Chapter 2
Early Transformation of Organic Matter:
The Diagenetic Pathway from Organisms to Geochemical Fossils and Kerogen

2.1 Significance and Main Steps of Early Transformations

The time covering sedimentation processes and residence in the young sediment, freshly deposited, represents a very special stage in the carbon cycle. The first few meters of sediment, just below the water–sediment contact, represent the interface through which organic carbon passes from the biosphere to the geosphere. The residence time of organic compounds in this zone of the sedimentary column is long compared to the lifetime of the organisms, but very short compared to the duration of geological cycles: a 1-m section often represents 500 to 10000 years. During sedimentation processes, and later in such young sediments, organic material is subjected to alterations by varying degrees of microbial and chemical actions. As a result its composition is largely changed, and its future fate during the rest of the geological history predetermined within the framework of its subsequent temperature history.

When comparing the nature of the organic material in young sediments with that of the living organisms from which it was derived, the striking point is that most of the usual constituents of these organisms, and particularly the biogenic macromolecules, have disappeared. Proteins, carbohydrates, lipids, and lignin in higher plants amount to nearly the total dry weight, on an ash-free basis, of the biomass living in subaquatic or subaerial environments. The total amount of the same compounds that can be extracted from very young sediments is usually not more than 20% of the total organic material, and often less. This situation results from degradation of the macromolecules by bacteria into individual aminoacids, sugars, etc. As monomers, they are used for nutrition of the microorganisms, and the residue becomes polycondensed, forming large amounts of brown material, partly soluble in diluted NaOH, and resembling humic acids.

As time and sedimentation proceed, the sediment is buried to several tens of meters. Most of the organic material becomes progressively insoluble as a result of increasing polycondensation associated with loss of superficial hydrophilic functional groups. This completely insoluble organic matter from young sediments has received limited attention until recently. It is called “humin” by the few soil scientists who have worked on sub-aquatic soils. In ancient sediments the insoluble organic matter, called kerogen, is obtained by demineralization (HCl, HF) of the rock. This procedure is not degradative for ancient organic matter, as shown by Durand et al. (1977) on coals and oil shales. The situation is rather different in young sediments, where an important part of the humin can be hydrolyzed by this procedure (Huc, 1973). The hydrolyzable fraction progres-
sively decreases with burial. Thus humin, collectively with other insoluble organic matter such as pollen, spores, etc. may be considered as a precursor of kerogen, but the terms *humin* and *kerogen* are not strictly equivalent. Petroleum geochemists consider kerogen as the main source of petroleum compounds.

The whole process is referred to here as *diagenesis* and leads from *biopolymers* synthesized by living organisms to *geopolymers* (kerogen) through fractionation, partial destruction and rearrangement of the building stones of the macromolecules. For convenience in the discussion, three steps will be considered in the following paragraphs (Fig. II.1.1):

- Biochemical degradation
- Polycondensation
- Insolubilization

It has to be realized that the first and the second step follow in immediate succession, resulting in a zone where both processes are active at the same time. This zone comprises to some extent the water and the top layer of the sediment. Nevertheless, small or minute amounts of aminoacids, lipids and sugars are still found even in very old rocks. Insolubilization may also start early for some organic material, but humic acids, which are soluble in dilute NaOH, are still found at several hundred meters depth in sediments containing abundant detrital material of continental origin.

### 2.2 Biochemical Degradation

The four constituents of the young sediments are minerals, organic matter from dead plants or animals, interstitial water, and living benthic organisms. The last ones usually include a wide range of forms, but microorganisms are the most active and widely distributed in shallow water sediments. They are usually less important and under deep oceanic conditions.

#### a) Microbial Activity

Microorganisms — mostly bacteria, actinomycetes, fungi and algae — are abundant in sub-aerial soils, waters, and sediments deposited under moderate water depths. Their normal activity is the decomposition of organic matter, thus providing energy and/or material to build up the constituents of their cells.

In aquatic environments, bacteria seem to be especially important: they are present in both sea and lake waters. In certain sites, they are abundant in the uppermost half meter of the young sediment. As burial continues, the quantity of bacteria and other microorganisms decreases rapidly with depth (Table II.2.1). Since photosynthesis is impossible inside the sediment, the energy necessary for the synthesis of microbial constituents is obtained there by degradation of existing carbon compounds (Debyser, 1969), essentially through respiration under aerobic conditions and fermentation under anaerobic conditions. The material utilized for synthesis is also normally taken from existing organic compounds.