ABSTRACT

Bacteria grow preferentially in biofilms. This mode of growth allows these organisms to set up highly structured, physiologically cooperative communities because they remain in stable juxtaposition to the colonized surface and to each other. Planctonic bacteria cannot establish these highly organized consortia. As a consequence, the focused bacterial biodeterioration of insoluble substrates and microbially influenced corrosion of metals are both dependant on biofilm formation. Furthermore, the biodeterioration of complex soluble organic substrates requires more than one species of bacteria; biofilm formation is therefore also a sine qua non in these processes. We must understand biofilms if we are to understand and control biodeterioration.

INTRODUCTION

Since the birth of microbiology in the times of Pasteur and Koch, the study of bacteria has traditionally been conducted on in vitro pure cultures rather than on the organism in contact with its habitat. Two centuries of intensive study have produced an exhaustive and very useful perception of the amazing genetic and physiological capabilities of bacterial cells; this perception has resulted in the production of a myriad of useful products such as vaccines, antibiotics, and genetically engineered organisms. In the past two decades, methods have been developed to allow the detailed chemical examination of bacteria in situ in their native habitats and we are led to the inescapable conclusion that phenotypic plasticity is actually the most amazing characteristic of the bacteria cell (1). It is now apparent that cells grown in pure in vitro cultures bear very little resemblance to cells of the same species growing in a specific natural habitat. Bacterial cells adapt themselves chameleon-like to virtually every microniche that they occupy. At almost the same time that M.R.W. Brown and his colleagues discovered phenotypic plasticity in bacteria, we began to use morphological methods to examine bacteria directly as they grew in a variety of natural systems.

DIRECT EXAMINATIONS OF BACTERIA

Early insights were developed by Marshall and his colleagues (2) who, in their examinations of the growth of marine bacteria, noted the pronounced tendency of these organisms to adhere to surfaces and then to divide to form adherent microcolonies and biofilms (Fig. 1)(3). When a wide variety of nutrient-sufficient natural and industrial
ecosystems had been examined quantitatively, it became clear that the majority of the bacterial cells in these systems actually grow in exopolysaccharide-enclosed adherent biofilms on available surfaces. An accurate estimate of the physiological activity of bacteria within an aquatic system could, therefore, only be obtained by including the direct study of intact mixed-species biofilms (Fig. 1). Meanwhile, direct examination of microorganisms in the very nutrient-poor zones of the deep oceans revealed yet another profound bacterial adaptation to oligotrophic conditions - the formation of very small (<0.3 μm) starved dormant ultramicrobacteria (4). There is very little resemblance between the full-sized planctonic (floating) cells studied conventionally in vitro pure cultures and the same organism grown in nutrient-sufficient or in nutrient-poor natural environments.

![Diagram of natural adherent biofilm](image)

**Fig. 1.** Diagrammatic representation of a natural adherent biofilm in which bacteria (open circles) live within a continuous matrix of exopolysaccharide made by themselves and by their algal symbionts. The diagrams speculates concerning processes within this microbial biofilm, where diatoms and blue-green algae (cyanobacteria) are physiologically integrated with the adherent bacteria. **BG:** blue-green bacteria; **D:** diatoms; **DOC:** dissolved organic carbon; **LC:** lysed cyanobacteria; **MC:** microcolony

**BIOFILM BACTERIA IN BIODETERIORATION**

The conditions encountered by bacterial cells within a biofilm microniche differ radically from those in the bulk fluid of any given ecosystem. Unlike planctonic cells, they live within hydrated matrices where they remain in a restricted orientation to the coloniz-