Perspectives

Jeewanu, or the 'particles of life'

The approach of Krishna Bahadur in 20th century origin of life research

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Starting in the 1960s, the Indian chemist Krishna Bahadur, from the University of Allahabad, published on organic and inorganic particles that he had synthesized and baptized '*Jeewanu*', or 'particle of life'. Bahadur conceived of the *Jeewanu* as a simple form of the living. These studies are presented in a historical perspective and positioned within mid-20th century research on the origin of life, notably the so-called 'coacervate theory' of the Soviet biochemist Aleksandr I Oparin. The concepts of life proposed by Bahadur, Oparin and others are discussed from a historical standpoint.

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1. Beginnings

We shall start where it probably all began, in the water. According to ancient Hindu scriptures, or so tells us the Indian chemist Krishna Bahadur, life emerged there from an interplay of the primary elements. Later, in the second half of the 20th century, watery solutions of diverse substances were fundamental to address the problem of the origin of life, such as the formation of cell-like structures. In his laboratory at the University of Allahabad, Bahadur dissolved and mixed various chemicals, and after shaking and illuminating these in glass flasks for days or weeks, he discovered that particles had formed in the fluids. He observed these microscopically, determined their chemical composition and reported about their motion, growth and multiplication. The globules were surrounded by a membrane-like layer, and he baptized them, somewhat enigmatically, *Jeewanu*. With astonishing ease, Bahadur actually considered the *Jeewanu* a simple form of life created in the laboratory and potentially similar to what could have existed in the earth's biochemical dawn (figure 1).

With a distance of almost 50 years, and a perspective based only on published records, the scenario might sound rather curious. And indeed, this episode of science is difficult to probe for several reasons. How to picture the mindset of an author who quoted classic texts of the Indian tradition, such as the Vedas, alongside with the biologist JBS Haldane, or biochemists JD Bernal and Alexander I Oparin, and about whom there is hardly any information available apart from his publications? Archival research or interviews in India might, of course, change the picture completely, but for now the account has to remain lacunary in many respects. However, even the provisional story given here helps to recollect a controversial and largely forgotten research project linked to many important scientific developments of the last century. What is more, this story shows the co-presence of very different 'molecular biological' approaches throughout the 20th century, and it will allow us to cast light on different and shifting material models and conceptions of the living. To avoid misunderstandings, I shall add here that the aim of my historical analysis is not to deliver a scientific judgement on Bahadur's work with respect to the state of the art in origin of

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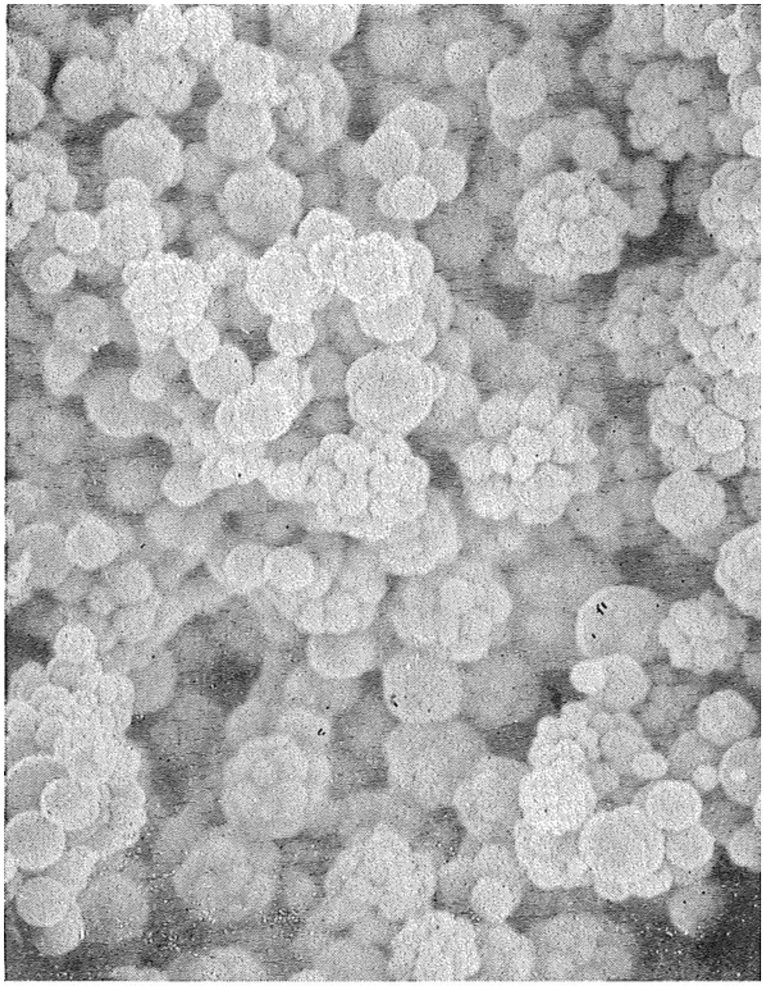

Scanning electron micrograph of Jeewanu,
(x 2000, *by the courtesy of Dr. A.E. Smith of Concordia University, Montreal, at present in Ames Research Center, NASA, Moffett F ield, California*).

Figure 1. Electron micrograph of *Jeewanu*. The figure was published in the appendix of the book that Krishna Bahadur and his wife S Ranganayaki published in 1981. In addition to electron micrographs that were taken at NASA's Ames Research Center, numerous microscopical images of *Jeewanu* using different staining and fixation methods were included as well. From Bahadur and Ranganayaki (1981, p 241). Mr Sanjay Agarwal, Allahabad, is thanked for permission to reproduce the figure.

life research. For reasons to be exposed, Bahadur's studies were untimely, in a sense idiosyncratic and controversial. The project sank into oblivion; however, it was mentioned here and there, very recently, for example, in a historical perspective on protocell research. From both scientists and historians of science, the author of the present paper has noticed very different and controversial assessments of Bahadur, his work and how to think about it nowadays (if at all). These differing opinions might reflect attitudes towards certain fields of science as well as more personal aspects. Beyond the false impasse of digression from the true path of science or neglected insight, I shall argue that cases such as Bahadur's deserve historical attention as well in order to understand how science was and presumably is carried out in the real world, as a heterogeneous and widely ramified field of human cultural activity.

2. Krishna Bahadur and *Jeewanu*, the particle of life

Published literature does not tell us much about who Krishna Bahadur was. He must have been affiliated to the Chemistry Department of the University of Allahabad in the northern Indian state of Uttar Pradesh from at least the mid-

1950s until the 1980s. His wife, S Ranganayaki, was a long-term collaborator and frequent co-author. Some of Bahadur's publications appeared in international journals, and he was connected to important figures in research on the origin and fundamentals of life, such as in NASA's Exobiology Division (Dick and Strick 2004). He was there and not: At the noted Moscow conference on 'The origin of life on the earth' in 1957, or so Aleksandr I Oparin lets us know, he could not be personally among J Desmond Bernal, Erwin Chargaff, Stanley L Miller, Linus Pauling and many others, but he sent a paper that was included in the proceedings (Oparin *et al.* 1959). More than a quarter century later, in 1983, he could be spotted on a group picture taken at a conference on 'Clays and the origin of life', organized by molecular biologist A Graham Cairns-Smith in Glasgow: a stout man gazing firmly into the objective (Dick and Strick 2004, p 74).

Considerably more can be gleaned about Bahadur's work from his publications on the 'particle of life', or *Jeewanu.* Here, we shall start with a look at words and books rather than at laboratory research. The term *Jeewanu* is composed of the Sanskrit words *jeewa*, life, and *aNu*, the smallest part of something, or the indivisible. For Western readers, and Far Eastern, it may be added that in contemporary Hindi *jeewanu* also designates unicellular organisms such as bacteria. Bahadur linked his work to the Indian philosophical tradition not only through the use of a Sanskrit term but also by pointing to ideas on the origin of life from the Vedas. My analysis suggests that these terms and references were by no means chosen arbitrarily – as they presumably never are – and that they are revelatory about the framework within which to understand Bahadur's concept of life.

From a starting point in two Vedic texts, the Rig- and the Atharvaveda, Bahadur drew a long line through the history of thought on the relation of mere matter to organisms, the emergence of life and the problem of spontaneous generation. There are, of course, Aristotle and usual suspects such as Antoni van Leeuwenhoek, Louis Pasteur or Ernst Haeckel, as well as Svante Arrhenius or Friedrich Engels (Bahadur 1966). Bahadur connected these positions to the realm of mid-20th century biochemical research on the origin of life, where his own work should be placed. In 1964, he authored four papers on *Jeewanu* in the German *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene* (Bahadur 1964a, b; Bahadur and Ranganayaki 1964; Bahadur *et al.* 1964), followed 2 years later by the monograph *Synthesis of Jeewanu, the protocell* (Bahadur 1966) and a book entitled *Origin of life. A functional approach* in 1981 (Bahadur and Ranganayaki 1981).

A good starting point to explain his experimental work is a paper published in *Nature* some years before the articles on *Jeewanu*. Bahadur reported on a synthesis of amino acids from paraformaldehyd plus colloidal molybdenum oxide or potassium nitrate and ferric chloride by sunlight (Bahadur *et al.* 1958). It appears that this experimental approach was seminal for the assays to produce *Jeewanu*. Here, sterilized and buffered aqueous mixtures containing a carbon source, e.g. citric acid, inorganic catalysts such as colloidal molybdenum or iron oxides, and further minerals were illuminated while shaking, which led to the formation first of amino acids and peptides, as detected by paper chromatography, and then of globules in the micrometer range (e.g. Bahadur and Ranganayaki 1964).[1] Bahadur preferred sunlight or electric bulbs to sources of ultraviolet radiation, arguing the latter would re-destroy forming entities (Bahadur 1966). The 1966 monograph comprises an appendix of micrographs that documents the variability of the *Jeewanu*, which ranged from simple globules to rhizomatic structures. Time series photographs provided evidence for growth and development of the particles, while differing refractory indices, or so it was stated, made a denser lumen distinguishable from an outer, membrane-like layer. Budding particles were observed, and the increase in number was recorded by microscopic countings. In older 'cultures', Bahadur observed the formation of aggregates (Bahadur 1966). To produce *Jeewanu*, varying and complex starting mixtures were utilized. Other than citric acid, paraformaldehyde provided a carbon source, and *Jeewanu* also resulted from mixtures with added peptides. Inorganic substances such as colloidal ferric chloride or molybdenum compounds supposedly acted as catalysts. Furthermore, Bahadur reported about *Jeewanu* based on cuprous oxides, purely inorganic but with similar morphologies and activities (Bahadur 1966).

Chemical analyses of the particles were indicative of amino acids, and certain substances were allegedly enriched in the medium, whereas others, such as more complex organic molecules, accumulated within the *Jeewanu*. This process of repartition was interpreted as a form of metabolism (Bahadur *et al.* 1964, Bahadur 1966). Moreover, ammonium molybdate or ascorbic acid preserved the activity of the particles, which could also be 'subcultured' in special media (Bahadur 1964a). Until the 1980s, follow-up publications from Bahadur's group scrutinized many of these aspects in greater detail.[2] Bahadur and Ranganyaki's 1981 book, for example, comprises electron micrographs of *Jeewanu* taken at NASA's Ames Research Center in California by Adolph Smith, a collaboration partner of Bahadur (*see* also Dick and Strick 2004, p 257, footnote 77).

[1] *See* Bahadur 1964a, b; Bahadur and Ranganayaki 1964; Bahadur *et al.* 1964 and Bahadur 1966 for details on synthesis, morphology and activity.

[2] Gánti (2003) discusses some of these.

3. From the origin of life towards synthetic biology: Contexts of Bahadur's research

At the risk of neglecting other influences that may have stimulated Bahadur, I shall focus here on the most important figure, which was the Soviet biochemist Aleksandr I Oparin (1894–1980). Oparin, whose scientific work on the origin of life melded with his first materialistic and later dialectical Marxist outlook, was an important figure of science in the Soviet Union, and he was involved in the Lysenko controversy as well (e.g. Farley 1977; Graham 1993). Since the 1920s, Oparin reportedly brought the term 'origin of life' to broader attention, thus highlighting an evolutionary and hence gradual emergence of life in opposition to older concepts of 'spontaneous generation' (Fox 1968; Farley 1977). In 1936, a book *The Origin of Life* appeared in Russian, and upon its translation into English 2 years later, Oparin became a major figure in the field (e.g. Bernal 1967; Miller *et al.* 1997). In addition to his proposition of a prebiotic 'soup' and the precedence of heterotrophy to autotrophy, another important output of Oparin's work was to employ the concept of so-called coacervates to explain and model the formation of cell-like structures (Oparin 1957; Farley 1977). The Dutch chemist HG Bungenberg de Jong had coined the term coacervate (from the Latin *acervus*: heap, mass) to designate liquid layers rich in colloids that resulted from segregations of certain colloidal suspensions (Bungenberg de Jong 1932). In Bungenberg de Jong's description, coacervation was distinguished from coagulation ('Ausflockung' in the German original), yet it remained a concept with fluid boundaries. Coacervate droplets possessed differentiated surfaces and were thus compared to cellular components such as membranes or vacuoles (*l.c.*). Oparin seized the analogies between coacervates and the behaviour of living cells and developed models for the segregation of high-molecular-weight organic polymers from liquids such as the primordial soup (Oparin 1957). Like Bungenberg de Jong, he argued for a role of complex, reversible coacervates in this process, which contained two or more substances of different charges and solvation properties. The experiments were often carried out with natural products such as gelatin or gum arabic, and Oparin reported about coacervates containing proteins and nucleic acids (Oparin 1957). By including enzymes in these, metabolically active particles were obtained, which he considered as representative for gradual steps between matter and the living.

In the 1950s, origin of life research was spurred by the well-known Miller–Urey experiments on an abiotic synthesis of amino acids by electric discharges, and the field became entangled with the newly forming exobiology, most prominently under the umbrella of the NASA (Dick and Strick 2004; Morange 2007). In these years, Oparin and his work clashed with protagonists of genetics and the newly forming molecular biology (Farley 1977; Graham 1993). Surely, the heritage of colloidal chemistry borne by the coacervate theory, and complex cell-like models that were quite different to molecular objects such as viruses, marked big differences between these two camps. In retrospect, the impact of molecular genetics seems to have transformed the field to such an extent that otherwise well-disposed scientists consider Oparin's coacervate theory of 1936 as 'necessarily premature' (Miller *et al.* 1997, p 353).

In addition to Oparin, Bahadur quoted an influential article that the biologist John BS Haldane (1892–1964) had written on the origin of life. Haldane emigrated to India in 1957 and worked there until his death (Clark 2008); yet, I cannot report evidence of any contact between the two researchers. Moreover, we find mention of J Desmond Bernal (1901–1971), who also opined a gradual development from the inorganic to the living. More widely known for his crystallographic studies of organic molecules, Bernal must have penned his *The origin of life* (1967) shortly after or in parallel to Bahadur's articles, though the latter's works are not quoted. Interestingly, Bernal's book comprises an appendix with early texts from both Oparin and Haldane. All three authors were convinced Marxists for whom the broader philosophical and social frame of their scientific work was very important. Bernal, for example, spoke of 'rational accounts of the origin of life' (Bernal 1967, p 159) as opposed to metaphysical explanations or religious beliefs and stated emphatically:

> 'Life is beginning to cease to be a mystery and becoming practically a cryptogram, a puzzle, a code that can be broken, a working model that sooner or later can be made' (Bernal 1967, p 165).

With respect to his concrete laboratory work, Bahadur frequently quoted the American biochemist Sydney W Fox (1912–1998), whose studies of so-called proteinoids or microspheres date from the same years (e.g. Fox 1968). Produced from heated and dissolved peptides, these microscopic particles were similar to *Jeewanu*, yet their composition less complex (Dick and Strick 2004; Gánti 2003).

Bahadur's publications were ambivalently received, and the overall attention of the scientific community seemed limited. A short paper claiming an experimental confirmation of early *Jeewanu* works exists, although the issue whether the 'microscopic objects' were alive or not was left open (Briggs 1965). In contrast, the critique of biochemist Cyril Ponnamperuma (1923–1994), then a leading figure of NASA's Exobiology Division, was fierce and probably influential. Together with coworker Linda Caren, he lamented the 'confusing manner in which the experimental procedures [of the *Jeewanu* work in general, MG] were presented'; they questioned the sterility of the mixtures and speculated that multiplication of the particles could have resulted from mechanical breakage by shaking (Caren and Ponnamperuma 1967, quote p 3). In the same vein, the team demurred that 'the large number of chemically undefined substances in the protenoid jeewanu experiments preclude a meaningful interpretation' (*l.c.*, p 4). It should be noted, however, that the paper only reviewed, compared and re-interpreted data published by Bahadur or others and did not refer to any attempt of the authors to reproduce the work. Accordingly, Caren and Ponnamperuma concluded that '[At] present, the nature and properties of the jeewanu remains to be clarified' (*l.c.*, p 4).[3]

The years from *c.* 1960 to 1980 brought about far-reaching changes in the methods and interests of biochemistry and growing molecular biology. Bahadur, however, followed a rather constant path throughout these decades (Bahadur and Ranganayaki 1981). Not many quotes of his work can be found, but in the 1980s, the Hungarian chemist Tibor Gánti discussed *Jeewanu* at length in his 'Chemoton theory', published first in Hungarian and translated into English only in 2003. Gánti's concept of the chemoton as a system of autocatalytic chemical reactions has been compared to Manfred Eigen's hypercycles. In the context of self-organizing structures, Gánti considered the *Jeewanu* a promising model system to understand the origin and fundamentals of life, and one that had never received due attention (Gánti 2003). Referring to publications of Bahadur's group from the 1980s, he regarded three types of chemical reactions akin to biological photosynthesis as experimentally demonstrated. Accordingly, *Jeewanu* would be involved in the splitting of water, assimilation of CO_2 and fixation of nitrogen.[4] Gánti's explanation why the scientific community was nonetheless ignorant or even dismissive of Bahadur's work was quite explicit and shall thus be reported here:

> 'Bahadur and his co-workers *believe* that *Jeewanus* live, *i.e.* that they are simple living systems. However, the scientific world *believes* that they are inanimate artefacts and it does not even consider the results, let alone tries to disprove them. Nevertheless, there is a significant difference between these two beliefs. The basis for the belief of Bahadur and co-workers is the experience and experimental observations of three decades. As a contrast, the belief of the scientific world is based on prejudice. It is prejudice, first against the unusual, unexpected, and strange experimental results, and second against the modest, too simple, and hardly equipped experimental methods' (Gánti 2003, p 504; italicized in original).

I shall return to the methodical aspects both Gánti and Ponnamperuma have referred to in the conclusion.

Recently, *Jeewanu* have been mentioned in a theoretical paper on the evolutionary dynamics of chemical units such as liposomes as one of the many experimental attempts to produce 'phase-separated individuals' (Fernando and Rowe 2007, p 154). Without claiming to be exhaustive on the subject, I would like to mention another contemporary work that reports about globular structures in the micrometer range synthesized from sugars and ammonia. The author speculates that these might be similar to 'containers for prebiotic catalytic processes relevant to the origin of life' (Weber 2005, p 523). The studies on *Jeewanu* have also been mentioned in a survey on the history of protocell research, amidst a tradition of cell models somewhat distanced from the mainstream of molecular or cell biology (Hanczyc 2009). The heritage of physical and colloidal chemistry looms large in this perspective: In addition to Bungenberg de Jong and Oparin, 19th century models of cells are mentioned, such as the particles the German physiological chemist Moritz Traube (1826–1894) created from copper sulphate and potassium ferrocyanide. The zoologist Otto Bütschli (1848–1920) is cited for experiments with droplets of olive oil mixed with potash solutions, in which he observed the formation of pseudopodia-like, moving appendices. It is noteworthy that these sometimes grossly synthetic, material analogies of cells nowadays receive a place as historically related to protocell and synthetic biology research.[5]

4. *Jeewanu* and concepts of life in history

Surely, practising scientists today might wonder what this in many respects unconventional research programme and its ambiguous and shifting reception might stand for. Here was a scientist, distant from the hotspots of research and yet linked to them, who built on a tradition – colloidal chemistry – which appears anachronistic to the age. His publications surfaced here and there, but it seems that the *Jeewanu* have never been thoroughly scrutinized or experimentally developed. Very recently, Bahadur's approach has aroused some historical

[3] Dick and Strick (2004, p 257, footnote 77) report that Bahadur, unlike Sydney W Fox, became *persona non grata* among the NASA exobiology network after the publication of this paper.

[4] Experiments demonstrating carbon dioxide reduction and nitrogenase activity of *Jeewanu*-like particles were repeated by Bahadur and collaborator Adolph Smith from NASA's Ames Research Center in the early 1980s, using state-of-the-art equipment (Smith *et al.* 1981). I would like to thank C Grier Sellers for this information

[5] The organically shaped, self-assembling mineral structures produced by French biologist Stéphane Leduc (1853–1939), discussed by Evelyn Fox Keller (2002), are another case in point. Leducs reception would provide an interesting reading with regard to Bahadur, who also quoted these studies.

interest in the auto-historiography of a discipline that is often considered novel, synthetic biology.

The contested and in a strict sense unresolved status of Bahadur's *Jeewanu*, I assume, might not be untypical for many scientific and technological projects one encounters in journals or books from past times. When scientific interests shifted and different techniques were introduced, and when the protagonists changed, it simply went quiet about these projects. Nevertheless, to get a more adequate picture of science and technology's history beyond success stories, the notorious predecessor or spectacular errs and failures, it might be worthwhile to picture these often poorly documented stories from the fringes as well, to ask why they went down this road and what this can tell us about science.

In the case of Bahadur, a limited circulation of his publications might provide one explanation. The four main papers on *Jeewanu* appeared in a mainly German language journal, and a WorldCat-search today locates only one copy of his 1966 monograph throughout Europe.[6] In another respect, the statements of both Bahadur's strongest advocate, Gánti, and his fiercest critics, Caren and Ponnamperuma, are informative. Whether one considers it as a drawback or a virtue, Bahadur did not stick to the work style of his time. His equipment was technically simple, involving standard chemicals, glassware and shakers. Light microscopes or basic methods of analytic chemistry such as paper chromatography were employed to examine the products. Instead of using ultraviolet lamps, the energy was supplied by electric bulbs, or the sun over Allahabad. In contrast, the assays to produce *Jeewanu* were very complex regarding ingredients, with Bahadur varying the protocols frequently and documenting them somewhat idiosyncratically. Referring to a distinction introduced by Lynn Margulis, historians of science Steven J Dick and James E Strick have classified Bahadur among the so-called '*gemischers*' of origin-of-life research, as opposed to microanalytic approaches (Margulis 1973; Dick and Strick 2004). These former, baptized for the Yiddish term '*gimish*', meaning mixture, would fill their glass flasks with a plethora of substances, incubate them for long times under sometimes changing conditions and then investigate the mix for products. In the molecular life sciences, an approach of this sort could of course easily be criticized, and indeed it was probably more difficult to re-establish or build upon than on reductionist, technically specified protocols.

In Bahadur's case, the *gimish* contained a product the material qualities of which seemed to have transcended what was written about the particle, since neither Bahadur nor Gánti provide thorough explanations of the *Jeewanu's* formation or functioning. As the controversy has shown, scientists could consider this as a disadvantage of the model, or as a possibility for further research with unexpected outcomes.

More philosophically, this story pertains to concepts of life and hence to hypotheses about its beginnings as well as possible artificially created forms. Reading Bahadur's publications, the ease with which he stated that *Jeewanu* actually *were* alive is striking, inasmuch as the creation of life does not appear something too exceptional or dramatic to him. He went a step further than Oparin, for example, when he stated, 'If life is defined in terms of growth, multiplication and metabolic activity these units [the *Jeewanu*, MG] are living though these have been prepared from lifeless matter' (Bahadur 1964b, p 602).

In comparison with a definition of a living system from 2009, the concept endorsed by Bahadur is much more reduced and hence more inclusive. The contemporary definition shares two requirements with Bahadur, which are an 'identity over time by localizing all its components' and the 'use of free energy from its environment to digest environmental resources in order to maintain itself, grow and ultimately reproduce' (Rasmussen *et al.* 2009 p XIII).[7] The third condition required today is that the entities and processes need to be 'under the control of inheritable information that can be modified during reproduction' (*l.c.*). Such gene-like entities appear rather peripheral in Bahadur's perspective, although he mentioned informational concepts here and there (e.g. Bahadur and Ranganayaki 1964). Presumably, this must have put him at odds with the molecular biological mainstream of his time. For Bahadur, life is a phenomenon of the surface, studied as visible development or motion in the microscope or scrutinized and conceptualized by means of chemistry as a defined, self-sustaining molecular structure.[8] Following Dick and Strick (2004), these different concepts of life can be aligned with the methodological camps of the researchers: whereas *gemishers* such as Bahadur would be sympathetic with a 'metabolism-first' scheme, microanalytics would preferentially opt for a 'gene-first', or 'information-first', explanation. The role of general physicochemical principles

[6] I cannot report anything about the circulation of his work in India or among the Russian language community here.

[7] Obviously, at any time multiple definitions and interpretations have coexisted. Popa (2004) provides a chronology, one of which, attributed to Antonio Lazcano, shall suffice here: "Life is like music; you can describe it, but you cannot define it".

[8] Bahadur repeatedly referred not only to growth but also to the motility of *Jeewanu*, which he apparently documented on films. Microcinematography, which has been used in cell research since the beginning of the 20th century, obviously highlights another level of the living than mid-century molecular biology (*see* e.g. Landecker 2006). The interest in such *in vivo* observational techniques parallels Bahadur with the case of South African microbiologist Adrianus Pijper, who proposed an alternative explanation for the function of bacterial flagella in the post-war years (Strick 1996).

and constraints in the formation and development of living structures in contrast to processes specific to today's biological world has been debated repeatedly. Newman and Comper, for example, distinguish 'generic physical' from 'genetic', i.e. specific biological, mechanisms in morphogenesis and pattern formation of tissues (Newman and Comper 1990).

Regarding Bahadur's concept of life, one should also recall his references to scriptures of the Indian philosophical tradition. The older Vedas, such as the Rig- and the Atharvaveda, drew a less definite boundary of living and non-living (Glasenapp 1949). One could add that the *Samkhya*, an atheistic school of Indian philosophy, conceived of matter (*prakriti* in Sanskrit, as opposed to *purusha*, the immaterial self) as composed of atoms, and that changes such as from the inorganic to the living and back were explained by change in aggregation and position of these atoms (e.g. Dasgupta 1924; Srinivasiengar 1934). On a general level, this ancient philosophical framework resonates with the materialistic themes of Bahadur and his scientific environment. Here, life was considered as immanent to the material world, and it emerged from the inanimate through a series of gradual steps. Or, as Oparin put it:

> 'Matter never remains at rest, it is constantly moving and developing and in this development, it changes over from one form of motion to another and yet another, each more complicated and harmonious than the last. Life thus appears as a particular, very complicated form of the motion of matter, arising as a new property at a definite stage in the general development of matter' (Oparin 1957, p xii).

Consequently, organisms are considered as complex, spatially organized structures undergoing ordered physical and chemical changes within themselves and with their environment (*see* Oparin 1957, p 301). The cosmological implications of this broad developmental perspective become obvious in Bernal's somewhat ornate definition of life as 'a partial, continuous, progressive, multiform and conditionally interactive, self-realization of the potentialities of atomic electron states' (Bernal 1967, p 168). From the physical development of the universe to the first steps of biogenesis, everything seems to be governed by the all-embracing potentialities of matter, and so it may appear as only consequential that Bahadur and Ranganayaki, musing about 'life in a wider sense', referred to the 'birth' or 'metabolism' of stars, and interpreted the formation of elements such as hydrogen, carbon, nitrogen and oxygen in terms borrowed from organic evolution (Bahadur and Ranganayaki 1981). The roots of such monist accounts of nature could obviously be traced back to scientific and philosophical traditions of the 19th century and far beyond. Materialistic as they were, teleological overtones cannot be overheard, and if one wanted to distinguish these mid-20th century conceptions from contemporary accounts on the problem, the contingency attributed nowadays to self-organizing processes presumably marks a prominent difference.

Returning to *Jeewanu*, the role they played in Bahadur's and others scientific thinking and working, as well as some reasons for the controversy about them, should have become clearer. In light of the notion of life as organized processes of structured matter, we may also understand why Bahadur went as far as to consider the particles alive, and why this appeared less far-reaching to him than it may have for his contemporaries or for today's readers. Questions of heredity and evolution are put and responded to very differently in contemporary science than against the background of Bahadur's or similar concepts of life. And one could speculate about another general change in investigating the origin of life, or the problem of abiogenesis: in the mid-20th century perspective sketched here, this issue was a biochemical research programme deeply embedded in fundamental, sometimes metaphysical or ideological questions of *understanding* nature. In contrast, one could conjecture that investigations and concepts of the living today are more inspired by technological projects, such as the construction of protocells or synthetic organisms. The fact that such endeavours of *making* life mostly do not include an explicit philosophical scope of the sort we have seen does of course not mean that they are less embedded in other contexts and frameworks of human activity.

Be that as it may, although Krishna Bahadur thought of *Jeewanu* very much as a model for the origin of existing life, in a historical perspective one should consider them as an attempt to synthesize things living, too. It has to be awaited what the current century will make of concepts of life inspired by novel creations from the laboratory and less closely tied to the organisms found on the earth at present. Consequently, it has to remain unresolved as well what place Bahadur's *Jeewanu* will occupy in histories of the life sciences written from these future standpoints.

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