3.1 Convergent Synthesis and the Origin of RNA-Based Life

The evolution of natural products on earth has fascinated scientists and laymen alike for many years. A vast literature has been accumulated concerning the hypothetical interface of the prebiotic (chemical) and the organismic (biochemical) phases (50, 60). Nevertheless the entire concept, including the validity of its experimental basis, has more recently been questioned. Indeed the concept introduces a problem of the hen-and-egg type. Which ones came first — the complex molecules with genetic and enzymatic potential or the molecules generated by such catalytic macromolecules? Cairns-Smith (10) gave the sole reasonable answer: genes and enzymes. According to this author the most central molecules of life are the same in all organisms on earth today. Hence all life has descended from a common ancestor in which the central biochemical system was already fixed. That it should have remained fixed for so long is surely because of the critical interdependence of all components of the central highly complex machinery. Hence the ancestor must be situated at a quite high position of the evolutionary tree, preceded by simpler forms in which chemical reactions were catalyzed initially by geochemical genetic material such as clay crystals and metal ions. In the resulting progressively more sophisticated system “genetic takeover” must have occurred, the inorganic material having been gradually replaced by an organic one, preferentially endowed with information-carrying capacity and catalytic activity. So far only one macromolecule is known to possess such a double capacity: RNA (12). However, direct synthesis of RNA is an improbable event. The enzyme catalyzing its in vitro formation is far too complex to have had a clay template analogue on primitive earth (10).

Cairns-Smith’s enigma stimulates consideration of the intermediate forms of the genetic takeover in which inorganic and organic materials co-exist. Both types of catalysts in separation may be inefficient. Together each one may be responsible for the partial synthesis of a complex molecule. To join these parts into macromolecules such as RNA, it would conceivably suffice to rely on a possibly pre-existing general dehydration catalyst. McKey (58) also proposed a double pathway theory in order to rationalize the biosynthesis of indole-iridoid alkaloids in species of the Gentianiflorae [sensu Dahlgren (18)]. Thus the same concept may justify the synthesis of complex molecules at the two extremes of the organismic and molecular spectra: macromolecules (RNA, etc.) in the most primitive pro-biotic

* This chapter is dedicated to the memory of Prof. Dr. Rolf Dahlgren (1932–1987), Botanical Museum, University of Copenhagen, who courageously broke away from tradition, introducing chemical data not only for refinement but as decisive criteria in the construction of his system of angiosperm classification.
Fig. 3.1. The two strategies of chemical synthesis — convergent synthesis (above) and linear synthesis (below) — are exemplified. Molecules and molecular fragments are represented by capital letters (11)

unicorpuscular forms, and micromolecules (indole-iridoid alkaloids) in the highly developed pluricellular plants. Hence there is no reason to believe that it does not apply to intermediate organisms as well.

The organic chemist will find this hypothesis reasonable. Indeed he recognizes the potential advantages of a convergent synthesis (Fig. 3.1). “If, for example, a molecule consists of two major fragments, G and H, and a side chain, I, it is more efficient to synthesize G and H separately and then combine them, rather than make G first and build H upon it, step by step. The overall yield in a synthetic sequence is the product of the yields of the individual steps so total yield tends to decrease with an increasing number of steps in a sequence. A linear sequence maximizes the number of steps to which the original starting materials must be subjected. A convergent synthesis, in contrast, allows one to build up separate fragments and then combine them; the number of steps to which each set of starting materials is subjected is thus decreased” (11).

“Convergent synthesis” in the former paragraph is used to describe a certain strategy of synthetic organic chemistry. The term convergence, used by biologists, has a totally different meaning, being defined as the resemblance of structure due to adaptation to similar environmental conditions that have occurred in different evolutionary lines.

The formation of new, more effective molecular systems by the interaction of two (or more) precursors, each of them already endowed with its own evolutionary history, has an analogy on the level of organisms. According to the endosymbiotic theory defended by Margulis (53), several classes of cellular organelles — mitochondria, plastids, and even perhaps flagella — had once been free-living bacteria that were acquired symbiotically and in a certain sequence by host prokaryotes.

Having recognized the possibility of forming molecular and organismic systems by adding part-structures, it is most important to consider the peculiarity that the characteristics of the whole cannot be deduced from the knowledge of the components. The appearance of new and unexpected characteristics in wholes has been designated as emergence. Although yet a more philosophical than practi-