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New Insights on the Origin of Life: The Role of Silico-Carbonates of Ba (II) to Preserve DNA against Highly Intense UV Radiation

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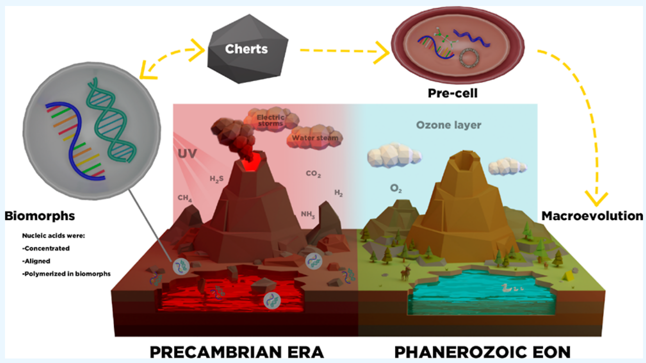
ABSTRACT: Understanding the origin of life on our planet has generated diverse theories. Currently, the theory is that life has a single origin; however, its starting point has not been defined. As evidenced, it is indispensable to unify the different theories to reach a single theory that would also allow linking the different areas of knowledge to finally understand the mechanism by which life originated on Earth. In this regard, aiming at contributing to the unification of the diverse theories on the origin of life, in this work, the hypothesis based on the condition that silica-carbonates of alkaline earth metals, called biomorphs, are the ones that could unify all the proposed theories on the origin of life is proposed. Aimed at evaluating if this hypothesis is viable, this work assessed whether biomorphs are able to protect the DNA from continuous UV radiation under two conditions that emulate the habitats that could have co-existed in the Precambrian and, after the radiation, evaluated the time during which DNA remained inside the biomorphs. Our results showed that biomorphs can protect the DNA for months after continuous UV exposure. It was also determined that biomorphs protect the DNA from external factors in different habitats, like normal atmospheric conditions and in aqueous environments. The obtained data allowed me to infer that biomorphs may be the gap that unifies the diverse proposed theories on the origin of life in our Planet.



1. INTRODUCTION

The origin of life is one of the most impassioned and intriguing subjects that humanity has attempted to solve from the different areas of knowledge like chemistry, biology, physics, geochemistry, entropy, and information theory.[1−8] Notwithstanding, it has been concluded that an interdisciplinary approach is indispensable to understand the start of life.[2] Currently, the theory is that life has a single origin, which became consolidated in the XIX and XX centuries because there were only hypotheses without any scientific background before that. Among the first hypotheses was that of spontaneous generation posed by Aristoteles; the influence of this philosopher was so significant that his hypothesis prevailed from the IV century B.C. until the XIX century.[9,10] The spontaneous generation theory for macroscopic organisms was refuted by Francesco Redi;[11] however, not everyone was convinced, and those in favor of this hypothesis indicated that the experiment did not apply to microorganisms and continued to maintain that microscopic organisms spontaneously originated. It was until 1886 that Louis Pasteur refuted the spontaneous generation of microorganisms, a fact that definitively rejected this hypothesis. Another hypothesis is that of panspermia, which considers that life in our planet was distributed by asteroids, comets, meteorites, among others.[12,13] Nowadays, a plausible theory is that of abiogenesis, which explains that life originated through a series of chemical reactions through which inorganic material gave origin to organic material, then to the earlier cells, and finally to the last universal common ancestor (LUCA).[14] This theory has been demonstrated by several scientists, like Oparin and Haldane, whose hypotheses indicated that the origin of life was possible through the primordial soup, considering that the environmental factors of the primigenial era together with the simple molecules provided the adequate conditions to form the first organic blocks to give rise to primigenial cells.[13,15,16] Miller and Urey, in 1953, provided experimental evidence that confirmed the Oparin theory[17−19] by emulating in the laboratory the conditions found in the primigenial Earth. From simple molecules like that of hydrogen gas, water steam, methane, and ammonia, in the presence of UV, a source of energy and heat, they were able to obtain amino acids and other organic molecules.[17,20] Other theories have been raised based on the sulfide-iron world.[16] However, in these hypotheses, the origin of the genetic information is not considered. The most recent hypothesis based on nucleic acids is a good approx-

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imation to understand the origin of life, though it is unable to solve the dogma of the origin of life.[2,21−23] As evidenced, until now, there is no common theory on the origin of life that will link all the proposed theories and allow understanding the mechanism by which the earlier cells, followed by LUCA, and, finally, the different forms of life as known currently arose from simple chemical cells. Although there are gaps among the different hypotheses, a common idea is that minerals played an important role in the synthesis of simple chemical molecules as well as in the polymerization, replication, protection, and conservation of the simple organic compounds until becoming part of the primitive organism.[16] From this organism, the cell membrane would be formed, favoring more complex organisms.[24−26] A decade ago, a theory was proposed to contribute to the origin of life, which is based on that all physical morphologies, starting with the inanimate to the animated kingdom, and from micro, meso, and macrocosmic scales, are based on the sole geometric entity, the gyre.[2] The structure of the organisms is based on the gyro model that corresponds basically to circular patterns, such as a spiral, a vortex, or a verticil.[2] In this way, it could be explained why inorganic structures present morphologies emulating organisms. Notwithstanding, this theory also poses some questions that have not been solved yet, just like the other theories. These hypotheses need to be unified to reach a theory that besides linking the different areas of knowledge, will finally allow us to understand the mechanism by which life originated on Earth. In this sense, aimed at contributing to the unifying of the diverse theories on the origin of life, our research team has proposed that the calcium, strontium, or barium silica-carbonates, named biomorphs, contribute to the possible unification of all the proposed theories on the origin of life.[27] In this way, biomorphs are considered as one of the gaps that can contribute to the unification of the theories proposed many decades ago. Although we have demonstrated that biomorphs internalize DNA, just like cells, it is necessary to perform more experimental studies to respond to the posed questions and contribute to this field of study. Some of these questions are: (i) Is the DNA, internalized in the biomorphs, able to tolerate continuous UV radiations? (ii) Does the DNA remain viable after having been irradiated by UV? (iii) Are the biomorphs able to protect the DNA that is internalized in them in different media, for example, in the air or in solution? (iv) Are biomorphs the cherts of the Precambrian? To respond to these and other questions, the objective of this work is to evaluate whether biomorphs are able to protect the internalized DNA from the continuous UV radiation in the air and in solution, as well as after the radiation, and to assess the time that the DNA remains inside the biomorphs. The latter will allow us to elucidate whether the biomorphs could indeed be one of the first inorganic structures (cherts of the Precambrian) that allowed the first biomolecules to remain isolated from the environment in the Precambrian, favoring the origin of life as manifested in the formation of the protocell. The morphology of the synthesized biomorphs was evaluated through scanning electron microscopy (SEM). The obtained microphotographs revealed that the biomorph's morphology is not affected by UV radiation. The chemical composition, the crystalline structure, and the presence of the molecular kerogen biomarkers were determined through Raman. Analyses of biomorphs through confocal microscopy revealed that biomorphs did indeed protect the DNA from UV radiation for at least eight months. This is a significant result, as it will lead us to think that biomorphs can indeed be the Apex microfossils that have been conserved in biomolecules from the very beginning of life up to the present. Our results support the idea that biomorphs are possibly one of the mineral inorganic structures that participated in the origin of life by isolating and protecting the first molecules and biomolecules of the different environments or habitats found in the primigenial era. This is supported also because biomorphs are mineral crystalline structures that present diverse biological morphologies;[27−36] biomorphs present similitude with some Apex fossils;[37] biomorphs are proposed as one of the inorganic structures in which biomolecules formed in the Precambrian were concentrated, aligned, polymerized, and protected from the prevailing conditions in the primitive era;[27] and it has been inferred that biomorphs are possibly the cherts of the Precambrian that were kept invisible until their discovery.[27] These characteristics fulfilled by biomorphs led me to propose them as one of the first inorganic structures where biomolecules were isolated from the environment in the Precambrian and as the gap between the Precambrian and our current era.

2. EXPERIMENTAL SECTION

2.1. Organisms Used for DNA Extraction. The organisms used to extract the DNA were *Equisetum arvense* and *Candida albicans*.

2.1.1. C. albicans. The genomic DNA from *C. albicans* was obtained following the protocol previously reported by our research team.[27] Briefly, the yeast cells, suspended in 600 μL of urea buffer (7 M urea, 0.35 M NaCl, 50 mM Tris-HCl, pH 8.0, 20 mM EDTA, 1% *N*-lauroylsarcosine), were lysed with liquid nitrogen. Then, they were supplemented with 600 μL of a phenol/chloroform/isoamyl alcohol solution (25:24:1) and centrifuged at 12,000 *g* for 10 min. The aqueous phase was recovered and placed in a new Eppendorf tube. This step was repeated until the organic phase was no longer visible. DNA was precipitated by adding an equal volume of isopropanol to the supernatant recovered from the previous step, mixed by tube inversion, and the resulting mixture was centrifuged at 14,000 *g* for 10 min. The obtained pellet was resuspended in 500 μL of cold 70% ethanol, vortexed, and centrifuged at 12,000 *g* for 10 min. The supernatant was discarded and the pellet was left to dry at room temperature. The pellet was resuspended in sterile nucleases-free water, adding 1 μL of RNAse (20 mg/mL) to each tube, and incubating at 37 °C for 20 min. The obtained genomic DNA was used to form the biomorphs.

2.1.2. E. arvense. The DNA of *E. arvense* was extracted following the methodology previously described by Cuéllar-Cruz et al., 2022.[27] Briefly, 50 mg of vegetal tissue was weighted and crushed in a mortar with liquid nitrogen until achieving a fine powder. The powdered tissue was suspended in 350 μL of lysis-DRP buffer (kit all-in-one from Bio Basic Inc., Markham, ON, Canada), and the mixture was incubated in a double boiler for 10 min at 70 °C and centrifuged at 12,000 *g* for 3 min at 4 °C. The supernatant, containing the DNA, was transferred to a purification column and centrifuged at 9000 *g* for 1 min at room temperature. The DNA of the membrane was purified and recovered through a series of solutions provided in the used kit. Finally, the DNA was suspended in 50 μL of endonuclease-free water and stored at −20 °C until its use for the synthesis of biomorphs.

2.2. Electrophoretic Analysis. Visualization of both DNAs was performed through denaturalized 0.8% agarose gel electrophoresis.[38] The gel was 0.1% ethidium bromide stained, and the

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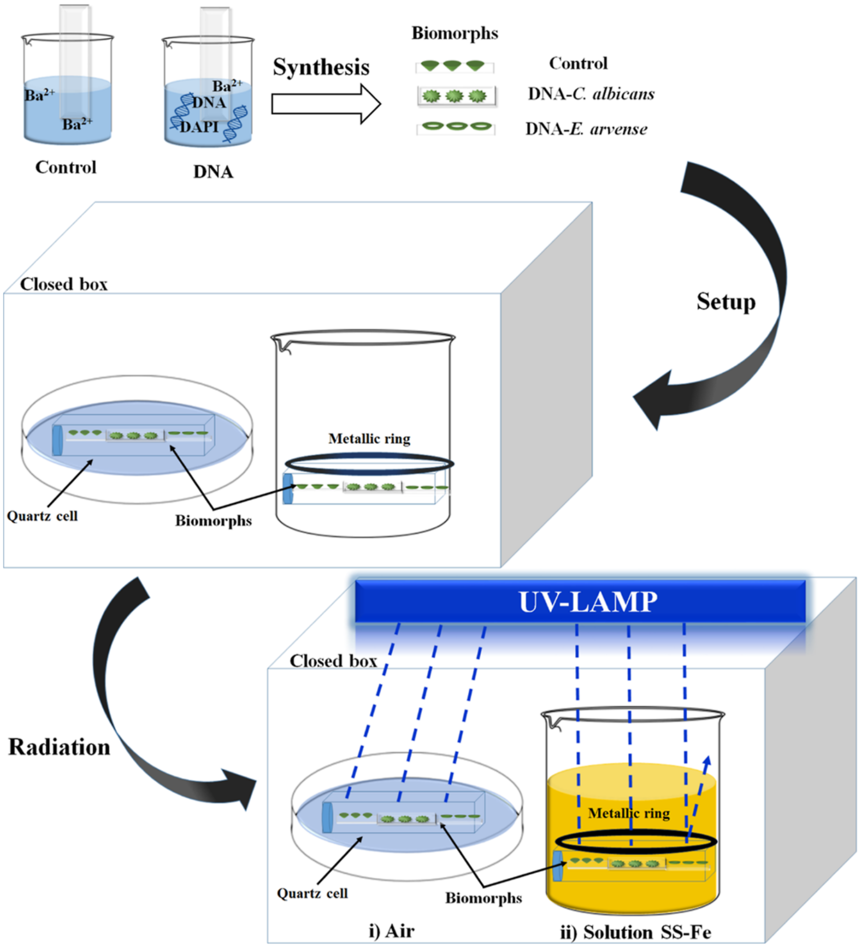

Figure 1. Biomorphs synthesized with or without DNA from *C. albicans* or *E. arvense* and then irradiated with UV light (254 nm) in two different media: air and solution, as described above.

bands were observed in an UV light transilluminator (Gel Doc XR System, Bio-Rad, Hercules, CA, USA).

2.3. Spectrophotometric Analysis. The quality and concentration of DNA samples were assessed with a spectrophotometer (Nanodrop, 2000 Technologies, Inc., Wilmington, DE, USA). The absorbance of each sample was measured at 230, 260, and 280 nm to estimate their quality ratios, A260 nm/A280 nm and A260 nm/A230 nm. For the analysis of the DNA contained in the bimorphs, we took, for each of the samples, the total amount of synthesized biomorphs that was suspended in 10 μL of 100 mM NaOH, in turn taking 2 μL of this solution to be analyzed through spectrophotometry.

2.4. Formation of Biomorphs. The formation of barium biomorph compounds was attained through the gas diffusion method.[39] Experiments were performed in glass plates of 5 mm in length, 5 mm in width, and 1 mm in thickness. The glass plate was placed inside a crystallization cell with a final volume of 200 μL. The biomorph was prepared by mixing 1000 ppm sodium metasilicate, 20 mM barium chloride, and with or without 50 ng of genomic DNA. In the mixtures of biomorph synthesis with DNA, the fluorescent 2-(4-amininophenyl)-1*H*-indole-6-carboxamidine (DAPI) marker was added. Finally, the pH of the mixture was adjusted to 11.0 with sodium hydroxide. All reagents were from Sigma-Aldrich (St. Louis, MO, USA). Once the synthesis of biomorphs with or without DNA had been achieved, the control biomorphs (without DNA) and those containing DNA were placed inside a quartz cell and irradiated with high-frequency UV light (254 nm) in two different conditions: (i) direct UV radiation of the biomorph synthesized cells (UV radiation waves traveled through the air to irradiate the biomorphs); and (ii) the second group of biomorphs was treated as follows: The glass plates containing the biomorphs with/without DNA were located inside the quartz cell. Then, once placed on the bottom of the 5 L beaker, it was filled with air or silica solution (4000 ppm) and Fe (3+) solution at 0.55 mM in concentration (this solution will be named SS-Fe; strictly speaking, it should be SS-Fe^{3+}). Finally, the quartz cell was supported by a metallic ring to avoid floating of the quartz cell. The UV exposure was performed by illuminating the experimental chamber for 7 days (Figure 1). Experiments were performed in triplicate.

2.5. Labeling of Biomorphs with 2-(4-Amininophenyl)-1*H*-indole-6-carboxamidine (DAPI). DNA was labeled with the fluorescent DAPI or bisbenzimidazole marker as a previous step of its incorporation into biomorphs, which were visualized through confocal microscopy. DNA staining and its incorporation into biomorphs was according to Cuéllar-Cruz et al., 2022.[27] It was decided to label the DNA with the fluorescent marker DAPI because this marker binds selectively to the minor groove of the double-stranded DNA. This implies that DAPI only binds to the minor groove of the DNA when its structure has been formed and is intact. In contrast, if the DNA has been degraded, DAPI does not bind because the double-stranded structure would not exist.

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2.6. Characterization of Biomorphs. Biomorphs were observed through scanning electron microscopy (SEM) and analyzed through Raman spectroscopy and confocal microscopy.

2.6.1. Scanning Electron Microscopy (SEM). Biomorphs were observed by means of SEM microphotographs in a TESCAN microscope (Brno, Czech Republic) model VEGA3 SB, with a secondary electron detector (SED) from 10 to 20 kV in high vacuum conditions (work distance of 10 mm).[27]

2.6.2. Confocal Microscopy. Confocal microscopy was carried out using a Zeiss LSM700 scanning laser confocal microscope and image software (Zen 2011, Carl Zeiss MicroImaging GHBH, Jena, Germany). Confocal images were acquired using an EC PlnN 10×/0.3 DICI and N Achro Pln 63×/0.85 objective lens and a 405 nm laser. Vertical optical sectioning at every position with a slice thickness of 1 μm was used to generate *Z*-direction series.

2.6.3. Raman Spectroscopy. Raman spectrum measurements were recorded with a WITec alpha300 R (WITec GmbH, Ulm, Germany), using a Nd:YVO4 green laser with a wavelength of 532 nm and 672 lines/mm grating, as previously described.[27]

3. RESULTS AND DISCUSSION

3.1. Biomorphs Protect DNA from UV Radiation. Biomorphs were synthesized without DNA (control) or with DNA from *E. arvense* or *C. albicans*. We chose to work with these two organisms because *E. arvense* presents two main characteristics: (i) it is a primitive plant that has inhabited the Earth for millions of years, and (ii) it possesses a high percentage of silicon, which is relevant as a high concentration of silicon existed also in the Precambrian.[40] Regarding *C. albicans*, this is a eukaryote microorganism found in diverse habitats, from water and soil to the human host.[41] Once biomorphs were synthesized in the different conditions, they were exposed for 7 consecutive days to UV light in two different media: air and the other was the SS-Fe$^{(3+)}$ (called thereafter SS-Fe only) solution, to emulate the two conditions co-existing in the Precambrian[42−45] and to evaluate whether one of the two media was most probable for the preservation of biomolecules. In this way, it would be possible to support our proposed hypothesis regarding that the biomorphs might have been one of the first inorganic structures in which protomolecules became isolated and protected from the adverse conditions prevailing in that era. Once synthesized, the biomorphs were observed through SEM. Figure 2 shows that control biomorphs irradiated with UV light in both conditions (air and SS-Fe) presented a morphology of leaves and flowers (Figure 2A). The biomorphs with DNA from *C. albicans* exposed to UV showed a morphology emulating a flower in both conditions (Figure 2B). The biomorphs synthesized with the DNA from *E. arvense* presented hollow structures with flower and leaf morphology (Figure 2C). The morphologies of biomorphs in all assessed conditions correspond to the characteristic morphologies previously reported.[27−36] These are interesting results as they reveal that the morphology of the biomorphs was not modified by the UV light; thus, this could be considered as the first evidence that, at least in terms of morphology, biomorphs are not modified by the intense radiation to which they were exposed for 7 consecutive days. The origin of life is tied to solar light, and, in the Precambrian, without an ozone layer, the UV rays passed directly to the terrestrial atmosphere. Currently, it is known that UV light generates free radicals, damaging biomolecules and leading to their rupture. In contrast to what is known in this sense, it has been postulated that the UV radiation in the primitive era must have favored the synthesis of the first organic molecules through photolysis[46] because, under laboratory conditions, when emulating the primigenial conditions with UV radiation, amino acids and organic chemical compounds are obtained.[17,19]

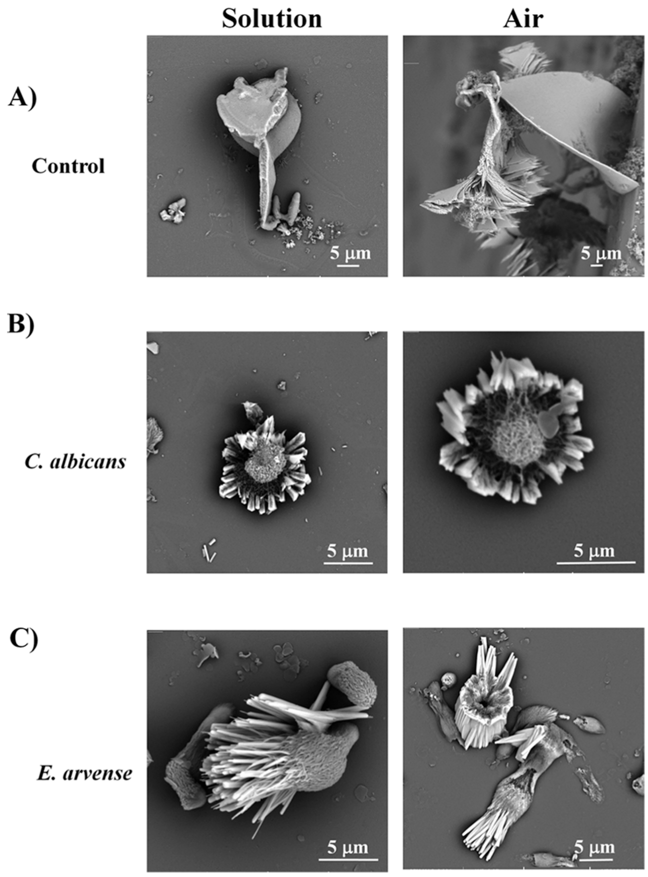

Figure 2. Microphotographs of barium biomorphs exposed for 7 days to UV radiation in conditions of air and SS-Fe solution. (A) Control (without DNA); (B) DNA of *E. arvense*; (C) DNA of *C. albicans*.

However, we still have not been able to describe a mechanism by which the first biomolecules, once synthesized, protected themselves from the intense ionizations so they could isolate, concentrate, align, polymerize themselves, and then give origin to the protocell. Although it is true that photolysis by UV radiation was necessary for the formation of the first organic molecules, there must have been another mechanism that isolated them, once synthesized, from the environment for their preservation. Therefore, I propose that biomorphs could have been one of these first inorganic crystalline structures that favored the isolation of the DNA from the ionizing environment existing in the Precambrian. The fact that biomorphs did not modify their morphology due to UV rays' exposure (Figure 2) is the first evidence that supports our proposed hypothesis.

Once the microphotographs of the biomorphs had been obtained through SEM, we determined the chemical composition and the crystalline structure of the barium biomorphs through Raman spectroscopy. This method was chosen because it is a high-resolution method that provides, within seconds, both chemical and structural information of any compound, allowing the identification of the presented polymorphs.[45,47] In the Raman spectrum corresponding to the control sample exposed to UV in the SS-Fe, peaks at 139, 152, 225, and 1058

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cm^{-1} were identified (Table 1). For the control in air, peaks at 138, 154, 224, and 1059 cm^{-1} were found (Table 1). In both samples, these vibrations correspond to the aragonite-type $BaCO_3$ polymorph, called witherite.[48,49]

Table 1. Identification through Raman Spectroscopy of the Polymorphs of Barium Silica-Carbonate Biomorphs[a]

type of DNA	type of synthesis	Raman (λ cm^{-1})	composition/biotic or abiotic
control	solution	139, 152, 225, 1058	witherite/abiotic
	air	138, 154, 224, 1059	witherite/abiotic
C. albicans	solution	137, 138, 155, 220, 368, 690, 743, 1057, 1058, 1459, 1611, 1612, 3429	witherite/biotic
	air	138, 150, 221, 690, 748, 1058, 1467, 1611, 1612, 1677, 1811, 2921, 3501	witherite/biotic
E. arvense	solution	115, 135, 223, 689, 1056, 1460, 1608−1612, 2905	witherite/biotic
	air	135, 153, 221, 690, 1057, 1344, 1556, 1609, 1789	witherite/biotic

[a]The control sample does not contain DNA.

In the barium biomorphs containing DNA from *C. albicans* and exposed to UV in the SS-Fe medium and those UV-ionized in the air, peaks were found that correspond to witherite, plus four and seven peaks at approximately 1300−1400, 1600−1800, 2900, and 3500 cm^{-1} (Table 1). These additional peaks are compatible with kerogen, which has been proposed and considered as a marker of biogenicity.[50,51] In the biomorphs synthesized with the DNA from *E. arvense*, the witherite polymorph with the kerogen peaks was identified just like with the DNA from *C. albicans* (Table 1). Regarding kerogen, this had been previously identified in biomorphs with DNA[27] and it is of special relevance because the carbon isotopic composition of biogenic kerogen and carbonate carbon co-exist since the primigenial era, and kerogen has been identified in the Apex cherts.[50,51] The fact that kerogen was identified in the biomorphs containing DNA exposed to ionizing radiation for 7 days (Table 1) is the second piece of evidence showing that biomorphs were possibly the structure that isolated and protected the DNA from the UV rays present in the Precambrian. Although kerogen in biomorphs with DNA had been identified previously,[27] it has not been determined whether biomorphs were able to protect the DNA in extreme adverse conditions, like an ionizing radiation. This result is significant because it allowed inferring that biomorphs could indeed be the Apex chert microfossils[27,51] that conserved the biomolecules from the very beginning of life up to the present.

3.2. Biomorphs Protect the DNA from UV Radiations in Different Environments. Once evidencing that biomorphs conserve their morphology and crystalline habit when exposed to UV radiation in air or SS-Fe solution for 7 days (Figure 2, Table 1), the next question was to corroborate whether the DNA was intact and inside the structure of the biomorph. Being able to demonstrate that the DNA is intact inside the biomorph after UV exposure is the key piece of evidence that will back biomorphs as the primigenial structures that isolated and conserved the DNA since the early stages of formation.

To evaluate whether DNA was conserved in biomorphs after UV exposure, as previously described,[27] synthesized biomorphs were visualized under brightfield and fluorescence (Figures 3−6) microscopy. It is worth mentioning that through confocal microscopy, biomorphs were subjected to several fine optical sections for subsequent 3-dimensional reconstructions, i.e., in the depth plane of the sample, providing a 3-dimensional image with the information coming from the *x*, *y*, and *z* planes. In this way, changes in the expression and distribution of molecules in organelles are obtained, as well as the co-localization of membrane and intracellular biomolecules.[52,53]

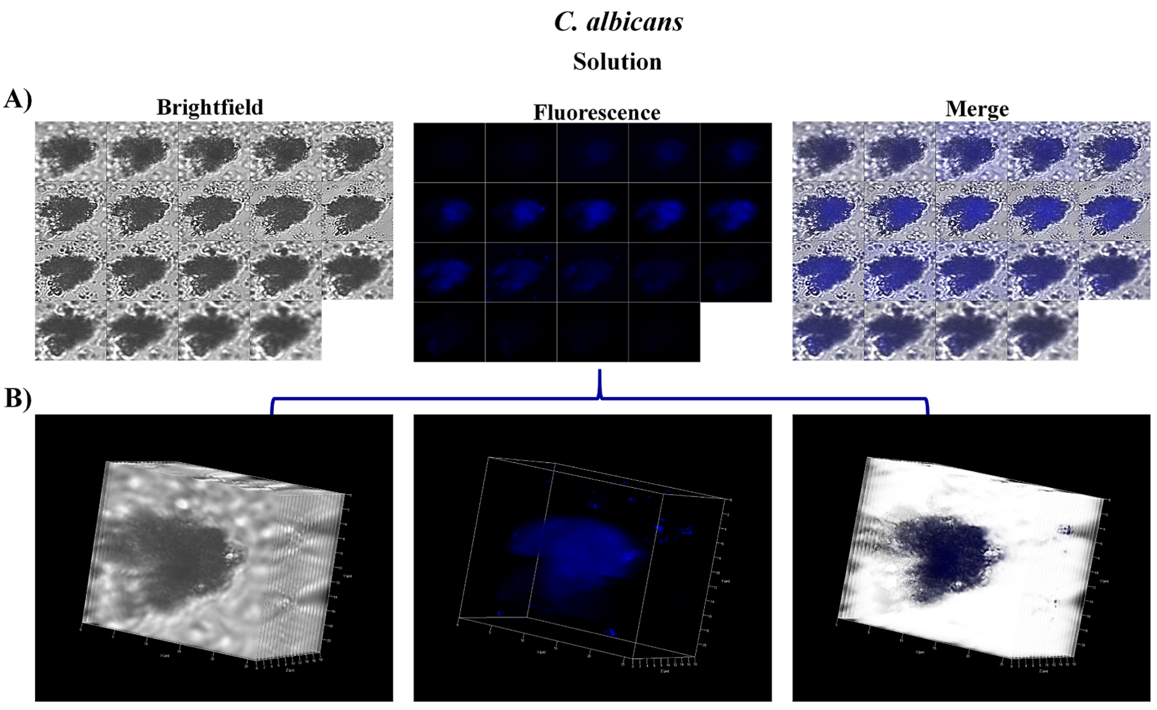

Figure 3. Biomorphs synthesized in the present of DNA*C.albicans*-DAPI, in SS-Fe, visualized through confocal microscopy. Microphotographs obtained by: (A) brightfield and confocal microscopy; and (B) tridimensional image (3D).

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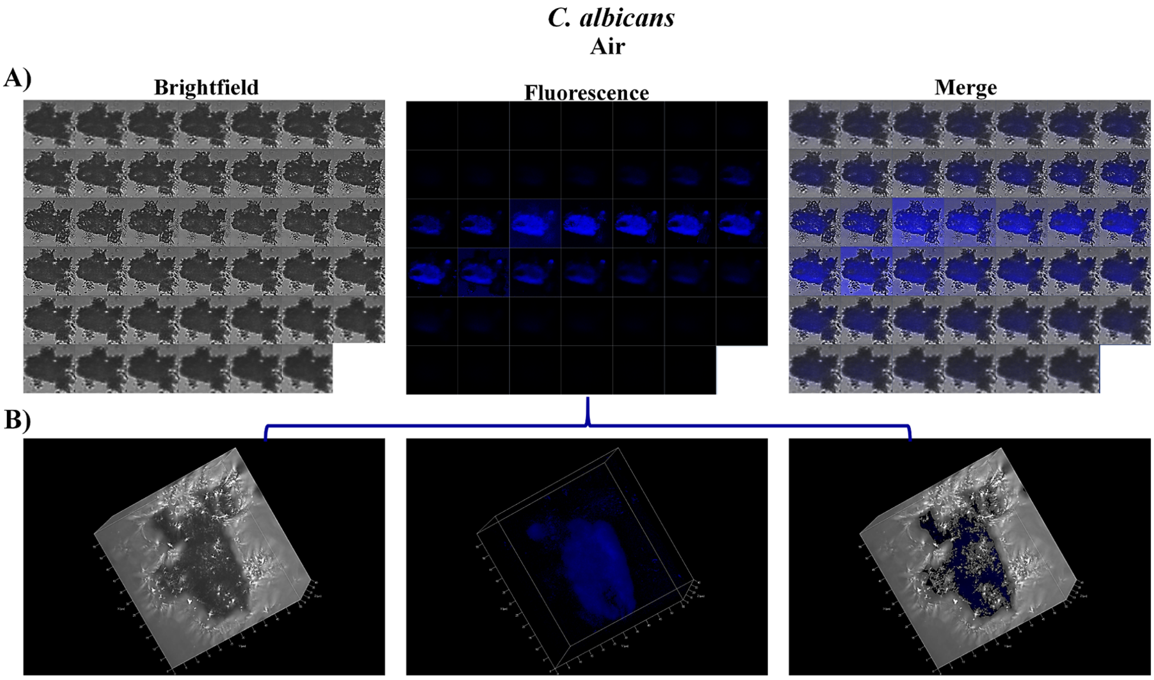

Figure 4. Microphotographs of biomorphs synthesized in the presence of DNA*C.albicans*-DAPI, in air, obtained through confocal microscopy. (A) Brightfield and confocal microscopy; (B) tridimensional image (3D).

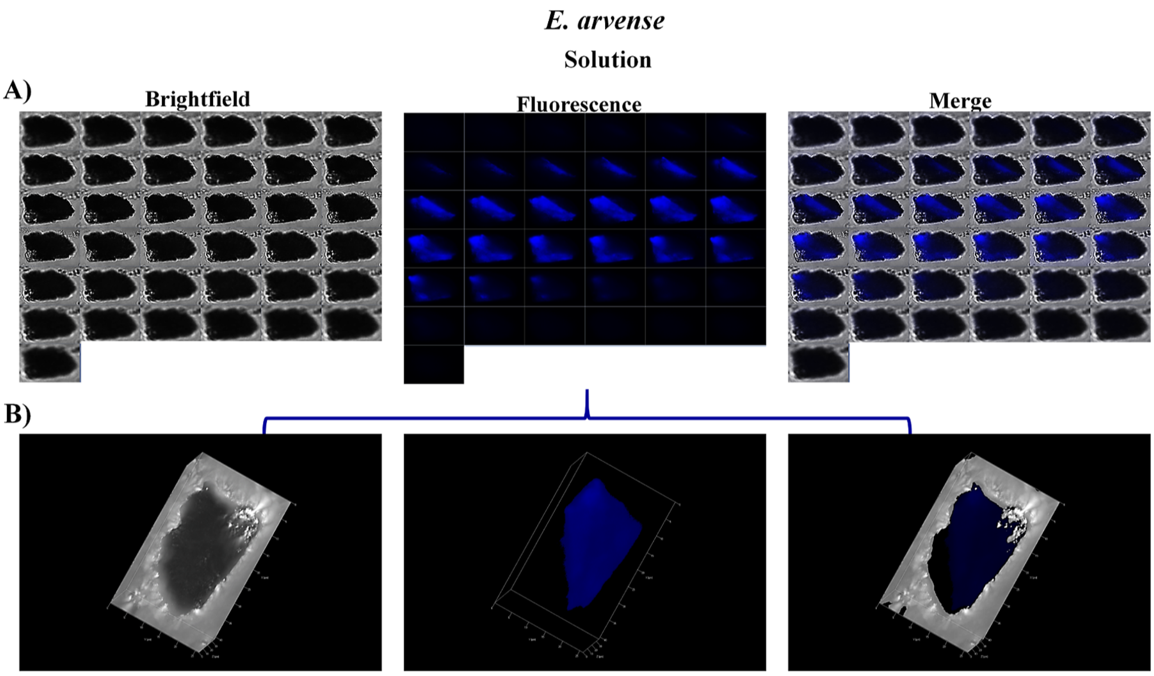

Figure 5. Representative microphotograph of the optical sections and 3D reconstructions of the biomorphs synthesized in the presence of DNA *E.arvense*-DAPI, exposed to UV in the SS-Fe medium. (A) Brightfield and confocal microscopy; (B) tridimensional image (3D).

Evaluating whether the DNA was conserved intact after 7 days of continuous UV exposure in either air or SS-Fe solution is relevant, as these were conditions co-existing in the primigenial era. Additionally, having air as a medium, UV rays irradiate directly on biomorphs, whereas the SS-Fe solution has been reported to protect the DNA from UV radiation.[42] This knowledge will help to elucidate whether life could originate, preferably in a silicon-rich aqueous medium, or whether the synthesis of the first organic molecules was achieved indistinctly in the different habitats existing in that era.

In the biomorphs containing DNA from *C. albicans* and exposed to UV light in the SS-Fe medium, fluorescence was observed localized inside the biomorphs (Figure 3, Video 1 as Supporting Information), indicating that in this case the biomorphs protected the DNA from the external UV radiation. Additionally, a tridimensional analysis (Figure 3B) of the biomorphs was performed to visualize whether the DNA was indeed inside the biomorphs, and, as shown in Figure 3B and the Video 1, the DNA from *C. albicans* is inside the biomorphs.

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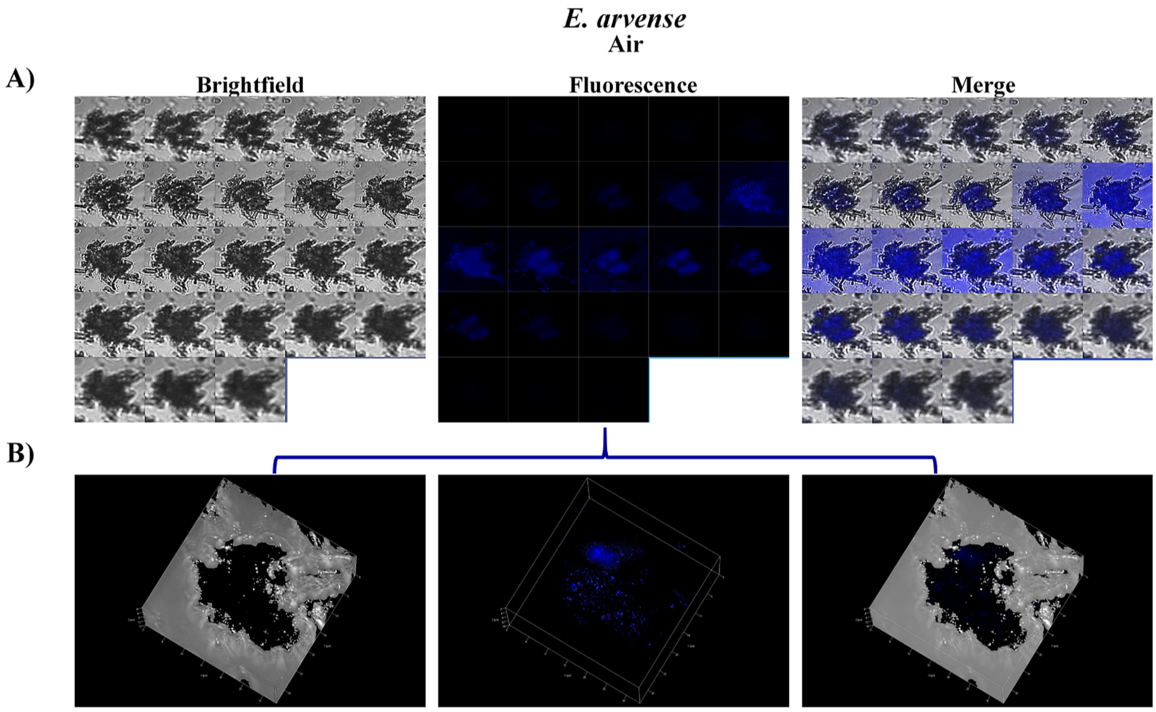

Figure 6. Representative microphotograph of the optical sections and tridimensional reconstructions of biomorphs synthesized in the presence of DNA*E.arvense*-DAPI, exposed to UV in an air medium. (A) Brightfield and confocal microscopy; (B) tridimensional image (3D).

This result shows that DNA is conserved inside the biomorphs after their exposure to UV light; this could be because the SS-Fe solution confers protection to the DNA, as described by other authors.[42] Even if this hypothesis were true, it would indicate that in this condition, the origin of life and its conservation during the Precambrian were plausible, which, in turn, would support the theory that life originated in water currents.[54−57]

The other evaluated atmospheric condition is precisely that corresponding to life having originated in the soil and mineral crystalline structures like the biomorphs, in which UV rays traveled through the air. For this reason, we evaluated the biomorphs with the DNA from *C. albicans* that were exposed to UV in the air and found the DNA inside the biomorphs (Figure 4). The 3D analysis of biomorphs confirmed that they contained DNA (Figure 4B, Video 2 as Supporting Information).

This information indicates that biomorphs protect the DNA from UV radiation in the air and indicates that life could also have originated in the soil, but with the help of crystalline inorganic structures like biomorphs. The latter would support the theory that the pioneer organism contained one mineral part and another organic one,[16] as well as that the mineral structures were the ones that isolated, concentrated, aligned, polymerized, and protected the DNA biomolecules.

Additionally, to demonstrate that the obtained results were independent of the used DNA, it was necessary to evaluate whether biomorphs are able to protect the DNAs coming from different organisms and, thus, from different G−C content. For this, we evaluated the biomorphs synthesized with the DNA from *E. arvense* exposed to UV using SS-Fe as a medium. The optical sections of several biomorphs in this condition revealed that the DNA is localized in their inside (Figure 5, Video 3 as Supporting Information).

This fact is relevant as it indicates that biomorphs, independently from the biomolecule's chemical composition, can protect the DNA from the external environment. Besides, to evaluate whether biomorphs with the DNA from *E. arvense* protect the DNA from UV radiation in the air, biomorphs were analyzed in this condition, as shown in Figure 6, the DNA is in their inside (Figure 6, Video 4 as Supporting Information).

Another question posed was whether biomorphs, after being exposed to UV for 7 days, could conserve the DNA for a longer time; for this, the UV-irradiated biomorphs were exposed to the environment for eight months. After this time, the analysis was performed again to know whether DNA had been preserved in their interior. The analysis revealed that the DNA was preserved inside the biomorphs in both conditions (air and SS-Fe), indicating that biomorphs are structures that protect the DNA for a long time. Additionally to the DAPI-DNA assays, DNA stability inside the biomorphs was also assessed through spectrophotometry. This technique is the only one that currently allows evaluating quantitatively quality and purity of the DNA. The handled biomorph samples present experimental characteristics that do not allow using other techniques. These are: (i) biomorphs are crystalline inorganic structures sized in the nanometer to micrometer scale; (ii) the concentration of the synthesized biomorphs is extremely low, which hinders extracting DNA with any conventional technique; (iii) biomorphs are synthesized on a glass surface, hence separating them from the surface is a very complex procedure. The characterization of biomorphs implies techniques and equipment not commonly available in research laboratories. In this way, the relation between the A260/A280 and A260/A230 absorbances is used to evaluate the purity of the samples. The A260/A280 relation is very stable, and if the value is within 1.8−2.0, it is considered that the DNA has an optimal purity. An A260/A280 relation of 1.6 to 1.8 is considered of acceptable purity. If the ratio is lower than the latter value, the DNA is considered not optimal. Whereas if the A260/A230 ratio lies in the interval of 1.8 to 2.2, it indicates that the DNA is pure. The

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biomorph samples with DNA from *C. albicans* or *E. arvense* treated in either condition were all assessed through spectrophotometry. Table S1 shows the values of the ratios corresponding to A260/A280 and A260/A230, revealing that all are within the optimal DNA purity interval.

From the latter, it can be inferred that biomorphs could be one of the first inorganic structures that allowed the isolation, concentration, alignment, polymerizations, and protection of the first biomolecules, allowing afterward the formation of the protocell, and evolution gave rise to the diverse organisms millions of years thereafter.

In this way, the obtained data reinforce our research team's proposal about biomorphs and their participation in the origin of life and, at the same time, the proposals of other research group, indicating that the first biomolecules were synthesized by the co-existence of a prebiotic soup and the minerals present in the primigenial era.[58−67] The latter would favor the formation of the protocell proposed by Wachtershauser in 2006.[16] Later on, from the pioneer organisms formed by the organic-mineral structure, the cell membrane would be formed, allowing for the formation of LUCA,[14] and then, through a macroevolution, all organisms would have been formed.[68] Another theory on the origin of life is based on the aqueous environments existing in the primigenial era; hence, it has been indicated that the silicon isotopes found in the Precambrian cherts were formed at seawater temperatures between 60 and 80 °C.[54] Other works that support this theory consider that in the early stages of the Earth, water steam favored the formation of the primigenial oceans, postulating that life originated in the volcanic vents where the first chemical reaction took place.[57] However, other authors postulate that hyper-thermophilic microorganisms that inhabit at temperatures of 110 °C, as well as organisms that inhabit the Earth at other temperatures, do not indicate the origin of life at these temperatures.[55,56]

Our results show that, independently of whether life originated in the atmospheric conditions prevailing in the soil and air or in an aqueous medium, biomorphs have the capacity to protect biomolecules against the external factors of the environment. Hence, the obtained results support my proposal that biomorphs could be that mineral crystalline structure that favored the origin of life and thus leading me to infer that they can actually be the missing gap between the Precambrian and the current era. The proposed hypothesis of biomorphs is based on the following evidence and characteristics of biomorphs: (i) biomorphs are crystalline mineral structures that depict diverse biological morphologies;[27−36] (ii) they present similitude with some Apex fossils;[37] (iii) they have been proposed as biomarkers in crystalline minerals (this work and[27]); (iv) they are able to conserve nucleic acids in their interior, as found in the cells, during long periods (this work); (v) they are proposed as one of the first inorganic structures in which the biomolecules formed in the Precambrian were concentrated, aligned, polymerized, and protected from the conditions existing in the primitive era;[27] (vi) it has been inferred that biomorphs are possibly the Precambrian cherts that were kept invisible until their discovery (this work and[27]); (vii) biomorphs protect the DNA from external factors in different habitats, as are normal atmospheric conditions and in an aqueous medium (this work); (viii) biomorphs protect the DNA independently of their G−C composition (this work); and (ix) biomorphs could be the gap that unifies the diverse proposed theories on the origin of life in our planet (this work and[54−67]).

The nine characteristics fulfilled by biomorphs led me to propose them as one of the first inorganic structures where biomolecules isolated from the harsh environment prevailing in the Precambrian and as the gap between the Precambrian and our current era.

4. CONCLUSIONS

Our results support the hypothesis that biomorphs could possibly be the inorganic mineral structures that participated in the origin of life by isolating and protecting the first molecules and biomolecules from diverse environments or habitats of the primigenial era. Hence, biomorphs have allowed me to infer how life originated on Earth. My proposal on the origin of life, based on biomorphs, aside from contributing to a better understanding in this area of knowledge, provides clarity on why, until now, the organisms keep being formed by this mineral-organic part, which has been proposed since the pioneer organism.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsomega.3c03516.

Determination of the DNA contained in the biomorphs exposed to UV (PDF)

Tridimensional (3D) reconstruction of the biomorphs synthesized in the presence of $DNA_{C.albicans}$-DAPI in SS-Fe visualized through confocal microscopy (MP4)

3D image of the biomorphs synthesized in the presence of $DNA_{C.albicans}$-DAPI in air visualized through confocal microscopy (MP4)

3D image of the biomorphs synthesized in the presence of DNA*E.arvense*-DAPI in the SS-Fe medium visualized through confocal microscopy (MP4)

3D image of the biomorphs synthesized in the presence of DNA*E.arvense*-DAPI in air visualized through confocal microscopy (MP4)

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Notes

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