, 1253 (Abst.)

[3] Grybeck & Finney: AM 1968, 1530; Baker *et al.*: Austral. J. Chem. 1992, 1441 (str)

2.BA.35. **Eucairite-Naumannite Group**. In **eucairite**, sheets of corner-sharing flattened $CuSe_4$ tetrahedra // (001) alternate with sheets containing Ag atoms coordinated to 4 Ag and 1 Se. The **naumannite** structure is closely related to that of acanthite, with Se in body-centred cubic close-packing and Ag in the interstices; the Ag atoms are in tetrahedral and approximately triangular coordination; Se is surrounded by 9 Ag atoms.

Eucairite (Berzelius, 1818[1])	CuAgSe (<190 °C)	Orthorhombic, Pmmn (59)(pseudo-tetragonal) a = 4.10, b = 20.35, c = 6.31Å	 Z = 10

Aguilarite	Ag_4SeS	Orthorhombic	
(Genth, 1891[2])		a = 4.33, b = 7.09, c = 7.76Å	Z = 2
Naumannite	$\alpha\text{-}Ag_2Se$ (<128 °C)	Orthorhombic, $P2_12_12_1$ (19)	
(Haidinger, 1845[3])		a = 4.33, b = 7.06, c = 7.76Å	Z = 4

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[1] Frueh *et al.*: ZK 1957/108, 389 (str)
[2] Petruk *et al.*: CM 1974, 365
[3] Wiegers: AM 1971, 1882 (str)

2.BA.40. **Henryite-Hessite Group**. In **hessite**, edge-sharing $AgTe_4$ tetrahedra form sheets // (100) that are linked by corner-sharing tetrahedra. In **stützite**, highly mobile Ag atoms in a Te framework form Frank-Kasper polyhedra; Te is in tetrahedral sites and also forms Te_2 dumbbells.

Henryite	$Cu_4Ag_3Te_4$	Cubic, F-cell	
(Criddle *et al.*, 1983[1])		a = 12.20Å	Z = 8
Cervelleite	Ag_4TeS	Cubic, P-cell	
(Criddle *et al.*, 1989[2])		a = 14.03Å	Z = 24
Hessite	$\alpha\text{-}Ag_2Te$ (<155 °C)	Monoclinic, $P2_1/c$ (14)	
(Fröbel, 1843[3])		a = 8.16, b = 4.47, c = 8.98Å	
		β = 124.2°	Z = 4
Kurilite	$Ag_2(Te,Se)$	Cubic, $Pm\bar{3}m$ (221) or $P\bar{4}3n$ (218)	
(Kovalenker *et al.*, 1989[4])		a = 11.27Å	Z = 24
Stützite	$Ag_{5-x}Te_3$	Hexagonal, $P\bar{6}2m$ (189)	
(Schrauf, 1878[5])	(x = 0.24–0.36)	a = 13.46, c = 16.92Å	Z = 14
Benleonardite	$Ag_8Te_2(Sb,As)S_3$	Tetragonal	
(Stanley *et al.*, 1986[6])		a = 6.60, c = 12.73Å	Z = 2
Tsnigriite	$Ag_9Te_3SbS_3$	Monoclinic, P2/m (10) or Pm (6)	
(Sandomirskaya *et al.*, 1992[7])		a = 8.89, b = 8.29, c = 19.50Å	
		β = 97.0°	Z = 4

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[1] BM 1983, 511; AM 1985, 216 (Abst.)
[2] EJM 1989, 371; AM 1990, 1431 (Abst.)
[3] Van der Lee & de Boer: AC 1993.C, 1444 (str)
[4] Min. Zhur. 1989(6), 3; AM 1992, 208 (Abst.)
[5] Imamov & Pinsker: Sov. Phys. Cryst. 1966, 182 (str); Peters *et al.*: Z. anorg. allg. Chem. 1996/622, 1823 (str)
[6] MM 1986, 681; AM 1988, 439 (Abst.)
[7] ZVMO 1992(5), 95; AM 1994, 389 (Abst.)

2.BA.45. **Argyrodite Group**. In **argyrodite**, GeS_4 tetrahedra, AgS_4 tetrahedra, AgS_3 triangles, AgS_2 linear units and additional S atoms are connected into a framework.

Argyrodite	Ag_8GeS_6	Orthorhombic, $Pna2_1$ (33)	
(Weisbach, 1886[1])		a = 15.15, b = 7.48, c = 10.59Å	Z = 4
Canfieldite	Ag_8SnS_6	Orthorhombic, $Pna2_1$ (33)	
(Penfield, 1894[2])	(<172 °C)	a = 15.30, b = 7.55, c = 10.70Å	Z = 4

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[1] Eulenberger: Mh. Chem. 1977/108, 901 (str)

[2] Wang: Mh 1978, 269

With Au

2.BA.50. **Petzite Group**. **Petzite** has a garnet-like structure consisting of edge-sharing $Ag[Te_4Ag_2Au_2]$ and $Au[Ag_6Te_2]$ polyhedra.

Uytenbogaardtite	Ag_3AuS_2	Tetragonal, $P4_122$ (91) or $P4_1$ (76)	
(Barton *et al.*, 1978[1])		a = 9.68, c = 9.81Å	Z = 8
Fischesserite	Ag_3AuSe_2	Cubic, $I4_132$ (214)	
(Johan *et al.*, 1971[2])		a = 9.97Å	Z = 8
Petzite	Ag_3AuTe_2	Cubic, $I4_132$ (214)	
(Haidinger, 1845[3])		a = 10.39Å	Z = 8

Related Minerals

Petrovskaite	AgAu(S,Se)	Monoclinic, P2/m (10), Pm (6) or P2 (3)	
(Nesterenko *et al.*, 1984[4])		a = 4.94, b = 6.67, c = 7.22Å	
		β = 95.7°	Z = 4
Penzhinite	$Ag_4Au(S,Se)_4$	Hexagonal, $P6_322$ (182)	
(Bochek *et al.*, 1984[5])		a = 13.78, c = 16.98Å	Z = 18

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[1] CM 1978, 651; AM 1980, 209 (Abst.)

[2] BM 1971, 381; AM 1972, 1554 (Abst.)

[3] Frueh: AM 1959, 693 (str); Chamid *et al.*: Sov. Phys. Cryst. 1978, 267 (str)

[4] ZVMO 1984, 602; AM 1985, 1331 (Abst.)

[5] ZVMO 1984, 356; AM 1985, 875 (Abst.)

2.BA.55. **Bezsmertnovite Group**. Structures not known.

Bezsmertnovite	$Cu(Au,Ag)_4(Te,Pb)$	Orthorhombic (pseudo-cubic)	
(Spiridonov & Chvileva, 1979[1])		a = 24.21 b = 4.02, c = 16.24Å	Z = 16
Bogdanovite	$(Cu,Fe)_3Au_5(Te,Pb)_2$	Pseudocubic, probably orthorhombic	
(Spiridonov *et al.*, 1979[2])		a' = 4.09Å	Z' = ½
Bilibinskite	$Cu_2Au_3PbTe_2$	Cubic (gold superstructure)	
(Spiridonov *et al.*, 1978[3])		a' = 4.10Å	Z' = ½

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[1] Dok. Akad. Nauk SSSR 1979/249, 185; AM 1981, 87 (Abst.)
[2] AM 1979, 1329 (Abst.)
[3] ZVMO 1978, 310; AM 1979, 652 (Abst.)

2.BB. With Ni

2.BB.05. **Heazlewoodite Group**. In **heazlewoodite**, Ni occupies tetrahedral sites in a body-centred cubic lattice of S atoms; the NiS_4 tetrahedra share edges, resulting in short Ni-Ni distances.

Heazlewoodite	Ni_3S_2	Trigonal, R32 (155)	
(Petterd, 1896[1])		a = 5.74, c = 7.14Å	Z = 3
Oregonite	Ni_2FeAs_2	Trigonal	
(Ramdohr & Schmitt, 1959[2])		a = 6.08, c = 7.13Å	Z = 3
	Related Mineral		
Vozhminite	$(Ni,Co)_4(As,Sb)S_2$	Hexagonal	
(Rudashevskiy *et al.*, 1982[3])		a = 17.46, c = 7.20Å	Z = 18

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[1] Parise: AC 1980.B, 1179 (str)
[2] Mh 1959, 239; AM 1960, 1130 (Abst.)
[3] ZVMO 1982, 480; AM 1983, 645 (Abst.)

2.BB.10. **Hauchecornite Group**. In **hauchecornite**, NiS_4 square planes share corners and edges to form a 3-dimensional framework strengthened by bonding to $Bi^{[6]}$ and $Sb^{[8]}$ atoms.

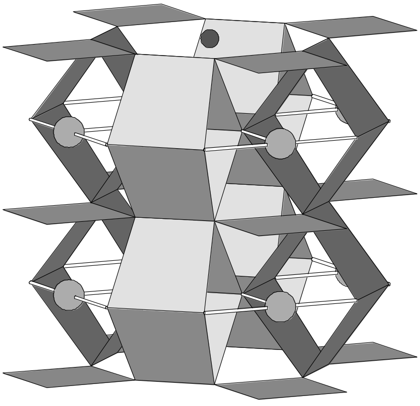

Fig 2.BB.10. *The structure of hauchecornite, projected with c-axis vertical. Square planes = NiS_4; light larger spheres with bonds = Bi; smaller dark sphere near top of diagram = Sb.*

Arsenohauchecornite (Gait & Harris[1])	$(As_{0.5}Bi_{0.5})(NiBi)Ni_8S_8$	Tetragonal, I4/mmm (139) a = 10.27, c = 10.81Å	Z = 4
Hauchecornite (Scheibe, 1892[2])	$Sb(NiBi)Ni_8S_8$	Tetragonal, P4/mmm (123) a = 7.30, c = 5.40Å	Z = 1
Bismutohauchecornite (Just, 1980[3])	$Bi_2Ni_9S_8$	Tetragonal, P4/mmm (123) a = 7.37, c = 5.88Å	Z = 1
Tellurohauchecornite (Gait & Harris, 1980[4])	$TeBiNi_9S_8$	Tetragonal, P4/mmm (123) a = 14.64, c = 10.87Å	Z = 8
Tučekite (Just & Feather, 1978[5])	$Sb_2Ni_9S_8$	Tetragonal, P4/mmm (123) a = 7.17, c = 5.40Å	Z = 1

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[1] MM 1980, 877; Grice & Ferguson: CM 1989, 137 (str)
[2] Kocman & Nuffield: CM 1974, 269 (str)
[3] MM 1980, 873; AM 1981, 436 (Abst.)
[4] MM 1980, 877; AM 1981, 436 (Abst.)
[5] MM 1978, 278; AM 1979, 465 (Abst.)

2.BB.15. **Pentlandite Group**. The structures are based on cubic close-packed S atoms with metal atoms in the interstices. In **pentlandite**, eight edge-sharing $(Ni,Fe)S_4$ tetrahedra form clusters that are combined into a framework by $Fe^{[6]}$ octahedra; each cluster shares corners with 12 neighbouring clusters. The structures of **cobalt pentlandite** and **argentopentlandite** are similar, except that in argentopentlandite, the octahedral site is occupied by Ag. In **godlevskite**, edge-sharing $Ni[S_4]$ tetrahedra form 3-membered chains // [100], [001] and [010]; the [001] and [010] chains form a 5-membered cross; edge-sharing $Ni[S_5]$ square pyramids form 4-fold clusters and chains // [101].

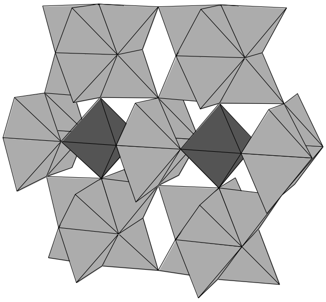

Fig 2.BB.15. A fragment of the pentlandite structure showing clusters of $(Ni,Fe)S_4$ tetrahedra (light) and FeS_6 octahedra (dark).

Pentlandite	$Fe(Ni,Fe)_8S_8$	Cubic, $Fm\bar{3}m$ (225)	
(Dufrenoy, 1856[1])		a = 10.04Å	Z = 4
Cobalt pentlandite	$(Co,Ni,Fe)_9S_8$	Cubic, $Fm\bar{3}m$ (225)	
(Kouvo *et al.*, 1959[2])		a = 9.93Å	Z = 4
Argentopentlandite	$Ag(Ni,Fe)_8S_8$	Cubic, $Fm\bar{3}m$ (225)	
(Rudashevskiy *et al.*, 1977[3])		a = 10.52Å	Z = 4
Shadlunite	$(Pb,Cd)(Fe,Cu)_8S_8$	Cubic, $Fm\bar{3}m$ (225)	
(Evstigneeva *et al.*, 1973[4])		a = 10.91Å	Z = 4
Manganese-shadlunite	$(Mn,Pb)(Cu,Fe)_8S_8$	Cubic, $Fm\bar{3}m$ (225)	
(Evstigneeva *et al.*, 1973[5])		a = 10.73Å	Z = 4
Geffroyite	$(Cu,Fe,Ag)_9(Se,S)_8$	Cubic, $Fm\bar{3}m$ (225)	
(Johan *et al.*, 1982[6])		a = 10.89Å	Z = 4

Related Minerals

Godlevskite	$(Ni_{8.7}Fe_{0.3})S_8$	Orthorhombic, C222 (21)	
(Kulagov *et al.*, 1969[7])		a = 9.34, b = 11.22, c = 9.43Å	Z = 4
Kharaelakhite	$(Pt,Cu,Pb,Fe,Ni)_9S_8$	Orthorhombic, Pmmm (47),	
(Genkin *et al.*, 1985[8])		Pmm2 (25) or P222 (16)	
		a = 9.71, b = 8.33, c = 14.50Å	Z = 4

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[1] Rajmani & Prewitt: CM 1973, 169 (str)
[2] AM 1959, 897; Rajmani & Prewitt: CM 1975, 75 (str)
[3] ZVMO 1977, 688; MA 79–762 (Abst.); Hall & Stewart: CM 1973, 169 (str)
[4] ZVMO 1973, 63; AM 1973, 1114 (Abst.)
[5] *idem*
[6] TMPM 1982/29, 151; AM 1982, 107 (Abst.)
[7] AM 1970, 317 (Abst.); Fleet: AC 1987.C, 2255 (str)
[8] Min. Zhur. 1985(1), 78; AM 1989, 1215 (Abst.)

2.BC. With Rh, Pd, Pt, etc.

2.BC.05. **Prassoite Group**. In **prassoite**, RhS_6 octahedra and RhS_4 square planes share corners to form a framework. **Palladseite** is isostructural.

Prassoite	$Rh_{17}S_{15}$	Cubic, $Pm\bar{3}m$ (221)	
(Kingston, 1977[1])		a = 9.91Å	Z = 2
Palladseite	$Pd_{17}Se_{15}$	Cubic, $Pm\bar{3}m$ (221)	
(Davis *et al.*, 1977[2])		a = 10.64Å	Z = 2

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[1] Cabri: CIMM Spec. Vol. 1981, 132; Geller: AC 1962, 1198 (str)
[2] MM 1977, 123; AM 1977, 1059 (Abst.); Geller: AC 1962, 713 (str)

2.BC.10. **Oosterboschite**. Structure not known.

Oosterboschite	$(Pd,Cu)_7Se_5$	Orthorhombic	
(Johan *et al.*, 1970[1])		a = 10.42, b = 10.60, c = 14.43Å	Z = 8

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[1] BM 1970, 476; AM 1972, 1553 (Abst.)

2.BC.15. **Chrisstanleyite**. Structure not known.

Chrisstanleyite	$Pd_3Ag_2Se_4$	Monoclinic, $P2_1/m$ (11) or $P2_1$ (4)	
(Paar *et al.*, 1998[1])		a = 6.35, b = 10.39, c = 5.68Å	
		β = 114.9°	Z = 2

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[1] MM 1998, 257; AM 1998, 134 (Abst.)

2.BC.20. **Telargpalite-Sopcheite Group** (with Te). In **keithconnite**, the Pd and Te atoms form chains // [0001]. **Vasilite** has a complicated framework structure, with 12 Pd in (nearly) linear 2S coordination, and 4 Pd in trigonal-pyramidal 3S coordination with Pd at the apex.

Vasilite	$Pd_{16}S_7$ (~ 2.5Cu, 0.4Te)	Cubic, $I\bar{4}3m$ (217)	
(Atanasov, 1990[1])		a = 8.92Å	Z = 2
Oulankite	$(Pd,Pt)_5(Cu,Fe)_4SnTe_2S_2$	Tetragonal	
(Barkov *et al.*, 1996[2])		a = 9.04, c = 4.94Å	Z = 2
Telargpalite	$(Pd,Ag)_3Te$ (?)	Cubic	
(Kovalenker *et al.*, 1974[3])		a = 12.60Å	Z = 16
Keithconnite	$Pd_{20}Te_7$	Trigonal, $R\bar{3}$ (148)	
(Cabri *et al.*, 1979[4])		a = 11.46, c = 11.30Å	Z = 3
Telluropalladinite	$Pd_{2.25}Te$	Monoclinic, $P2_1/c$ (14)	
(Cabri *et al.*, 1979[5])		a = 7.45, b = 13.95, c = 8.82Å	
		β = 91.9°	Z = 16
Temagamite	Pd_3HgTe_3	Orthorhombic (pseudo-hexagonal)	
(Cabri *et al.*, 1973[6])		a = 11.57, b = 12.16, c = 6.76Å	Z = 6
Borovskite	Pd_3SbTe_4	Cubic	
(Yalovoi *et al.*, 1973[7])		a = 5.79Å	Z = 1
Sopcheite	$Pd_3Ag_4Te_4$	Orthorhombic	
(Orsoev *et al.*, 1982[8])		a = 9.65, b = 7.91, c = 11.04Å	Z = 4

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[1] CM 1990, 687; AM 1991, 1435 (Abst.); Matković *et al.*: J. Less-Comm. Metals 1976/50, 165 (str, synth. $Pd_{16}S_7$)

[2] EJM 1996, 311; AM 1996, 1514 (Abst.)

[3] ZVMO 1974, 595; AM 1975, 489 (Abst.); Begizov & Batashev: Dok. Akad. Nauk SSSR 1978/243, 1265

[4] CM 1979, 589; AM 1981, 1275 (Abst.); Wopersnow & Schubert: J.Less-Comm. Metals 1977/51, 35 (str)

[5] CM 1979, 589; AM 1981, 1275 (Abst.); Matković & Schubert: J. Less-Comm. Metals 1978/58, P39 (str)

[6] CM 1973, 193; AM 1975, 947 (Abst.)

[7] ZVMO 1973, 427; AM 1974, 873 (Abst.)

[8] ZVMO 1982, 114; AM 1983, 472 (Abst.)

2.BC.25. **Luberoite**. $PtSe_6$ distorted octahedra and $PtSe_5$ pyramids share edges and faces to form a dense framework.

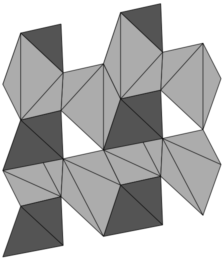

Fig 2.BC.25. *The structure of luberoite projected on (010), c-axis vertical. Light polyhedra = $PtSe_6$; dark polyhedra = $PtSe_5$.*

Luberoite (Jedwab *et al.*, 1992[1])	Pt_5Se_4	Monoclinic, $P2_1/c$ (14) a = 6.58, b = 4.60, c = 11.10Å β = 101.6°	Z = 2

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[1] EJM 1992, 683; AM 1993, 450 (Abst.); Matković & Schubert: J. Less-Comm. Metals 1977/55, 185 (str)

2.BD. With Hg, Tl

2.BD.05. **Balkanite-Imitérite Group** (with Hg). In **imitérite**, AgS_3 triangles are linked into a framework by linearly coordinated $Hg^{[2]}$ atoms.

Gortdrumite (Steed, 1983[1])	$(Cu,Fe)_{19}Hg_6S_{16}$	Orthorhombic a = 14.96, b = 7.90, c = 24.10Å	Z = 4
Balkanite (Atanassov & Kirov, 1973[2])	$Cu_9Ag_5HgS_8$	Orthorhombic, Pmmm (47), P222 (16) or Pmm2 (25) a = 10.62, b = 9.42, c = 3.92Å	Z = 1
Danielsite (Nickel, 1987[3])	$(Cu,Ag)_{14}HgS_8$	Orthorhombic a = 9.64, b = 9.18, c = 18.16Å	Z = 4
Imitérite (Guillou *et al.*, 1985[4])	Ag_2HgS_2	Monoclinic, $P2_1/c$ (14) a = 4.04, b = 8.01, c = 6.58Å β = 107.1°	Z = 2

Petrovicite (Johan *et al.*, 1976[5])	$Cu_3PbHgBiSe_5$	Orthorhombic, Pnam (62) or $Pna2_1$ (33) a = 16.18, b = 14.68, c = 4.33Å	Z = 4
Donharrisite (Paar *et al.*, 1989[6])	$Ni_8Hg_3S_9$	Monoclinic, C2/m (12), Cm (8) or C2 (5) a = 11.66, b = 6.91, c = 10.92Å β = 97.4°	Z = 2

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[1] MM 1983, 35; AM 1984, 407 (Abst.)
[2] AM 1973, 11
[3] AM 1987, 481; Kato & Nickel: AM 1988, 187
[4] BM 1985, 457 (str); AM 1986, 1277 (Abst.)
[5] BM 1976, 310; AM 1977, 594 (Abst.)
[6] CM 1989, 257; AM 1990, 706 (Abst.)

2.BD.10. **Carlinite**. Structure not known.

Carlinite (Radtke & Dickson, 1975[1])	Tl_2S	Trigonal, R3 (146) a = 12.12, c = 18.18Å	Z = 27

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[1] AM 1975, 559

2.BD.15. **Thalcusite-Sabatierite Group**. The **chalcothallite** structure consists of mackinawite-like layers // (001) of edge-sharing $(Cu,Fe)S_4$ tetrahedra alternating with layers containing $Cu(S_2Sb_2)$ tetrahedra and $CuSb_4$ square planes, with short metal-metal distances // (001); the layers are linked by $Tl^{[8]}$ atoms.

Thalcusite (Kovalenker *et al.*, 1976[1])	$Cu_3FeTl_2S_4$	Tetragonal, I4/mmm (139), etc. a = 3.88, c = 13.25Å	Z = 1
Murunskite (Dobrovolskaya *et al.*, 1981[2])	$K_2Cu_3FeS_4$	Tetragonal, I4/mmm (139), etc. a = 3.88, c = 13.10Å	Z = 1
Bukovite (Johan & Kvaček, 1971[3])	$Cu_3FeTl_2Se_4$	Tetragonal, I4/mmm (139) a = 3.98, c = 13.70Å	Z = 1
Rohaite (Karup-Møller, 1978[4])	Cu_5TlSbS_2	Orthorhombic, Pmmm (47), etc. (pseudo-tetragonal) a = 3.80, b = 3.80, c = 20.99Å	Z = 2
Chalcothallite (Semenov *et al.*, 1967[5])	$(Cu,Fe)_6Tl_2SbS_4$	Tetragonal, I4/mmm (139) a = 3.83, c = 34.28Å	Z = 2
Sabatierite (Johan *et al.*, 1978[6])	Cu_6TlSe_4	Orthorhombic a = 3.99, b = 5.62, c = 9.78Å	Z = 1
Crookesite (Nordenskiöld, 1866[7])	Cu_7TlSe_4	Tetragonal, $I\bar{4}$ (82) a = 10.45, c = 3.93Å	Z = 2

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[1] ZVMO 1976, 202; AM 1977, 396 (Abst.); Makovicky *et al.*: Ah 1980/138, 122
[2] ZVMO 1981, 468; AM 1982, 624 (Abst.)
[3] BM 1971, 529; AM 1972, 1910 (Abst.); Makovicky *et al.*: Ah 1980/138, 122
[4] AM 1980, 208 (Abst.); Makovicky *et al.*: Ah 1980/138, 122
[5] AM 1968, 1775 (Abst.); Makovicky *et al.*: Ah 1980/138, 122 (str)
[6] BM 1978, 557; AM 1979, 1331 (Abst.); Berger: ZK 1987/181, 241
[7] Johan: CR 1987/304, 1121; Berger: ZK 1987/181, 241

2.BE. With Pb (Bi)

2.BE.05. **Betekhtinite-Furotobeite Group**. In **betekhtinite**, face-sharing (?) PbS_{3+3} trigonal prisms form columns // [001]; corner-sharing CuS_3 triangles form 2-periodic double chains // [001]; both are linked by CuS_4 tetrahedra.

Betekhtinite	$(Cu,Fe)_{21}Pb_2S_{15}$	Orthorhombic, Immm (71)	
(Schüller & Wohlmann, 1955[1])		a = 14.67, b = 22.80, c = 3.86Å	Z = 2
Furutobeite	$(Cu,Ag)_6PbS_4$	Monoclinic, C2 (5), Cm (8) or C2/m (12)	
(Srigaki *et al.*, 1981[2])		a = 20.02, b = 3.96, c = 9.70Å	
		β = 101.6°	Z = 4
Arcubisite	$CuAg_6(Bi,Pb)S_4$		
(Karup-Møller, 1976[3])			
Larosite	$(Cu,Ag)_{21}(Pb,Bi)_2S_{13}$	Orthorhombic (?)	
(Petruk, 1972[4])		a = 22.15, b = 24.03, c = 11.67Å	Z = 10

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[1] Geologie 1955, 535; AM 1956, 371 (Abst.); Dornberger-Schiff & Höhne: AC 1959, 646 (str)
[2] BM 1981, 737; AM 1982, 1075 (Abst.)
[3] Lithos 1976, 253; AM 1978, 424 (Abst.)
[4] CM 1972, 886; AM 1974, 382 (Abst.)

2.BE.10. **Shandite Group**. In **parkerite**, face-sharing $Ni(Bi_4S_2)$ octahedra form sheets // (010). **Shandite** has $Ni(Pb_4S_2)$ octahedra.

Shandite	$Ni_3Pb_2S_2$	Trigonal, R$\bar{3}$m (166)	
(Ramdohr, 1950[1])		a = 5.59, c = 13.58Å	Z = 3
Rhodplumsite	$Rh_3Pb_2S_2$	Trigonal, R$\bar{3}$m (166)	
(Genkin *et al.*, 1983[2])		a = 5.73, c = 14.00Å	Z = 3
Parkerite	$Ni_3Bi_2S_2$	Orthorhombic, Pmam (51)	
(Scholtz, 1936[3])		a = 5.55, b = 5.73, c = 4.05Å	Z = 1

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[1] Peacock & McAndrew: AM 1950, 425; Claus *et al.*: Mh 1978, 256 (str)
[2] Min. Zhur. 1983(2), 87; MA 1984, 3588 (Abst.)
[3] Fleet: AM 1973, 435 (str); Brower et al.: AM 1974, 296 (monoclinic superstructure, Z = 8)

2.C: Metal Sulfides, M : S = 1 : 1 (and similar)

Subdivisions 2.CA. – 2.CE.

- 2.CA. With Cu
  - 2.CA.05. Covellite group
  - 2.CA.10. Nukundamite
- 2.CB. With Zn, Fe, Cu, Ag, etc.
  - 2.CB.05. Sphalerite group
  - 2.CB.10. Chalcopyrite group
  - 2.CB.15. Stannite-kesterite group
  - 2.CB.20. Luzonite-briartite group
  - 2.CB.25. Hemusite-morozeviczite group
  - 2.CB.30. Vinciennite group
  - 2.CB.35. Germanite-mooihoekite group
  - 2.CB.40. Lautite
  - 2.CB.45. Wurtzite group
  - 2.CB.50. Enargite group
  - 2.CB.55. Cubanite-mohite group
  - 2.CB.60. Raguinite-picotpaulite group
  - 2.CB.65. Argentopyrite group
  - 2.CB.70. Sulvanite group
  - 2.CB.75. Vulcanite-empressite group
- 2.CC. With Ni, Fe, Co, etc.
  - 2.CC.05. Nickeline group
  - 2.CC.10. Pyrrhotite group
  - 2.CC.15. Westerveldite group
  - 2.CC.20. Millerite group
  - 2.CC.25. Mackinawite
  - 2.CC.30. Braggite group
- 2.CD. With Sn, Pb, Hg, etc.
  - 2.CD.05. Herzenbergite group
  - 2.CD.10. Galena group
  - 2.CD.15. Matildite group
  - 2.CD.20. Aramayoite-diaphorite group
  - 2.CD.25 Cinnabar

2.CA. With Cu

2.CA.05. **Covellite Group**. In **covellite**, double sheets of CuS_4 tetrahedra // (0001) connected by S-S bonds // [0001] alternate with sheets of Cu in triangular coordination. The **klockmannite** structure is similar.

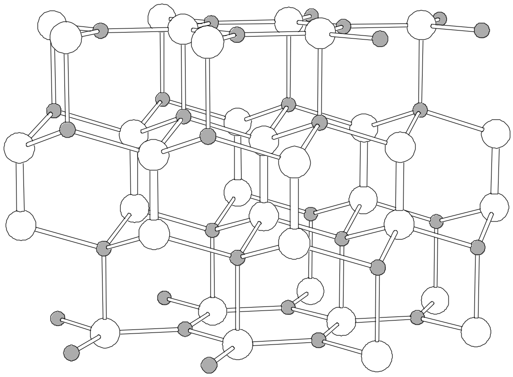

Fig 2.CA.05. *Clinographic projection of the covellite structure. Large spheres = S; small dark spheres = Cu; the S-S bond is shown as a wider rod than the Cu-S bonds.*

Covellite CuS Hexagonal, $P6_3/mmc$ (194)
(Beudant, 1832[1]) a = 3.79, c = 16.34Å Z = 6

Klockmannite	CuSe	Hexagonal, $P6_3/mmc$ (194)	
(Ramdohr, 1928[2])		a = 3.94, c = 17.25Å	Z = 6
Idaite	~ Cu_5FeS_6	Hexagonal	
(Frenzel, 1958[3])		a = 3.90, c = 16.95Å	Z = 1

---

[1] Berry: AM 1954, 504 (str); Evans & Konnert: AM 1976, 996 (str)

[2] Berry, idem; Effenberger & Pertlik: Mh 1981, 197 (str)

[3] Mh 1958, 142; AM 1958, 1219 (Abst.); Yund: AM 1963, 672; Frenzel: AM 1963, 676

2.CA.10. **Nukundamite**. Thick layers of edge- and corner-sharing $(Cu,Fe)S_4$ tetrahedra // (0001) alternate with S_2 sheets.

Nukundamite	~ $Cu_{3.4}Fe_{0.6}S_4$	Trigonal, $P\bar{3}m1$ (164)	
(Rice *et al.*, 1979[1])		a = 3.78, c = 11.19Å	Z = 1

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[1] MM 1979, 193; AM 1980, 407 (Abst.); Sugaki *et al.*: AM 1981, 398 (str)

2.CB. With Zn, Fe, Cu, Ag, etc.

2.CB.05. **Sphalerite Group**. Corner-sharing $M^{[4]}$ and $X^{[4]}$ tetrahedra form cubic or pseudo-cubic frameworks; viewed along [111], the layers are stacked A-B-C (*cf* wurtzite, 2.CB.45). Homeotype of diamond.

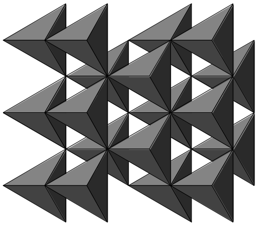

Fig 2.CB.05. *Two layers of the sphalerite structure projected on (111), showing corner-sharing ZnS_4 tetrahedra.*

Sphalerite	ZnS	Cubic, $F\bar{4}3m$ (216)	
(Glocker, 1847[1])		a = 5.41Å	Z = 4
Hawleyite	CdS	Cubic, $F\bar{4}3m$ (216)	
(Traill & Boyle, 1955[2])		a = 5.82Å	Z = 4

Metacinnabar (Moore, 1870[3])	HgS	Cubic, F$\bar{4}$3m (216) a = 5.87Å	 Z = 4
Stilleite (Ramdohr, 1956[4])	ZnSe	Cubic, F$\bar{4}$3m (216) a = 5.67Å	 Z = 4
Tiemannite (Naumann, 1855[5])	HgSe	Cubic, F$\bar{4}$3m (216) a = 6.08Å	 Z = 4
Coloradoite (Genth, 1877[6])	HgTe	Cubic, F$\bar{4}$3m (216) a = 6.45Å	 Z = 4

Related Mineral

Isocubanite (Caye *et al.*, 1988[7])	$CuFe_2S_3$ (>200–210 °C)	Cubic, Fm$\bar{3}$m (225) a = 5.30Å	 Z = 4/3
Sakuraiite (Kato, 1965[8])	(Cu,Zn,Fe,In,Sn)S	Cubic, P432 (207), P$\bar{4}$3m (215) or Pm$\bar{3}$m (221) a = 5.46Å	 Z = 4

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[1] Ewald: Ann. Phys. 1914, 257 (str)
[2] AM 1955, 555
[3] Aurivilius: Acta Chem. Scand. 1964, 1552 (str)
[4] AM 1957, 584 (Abst.); McIntyre *et al.*: AC 1980.A, 482 (str)
[5] Earley: AM 1950, 337; deJong: ZK 1926/63, 466 (str)
[6] Thompson: AM 1949, 342; deJong: *idem*
[7] MM 1988, 509; AM 1989, 503 (Abst.)
[8] AM 1968, 1421 (Abst.); Kissin & Owens: CM 1986, 679

2.CB.10. **Chalcopyrite Group**. Corner-sharing $M^{[4]}$ and $X^{[4]}$ tetrahedra form cubic or pseudo-cubic frameworks, as in sphalerite, but with cation ordering.

Chalcopyrite (Henckel, 1725[1])	$CuFeS_2$	Tetragonal, I$\bar{4}$2d (122) a = 5.29, c = 10.42Å	 Z = 4
Gallite (Strunz *et al.*, 1958[2])	$CuGaS_2$	Tetragonal, I$\bar{4}$2d (122) a = 5.35, c = 10.48Å	 Z = 4
Roquésite (Picot & Pierrot, 1963[3])	$CuInS_2$	Tetragonal, I$\bar{4}$2d (122) a = 5.51, c = 11.05Å	 Z = 4
Eskebornite (Ramdohr, 1949[4])	$CuFeSe_2$	Tetragonal, P$\bar{4}$2c (112) a = 5.53, c = 10.48Å	 Z = 4
Lenaite (Amuzinsky *et al.*, 1995[5])	$AgFeS_2$	Tetragonal, $P4_2mc$ (105) ? a = 5.64, c = 10.34Å	 Z = 4
Laforêtite (Meisser *et al.*, 1999[6])	$AgInS_2$	Tetragonal, I$\bar{4}$2d (122) a = 5.88, c = 11.21Å	 Z = 4

Related Mineral

Isochalcopyrite	$CuFeS_2$ (>~550 °C)	Cubic, $I\bar{4}3m$ (217)	
(Missack *et al.*, 1989[7])		a = 10.61Å	Z = 16

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[1] Hall & Stewart: AC 1973.B, 579 (str)
[2] Mh 1958, 241; AM 1959, 906 (Abst.)
[3] BM 1963, 7; AM 1963, 1178 (Abst.)
[4] Delgado *et al.*: Mater. Res. Bull. 1992, 367 (str)
[5] ZVMO 1995 (5), 85; AM 1996, 1283 (Abst.)
[6] EJM 1999, 891; AM 2000, 875 (Abst.)
[7] Min. Deposita 1989, 82; AM 1990, 432 (Abst.); Hiller & Probsthain: ZK 1956/108, 108 (str)

2.CB.15. **Stannite-Kesterite Group**. Corner-sharing $M^{[4]}$ and $X^{[4]}$ tetrahedra, as in sphalerite, but with cation ordering.

Kuramite	Cu_3SnS_4	Tetragonal, $I\bar{4}2m$ (121)	
(Kovalenker *et al.*, 1979[1])		a = 5.45, c = 10.75Å	Z = 2
Stannite	Cu_2FeSnS_4	Tetragonal, $I\bar{4}2m$ (121)	
(Beudant, 1832[2])		a = 5.45, c = 10.76Å	Z = 2
Černýite	Cu_2CdSnS_4	Tetragonal, $I\bar{4}2m$ (121)	
(Kissin *et al.*, 1978[3])		a = 5.49, c = 10.85Å	Z = 2
Velikite	Cu_2HgSnS_4	Tetragonal, $I\bar{4}$ (82)	
(Kaplunnik *et al.*, 1977[4])		a = 5.57, c = 10.88Å	Z = 2
Hocartite	Ag_2FeSnS_4	Tetragonal, $I\bar{4}2m$ (121)	
(Caye *et al.*, 1968[5])		a = 5.74, c = 10.96Å	Z = 2
Pirquitasite	Ag_2ZnSnS_4	Tetragonal, $I\bar{4}2m$ (121) or $I\bar{4}$ (82)	
(Johan & Picot, 1982[6])		a = 5.79, c = 10.83Å	Z = 2
Ferrokesterite	$Cu_2(Fe,Zn)SnS_4$	Tetragonal, $I\bar{4}$ (82)	
(Kissin & Owens, 1989[7])		a = 5.43, c = 10.88Å	Z = 2
Kesterite	$Cu_2(Zn,Fe)SnS_4$	Tetragonal, $I\bar{4}$ (82)	
(Orlova, 1956[8])		a = 5.43, c = 10.87Å	Z = 2

Related Mineral

Stannoidite	$Cu_8(Fe,Zn)_3Sn_2S_{12}$	Orthorhombic, I222 (23)	
(Kato, 1969[9])		a = 5.41, b = 10.77, c = 16.12Å	Z = 2

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[1] ZVMO 1979, 564; AM 1980, 1067 (Abst.)
[2] Brockway: ZK 1934/89, 434 (str); Hall *et al.*: CM 1978, 131 (str)
[3] CM 1978, 139; AM 64 (1979), 653 (Abst.); Szymanski: CM 1978, 147 (str)
[4] AM 1977, 1260 (Abst.); Gruzdev *et al.*: ZVMO 1997 (4), 71; Kabalov *et al.*: Cryst Repts. 1998, 16 (str)
[5] BM 1968, 383; AM 1969, 573 (Abst.)
[6] BM 1982, 229; AM 1983, 1249 (Abst.)
[7] CM 1989, 673; AM 1990, 1432 (Abst.)
[8] AM 1959, 1329 (Abst.); Hall *et al.*: CM 1978, 131 (str)
[9] AM 1969, 1495 (Abst.); Kudoh & Takéuchi: ZK 1976/144, 145 (str)