SIMULATION OF ORGANISMIC MORPHOLOGY AND BEHAVIOR BY SYNTHETIC POLY-α-AMINO ACIDS*

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Abstract: Experiments imitating spontaneous geothermal occurrences have yielded most of the amino acids found in protein. All of the amino acids found in protein are simultaneously condensed, by heating in a range of appropriate conditions, to polymers which have many of the properties of proteins. These properties include molecular weights of many thousand, digestibility by proteolytic enzymes, and catalytic activities. One of the other properties is the tendency to form structured units; these units have many of the attributes of biocells. The processes indicated, and others, comprise a conceptual continuum which, according to accumulated information, must have occurred under the conditions existing in regions of the primitive Earth.

Резюме: В экспериментах, имитирующих определенные геотермические условия, получено большое количество аминокислот, входящих в состав белков. Все аминокислоты, входящие в белки, одновременно конденсируются при нагревании в соответствующих условиях, образуя полимеры, которые обладают многими свойствами белков. Этими свойствами являются: молекулярный вес, равный нескольким тысячам, переваривание протеолитическими ферментами и каталитическая активность. Одним из свойств является также тенденция к образованию структурных единиц; последние имеют много характерных признаков живой клетки. Эти, а также некоторые другие реакции позволяют предположить непрерывный процесс, который в соответствии с накопленной информацией должен был происходить в условиях первичной атмосферы соответствующей геологической эпохи.

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Experiments performed in terrestrial laboratories have indicated how complex macromolecules of an organismic type and protocells of complex structure might have arisen spontaneously on the Earth in simple processes.[1, 2] The mechanistic premise alone demands that life must have arisen spontaneously from inanimate systems.[2] Experiments made possible by this premise have specified a range of conditions, mainly thermal, in which such molecules and systems might originate.[1] The emergence in such acellular experiments of polymers which respond positively to almost all general tests for protein and, on the other hand, of polymers which test like polynucleotides, has broadened the interpretation of the results of tests which may in the future be performed on material on or from Mars.[2]

(The origin of net optical activity, regarded by some as unique to life, could hav arisen also acellularly. Such possibilities have been illustrated by experiments—see Fox, Johnson and Vegtosky,[3] Wald,[4] Ulbricht,[5] Harada,[6] and the bibliography to reference 6.)

The geophysical possibilities for the necessary reaction conditions are documented,[7] and new data have recently been added to the literature.[8] The question of whether these terrestrial conditions exist or existed on Mars deserves rigorous investigation in the same mode as the question of whether Mars is an abode of life. Some generalizations may be considered tentatively, however.

One concept stems from back-extrapolation of the Darwinian emphasis on the hereditary constitution of an organism as contrasted to its control by the environment. Back-extrapolation of the Darwinian evaluation to the molecular reactions preceding life would suggest for them internal self-limitations. Extensive study of variations of reactions modeling prebiological synthesis yields an evaluation that they were indeed inexorable and determinant.[9, 10] In this view, the inexorable reactions would occur as changing geological, or changing Martian, conditions happened to fall into the appropriate range, such as has been identified in the laboratory. While many of such sets of conditions have been widespread throughout the history of the Earth, evidence related to their frequency on Mars or other extraterrestrial bodies has yet to be accumulated.

The stability of polymers and of organized microparticles under dry or almost dry conditions is now known to be such that, once formed, indefinitely long survival of such units on the surface of Mars can be visualized.

More than two dozen tests or combinations of tests for protein are positive for the poly-α-amino acids, proteinoids, which result from heating 18 initially dry proteinogenous α-amino acids in mixtures containing sufficient aspartic acid and glutamic acid.[1, 2] Most of the 18 amino acids are principal products when methane, ammonia, and water are subjected to volcanic temperatures.[11] No other amino acids result. Thermal oligonucleotides produced in polyphosphoric acid are split by ribonuclease and by venom phosphodiesterase.[12, 13]

One of the more recently described properties of the thermal poly-α-amino acids is their tendency to produce carbon dioxide from glucose.[14]

The morphological potentialities are illustrated by the fact that synthetic microparticles resemble the organized elements reported as occurring in the carbonaceous chondrites (Figs. 1–3). The particles found in carbonaceous chondrites are either terrestrial contaminants or they are indigenous to the meteorites. In either mode, they are a product of a natural process of one kind or the other. Their structure is imitated by the synthetic microparticles. The necessary conditions of temperature range and moisture content required by the laboratory experiments are found in the chondrites.[14] If such conditions have existed on Mars, a similar development of molecules, macromolecules, and morphological units may be anticipated. The finding of the latter structures in telemetered scans of Mars, or the finding of division of such units, for example, would thus not signify the presence on Mars of a terrestrial type of cellular life.

In Fig. 4, several phenomena are visible in a photomicrograph taken in 1962. The picture shows three phenomena in particular. One is a selective diffusion (*a*). Under the influence of raised pH the polymer within the unit is diffusing outward through a boundary having a similar amino acid composition. Secondly, some of the microspheres are cleaving, in a septate fashion (*b*). Thirdly, a phenomenon suggesting growth is seen (*c*). In this interpretation, a simple shift in depth of focus should be considered as an explanation.

Figure 1. "Life-like" microparticle from Orgueil meteorite, *left*. Microparticle of thermal proteinoid from the laboratory, *right*. (Fig. 8 in ref. 1.)

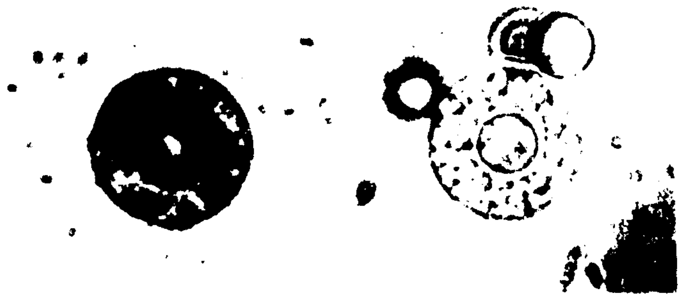

Figure 2. "Life-like" microparticle from Orgueil meteorite, *left*. Microparticle of thermal proteinoid from the laboratory, *right*. (Fig. 9 in ref. 1.)

Figure 3. "Life-like" form from Orgueil meteorite undergoing what has been described as cell division, *left*. Synthetic microparticle from the laboratory, *right*, following simple increase in pH. (Fig. 10 in ref. 1.)

The difference, or similarity, of compositions of the material within the microsphere and in the boundary are seen in Table 1. In Fig. 5 a final separation of daughter fragments of a proteinoid particle which has undergone division in the presence of magnesium chloride is seen. Whether growth, or a false simulation of it, was seen in the time-lapse sequence projected earlier, that kind of enlargement could be mistaken for growth. In Fig. 6, growth of a "bud" is however clearly evident. Many similar increases have been seen in the laboratory.

In Fig. 7, photographic evidence of a simulation of motility is presented. Sufficient requirements for such behavior are a suspension of an asymmetric zinc-containing proteinoid microparticle and the addition of ATP to the suspension. The asymmetric particle can be seen to move in fields in which the uniform particles are otherwise quiescent except for limited motion

TABLE 1

Composition of Boundaries and of Whole Microspheres

	Composition of Polymer	
Amino Acid	in Microsphere	in Boundary
Lysine	2.13[a]	1.48
Histidine	0.65	0.73
Ammonia	4.92	6.38
Arginine	0.83	1.18
Aspartic acid	67.57	72.97
Threonine	—	—
Serine	—	—
Glutamic acid	13.30	9.64
Proline	0.21	0.23
Glycine	1.10	1.06
Alanine	2.97	2.00
Half-cystine	1.36	0.99
Valine	0.84	0.55
Methionine	0.37	0.17
Isoleucine	0.38	0.23
Alloisoleucine	0.45	0.22
Leucine	0.86	0.56
Tyrosine	0.98	0.80
Phenylalanine	1.08	0.80

[a] Values are given in mole percent.

which has a Brownian appearance. The particle also rotates. In Fig. 8 rotation of contents within a boundary, after an increase of pH, is seen.

In summary, this paper has presented reference to the fact that poly-α-amino acids or polynucleotides produced under planetarily plausible conditions can give many positive tests for natural polymers such as proteins or polynucleotides. This paper has presented also photomicrographs showing how the size, shape, morphology, selective diffusion, growth, division, motility, and internal streaming of synthetic microparticles might similarly yield test results which might otherwise be taken as signs of life. No nucleic acids are present. Only the self-organizing properties of thermal poly-α-amino acids[15] account for these phenomena. Such developments are consistent with a general prediction made by George Wald in 1954[16] that the origin of the cell could eventually be understood as due to the internal properties of the material of which it was composed.

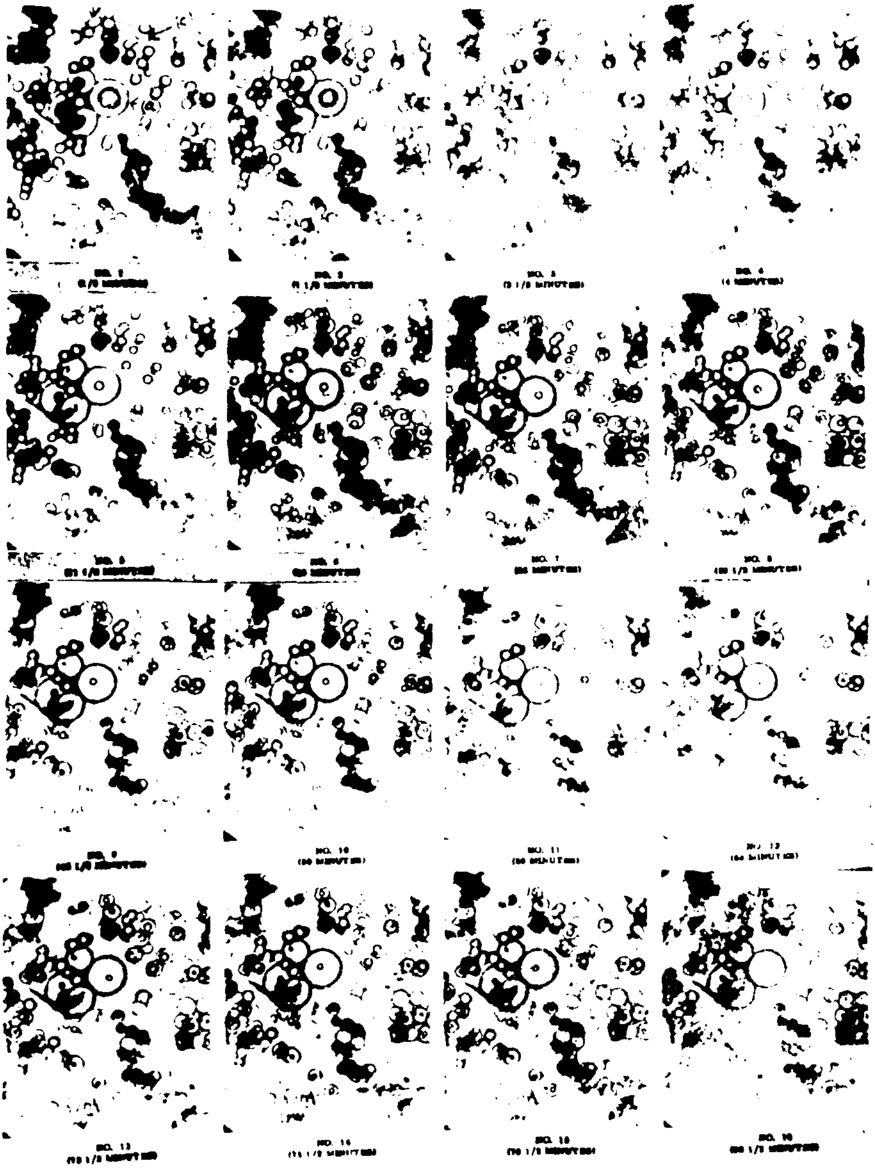

Figure 4. Frames from a time-lapse sequence showing septate division of proteinoid microspheres. Frame *n* precedes frame *n* + 1 by 30 seconds. The suspension of proteinoid microparticles is not uniform in diameter since the solution was boiled 10 min instead of the usual 10 sec. McIlwain buffer of pH 6 has been added. (From Fox and Yuyama.[15])

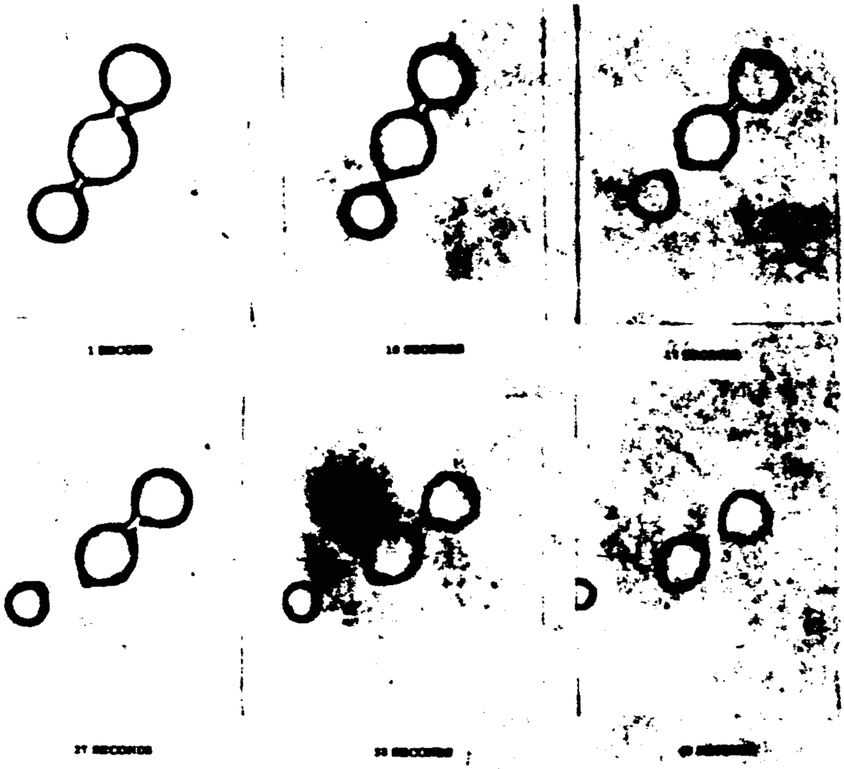

Figure 5. Final separation of daughter fragments of proteinoid microparticle subjected to raised pH.

Incidentally, the difficulty of defining life[2, 17, 19] is more vividly understood on the basis that various attributes of life might be successively introduced into a simple lifeless system, as the model suggests.

Other investigations in our laboratory, not presented here, yield phenomena which can also simulate behavior otherwise associated with vital processes. These apparently complex units and processes occur in simple ways, as in natural experiments. The products are, in the large sense of the word, artifacts. Though produced by human hands, the mode of production is imputable to the geological locale.[8] As Philip Morrison[20] has also emphasized, life must have arisen from some kind of artifact, almost certainly in the micron range of size. Morrison also emphasizes that the "ele-

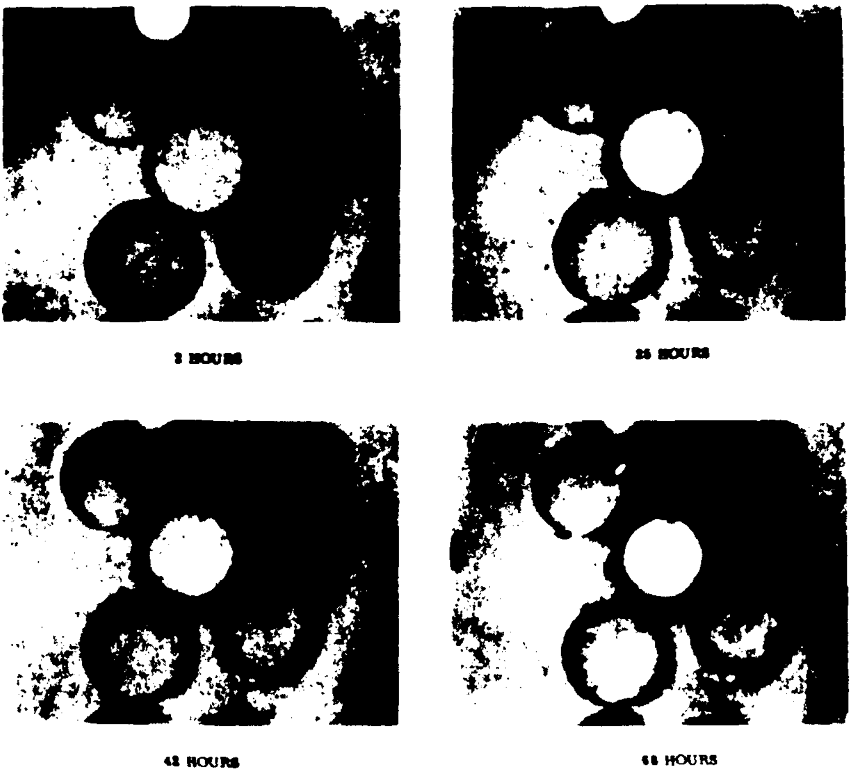

Figure 6. Growth of a "bud" on a proteinoid microparticle.

ments" found in meteorites may be natural nonvital experiments. In the context of the search for extraterrestrial life, the illustrative results presented here demonstrate that some telemetered data which might resemble living particles in many ways, cannot be interpreted as sure signs of life.

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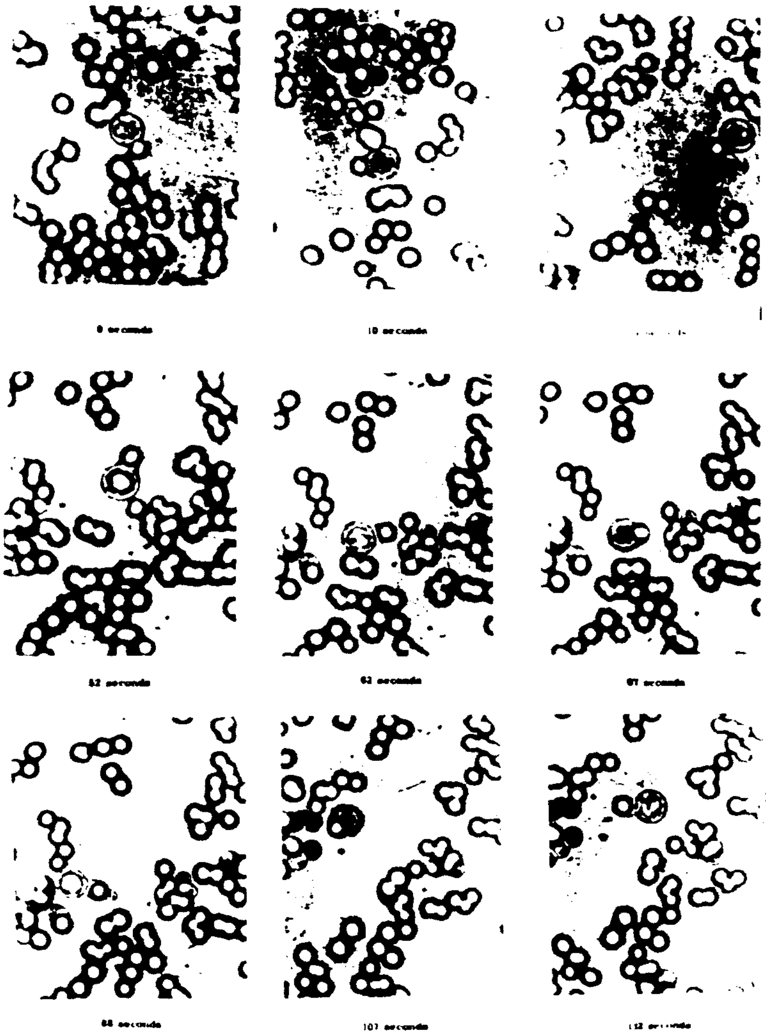

Figure 7. Simulation of motility by an asymmetric proteinoid microparticle which moves nonrandomly in fields and from field to field.

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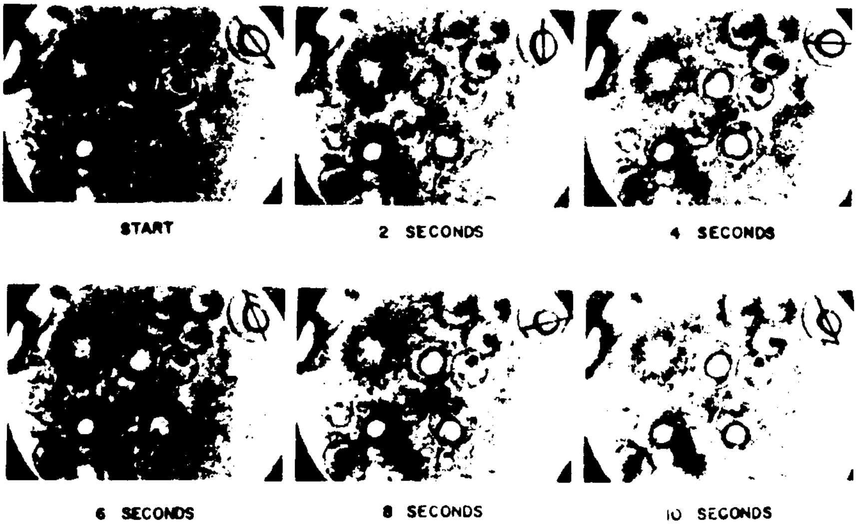

Figure 8. Rotation of interior with a boundary of proteinoid. The pH has been increased from that of the original suspension. The original microspheres have been aged for many days at approximately pH 3. The arrow in each frame indicates the major axis.

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