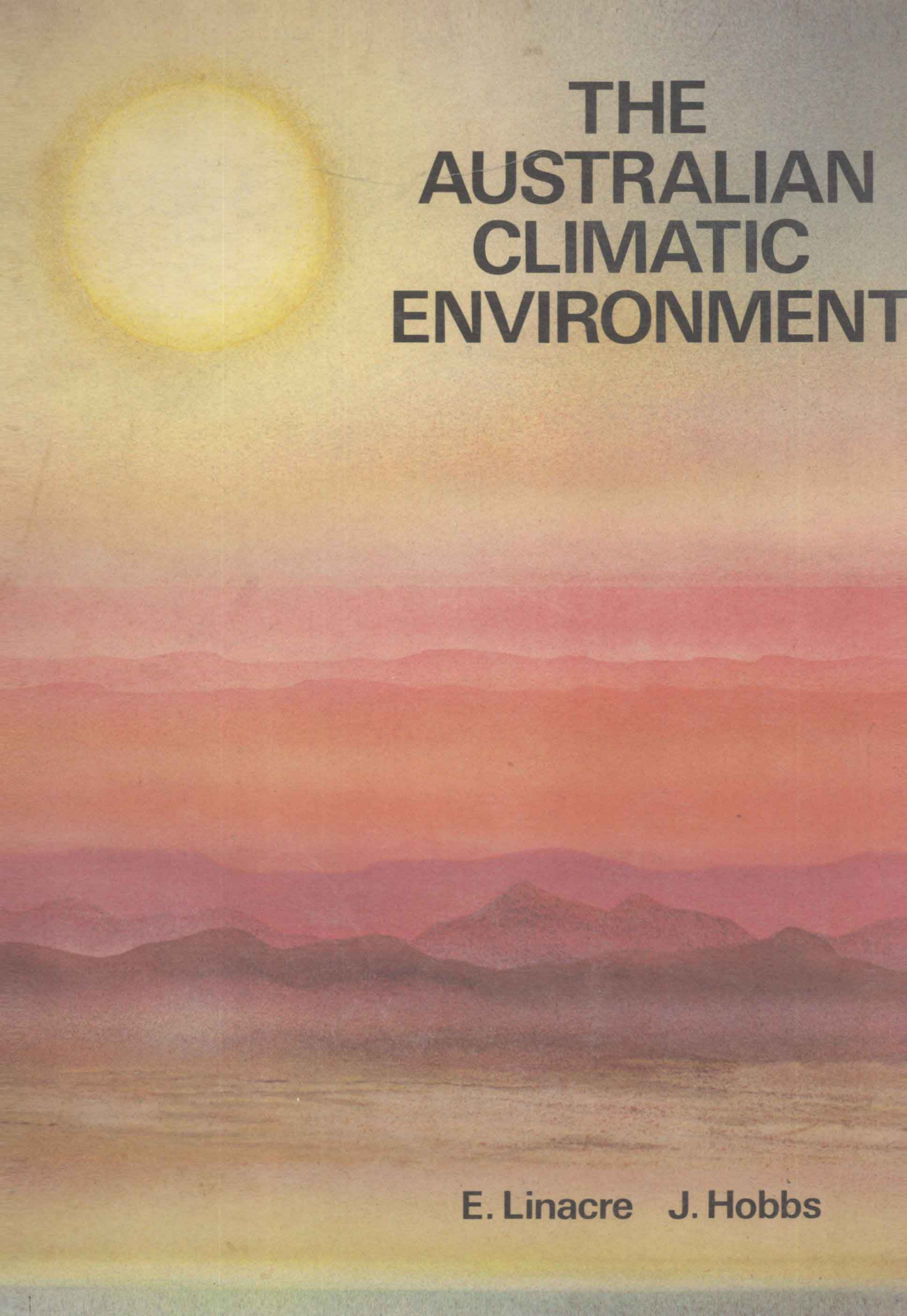
THE AUSTRALIAN CLIMATIC ENVIRONMENT



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The Australian Climatic Environment

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Foreword

This book is being published at the height of a new public awareness of climate as a factor in the world economy. Since 1971 we have witnessed dramatic anomalies of weather that have starved people and animals in Africa, upset prices of cereals on the world market, and reduced such well-watered countries as the United Kingdom to considering freshwater imports from overseas. It is not, in fact, obvious that these strange events have been in any way unique, or that this signals a lasting, hostile change in the Earth's climate. What they have done, however, is to sharpen public interest and scrutiny, and they have led to the inevitable question: will they continue?

At present such questions have to be ducked by the meteorologist, because of the difficulty of predicting variation of climate, or adequately explaining the past. The meteorologist is in the strange position of knowing the laws that govern the atmosphere's behaviour, yet being unable to use those laws in long-range prediction. In part this arises from a lack of observation, now being rapidly improved by new satellite techniques of the formidable World Weather Watch Programme organised by the World Meteorological Organisation in most national states. But for the most part it arises from ignorance of just *how* the atmosphere functions within the broad constraints of these governing laws.

It is easy to dismiss this failure as being due to poor thinking and inadequate research. Scientists who work on easier problems (and most problems *are* easier!) are especially apt to take this line. Such strictures are not justified. The atmosphere is an extremely complex system that interacts in vital ways with oceans, living organisms and the continental surfaces. It is notoriously difficult to study such interactive systems and climate is no exception.

It is now quite clear that fundamental progress towards prediction will require a closer understanding of how surface exchange processes influence the properties and circulation of the atmosphere. This will involve marrying the outlooks of those who study surface processes—physical climatologists, agricultural meteorologists, hydrologists, soil physicists, oceanographers and others—with those who try to model the world's wind systems in the language of applied mathematics. And it will be necessary to train generations of students to whom such a marriage comes easily.

The authors of this volume have addressed these problems with vigour and imagination, not to mention clarity. They have themselves contributed extensively to the research background, and have well-deserved reputations as teachers. Moreover they have worked in that long-neglected half of the world called the southern hemisphere. The literature of world climate is still to a large extent based on northern hemisphere experience and techniques. Often it is assumed that the two hemispheres are so coupled together that this doesn't matter. Recent evidence refutes that view so it is necessary to rescue Australian, New Zealand, South American and South African students from the clutches of northern authors, like myself!

Linacre and Hobbs have done this admirably. Their primary focus is on Australian climates, but the rest of the hemisphere is not ignored. The basic physics, chemistry and biology of the atmosphere are, of course, universal, and they are so treated in the book, even if weather maps differ so much between the hemispheres because of the reversal of the Coriolis effect.

The book goes all the way from the basic universal science to the impact of climate on the human economy and health. The text is reinforced by quantitative problems (of which there is never any lack in professional practice) and a comprehensive bibliography. It should go far to create the awareness of proper scope that we must demand of future climatologists.

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Director of the Institute of Environmental Studies, Toronto

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Preface

This introductory text is meant to be useful to school teachers, tertiary students who are taking geography or meteorology courses, and to the intelligent layman. It is intended that the book can be understood without previous training and that it should provide a broad foundation for further reading in geography, meteorology, ecology, natural resources, or environmental studies. Emphasis is placed on the explanation and relevance of climates in the southern hemisphere, especially Australia.

The main text of the book is non-mathematical so that the concepts and processes can be understood by anyone. It can be used for self-tuition. Each major concept is put in italics when first mentioned and explained. The student will find the self-assessment tests helpful. Numerical exercises are followed by solutions that demonstrate various techniques of problem solving. Numerous references are given to further readings.

Teachers will find the index useful, and also the suggestions for essay questions. SI units are defined and their interrelationships listed. Tabulated data are provided on climates of Australia and other southern hemisphere regions. The measurements quoted include several resulting from the work of students; teachers may car to arrange similar measurements in their own town.

One feature of the book is the number of cross references within it, which emphasise the coherence of the subject. Where further details are to be found in a later chapter, only the chapter number is mentioned. When more information has been given previously, reference is made to the relevant section.

The references for most of the papers and books used as sources are given in Chapters 26 and 27. The references for those illustrations and tables that are not original are given in terms of the original source and, in many cases, of a more recent and more accessible secondary source, for the convenience of those wanting to study a point in more detail. We hope that this introductory survey will induce readers to explore further the intriguing ramifications of climatology.

Edward Linacre
John Hobbs

The Metric Conversion Board has checked that the correct metric units have been used throughout the book. However, some of the diagrams do not have approved metric units because they have been taken from other publications.

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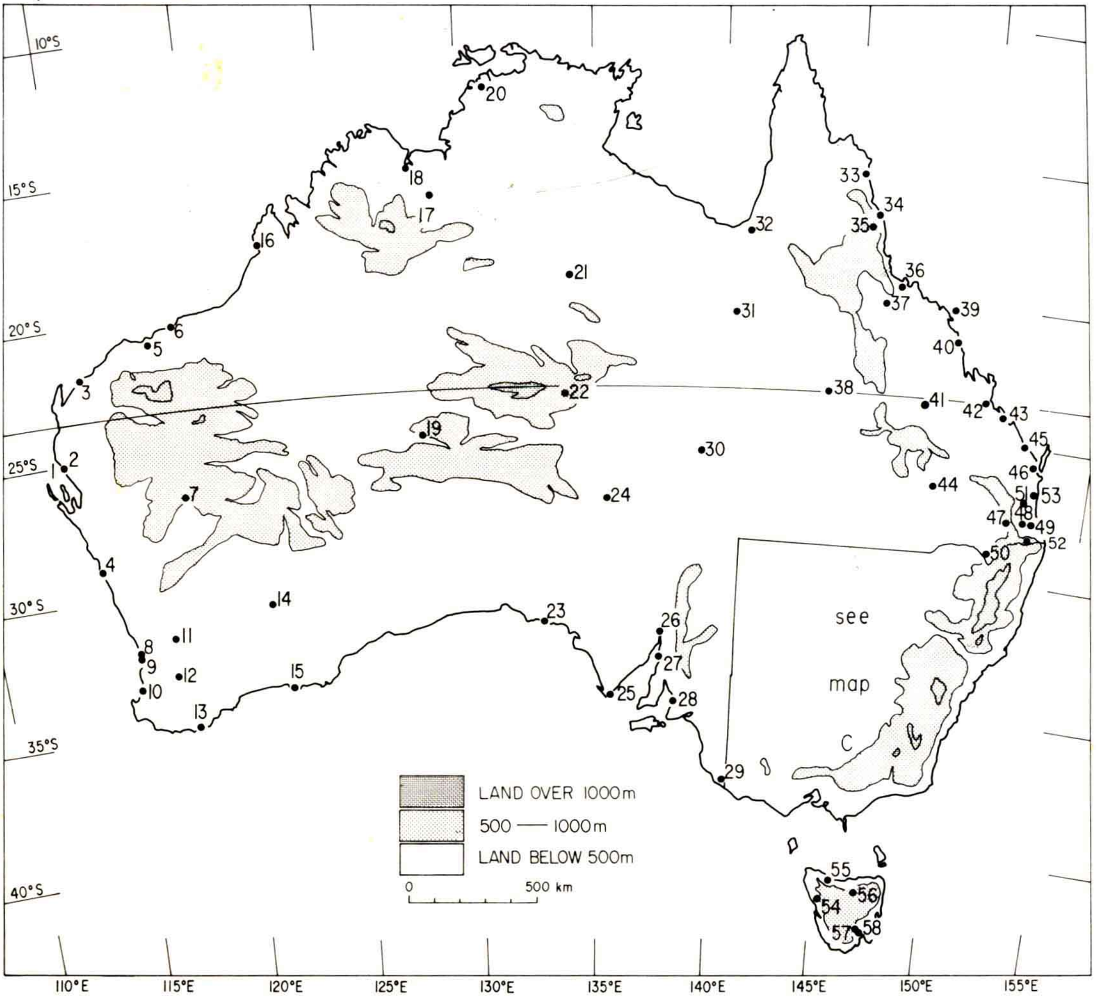
We also acknowledge the professional skill and hard work of Rosalind Stew, the book's editor.

Map A.

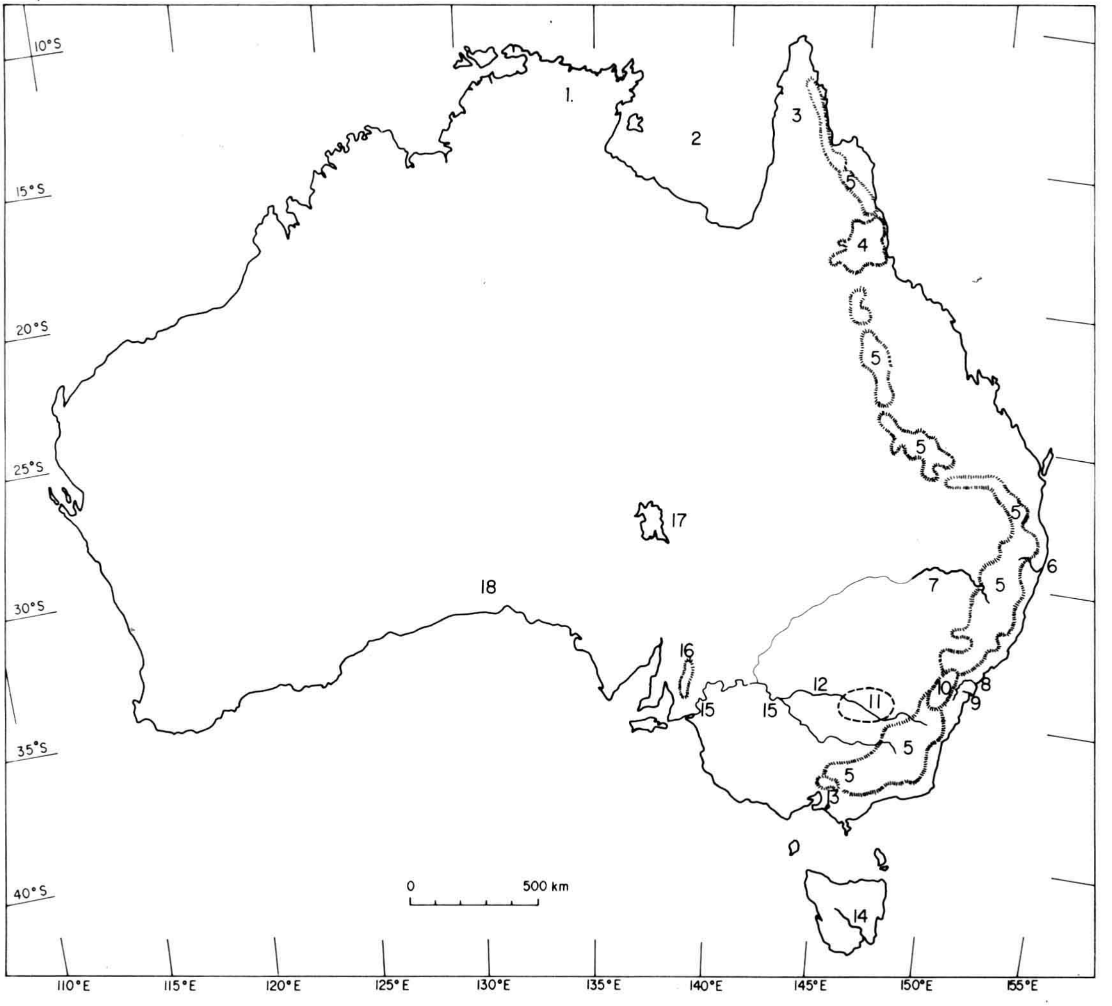


MAP A: Some places within Australia mentioned in the book

Place	Location No.	Place	Location No.
Adelaide	28	Maryborough	46
Albany	13	Meekatharra	7
Alice Springs	22	Mt Gambier	29
Atherton	35	Mt Wellington	57
Birdsville	30	Normanton	32
Brisbane	49	Narrogin	12
Broome	16	Onslow	3
Bunbury	10	Oodnadatta	24
Bundaberg	45	Perth	8
Burnie	55	Port Augusta	26
Cairns	34	Port Hedland	6
Carnarvon	2	Port Lincoln	25
Ceduna	23	Port Pirie	27
Charters Towers	37	Rockhampton	42
Cloncurry	31	Roma	44
Cooktown	33	Shark Bay	1
Crohamhurst	51	Springbrook	52
Cunderdin	11	Tennant Creek	21
Darwin	20	Tewantin	53
Emerald	41	Texas	50
Esperance	15	Toowoomba	47
Fremantle	9	Townsville	36
Geraldton	4	Whim Creek	5
Giles	19	Wyndham	18
Gladstone	43	Zeehan	54
Hayman Island	39		
Hobart	58		
Ipswich	48		
Kalgoorlie	14		
Kimberley	17		
Launceston	56		
Longreach	38		
Mackay	40		

Location No.	Place
Western Australia	
1	Shark Bay
2	Carnarvon
3	Onslow
4	Geraldton
5	Whim Creek
6	Port Hedland
7	Meekatharra
8	Perth
9	Fremantle
10	Bunbury
11	Cunderdin
12	Narrogin
13	Albany
14	Kalgoorlie
15	Esperance
16	Broome
17	Kimberley
18	Wyndham
19	Giles
Northern Territory	
20	Darwin
21	Tennant Creek
22	Alice Springs
South Australia	
23	Ceduna
24	Oodnadatta
25	Port Lincoln
26	Port Augusta
27	Port Pirie
28	Adelaide
29	Mt Gambier
Queensland	
30	Birdsville
31	Cloncurry
32	Normanton
33	Cooktown
34	Cairns
35	Atherton
36	Townsville
37	Charters Towers
38	Longreach
39	Hayman Island
40	Mackay
41	Emerald
42	Rockhampton
43	Gladstone
44	Roma
45	Bundaberg
46	Maryborough
47	Toowoomba
48	Ipswich
49	Brisbane
50	Texas
51	Crohamhurst
52	Springbrook
53	Tewantin
Tasmania	
54	Zeehan
55	Burnie
56	Launceston
57	Mt Wellington
58	Hobart

Map B



MAP B: Regions in Eastern Australia mentioned in the book

Region	Location No.
Atherton Tableland	4
Arnhem Land	1
Blue Mountains	10
Cape York Peninsula	3
Dandenong Ranges	13
Derwent River	14
Gt Dividing Range	5
Gwydir River	7
Gulf of Carpentaria	2
Hawkesbury River	8
Lake Eyre	17
Mt Lofty Ranges	16
Murray River	15
Murrumbidgee River	12
Nullabor Plain	18
Parramatta River	9
Richmond River	6
Riverina Area	11

Location No.	Region
1	Arnhem Land
2	Gulf of Carpentaria
3	Cape York Peninsula
4	Atherton Tableland
5	Gt Dividing Range
6	Richmond River
7	Gwydir River
8	Hawkesbury River
9	Parramatta River
10	Blue Mountains
11	Riverina Area
12	Murrumbidgee River
13	Dandenong Ranges
14	Derwent River
15	Murray River
16	Mt Lofty Ranges
17	Lake Eyre
18	Nullabor Plain

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Part I

Energy Flows in the Atmosphere

1 The Atmosphere

1.1 Introduction

Our lives depend on the atmosphere, because we need air to breathe and rain to drink and to moisten the soil which provides our food. We live at the bottom of an ocean of air and depend on the atmosphere in the way that a fish depends on water. The vagaries of the atmospheric conditions which make up "the weather" affect our feelings of well-being, our safety, power supplies, transport networks and many other aspects of existence. The skies are a topic for everyday small talk and provide inspiration for poets. The history of mankind has been influenced by storms, crop failures and plagues due to bad weather, and man's future depends upon maintaining a favourable climate.

In view of this, the study of the atmospheric environment characteristic of a place, its *climate*, is a relevant topic. The study of climate is closely connected with practical problems of urban air-pollution, agriculture and the problems of populating northern Australia, for instance. The scientific study of climate, *climatology*, is a subject which is also intellectually challenging. Why are climates what they are? How are they changing? How do they affect reservoir construction, building regulations, automobile-emission limits and so on? What were climates like in times past? These are important but difficult questions and seeking the answers is a fascinating pursuit.

In beginning our consideration of the climatic environment, we note firstly that climate is an abstraction, a generalisation, as unreal as the average family with two-and-a-half children. Secondly, climate does not consist simply of mean conditions. These are important but the frequency of extreme events may be even more significant in agriculture, for example. Floods and droughts do not cancel each other out; they compound the rigour of a climate. Extreme frost or heat-wave conditions may be especially important to health.

Climatology is closely linked with *meteorology*, the science of atmospheric processes. The distinction is customarily expressed in terms of the length of time involved. Relatively brief single events, like flooding rains, are regarded as meteorological: meteorology is taken to be the study of events lasting seconds, weeks or a few months at most. In short, meteorological processes underlie the weather, whose aggregate is the climate, though the distinction between meteorology and climatology becomes increasingly blurred. On the one hand, climatology ceases to be simply descriptive and is nowadays concerned with explanation, while on the other, meteorologists now study gradual changes of climate and the processes involved. A satisfactory understanding either of climate or of the long-term implications of meteorological events requires consideration of both. For example, wet climates in particular regions can be explained only in terms of the meteorology of rain formation.

In the following chapters we shall deal with basic meteorology and the resulting climates. We begin with a look at the atmosphere itself.

1.2 Origin of the Atmosphere

The planet Mercury and our moon are airless; Mars has extremes of temperature, high winds and dust storms; Venus has acid clouds; so their atmospheres differ greatly from our congenial environment. However, the gaseous envelope around the Earth has changed considerably since the early part of this planet's history.

Current thinking suggests that the Earth was formed about 4500 million years ago, and that its primary atmosphere was composed mainly of hydrogen expelled from the rock by the bombardment of solar rays. A secondary atmosphere then began to form from gases emitted by the molten materials of the Earth's interior. Initially this atmosphere was mostly water vapour, methane, ammonia and hydrogen, as on other planets today. About 3000 million years ago,[1] the cooling of rocks gave off the kinds of gases now emitted by volcanoes—water vapour, nitrogen and carbon dioxide. None of these gases contains free oxygen. The absence of oxygen in the early atmosphere is demonstrated by the oxygen-deficient composition of rocks formed at that time.

It remains uncertain how free oxygen came into the atmosphere, but there are several theories. One involves the splitting of molecules of water vapour by solar radiation, thus forming separate hydrogen and oxygen atoms. Hydrogen is light and relatively mobile and would tend to escape from the Earth's gravitational field into space. The oxygen remaining is thought to have absorbed the radiation responsible for the splitting, thus blocking the splitting of more water vapour and limiting oxygen production to about one thousandth of present amounts. This automatic regulation of oxygen formation from water vapour is called the *Urey effect*.

Further creation of oxygen depended on the process of *photosynthesis*, which occurs in some bacteria and in the leaves of plants. Photosynthesis, the basic process of plant life, involves the combination of carbon dioxide, water and sunlight energy to form oxygen and carbohydrates, the building-block of plant tissue.[2] This affected the amount of oxygen in the atmosphere from about 2000 million BP: before that, life in simpler forms had evolved without oxygen. Photosynthesis gradually increased the oxygen content of the atmosphere until about one hundredth of the present oxygen concentration was reached at 1000 million BP. At this stage, the evolution of life went into higher gear with the development of *respiration*, the reverse of photosynthesis, which involves the combination of carbohydrates with atmospheric oxygen and results in the release of carbon dioxide and energy. Thus, photosynthesis in the leaves, and respiration elsewhere in a plant, effectively carry solar energy throughout the plant for use in various physiological processes such as water intake and hormone transport. Much more complicated plants became possible, permitting their extension into a wider range of environments. The increased vegetation then made further oxygen by photosynthesis.

Before there was much oxygen in the atmosphere, sterilising radiation from the Sun could reach to ground level and so prevent the development of any life in exposed situations. Living material could only exist under water at depths of at least 10 metres. Life in shallower water became possible as the atmospheric oxygen concentration increased, with the consequent advantage of better access to the atmospheric carbon dioxide needed for photosynthesis. By about 400 million BP the atmosphere contained sufficient oxygen to allow life to exist on land and, as a result, another rapid acceleration of the evolutionary process took place, with an increase of oxygen to present levels by about 300 million BP.

That account of the history of our atmosphere is based on current literature. The subject is controversial and many aspects still are disputed and require clarification. However, it is clear that an important component of the atmosphere derives from plants. The atmosphere is also controlled by plants now: for example, forest fires would burn more fiercely if the oxygen content of the atmosphere were to increase, reducing the amount of vegetation and resulting in decreased oxygen production which would restore the *status quo*. Moreover, an increase in the normal oxygen content of the atmosphere would subtract from the amount existing in carbon dioxide, so the latter's concentration in the atmosphere would fall, allowing extra heat loss from the earth (Chapter 2). Global temperatures would then decrease so that photosynthesis rates would decrease, which again would restore lower oxygen levels. In other words, the oxygen concentration appears to be automatically held steady by the vegetation. However, the plant-atmosphere relationship acts both ways. Not only do plants affect the air's composition but

[1] This is written as 3×10^9 BP, where BP stands for "before the present", taken to be 1950.

[2] An equation which roughly expresses the photosynthetic reaction is as follows:

$$\textbf{sunlight} + 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

also they themselves evolve to suit the Earth's atmospheric conditions (Chapter 22).

1.3 Composition of the Earth's Atmosphere

The atmosphere is a mixture of various gases achieved by simple addition, without chemical reaction. It also contains water vapour, dust, and liquid or solid particles in quantities which vary with time, location and altitude. Nevertheless, gases such as nitrogen and oxygen are found in the same constant proportions, mixed to uniformity up to roughly 80 km altitude. Over 98% of the total mass of air is due to nitrogen and oxygen. If the components of a litre of air were separated, then 0.7809 litres (written as 780.9 millilitres or 780.9 ml)[3] would be occupied by nitrogen. In other words, 78.1% of the atmosphere's volume is nitrogen. The proportion would be slightly different if masses were considered instead of volumes, because the densities of nitrogen and air are not the same. The proportion of unit mass of air accounted for by the mass of the nitrogen would be 75.5%. For oxygen the figures are 21.0% by volume and 23.1% by mass, for argon 0.93% by volume and 1.28% by mass, for carbon dioxide approximately 0.03% by volume and 0.045% by mass. There are also traces of other gases such as neon, helium, krypton, hydrogen and xenon. In addition, air near the ground at the equator may contain 2.6% by volume of water vapour, while the colder air at latitude 70° might have as little as 0.2%. Above, at levels up to about 1000 kilometres, there are greater proportions of oxygen. Higher still there is relatively more helium, then relatively more hydrogen, because gravitational sorting leads to greater proportions of these lighter gases.

The amounts of carbon dioxide near ground level are affected by the gas being dissolved in the oceans, by plant uptake and by man's activities. There are 2.4 million million tonnes of carbon dioxide in the atmosphere but many times more in the oceans, which readily dissolve it, especially where the water is cold near the poles. The growth of plants in the northern hemisphere summer lowers the atmospheric concentration from 310 ml to 305 ml in each cubic metre of air (written as 310–305 ml/m^3). However, during the rest of the year respiration is the dominant plant process and it restores carbon dioxide to the atmosphere. Variations in carbon-dioxide levels are less in the southern hemisphere, where the land area is only half that in the north and the vegetation is correspondingly less. The industrial nations are also mostly in the northern hemisphere; man's contribution to atmospheric carbon dioxide in 1960 was about 11 thousand million tonnes annually from the combustion of the carbon in oil, coal, natural gas, peat and wood.

It is important to realise the dynamic character of the atmosphere's components. Each molecule of carbon dioxide is continually undergoing a slow cycle of change: from a gas it becomes part of plant tissue, with subsequent respiration by plants or animals, maybe solution in ocean water and then escape back into the atmosphere (Fig. 1.1).

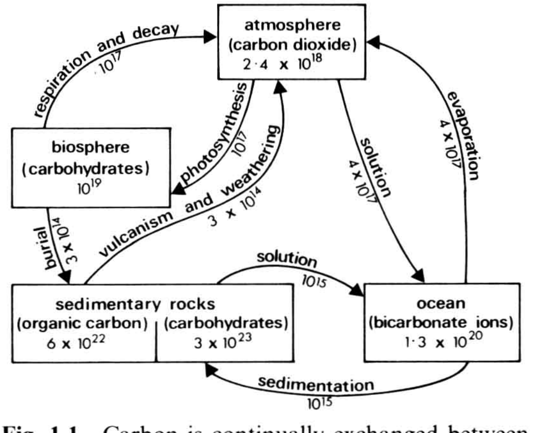

Fig. 1.1 Carbon is continually exchanged between the atmosphere, the oceans, the biosphere and sedimentary rocks. The diagram shows the amounts (in grams of carbon dioxide) at each stage in the cycle, and the annual rates of transfer of carbon dioxide between stages. (*After Goody and Walker, 1972, p. 127. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA.*)

[3] The definitions and inter-relationships of various metric units of measurement are given in Table 25.1 in Chapter 25.

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