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BIOCHEMISTRY AND GENETICS OF CELLULOSE DEGRADATION

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Biochemistry and Genetics of Cellulose Degradation

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Biochemistry and Genetics of Cellulose Degradation

Proceedings of a symposium, organized by the Federation of the Microbiological Societies and the French Society for Microbiology, on 7–9 September 1987

PREFACE

This Symposium organized by the Federation of European Microbiological· Societies and the French Society for Microbiology, was held on the campus of the Pasteur Institute, Paris, France, on September 7-9, 1987.

When we decided, three years ago, to submit to the FEMS Council a project for a Symposium mainly focused on basic aspects of cellulose degradation, we were a little uncertain about the interest that such a Symposium would arouse in the scientific community. The response exceeded our highest expectations since we received about 250 applications coming from 37 countries from all over the world.

In the early eighties, cellulose degradation was considered a priority in many countries, mainly because of potential applications. Advances in this field were expected to bring a significant contribution to solving, at least in part, the energy crisis by utilization of biomass. As for many other biotechnological potentialities, it rapidly turned out that, in addition to economical or polical considerations, cellulose utilization was seriously limited by an inadequacy of basic knowledge. Though it is more difficult now than five years ago to raise public or private funding, to study cellulose degradation, it appears that many laboratories are still actively working in this field. This is probably due to the fact that, while keeping all the expected potentialities for applications, degradation of cellulosic or lignocellulosic compounds remains a very attractive subject for basic research. This is because the structures of these compounds are particularly resistant to degradation and because of the variety of microorganisms, bacteria and fungi, aerobes or anaerobes, mesophiles or thermophiles, which are able to use them as a carbon and energy source.

The title of the Symposium "Biochemistry and Genetics of Cellulose Degradation" is somewhat restrictive since chemical and physico-chemical approaches were presented and a part of the Symposium was devoted to degradation of hemicellulose and lignocellulose.

This convergence of different approaches to the same problem by chemists, physico-chemists, biochemists and geneticists is, in our opinion, the first stage of an imperative requirement for making significant progress during the coming few years. The second stage is, of course, that collaboration starts wherever possible between specialists from different fields. It goes without saying, however, that a collaboration between scientists of the same speciality and studying the same organism is highly recommended. We hope that this Symposium has contributed to the establishment or to the improvement of both types of collaboration. We are also confident that our deliberations will lead to the improvement of industrial processes dealing with biomass utilization.

In planning the Scientific Programme, we tried to give to the speakers an opportunity to present a comprehensive survey of some problems related to three main topics : Biochemistry of cellulose degradation; Genetics of cellulolytic microorganisms; Biodegradation of hemicellulose and lignocellulose. This part of the Programme, which could not cover all the aspects and the systems which deserve to be discussed, was completed by the presentation of 120 posters whose titles are listed at the end of this book. In addition, as any progress in research depends on the development of techniques and methodologies, a Round Table, devoted to some aspects of these matters, was held at the end of the Symposium.

Amongst the large amount of information accumulated during the Symposium, the high number of different species studied in different laboratories is worth noting. Among some 80 strains of bacteria or fungi refered to during the Symposium, the most studied organism is Trichoderma reesei, followed by Clostridium thermocellum and Phanerochaete chrysosporium. However, a wealth of data is also being accumulated on other organisms. Another striking feature is the exponential development of molecular genetics both in prokaryotic and eukaryotic organisms. Consequently more than 30 genes, coding for endoglucanases, exoglucanases, β-glucosidases, xylanases, and ligninases, are now available for further study. Biochemistry also progresses, but at a slower pace than molecular genetics. This is mainly due to the complexity of the substrates and to the fact that even hydrolysis of the simplest compound, pure crystalline cellulose, requires the cooperative action of several enzymes, sometimes organized in well-defined structures.

However new models were proposed for our consideration. Hopefully current studies on the mechanisms of action, the tridimensional structure of individual enzymes and on the organization of multienzyme complexes will contribute to improve our knowledgde in this field.

Without the generous financial support provided by our sponsors, listed on page , this Symposium would not have been possible. We are grateful to the Direction of the Pasteur Institute who kindly put at our disposal a number of logistic facilities. We appreciate the help of all the members of the Organizing Committee for the provision of the administrative skills required for a functional and financially equilibrated organization. We would like also to thank all the participants who contributed a chapter to this book and who, by depositing their manuscripts in good time, made possible a rapid publication.

Jean-Paul AUBERT
Pierre BEGUIN
Jacqueline MILLET

October, 1987

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CONTENTS

ROUND TABLE

Introductory lecture

CELLULOSE DEGRADATION AND THE CARBON CYCLE

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1. INTRODUCTION

Renewable resources of reduced carbon are of great value for biotechnological processes. At present sucrose and starch are especially important in this respect, but not so much cellulose. The latter occurs in nature primarily as lignocellulose, which - because of its complex structure - is subject to a rather slow biological degradation. Therefore, extensive research activities have focussed on the biochemistry and the genetics of the enzyme systems which are involved in the degradation of lignin and in the hydrolysis of cellulose. The results obtained so far and those that will be obtained in the near future are of great scientific value; they may also have practical implications if they lead to a biotechnological process of lignocellulose degradation which is economically feasible. In this connection the question may be asked whether an extensive utilization of lignocellulose for biotechnological purposes could have an effect on the carbon cycle of our planet.

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2. The global carbon cycle

Life on earth can exist for a long period of time because of the cycles of matter. The four major cycles are those of carbon, nitrogen, sulfur and phosphorous. Here, only the cycle of carbon is considered. An overview of the carbon budget on earth is given in Table 1; figures are in Gigatons (Gt) carbon.

TABLE 1

The carbon budget of the earth[a]

Carbon reservoir	Organic carbon (Gt)[b]	CO_2/HCO_3^- (Gt)
Atmosphere	3.2	712
Land	~2 500	various carbonates
phytomass-830 animals-2 bacteria and fungi-3 litter-90 soil organic carbon-1500		
Oceans living organisms-3 dissolved organic carbon~1000	1 000	37 400
Lithosphere	16 000 000[c]	various carbonates

[a] Data taken from B. Bolin (1)
[b] Gigatons = 10^9 tons
[c] These reservoirs contain fossil carbon, ~10.000 Gt can possibly be recovered

Comparatively little carbon is present in the atmosphere: about 715 Gt. The land contains approximately three times as much organic carbon. Notably, most of it is present in the phytomass and in soil organic carbon which primarily stems from lignocellulose. The ocean's organic carbon content including the biota is about half of the amount on land. Of course, a vast amount of inorganic carbon is present here.

Important but sometimes neglected in discussions is the non-carbonate carbon in the lithosphere, in the sediments of the continental crust and of the ocean crust. Together these are 16 x 10^6 Gt. From this enormous amount about 10.000 Gt - less than 0.1 % - are present as oil, gas or coal reserves that possibly can be recovered; the major part, however, is finely dispersed.

A summary of these data leads to remarkable conclusions. Most of the carbon on earth which ever has been fixed through the Calvin cycle is present in the lithosphere - it is about 5.000 times as much as found in , what is usually called nature. No doubt, this material stems to a large extent from lignocellulose. Its residence time is several million years. Organic carbon of living organisms is primarily organic carbon of phytomass. From the 830 Gt carbon of plant materials approximately 700 Gt are present in long-lived biota - again this is lignocellulose to a large extent.

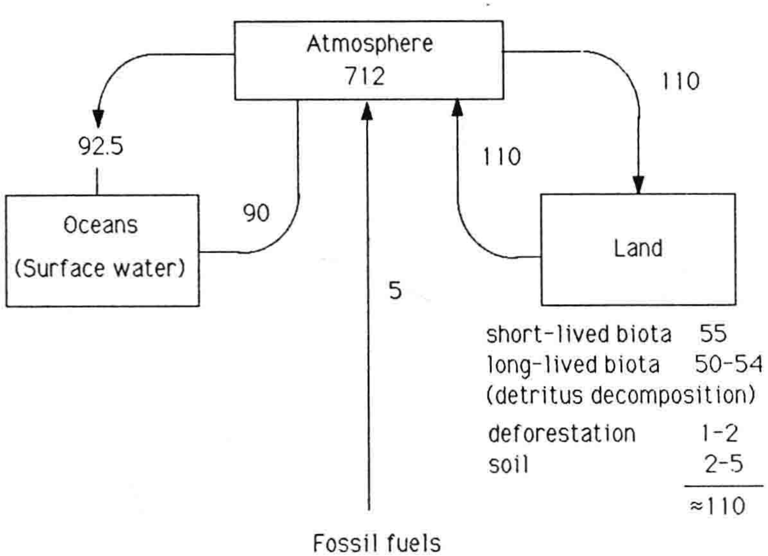

Fig. 1 Annual carbon fluxes (1,2), figures are Gigatons