Amorphous Magnesium Carbonate (AMC, $MgCO_3 \cdot nH_2O$)

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This document may be regarded as a companion to the "Amorphous Calcium Carbonate (ACC, $CaCO_3 \cdot nH_2O$)" note of January 15, 2026, which is available at this weblink.

A non-exhaustive review of previous literature dedicated to the synthesis and characterization of amorphous magnesium carbonate (AMC, $MgCO_3 \cdot nH_2O$) powders is provided. (*The Appendix will present a past experiment I performed to synthesize crystalline hydromagnesite, $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$, at the kg scale.*)

In case of researchers interested in learning more about the synthesis of amorphous carbonates (especially of the alkali earth elements of Mg and Ca) comes across something about ACC, then the same person may ask this question: "how about AMC, can one synthesize AMC in a manner similar to ACC?" This technical note was prepared with an intent to confidently answer such questions.

If and when CCS (carbon capture and storage) is considered to be the injection of CO_2 into a solid (igneous basaltic or ultramafic rocks) and/or liquid medium to store it there forever (*hopefully*), then CCS involves one or more of the four "trapping" mechanisms: (a) stratigraphic (structural), (b) residual, (c) solubility and (d) mineral [1].

Stratigraphic and residual trappings can store CO_2 as a high-density free phase. Solubility trapping allows CO_2 to be stored in its soluble state. On the other hand, mineral trapping is based on the chemical reactions between the injected CO_2 and alkaline minerals in the host rock and leads to the precipitation of carbonate that effectively locks up the CO_2 "forever" (hopefully). 60-70% of total carbon in Earth's crust is present in the form of carbonates, of which >90% are calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) [1-3]. Amorphous calcium carbonate (ACC) and amorphous magnesium carbonate (AMC) are formed as precursors to these crystalline carbonates in aqueous solutions that include metal ions (Ca^{2+} and Mg^{2+}) and (bi)carbonate ions at temperatures ≤35°C. This is why we are preparing technical notes on ACC and AMC.

Aside from CCS, the utilization of CO_2 (pure or flue gas of cement plants and coal-burning power plants, *etc.*) in wet pre-cast concrete, dry pre-cast concrete, ready mix concrete and as supplemental cementitious materials) was successfully demonstrated at industrial scales, which are open to public through the published patents of Solidia Technologies. Right at the moment of initial contact of CO_2/(bi)carbonate ions with Ca-silicate powders or Mg-containing Ca-silicate or Mg-silicate powders, ACC or AMC would form as precursors (*i.e.*, the first phases to form).

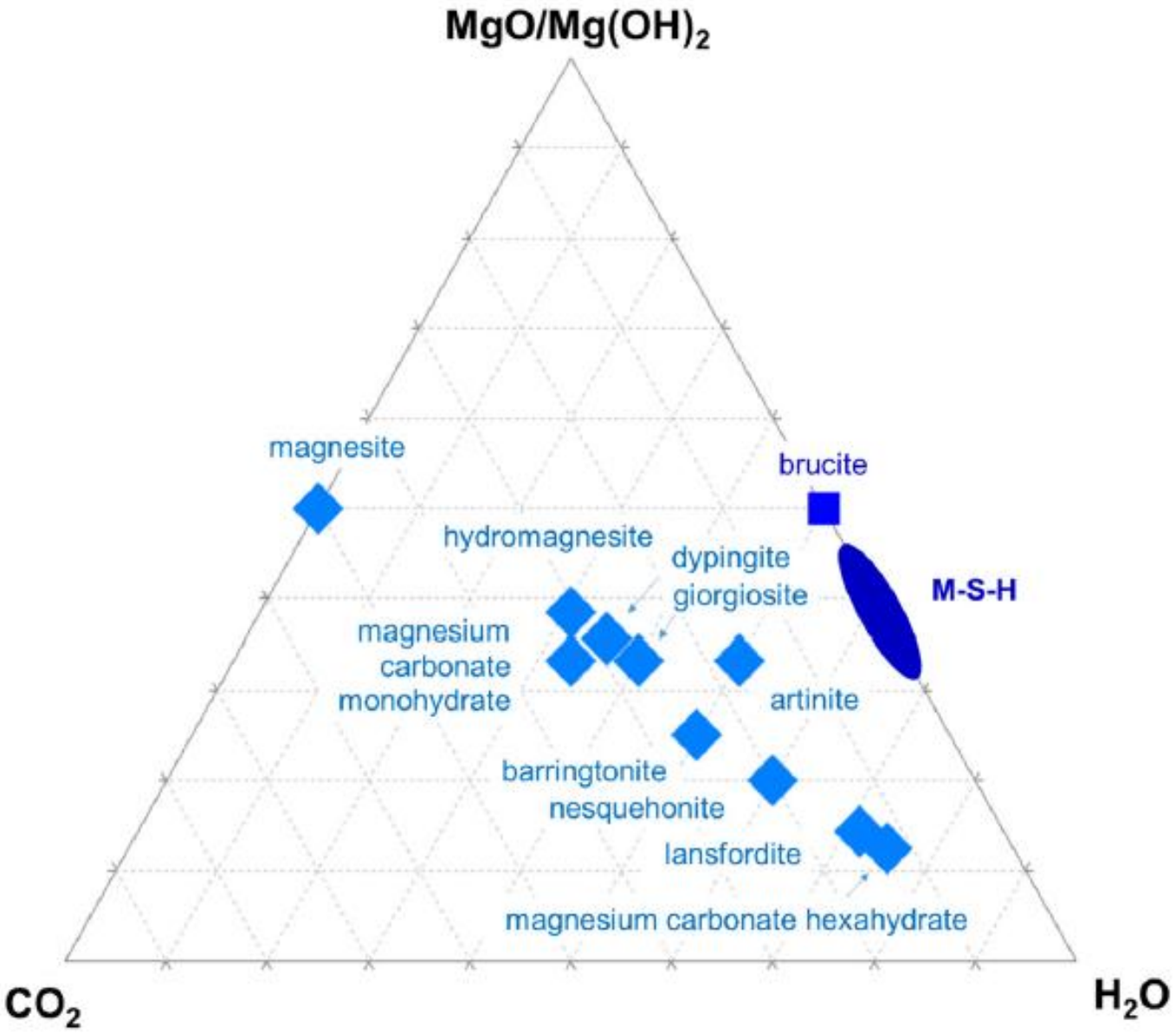
[1] Gi. Yamamoto, A. Kyono, and S. Okada, "Structural variations of amorphous magnesium carbonate during nucleation, crystallization, and decomposition of nesquehonite $MgCO_3 \cdot 3H_2O$," *Physics and Chemistry of Minerals*, 50, 5 (2023).
[2] J. M. Hunt, "Distribution of carbon in crust of earth," *American Association of Petroleum Geologists Bulletin*, 56, 2273-2277 (1972).
[3] R. J. Reeder, "Crystal chemistry of the rhombohedral carbonates," *Reviews in Mineralogy & Geochemistry*, 11, 1-47 (1983).

AMC (amorphous magnesium carbonate, $MgCO_3 \cdot nH_2O$) would form upon mixing an aqueous solution containing a water-soluble salt of magnesium (such as $MgCl_2 \cdot 6H_2O$, $Mg(NO_3)_2 \cdot 6H_2O$ or $Mg(CH_3COO)_2 \cdot 4H_2O$) at the proper concentration and an aqueous solution having dissolved Na_2CO_3 (carbonate ions could also be received from K_2CO_3 or $(NH_4)_2CO_3$), again, at the proper concentration. The temperature of mixing ought to be 20°C or lower. What we meant here by "proper concentration" is that the $[Mg^{2+}]/[CO_3^{2-}]$ ratio in the mother solution should be equal to unity. This is how researchers synthesize AMC to characterize it.

There is one important requirement in this kind of synthesis though; one should be able to very quickly separate (either by using a 0.22 μm membrane filter or by centrifugation) the formed submicron particles from that turbid aqueous solution containing both Mg^{2+} and CO_3^{2-} ions, and the separated solids must be dried (at least overnight) at a low temperature (such as the ambient of a climate-controlled laboratory, 20-23°C) or lyophilized.

The above is the same synthesis approach used to produce ACC (amorphous calcium carbonate, $CaCO_3 \cdot nH_2O$) which we discussed at length in the technical note here.

There is a significant difference between the CaO-CO_2-H_2O ternary system and the MgO-CO_2-H_2O ternary system. The tie line CaO-CO_2 of the CaO-CO_2-H_2O ternary has one anhydrous $CaCO_3$ phase (which may crystallize at a given set of thermochemical conditions in one or more of the polymorphic forms, namely vaterite, aragonite and calcite). The CaO-H_2O tie line hosts $Ca(OH)_2$, portlandite. The inside of the CaO-CO_2-H_2O ternary has only two hydrated calcium carbonate phases, namely, monohydrocalcite and ikaite. Visit our technical note on the CaO-CO_2-H_2O ternary system here. However, as we will show in the following pages, the MgO-CO_2-H_2O ternary phase diagram is much richer in terms of the number of compounds it has.



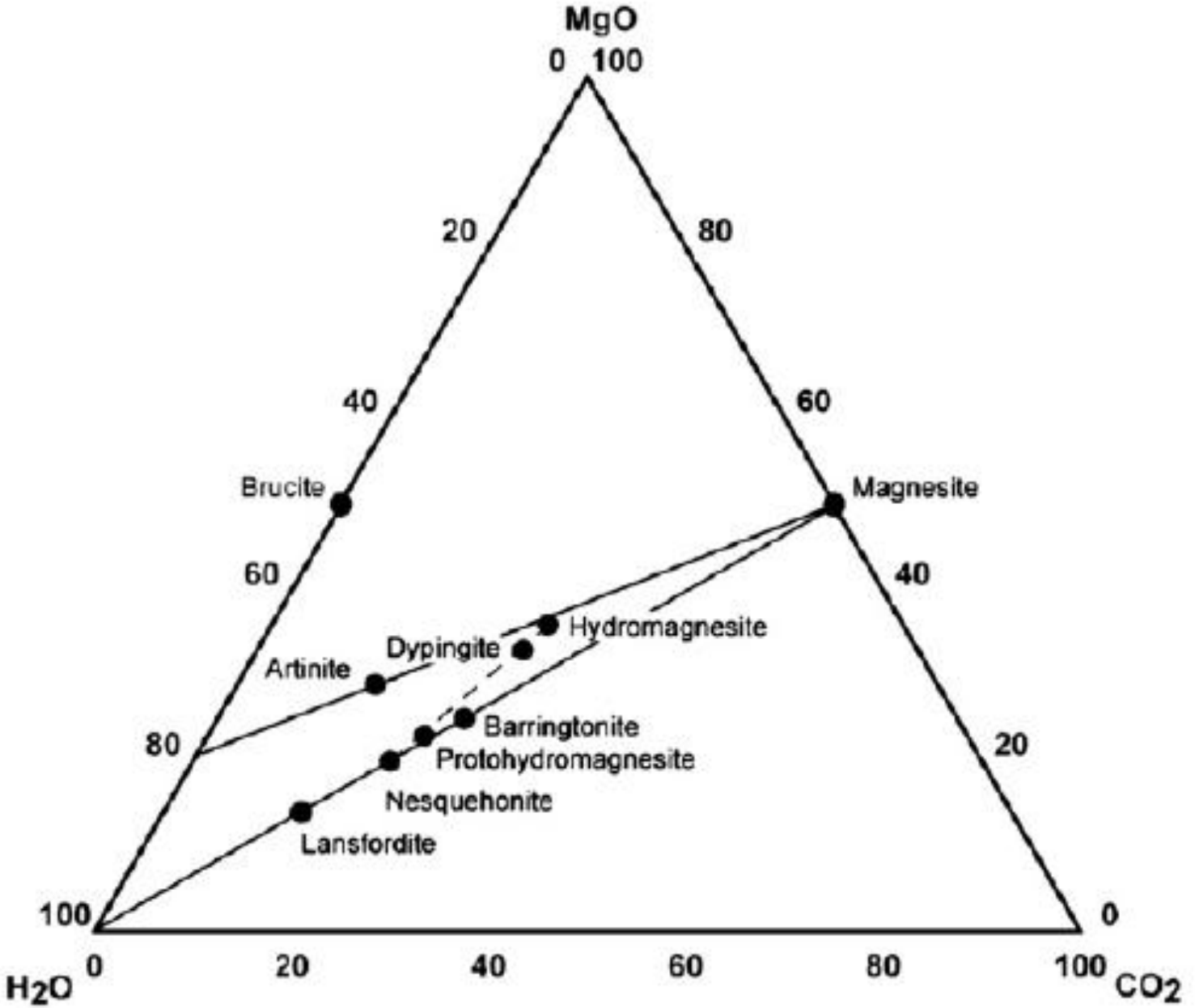
The source of this ternary phase diagram is cited below [4]. Since the article of Ref. 4 was mainly focused on M-S-H (magnesium silicate hydrate), the author placed an ellipsoid labeled as M-S-H; the placement of that M-S-H ellipsoid on the tie line between MgO and H2O in such a diagram is inappopriate, M-S-H does not belong to the MgO-CO2-H2O ternary system.

However, the hydroxycarbonate or hydrated carbonate phases named inside the ternary diagram are correct.

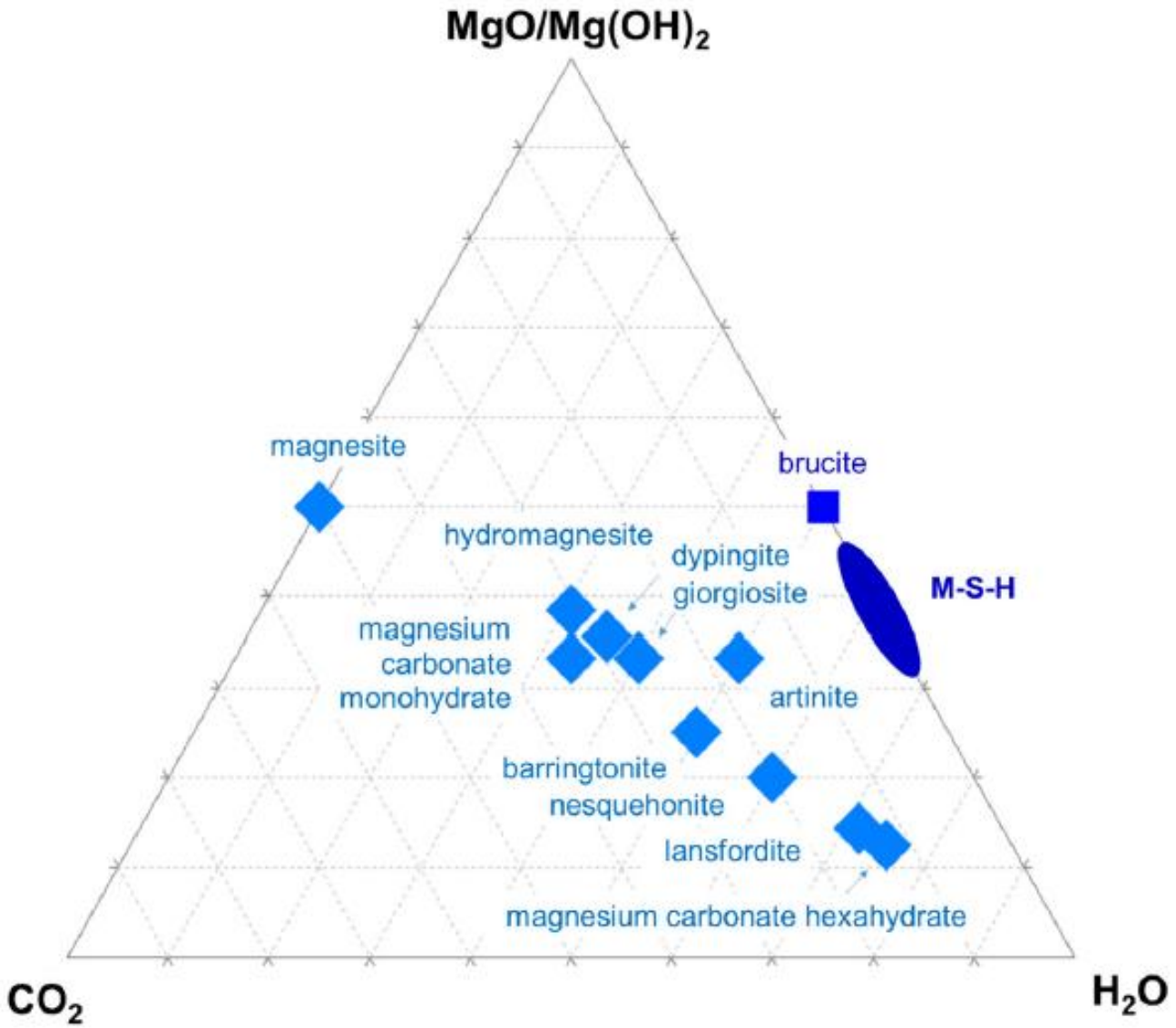
Magnesite = $MgCO_3$ Brucite = $Mg(OH)_2$
Hydromagnesite = $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$
Dypingite = $Mg_5(CO_3)_4(OH)_2 \cdot 5H_2O$
Giorgiosite = $Mg_5(CO_3)_4(OH)_2 \cdot 6H_2O$
Artinite = $Mg_2(CO_3)(OH)_2 \cdot 3H_2O$
Barringtonite = $MgCO_3 \cdot 2H_2O$
Nesquehonite = $MgCO_3 \cdot 3H_2O$
Lansfordite = $MgCO_3 \cdot 5H_2O$

[4] E. Bernard, “Research progress on magnesium silicate hydrate (M-S-H) phases and future opportunities,” *RILEM Technical Letters*, 7, 47-57 (2022).

One may also use this [5] ternary phase diagram for the MgO-CO2-H2O system since it does not have M-S-H superficially affixed to the MgO-H2O tie line.



[5] P. Benezeth, G. D. Saldi, J. D. Dandurand, and J. Schott, "Experimental determination of the solubility product of magnesite at 50 to 200°C," *Chemical Geology*, 286, 21-31 (2011).



Let's set the nomenclature straight.

One has **4** "**hydrated magnesium hydroxycarbonate**" phases in the MgO-CO2-H2O ternary phases diagram that are

Hydromagnesite = $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$
Dypingite = $Mg_5(CO_3)_4(OH)_2 \cdot 5H_2O$
Giorgiosite = $Mg_5(CO_3)_4(OH)_2 \cdot 6H_2O$
Artinite = $Mg_2(CO_3)(OH)_2 \cdot 3H_2O$.

In addition to the above, there are **5 hydrated magnesium carbonate** phases:

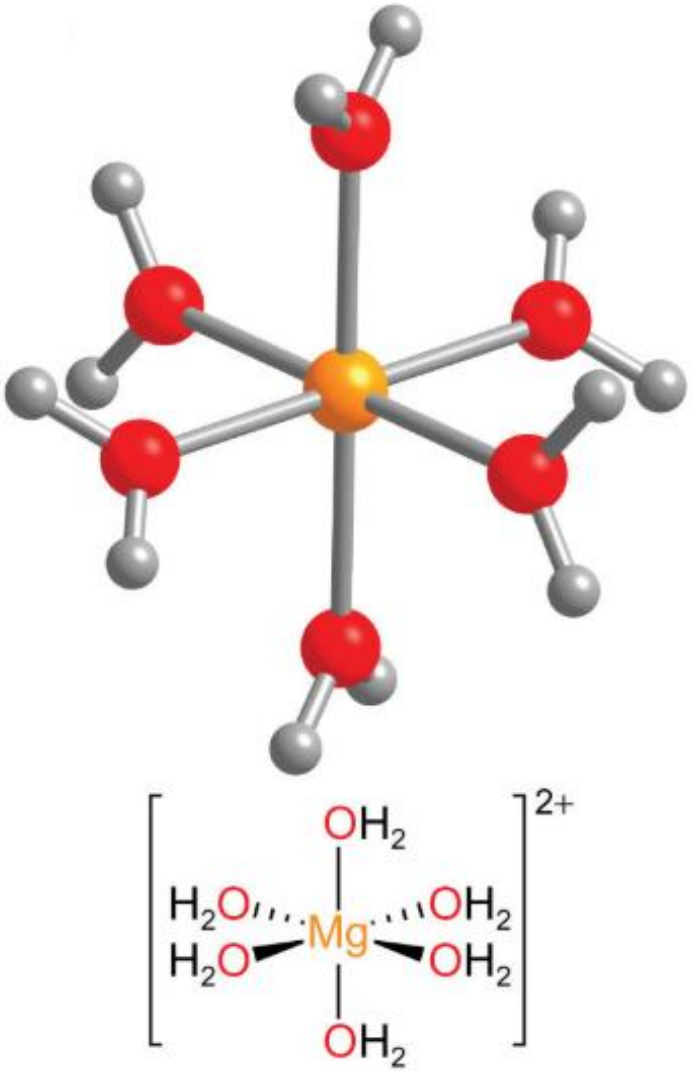
Magnesium carbonate monohydrate = $MgCO_3 \cdot H_2O$
Barringtonite = $MgCO_3 \cdot 2H_2O$
Nesquehonite = $MgCO_3 \cdot 3H_2O$
Lansfordite = $MgCO_3 \cdot 5H_2O$
Magnesium carbonate hexahydrate = $MgCO_3 \cdot 6H_2O$

- AMC (= $MgCO_3 \cdot nH_2O$) contains some water in its non-crystalline (*i.e.*, X-ray-amorphous) solid structure, indicated by the value of *n* in its formula. As a result of this, even if one is able to synthesize single phase AMC (by using one of the chemical routes we will cite and review below), the complete dehydration of AMC at temperatures between 80 and 125°C will not result in the formation of anhydrous $MgCO_3$ at atmospheric pressure (1 atm). Initially dry and X-ray-amorphous AMC will not be stable when it comes in contact with liquid water, it will form crystalline nesquehonite. $(MgCO_3 \cdot nH_2O + H_2O \rightarrow MgCO_3 \cdot 3H_2O)$

- This is the main difference between ACC of $CaO\text{-}CO_2\text{-}H_2O$ and AMC of $MgO\text{-}CO_2\text{-}H_2O$. Upon heating ACC, it will transform into one of the anhydrous polymorphs of $CaCO_3$, namely, vaterite, aragonite and calcite with time. Interestingly, ACC transforms, even upon heating in moist gaseous atmospheres, again into one or more of the anhydrous $CaCO_3$ polymorphs, namely, calcite, aragonite or vaterite, by gradually losing its structural water.

Why would one observe four different “magnesium hydroxycarbonate”-based crystalline phases in the MgO-CO2-H2O ternary system while one would not encounter any such phases in the CaO-CO2-H2O ternary? One reason is: aqueous Mg^{2+} cations (with a small ionic radius of 0.72 Å) will readily be octahedrally coordinated with six H2O molecules as shown in the below sketch to form stable $Mg(H2O)_6^{2+}$ clusters in *aqua* [6].

$CO3^{2-}$ then starts its chemical invasion of the below cluster, by replacing some of the H2O molecules of the octahedron.



[6] https://www.chemtube3d.com/beh2042-structure-and-mgh2062/

It will now be useful to look at the crystal structures of some of the crystalline phases of both MgO-CO2-H2O and CaO-CO2-H2O ternary systems with the purpose of revealing the “coordination numbers” of Mg^{2+} and Ca^{2+} ions in the solid phases.

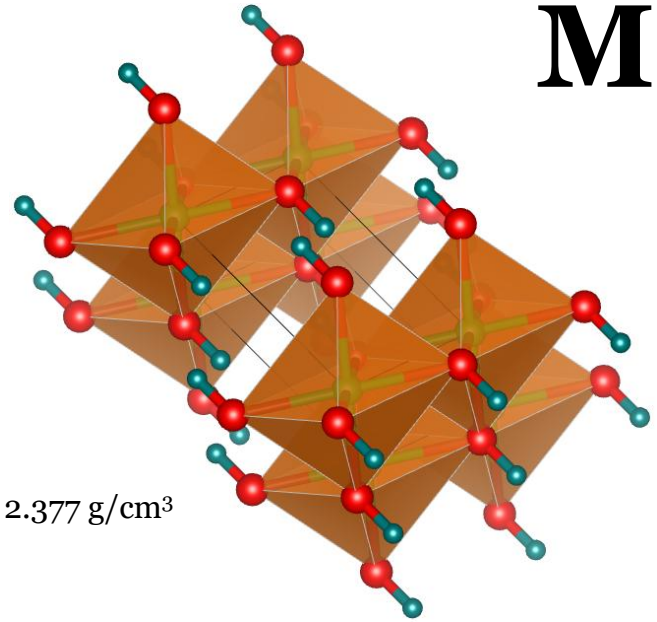
(“Coordination number” is the number of nearest-neighbor ions that surround a central ion of interest, such as Mg^{2+} or Ca^{2+}.)

• The crystal structure drawings of the following pages are prepared by using the shareware VESTA, available for download at this weblink. This software can also generate the expected X-ray diffraction data (including the 2θ, d-spacings, relative intensities and the whole pattern) for a given phase based on its CIF (crystallographic information file), if that file is available. One open source for CIF files is https://www.rruff.net/. The CIF files listed below were used for the phases of concern of this document.

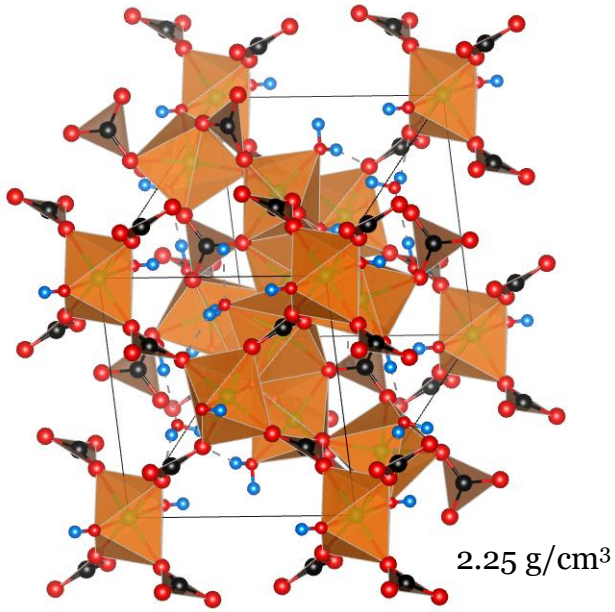
$Mg(OH)_2$, *brucite*: amcsd 0014731
$MgCO_3$, *magnesite*: amcsd 0000990
$Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$, *hydromagnesite*: amcsd 0009586
$MgCO_3 \cdot 3H_2O$, *nesquehonite*: amcsd 0014644
$Mg_2(CO_3)(OH)_2 \cdot 3H_2O$, *artinite*: amcsd 0009620
$MgCO_3 \cdot 5H_2O$, *lansfordite*: amcsd 0015442
$Mg_2(CO_3)(OH)_2$, *pokrovskite*: amcsd 0007185
$CaCO_3$, *calcite*: amcsd 0000098
$CaCO_3$, *aragonite*: amcsd 0000233
$CaCO_3$, *vaterite*: amcsd 0019141
$CaCO_3 \cdot H_2O$, *monohydrocalcite*: amcsd 0004611
$CaCO_3 \cdot 6H_2O$, *ikaite*: amcsd 0010853

• The exemplary Ca-O and Mg-O distances of calcite and magnesite, respectively, are obtained by using the open software MERCURY, available at this weblink, by again using the respective CIF files of above. (The open access software AVOGADRO (weblink) may also be used to obtain such distances in the structures of crystalline phases by using their respective CIF files.)

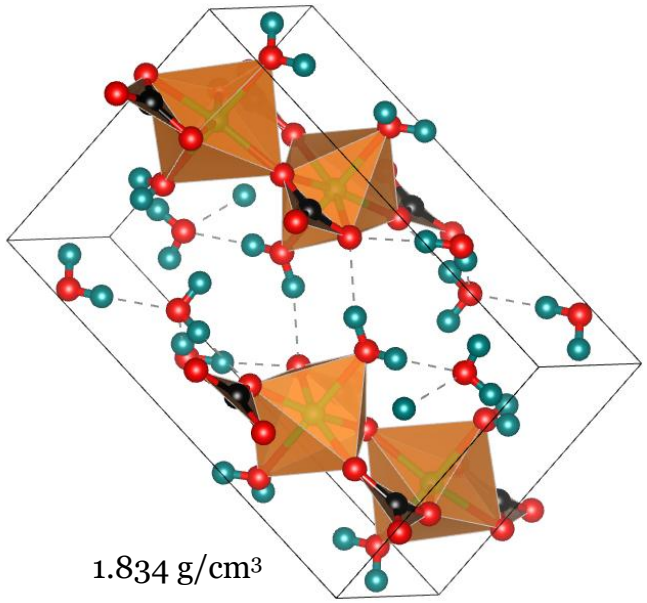
Mg



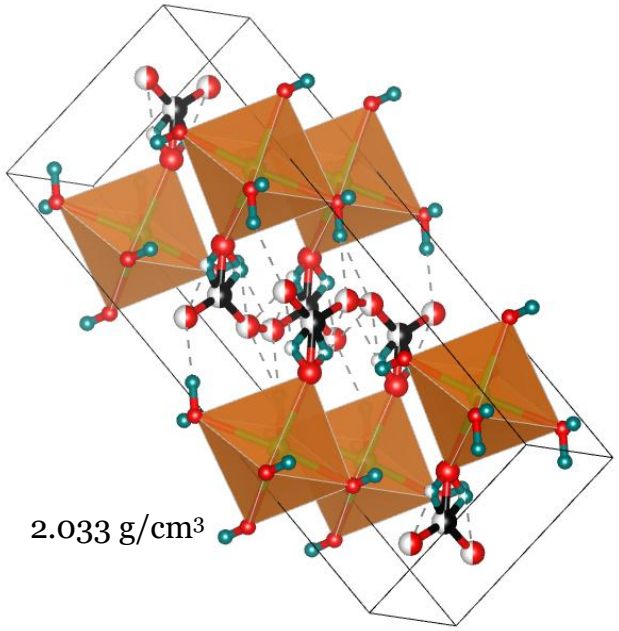
Mg(OH)2 / hexagonal



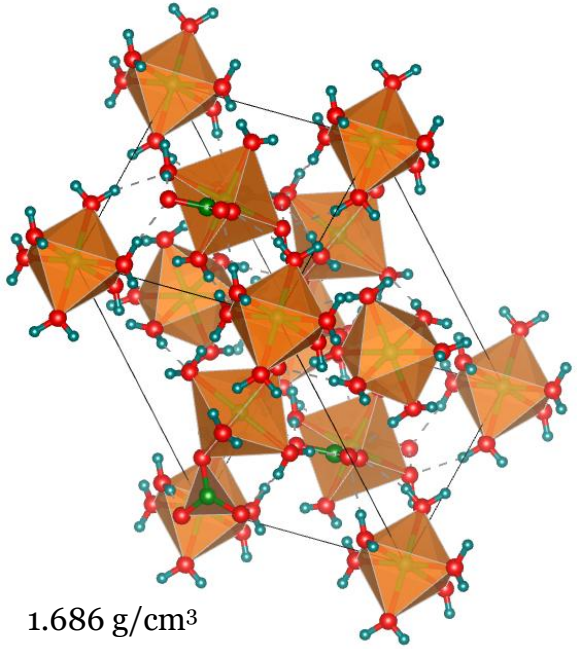
Hydromagnesite / monoclinic



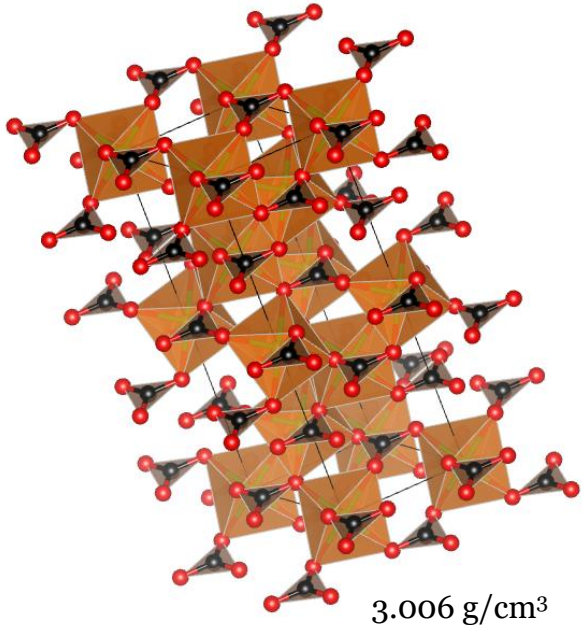
Nesquehonite / monoclinic



Artinite / monoclinic



Lansfordite / monoclinic



MgCO3 / rhombohedral

Mg^{2+} is in **octahedral coordination (*i.e.*, CN=6)** in all phases shown here

CN: coordination number

radius of Mg^{2+} in **6** coordination= **0.72 Å**

C: black
H: blue
Mg^{2+} ions are located inside the brown octahedra

What did the data of the previous pages indicate?

(*i*) Mg^{2+} ions prefer to be surrounded by six water molecules when they are in water,

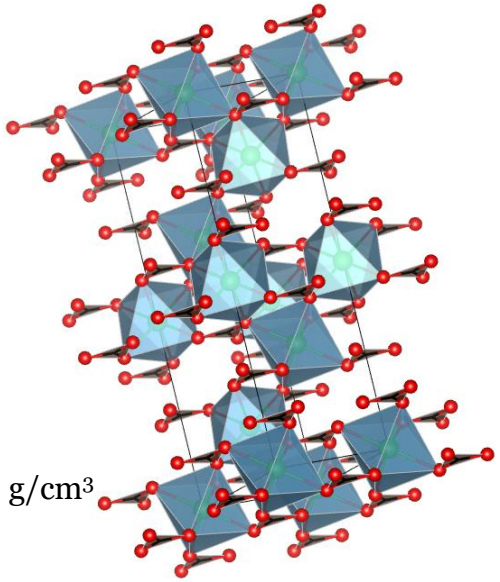
(*ii*) Mg^{2+} ions still prefer to be surrounded by six oxygens (*i.e.*, Mg^{2+} ions occupy the octahedral sites in between six oxygens) upon the removal of water (*i.e.*, from the mother liquor* or supernatant) and subsequent *in aqua* crystallization into the one or more of solid phases shown in the previous page.

• AMC (amorphous magnesium carbonate) is the "*mother of all*" of those hydrated Mg carbonates and hydrated Mg hydroxycarbonates.

Let's see, in the next page whether Ca^{2+} ions would have this "coordination number consistency" in the solid carbonate and hydrated carbonate phases they may form or not.

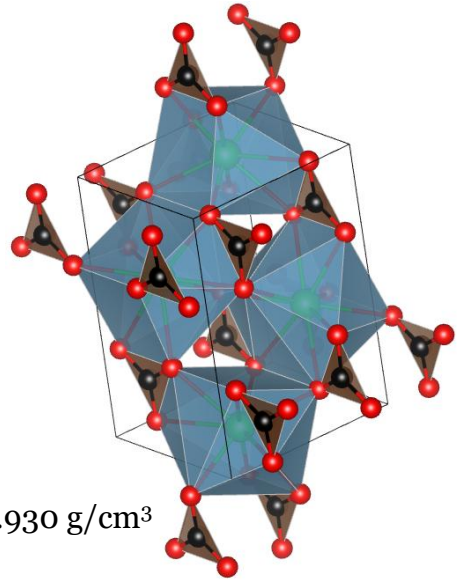
* The term "mother liquor" originates from the German chemistry literature, *i.e.*, *mutterlauge* or *mutterlikör*. Although I used the term mother liquor frequently in my academic publications, the majority of the science community goes with the term supernatant.

Ca



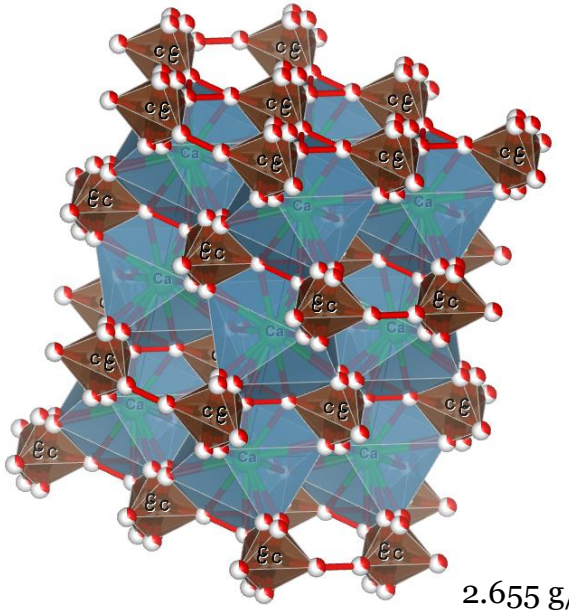
2.710 g/cm³

Calcite / rhombohedral
CN of Ca^{2+} = 6



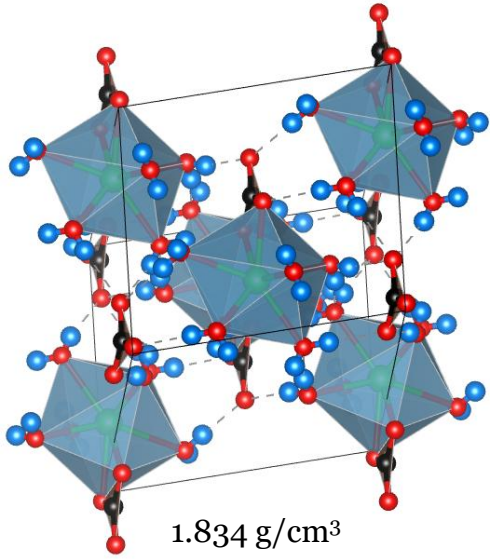
2.930 g/cm³

Aragonite / orthorhombic
CN of Ca^{2+} = 9



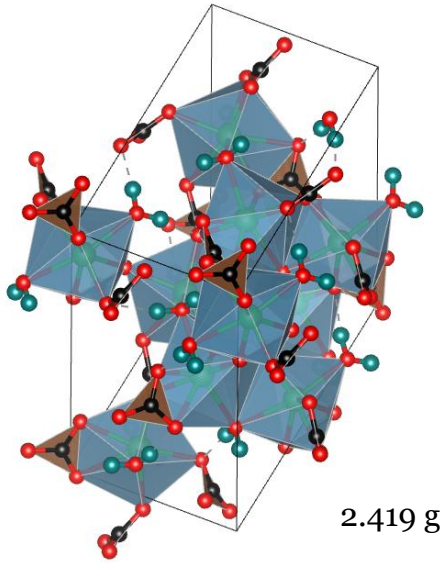
2.655 g/cm³

Vaterite / hexagonal
CN of Ca^{2+} = 12



1.834 g/cm³

Ikaite / monoclinic
CN of Ca^{2+} = 8



2.419 g /cm³

Monohydrocalcite / hexagonal
CN of Ca^{2+} = 8

C: black
H: blue

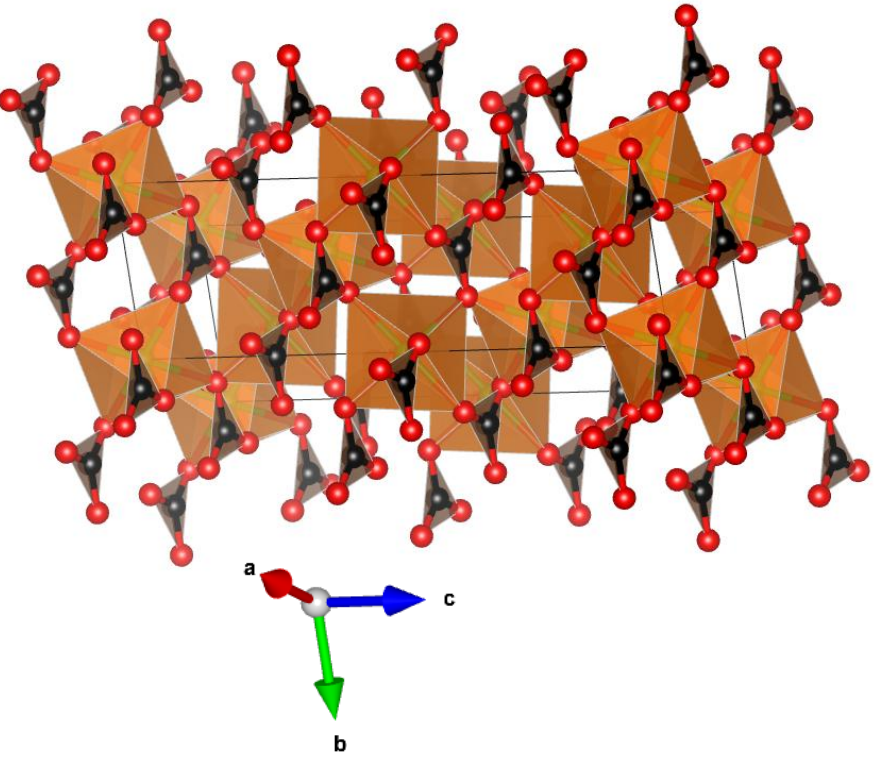
Ca^{2+} ions are located inside the greenish/bluish polyhedra

radius of Ca^{2+} in 6 coordination= **1.08 to 1.14 Å**

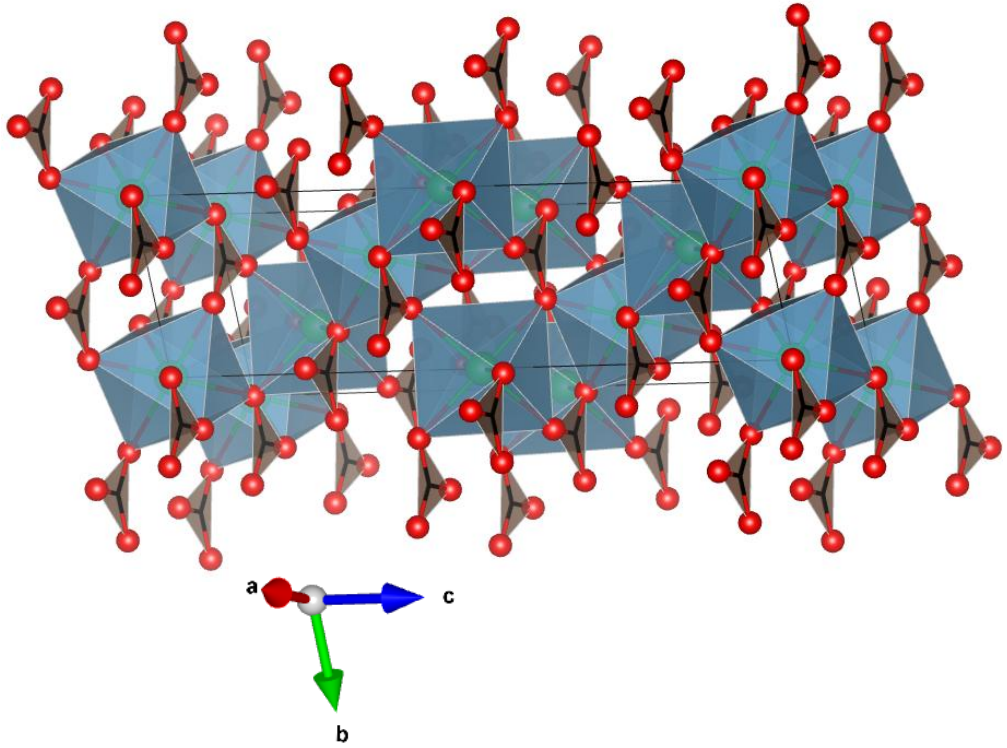
radius of Ca^{2+} in 8 coordination= **1.12 Å**

radius of Ca^{2+} in 9 coordination= **1.18 to 1.20 Å**

radius of Ca^{2+} in 12 coordination= **1.35 Å**



Magnesite, **MgCO3** / rhombohedral
R -3 c (167) 52.197 wt% CO2
a=b=4.635 Å
c=15.019 Å
V=**279.429** Å^3
Density: **3.006** g/cm^3
x, y, z
Mg: 0, 0, 0 (in octahedra)
C: 0, 0, 0.25
O: 0.2778, 0, 0.25



Calcite (**$CaCO_3$**) / rhombohedral
R -3 c (167) 43.972 wt% CO2
a=b=4.990 Å
c=17.062 Å
V=**367.916** Å^3
Density: **2.710** g/cm^3
x, y, z (atomic coordinates)
Ca: 0, 0, 0 (in octahedra)
C: 0, 0, 0.25
O: 0.2578, 0, 0.25

Ca-O distance
in calcite: **2.3574** Å

C-O distance
in calcite: **1.2864** Å

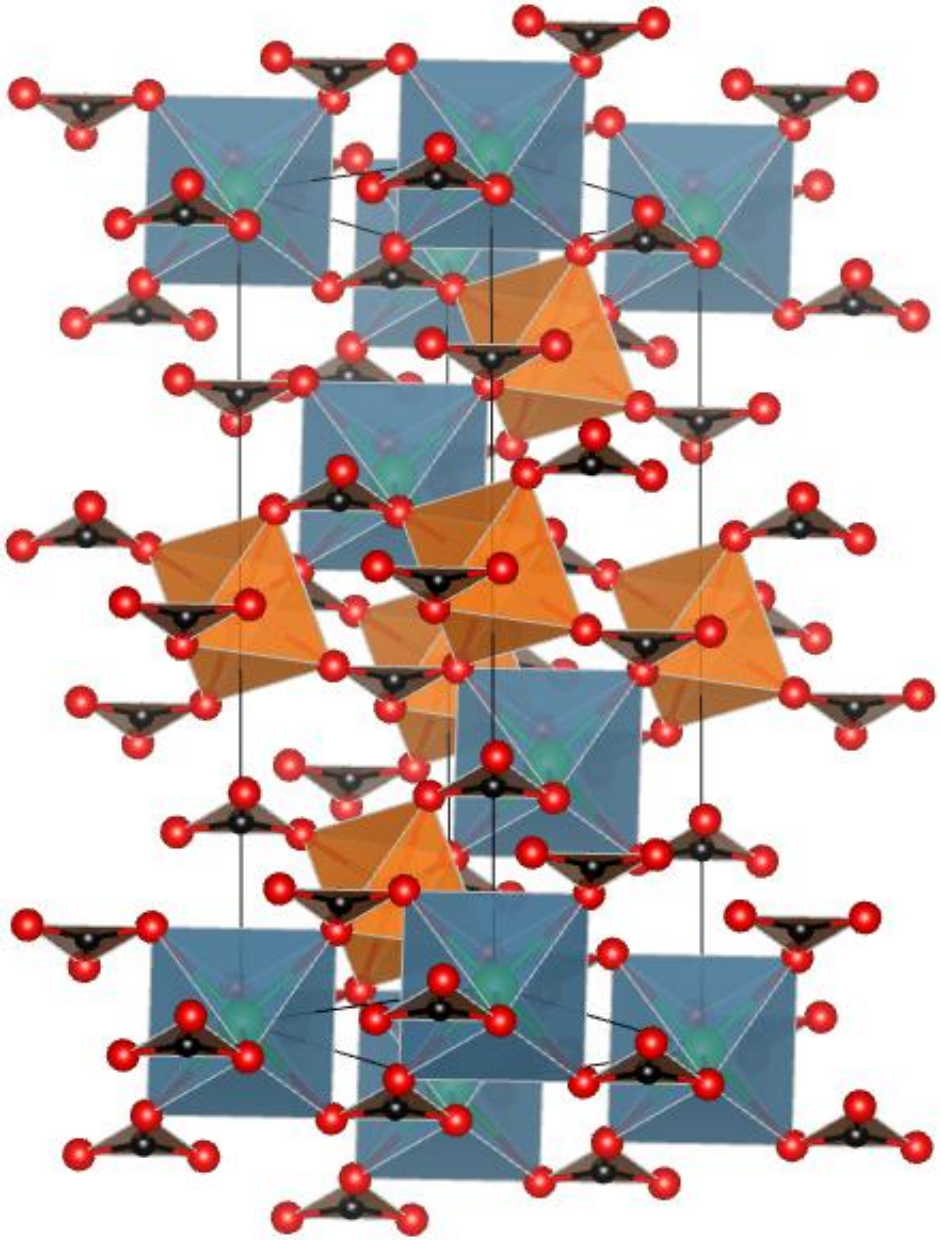
Mg-O distance
in magnesite: **2.1018** Å

C-O distance
in magnesite: **1.2876** Å

The ionic radius difference between Mg^{2+} and Ca^{2+} (0.72 *vs* ~1.1 Å) is responsible from the significant difference observed in the Mg-O and Ca-O distances.

What is the coordination number of Ca^{2+} and Mg^{2+} ions in dolomite ($CaMg(CO_3)_2$)?

(Neat dolomite is $CaCO_3 \cdot MgCO_3$, an ordered solid solution between magnesite and calcite.)



Dolomite, **CaMg(CO3)2** / rhombohedral
CIF: amcsd 0000584

R -3 (148) 47.733 wt% CO2
a=b=4.8033 Å
c=15.9840 Å
V=**309.371** Å^3
Density: **2.876** g/cm^3

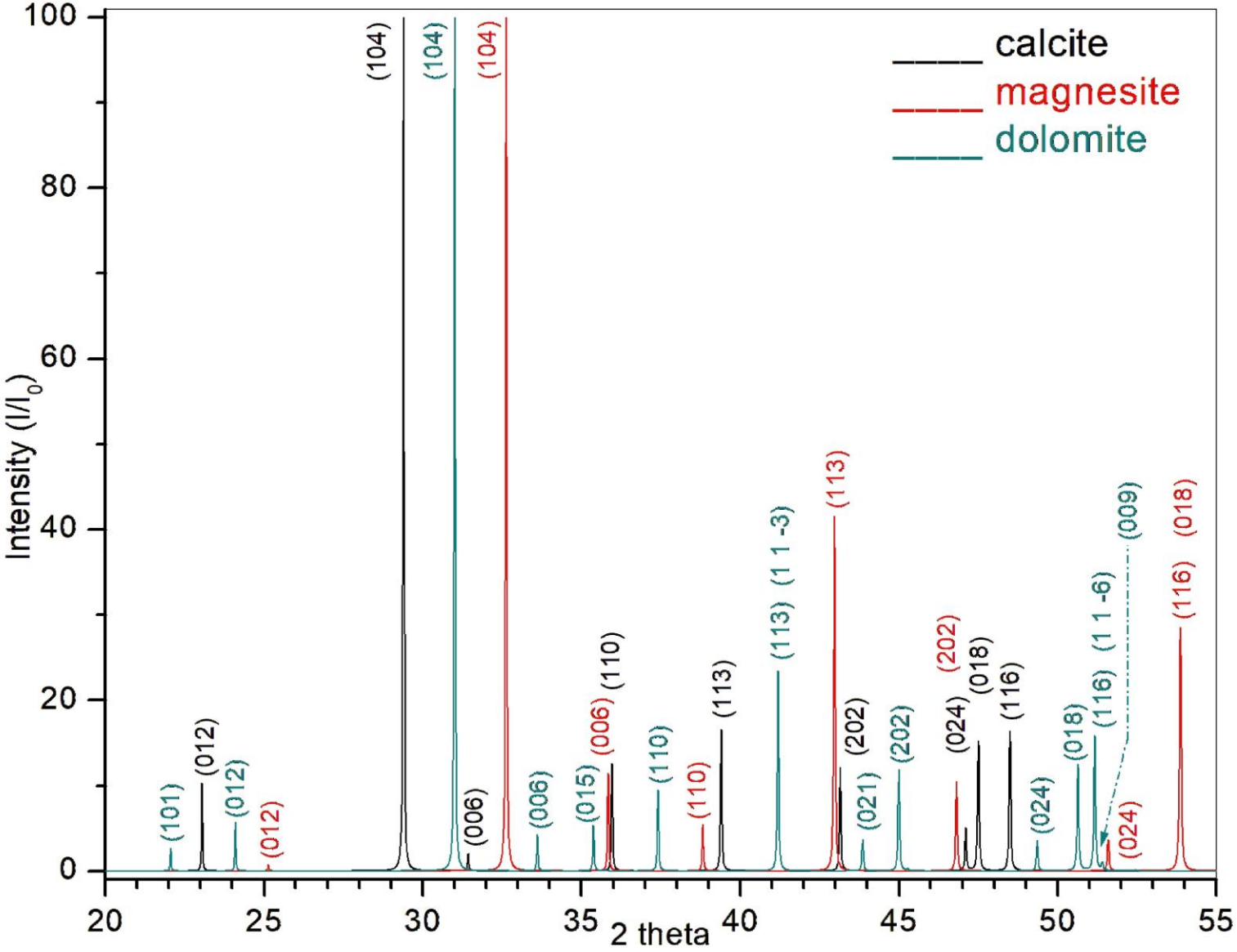
x, y, z
Ca: 0, 0, 0 (in octahedra)
Mg: 0, 0, 0.5 (in octahedra)
C: 0, 0, -0.2423
O: 0.2829, 0.0350, -0.2440

Ca-O distance: **2.3783** Å
Mg-O distance: **2.0827** Å
C-O distance: **1.2834** Å

Ca: green
Mg: brown
C: black
H: blue

Ca^{2+} and Mg^{2+} ions with **CN=6** are located inside the greenish and brown octahedra, respectively

dolomite mineralized at
"Dolomites" of Italy



• It is easy to differentiate between pure calcite, pure magnesite and dolomite using XRD.

• We previously demonstrated the difference between the XRD patterns of pure "calcite" and "magnesian-calcite" (the latter of which is a solid solution between calcite and magnesite) here and here.

• "Magnesian-calcite" is characterized by the ICDD-PDF cards, *e.g.*, 00-043-0697, 01-086-2336 or 04-013-2116.

• The extensive work of *Emeritus* Prof. L. Bruce Railback (weblink) shall be more than useful for researchers who are interested in the formation of $CaCO_3$, $MgCO_3$ or their solid solutions (dolomite) under various thermochemical conditions.

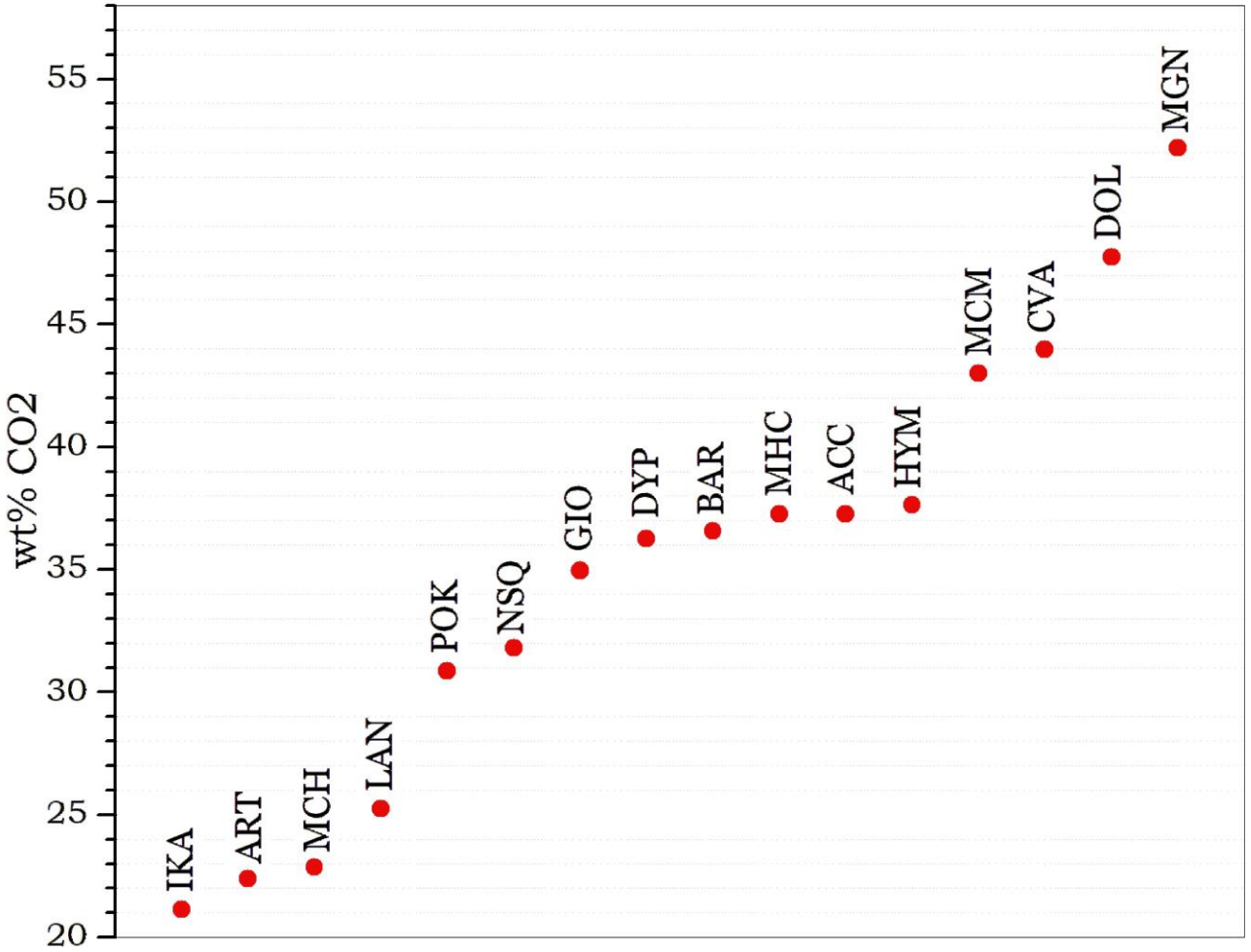
• Although calcite and magnesite share the same crystal lattice and space group (of Hermann-Mauguin No. 167), the significant separation between their XRD peaks is due to (*i*) the atomic scattering factor and atomic number (12 *vs* 20, *i.e.*, $1s^2 2s^2 2p^6 3s^2$ vs $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$) and (*ii*) the ionic radius difference (0.72 *vs* ~1.1 Å) between Mg and Ca. (Dolomite's space group (#148) is different, that results in a slightly different set of *hkl*'s.)

A. C. Tas

• This Table we prepared gives the names and formula of all common anhydrous carbonates, hydrated carbonates and hydrated hydroxycarbonates of Ca and Mg, together with the weight percent CO2 each phase contains. I made the abbreviations up; they are not based on previous literature.

Although AMC is not included in this Table, its formula is similar to that of "Mg-carbonate monohydrate."

Name	Abbreviation	Formula	wt% CO2
Magnesite	MGN	$MgCO_3$	52.197
Mg-carbonate monohydrate	MCM	$MgCO_3 \cdot H_2O$	43.008
Barringtonite	BAR	$MgCO_3 \cdot 2H_2O$	36.570
Nesquehonite	NSQ	$MgCO_3 \cdot 3H_2O$	31.808
Lansfordite	LAN	$MgCO_3 \cdot 5H_2O$	25.236
Mg-carbonate hexahydrate	MCH	$MgCO_3 \cdot 6H_2O$	22.873
Hydromagnesite	HYM	$Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$	37.644
Dypingite	DYP	$Mg_5(CO_3)_4(OH)_2 \cdot 5H_2O$	36.248
Giorgiosite	GIO	$Mg_5(CO_3)_4(OH)_2 \cdot 6H_2O$	34.951
Artinite	ART	$Mg_2(CO_3)(OH)_2 \cdot 3H_2O$	22.376
Pokrovskite	POK	$Mg_2(CO_3)(OH)_2$	30.856
Calcite, Vaterite, Aragonite	CVA	$CaCO_3$	43.972
Monohydrocalcite	MHC	$CaCO_3 \cdot H_2O$	37.264
Ikaite	IKA	$CaCO_3 \cdot 6H_2O$	21.140
Amorphous Ca-carbonate	ACC	$CaCO_3 \cdot H_2O$	37.264
Dolomite	DOL	$Ca_{0.5}Mg_{0.5}CO_3$	47.733



• The plot uses the wt% CO2 data of the Table. Magnesite (MGN, $MgCO_3$) has the highest CO2 content, where that of ikaite is the lowest.

• The Table and the plot could perhaps help the CO2 capture researchers to select and target, if their given industrial process lets them (*economically*) to do so, the compound to form to maximize the CO2 capturing ability of the process.

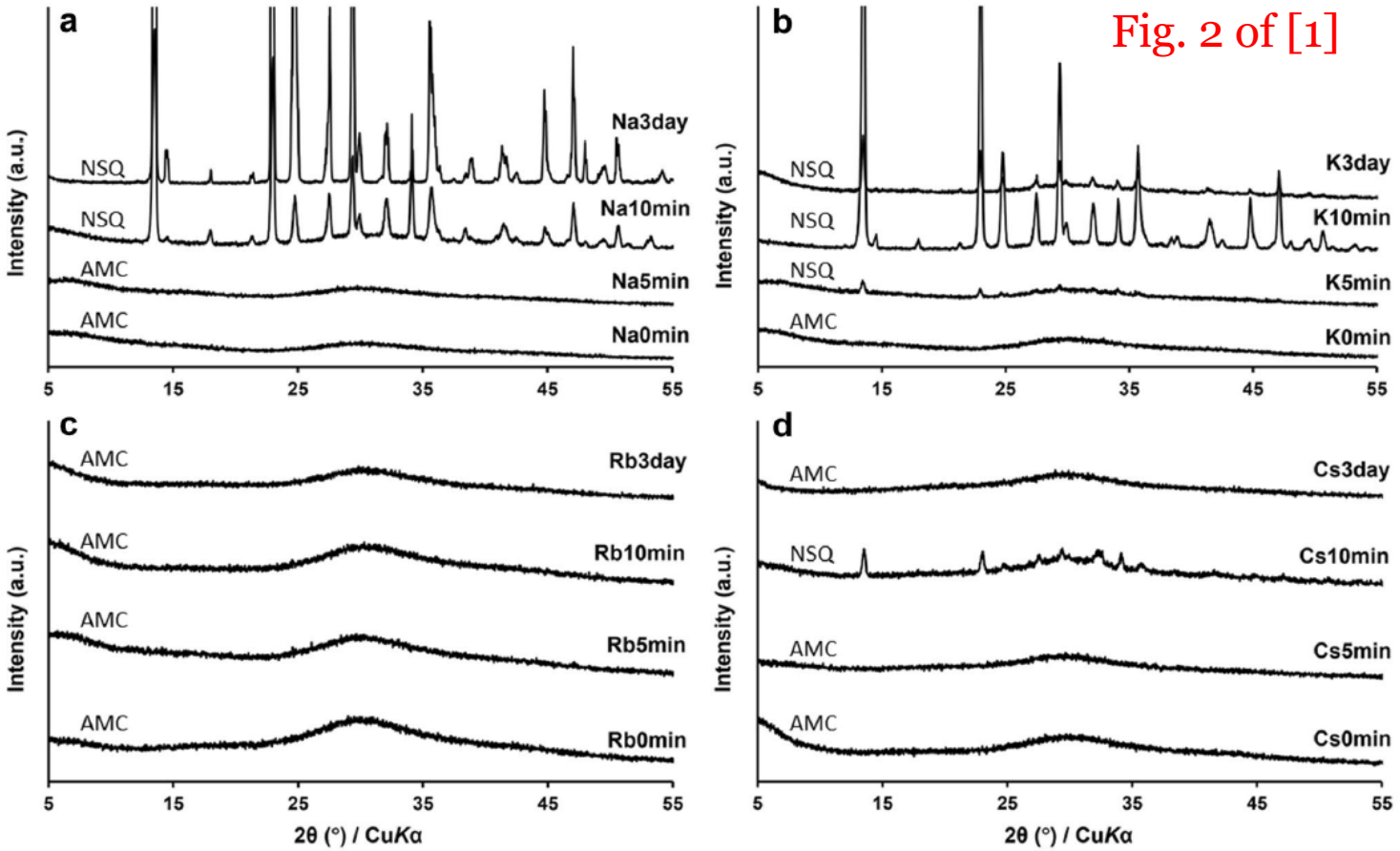
A. C. Tas

We can now start looking at the previous literature over a few select peer-reviewed Journal articles.

A good and simple example to the "AMC synthesis procedure" was provided by Yamamoto *et al.* [1]. Their procedure consisted of mixing 10 mL of 0.5 M MgCl2·6H2O aqueous solution with 10 mL of 0.5 M aqueous solution of **Na**2CO3 (or **K**2CO3 or **Rb**2CO3 or **Cs**2CO3) at 20°C in an open-to-air system. A white suspension was formed immediately and the solids were quickly removed from the suspension by filtering, washing with distilled water; followed by drying overnight in air at the ambient temperature.

- Ionic radii -- Mg^{2+}: 0.72, Na^{+}: 0.95 to 1.02, K^{+}: 1.33 to 1.38, Rb^{+}: 1.47 to 1.49, and Cs^{+}: 1.67 to 1.81 Å

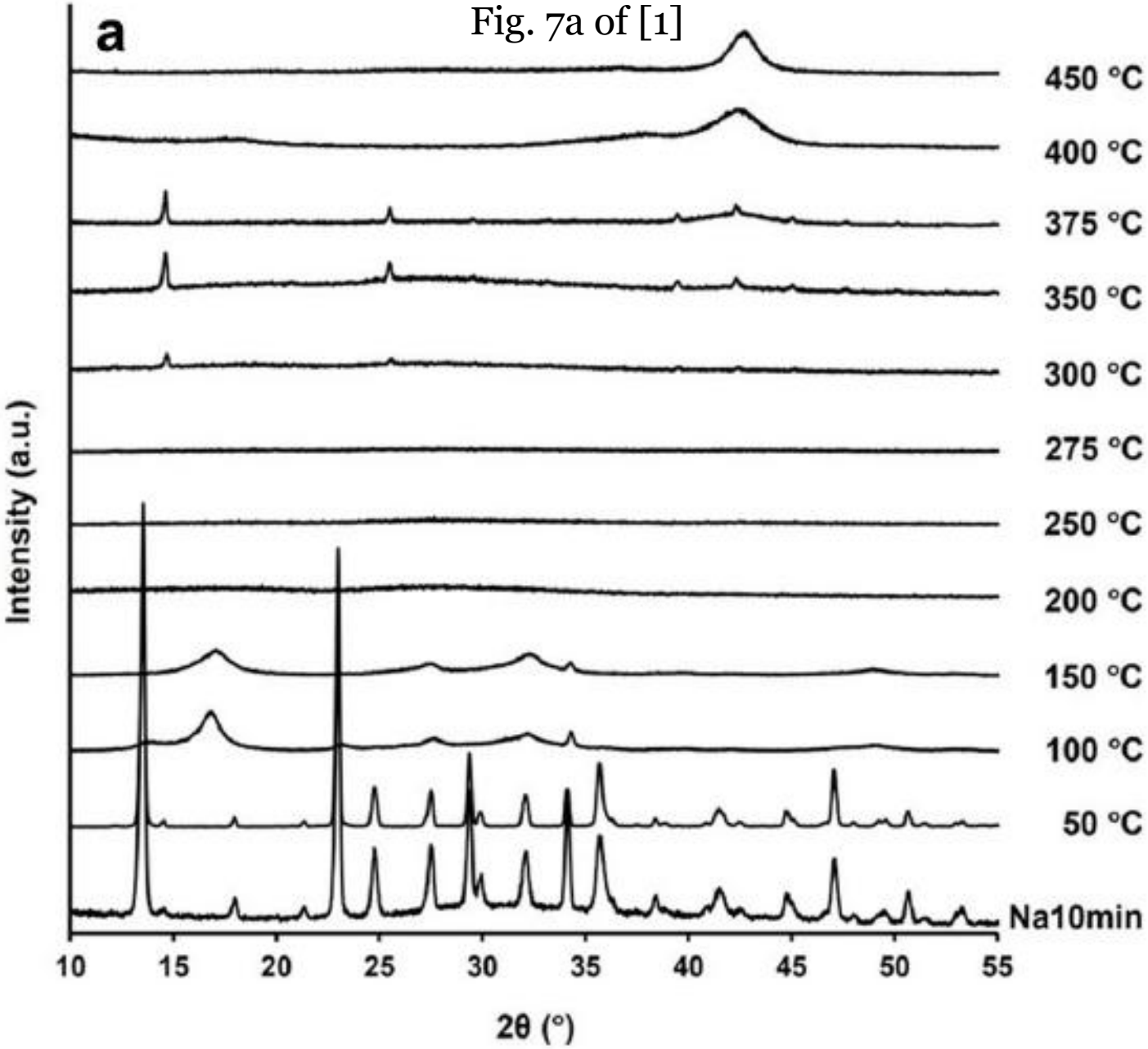
Fig. 2 of [1]



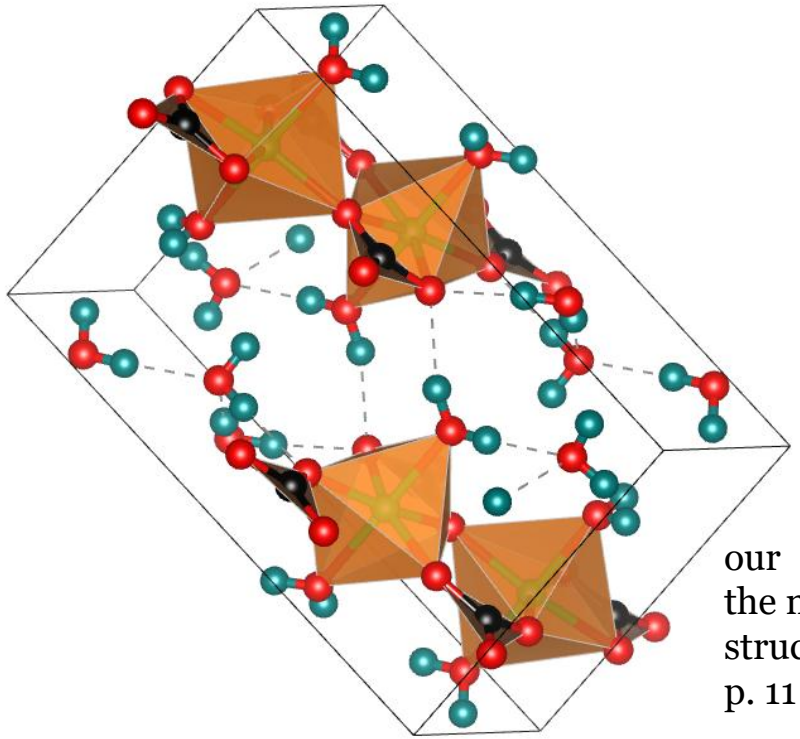
- The AMC precipitates formed by using Na2CO3 must be separated from their mother liquor after 5 min, otherwise they will crystallize into nesquehonite.
- We see that while the smaller spectator cations of Na^{+} and K^{+} did not suppress the crystallization of the initially formed AMC to nesquehonite (NSQ) when filtering was performed 10 min after the initial mixing of Mg^{2+}, alkali cation and CO_3^{2-} anions, the bigger spectator cations of Rb^{+} and Cs^{+} well-suppressed the crystallization of AMC even after 3 days of the stay of solids in their mother liquors before filtering.

[1] Gi. Yamamoto, A. Kyono, and S. Okada, "Structural variations of amorphous magnesium carbonate during nucleation, crystallization, and decomposition of nesquehonite MgCO3·3H2O," *Physics and Chemistry of Minerals*, 50, 5 (2023).

Fig. 7a of [1]



• Yamamoto *et al.* [1] heated (at various temperatures shown in this plot) the solids stayed in their mother liquors for 10 min before filtering (of $MgCl_2{\cdot}6H_2O$+Na_2CO_3 solution mixture) to find that the nesquehonite structure completely collapses (to form an amorphous phase) when the heating temperature was 200, 250 or 275°C.



our depiction of the nesquehonite structure (from p. 11 above)

[1] Gi. Yamamoto, A. Kyono, and S. Okada, "Structural variations of amorphous magnesium carbonate during nucleation, crystallization, and decomposition of nesquehonite $MgCO_3{\cdot}3H_2O$," *Physics and Chemistry of Minerals*, 50, 5 (2023).

• The Yamamoto *et al.* [1] study showed that it is possible to synthesize AMC by mixing $MgCl_2 \cdot 6H_2O$ and Na_2CO_3 at 20°C followed by immediate filtering, washing and drying in air overnight again at 20°C.
• Referring to our detailed technical note (its pp. 13 through 18) on the synthesis of ACC (amorphous calcium carbonate), the findings of the study of Yamamoto *et al.* [1] slightly differed along the below points from the studies on ACC synthesis by Kojima *et al.* [7] and Koga *et al.* [8], which we discussed in our ACC document.
(1) Both Kojima *et al.* [7] and Koga *et al.* [8] added NaOH to the water-based $CaCl_2 \cdot 2H_2O$ + Na_2CO_3 mixtures to carry the synthesis of ACC at pH values >12. Yamamoto *et a*l. [1] study on AMC synthesis, on the other hand, did not necessitate the pH increase by adding NaOH. This seemed to tell that in order to form AMC, one should not necessarily perform the synthesis at highly alkaline pH ranges (12 to 13.5). Theoretically, while the pH of 0.5 M Na_2CO_3 solution would have a pH at around 11.8, the pH of 0.5 M $MgCl_2 \cdot 6H_2O$ solution will have a pH of about 6. Mixing of these two solutions with one another, as Yamamoto *et al.* [1] did, would decrease the pH to significantly below 11. (2) While Kojima *et al.* [1] also studied the effect of ACC synthesis temperature (*i.e.*, 0°C vs 20°C) at pH values in the vicinity of 13, Koga *et al.* [8] only worked at a constant temperature of 5°C and very high pH. It will be difficult to assert that AMC can form at the ambient T rather easily; it would have been quite informative to synthesize ACC and AMC in the same lab in parallel experiments (*i.e.*, Yamamoto *et al.* [1]-AMC vs Kojima *et al.* [7]-ACC). My extensive experience on *in vitro* Ca-carbonate synthesis indicates that when one mixes equimolar $CaCl_2 \cdot 2H_2O$ and Na_2CO_3 solutions with one another at unadjusted pH, a mixture of vaterite and calcite will be the product to observe even after immediate filtration. $MgCl_2$ usage *in lieu* of $CaCl_2$ may change this picture.

[1] Gi. Yamamoto, A. Kyono, and S. Okada, "Structural variations of amorphous magnesium carbonate during nucleation, crystallization, and decomposition of nesquehonite $MgCO_3 \cdot 3H_2O$," *Physics and Chemistry of Minerals*, 50, 5 (2023).
[7] Y. Kojima, A. Kawanobe, T. Yasue, and Y. Arai, "Synthesis of amorphous calcium carbonate and its crystallization," *Journal of The Ceramic Society of Japan*, 101, 1145-1152 (1993).
[8] N. Koga, Y .Nakagoe, and H. Tanaka, "Crystallization of amorphous calcium carbonate," *Thermochimica Acta*, 318, 239-244 (1998).

Purgstaller *et al.* [9] reported the solubility of pure AMC (although their study was mainly focused on the chemical physical properties ACMC, *i.e.*, amorphous calcium magnesium carbonate) and the number of water molecules in its solid structure. Purgstaller *et al.* [9] prepared their samples by mixing 80 mL of 0.25 M aqueous $MgCl_2 \cdot 6H_2O$ solutions and 80 mL of 0.25 M aqueous solutions of Na_2CO_3 at RT, followed by immediate filtration (using 0.2 μm membranes) and washing with ultrapure water, where the drying of the recovered precipitates were performed by freeze-drying. The below plot shows that the value of n in AMC (=$MgCO_3 \cdot nH_2O$) could vary between 0.8 and 1.25.

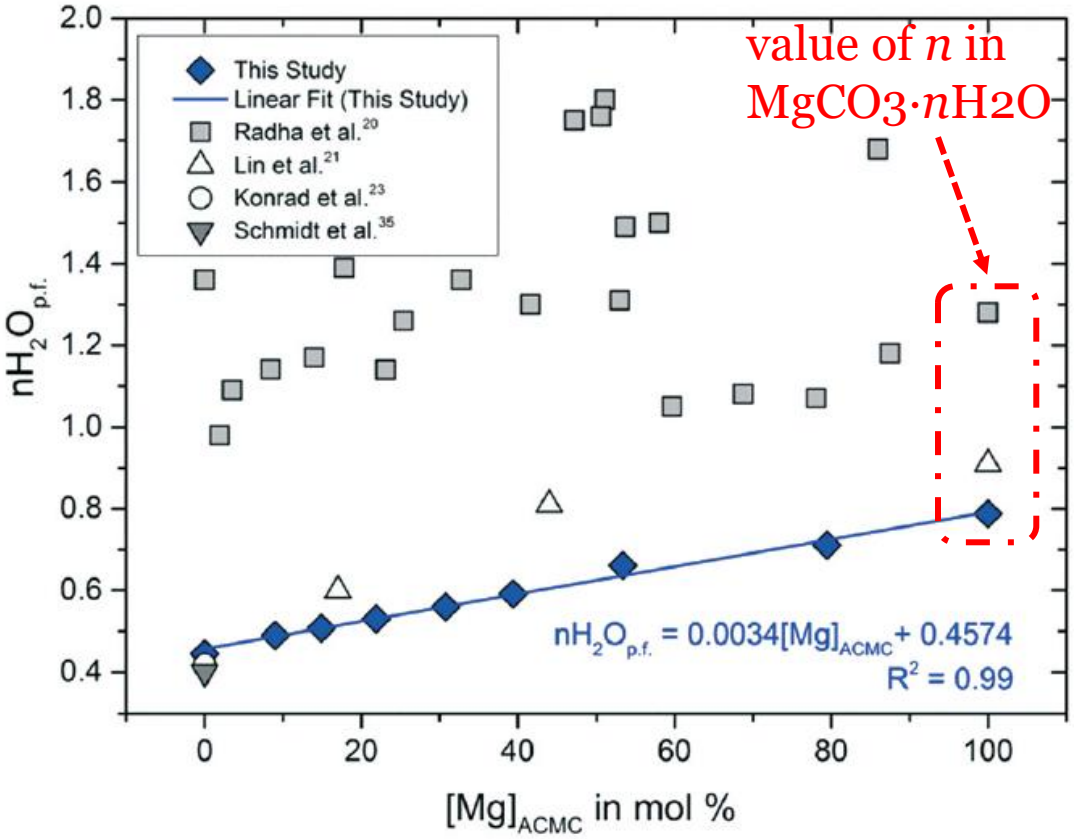


Fig. 2 of [9]

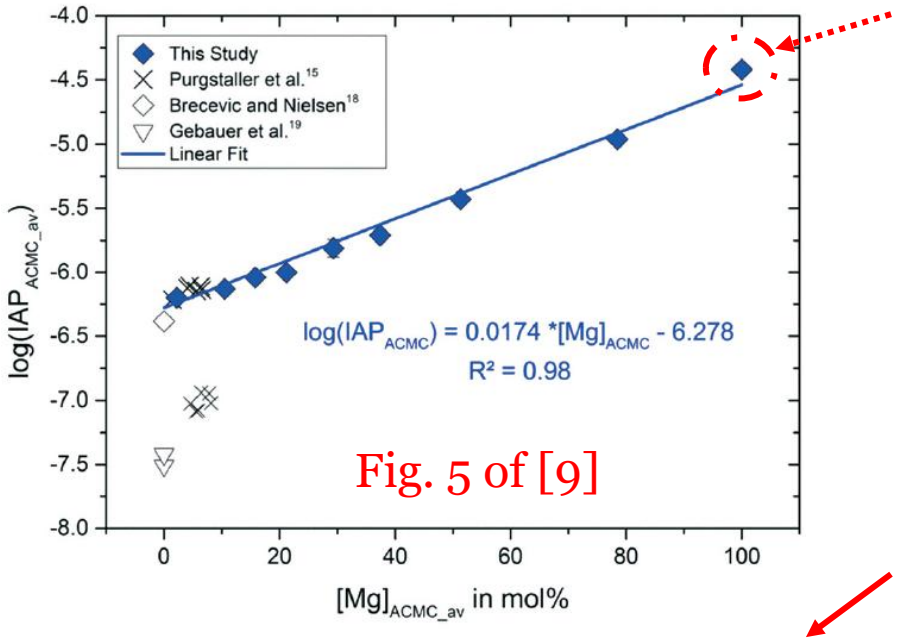


Fig. 5 of [9]

• The value of this point, by using the linear fit equation authors [9] provided, turns out to be **-4.54**. Therefore, In comparison to the data of the below Table, AMC has a solubility in water much higher than that of ACC.

Temperature (°C)	**ACC** (*log* K_{SP}) [10]	**vaterite** (*log* K_{SP}) [11]	**aragonite** (*log* K_{SP}) [11]	**calcite** (*log* K_{SP}) [11]
10	-6.27			
25	-6.39			
40	-6.59			
55	-6.82			
25		-7.91	-8.33	-8.48
37		-8.05	-8.40	-8.56

[9] B. Purgstaller, K. E. Goetschl, V. Mavromatis, and M. Dietzel, "Solubility investigations in the amorphous magnesium calcium carbonate system," *CrystEngComm*, 21, 155-164 (2019).

In another paper, Yamamoto *et al.* [10] reported the effect of synthesis temperature on the structure of AMC using synchrotron X-ray scattering and TGA/DTA experiments. Their synthesis method was essentially similar to that of Ref. 7 we discussed above. Aliquots of separate 0.5 M $MgCl_2 \cdot 6H_2O$ and 0.5 M Na_2CO_3 aqueous solutions were first kept at 20, 60 and 80°C, followed by mixing. They reported that all mother liquors of AMC (upon mixing) had a pH of about 10.5. The formed precipitates were immediately filtered, washed with distilled water, and dried overnight in air at RT. Yamamoto *et al.* [10] attempted to estimate the water content of their AMC samples using TGA/DTA. Approximately 10 mg of AMC and an α-alumina reference powder (DTA works with a reference powder) were placed in Al pans, and subsequently heated from 50 to 550°C at a heating rate of 10°C/min under argon flow at the rate of 200 mL/min.

Sample label	TGA weight loss (%)	Value of *n* in $MgCO_3 \cdot nH_2O$
AMC20	32	2.2
AMC60	29	1.9
AMC80	26	1.6

• This is a table we prepared by using the data reported by Yamamoto *et al.* [10]. They did not provide the actual TGA plot.

• Yamamoto *et al.* [10] concluded that the average formula of AMC could be $MgCO_3 \cdot \mathbf{2}H_2O$ by using the data of the above table; and also stated that their formula also corroborated the findings of Tanaka *et al.* [11]. In stark contrast, ACC ($CaCO_3 \cdot H_2O$) has one water in its formula [12].

[10] Gi. Yamamoto, A. Kyono, and S. Okada, "Temperature dependence of amorphous magnesium carbonate structure studied by PDF and XAFS analyses," *Scientific Reports*, 11, 22876 (2021).
[11] J. Tanaka, J. Kawano, T. Nagai, and H. Teng, "Transformation process of amorphous magnesium carbonate in aqueous solution," *Journal of Mineralogical and Petrological Sciences*, 114, 105–109 (2019).
[12] A. C. Tas, "Amorphous calcium carbonate, ACC," January 14, 2026.

As we will see in the following pages, amorphous magnesium carbonate (AMC) produced in mother liquors containing Mg^{2+} (aq) and CO_3^{2-}/HCO_3^- (aq) results in the formation of extensively agglomerated nanoparticles. Moreover, such solids of nanoscale possess a high BET (*Brunauer-Emmett-Teller* [13]) surface area and their mesopores would be filled with physically adsorbed/retained liquid water. Overnight drying in air of such AMC material, even without using a powerful desiccator filled with fresh anhydrite or silica gel beads or vacuumed, will not be able to remove all the physically adsorbed water, this was why Yamamoto *et al.* [10] should have provided the actual TGA data. Apparently, they assumably reported the total weight loss that occurred between 50 and 550°C. The removal of physically adsorbed water in mesoporous materials requires temperatures higher than 105°C. When one is interested in determining the structural water (that is shown in its formula) in AMC, one must subtract the amount of physically adsorbed water from the total weight loss observed (by TGA). The paper [10] did not clearly address this point.

The work of Purgstaller *et al.* [9], which we discussed in p. 23, provided a more reliable experimental approach and data towards the determination of the structural water that should appear in the formula of AMC (*i.e.*, its structural water content on a mole percentage basis) since they used freeze-drying (lyophilization) rather than air drying at RT. Lyophilization (by sublimation) can better remove the physically adsorbed water.

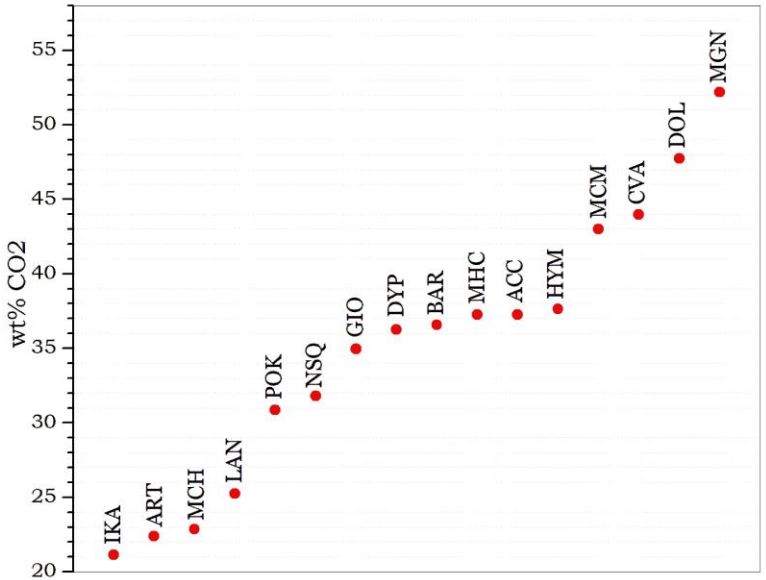
As a result, I would take the formula of AMC as $MgCO_3 \cdot \mathit{0.8\text{-}1.25}H_2O$, or approximately $MgCO_3 \cdot H_2O$, based on the study of Purgstaller *et al.* [9] until I test it myself.

[9] B. Purgstaller, K. E. Goetschl, V. Mavromatis, and M. Dietzel, "Solubility investigations in the amorphous magnesium calcium carbonate system," *CrystEngComm*, 21, 155-164 (2019).

[10] Gi. Yamamoto, A. Kyono, and S. Okada, "Temperature dependence of amorphous magnesium carbonate structure studied by PDF and XAFS analyses," *Scientific Reports*, 11, 22876 (2021).

[13] S. Brunauer, P. H. Emmett, and E. Teller, "Adsorption of gases in multimolecular layers," *Journal of the American Chemical Society*, 60, 309–319 (1938).

Carbon capture and utilization (CCU) has attracted significant interest due to the rising concerns about increasing emissions of greenhouse gases due to the increasing world population, deforestation, and accelerated industrialization even in once rural areas. Mineral trapping *via* $MgCO_3$ precipitation is a promising strategy, though restricted by the slow rate of magnesite ($MgCO_3$) formation and high temperatures and high CAPEX needed [14] to avoid the formation of hydrated minerals. Amorphous magnesium carbonate (AMC) is a transient (precursor) phase, determining the characteristics of the final crystalline anhydrous, hydrated and/or hydrated hydroxycarbonate magnesium carbonate phase(s) as we discussed, until now, in this pamphlet. As we had shown above, and as seen in the below plot (MGN=$MgCO_3$) we prepared, anhydrous $MgCO_3$ has by far the highest CO_2 sequestration ability.



F. S. de Vico *et a*l. [15] studied the formation of AMC by using anhydrous $MgCl_2$ and K_2CO_3. They also studied the effect of tri-sodium citrate dihydrate additions to the above solutions (in parallel, separate experiments) and found that the presence of citrate anions in their Mg^{2+}, K^+ and CO_3^{2-} solutions increased the incubation time prior to AMC nucleation. Apparently, de Vico *et al.* [15] were not able to see and cite the Yamamoto *et al.* [1] article which was published in 2023. One needs to remember that Yamamoto *et al.* [1] showed the effects of spectator cations Na^+, K^+, Rb^+ or Cs^+ in AMC nucleation solutions and observed that using Na_2CO_3 instead of K_2CO_3 would increase the incubation time a bit (besides more expensive Rb_2CO_3 and Cs_2CO_3).

[14] R. M. Santos, W. Verbeeck, P. Knops, K. Rijnsburger, Y. Pontikes, and T. van Gerven, "Integrated mineral carbonation reactor technology for sustainable carbon dioxide sequestration: 'CO2 energy reactor'," *Energy Procedia*, 37, 5884-5891 (2013).

[15] F. S. De Vico, S. Bonilla-Correa, G. Pelayo-Punzano, K. Elert, C. Rodríguez-Navarro, and E. Ruiz-Agudo, "Additive impact on early-stage magnesium carbonate mineralization," *Geochemical Perspective Letters*, 32, 46-51 (2024).

Below is the experimental procedure of the study of de Vico *et al*. [15].

AMC precipitation experiments were carried out at a fixed pH of 11, maintained by NaOH addition. A 100 mM anhydrous $MgCl_2$ solution was continuously added at a rate of 0.12 mL/min to a 50 mM K_2CO_3 solution at RT. Tri-sodium citrate dihydrate (over the dosage range of 0.04 to 5 mM) was added to the carbonate solution when studying the effect of citrate anions. The formed precipitates were immediately filtered out of the solutions (using membranes with an effective opening size of 0.2 μm), unfortunately, the authors did not specify their drying process.

The de Vico *et al*. [15] article provided SEM and TEM photomicrographs, XRD patterns, FTIR spectra and TGA/DSC data (25 to 950°C, at a heating rate of 10°C/min under an air flow through the TGA/DSC module at the rate of 120 mL/min).

We will reproduce these data in the following pages with our own comments whenever warranted.

[15] F. S. De Vico, S. Bonilla-Correa, G. Pelayo-Punzano, K. Elert, C. Rodríguez-Navarro, and E. Ruiz-Agudo, "Additive impact on early-stage magnesium carbonate mineralization," *Geochemical Perspective Letters*, 32, 46-51 (2024).

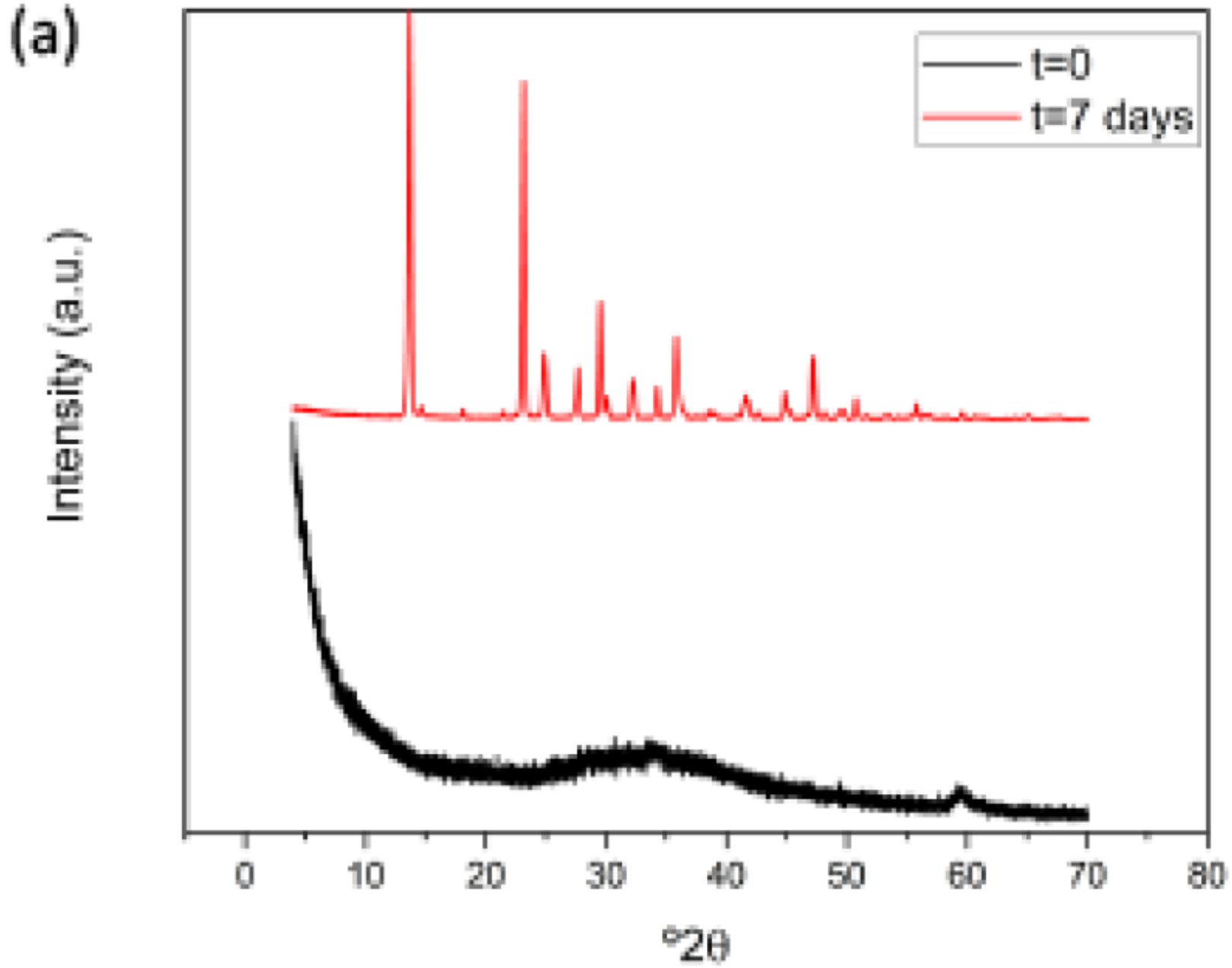


Fig. S-3a of de Vico *et al.* [15]
XRD

Immediately recovered precipitates (black trace) were amorphous (*i.e.*, AMC).

The sample of the red trace corresponds to solids recovered from the mother liquor after stirring at 25°C for 7 days. (*a chemical ageing process*) The red pattern is that of nesquehonite, confirming the report of Yamamoto *et al.* [1].

AMC prepared from a mixture of MgCl2 and alkali carbonate solutions would transform into nesquehonite when they were kept in the mother liquor for more than few minutes.

[15] F. S. De Vico, S. Bonilla-Correa, G. Pelayo-Punzano, K. Elert, C. Rodríguez-Navarro, and E. Ruiz-Agudo, "Additive impact on early-stage magnesium carbonate mineralization," *Geochemical Perspective Letters*, 32, 46-51 (2024).

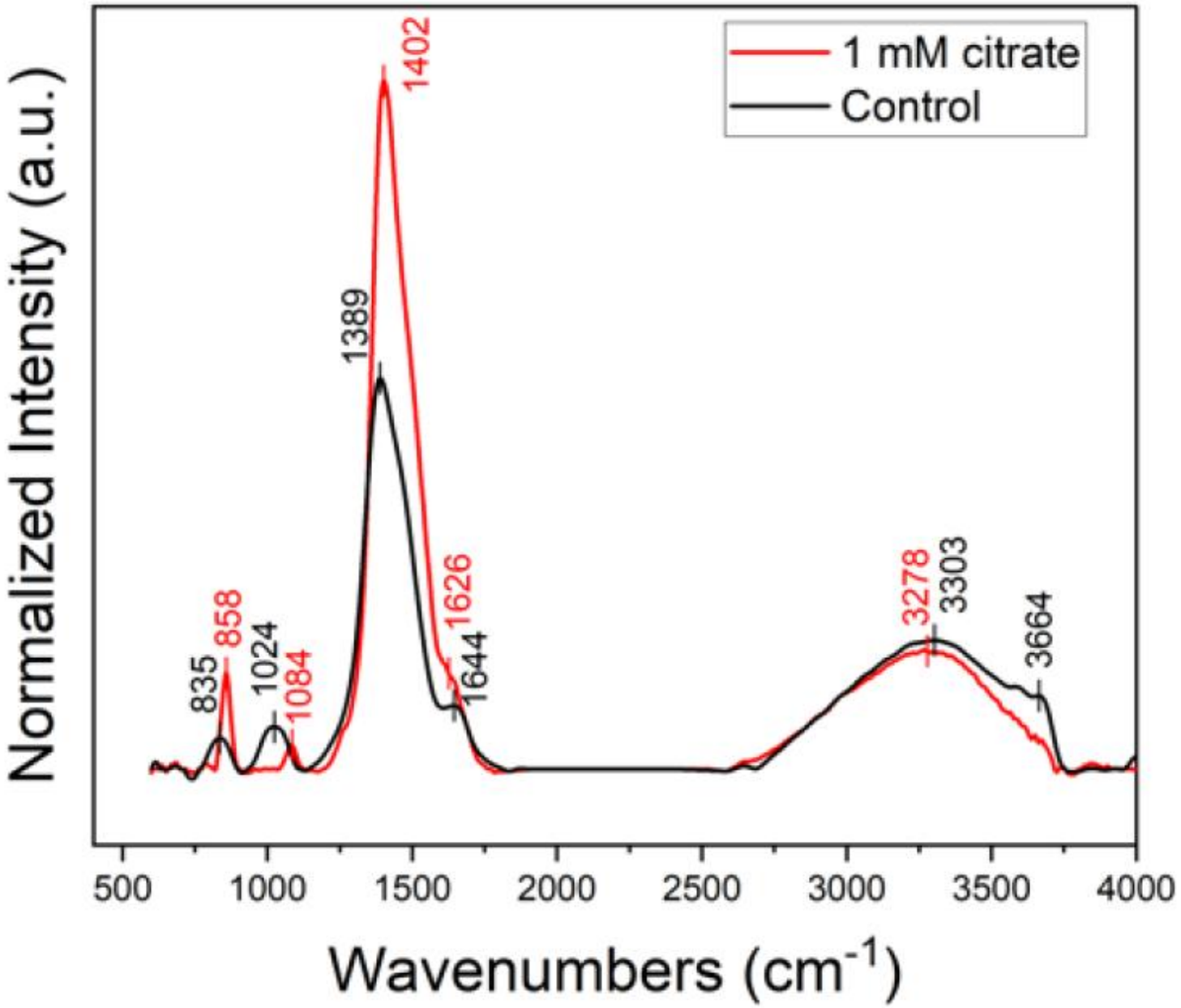


Fig. S-4 of de Vico *et al.* [15]
ATR-FTIR

black trace: immediately recovered AMC precipitates

The effect of citrate anions (red trace) in solution is outside the scope of this note.

The black trace is useful for the following researchers who want to characterize AMC by ATR-FTIR or FTIR. We would like to refer the readers to p. 21 of our ACC note. The most important IR bands for AMC of de Vico *et al.* [15] are those observed at 835 and 1024 cm^{-1}. In ACC, this couple of IR bands were observed at 864 and 1073 cm^{-1}. As we stated before on p. 26 of our ACC document, the band at 3664 cm^{-1} could well be that of trace amounts of brucite (Mg(OH)2) nuclei.

[15] F. S. De Vico, S. Bonilla-Correa, G. Pelayo-Punzano, K. Elert, C. Rodríguez-Navarro, and E. Ruiz-Agudo, "Additive impact on early-stage magnesium carbonate mineralization," *Geochemical Perspective Letters*, 32, 46-51 (2024).

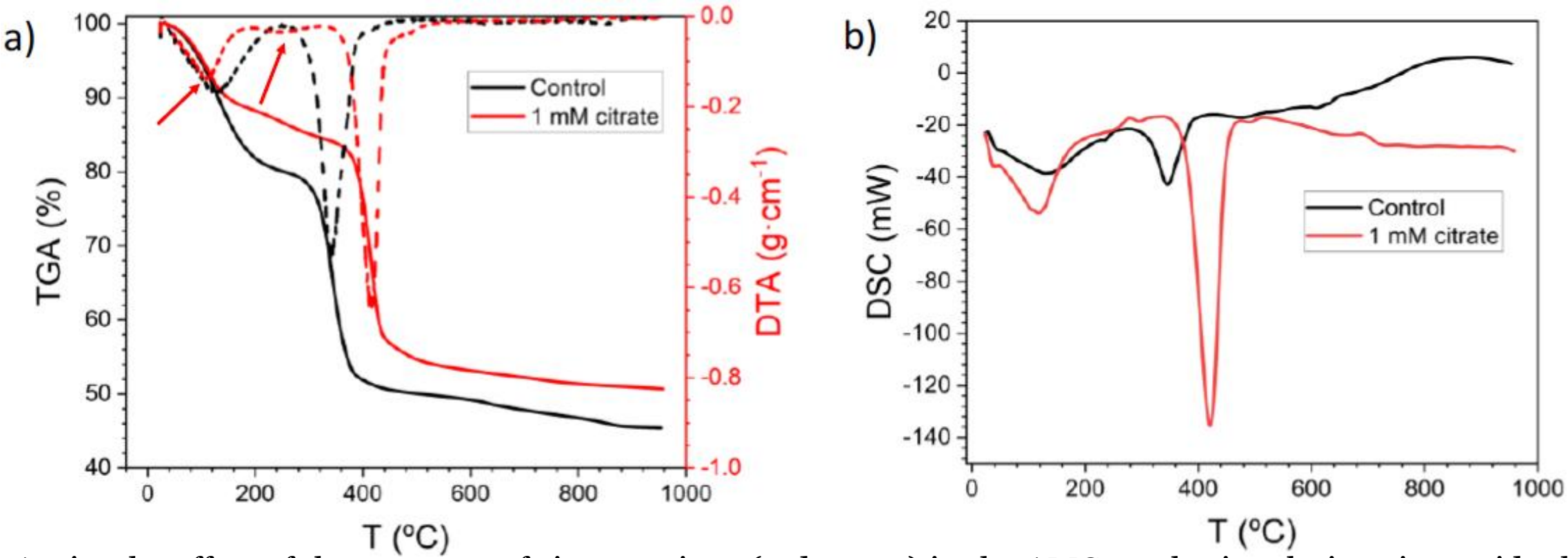


Fig. S-5 of de Vico *et al.* [15]

TGA + DSC

Again, the effect of the presence of citrate anions (red traces) in the AMC synthesis solutions is outside the range of interest of this note (essentially since one can use any other alkali salts of any other carboxylic acid or else as nucleation suppressing agent); this field of "increasing the incubation time of AMC" seems to be wide open and not yet filled by many researchers.

The loss of physically adsorbed water starts immediately (upon heating) and continues until 160-175°C. The structural water (see p. 11 above for H2O bound to Mg octahedra) loss occurs between 175 and 280°C, just before the onset of decarbonation.

[15] F. S. De Vico, S. Bonilla-Correa, G. Pelayo-Punzano, K. Elert, C. Rodríguez-Navarro, and E. Ruiz-Agudo, "Additive impact on early-stage magnesium carbonate mineralization," *Geochemical Perspective Letters*, 32, 46-51 (2024).

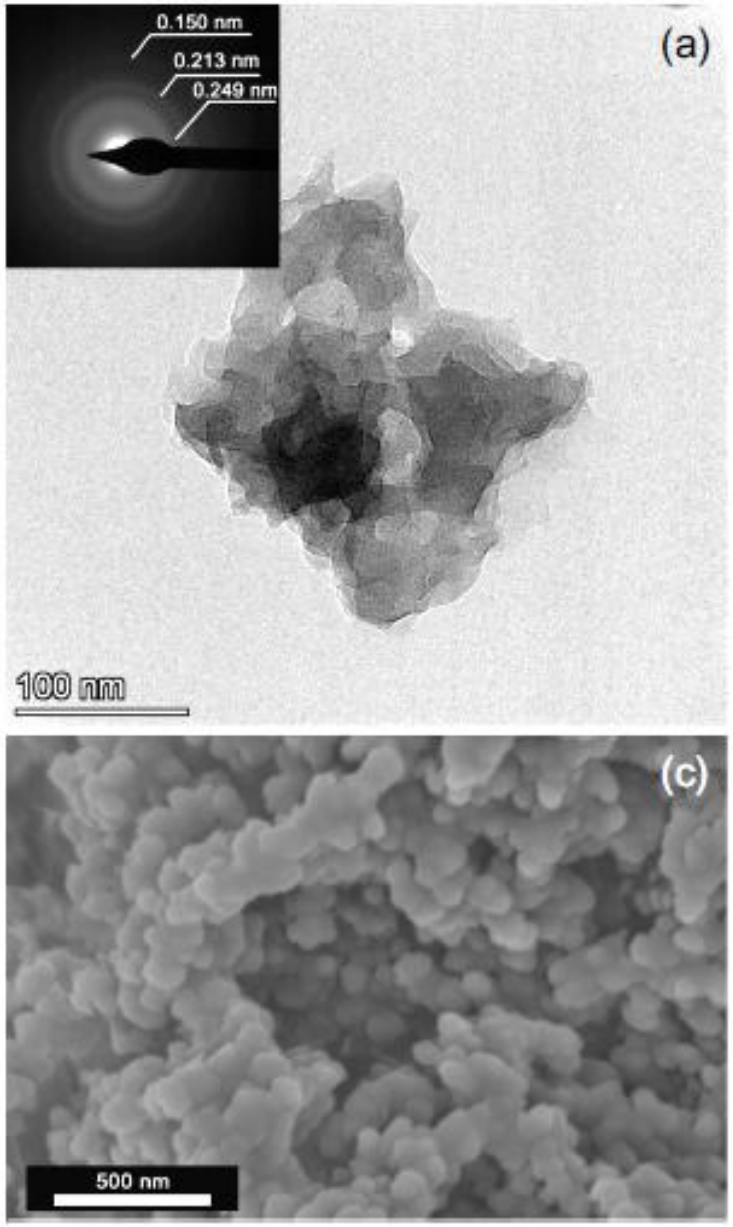


Fig. 3a (**TEM**)
and
Fig. 3c (**SEM**),

photographic images of AMC synthesized (*without any citrate anions being present in the solutions*) by de Vico *et al.* [15]

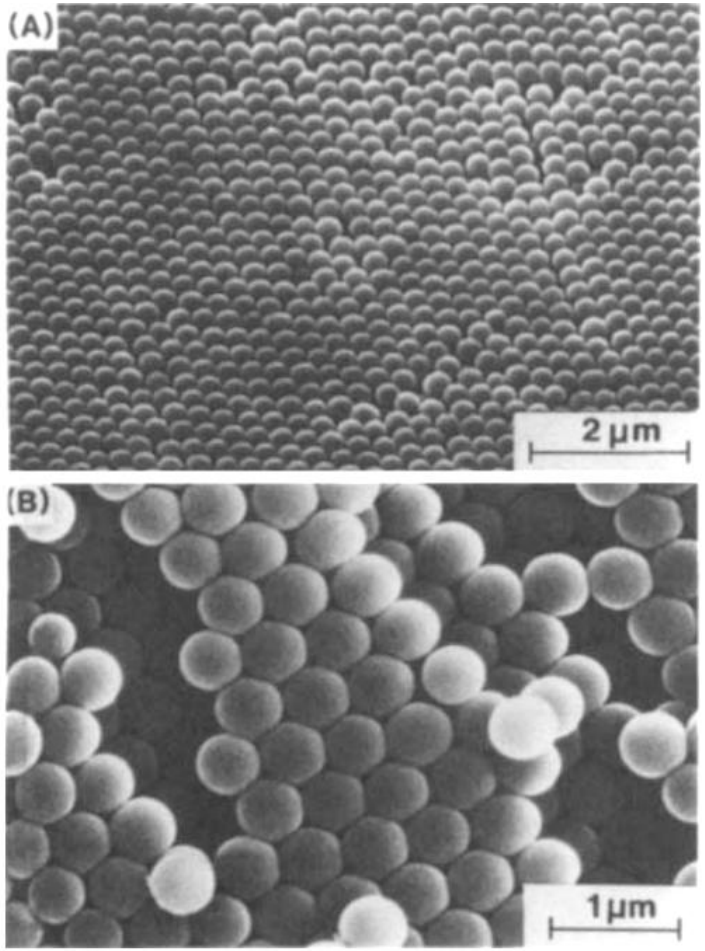
AMC first forms/nucleates in the form of embryo/clusters (at the Ångstrom scale) which are too small to be imaged in such macro-photographs. Those embryo/clusters do then rapidly grow into nanospheres and within few minutes those once individual nanospheres fuse to one another to yield micron-sized particle aggregates (of Fig. 3c).

If de Vico *et al.* [15] wanted to form mondisperse nanospheres they needed to decrease the concentrations of the MgCl2 and K2CO3 solutions. When one uses such concentrated (100 mM and 50 mM) solutions of Mg^{2+} and CO_3^{2-}, then the "fusion of the individual nanospheres to one another" would be inevitable, as seen here. When one adds certain polymeric macromolecules into the mother liquors of AMC syntheses, then such macromolecules would not let that "fusion" to happen. When one has this much agglomeration visible, I advise not to use the magic/marketing word of "nanoparticles."

[15] F. S. De Vico, S. Bonilla-Correa, G. Pelayo-Punzano, K. Elert, C. Rodríguez-Navarro, and E. Ruiz-Agudo, "Additive impact on early-stage magnesium carbonate mineralization," *Geochemical Perspective Letters*, 32, 46-51 (2024).

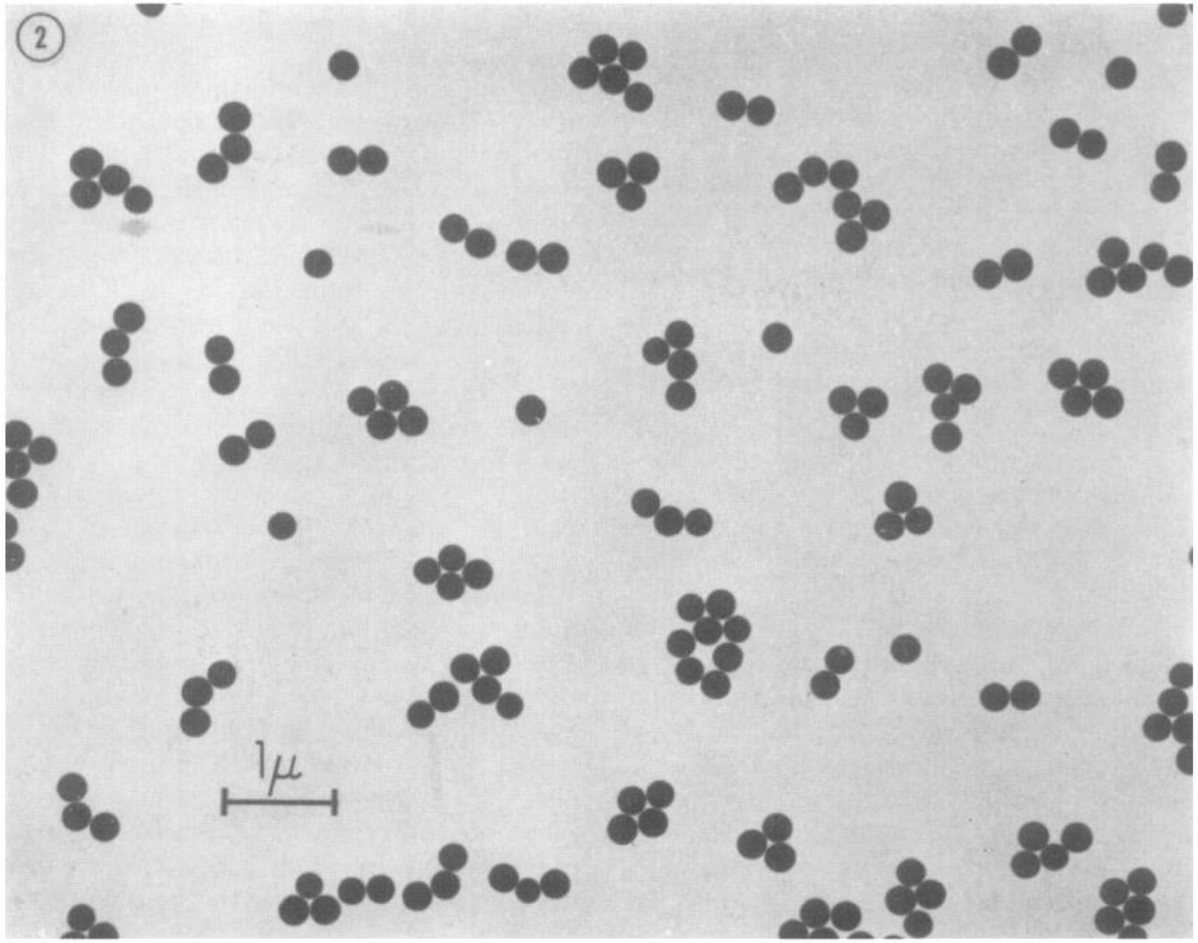
It is now useful to share a couple of meticulous articles [16, 17] focused on the synthesis of "amorphous silica." Both of these synthesis articles started with quite well-known, polymeric silicate solutions, namely, tetraalkyl silicates.

Fig. 9 of [16]



These are monodisperse submicron particles.

Fig. 2 of [17]



[16] M.D. Sacks and T-Y. Tseng, "Preparation of SiO2 glass from model powder compacts: I, Formation and characterization of powders, suspensions, and green compacts," *Journal of The American Ceramic Society*, 67, 526-532 (1984).

[17] W. Stoeber, A. Fink, and E. Bohn, "Controlled growth of monodisperse silica spheres in the micron size range," *Journal of Colloid and Interface Science*, 26, 62-69 (1968).

Tanaka *et al.* [11] synthesized AMC by mixing 25 mL of 0.2 M $MgCl_2$ and 25 mL of 0.2 M Na_2CO_3 solutions in a PTFE beaker at RT. After mixing, they stirred the white suspension at 15°C for a short period of time, followed by 0.2 m membrane filtering, drying overnight in a desiccator pumped down to 0.1 MPa. They reported that the precipitates were amorphous (*via* XRD).

Fig. 1 of [11], TEM image of AMC with SAED inset

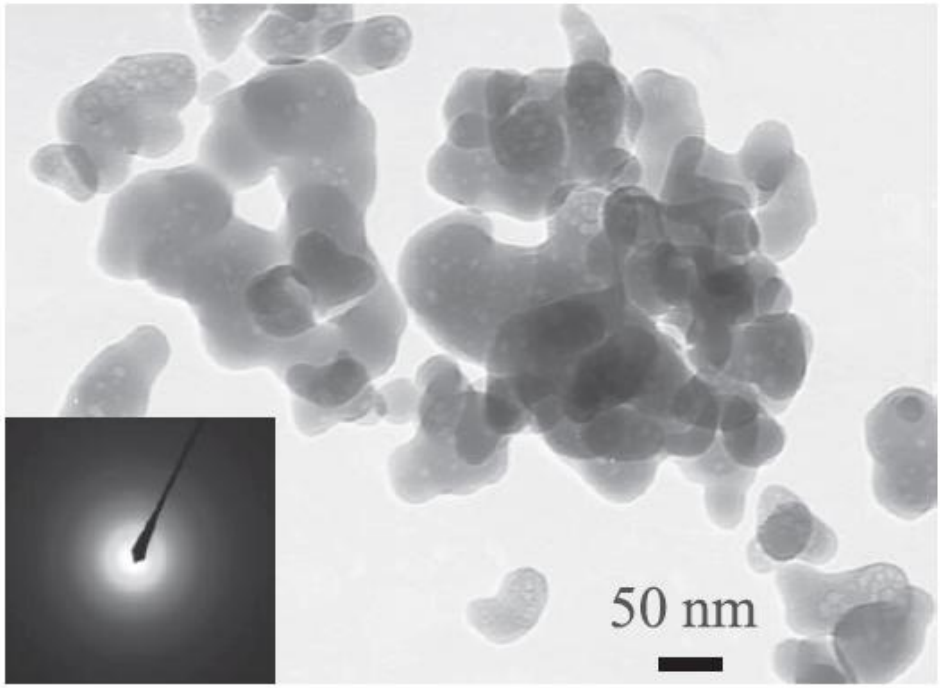
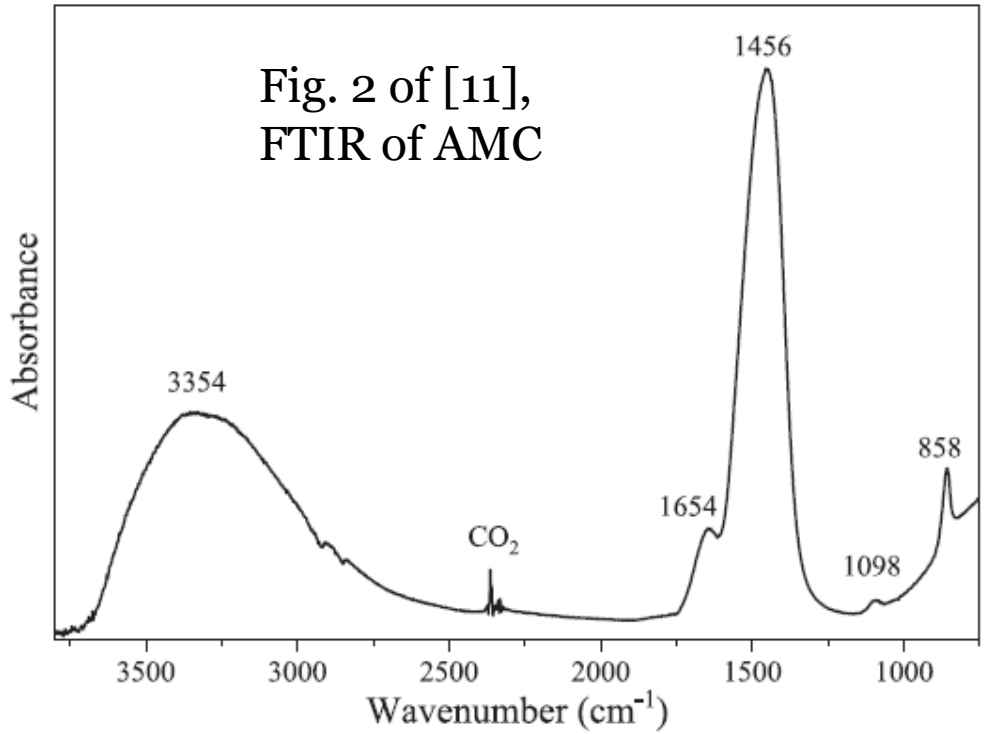


Fig. 2 of [11], FTIR of AMC



- The IR bands of significance observed in this Tanaka *et al.* [11] study at 858 and 1098 cm^{-1} do not match with those reported by de Vico *et al.* [15] as 835 and 1024 cm^{-1} (*p. 29*). De Vico *et al.* [15] were using K_2CO_3 in contrast to Na_2CO_3 of Tanaka *et al.* [11]. However, we do think that this mismatch could well be based on the difference between the time the AMC precipitates waited before the collection of their respective FTIR data in each study. AMC is a transient phase in its pure form, unless it is chemically stabilized.

[11] J. Tanaka, J. Kawano, T. Nagai, and H. Teng, "Transformation process of amorphous magnesium carbonate in aqueous solution," *Journal of Mineralogical and Petrological Sciences*, 114, 105–109 (2019).

Tanaka *et al.* [11] reported that they were monitoring the morphology of the precipitates by using an optical microscope, "as a function of increasing time after mixing," and they provided the below microscope and XRD data.

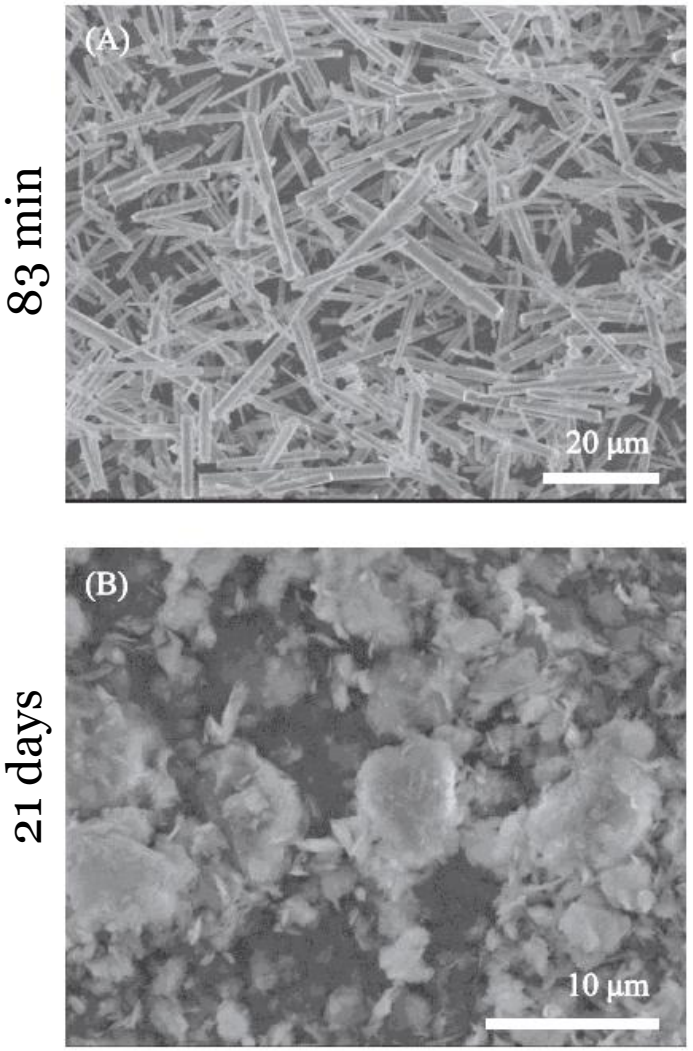


Figure 5. SEM image of precipitates (A) 5000 s and (B) 1800000 s after mixing.

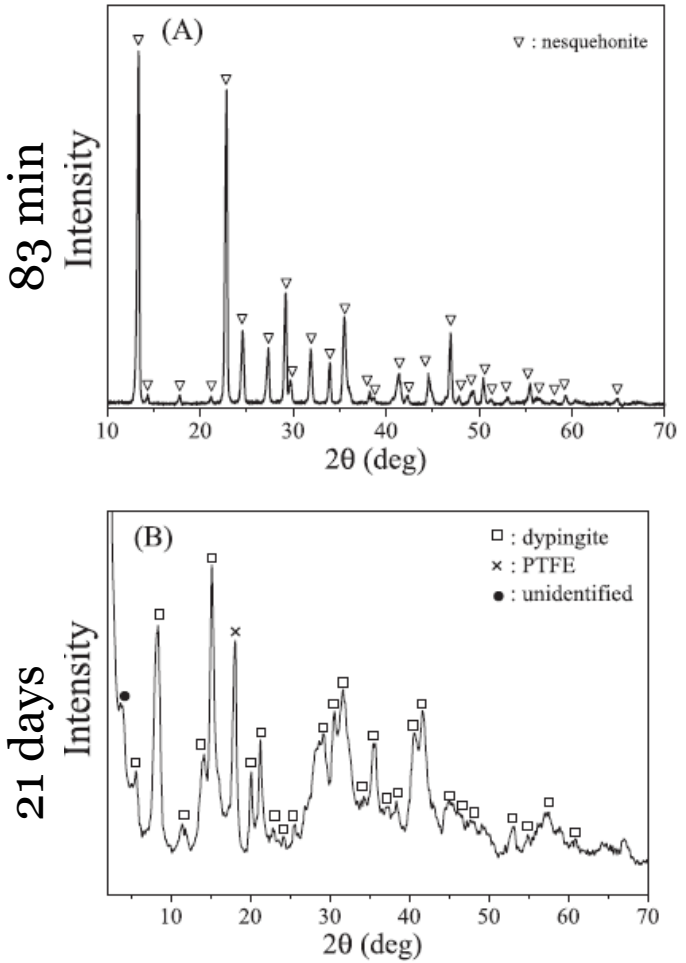


Figure 6. Powder XRD patterns of precipitates (A) 5000 s and (B) 1800000 s after mixing. (A) All peaks are agreement with the pattern of nesquehonite (Stephan and MacGillavry, 1972). (B) Almost all of peaks correspond to X-ray powder data reported by Raade (1970) in the range 2θ = 5.8–60.9°.

- Tanaka *et al.* [11] kept the AMC in its solution for extended periods prior to collecting the data shown here.

- This is a 4 pages-long brief article, excluding its extra page for references. When one has excellent data and results, there is no need to publish a 17 to 20 pages-long article filled with speculations, beliefs, and projections.

- Common points of the articles of our pamphlet: AMC is a transient phase, in minutes it will transform into nesquehonite ($MgCO_3 \cdot 3H_2O$), then over the course of days it will transform into dypingite ($Mg_5(CO_3)_4(OH)_2 \cdot 5H_2O$).

[11] J. Tanaka, J. Kawano, T. Nagai, and H. Teng, "Transformation process of amorphous magnesium carbonate in aqueous solution," *Journal of Mineralogical and Petrological Sciences*, 114, 105–109 (2019).

I was not able to include the crystal structure drawing of dypingite ($Mg_5(CO_3)_4(OH)_2 \cdot \mathbf{5}H_2O$) to p. 11 above since there is no CIF (crystallographic information file) available for it in open crystallography databases, such as https://www.rruff.net/.

The difference between the stoichiometry of hydromagnesite ($Mg_5(CO_3)_4(OH)_2 \cdot \mathbf{4}H_2O$) and dypingite is "one water molecule."

The below technical note [12] on dypingite, authored by Gunnar Raade, could be interesting to many.
http://www.nags.net/Mineralsymposium/2012/2012-Raade.pdf

Tanaka *et al.* [11] stated that the dypingite phase they formed and X-rayed during their study was in perfect agreement (in terms of the XRD peak positions and intensities) with that provided by Gunnar Raade back in 1970 [19].

[18] G. Raade, "Dypingite, my first mineral - forty-two years later," in *Kongsberg Mineralsymposium 2012. Norsk Bergverksmuseum Skrifter (=Norwegian Mining Museum)*, Publication No. 49, pp. 53-63 (2012).
[19] G. Raade, "Dypingite, a new hydrous basic carbonate of magnesium, from Norway," *American Mineralogist*, 55, 1457–1465 (1970).

Another interesting article from Yamamoto *et al.* [20]:

"*MgCl2 and Na2CO3 were used as starting materials. Solutions of 0.5 M MgCl2 and 0.5 M Na2CO3 were mixed at a 1:1 volume ratio at 60°C. The white suspension was stirred at about 1000 rpm at the same temperature for 2 h after mixing. The pH value in the solution was stabilized at about 11. The precipitate was filtered out and washed with distilled water. Finally, it was dried overnight in air. The precipitates were crystalline dypingite.*"

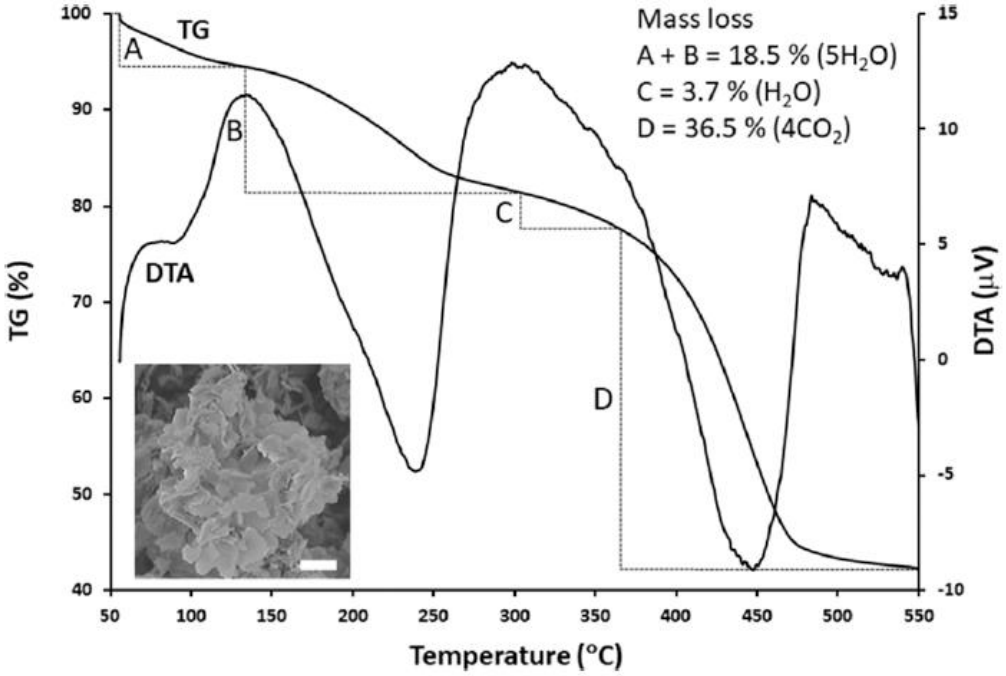


Fig. 1 of Ref. 20
TGA/DTA

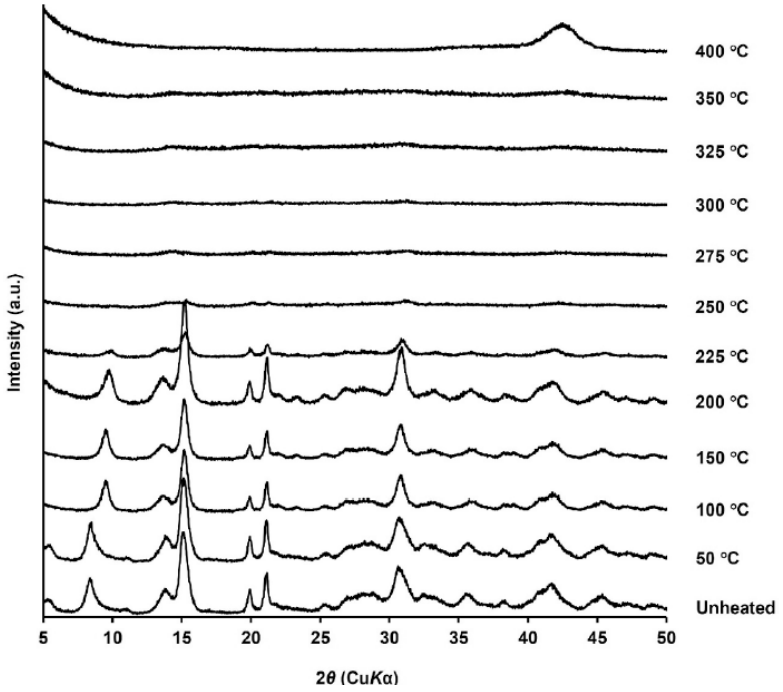


Fig. 2 of Ref. 20
XRD patterns of the precipitates as a function of increasing calcination (in air) temperature

What is in this XRD data?

Dypingite structure collapsed upon heating to around 275°C and the crystallization of MgO took place at 400°C.

This is way different a response to heat than that of any crystalline calcium carbonates and ACC.

It means that one can have a "carbonated magnesium moiety" at 300°C if this processing recipe of Ref. 20 is followed.

[20] Gi. Yamamoto, A. Kyono, and S. Okada, "Thermal decomposition process of dypingite $Mg_5(CO_3)_4(OH)_2 \cdot 5H_2O$," *Materials Letters*, 308, 131125 (2022).

The dissertation by Dr. JiaoJiao Yang (at Uppsala University, Sweden, 2018) is entitled "Amorphous magnesium carbonate nanomaterials: Synthesis, characterization and applications." A digital copy of it is available here [21].

Below is how J. Yang synthesized the AMC powders.

"*Pure MgO powder was dispersed in methanol at a 1:15 (g:mL) ratio in a glass bottle and placed under 4 bar CO2 pressure with stirring for 4 d at RT. The pressure was then released and 5 mL of product from the reaction was added dropwise to 250 mL ethyl acetate (liquid, formula: CH3COOC2H5) under stirring. The solids were recovered from this solution by centrifugation at 4696 g (for 10 min), followed by drying at either 25° or 50°C. After drying, all samples were calcined at 250°C with a temperature ramp rate of 1°C/min and a hold time of 30 min. After that, the obtained materials were ground using a mortar* [21]."

This is an expensive recipe for AMC synthesis (since it is using (1) methanol, (2) an autoclave and (3) liquid ethyl acetate) in comparison to other work we cited in this pamphlet. The autoclave is the least expensive item; the chemicals they suggest are expensive.

[21] JiaoJiao Yang, "Amorphous magnesium carbonate nanomaterials: Synthesis, characterization and applications," *Ph.D. dissertation*, Uppsala University, 2018.

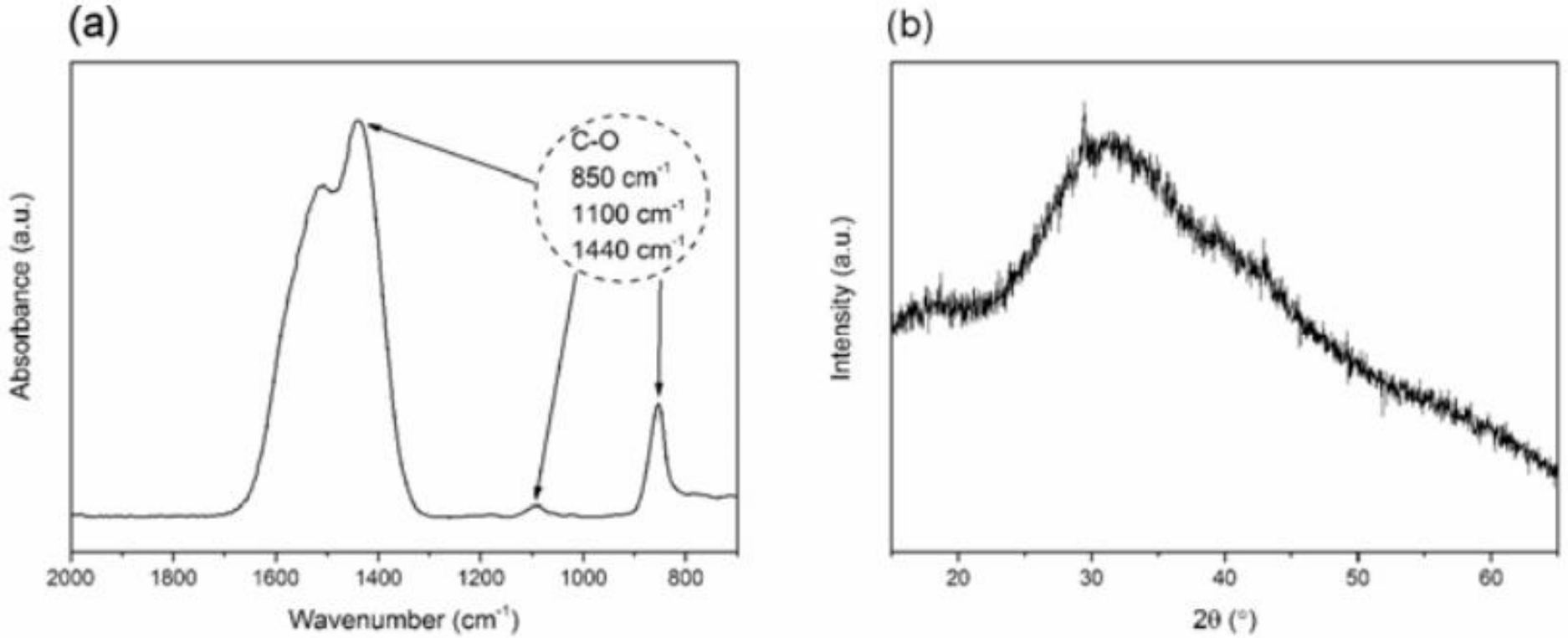


Figure 7. (a) IR spectra of the AMN. The CO_3^{2-} absorbance peaks are indicated at 850, 1100 and 1440 cm^{-1}. (b) XRD pattern of the AMN. The halo peak between 25° and 40° shows the existence of an amorphous phase. Unreacted MgO is evidenced by the small peaks at approximately 29° and 42°.

Fig. 7 of Ref. 21

[21] JiaoJiao Yang, "Amorphous magnesium carbonate nanomaterials: Synthesis, characterization and applications," *Ph.D. dissertation*, Uppsala University, 2018.

Extensively aggregated and 'fused to one another" submicron particles

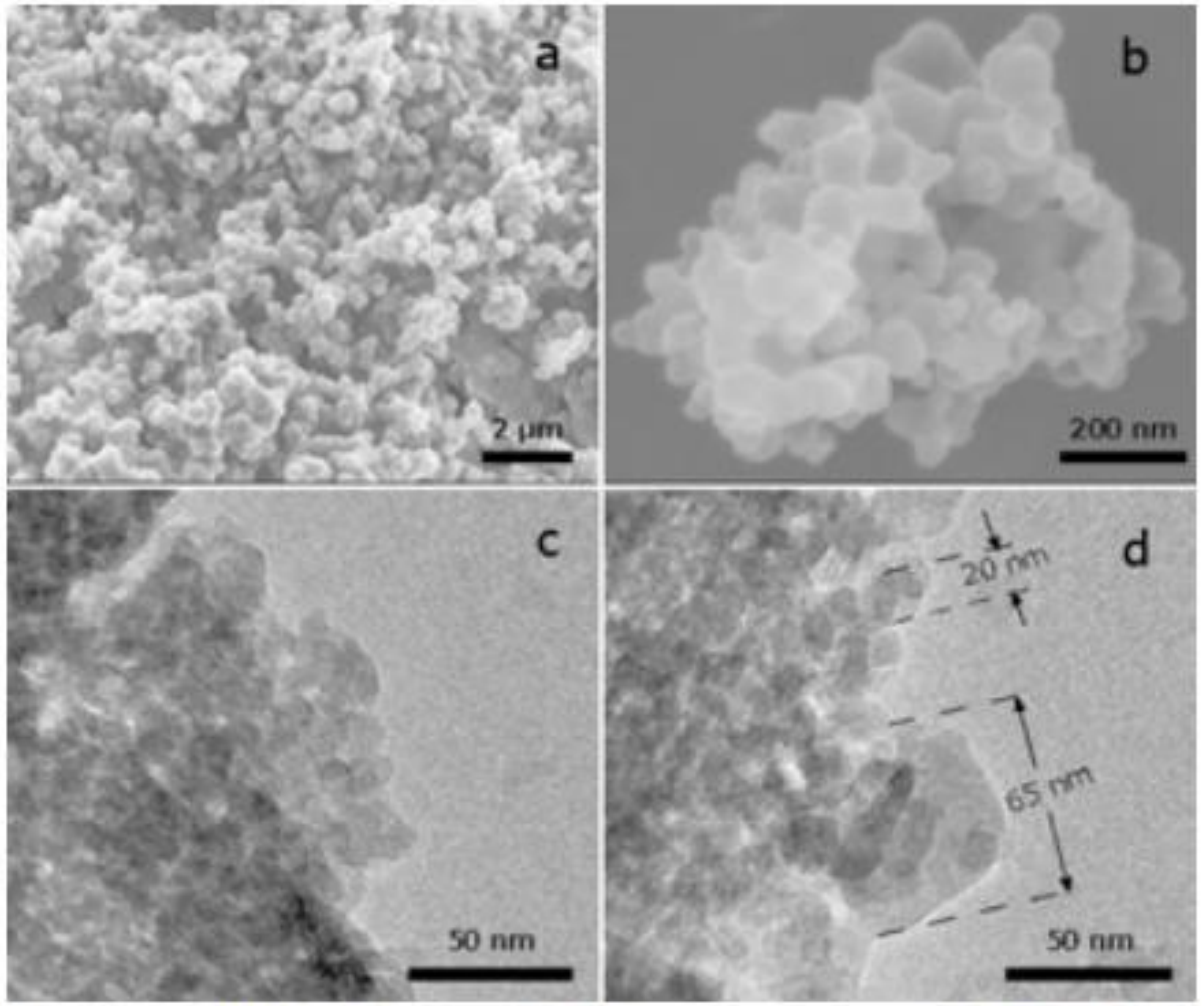


Figure 8. SEM (a and b) and TEM (c and d) images of AMN-25.

Fig. 8 of Ref. 21

Since there was no water in the reaction autoclave (and during washing with liquid ethyl acetate), the author was able to maintain the amorphous character for 4 days in the CO2-filled autoclave.

[21] JiaoJiao Yang, "Amorphous magnesium carbonate nanomaterials: Synthesis, characterization and applications," *Ph.D. dissertation*, Uppsala University, 2018.

When Nguyen *et al.* [22] performed the carbonation of brucite (Mg(OH)2) in stirred aqueous slurries having NaHCO3 (from 1 to 28 d), their product turned out to be a mixture of nesquehonite, dypingite, artinite and giorgiosite as shown in the XRD patterns below [22]. One cannot obtain a high solution pH when using NaHCO3.

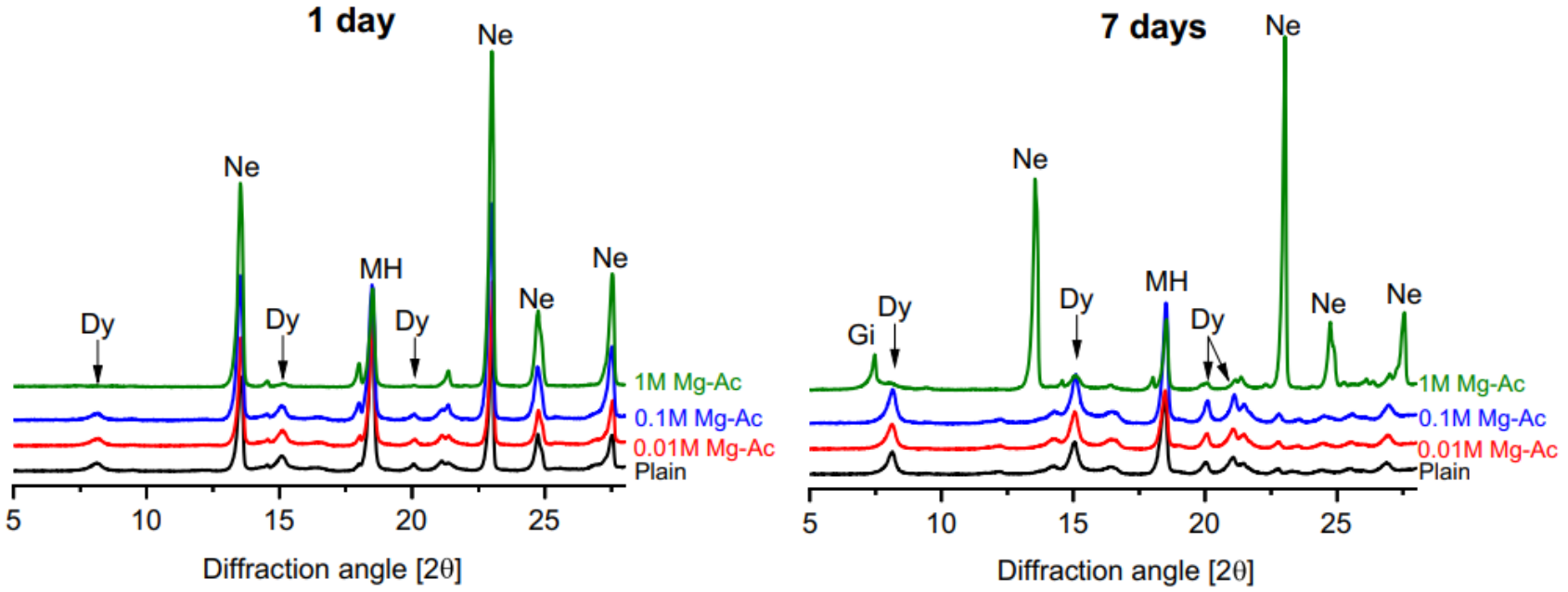


Fig. 1 of Ref. 22

- As any careful reader will catch even from the title of Ref. 22 below, Nguyen *et al.* [22] were using Mg-acetate solutions; however, we have been the first to use Mg-acetate solutions (which we developed and named it as "MagCet mineral additive" solutions) in 2016 as a carbonation accelerator in the CO2-curing of "Solidia cement®-based concrete" when we were working at Solidia Technologies, Inc. from 2015 to 2022 [23].

[22] H. Nguyen, H. Santos, H. Sreenivasan, W. Kunther, V. Carvelli, M. Illikainen, and P. Kinnunen, "On the carbonation of brucite: Effects of Mg-acetate on the precipitation of hydrated magnesium carbonates in aqueous environment," *Cement and Concrete Research*, 153, 106696 (2022).

[23] A. C. Tas, *et al.*, "Carbonatable calcium silicate-based cements and concretes having mineral additives, and methods thereof," *U.S. Patent No.* 11,352,297 B2 (filing date: March 23, 2017, patent grant date: June 7, 2022).

We shall note that $MgCO_3$ (magnesite) is a naturally-occurring mineral and it is historically used in the production of certain refractory bricks (known as magnesite bricks) as the MgO source.

There are vendors (*e.g.*, "Garrison Minerals," https://www.garrisonminerals.com/technical-information-other) which supply different grades (pharma, food, *etc.*) of $MgCO_3$ as an amorphous white powder.

To conclude, the refereed Journal articles we reviewed in this document all proved that

(1) AMC (amorphous magnesium carbonate) can be synthesized/formed easily in aqueous solutions, without using any crystallization inhibiting organics, having Mg^{2+} and CO_3^{2-} ions,
(2) if AMC solid precipitates are quickly removed from their mother liquors, they can be dried in air and can preserve their amorphous structures (without transforming into any other crystalline hydrated MG carbonates) and can even survive the XRD runs,
(3) if the AMC precipitates are left in their mother liquors for about 80-90 minutes they will crystallize first into nesquehonite then (at longer times in water) into dypingite,
(4) AMC has a solubility (in water) higher than that of ACC (amorphous calcium carbonate),
(5) dry AMC powders (in no contact with water) do not crystallize in hours or days.

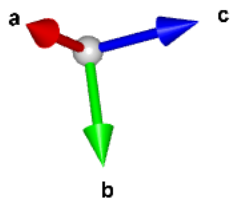
We did not add the natural mineral "pokrovskite" to the introductory pages of 4, 6 and 11 of this pamphlet, essentially since there is no open literature on its synthesis. Pokrovskite was named in honor of mineralogist Pavel Pokrovski. Below is the crystal structure drawing prepared by using its CIF file and Vesta.

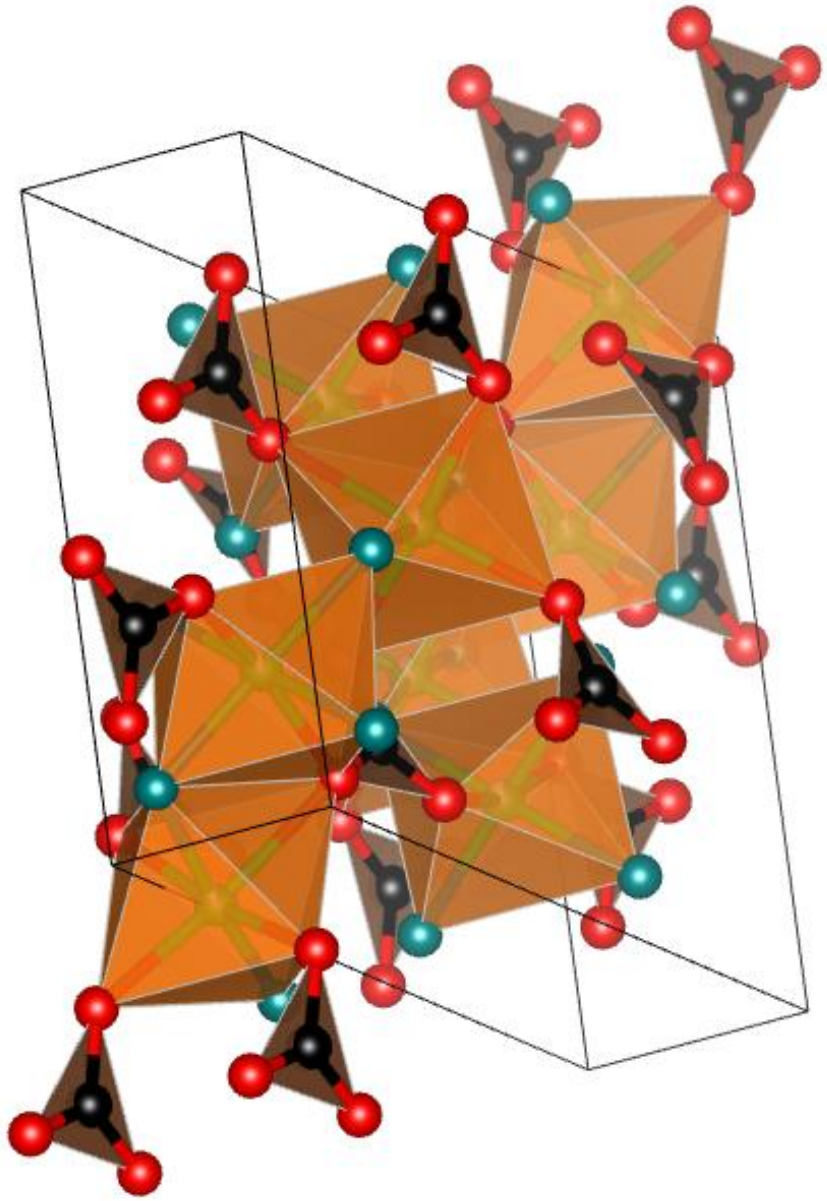
Mg: green (*in brown octahedra*)

H: blue

O: red

C: black





Pokrovskite, **$Mg_2(CO_3)(OH)_2$** / monoclinic
(can also be regarded as dehydrated artinite)
Amcsd database code: amcsd 0007185

P 1 21/a1 (14) 30.856 wt% CO_2
a=12.2396 Å
b=9.3506 Å
c=3.1578 Å
V=**359.119** $Å^3$
Density: **2.530** g/cm^3

	x, y, z (coordinates)
Mg1	0.2122, 0.0045, 0.983
Mg2	0.3989, 0.771, 0.574
C	0.1503, -0.2637, 0.5365
O1	0.1499, -0.1279, 0.4448
O2	0.2400, -0.3377, 0.5307
O3	0.0612, -0.3249, 0.6339
O-H4	0.3656, 0.9162, 0.0620
O-H5	0.4294, 0.6266, 0.1030

APPENDIX-1

APPENDIX-2

(*my own unpublished work*)

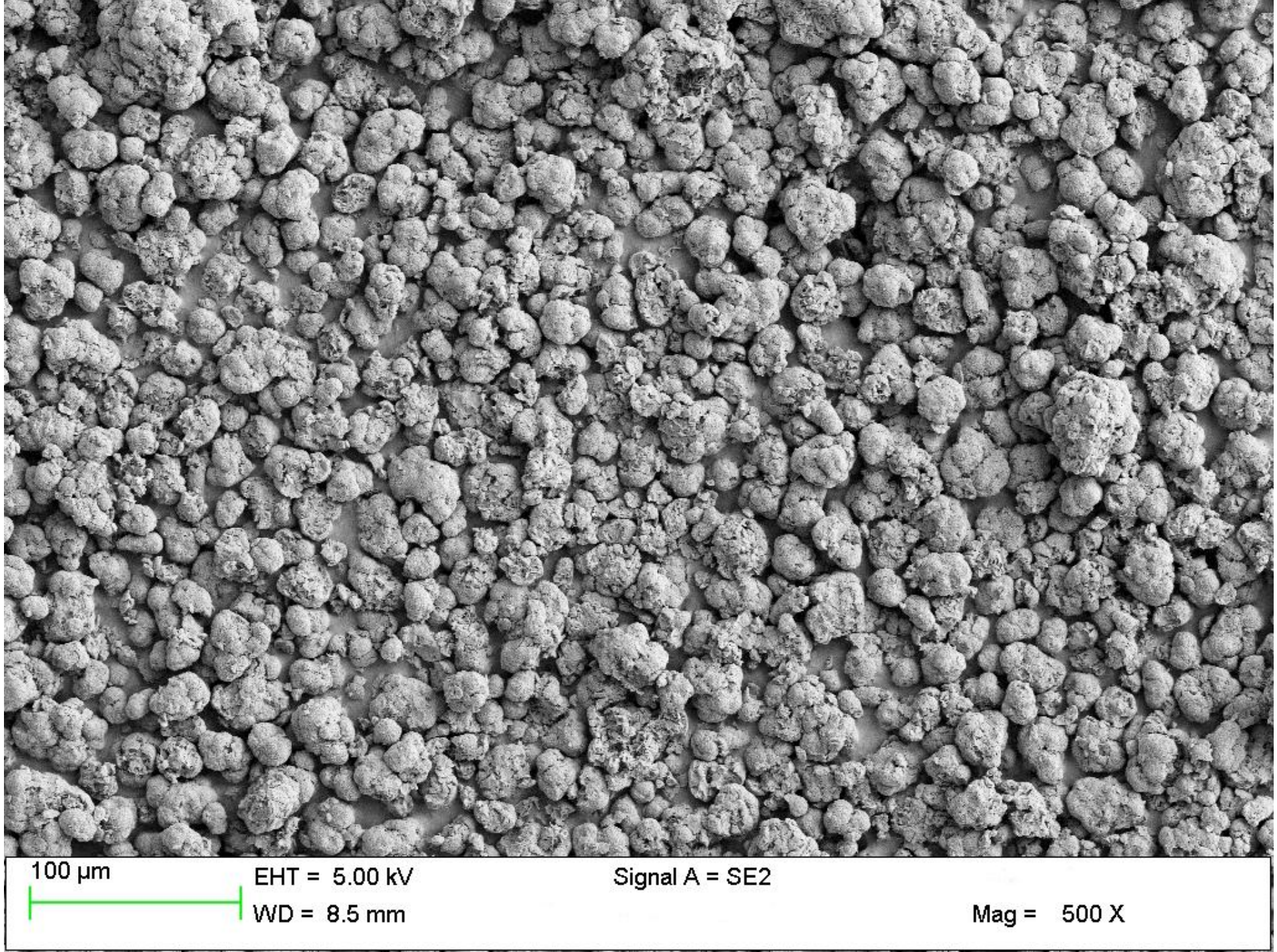
Simple hydromagnesite synthesis recipe starting with a MgO slurry

a clean polypropylene pitcher
+ fine, industrial-grade MgO powder
+ distilled water
+ stir at RT (in air) for a few minutes with a stirring rod to form a viscous slurry
+ place the slurry pitcher into a CO_2 chamber (with stirring capability)
+ close and seal the chamber, fill it with CO_2 ($2>P>1$ atm)
+ heat the chamber to 35°C and start stirring the slurry in the pitcher
+ stir the slurry in the CO_2-filled (initially) chamber for 17-18 h
+ pour the cream-like product into a Buechner funnel with a coffee filter in it
+ wash the product with a small amount of water
+ dry it at 45°C for 2 days to obtain a very smooth, free-flowing powder
+ collect XRD data and SEM images
+ XRD results: single phase hydromagnesite ($Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$), without any unreacted MgO or $Mg(OH)_2$

before washing with water

after washing with water

Here come three SEM photomicrographs of the produced hydromagnesite
(*at different magnifications*)

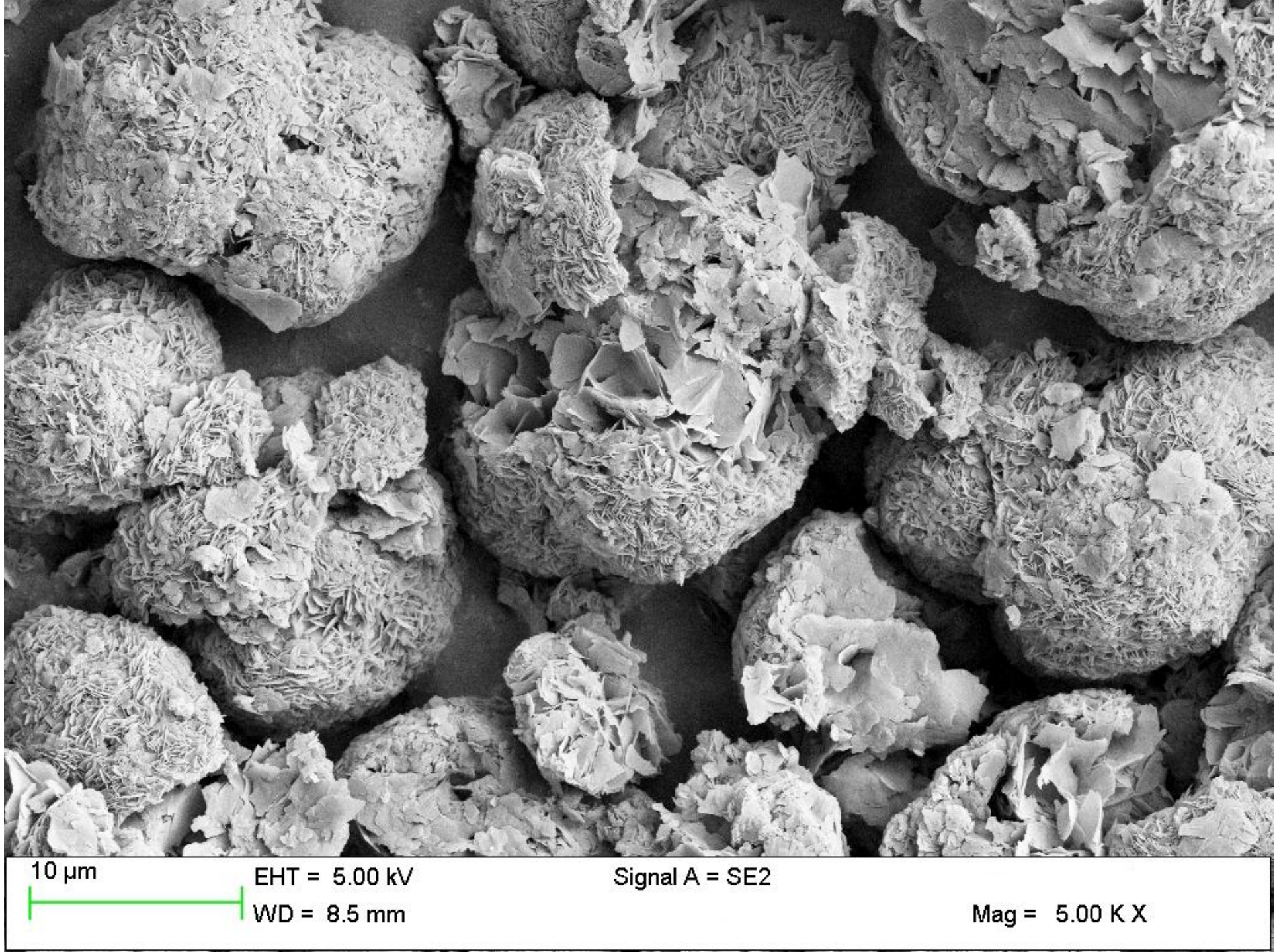


in situ
micro-granulation,

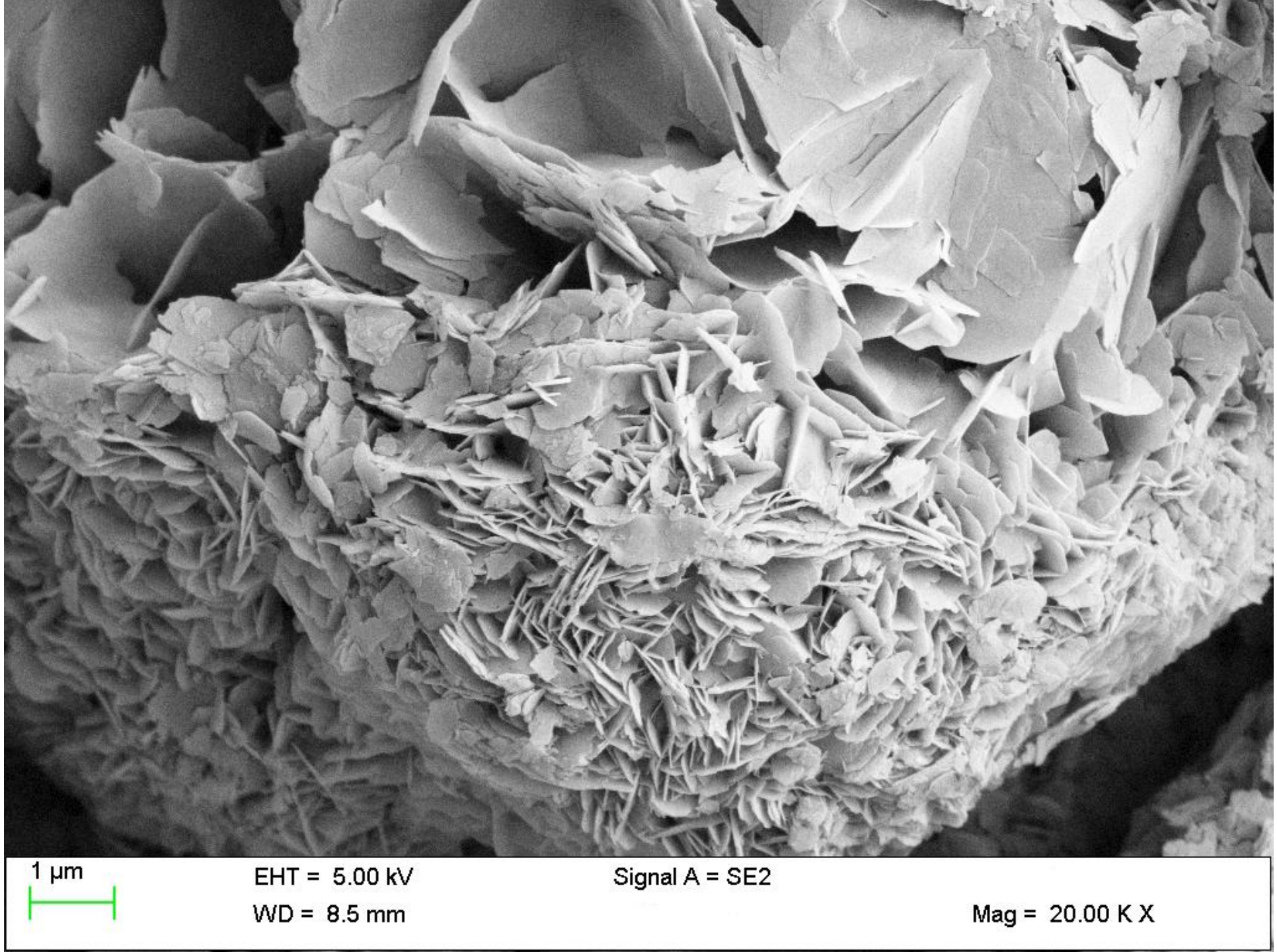
granule size depends on the stirring rate,

these globular granules impart the powder its impressive flow character,

the starting MgO's particle size was incomparably smaller than that of the granules seen here.



A. C. Tas



hydromagnesite granules consist of interlocking, intermingling, nano-thick flakes of hydromagnesite

APPENDIX-3

- An excerpt from the Abstract of this article [24]:

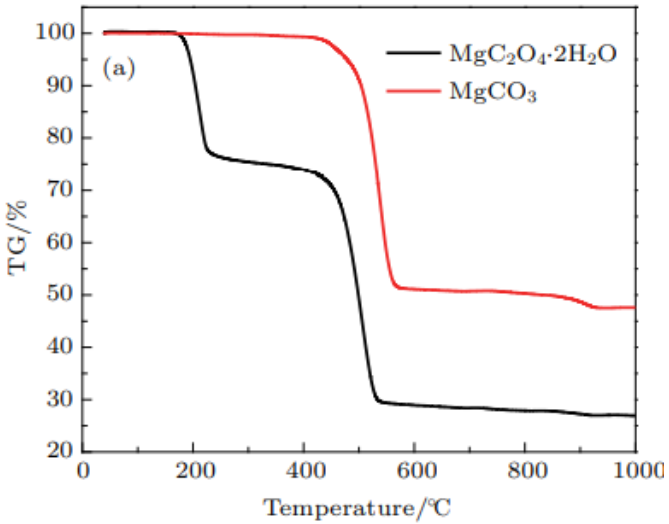
"*By using magnesium oxalate dihydrate (MgC2O4·2H2O) as starting material, MgCO3 sample is successfully synthesized by a solid reaction under high temperature and high pressure for the first time in this work. The properties of as-synthesized sample are investigated by X-ray powder diffraction and Raman spectroscopy. Neither of them shows any impurities existing in the sample. Significantly, the crystallinity quality is greatly improved in the terms of the maximum grain sizes up to 200 micrometers, which could provide a base for MgCO3 single crystal growth in the future.*"

- The pressures used in this study are extremely high, this process in its current form is not suitable to produce anhydrous MgCO3 at the ton scale.

Table 1. Results of assessment phase by high pressure synthesis from $MgC_2O_4 \cdot 2H_2O$ under various conditions.

合成条件	产物 (XRD 结果)
0.5 GPa, 200 °C, 1 h	$MgC_2O_4 \cdot 2\ H_2O$
0.5 GPa, 300 °C, 1 h	$MgCO_3$
0.5 GPa, 700 °C, 1 h	$MgCO_3$
0.5 GPa, 800 °C, 1 h	MgO
1.0 GPa, 200 °C, 1 h	$MgC_2O_4 \cdot 2\ H_2O$
1.0 GPa, 300 °C, 1 h	$MgCO_3$
1.0 GPa, 400 °C, 1 h	$MgCO_3$
1.0 GPa, 500 °C, 1 h	$MgCO_3$
1.0 GPa, 700 °C, 1 h	$MgCO_3$
1.0 GPa, 800 °C, 1 h	$MgCO_3$
1.5 GPa, 200 °C, 1 h	$MgC_2O_4 \cdot 2\ H_2O$
1.5 GPa, 300 °C, 1 h	$MgCO_3$
1.5 GPa, 800 °C, 1 h	$MgCO_3$

data from Ref. 24



[24] L. Wen, L.-Z. Ming, W. Lu-Ying, C. Lin, L. He-Ping, "High pressure synthesis of **anhydrous magnesium carbonate (MgCO3)** from magnesium oxalate dihydrate (MgC2O4·2H2O) and its characterization," *Acta Physica Sinica*, 66, 036202 (2017).