

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 $2c/(a+b)$, $2b/(a+c)$ 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 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 – Al-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 класификация 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 основното отношение c/a на минералите с висока симетрия или $2c/(a+b)$, $2b/(a+c)$ и $2a/(b+c)$ 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 P-тип. Тези обозначения съответстват на верижни, скелетни и слоестоподобни структури, респективно ино-, текто- и филоструктури. В предложената класификация са включени три геохимични асоциации сред карбонатните минерали – Al-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(CO₃)₂ – barytocalcite, paralstonite and Alstonite (Kostov, Kostov, 1999).

Barytocalcite BaCa(CO₃)₂ is monoclinic *P2₁/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 pseudo-hexagonal 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 [UO₂(CO₃)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 *Pmnm*, *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, *P2₁/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, *P2₁/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 99°45', *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₎ → A^b_i → A^b_[010], with possible elongation of the first habit along the [001] and [100] direction.

Nahcolite NaHCO₃ is monoclinic-prismatic, *P2₁/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 increases 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 spherulites (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, *C2/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 {201} 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 2*c*/(*a*+*b*) 0.30 malachite is a distinct A^c mineral. Occurs predominantly as mamillary, botryoidal and tuberoso aggregates with radiate texture, the symmetry of which is described with spheroidal, hemispheroidal, conical and other similar forms.

ISOMETRIC AND PSEUDOISOMETRIC TYPES

Among the isometric carbonates are tychite Na₆Mg₂(CO₃)₄(SO₄) and northupite Na₃Mg(CO₃)₂Cl, both *Fd3*, *a* 13.90 and 14.02 Å, *Z*=8 and *Z*=16 respectively, and both occurring as octahedral crystals, as well as zaraitite Ni₃CO₃(OH)₄·4H₂O, *a* 6.16 Å, *Z*=2.

Calcite and aragonite CaCO₃ are polymorphs, *R 3c* and *Pmnc* 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 $R\bar{3}$, but again based on calcite structure are dolomite $\text{CaMg}(\text{CO}_3)_2$, ankerite $\text{Ca}(\text{Fe,Mg,Mn})(\text{CO}_3)_2$ and kutnahorite $(\text{Ca,Mn,Mg,Fe})(\text{CO}_3)_2$, 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 CaCO_3 is ditrigonal-scalenohedral, $R\bar{3}c$, a 4.98, c 17.02 Å, $Z=6$; a_{rh} 6.37 Å, α 47°07' (the cleavage rhombohedral cell with $101^\circ55'$), $Z=2$. 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 $101^\circ55'$. By replacement of the sodium atoms in the so distorted NaCl lattice by calcium, and the chlorine atoms by triangular CO_3 groups, the structure of calcite is thus obtained. The flat CO_3 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 $\{10\bar{1}1\}$ corresponds to the weak bonds existing between the Ca atoms and CO_3 groups arranged in a three-dimensional chessboard manner. As predicted by the PBC theory $\{10\bar{1}1\}$ 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 $\{0001\}$, $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$, 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 $\{10\bar{1}0\}$, $\{01\bar{1}2\}$, $\{21\bar{3}1\}$, $\{0001\}$, $\{10\bar{1}1\}$, $\{02\bar{2}1\}$, $\{40\bar{4}1\}$, $\{11\bar{2}0\}$, $\{10\bar{1}2\}$, $\{05\bar{5}4\}$, $\{03\bar{3}2\}$, $\{31\bar{4}2\}$, $\{35\bar{8}4\}$, $\{54\bar{9}1\}$ and $\{32\bar{5}1\}$. The crystal habit of calcite is extremely varied ranging from thin to thick tabular, flat rhombohedral usually with $\{01\bar{1}2\}$, obtuse to acute rhombohedral, cuboid, pseudooctahedral, scalenohedral and prismatic. Twinning on $\{0001\}$ and $\{01\bar{1}2\}$ is very common, on $\{10\bar{1}1\}$ and $\{02\bar{2}1\}$ rather rare. A structural analysis of the most commonly encountered habits of calcite extended Kalb's (1929) sequence with two other habits: $\{0001\} \rightarrow \{10\bar{1}1\} \rightarrow \{21\bar{3}1\} \rightarrow \{10\bar{1}0\} + \{0001\} \rightarrow \{10\bar{1}0\} + \{01\bar{1}2\} \rightarrow \{01\bar{1}2\} \rightarrow \{02\bar{2}1\}$ (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 $\{01\bar{1}2\}$ to pseudoisometric and finally to scalenohedral $\{21\bar{3}1\}$ 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 $\{40\bar{4}1\}$ to pseudooctahedral $\{40\bar{4}1\} + \{0001\}$ 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 $\{0001\}$, $\{01\bar{1}2\}$ and $\{02\bar{2}1\}$ from Siberian deposits in Russia have been subdivided into 4 main habit types: 1 – prismatic (pseudo quartz habit) with $\{11\bar{2}0\}$, the scalenohedron $\{35\bar{8}4\}$ and the rhombohedra $\{02\bar{2}1\}$ and $\{10\bar{1}1\}$; 2 – rhombohedral with $\{02\bar{2}1\}$ or $\{03\bar{3}2\}$ and additional $\{32\bar{5}1\}$, $\{12\bar{3}2\}$ and $\{31\bar{4}1\}$ forms; 3 – bipyramidal with $\{88\bar{1}63\}$, $\{21\bar{3}1\}$, $\{32\bar{5}1\}$ and $\{0001\}$ forms; and 4 – scalenohedral with dominating $\{35\bar{8}4\}$ and $\{53\bar{8}0\}$ or $\{12\bar{3}2\}$ and $\{11\bar{2}0\}$ 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, $Pn\bar{c}m$, 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 CO_3 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 pseudo-hexagonal 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 pseudo-hexagonal twins prismatic down to pseudoisometric or thick tabular composite crystals.

Isostructural strontianite SrCO_3 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 $(l)^\circ_{(001)}$ and pseudoisometric $(l)_i$ to long prismatic and spear-like (compare Franke et al., 1984). Usually they are pseudo-hexagonal, 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 BaCO_3 , also isostructural with aragonite, is found almost invariably as pseudo-hexagonal bipyramidal, twinned on $\{110\}$ crystals, the twinned habits varying from flat to steeper bipyramidal $(l)^\circ_{(021)}$ types and long prismatic $(l)^\circ_{(010)}$ forms capped by pseudobipyramid – twinned $\{021\}$ form.

Cerussite PbCO_3 is orthorhombic-bipyramidal, $Pm\bar{c}n$, a 5.15, b 8.47, c 6.11 Å, $Z=4$. The mineral is isostructural with aragonite, again of the $(l)^\circ$ 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 quoted on a single crystal, richest in forms being the tabular habits.

Bastnäsité-(REE) $(\text{REE})\text{CO}_3\text{F}$ is ditrigonal-bipyramidal, $C\bar{6}2c$, a 7.16, c 9.79 Å, $Z=6$. Varieties are bastnäsité-(Ce), bastnäsité-(La) and bastnäsité-(Y). Its structure consists of layers of REE and F atoms parallel to $\{0001\}$ alternating with sheets of CO_3 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 $\{10\bar{1}0\}$ cleavage, however fits pseudoisometricity, and for morphological purposes the mineral is accepted therefore as an (l) type. The crystals of bastnäsité-(REE) are mostly tabular $\{0001\}$ with observed additional forms $\{10\bar{1}0\}$, $\{11\bar{2}0\}$, $\{10\bar{1}3\}$, $\{10\bar{1}2\}$, $\{10\bar{1}1\}$ and $\{11\bar{2}2\}$. The tendency of the habit trend should run generally $(l)_{(0001)} \rightarrow (l)_i \rightarrow (l)_{(10\bar{1}0)}$, with increase of crystallization rate, modifications of the habits due also to admixed other cations and substitution of F for H_2O . Change of the pH of the solutions should also be taken into consideration.

Certain other REE carbonates are structurally and paragenetically related to bastnäsité-(REE). Such are parisité-(Ce) $\text{Ca}(\text{Ce},\text{La})_2(\text{CO}_3)_3\text{F}_2$, röntgenité-(Ce) $\text{Ca}_2(\text{Ce},\text{La})_3(\text{CO}_3)_5\text{F}_3$ and synchysité-(Ce) $\text{Ca}(\text{Ce},\text{La})(\text{CO}_3)_2\text{F}$, the three or them based on the bastnäsité-(REE) structure, but with a repeat c parameter and space group – $R\bar{3}$; for parisité-(Ce) a 7.18, c

84.1 Å, $Z=18$, for röntgenité-(Ce) a 7.13, c 69.4 Å, $Z=9$ and for orthorhombic synchysité-(Ce) a 7.11, c 54.7 Å, $Z=18$. Parisité-(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 $\{11\bar{2}1\}$, modified by $\{0001\}$, $\{11\bar{2}0\}$, $\{10\bar{1}1\}$, $\{20\bar{2}1\}$, $\{50\bar{5}2\}$, $\{11\bar{2}3\}$ and analogous forms.

Similar both in structure and habits is cordylité-(Ce) $\text{Ba}(\text{Ce},\text{La})_2(\text{CO}_3)_3\text{F}_2$, hexagonal, with a 4.35, c 22.8 Å and $Z=2$, the crystals of which are short prismatic to equant, combinations of $\{10\bar{1}0\}$, $\{40\bar{4}5\}$, $\{10\bar{1}1\}$, $\{20\bar{2}1\}$, $\{40\bar{4}1\}$ and $\{0001\}$. Its occasional sceptre development, long prismatic topped by pseudoisometric hexagonal combinations of equally developed $\{40\bar{4}5\}$, $\{20\bar{2}1\}$ and $\{10\bar{1}0\}$ forms, obviously as a later generation, crystallizing under lower supersaturation, adds weight to the habit trend given for bastnäsité. Another REE carbonate, closely related to the enumerated minerals, is ancylité-(Ce) $\text{SrCe}(\text{CO}_3)_2(\text{OH})\cdot\text{H}_2\text{O}$, which, however, is orthorhombic, occurring usually as pseudo-octahedral crystals, combinations almost exclusively of $\{111\}$ and $\{120\}$ with no cleavage, hence pseudoisometric $(l)^\circ$ type.

Phosgenité $\text{Pb}_2\text{CO}_3\text{Cl}_2$ is tetragonal-trapezohedral, $P4_212(?)$, a 8.15, c 8.87 Å, $Z=4$. With its c/a ratio 1.09, the mineral is typically of a pseudoisometric (l) 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 CO_3 groups arranged almost parallel to the c axis. The crystals of phosgenité 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 $(l)_{(001)} \rightarrow (l)_i \rightarrow (l)_{(110)}$ respectively $(l)_{(111)}$.

Azurité $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$ is monoclinic-prismatic, $P2_1/c$, a 4.96, b 5.84, c 10.29 Å, β $92^\circ 24'$, $Z=2$. The structure of azurité is presented by Cu atoms in square coordinated by O and OH anions, the triangular CO_3 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 CO_3 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 $2c/(a+b)=0.95$, underlining an $(l)^\circ$ type morphology).

The crystals of azurité are usually highly modified and display great variety of habit. Known are about 200 forms, most prominent being $\{110\}$, $\{001\}$, $\{010\}$, $\{100\}$, $\{102\}$, $\{111\}$, $\{013\}$, $\{011\}$, $\{1\bar{1}01\}$ and $\{1\bar{1}02\}$. Rare twins are quoted on $\{1\bar{1}01\}$, $\{1\bar{1}02\}$ and $\{100\}$. Taking into account the structural scheme of azurité 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 $(I)^c(102) \rightarrow (I)_i^c \rightarrow (I)^c(001)$, 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) $\text{NaCaSr}_3\text{Y}(\text{CO}_3)_6 \cdot 3\text{H}_2\text{O}$ is triclinic, $P1$, 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 $\text{Na}_3(\text{HCO}_3)(\text{CO}_3) \cdot 2\text{H}_2\text{O}$ is monoclinic-prismatic, $C2/c$, 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 $\text{Zn}_5(\text{CO}_3)_2(\text{OH})_2$, monoclinic-prismatic, $C2/m$, 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) $(\text{La,Ce})_2(\text{CO}_3)_3 \cdot 8\text{H}_2\text{O}$ is orthorhombic-bipyramidal, 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 $(\text{Zn,Cu})_5(\text{CO}_3)_2 \cdot (\text{OH})_6$, 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 $P^b_{(010)} \rightarrow P^b_i \rightarrow P^b_{[010]}$ is assumed in accordance with the other such planar type minerals.

Adamsite-(Y) $\text{NaY}(\text{CO}_3)_2 \cdot 6\text{H}_2\text{O}$ is triclinic $P\bar{1}$, a 6.26, b 13.05, c 13.22 Å, α 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 $\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$ 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 $\{0001\}$, $\{10\bar{1}2\}$, $\{10\bar{1}4\}$, $\{10\bar{1}1\}$ and $\{20\bar{2}1\}$. 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: $P_{(0001)} \rightarrow P_i \rightarrow P_{(10\bar{1}2)} \rightarrow P_{(10\bar{1}0)}$.

Leadhillite $\text{Pb}(\text{CO}_3)_2(\text{SO}_4)(\text{OH})_2$, 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 pseudo-hexagonal 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 $\{001\}$,

pseudorhombic $\{211\} + \{\bar{1}42\}$ combinations, pseudo-hexagonal equant, rich in forms, and prismatic $\{001\}$. Reederite $(\text{Na,Mn,Fe})_{15}\text{Y}_2(\text{CO}_3)_9(\text{SO}_3\text{F})\text{Cl}$, is also a typical planar P type mixed carbonate-sulphite mineral, also hexagonal, $P\bar{6}$, 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 carbonate-bearing 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. Al-Mg-Fe(Ni,Co,Mn) assemblages

1.1. Axial (A-type) structures

Barringtonite $\text{MgCO}_3 \cdot 2\text{H}_2\text{O}$
 Nesquehonite $\text{MgCO}_3 \cdot 3\text{H}_2\text{O}$
 Langsfordite $\text{MgCO}_3 \cdot 5\text{H}_2\text{O}$
 Artinite $\text{Mg}_2(\text{CO}_3)(\text{OH})_2 \cdot 3\text{H}_2\text{O}$
 Chlorartinite $\text{Mg}_2(\text{CO}_3)\text{Cl}(\text{OH}) \cdot 3(\text{H}_2\text{O})$
 Loseyite $(\text{Mn,Zn})(\text{CO}_3)_2(\text{OH})_{10}$
 Hellyerite $\text{NiCO}_3 \cdot 6\text{H}_2\text{O}$
 Kambaldaite $\text{NaNi}_4(\text{CO}_3)_3(\text{OH})_3 \cdot 3\text{H}_2\text{O}$
 Dawsonite $\text{NaAl}(\text{CO}_3)(\text{OH})_2$
 Alumohydrocalcite $\text{CaAl}_2(\text{CO}_3)_2(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
 Paraalumohydrocalcite $\text{CaAl}_2(\text{CO}_3)_2(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
 Sergeevite $\text{Ca}_2\text{Mg}_{11}(\text{CO}_3)_9(\text{HCO}_3)(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
 Dresserite $\text{Ba}_2\text{Al}_4(\text{CO}_3)_4(\text{OH})_2 \cdot 3\text{H}_2\text{O}$
 Hydrotresserite $\text{BaAl}_2(\text{CO}_3)_2(\text{OH})_4 \cdot 3\text{H}_2\text{O}$
 Strontiodresserite $\text{SrAl}_2(\text{CO}_3)_2(\text{OH})_4 \cdot 3\text{H}_2\text{O}$
 Sahamalite-(Ce) $(\text{Mg,Fe})(\text{Ce,L,Nd})_2(\text{CO}_3)_4$
 Holdawayite $\text{Mn}_6(\text{CO}_3)_2(\text{OH})_7(\text{Cl,OH})$

1.2. Planar (P-type) structures

Scarbroite $\text{Al}_5(\text{CO}_3)(\text{OH})_{13} \cdot 5\text{H}_2\text{O}$
 Hydroscarbroite $\text{Al}_{14}(\text{CO}_3)_3(\text{OH})_{36} \cdot n\text{H}_2\text{O}$
 Pokrovskite $\text{Mg}_2(\text{CO}_3)(\text{OH})_2 \cdot 0.5\text{H}_2\text{O}$
 Hydromagnesite $\text{Mg}_5(\text{CO}_3)_4(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
 Manasseite $\text{Mg}_6\text{Al}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$
 Hydrotalcite $\text{Mg}_6\text{Al}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$
 Chlormanasseite $\text{Mg}_6\text{Al}_2(\text{CO}_3)(\text{OH})_{16}\text{Cl}_2 \cdot 4\text{H}_2\text{O}$
 Barbertonite $\text{Mg}_6\text{Cr}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$
 Stichtite $\text{Mg}_6\text{Cr}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$
 Sjögrenite $\text{Mg}_6\text{Fe}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$
 Pyroaurite $\text{Mg}_{10}\text{Fe}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$
 Coalingite $\text{Mg}_6\text{Fe}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$
 Desautelsite $\text{Mg}_6\text{Mn}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$
 Indigerite $\text{Mg}_2\text{Al}_2(\text{CO}_3)_4(\text{OH})_2 \cdot 15\text{H}_2\text{O}$
 Brugnatellite $\text{Mg}_6\text{Fe}(\text{CO}_3)(\text{OH})_{13} \cdot 4\text{H}_2\text{O}$
 Chlormagaluminite $(\text{Mg,Fe})_4\text{Al}_2(\text{OH})_{12}(\text{Cl}_2, \text{CO}_3) \cdot 2\text{H}_2\text{O}$
 Nullagingite $\text{Ni}_2(\text{CO}_3)(\text{OH})_2$
 Otwayite $(\text{Ni,Mg})_2\text{CO}_3(\text{OH})_2 \cdot \text{H}_2\text{O}$
 Takovite $\text{Ni}_6\text{Al}_2(\text{CO}_3, \text{OH})(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$

Eardleyite $\text{Ni}_6\text{Al}_2(\text{CO}_3)(\text{OH})_{16}\cdot 4\text{H}_2\text{O}$
 Reevesite $\text{Ni}_6\text{Fe}_2(\text{CO}_3)(\text{OH})_{16}\cdot 4\text{H}_2\text{O}$
 Widgiemoolthalite $\text{Ni}_5(\text{CO}_3)_4(\text{OH})_{2,4}\cdot 5\text{H}_2\text{O}$
 Comblainite $\text{Ni}_6\text{Co}_2(\text{CO}_3)(\text{OH})_{16}\cdot 4\text{H}_2\text{O}$
 Gaspeite $(\text{Ni},\text{Mg},\text{Fe})\text{CO}_3$
 Quintinite-2H $\text{Mg}_4\text{Al}_2(\text{CO}_3)(\text{OH})_{12}\cdot 3\text{H}_2\text{O}$
 Quintinite-3T $\text{Mg}_4\text{Al}_2(\text{CO}_3)(\text{OH})_{12}\cdot 3\text{H}_2\text{O}$
 Caresite-3T $\text{Fe}_4\text{Al}_2(\text{CO}_3)(\text{OH})_{12}\cdot 3\text{H}_2\text{O}$
 Charmarite-2H $\text{Mn}_4\text{Al}_2(\text{CO}_3)(\text{OH})_{12}\cdot 3\text{H}_2\text{O}$
 Charmarite-3T $\text{Mn}_4\text{Al}_2(\text{CO}_3)(\text{OH})_{12}\cdot 3\text{H}_2\text{O}$
 Wermlandite $\text{Ca}_2\text{Mg}_{14}(\text{Al},\text{Fe})_4(\text{CO}_3)(\text{OH})_{42}\cdot 15\text{H}_2\text{O}$

1.3. (Pseudo-)Isometric, (I) resp. I-type structures

Eitelite $\text{Na}_2\text{Mg}(\text{CO}_3)_2$
 Northupite $\text{Na}_3\text{Mg}(\text{CO}_3)_2\text{Cl}$
 Tychite $\text{Na}_6\text{Mg}(\text{CO}_3)_2\text{Cl}$
 Huntite $\text{CaMg}(\text{CO}_3)_4$
 Tunisite $\text{NaCa}_2\text{Al}_4(\text{CO}_3)_4(\text{OH})_8\text{Cl}$
 Dashkovaite $\text{Mg}(\text{HCO}_3)_2\cdot 2\text{H}_2\text{O}$
 Baylissite $\text{K}_2\text{Mg}(\text{CO}_3)_2\cdot 4\text{H}_2\text{O}$
 Magnesite MgCO_3
 Siderite FeCO_3
 Rhodochrosite MnCO_3
 Spherochrosite CoCO_3
 Dolomite $\text{CaMg}(\text{CO}_3)_2$
 Ankerite $\text{Ca}(\text{Fe},\text{Mg},\text{Mn})(\text{CO}_3)_2$
 Kutnahorite $\text{CaMn}(\text{CO}_3)_2$
 Norsethite $\text{BaMg}(\text{CO}_3)_2$
 Zaratite $\text{Ni}_3(\text{CO}_3)(\text{OH})_2\cdot 4\text{H}_2\text{O}$

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

2.1. Axial (A-type) structures

Kalicinite KHCO_3
 Teschemacherite NH_4HCO_3
 Wegscheiderite $\text{Na}_5(\text{CO}_3)(\text{HCO}_3)_3$
 Nahcolite NaHCO_3
 Gaylussite $\text{Na}_2\text{Ca}(\text{CO}_3)_2\cdot 5\text{H}_2\text{O}$
 Trihydrocalcite $\text{CaCO}_3\cdot 3\text{H}_2\text{O}$
 Pentahydrocalcite $\text{CaCO}_3\cdot 5\text{H}_2\text{O}$
 Ikaite $\text{CaCO}_3\cdot 6\text{H}_2\text{O}$
 Brenkite $\text{Ca}_2(\text{CO}_3)\text{F}_2$
 Barytocalcite $\text{BaCa}(\text{CO}_3)_2$
 Defernite $\text{Ca}_3\text{CO}_3(\text{OH},\text{Cl})_4\cdot \text{H}_2\text{O}$
 Tulioikite $\text{Na}_6\text{BaTh}(\text{CO}_3)_6\cdot 6\text{H}_2\text{O}$
 Petersenite-(Ce) $\text{Na}_4(\text{Ce},\text{La},\text{Nd})_2(\text{CO}_3)_5$
 Shomiokite-(Y) $\text{Na}_3\text{Y}(\text{CO}_3)_3\cdot 3\text{H}_2\text{O}$
 Lokkaite-(Y) $\text{CaY}_4(\text{CO}_3)_7\cdot 9\text{H}_2\text{O}$
 Kukharenkoite-(Ce) $\text{Ba}_2\text{Ce}(\text{CO}_3)_3\text{F}$

2.2. Planar (P-type) structures

Vaterite CaCO_3
 Nyereraite $\text{Na}_2\text{Ca}(\text{CO}_3)_2$
 Shortite $\text{Na}_2\text{Ca}_2(\text{CO}_3)_3$
 Gregoryite $(\text{Na}_2,\text{K}_2,\text{Ca})\text{CO}_3$
 Rouvilleite $\text{Na}_3\text{Ca}_2(\text{CO}_3)_3\text{F}$
 Fairchildite $\text{K}_2\text{Ca}(\text{CO}_3)_2$
 Bütschliite $\text{K}_2\text{Ca}(\text{CO}_3)_2$
 Tengerite-(Y) $\text{Y}_2(\text{CO}_3)_3\cdot 2\cdot 3\text{H}_2\text{O}$
 Calkinsite-(Ce) $(\text{Ce},\text{La})_2(\text{CO}_3)_3\cdot 4\text{H}_2\text{O}$
 Adamsite-(Y) $\text{NaY}(\text{CO}_3)_2\cdot 6\text{H}_2\text{O}$
 Lanthanite-(La) $(\text{La},\text{Dy},\text{Ce})_2(\text{CO}_3)_3\cdot 8\text{H}_2\text{O}$
 Thermonatrite $\text{Na}_2(\text{CO}_3)\cdot \text{H}_2\text{O}$

Trona $\text{Na}_3(\text{HCO}_3)(\text{CO}_3)\cdot 2\text{H}_2\text{O}$
 Natron $\text{Na}_3\text{CO}_3\cdot 10\text{H}_2\text{O}$
 Kozoite-(Nd) $\text{Nd}(\text{CO}_3)(\text{OH})$
 Galgenbergite-(Ce) $\text{Ca}(\text{Ce},\text{Nd},\text{La})_2(\text{CO}_3)_4\cdot \text{H}_2\text{O}$
 Kamphaugite-(Y) $\text{Ca}(\text{Y},\text{REE})(\text{CO}_3)_2(\text{OH})\cdot \text{H}_2\text{O}$
 Kimuraite-(Y) $\text{CaY}_2(\text{CO}_3)_4\cdot 6\text{H}_2\text{O}$
 Weloganite $\text{Sr}_3\text{Na}_2\text{Zr}(\text{CO}_3)_6\cdot 3\text{H}_2\text{O}$
 Thomasclarkite-(Y) $\text{Na}(\text{Y},\text{REE})(\text{HCO}_3)(\text{OH})_3\cdot 4\text{H}_2\text{O}$
 Mckelveyite-(Y) $\text{Ba}_3\text{Na}(\text{Ca},\text{U})\text{Y}(\text{CO}_3)_6\cdot 3\text{H}_2\text{O}$
 Gysinite-(Nd) $\text{Pb}(\text{Nd},\text{La})(\text{CO}_3)_2(\text{OH})\cdot \text{H}_2\text{O}$
 Sheldrickite $\text{NaCa}_3(\text{CO}_3)_2\text{F}_3\cdot \text{H}_2\text{O}$
 Rouvilleite $\text{Na}_3(\text{Ca},\text{Mn},\text{Fe})_2(\text{CO}_3)_3\text{F}$
 Huanghoite-(Ce) $\text{BaCe}(\text{CO}_3)_2\text{F}$
 Zhonghuacerite-(Ce) $\text{Ba}_2\text{Ce}(\text{CO}_3)_3\text{F}$
 Lukechangite-(Ce) $\text{Na}_3\text{Ce}_2(\text{CO}_3)_4\text{F}$

2.3. Pseudo-Isometric, (I)-type structures

Zabuyelite Li_2CO_3
 Natrite Na_2CO_3
 Calcite CaCO_3
 Aragonite CaCO_3
 Strontianite SrCO_3
 Witherite BaCO_3
 Pirssonite $\text{CaNa}_2(\text{CO}_3)_2\cdot 2\text{H}_2\text{O}$
 Monohydrocalcite $\text{CaCO}_3\cdot \text{H}_2\text{O}$
 Zemkorite $(\text{Na},\text{K})_2\text{Ca}(\text{CO}_3)_2$
 Alstonite $\text{BaCa}(\text{CO}_3)_2$
 Paralstonite $\text{BaCa}(\text{CO}_3)_2$
 Olekminskite $\text{Sr}(\text{Sr},\text{Ca},\text{Ba})(\text{CO}_3)_2$
 Ewaldite $\text{Ba}(\text{Ca},\text{Y},\text{Na},\text{K})(\text{CO}_3)_2$
 Benstonite $\text{Ba}_6\text{Ca}_7(\text{CO}_3)_{13}$
 Carbocernaite $(\text{Ca},\text{Na})(\text{Sr},\text{Ce},\text{Ba})(\text{CO}_3)_2$
 Burbankite $(\text{Na},\text{Ca})_3(\text{Sr},\text{Ba},\text{Ce})_3(\text{CO}_3)_5$
 Calcio-burbankite $(\text{Na},\text{Ca})_3(\text{Sr},\text{Ba},\text{Ce})_3(\text{CO}_3)_5$
 Khanneshite $(\text{Na},\text{Ca})_3(\text{Ba},\text{Sr},\text{Ce},\text{Ca})_3(\text{CO}_3)_5$
 Remondite-(Ce) $\text{Na}_3(\text{Ce},\text{La},\text{Ca},\text{Na},\text{Sr})_3(\text{CO}_3)_5$
 Ancylyte-(Ce) $\text{SrCe}(\text{CO}_3)_2(\text{OH})\cdot \text{H}_2\text{O}$
 Ancylyte-(La) $\text{Sr}(\text{La},\text{Ce})(\text{CO}_3)_2(\text{OH})\cdot \text{H}_2\text{O}$
 Calcio-ancylyte-(Ce) $(\text{Ca},\text{Sr})\text{Ce}_3(\text{CO}_3)_4(\text{OH})_3\cdot \text{H}_2\text{O}$
 Calcio-ancylyte-(Nd) $\text{Ca}(\text{Nd},\text{Ce},\text{Gd},\text{Y})_3(\text{CO}_3)_4(\text{OH})_3\cdot \text{H}_2\text{O}$
 Bastnäsite-(Ce) $(\text{Ce},\text{La})(\text{CO}_3)\text{F}$
 Bastnäsite-(La) $(\text{La},\text{Ce})(\text{CO}_3)\text{F}$
 Bastnäsite-(Y) $(\text{Y},\text{Ce})(\text{CO}_3)\text{F}$
 Hydroxylbastnäsite-(Ce) $(\text{Ce},\text{La})(\text{CO}_3)(\text{OH},\text{F})$
 Hydroxylbastnäsite-(La) $(\text{La},\text{Ce})(\text{CO}_3)(\text{OH},\text{F})$
 Hydroxylbastnäsite-(Nd) $(\text{Nd},\text{Ce},\text{La})(\text{CO}_3)(\text{OH},\text{F})$
 Parisite-(Ce) $\text{Ca}(\text{Ce},\text{La})_2(\text{CO}_3)_3\text{F}$
 Parisite-(Nd) $\text{Ca}(\text{Nd},\text{Ce},\text{La})_2(\text{CO}_3)_3\text{F}$
 Röntgenite-(Ce) $\text{Ca}_2(\text{Ce},\text{La})_3(\text{CO}_3)_5\text{F}_3$
 Synchysite-(Ce) $\text{Ca}(\text{Ce},\text{La})(\text{CO}_3)_2\text{F}$
 Synchysite-(Nd) $\text{Ca}(\text{Nd},\text{La})(\text{CO}_3)_2\text{F}$
 Synchysite-(Y) $\text{Ca}(\text{Y},\text{Ce})(\text{CO}_3)_2\text{F}$
 Cordylite-(Ce) $\text{NaBaCe}_2(\text{CO}_3)_4\text{F}$
 Donnayite-(Y) $\text{NaCaSr}_3\text{Y}(\text{CO}_3)_6\cdot 3\text{H}_2\text{O}$
 Horvathite-(Y) NaYCO_3F_2
 Stenonite $(\text{Sr},\text{Ba},\text{Na})_2\text{AlCO}_3\text{F}_5$
 Barentsite $\text{Na}_7\text{AlH}_2(\text{CO}_3)_4\text{F}_4$
 Montroyalite $\text{Sr}_4\text{Al}_8(\text{CO}_3)_3(\text{OH},\text{F})_{26}\cdot 10\text{-}11\text{H}_2\text{O}$

3. Zn-Cu-Pb(U) assemblages

3.1. Axial (A-type) structures

Malachite $\text{Cu}_2(\text{CO}_3)(\text{OH})_2$

Glaukosphaerite $(\text{Cu,Ni})_2(\text{CO}_3)(\text{OH})_2$
 Loseyite $(\text{Mn,Zn})_7(\text{CO}_3)_2(\text{OH})_{10}$
 Sclarite $(\text{Zn,Mg,Mn})_4\text{Zn}_3(\text{CO}_3)_2(\text{OH})_{10}$
 Shannonite $\text{Pb}_2\text{O}(\text{CO}_3)$
 Schuilingite $\text{Pb}_3\text{Cu}_2\text{Ca}_6(\text{CO}_3)_8(\text{OH})_6 \cdot 6\text{H}_2\text{O}$
 Sharpite $(\text{UO}_2)(\text{CO}_3) \cdot \text{H}_2\text{O}$
 Bayleyite $\text{Mg}_2(\text{UO}_2)(\text{CO}_3)_3 \cdot 18\text{H}_2\text{O}$
 Swartzite $\text{CaMg}(\text{UO}_2)(\text{CO}_3)_3 \cdot 12\text{H}_2\text{O}$
 Zellerite $\text{Ca}(\text{UO}_2)(\text{CO}_3)_2 \cdot 5\text{H}_2\text{O}$
 Metazellerite $\text{Ca}(\text{UO}_2)(\text{CO}_3)_2 \cdot 3\text{H}_2\text{O}$
 Urancalcrite $\text{Ca}(\text{UO}_2)_3\text{CO}_3(\text{OH})_6 \cdot 3\text{H}_2\text{O}$
 Voglite $\text{Ca}_2\text{Cu}(\text{UO}_2)_2(\text{CO}_3)_3 \cdot 14\text{H}_2\text{O}$
 Fontanite $\text{Ca}(\text{UO}_2)(\text{CO}_3)_4 \cdot 3\text{H}_2\text{O}$
 Oswaldpeetersite $(\text{UO}_2)_2(\text{CO}_3)(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
 Astrocyanide-(Ce) $\text{Cu}_2(\text{Ce,Nd,La})(\text{UO}_2)(\text{CO}_3)_5(\text{OH})_2 \cdot 1,5\text{H}_2\text{O}$
 Szymanskiite $\text{Hg}_{10}\text{Ni}_6(\text{CO}_3)_{12}(\text{H}_3\text{O})_8 \cdot 3\text{H}_2\text{O}$

3.2. Planar (P-type) structures

Hydrozincite $\text{Zn}_5(\text{CO}_3)_2(\text{OH})_6$
 Aurichalcite $(\text{Zn,Cu})_5(\text{CO}_3)_2(\text{OH})_6$
 Claraite $(\text{Cu,Zn})_3(\text{CO}_3)(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
 Zaccagnaite $\text{Zn}_4\text{Al}_2(\text{CO}_3)(\text{OH})_{12} \cdot 3\text{H}_2\text{O}$
 Chalconatrite $\text{Na}_2\text{Cu}(\text{CO}_3)_2 \cdot 3\text{H}_2\text{O}$
 Cuproartinite $(\text{Cu,Mg})_2(\text{CO}_3)(\text{OH})_2 \cdot 3\text{H}_2\text{O}$
 Glaukosphaerite $(\text{Cu,Ni})_2(\text{CO}_3)(\text{OH})_2$
 Kolwezite $(\text{Cu}^{2+},\text{Co})_2(\text{CO}_3)(\text{OH})_2$
 Mcquinnessite $(\text{Mg,Cu}^{2+})_2(\text{CO}_3)(\text{OH})_2$
 Rosasite $(\text{Cu}^{2+},\text{Zn})_2(\text{CO}_3)(\text{OH})_2$
 Zincrosasite $(\text{Zn,Cu}^{2+})_2(\text{CO}_3)(\text{OH})_2$
 Decrespignyite-(Y) $(\text{Y,REE})_4\text{Cu}(\text{CO}_3)_4\text{Cl}(\text{OH})_5 \cdot 2\text{H}_2\text{O}$
 Rutherfordine $(\text{UO}_2)(\text{CO}_3)$
 Blatonite $(\text{UO}_2)(\text{CO}_3) \cdot \text{H}_2\text{O}$
 Joliotite $(\text{UO}_2)(\text{CO}_3) \cdot 2\text{H}_2\text{O}$
 Cejkaite $\text{Na}_4(\text{UO}_2)(\text{CO}_3)_3$
 Liebigite $\text{Ca}_2(\text{UO}_2)(\text{CO}_3)_3 \cdot 10\text{H}_2\text{O}$
 Rabbittite $\text{Ca}_3\text{Mg}_3(\text{UO}_2)_2(\text{CO}_3)_6 \cdot 18\text{H}_2\text{O}$
 Wyartite $\text{Ca}_3\text{U}(\text{UO}_2)_6(\text{CO}_3)_2(\text{OH})_8 \cdot 4\text{H}_2\text{O}$
 Znuccalite $\text{CaZn}_{12}(\text{UO}_2)(\text{CO}_3)_3(\text{OH})_{22} \cdot 4\text{H}_2\text{O}$
 Widenmannite $\text{Pb}_2(\text{UO}_2)(\text{CO}_3)_3$
 Hydrocerussite $\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$
 Plumbonacrite $\text{Pb}_{10}(\text{CO}_3)_6\text{O}(\text{OH})_6$
 Petterdite $\text{PbCr}_2(\text{CO}_3)_2(\text{OH})_4 \cdot \text{H}_2\text{O}$
 Dundasite $\text{PbAl}_2(\text{CO}_3)_2(\text{OH})_4 \cdot \text{H}_2\text{O}$
 Barstowite $\text{Pb}_4(\text{CO}_3)\text{Cl}_6 \cdot \text{H}_2\text{O}$
 Bismutite $\text{Bi}_2\text{O}_2(\text{CO}_3)$
 Kettnerite $\text{CaBi}(\text{CO}_3)\text{OF}$
 Beyerite $\text{CaBi}_2(\text{CO}_3)_2\text{O}_2$
 Clearcreekite $\text{Hg}_3(\text{CO}_3)(\text{OH}) \cdot 2\text{H}_2\text{O}$
 Peterbaylissite $\text{Hg}_3(\text{CO}_3)(\text{OH}) \cdot 2\text{H}_2\text{O}$
 Astrocyanite-(Ce)
 $\text{Cu}_2(\text{Ce,Nd,La})_2(\text{UO}_2)(\text{CO}_3)_5(\text{OH})_2 \cdot 1,5\text{H}_2\text{O}$
 Shabaite-(Nd) $\text{Ca}(\text{Nd,Sm,Y})_2(\text{UO}_2)(\text{CO}_3)_4(\text{OH})_2 \cdot 6\text{H}_2\text{O}$
 Bijvoetite-(Y) $(\text{Y,Dy})_2(\text{UO}_2)_4(\text{CO}_3)_4(\text{OH})_6 \cdot 11\text{H}_2\text{O}$

3.3. Pseudo-isometric, (I)-type structures

Smithsonite ZnCO_3
 Minrecordite $\text{CaZn}(\text{CO}_3)_2$
 Otavite CdCO_3
 Azurite $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$
 Callaghanite $\text{Cu}_2\text{Mg}_2(\text{CO}_3)(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
 Cerussite PbCO_3
 Phosgenite $\text{Pb}(\text{CO}_3)\text{Cl}_2$
 Grimselite $\text{K}_3\text{Na}(\text{UO}_2)(\text{CO}_3)_3 \cdot \text{H}_2\text{O}$

Andersonite $\text{Na}_2\text{Ca}(\text{UO}_2)(\text{CO}_3)_3 \cdot 6\text{H}_2\text{O}$
 Albrechtschraufite $\text{Ca}_4\text{Mg}(\text{UO}_2)_2(\text{CO}_3)_6\text{F}_2 \cdot 17\text{H}_2\text{O}$

3.4. Amorphous

Georgeite $\text{Cu}_2\text{CO}_3(\text{OH})_2$

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