SYSTEMATICS AND CRYSTAL GENESIS OF CARBONATE MINERALS

Ivan Kostov, Ruslan I. Kostov

University of Mining and Geology "St. Ivan Rilski", Sofia 1700; rikostov@mgu.bg

ABSTRACT. A dual crystal structural and paragenetic principle (Kostov, 1993; Kostov, Kostov, 1999) has been applied to a rational classification of the carbonate minerals. Main divisions (associations) are based on geochemically allied metals in the composition of these minerals, and subdivisions (axial, planar, pseudoisometric and isometric types) on their overall structural anisometricity. The latter provides both structural similarity and genetic information, as manner of crystal growth in geological setting under different conditions of crystallization. The structural anisometricity may conveniently be presented by the *c/a* ratio of the minerals with high symmetry and by the 2*cl*(*a+b*), 2*b*(*a+c*) and 2*a*(*b+c*) ratios for the low symmetry minerals. The respective ratios are less, nearly equal, equal or above 1.00. The unit cell or sub-cell and the corresponding structures are denoted as axial or A-type, pseudo-isometric or (I)-type, isometric or I-type and planar or P-type, notations which correspond to chain-like, framework and sheet-like structures, respectively ino-, tecto- and phyllo-structures. The classification includes three geochemical assemblages among the carbonate minerals – AI-Mg-Fe(Ni,Co,Mn), Na-Ca-Ba(K)-REE and Zn-Cu-Pb(U).

СИСТЕМАТИКА И КРИСТАЛОГЕНЕЗИС НА КАРБОНАТНИТЕ МИНЕРАЛИ

Иван Костов, Руслан И. Костов

Минно-геоложки университет "Св. Иван Рилски", София 1700; rikostov@mgu.bg

РЕЗЮМЕ. Въз основна на двоен структурен и парагенетичен принцип (Kostov, 1993; Kostov, Kostov, 1999) е предложена рационална класификиция на карбонатните минерали. Главните раздели (асоциации) са базирани на геохимично свързани метали в състава на тези минерали, а подразделенията (аксиални, планарни, псевдоизометрични и изометрични типове) – на общата им структурна анизометричност. Последната дава идея едновременно за структурно подобие и генетична информация, например начин на кристален растеж в геоложка среда с различни условия на кристализация. Структурната анизометрия може да бъде представена от осното отношение *с/а* на минералите с висока симетрия или 2*c*/(*a+b*), 2*b*/(*a+c*) и 2*a*/(*b+c*) на минералите с ниска симетрия. Получените отношения ще бъдат по-малки, почти равни, равни или по-големи от 1.00. Елементарните клетки или субклетки и съответни структури се обозначават като аксиални или А-тип, псевдоизометрични или (I)-тип, изометрични или I-тип и планарни или Р-тип. Тези обозначения съответни и слоестоподобни структури, респективно ино-, текто- и филоструктури. В предложената класификация са включени три геохимични асоциации сред карбонатните минерали – AI-Mg-Fe(Ni,Co,Mn), Na-Ca-Ba(K)-REE и Zn-Cu-Pb(U).

INTRODUCTION

Crystal chemical approach to the classification of carbonate minerals has been applied in several specific to carbonates publications as well as in general mineralogical works (for example, Povarennykh, 1972; White, 1974; Effenberger et al., 1981; Zemann, 1981; 1989; *Carbonates…*, 1983; Railsback, 1999). The basic criteria used for classification of minerals are suitably summarized by Lima-de-Faria (1983), Strunz (1984) and Godovikov (1997). The majority of carbonate minerals are secondary products, formed during weathering or sedimentation. Hence most of them occur as aggregates, crusts, earthy or pulverant masses, rarely in crystals. Calcite is one of the restricted polygenetic representatives.

A dual crystal structural and paragenetic principle, worked out by the first of the authors (Kostov, 1960; 1965; 1968; 1977; 1993; Kostov, Kostov, 1999) has been applied to a rational classification of the carbonate minerals. Main divisions (associations) are based on geochemically allied metals in the composition of these minerals, and subdivisions (axial, planar, pseudoisometric and isometric) on their overall structural anisometricity. The latter provides both structural similarity and genetic hint, viz. manner of crystal growth in geological setting under different conditions of crystallization. The overall structural anisometricity may conveniently be presented by the c/a ratio of the minerals with high symmetry and by the 2c/(a+b), 2b/(a+c) and 2a/(b+c) ratios for the low symmetry minerals. The respective ratios are less, nearly equal, equal or above 1.00, the unit cell or sub-cell and the corresponding structures denoted as axial or A-type, pseudo-isometric or (I)-type, isometric or I-type and planar or P-type, notations which correspond to chain-like, framework and sheet-like structures, respectively ino-, tecto- and phyllo-structures.

The notations A, (I) and P offered are further enriched by adding as superscript the direction of structural anisometricity for the low symmetry minerals – A^c , A^b and A^a , (I)^c, (I)^b and (I)^a, and P^c, P^b and P^a. The A, (I) and P notations remain for the minerals with spindle symmetry. Use is made of the indices (*hkl*) of the crystal habit form and [*uvw*] symbols for elongation added as subscripts. Combinations of both indicate form and elongation.

Such type of systematic has been already applied to other mineral classes as well – oxide (Kostov, 1964), silicate (Kostov, 1975), sulphide (Kostov, Minčeva-Stefanova, 1982), phosphate and related (Kostov, 1986), sulphate (Kostov, 2000) and borate (Kostov, Kostov, 2002) minerals (for review of all classes of minerals see Kostov, 1993; Kostov, Kostov, 1999).

PROPOSED CLASSIFICATION OF CARBONATE MINERALS

Within about 220 carbonate minerals, axial, pseudoisometric and planar types are approximately equally represented. Important from a crystallochemical point of view are the triangular CO₃ groups in the carbonates, which, commanded by the size and peculiarities of the cations, may acquire different orientation. The general tendency is these groups to follow certain plane or axis of symmetry. Thus in the most important groups of calcite and aragonite, the oblate CO₃ groups are in the planes perpendicular to the *c* axis, in certain rare earth carbonates, exemplified by bastnasite, they are parallel to it. Within a plane these groups may be either equally or differently orientated, as in calcite-aragonite and the polymorphic minerals with composition $BaCa(CO_3)_2$ – barytocalcite, paralstonite and Alstonite (Kostov, Kostov, 1999).

Barytocalcite BaCa(CO₃)₂ is monoclinic $P2_1/m$, a 8.09, b 5.23, c 6.54 Å, β 106°05', Z=2, with perfect {210} cleavage, habit forms {100}, {111}, {131} and {210}, hinting on an axial A^c type mineral. Paralstonite BaCa(CO₃)₂ is trigonal P321, a 8.69, c 6.15 Å, Z=3, and alstonite BaCa(CO₃)₂ – triclinic C 1 or C1, occurring almost invariably as steep pseudohexagonal

C1, occurring almost invariably as steep pseudohexagonal bipyramidal crystals, due to repeated twinning on $\{110\}$. The position of the CO₃ groups in the three polymorphs differs in accordance with the coordination of the Ca and Ba atoms.

In the uranyl carbonates, the CO₃ groups are closely attached to the UO₂ group, forming thus rather stable $[UO_2(CO_3)_3]^{4-}$ and other less stable structural units. The uranyl coordination polyhedron is represented by obtuse hexagonal bipyramid, the equatorial corners of which are occupied by oxygen from the CO₃ groups, the polar oxygens of the uranyl linked to other cations. Rutherfordine (UO₂)CO₃, which is orthorhombic *Pmmn*, *a* 4.84, *b* 9.29 Å, *Z*=2, is a good example of uranyl carbonates, possessing a planar P^b type structure (cleavage on {010} corresponding to layered arrangement of the uranyl-carbonate groups), but occurring usually as fibrous crystals along either [001] or [100] zone. The following examples of different structural types among carbonate minerals can be introduced (Kostov, Kostov, 1999, with additions).

AXIAL TYPES

Nesquehonite MgCO₃.3H₂O is monoclinic-prismatic, P_{21}/n , a 7.68, b 5.39, c 12.00 Å, β 90°45', Z=4; originally considered to be orthorhombic. Judging from the unit cell parameters the mineral is axial of the A^b types, which is in accordance with its prismatic and acicular [010] crystals, as well as with its apparent {101} perfect cleavage. Forms observed are along the [010] zone. Originally it is found as stalactitic aggregates and incrustations, formed through dehydration from lansfordite MgCO₃.5H₂O. The latter is also monoclinic-prismatic, P_{21}/m , a 12.50, b 7.57, c 7.35 Å, β 101°49', its short prismatic crystals, rather enriched in forms, possessing perfect {100} and {001} cleavages. Thus, like nesquehonite, it is again an A^b type mineral. Such is also artinite Mg₂CO₃(OH)₂.3H₂O, monoclinic-

sphenoidal, C2, *a* 16.69, *b* 3.15, *c* 6.21 Å, β 99⁰45', Z=2, found usually as fibrous aggregates. Typical A^b type is loseyite (Mn,Zn)₇(CO₃)₂(OH)₁₀, monoclinic, A2/a, *a* 16.2, *b* 5.6, *c* 15.0 Å, β 95[°]24', with no observed cleavage, but with strongly elongated [010] lath-like crystals. The general tendency of habit variation of the three minerals is inferred to be A^b₍₀₁₀₎ \rightarrow A^b_i \rightarrow A^b_[010], with possible elongation of the first habit along the [001] and [100] direction.

Nahcolite NaHCO₃ is monoclinic-prismatic, $P2_1/n$, a 7.53, b 9.72, c 3.54 Å, β 93°19', Z=4. The mineral is distinctly axial A^c type, its prismatic to acicular [001] crystals modified usually by {110}, {120} and {010}. Additional forms observed are {101} and {111}, both corresponding to good cleavages. Artificially obtained crystals of the mineral are also prismatic A^c(110) with added forms {010} and {111}; increased supersaturation increses the significance of the {010} form and the elongation of the crystals along the [001] direction, single crystals transformed into contact or penetration {101} twins and finally into spherolites (Aslanyan et al., 1968).

Instructive A^c type is also fontanite Ca(UO₂)₃(CO₃)₄.3H₂O, orthorhombic, *Pmnm*, *a* 15.34, *b* 17.05, *c* 6.93 Å, exemplifying uranyl carbonates with chain-like arrangement of their atoms and CO₃ groups. With its {110} perfect cleavage gaylussite Na₂Ca(CO₃)₂.5H₂O, is also added to the A^C type minerals. It is monoclinic-prismatic, *C*2/*c*, *a* 14.35, *b* 7.78, *c* 11.21 Å, β 127°51', *Z*=4, and its crystals, however, are pseudooctahedral or elongated along [100].

Malachite Cu₂CO₃(OH)₂ is monoclinic-prismatic, P2₁/c, a 9.48, b 12.03, c 3.21 Å, β 98°42', Z=4. The structure of the mineral is presented by the oblate CO₃ groups placed parallel to the {201} plane, the copper atoms sited in a distorted octahedral coordination among oxygens and (OH) groups. Its perfect $\{\overline{2}01\}$ cleavage corresponds to the CO₃ layers, but its rare crystals are invariably fibrous or needle-like [001] with observed forms {110}, {100}, {010}, {001} and {201}. Common are twins on {100}. By its unit cell ratio 2c/(a+b) 0.30 malachite is a distinct A^c mineral. Occurs predominantly as mamillary, botryoidal and tuberose aggregates with radiate texture, the svmmetrv of which is described with spheroidal. hemispheroidal, conical and other similar forms.

ISOMETRIC AND PSEUDOISOMETRIC TYPES

Among the isometric carbonates are tychite $Na_6Mg_2(CO_3)_4(SO_4)$ and northupite $Na_3Mg(CO_3)_2CI$, both *Fd*3, *a* 13.90 and 14.02 Å, *Z*=8 and *Z*=16 respectively, and both occurring as octahedral crystals, as well as zaratite $Ni_3CO_3(OH)_{4.}4H_2O$, *a* 6.16 Å, *Z*=2.

Calcite and aragonite CaCO₃ are polymorphs, $R \ \overline{3}c$ and Pmcn space groups respectively, cerussite PbCO₃, together with witherite BaCO₃ and strontianite SrCO₃ are isostructural with aragonite. Isostructural with calcite are siderite FeCO₃, rhodochrosite MnCO₃, magnesite MgCO₃, spherocobaltite CoCO₃, smithsonite ZnCO₃ and otavite CdCO₃. Of lower

symmetry $R \overline{3}$, but again based on calcite structure are dolomite CaMg(CO₃)₂, ankerite Ca(Fe,Mg,Mn)(CO₃)₂ and kutnahorite (Ca,Mn,Mg,Fe)(CO₃)₂, their morphologies fitting that of calcite. Calcite, aragonite and their isostructural minerals form an isodimorphous series in which richest in forms are calcite and aragonite (Kostov, 1960).

Calcite CaCO₃ is ditrigonal-scalenohedral, $R \overline{3}c$, a 4.98, c 17.02 Å, Z=6; a_{rh} 6.37 Å, α 47°07' (the cleavage rhombohedral cell with 101°55'), Z=2. The structure of calcite can be presented by that of NaCl (halite) set up so that one of the four threefold axes is vertical and the structure then compressed along this threefold axis; the cube angle of 90° becomes 101°55'. By replacement of the sodium atoms in the so distorted NaCl lattice by calcium, and the chlorine atoms by triangular CO₃ groups, the structure of calcite is thus obtained. The flat CO₃ group follow planes perpendicular to the threefold axis. The true unit cell is evolved from such rhombohedral cell. Calcite, as known, is a widespread mineral paragenetic with different other minerals of origin ranging from magmatic, pegmatitic, hydrothermal, metasomatic, sedimentary and supergene (weathering) affiliations, thus providing hints for their genesis as well.

The structure of the dolomite group minerals is similar to that of calcite, but the distribution of the atoms along any threefold axis is alternately Ca and Mg (respectively Fe or Mn), which causes lowering of their symmetry. The perfect cleavage on $\{10\overline{1}\ 1\}$ corresponds to the weak bonds existing between the Ca atoms and CO₃ groups arranged in a three-dimensional chessboard manner. As predicted by the PBC theory $\{10\overline{1}\ 1\}$ corresponds to F faces as are the $\{100\}$ faces of NaCl (Hartman, 1982).

In contradistinction to the other carbonates, isostructural with calcite, for which up to about ten or fifteen crystal forms are registered, calcite is extremely rich in forms and habits, the forms exceeding 620. Apart from $\{0001\}$, $\{10\overline{1}0\}$ and $\{11\overline{2}0\}$, 5 dihexagonal prisms, 12 bipyramids, 28 positive and 56 negative rhombohedra, 128 positive and 96 negative scalenohedra have been counted (Brock, 1993). The most frequent and habit-modifying forms are $\{10\overline{1}0\}$, $\{01\overline{1}2\}$, $\{21\overline{3}1\}, \{0001\}, \{10\overline{1}1\}, \{02\overline{2}1\}, \{40\overline{4}1\}, \{11\overline{2}0\}, \{10\overline{1}2\}, \{$ $\{05\overline{5}4\}$, $\{03\overline{3}2\}$, $\{31\overline{4}2\}$, $\{35\overline{8}4\}$, $\{54\overline{9}1\}$ and $\{32\overline{5}1\}$. The crystal habit of calcite is extremely varied ranging from thin to thick tabular, flat rhombohedral usually with {0112}, obtuse to acute rhombohedral, cuboid, pseudooctahedral, scalenohedral and prismatic. Twinning on {0001} and {0112} is very common, on {1011} and {0221} rather rare. A structural analysis of the most commonly encountered habits of calcite extended Kalb's (1929) sequence with two other habits: {0001} \rightarrow {1011} \rightarrow {2131} \rightarrow {1010} + {0001} \rightarrow {1010} + $\{01\overline{1}2\} \rightarrow \{01\overline{1}2\} \rightarrow \{02\overline{2}1\}$ (Kashkai, Aliev, 1970).

Calcite morphology is presented on specimens from Fukuhara and Ashiomines, Japan, the first presented by calcite

veins, cutting contact-metamorphic limestone, the second by copper-lead-zinc ore veins and metasomatic deposits (Sunagawa, 1953). In both places the crystal habits of calcite run from tabular {0001} and flat rhombohedral { $01\overline{12}$ } to pseudoisometric and finally to scalenohedral { $21\overline{31}$ } or acute rhombohedral habits. The sequence in both sites is referred to continuous drop of the temperature or successive change in the pH of the solutions and selective adsorption of foreign ions on faces are accepted as an accidental habit-modifying factor.

Two generations of calcite habits varying from steep rhombohedral $\{40\overline{4}1\}$ to pseudooctahedral $\{40\overline{4}1\}$ + $\{0001\}$ and tabular $\{0001\}$ (reverse Kalb's order) is observed in cavities of mineralized Triassic dolomites in Bulgaria (Naidenova, Kostov, 1963). Most of the calcite crystals succeed acicular to fibrous aragonite, some of them perched on the latter.

Calcite (Iceland spar) crystals of economic significance displaying 25 different crystal forms and common twinning on $\{0001\}$, $\{01\overline{1}2\}$ and $\{02\overline{2}1\}$ from Siberian deposits in Russia have been subdivided into 4 main habit types: 1 – prismatic (pseudo quartz habit) with $\{11\overline{2}0\}$, the scalenohedron $\{35\overline{8}4\}$ and the rhombohedra $\{02\overline{2}1\}$ and $\{10\overline{1}1\}$; 2 – rhombohedral with $\{02\overline{2}1\}$ or $\{03\overline{3}2\}$ and additional $\{32\overline{5}1\}$, $\{12\overline{3}2\}$ and $\{31\overline{4}1\}$ forms; 3 – bipyramidal with $\{88\overline{1}\overline{6}3\}$, $\{21\overline{3}1\}$, $\{32\overline{5}1\}$ and $\{0001\}$ forms; and 4 – scalenohedral with dominating $\{35\overline{8}4\}$ and $\{53\overline{8}0\}$ or $\{12\overline{3}2\}$ and $\{11\overline{2}0\}$ forms (Andrusenko, 1971). The change of habits is presumed to have been triggered not by temperature, but by pressure and chemistry of the solutions.

Aragonite is orthorhombic-bipyramidal, Pncm, a 4.95, b 7.96, c 5.74 Å, Z=4. The difference in the structures of aragonite and calcite consists in the distribution of the calcium atoms: in calcite arranged in approximate cubic close packing, in aragonite - in hexagonal close packing. The CO3 oblate groups are parallel to (001) and sited between six calcium atoms, but are so placed, that while in calcite the oxygen touches two calcium atoms, in the case with aragonite each oxygen touches three calcium atoms. Distinct {010} cleavage, perpendicular to the longer b edge of the unit cell, hints on certain planarity but the morphological symmetry of the mineral is accepted as pseudoisometric (I)^c type, taking into account less distinct {110} and {011} cleavages. About 75 forms are quoted for aragonite crystals, prominent being {110}, {010}, {011}, {012}, {021}, {031}, {041}, {051}, {111}, {112}, {121}, {122}, {132}, {991}, {091} and {101} (compare Heijnen, 1986). Twinning on {110} is extremely common, by repetition leading to pseudohexagonal composite crystals, both of the contact and interpenetrant types. Thin polysynthetic lamellae are also observed inducing striations on {001}. Rather rare untwined crystals are usually short to long prismatic and acicular [001], i.e. (I)c_{(110)} \rightarrow (I)c_{[001]} types, the pseudohexagonal twins prismatic down to pseudoisometric or thick tabular composite crystals.

Isostructural strontianite SrCO₃ follows the morphology of aragonite, but for it simple crystals seem to be more frequent than twinned crystals, its habit more clearly ranging from thick tabular (I)^c₍₀₀₁₎ and pseudoisometic (I)^c_i to long prismatic and spear-like (compare Franke et al., 1984). Usually they are pseudohexagonal, but due to equal development of {110} and {010} forms. Twins, trillings, fourlings and polysynthetic crystals mimic those of aragonite. In contradistinction to aragonite strontianite displays almost perfect {110} and less perfect {021} cleavages. Witherite BaCO₃, also isostructural with aragonite, is found almost invariably as pseudohexagonal bipyramidal, twinned on {110} crystals, the twinned habits varying from flat to steeper bipyramidal (I)^c₍₀₂₁₎ types and long prismatic (I)^c₍₀₁₀₎ forms capped by pseudobipyramid – twinned {021} form.

Cerussite PbCO₃ is orthorhombic-bipyramidal, Pmcn, a 5.15, b 8.47, c 6.11 Å, Z=4. The mineral is isostructural with aragonite, again of the (I)^c type, with distinct {110} and {021} cleavages. More than 50 forms are registered on cerussite crystals most important being (observed rank): {010}, {110}, {111}, {021}, {001}, {012}, {100}, {011}, {130} and {102}. The crystal habit of cerussite is strongly modified, both as simple crystals and frequent {110} and less common {130} twins (see Lazarenko, Matkovskii, 1960). Distinct {110} and {021} cleavages with traceable cleavages on {010} and {012} add weight on the pseudoisometricity of the mineral, like the case is with all other minerals. While in the other aragonite type minerals the tendency of variation seems to follow the [001] direction, the crystal habits of cerussite tend to be tabular {010}, tabular {001}, pseudoisometric, prismatic [001] and prismatic [100] (compare Franke et al., 1981). Fine studies carried out on cerussite crystals from Hungary demonstrate the great variation of the crystal habits of this mineral (Tokody, 1926). Major forms observed on them are {010}, {110}, {021}, {012}, {130}, {100} and {111}, and up to 17 forms are guoted on a single crystal, richest in forms being the tabular habits.

Bastnäsite-(REE) (REE)CO3F is ditrigonal-bipyramidal, C 62c, a 7.16, c 9.79 Å, Z=6, Varieties are bastnäsite-(Ce). bastnäsite-(La) and bastnäsite-(Y). Its structure consists of layers of REE and F atoms parallel to {0001} alternating with sheets of CO₃ groups, axially arranged along the c axis. The structure with its c/a ratio is formally planar, but a sub-cell with halved c parameter turns it into a slightly axial type. Indistinct $\{10 \ \overline{1} \ 0\}$ cleavage, however fits pseudoisometricity, and for morphological purposes the mineral is accepted therefore as an (I) type. The crystals of bastnäsite-(REE) are mostly tabular $\{0001\}$ with observed additional forms $\{10\overline{1}0\}$, $\{11\overline{2}0\}$, $\{10\overline{1}3\}$, $\{10\overline{1}2\}$, $\{10\overline{1}1\}$ and $\{11\overline{2}2\}$. The tendency of the habit trend should run generally $(I)_{(0001)} \rightarrow (I)_i \rightarrow (I)_{(10\overline{1}0)}$, with increase of crystallization rate, modifications of the habits due also to admixed other cations and substitution of F for H₂O. Change of the pH of the solutions should also be taken into consideration.

Certain other REE carbonates are structurally and paragenetically related to bastnäsite-(REE). Such are parisite-(Ce) Ca(Ce,La)₂(CO₃)₃F₂, röntgenite-(Ce) Ca₂(Ce,La)₃(CO₃)₅F₃ and synchysite-(Ce) Ca(Ce,La)(CO₃) ₂F, the three or them based on the bastnäsite-(REE) structure, but with a repeat *c* parameter and space group -R3; for parisite-(Ce) *a* 7.18, *c*

84.1 Å, Z=18, for röntgenite-(Ce) *a* 7.13, *c* 69.4 Å, Z=9 and for orthorhombic synchysite-(Ce) *a* 7.11, *c* 54.7 Å, Z=18. Parisite-(Ce) possesses distinct to perfect parting on {0001}, due probably to alteration products or enhanced planarity of its structure. Its crystals (similar in habits for the other two minerals), however, are prismatic or acute hexagonal bipyramidal $\{11\overline{2}1\}$, modified by {0001}, $\{11\overline{2}0\}$, $\{10\overline{1}1\}$, $\{20\overline{2}1\}$, $\{50\overline{5}2\}$, $\{11\overline{2}3\}$ and analogous forms.

Similar both in structure and habits is cordylite-(Ce) Ba(Ce,La)₂(CO₃)₃F₂, hexagonal, with *a* 4.35, *c* 22.8 Å and *Z*=2, the crystals of which are short prismatic to equant, combinations of $\{10\overline{1}0\}$, $\{40\overline{4}5\}$, $\{10\overline{1}1\}$, $\{20\overline{2}1\}$, $\{40\overline{4}1\}$ and $\{0001\}$. Its occasional sceptre development, long prismatic topped by pseudoisometric hexagonal combinations of equally developed $\{40\overline{4}5\}$, $\{20\overline{2}1\}$ and $\{10\overline{1}0\}$ forms, obviously as a later generation, crystallizing under lower supersaturation, adds weight to the habit trend given for bastnäsite. Another REE carbonate, closely related to the enumerated minerals, is ancylite-(Ce) SrCe(CO₃)₂(OH).H₂O, which, however, is orthorhombic, occurring usually as pseudooctahedral crystals, combinations almost exclusively of $\{111\}$ and $\{120\}$ with no cleavage, hence pseudoisometric (I)^c type.

Phosgenite Pb₂CO₃Cl₂ is tetragonal-trapezohedral, *P*42₁2(?), a 8.15, c 8.87 Å, Z=4. With its c/a ratio 1.09, the mineral is typically of a pseudoisometric (I) type, it's pseudoisometricity underlined also by {001} and {110} distinct cleavages. In the structure of this mineral the Pb atoms are octahedral coordinated by four O and two Cl atoms, the CO₃ groups arranged almost parallel to the c axis. The crystals of phosgenite are usually thick tabular {001} or prismatic [001], less frequently bipyramidal {111}, forms added in such habits being {100}, {120}, {011}, {021} and {121}. The tendency of habit variations should run (I)₍₀₀₁₎ \rightarrow (I)_i \rightarrow (I)₍₁₁₀₎ respectively (I)₍₁₁₁₎.

Azurite Cu₃(CO₃)₂(OH)₂ is monoclinic-prismatic, *P*2₁/*c*, *a* 4.96, *b* 5.84, *c* 10.29 Å, β 92°24', *Z*=2. The structure of azurite is presented by Cu atoms in square coordinated by O and OH anions, the triangular CO₃ groups arranged approximately of two types: Cu(1) sited at the corners and in the centre of the (100) net of the unit cell, Cu(2) in pairs around the middle of (001) and (010) nets. Both copper atoms are surrounded by two oxygens and two hydroxyls. Each copper atom is surrounded by two oxygens and two hydroxyls. Each OH group is linked to three copper atoms, each oxygen of the CO₃ group linked with only one copper atom. Almost perfect cleavage on {011} and less perfect on {100} correspond to weak linkages in the structure. The latter is pronouncedly pseudoisometric (a sub-cell with halved *c* parameter is taken into consideration, the ratio 2*c*'/(*a*+*b*)=0.95, underlining an (I)^c type morphology).

The crystals of azurite are usually highly modified and display great variety of habit. Known are about 200 forms, most prominent being {110}, {001}, {010}, {100}, {102}, {111}, {013}, {013}, {011}, {\overline{101}} and {\overline{102}}. Rare twins are quoted on {\overline{101}}, {\overline{102}} and {100}. Taking into account the structural scheme of azurite the differentiation of the principal crystal

habits of this mineral as presented by Brasseur (1931) can be accepted, but with added tabular habits. The trend of habit variation is thus envisaged as (I)^c(001), respectively (I)^c(102) \rightarrow (I)^c₁ \rightarrow (I)^c(001), respectively (I)^c(010) and (I)^c(100) (Kostov, Kostov, 1999). Increase of supersaturation, eventually change of pH and influence of adatoms should follow such proposed trend.

Donnayite-(Y) NaCaSr₃Y(CO₃)₆.3H₂O is triclinic, *P*1, *a* 9.00, *b* 8.99, *c* 6.79 Å, α 102°46', β 116°17', γ 59°59', *Z*=1, with no clear cleavage, and is taken as an (I)^b type carbonate. It occurs as tabular, pseudoisometric and prismatic crystals.

PLANAR TYPES

Trona Na₃(HCO₃)(CO₃).2H₂O is monoclinic-prismatic, *C*2/*c*, *a* 20.41, *b* 3.49, *c* 10.31 Å, β 106°20', *Z*=4. The mineral is with perfect {100} cleavage, fitting the longest *a* edge of the unit cell, hence with a planar P^a type morphology. Its crystals are frequently elongated [010], hinting on certain axiality along the *b* axis. Forms met are {100}, {001}, {101}, {304}, {111} and {211}. Of the P^a type carbonate is also hydrozincite Zn₅(CO₃)₂(OH)₂, monoclinic-prismatic, *C*2/*m*, *a* 13.45, *b* 6.31, *c* 5.36 Å, β 95°30', *Z*=2. The mineral is also with perfect {100} cleavage, but occurs in nature usually as earthy, spheroidal, stalactitic and other aggregates.

Lanthanite-(Ce) (La,Ce)₂(CO₃)₃.8H₂O is orthorhombicbipyramidal, a 9.52, b 17.1, c 9.02 Å, Z=4. The mineral is with perfect, almost micaceous {010} cleavage, and should be taken as a representative of the P^b type morphology. Its crystals are thin to thick tabular {010} as indicated by both cleavage and the longest b edge of the unit cell. Aurichalcite (Zn,Cu)₅(CO₃)₂.(OH)₆, also orthorhombic, is with perfect {010} cleavage like lanthanite, hence of the same type, but occurring mostly as lath-like crystals elongated [001] and flattened {010}. For both, lanthanite and aurichalcite, a morphological trend of the type P^b₍₀₁₀₎ \rightarrow P^b₁ \rightarrow P^b_[010] is assumed in accordance with the other such planar type minerals.

Adamsite-(Y) NaY(CO₃)₂.6H₂O is triclinic *P* $\overline{1}$, *a* 6.26, *b* 13.05, *c* 13.22 Å, *a* 91.17°, *β* 103.70°, *γ* 89.99°, *Z*=4, with a layered structure and perfect {100} cleavage, representing a P^c structural type. Hydrocerussite Pb₃(CO₃)₂(OH)₂ is hexagonal, *a* 8.99, *c* 23.8 Å, with perfect {0001} cleavage and thin to thick tabular, and steep bipyramidal crystals. Forms observed are {0001}, {10 $\overline{1}2$ }, {10 $\overline{1}4$ }, {10 $\overline{1}1$ } and {20 $\overline{2}1$ }. As a secondary product in lead ore deposits it occurs in association with other secondary lead carbonates and sulphates, sometime as rather large, well formed crystals. The mineral is a good example of planar P type carbonates with a trend of habit development: P₍₀₀₀₁₎ \rightarrow P_i \rightarrow P_{(10 $\overline{1}2$) \rightarrow P_{(10 $\overline{1}0$).}}

Leadhillite Pb(CO₃)₂(SO₄)(OH)₂, transitional to the sulphates, is monoclinic-prismatic, $P2_1/a$, a 9.09, b 11.57, c 20.74 Å, β 90°30', Z=8. Its crystals are markedly pseudohexagonal with perfect {001] cleavage, representing P^c type morphology. About 45 forms are recognized on its crystals, the habits of which vary from thin to thick tabular {001}, pseudorhombohedral {211} + { $\overline{1}$ 42} combinations, pseudohexagonal equant, rich in forms, and prismatic [001]. Reederite (Na,Mn,Fe)₁₅Y₂(CO₃)₉(SO₃F)Cl, is also a typical planar P type mixed carbonate-sulphite mineral, also hexagonal, *P* $\overline{6}$, *a* 8.77, *c* 10.75 Å, *Z*=1. The mineral is with perfect {0001} cleavage in accordance with the *c/a* ratio 1.23, less pronounced than that of hydrocerussite, the *c/a* ratio of which is 2.72, hence more typical planar representative.

CLASSIFICATION

In the proposed classification a list of known carbonatebearing minerals, for which names have been approved by the International Mineralogical Association's Commission on New Minerals and Mineral Names have been included (formulae by Mandarino, 1999; with additions). The carbonate-bearing minerals that contain two or more other anions, such as sulphate, borate, arsenate, arsenite, phosphate, or silicate, have not been included.

1. AI-Mg-Fe(Ni,Co,Mn) assemblages

1.1. Axial (A-type) structures Barringtonite MgCO₃.2H₂O Nesquehonite MgCO₃.3H₂O Langsfordite MgCO₃.5H₂O Artinite Mg₂(CO₃)(OH)₂.3H₂O Chlorartinite Mg₂(CO₃)Cl(OH).3(H₂O) Loseyite (Mn,Zn)(CO₃)₂(OH)₁₀ Hellyerite NiCO₃.6H₂O Kambaldaite NaNi4(CO3)3(OH)3.3H2O Dawsonite NaAI(CO₃)(OH)₂ Alumohydrocalcite CaAl₂(CO₃)₂(OH)₄.3H₂O Paraalumohydrocalcite CaAl2(CO3)2(OH)4.6H2O Sergeevite Ca₂Mg₁₁(CO₃)₉(HCO₃)(OH)₄.6H₂O Dresserite Ba₂Al₄(CO₃)₄(OH)₂.3H₂O Hydrodresserite BaAl₂(CO₃)₂(OH)₄.3H₂O Strontiodresserite SrAl₂(CO₃)₂(OH)₄.3H₂O Sahamalite-(Ce) (Mg,Fe)(Ce,La,Nd)₂(CO₃)₄ Holdawayite Mn₆(CO₃)₂(OH)₇(CI,OH)

1.2. Planar (P-type) structures Scarbroite Al₅CO₃(OH)₁₃,5H₂O Hydroscarbroite AI₁₄(CO₃)₃(OH)₃₆.nH₂O Pokrovskite Mg₂(CO₃)(OH)₂.0,5H₂O Hydromagnesite Mg5(CO3)4(OH)2.4H2O Manasseite Mg₆Al₂(CO₃)(OH)₁₆.4H₂O Hydrotalcite Mg₆Al₂(CO₃)(OH)₁₆.4H₂O Chlormanasseite Mg6Al2(CO3)(OH)16Cl2.4H2O Barbertonite Mg₆Cr₂(CO₃)(OH)₁₆.4H₂O Stichtite Mg₆Cr₂(CO₃)(OH)₁₆.4H₂O Sjögrenite Mg₆Fe₂(CO₃)(OH)₁₆.4H₂O Pyroaurite Mg₁₀Fe₂(CO₃)(OH)₁₆.4H₂O Coalingite Mg₆Fe₂(CO₃)(OH)₁₆.4H₂O Desautelsite Mg6Mn2(CO3)(OH)16.4H2O Indigerite Mg₂Al₂(CO₃)₄(OH)₂.15H₂O Brugnatellite Mg6Fe(CO3)(OH)13.4H2O Chlormagaluminite (MgFe)₄Al₂(OH)₁₂(Cl₂,CO₃).2H₂O Nullagingite Ni₂(CO₃)(OH)₂ Otwavite (Ni,Mg)₂CO₃(OH)₂.H₂O Takovite Ni₆Al₂(CO₃,OH)(OH)₁₆.4H₂O

Eardleyite Ni₆Al₂(CO₃)(OH)₁₆.4H₂O Reevesite Ni₆Fe₂(CO₃)(OH)₁₆.4H₂O Widgiemoolthalite Ni₅(CO₃)₄(OH)₂.4-5H₂O Comblainite Ni₆Co₂(CO₃)(OH)₁₆.4H₂O Gaspeite (Ni,Mg,Fe)CO₃ Quintinite-2H Mg₄Al₂(CO₃)(OH)₁₂.3H₂O Quintinite-3T Mg₄Al₂(CO₃)(OH)₁₂.3H₂O Caresite-3T Fe₄Al₂(CO₃)(OH)₁₂.3H₂O Charmarite-2H Mn₄Al₂(CO₃)(OH)₁₂.3H₂O Charmarite-3T Mn₄Al₂(CO₃)(OH)₁₂.3H₂O Charmarite-3T Mn₄Al₂(CO₃)(OH)₁₂.3H₂O Charmarite-3T Mn₄Al₂(CO₃)(OH)₁₂.3H₂O

1.3. (Pseudo-)Isometric, (I) resp. I-type structures Eitelite Na₂Mg(CO₃)₂ Northupite Na₃Mg(CO₃)₂Cl Tychite Na₆Mg(CO₃)₂Cl Huntite CaMg(CO₃)₄ Tunisite NaCa2Al4(CO3)4(OH)8Cl Dashkovaite Mg(HCO₃)₂.2H₂O Baylissite K₂Mg(CO₃)₂.4H₂O Magnesite MgCO₃ Siderite FeCO3 **Rhodochrosite MnCO3** Spherocobaltite CoCO3 Dolomite CaMg(CO₃)₂ Ankerite Ca(Fe,Mg,Mn)(CO₃)₂ Kutnahorite CaMn(CO₃)₂ Norsethite BaMg(CO₃)₂ Zaratite Ni₃(CO₃)(OH)₂.4H₂O

2. Na-Ca-Ba(K)-REE assemblages

2.1. Axial (A-type) structures Kalicinite KHCO₃ Teschemacherite NH₄HCO₃ Wegscheiderite Na₅(CO₃)(HCO₃)₃ Nahcolite NaHCO3 Gaylussite Na₂Ca(CO₃)₂.5H₂O Trihydrocalcite CaCO₃.3H₂O Pentahydrocalcite CaCO₃.5H₂O Ikaite CaCO₃.6H₂O Brenkite Ca₂(CO₃)F₂ Barytocalcite BaCa(CO₃)₂ Defernite Ca₃CO₃(OH,CI)₄.H₂O Tuliokite Na₆BaTh(CO₃)₆.6H₂O Petersenite-(Ce) Na₄(Ce,La,Nd)₂(CO₃)₅ Shomiokite-(Y) Na₃Y(CO₃)₃.3H₂O Lokkaite-(Y) CaY4(CO3)7.9H2O Kukharenkoite-(Ce) Ba₂Ce(CO₃)₃F

2.2. Planar (P-type) structures Vaterite CaCO₃ Nyereraite Na₂Ca(CO₃)₂ Shortite Na₂Ca₂(CO₃)₃ Gregoryite (Na₂,K₂,Ca)CO₃ Rouvilleite Na₃Ca₂(CO₃)₃F Fairchildite K₂Ca(CO₃)₂ Bütschliite K₂Ca(CO₃)₂ Bütschliite K₂Ca(CO₃)₂ Calkinsite-(Ce) (Ce,La)₂(CO₃)₃.4H₂O Adamsite-(Y) NaY(CO₃)₂.6H₂O Lanthanite-(La) (La,Dy,Ce)₂(CO₃)₃.8H₂O Thermonatrite Na₂(CO₃).H₂O Trona Na₃(HCO₃)(CO₃).2H₂O Natron Na₃CO₃.10H₂O Kozoite-(Nd) Nd(CO₃)(OH) Galgenbergite-(Ce) Ca(Ce,Nd,La)₂(CO₃)₄.H₂O Kamphaugite-(Y) Ca(Y,REE)(CO₃)₂(OH).H₂O Kimuraite-(Y) CaY₂(CO₃)₄.6H₂O Weloganite Sr₃Na₂Zr(CO₃)₆.3H₂O Thomasclarkite-(Y) Na(Y,REE)(HCO₃)(OH)₃.4H₂O Mckelveyite-(Y) Ba₃Na(Ca,U)Y(CO₃)₆.3H₂O Gysinite-(Nd) Pb(Nd,La)(CO₃)₂(OH).H₂O Sheldrickite NaCa₃(CO₃)₂F₃.H₂O Rouvilleite Na₃(Ca,Mn,Fe)₂(CO₃)₃F Huanghoite-(Ce) BaCe(CO₃)₂F Zhonghuacerite-(Ce) Na₃Ce₂(CO₃)₄F

2.3. Pseudo-Isometric, (I)-type structures Zabuyelite Li2CO3 Natrite Na₂CO₃ Calcite CaCO₃ Aragonite CaCO₃ Strontianite SrCO3 Witherite BaCO₃ Pirssonite CaNa₂(CO₃)₂.2H₂O Monohydrocalcite CaCO₃.H₂O Zemkorite (Na,K)₂Ca(CO₃)₂ Alstonite BaCa(CO₃)₂ Paralstonite BaCa(CO₃)₂ Olekminskite Sr(Sr,Ca,Ba)(CO₃)₂ Ewaldite Ba(Ca,Y,Na,K)(CO₃)₂ Benstonite Ba₆Ca₇(CO₃)₁₃ Carbocernaite (Ca.Na)(Sr.Ce.Ba)(CO₃)₂ Burbankite (Na,Ca)₃(Sr,Ba,Ce)₃(CO₃)₅ Calcioburbankite (Na,Ca)₃(Sr,Ba,Ce)₃(CO₃)₅ Khanneshite (Na,Ca)₃(Ba,Sr,Ce,Ca)₃(CO₃)₅ Remondite-(Ce) Na₃(Ce,La,Ca,Na,Sr)₃(CO₃)₅ Ancylite-(Ce) SrCe(CO₃)₂(OH).H₂O Ancylite-(La) Sr(La,Ce)(CO₃)₂(OH).H₂O Calcio-ancylite-(Ce) (Ca,Sr)Ce₃(CO₃)₄(OH)₃.H₂O Calcio-ancylite-(Nd) Ca(Nd,Ce,Gd,Y)3(CO3)4(OH)3.H2O Bastnäsite-(Ce) (Ce,La)(CO₃)F Bastnäsite-(La) (La,Ce)(CO₃)F Bastnäsite-(Y) (Y,Ce)(CO₃)F Hydroxylbastnäsite-(Ce) (Ce,La)(CO₃)(OH,F) Hydroxylbastnäsite-(La) (La,Ce)(CO₃)(OH,F) Hydroxylbastnäsite-(Nd) (Nd,Ce,La)(CO₃)(OH,F) Parisite-(Ce) Ca(Ce,La)₂(CO₃)₃F Parisite-(Nd) Ca(Nd,Ce,La)₂(CO₃)₃F Röntgenite-(Ce) Ca2(Ce,La)3(CO3)5F3 Synchysite-(Ce) Ca(Ce,La)(CO₃)₂F Synchysite-(Nd) Ca(Nd,La)(CO₃)₂F Synchysite-(Y) Ca(Y,Ce)(CO₃)₂F Cordylite-(Ce) NaBaCe₂(CO₃)₄F Donnavite-(Y) NaCaSr₃Y(CO₃)₆.3H₂O Horvathite-(Y) NaYCO₃F₂ Stenonite (Sr,Ba,Na)₂AlCO₃F₅ Barentsite Na7AIH₂(CO₃)₄F₄ Montroyalite Sr₄Al₈(CO₃)₃(OH.F)₂₆.10-11H₂O

3. Zn-Cu-Pb(U) assemblages

3.1. Axial (A-type) structures Malachite Cu₂(CO₃)(OH)₂

Glaucosphaerite (Cu,Ni)₂(CO₃)(OH)₂ Loseyite (Mn,Zn)7(CO3)2(OH)10 Sclarite (Zn,Mg,Mn)₄Zn₃(CO₃)₂(OH)₁₀ Shannonite Pb₂O(CO₃) Schuilingite Pb3Cu2Ca6(CO3)8(OH)6.6H2O Sharpite (UO₂)(CO₃).H₂O Bayleyite Mg₂(UO₂)(CO₃)₃.18H₂O Swartzite CaMg(UO2)(CO3)3.12H2O Zellerite Ca(UO₂)(CO₃)₂.5H₂O Metazellerite Ca(UO₂)(CO₃)₂,3H₂O Urancalcarite Ca(UO₂)₃CO₃(OH)₆.3H₂O Voglite Ca₂Cu(UO₂)₂(CO₃),14H₂O Fontanite Ca(UO₂)(CO₃)₄.3H₂O Oswaldpeetersite (UO2)2(CO3)(OH)2.4H2O Astrocyanide-(Ce) Cu₂(Ce,Nd,La)(UO₂)(CO₃)₅(OH)₂.1,5H₂O Szymanskiite Hg10Ni6(CO3)12(H3O)8.3H2O

3.2. Planar (P-type) structures Hydrozincite Zn₅(CO₃)₂(OH)₆ Aurichalcite (Zn,Cu)5(CO3)2(OH)6 Claraite (Cu,Zn)₃(CO₃)(OH)₄.4H₂O Zaccagnaite Zn₄Al₂(CO₃)(OH)₁₂.3H₂O Chalconatrite Na₂Cu(CO₃)₂.3H₂O Cuproartinite (Cu,Mg)₂(CO₃)(OH)₂.3H₂O Glaukosphaerite (Cu,Ni)₂(CO₃)(OH)₂ Kolwezite (Cu²⁺,Co)₂(CO₃)(OH)₂ Mcquinnessite (Mg,Cu²⁺)₂(CO₃)(OH)₂ Rosasite (Cu²⁺,Zn)₂(CO₃)(OH)₂ Zincrosasite (Zn,Cu²⁺)₂(CO₃)(OH)₂ Decrespingnyite-(Y) (Y,REE)₄Cu(CO₃)₄Cl(OH)₅.2H₂O Rutherfordine (UO₂)(CO₃) Blatonite (UO₂)(CO₃),H₂O Joliotite (UO₂)(CO₃).2H₂O Cejkaite Na₄(UO₂)(CO₃)₃ Liebigite Ca₂(UO₂)(CO₃)₃.10H₂O Rabbittite Ca₃Mg₃(UO₂)₂(CO₃)₆.18H₂O Wyartite Ca₃U(UO₂)₆(CO₃)₂(OH)₈.4H₂O Znucalite CaZn12(UO2)(CO3)3(OH)22.4H2O Widenmannite Pb₂(UO₂)(CO₃)₃ Hydrocerussite Pb₃(CO₃)₂(OH)₂ Plumbonacrite Pb₁₀(CO₃)₆O(OH)₆ Petterdite PbCr₂(CO₃)₂(OH)₄.H₂O Dundasite PbAl₂(CO₃)₂(OH)₄.H₂O Barstowite Pb₄(CO₃)Cl₆.H₂O Bismutite Bi₂O₂(CO₃) Kettnerite CaBi(CO₃)OF Beyerite CaBi₂(CO₃)₂O₂ Clearcreekite Hg₃(CO₃)(OH).2H₂O Peterbaylissite Hg₃(CO₃)(OH).2H₂O Astrocyanite-(Ce) Cu₂(Ce,Nd,La)₂(ÚO₂)(CO₃)₅(OH)₂.1,5H₂O Shabaite-(Nd) Ca(Nd,Sm,Y)2(UO2)(CO3)4(OH)2.6H2O Bijvoetite-(Y) (Y,Dy)2(UO2)4(CO3)4(OH)6.11H2O

3.3. Pseudo-isometric, (I)-type structures Smithsonite ZnCO₃ Minrecordite CaZn(CO₃)₂ Otavite CdCO₃ Azurite Cu₃(CO₃)₂(OH)₂ Callaghanite Cu₂Mg₂(CO₃)(OH)₆.2H₂O Cerussite PbCO₃ Phosgenite Pb(CO₃)Cl₂ Grimselite K₃Na(UO₂)(CO₃)₃.H₂O Andersonite Na₂Ca(UO₂)(CO₃)₃.6H₂O Albrechtschraufite Ca₄Mg(UO₂)₂(CO₃)₆F₂.17H₂O

3.4. Amorphous Georgeite Cu₂CO₃(OH)₂

References

- Andrusenko, N. I. 1971. *Mineralogy and Genesis of Iceland Spar from the Siberian Platform*. Nauka, Moscow, 228 p. (in Russian)
- Aslanyan, S., I. Kostov, H. Neels. 1968. Komplexe Zwillinge und Sphärolithe von Nahcolith (NaHCO₃). – *Kristall u. Technik*, 3, 4, 619-627.
- Brasseur ,H. 1931. Sur la morphologie de l'azurite. Z. Kristall., 77, 177-238.
- Brock, K. J. 1993. The crystal forms of calcite. *Mineral. Rec.*, 24, 6, 451-461, 470.
- Carbonates: Mineralogy and Chemistry (Ed. by Reeder, R. J.). 1983. Reviews in Mineralogy, Mineralogical Society of America, 11, 394 p.
- Effenberger, H., K. Mereiter, J. Zemann. 1981. Crystal structure refinements of magnesite, calcite, rhodochrosite, siderite, smithsonite, and dolomite, with discussion of some aspects of the stereochemistry of calcite type carbonates. – Z. Kristallogr., 156, 233-243.
- Franke, W., K. Lenk, M. A. Ittyachen, P. K. Mohanan. 1981. The morphology of cerussite PbCO₃ grown in silica gel and on hydrothermal conditions. – *J. Crystal Growth*, *51*, 309-313.
- Franke, W., A. Hofer, B. Jelinski, K. Lenk. 1984. The morphology of witherite and strontianite grown in silica gel, by slow precipitation and on hydrothermal conditions. – *Crystal Res. Technol.*, 19, 12, 1565-1569.
- Godovikov, A. A. 1997. Structural-Chemical Systematics of Minerals. Russian Academy of Sciences, Fersman Mineralogical Museum, Moscow, 240 p. (in Russian)
- Hartman, P. 1984. On the growth of dolomite and kaolinite crystals. *N. Jb. Mineral. Mh.*, 2, 84-92.
- Heijnen, W. M. M. 1986. The structural morphology of aragonite. – N. Jb. Mineral. Abh., 154, 3, 223-245.
- Kalb, G. 1929. Bemerkungen zu den minerogenetischen Kristalltrachttypen des Kalkspates. – Centralbl. Mineral., Geol., Paläont. A, 4, 137-138.
- Kashkai, M. A., R. M. Aliev. 1979. Structural analysis of the most commonly encountered habit faces of calcite crystals from skarn deposits. – *Mineral. Mag.*, 37, 292, 929-933.
- Kostov, I. 1960. On the stability of the crystal forms of minerals. – Zap. Vses. Mineral. Obsht., 89, 1, 90-93 (in Russian).
- Kostov, I. 1964. The classification of oxides. In: Aspects of Theoretical Mineralogy in the U.S.S.R. Pergamon Press, New York, 221-224.
- Kostov, I. 1965. Crystal habit and mineral genesis. Bull. Inst. Geol., Sofia, 14, 33-49.
- Kostov, I. 1968. Notation and genetic significance of crystal habits. – In: V General Meeting, International Mineralogical Association, Cambridge, Papers & Proceedings, 100-109.
- Kostov, I. 1975. Crystal chemistry and classification of the silicate minerals. Geochem., Mineral., Petrol., 1, 5-41.

- Kostov, I. 1977. Crystal chemistry of the minerals: relationship between crystal structure, condition of crystallization and growth morphology. – *Geochem. Mineral. Petrol.*, 7, 3-21.
- Kostov I. 1986. Crystallogenetic trends in a rational systematics of phosphate and related minerals. *Geochem., Mineral. Petrol.*, 22, 3-13.
- Kostov, I. 1993. *Mineralogy*. 4th rev. ed., Technika, Sofia, 734 p. (in Bulgarian)
- Kostov, I. 2000. Mineral classifications re-visited with emphasis on a paragenetic-structural system. – *Geochem., Mineral. Petrol.*, 37, 5-11.
- Kostov, I., R. I. Kostov. 1999. Crystal Habits of Minerals. Bulgarian Academic Monographs, 1. Sofia. Co-published by Pensoft Publishers and Prof. Marin Drinov Academic Publishing House, 415 p.
- Kostov, I., R. I. Kostov. 2002. Structural-paragenetic classification of borate minerals. – *Mineral. Zhurnal, Kiev*, 24, 1, 5-9.
- Kostov I., J. Minčeva-Stefanova. 1982. Sulphide Minerals. Crystal Chemistry, Parageneses and Systematics. Bulgarian Academy of Sciences, Sofia; E.Schweizerbart'sche Verlagsbuchh. (Nägele u. Obermiller), Stuttgart, 212 p.
- Lazarenko, E. K., O. I. Matkovskii. 1960. Cerussites from the Zakarpatiye. *Mineral. Sbornik, Lvov, 14,* 304-324 (in Russian).
- Lima-de-Faria, J. 1983. A proposal for a structural classification of minerals. *Garcia de Orta, Ser. Geol., Lisboa, 6,* 1-2, 1-24.

Recommended for publication by Department of Mineralogy and Petrography, Faculty of Geology and Prospecting

- Mandarino, J. A. 1999. *Fleischer's Glossary of Mineral Species*. The Mineralogical Record, Tucson, 225 p.
- Naidenova, E., I. Kostov. 1964. Aragonite-calcite relations in one of the caves of Iskretz, district of Sofia. – Ann. Univ. Sofia, Fac. Géol. Géogr., 57, 1, 93-110 (in Bulgarian).
- Povarennykh, A. S. 1972. Crystal Chemistry Classification of Minerals. Plenum Press, New York (transl. from Russian).
- Reeder, R. J. 1983. Crystal chemistry of trigonal carbonates. In: Carbonates: Mineralogy and Chemistry. Reviews in Mineralogy, Mineralogical Society of America, 11, 13-69.
- Railsback, L. B. 1999. Patterns in the compositions, properties, and geochemistry of carbonate minerals. – Carbonates and Evaporites, 14, 1-20.
- Strunz, H. 1984. Moderne Mineral-klassifikationen. A historical review. – In: Proc. 27th International Geological Congress. Moscow 4-14 August 1984. VNU Science Press, Utrecht, The Netherlands, 10, 65-112.
- Sunagawa, I. 1953. Variation of crystal habit of calcite. *Rep. Geol. Surv. Japan*, 155, 1-66 (in Japanese).
- Tokody, L. 1926. Kristallographische Monographie der ungarischen Cerussite. – Z. Kristall., 63, 385-456.
- White, W. B. 1974. The carbonate minerals. In: The Infrared Spectra of Minerals (Ed. by Farmer, V. C.) Mineralogical Society of London, Monograph 4, 227-284.
- Zemann, J. 1981. Zur Stereochemie der Karbonate. Fortschritte der Mineralogie, 59, 95-116.
- Zemann, J. 1989. Crystal chemistry of magnesium carbonates and related compounds. – *Monograph Series on Mineral Deposits*, 28, 241-257.