of Rottnest's 1900*ha*.

Most of these lakes are exceedingly salty, up to seven times as salty as seawater in the dry season, and in one area a 2*ha* saltpan dries out each year leaving thick deposits of salt. Collecting salt from the Rottnest saltpan was one of Western Australia's earliest industries, and very large quantities were taken out in the past, as much as 1016 tonnes in a single year [Somerville, 1976].

One of the mysteries of Rottnest is where all this salt comes from. It has been suggested that it is washed out of the atmosphere — surprisingly large amounts of salt are contained in rain, even that falling well inland (1000*mm* of rain deposits about 500*Kg/ha* of salt on the West Australian coastal town of Geraldton, and over 170*Kg/ha* on Coolgardie, more than 500*km* inland). Another possibility is that seawater percolates through the porous Rottnest limestone into the lakes (which are below sealevel) and there evaporates.

There is a lot of salt in seawater — on average about 3.5% is dissolved solids, of which the majority (85%) is common salt, sodium chloride. In the open seas, the proportion varies both with latitude and proximity to land and river mouths, and with depth. Where does this salt come from and was there always so much of it?

The Ancient Seas

It seems a reasonable assumption that the source of the salt is the Earth's rocks — clearly most of the solid matter on Earth originates there, and even, as we have seen, at least some of the water. This salt circulates throughout the biosphere, coming from the sea onto the lands with wind and rain and returning through the rivers and underground aquifers.

As well as this rapid turnover, there is a much longer-term cycle in which salt is deposited in beds from continuing evaporation of water, and eventually converted into rock salt. Some rock salt beds are of great thickness, up to 400*m*. Salt deposits are in the process of formation today, and have been formed in rocks of varying ages stretching back at least as far as the Permian, some 300*my* ago. Before this they are not known with certainty.

There are grounds for believing that the salinity of the ancient seas was much less than that of today. The evidence is indirect, but reasonable. One interesting item concerns the composition of blood.

When creatures evolve to suit a change in their ecological conditions, when they cross the isocons, some of their characteristics are altered to suit the new conditions. But other of their characteristics are ecologically neutral, they have neither positive nor negative influence on the creatures' prospects of survival. With no forces pushing for a change, these neutral characteristics tend to remain unaltered.

We know that life on land evolved around 400*my* ago, in the Devonian, and it is believed that it evolved from fish through amphibians and on to reptiles. The blood of higher land creatures contains an appreciable amount of salt, but much less than that in seawater, around 1% as opposed to 3.5%. On the other hand, modern marine fishes have a blood salt level similar to that of seawater.

The inference is that the salt level of the ancient seas was much less than that of today.

To put a figure on this increase, if the change was regular from 1% to 3.5% in 400*my*, this is a rate of increase of 0.006%/*my*.

> *Proposition 10I*
> *The average salinity of seawater has increased continuously for at least the last 400my*

There is other evidence for this proposition. The most ancient groups of higher land plants with living descendants are the ferns and the cycads. Both these groups avoid saline water, being almost never found as seashore plants. The same is true of lower land plants, such as the mosses. This feature is understandable if, when these plants evolved (presumably from water plants), the seas were much less saline so that there was no incentive for these plants to develop the ability to live with salt.

On the other hand, plants which are at home in saline conditions are usually specialized members of younger, modern genera, such as the pistachio nut and the date palm. Some species of the recently evolved grasses, for example *Distichlis* (Australian beach grass), will grow when irrigated with seawater, and a tomato species native to the Galapagos Islands will actually grow in the sea. The ultimate is the group of seagrasses referred to in Chapter 6, true flowering plants whose ancestors undoubtedly evolved on land before re-adapting to live entirely under the sea.

Similarly, specific adaptions to cope with a salty environment are found in sea-going representatives of what we would regard as land animals. These adaptions give the ability to excrete excess salt in some way, usually with a mechanism related to tears [Morgan, 1982]. Seabirds secrete drops of an almost pure salt solution from nasal glands, shaking the drops off to eliminate salt. Normal land lizards do not produce tears, but the marine iguana of the Galapagos, the only sea-going lizard, does. Salt-water crocodiles 'cry', freshwater ones do not. And the only two land mammals with the ability to produce tears are man — and the elephant.

The inference is that when life on land first developed, the seas contained water which was much fresher than that of the modern oceans. We can restate Proposition 10I from the viewpoint of the evolution of life:

> *Proposition 10J*
> *Land creatures first evolved, around 400my ago, from sea creatures adapted to seawater much fresher than that of today*

This proposition also fits in well with the other Earth-expansion evidence we have had in this book. As with the Earth's water (Proposition 10D), the salt available at the surface would increase as the Earth expanded and more rock was taken into the active-domain zone. But, in contrast to this water, the salt would not be partly lost into space, and so its concentration relative to the water would increase.

The fact that the oldest rock salt deposits are around 300*my* old, while the first land probably appeared around 400*my* ago (Proposition 10C), also fits. Rock salt deposits could not form until there was enough land to enclose seas or lakes, and conditions arose suitable to achieve virtually complete evaporation of these waters, such as uplifted low domains not circled by mountains (which would give rise to freshwater inflow from rains).

An interesting feature of salt deposits are that they are often associated with deposits of petroleum, mineral oils. We will return to this point, and its significance, in Chapter 13.

Another interesting question is whether the *chemical composition* of the salts dissolved in seawater was different in former ages. We will look at evidence on this point in the next chapter, which deals with the Earth's atmosphere.

CHAPTER 11

THE EARTH'S ATMOSPHERE

"There is nothing particularly scientific about excessive caution. Science thrives on daring generalizations"

— Lancelot Hogben, 1938

We have seen that both the surface of the Earth, its interior, and the oceans which cover so much of its surface have apparently been subject to dramatic changes during our long geological history. Core, lithosphere, surface, and hydrosphere have all altered out of recognition. And now we will look at evidence of even more dramatic changes in the other component of the biosphere, the Earth's atmosphere.

Composition of the Atmosphere

The present atmosphere of the Earth consists mainly of about 78% nitrogen and 21% oxygen. The biggest minor component is the inert gas argon, making up 0.93%. Components at trace level include carbon dioxide (0.035%) and the inert gases neon, helium, krypton, and xenon (all well under 0.002%).

In addition, natural air always contains a certain amount of water vapour. This is often not emphasized (or even mentioned) in giving the composition of air, because it varies strongly with the air temperature, pressure, and humidity, but it is very important.

Saturated air (100% humidity) contains about 0.4% water vapour at freezing point (0°C), more than ten times the level of carbon dioxide. At 20°C, saturated air contains about 1.7% water vapour, and at 40°C, more than 4%.

In Western Australia, air humidity will nearly always reach 100% (making dew form) if the temperature falls to freezing, but will become much lower as the thermometer rises to 40°. Even so, the amount of water vapour in our air will nearly always be over 1%, so that water is the third largest component of our air.

Considerable attention has been paid recently to the level of the fifth largest component, carbon dioxide. This is because of its importance in the 'Greenhouse Effect', which we will look at later. For the moment, we need only note that, at about one-third of one percent, it is really a minor constituent of the atmosphere.

The evidence we shall look at now indicates that this was not always the case. In the past, carbon dioxide was once a major component of the atmosphere. And in the more distant past, it did not figure at all; the Earth's atmosphere has had several complete re-workings in its history, and its present composition bears no resemblance at all to that of the primitive Earth.

> *Proposition 11A*
>
> *The composition of the Earth's atmosphere has changed very markedly at different times in the past, and present and early compositions are completely different.*

Composition of the Early Atmosphere

If the composition of the young Earth's atmosphere was very different, what did it consist of? It is believed that the major components were hydrogen, methane, and ammonia.

There are a number of reasons for this belief. It accords well with what is known of the atmospheres of the other planets in our solar system (we will look at this more in Chapter 15). And it does fit in also with the types of sedimentary rocks known to have been formed in the past. For example, the great iron ore deposits of the world are in ancient Pre-Cambrian rocks, and are thought to have been laid down at a time when the Earth had a reducing atmosphere — an atmosphere with very little oxygen, such that iron would not rust in it like it does in our current oxidising atmosphere.

Later we will look also at biological evidence. But first we need to look at some of the physical properties of the gases which have been present in the Earth's atmosphere at different times (Table 11).

Table 11. Gases of the Atmosphere

Gas	Formula	Molecular Weight
Hydrogen	H_2	2
Methane	CH_4	16
Ammonia	NH_3	17
Water Vapour	H_2O	18
Nitrogen	N_2	28
Oxygen	O_2	32
Argon	A	40
Carbon Dioxide	CO_2	44

The molecular weight is very important because it has a vital effect on the escape velocity of the gas.

How Gases Work

The physical properties of gases have been studied for some centuries, and are now well-known and easy to understand. Many of these properties, such as change with different temperatures and pressures, depend only on the number of gas molecules present, and not on the type of molecules or mixture of these.

Other properties depend directly on the molecular weights of the molecules. These weights are just the sums of the weights of the atoms involved, with the weight of a hydrogen atom, the lightest element, taken as 1. A hydrogen molecule contains two atoms, so its molecular weight is equal to 2.

In a gas, all the molecules are in a state of continuous movement, flying back and forth in every direction. Some are travelling fast, others more slowly — there is a continuous distribution of speeds, from very fast to stationary. If these molecules are in a closed balloon, they continually beat against the sides of the balloon, exerting a pressure which keeps the balloon extended.

If a gas is heated up, on average its molecules move faster (molecular movement is the same thing as heat, in a gas) and so exert more pressure on the sides. Similarly, if the air in a balloon is squeezed down by outside pressure, there are more gas molecules hitting against a given area of the side, and so the internal pressure rises to match the outside one.

The interesting thing is that a particular volume containing a given number of molecules of a light gas shows exactly the same internal pressure as the same volume with the same

number of molecules of a heavier gas. But the *weight* of the gas depends directly on the molecular weights of the molecules involved. This is why a balloon filled with hydrogen will float; the gas in the balloon is less dense, because it contains the same number of lighter molecules. But to maintain the same internal pressure, the light molecules have to move faster, on average, than the heavy ones.

Flight into Space

The gas molecules making up the Earth's atmosphere are not in an enclosed space, but can mix freely. They beat against the Earth's surface, exerting what is called atmospheric pressure. What about straight up? Why don't they all fly straight off into space?

To be able to escape from the planet, gas molecules have to be able to climb out of the Earth's 'gravity well'. Figure 11.1 is a diagrammatic representation of this 'well' — not a real thing, just a mind model, a means of giving a graphic image of some physical laws.

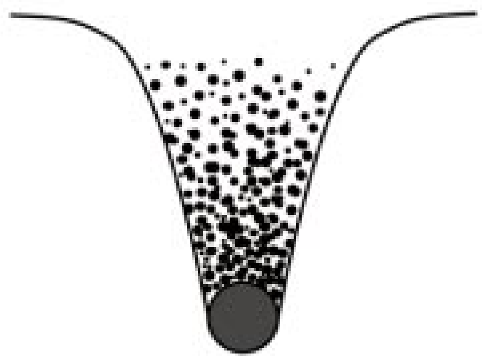

Fig. 11.1. Gas molecules in the Earth's gravity well

At the bottom of the well, on the Earth's surface, the gas molecules are thickly clustered and the air is dense. A gas molecule near the bottom which happened to be in flight straight up would most likely collide with another molecule on the way up, but the likelihood of such a collision would be less higher up where the air is thinner and there are fewer molecules around. A rising molecule which did not collide with another would gradually lose speed, as gravity pulled on it, and eventually would stop and fall back to the denser layers.

However, this mind model is called a well because it has a rim. At the rim of the well, the gravity of the Earth is exactly equal to the gravitational forces of the rest of the Universe — that is what the rim means in this image. If a gas molecule — or any other object, such as a spacecraft — is travelling upwards fast enough to be able to reach the rim before gravity saps off all its speed, it can pass the rim and go off into outer space.

Finally we come to the relevance of all this. Molecules of a lighter gas, which on average are travelling faster than those of a heavier gas, are more likely to attain this 'escape velocity' and leave the Earth forever.

Proposition 11B

Light atmospheric gases are much more likely to be lost from Earth into space than heavy gases

This is not a new Proposition, and not one disputed in any way today, but it is worth making a special point of it now, because of all its implications.

The Snow-Capped Mountains

We need to look now briefly at how air temperature and pressure alter as you go higher. Virtually all the phenomena we experience in the atmosphere, such as winds, clouds and rainfall, and pressure-related weather patterns, exist in the lower layer of the atmosphere, which is called the Troposphere. The troposphere is about 10*km* thick (more at the Equator, less at the poles), so even our highest mountains lie within it.

Within the troposphere, air temperatures fall as you go higher. There are many somewhat peculiar explanations for this to be found in textbooks, but it is really just a matter of the physics of gases — the thinner atmosphere higher up needs to be cooler to remain in equilibrium with the denser (and so warmer) layers below. If the effects of all local factors (latitude, season, special topography and so on) are taken out, the rate of fall of temperature with height works out at about 6°C/*km*. This fall is enough to allow snow to remain on the tops of high mountains in the summer, even in tropical areas.

Incidentally, this feature provides another virtually unrecognized reason for temperatures to increase as you go down mines. We looked at this in Chapter 9, where it was suggested that the observed rate of increase in the top 10*km* was around 25°C/*km*. We can see now that part of this increase, perhaps around a quarter of it, may be due purely to consequences of the physics of atmospheric gases.

Proposition 11C

Part of the temperature increase observed in going down mines stems from the same basis of atmosphere gas physics as that causing a fall in temperature with increasing altitude

Air pressure also decreases as you go higher, a direct consequence of climbing up the gravity well. As well as the more obvious results, a more subtle one comes from the fact that thinner air can 'hold' less water vapour. So there is a double reason for rain or snow to fall on mountains, because the temperatures are lower, and the pressures less.

Another apparently trivial consequence comes from the fact that water boils at a lower temperature under reduced temperatures. Because of this, it is not possible to hard-boil an egg in an open saucepan on the top of Mount Everest — the water boils below the temperature needed for the biochemical and physical processes involved in hardening the egg. We will return to this trivial point when we consider the fate of the dinosaurs, in Chapter 12.

The Great Reworkings

Apart from the fact that the early Earth's atmosphere probably contained little or no oxygen, but probably held a lot of methane and ammonia, very little is generally agreed concerning the history of our atmosphere. In what follows I will suggest a series of events which lend a much higher degree of detail to what happened.

The boundaries between the great geological eras, Pre-Cambrian, Paleozoic, Mesozoic, and Cenozoic, may have been assigned intuitively. But it seems that these boundaries have a physical basis too; they appear to be times of marked change in the atmosphere. In these changes, the role of carbon and its compounds appears to have been a crucial one.

This is not just a physical role. Carbon compounds are the basis of all life on Earth. While physical factors did have an influence, it appears that living organisms were the principal agents in achieving the Great Reworkings of our atmosphere.

The Role of Carbon

The great coal deposits of this planet were laid down in the Carboniferous and Permian periods which ended the Paleozoic. Coal is, of course, mostly carbon, and gave its name to the Carboniferous. Where did the carbon come from? The only credible major source is the atmosphere, presumably by conversion from gaseous hydrocarbons (compounds of carbon and hydrogen, especially methane) or possibly from free carbon dioxide.

The massive deposits of high-carbon rocks laid down at the end of the Paleozoic therefore imply a major change in the atmosphere at that time.

The period ending the Mesozoic era, the Cretaceous, was also apparently a time of major atmospheric change. Cretaceous means 'chalky', and chalk and limestone are forms of calcium carbonate, a compound of carbon, oxygen, and calcium. Again, the only credible ultimate source of the carbon is the atmosphere, in this case almost certainly from conversion of carbon dioxide.

The massive deposits of carbonate rock laid down at the end of the Mesozoic era imply a second major change in the atmosphere, involving a massive withdrawal of carbon dioxide from the atmosphere.

The size of the changes involved make them ones of kind, rather than degree. At the present day, estimates are that the ratio of carbon in rock deposits to that in the atmosphere is more than 90,000 to 1 [Beckmann, 1988], so the amount of carbon left in the atmosphere is very small, only one-hundredth of one percent of the whole. Almost everything that once was in the atmosphere has since been incorporated in the rocks.

Of course, both the coal deposits laid down in the Paleozoic and much of the carbonate deposits of the Mesozoic were formed through the action of living things. Most of the coal came from the giant plants of the Carboniferous swamps, and much of the carbonates from the shells of sea creatures, especially corals and molluscs.

The Primeval Earth's Atmosphere

It has been widely assumed that as part of its formation processes, the Earth inherited a primeval atmosphere consisting mostly of hydrogen, hydrocarbons such as methane, and ammonia. This is reasonable enough.

Hydrogen is the most common element in the Universe, and the hydrocarbons are a credible source for the carbon which exists in the biosphere. The ammonia would be the source of the nitrogen in our air. Both carbon and nitrogen are normal products from the nuclear conversion processes which go in stars, and we would expect them to combine with the abundant hydrogen. We will have further evidence in support of this when we look at the atmospheres of other planets, in Chapter 15.

Another common stellar conversion product is oxygen, the most abundant element on Earth. There would also be quite a lot of this, but it would combine immediately with hydrogen to form water. Whether this water would be liquid or vapour would depend on the conditions of heat and pressure on the early Earth.

It is assumed almost as being self-evident that the Earth was originally completely molten. There is, however, little real evidence for this assumption, and it may be that the primeval Earth was never in a particularly hot condition.

> *Proposition 11D*
> *The primeval Earth was never molten or at a particularly high temperature*

This Proposition appears never to have been examined in any detail, and whether it is true or not, we do not currently have enough evidence to say whether the Earth's initial water was liquid or gaseous. But it must have become liquid fairly early on, because water-deposited sedimentary rocks exist far back into the Precambrian.

We have also seen (Chapter 1) that abundant life on Earth did not appear until the start of the Cambrian, about 600*my* ago. However, primitive life existed considerably earlier, as far back as 3500*my* ago, through the vast reaches of the Precambrian. What was the nature of this primitive life, and how did it differ from that of today?

Again this is a question on which we have very little evidence, but there is one point of importance. It seems likely that these primitive life-forms lived without free oxygen, and were the forerunners of creatures such as the anaerobic bacteria of today, active in relatively minor oxygen-free environments such as the bottoms of swamps.

How the Precambrian Ended

We also have very little knowledge of the biochemical processes of these primitive organisms, but it seems possible that they were the motors which drove the conversion of the primitive atmosphere. All the higher forms of life which first appeared in the Cambrian were oxygen-breathers. Those which preceded them were probably not, instead they were lifeforms for which oxygen was a waste product. And in producing this waste product over a period of not thousands or millions of years, but extending to perhaps three billion years, two-thirds of the age of the Earth, they made the oxygen we breathe now.

At first all the oxygen they made would be chemically reacted with free hydrogen or the hydrocarbons, but eventually they would have used all this up. And this is the crucial point, the sharp division which marks the boundary between the Precambrian and the Cambrian is probably the time when free oxygen first became common in the Earth's atmosphere. It was this development which permitted the evolution of the oxygen-breathing life which predominates on the Earth today, it was the passing of this threshold which led to the surge in evolution at the start of the Paleozoic.

> *Proposition 11E*
> *The Precambrian-Cambrian boundary marks the time when free oxygen first became common in the atmosphere and permitted the development of oxygen-breathing life*

This was a massive change in the basic nature of the atmosphere. There may also have been changes in the seas as a reaction to this. In particular, the substances dissolved in seawater may have somewhat different.

There are some biochemical differences in lower forms of life which could be traced back to this time, such as the notable percentage of copper in the blood of cuttlefishes, a very ancient line of sea creatures. In more modern creatures this metal is usually replaced by iron. But the most notable change was the one in the shells of shellfish.

The sea creatures of the early Cambrian which possessed shells, skeletons, or other stiffening apparently mostly made this stiffening either out of silica or or calcium phosphate. More modern sea creatures normally use calcium carbonate. In one group of shellfish, the mollusc-like brachiopods, once very common but now rare, a change-over can be traced within the group. Brachiopods which developed at the start of the Cambrian have calcium phosphate shells, but those which had evolved by the end of it have calcium carbonate ones [Rhodes, 1960].

Perhaps not too much should be made of these differences. However, the seas and the substances dissolved within them have to exist in equilibrium with the atmosphere above, and if this changes in composition, we may expect the seas to be affected also.

> *Proposition 11F*
> *With the development of free oxygen in the air above the seas, changes occurred in the composition of substances dissolved in them*

The Paleozoic-Mesozoic Boundary

We have had evidence that the beginning of the Paleozoic was marked by the first significant amount of free oxygen in the Earth's atmosphere and by the appearance of oxygen-breathing life. Now we can look at what happened during the rest of the Paleozoic.

Of the 'primeval' atmospheric gases — hydrogen, methane, and ammonia — the first would have disappeared completely by the start of the Paleozoic, either completed reacted with the newly formed oxygen to give water, or evaporated off into space. It is likely that the last two would also have undergone transformation during the Paleozoic, the ammonia to form nitrogen and water, and the methane to give carbon dioxide and water. The chemical reactions involved can be easily worked out from Table 11, by adding oxygen to the original gases.

> *Proposition 11G*
> *Atmospheric ammonia was converted to nitrogen, and methane to carbon dioxide, during the course of the Paleozoic*

There are a few riders to add to this simple statement. The process suggested was unlikely to be sudden, and need not have been complete. There could still have been significant amounts of ammonia and methane left in the atmosphere at the end of the Paleozoic, but the proposal is that they were no longer major components.

In addition, as already noted, significant amounts of carbon had been taken out of the atmosphere by the end of the Paleozoic to form deposits of coal (and some oil). The only obvious source of this carbon was that in the atmosphere. Whether this carbon was in the form of the original methane or its conversion product, carbon dioxide, is not certain, but it is likely to have been the latter.

Although the question has probably never been examined in detail, it seems reasonable to assume that the plants which developed on land during the Devonian, Carboniferous, and Permian were at least similar enough to modern ones to be chlorophyll-based. This implies that they gained their energy and substance by photosynthesizing carbohydrates from carbon dioxide, water, and sunlight.

At the same time as the methane was being converted to carbon dioxide, it seems likely that the ammonia was being converted to nitrogen. Apart from the direct changes, there may have been an important indirect effect. Ammonia is alkaline, it dissolves easily in water to form a weak base. Carbon dioxide dissolves in water to form a weak acid, carbonic acid. The implication is that during the course of the atmospheric conversion, the seas changed their state from being weakly alkaline to weakly acid.

> *Proposition 11H*
> *The Paleozoic-Mesozoic boundary was marked by the disappearance of methane and ammonia as major atmospheric components, and the appearance of carbon dioxide and nitrogen in their place*

> *Proposition 11I*
> *Atmospheric changes at the Paleozoic-Mesozoic boundary caused a switch in the state of the seas from being weakly alkaline to weakly acidic*

These propositions are supported by observations from the plant world. The lower plants, such as the mosses, often prefer alkaline conditions, and for example can be seen growing on old lime mortar. Moulds grow on shower walls because of the alkaline conditions set up by the regular use of soap. However, higher plants have adapted, and can tolerate a wide range of acid, alkaline, and neutral conditions.

Modern Times: The Mesozoic-Cenozoic Boundary

The Mesozoic was the time of strongest development of life on land. It ended with the death of the dinosaurs and other marked changes in land life. Only with the onset of the Cenozoic do we begin to recognize all the plants and animals as relatives of those we know today.

It appears that the atmosphere of the Mesozoic was similar to that of today, with one notable exception. As well as the major components of nitrogen and oxygen, it had a third major component, carbon dioxide.

According to Chambers Encyclopaedia [Carbon, 1970], the relative amounts of carbon in different forms on the Earth are as follows (measured in million million tonnes):

Limestone etc. rocks	23,100
Dissolved in sea	22
As coal, oil etc	6.6
In atmosphere	0.68
In living plants, timber etc.	0.009

These figures are somewhat different from those in Beckmann [1988], who shows rather higher figures for almost all areas except the atmosphere itself (0.58 in 1860, 0.75 now), but the point is very obvious. Hardly any of the Earth's carbon is still left in the atmosphere, it has almost all been withdrawn and deposited in the rocks.

Since we know that a massive part of this withdrawal took place in the Mesozoic, especially in the Cretaceous (the Time of Chalk — calcium carbonate), it seems almost obvious that the boundary between the Mesozoic and the Cenozoic is the time by which carbon dioxide had ceased to form a significant part of the atmosphere.

> *Proposition 11J*
> *The Mezozoic-Cenozoic boundary marks the time at which carbon dioxide levels in the atmosphere had fallen to trace levels*

We will return to this point, also, when we consider the Greenhouse Effect in Chapter 17. For the moment we will just comment that this proposition is supported by the fact that modern plants have evolved to be carbon-dioxide hungry; they have produced mechanisms to chase after really quite tiny amounts in the air.

Many commercially-grown vegetables greatly improve their growth in a carbon-dioxide enriched atmosphere, up to five times the normal level (0.15% instead of 0.03%). But at even higher levels, around 0.5%, the carbon dioxide actually seems to become toxic [Beckmann, 1988]. It would be an interesting exercise, and a test of Proposition 11J, to see if the more ancient plant groups (such as the cycads and ferns) could tolerate a much higher carbon dioxide level.

The Pressure of Earth's Atmosphere

We have seen that there may have been some fundamental upheavals in the composition of the Earth's atmosphere in the past. Now we look at another aspect of the atmosphere: its pressure.

The pressure of the air on the Earth's surface is principally governed by two things — the mass of the atmosphere (how much there is of it) and the forces due to gravity. Once more we will find that the conditions of today are very different to what they may have been in the past.

One of the main factors here is, once more, the carbon dioxide. Working from Beckmann's figures, if all the carbon which he estimates is present in the rocks were in the atmosphere as carbon dioxide instead, this carbon dioxide would weigh some 35 times as much as the whole of the present atmosphere. In other words, if everything else was the same except this carbon was in the air instead of the rocks, we would be living under a pressure of 36 atmospheres.

This might seem incredible, but surprisingly enough, it fits in very well. In Chapter 15 we will see that on Venus, where the atmosphere is mostly carbon dioxide, its pressure at the surface is around 100 atmospheres. And there are several plausible reasons to account for the difference which does exist — we will look at these, too, later.

The conclusion seems inevitable that atmospheric pressures were very much higher in the Earth's past than they are now.

> *Proposition 11K*
> *Atmospheric pressures were very much higher on Earth in the past, because carbon now present in the rocks was formerly present in the air as atmospheric gases*

When we come to consider the effects of Earth expansion, we find that this jump is further compounded. A half-radius Earth would have a quarter of the surface area for the same amount of gas to press on, and so under otherwise equal conditions would have four times the atmospheric pressure, around 144 atmospheres.

> *Proposition 11L*
> *Atmospheric pressures were also higher in the past because the same amount of atmosphere was present on a much smaller Earth*

This calculation is obviously only a very first stab at giving a figure to the pressure. If we want to try and put a little more detail into the resulting figures, we need to take into account the period in the past when the carbon was taken out of the air, and its form in that air.

I have already suggested that at the beginning of the Paleozoic, some 600*my* ago, the carbon was in the form of methane. Methane has a molecular weight of 16 (Table 11), while carbon dioxide is the heaviest of the gases listed, with a molecular weight of 44. The ratio of weights is 2.75, and since the mass of the atmosphere and hence its pressure on the surface is directly dependent on the weights of its molecules, we would need to divide the above figure of 144 by this ratio. The result, for a methane atmosphere, is around 52 atmospheres.

More Cooking the Books

There are a number of other factors to take into account to try and derive more accurate figures. This is all new ground to break, and here I will just list some of these factors.

1. Figures for the amount of carbon in the Earth's crust are only estimates, and could be well out. For example, the figures in Beckmann [1988] are around twice those in Carbon

[1970].

2. Almost all the carbon in rocks has been deposited since the start of the Paleozoic.

3. If methane was being converted to carbon dioxide during the Paleozoic, this would increase the atmospheric mass and pressure.

4. Decrease in pressure due to Earth expansion and hence greater surface area would depend on the actual expansion experienced. For example, an Earth of half the present radius may not have been achieved till around 400my ago, while carbon deposition may have started 600my ago.

5. Substances later converted into atmospheric gases are likely to have been released from the Earth's interior as more surface was exposed, as with the Earth's water (Proposition 10D). These could include carbon dioxide.

6. A considerable amount of atmosphere is almost certain to have been lost into space in the past.

Factor 6 is a most important one, which we will look at again in Chapter 15.

The Pea-Soup Scenario

We have now arrived at a set of scenarios for the Earth's earlier atmospheres which differ fundamentally from any proposed elsewhere which I have been able to find. The conventional view is that while the primeval atmosphere contained carbon dioxide and ammonia, these were converted to give an air composition close to that of the present Earth within a few million years after life evolved [Cramer, 1988].

The scenarios I have presented depict atmospheres of very different composition, in particular of ones containing huge amounts of carbon dioxide compared to today. They are atmospheres of much higher pressures. And they may be ones of very different temperatures.

The higher pressures and temperatures lead to an important consequence which could make the scenarios even more extreme. Air at higher temperatures can hold a lot more water. For example, we have already seen that the amount of water the air can hold increases by a factor of 10 on going from 0°C to 40°. At a higher extreme, on reaching 100°C , water evaporates completely under normal pressure, and in theory at least the atmosphere could consist mostly of water vapour at this point.

Similarly, the temperature at which water condenses from steam (same as boiling point) increases markedly with higher pressures. At two atmospheres, it is up to 121°C, and at 12*atm* it has reached 190°. When the pressure of the air is reduced, as when it rises up to the clouds, it can hold less water and this condenses out as clouds or rain.

At this stage it is very hard to put even tentative figures to the water-vapour content of the Earth's earlier atmospheres, because so much is unknown. But it does seem quite likely that the air contained a great deal more water than it does now.

> *Proposition 11M*
> *The amount of water vapour held in the Earth's atmosphere during Paleozoic and Mesozoic times was much greater than now.*

As it would be present in gaseous form, this water would itself increase the atmospheric pressure. Water vapour is one of the lighter atmospheric gases (molecular weight 18), but if even 1% of the Earth's present water was moved into the atmosphere, it would more than triple the atmospheric pressure. Whether such movements in the past have significantly affected sealevels is too hard to work out at the moment, but it is a possibility worth raising.

We end up with scenarios in which the atmosphere is close to pea soup — very thick, very moist, very rich in 'Greenhouse Effect' gases. There is another consequence. It may have been perpetually cloudy. The creatures of the Cenozoic, those we start to regard as 'modern', may have been the first on Earth to see the stars.

> *Proposition 11N*
> *The Earth was completely shrouded in clouds at all times during the Paleozoic and the Mesozoic*

This Proposition is supported by evidence from Venus — a planet with a high-pressure, carbon-dioxide rich atmosphere, and one perpetually shrouded in clouds. There is also a further implication, relating to nitrogen fixation by thunderstorms.

Thunderbolts of Life

One of the beneficial effects of thunderstorms which is often overlooked is that they fix atmospheric nitrogen into a form which can be used directly by plants. Passage of high-energy thunderbolts through the mixture of nitrogen and oxygen in the air converts some of this to nitrogen oxides, which easily dissolve in water and react to give nitrates, directly usable by plants for food (so-called 'nitrogen-fixing' plants are actually symbiotic associates with micro-organisms which do the actual fixing).

Nitrates are a relatively scarce resource for wild plants, and thunderstorms provide quite a significant amount of their needs. In fact they must provide almost all that is not recycled from decaying organisms, either in the same spot or brought in as atmospheric nitrogen gases or dissolved in water. Since it is possible to grow a dense forest containing a lot of nitrogen fixed in its substance from an open field with very little, the nitrogen-transfer activities discussed must be quite significant.

Nitrate fixation through thunderbolts requires a nitrogen-oxygen atmosphere and clouds separated from the planet's surface by a layer of low-conductance air (to allow the build up of an electric-charge potential difference). One or both of these conditions may have been lacking in past eras, so the modern thunderbolt nitrogen-fixing mechanism may have been inoperative.

> *Proposition 11O*
> *Conditions necessary for atmospheric nitrogen fixing by thunderbolts were not always present in past eras*

Naturally such a situation would have its effects on plant life. In earlier times, there may

have been other nitrogen sources — we have seen that free ammonia may have been much more plentiful in the past. Modern plants are notably 'nitrogen-hungry', especially in our most highly-evolved areas, the tropical rainforests. That is why some of these plants, in the intensely competitive environment, have developed carnivorous habits — animals are a rich and mobile source of nitrogen.

Flying Creatures of the Past

There is further indirect evidence of a formerly much denser atmosphere, from the Earth's flying creatures. The maximum wingspan of the largest modern flying creature, the albatross, is about 3.5 metres. Creatures tend to evolve to the limits of what is physically possible, and it is unlikely that any modern bird with a wingspan much above 4 metres could survive.

However, fossil examples of flying creatures from the Cretaceous, such as the giant pterosaur *Quetzlcoatalus alcotaius*, are known with wingspans of over 12*m* [Cramer, 1988], three times this 'theoretical limit'! Similarly, fossil dragonflies have been found with much bigger wingspans than any modern flying insect. Obviously, as the atmosphere thickens, 'flying' moves towards 'swimming', and much bigger wingspans will be feasible at higher atmospheric pressures.

The giant extinct dinosaurs, such as Brontosaurus, were much bigger than any modern land creature, in fact probably bigger than any modern land creature could be (and still move). It has been suggested that creatures like Brontosaurus lived mostly in the water. Could it be that they actually lived on land, but in a much denser and more buoyant atmosphere?

Plants in a Denser Atmosphere

The physical structures of the ancient plants also suggest that they lived in atmospheres much denser than those applying today. The huge trees of Coal Measure times were apparently buoyed up by the dense air, since their cells were large water-filled sacs with comparatively thin walls [Rhodes, 1960], lacking the strength to stand up under today's conditions.

The modern survivors of the most ancient plants, such as the mosses, the ferns, and the cycads, are noted for their affinity for very moist conditions. One of the more primitive of the modern cycads, a *Zamia* species from the West Indies, actually has sperm which swim in water instead of the immobile pollen of modern plants. The high atmospheric density suggested also fits in well with the mild climatic conditions deduced for earlier times, with no strong winds.

It has often been remarked that the occurrence of the same fossils world-wide in rocks of the Paleozoic and Mesozoic means that conditions must have been much more uniform over the whole world then than they are now. This is true even if it is supposed that, say, fossils now found in the Arctic might have been moved up from warmer areas of origin by domain shifts, because there is no evidence of differing 'cold-weather' and 'warm-weather' fossils for those times, in contrast to modern flora and fauna.

Much more uniform conditions are what would be expected from much denser, moister atmospheres, with higher heat capacities. Temperatures at seaports are much less extreme than those in inland cities, because of the moderating influence of the sea, which is due to its high heat capacity. It would be useful to test whether ancient plants such as the cycads would fare better in much denser atmospheres than modern plants.

All this is positive, but indirect evidence. Wouldn't it be nice if there were direct evidence? And there is.

Truth Frozen in Amber

In an article entitled 'Dinosaur Breath', John Cramer [1988] reported on work done by Richard Kerr on the analysis of tiny air bubbles trapped in amber, and the suggested implications of this work. The amber, fossilized resin from extinct species of *Pinus*, those ancient nut trees, contains tiny air inclusions which Kerr analysed with a mass spectrometer, an instrument which accurately counts the proportion of different atoms in even very tiny samples.

Kerr found that the proportion of oxygen atoms in Cretaceous-amber bubbles 80*my* old was much higher than that in modern air, averaging around 30%. On the other hand, the amount of oxygen in bubbles from 40*my*-old Cenozoic samples was similar to that in modern air (about 21%).

The conclusion drawn from this was that the Cretaceous air was much richer in oxygen than that of today. Cramer also raises the question of how such large creatures were able to fly during the Cretaceous, and the suggestion given is that the dinosaurs' metabolisms were 'supercharged' by all the extra oxygen, enabling them to overcome the theoretical barriers to flight.

This may be an interesting example of drawing a wrong conclusion from correct data. The point is, that Kerr's technique only counts the number of oxygen atoms, not their chemical state. This excess oxygen could just as well be present as carbon dioxide, which would support the Propositions I have given above. This matter can be tested directly, by re-running analyses to see if carbon from carbon dioxide is present as well.

An even more telling point is mentioned in passing by Cramer. In many cases, the pressure inside the bubbles trapped in the amber was as high as 10 atmospheres. This was attributed to 'the geological forces that converted the pitch to amber'. Is it not more likely that the air trapped in the bubbles was already at a higher pressure? William of Occam would say yes!

CHAPTER 12

DEATH OF THE DINOSAURS

"Dinosaurs: the remains point to an organism resembling in some respects that of birds, in others that of mammals"

— Oxford English Dictionary

Everybody else seems to have had a stab at suggesting why the dinosaurs died out, so I don't mean to be left out. In fact, I will make not one suggestion, but three.

Suggestions already made cover a huge range, from simplistic to erudite, from common-sense to comedy. The dinosaurs died out because the Earth got too hot, or too cold, or too much radiation (frizzling them up) or too little (not enough mutations occurring to let them adapt). The climate became too wet, or too dry. Their food was eaten by the newly-evolved caterpillars of butterflies and moths, or their eggs were eaten by the cunning small mammals. The Earth was bombarded by meteorites or passed through the tail of a comet, with many dire effects. The list goes on and on — parasites, diseases, slipped discs, shrinking brains, over-specialization, racial old age, sunspots — even boredom!

One of the more recent theories is based on the discovery that a fine layer of material rich in the rare metal iridium is found close to the Cretaceous-Paleocene boundary in many locations scattered about the world. A layer of finely-divided carbon is also found at the same boundary. It is accepted that the creatures referred to as dinosaurs also disappeared at this time, which marks the change from the second (Mesozoic) to the third and current (Cenozoic) great period of life, some 70*my* ago.

The suggestion is that a huge chondritic meteor collided with the Earth at this time, that this meteor was rich in iridium which was scattered throughout the atmosphere in a very dense dust-storm, bringing on a sort of 'nuclear winter' which was connected with the extinction of the dinosaurs [Cramer, 1988]. Cramer also adds the suggestion that the carbon layer is soot from an immense world-wide fire which was promoted by the high oxygen levels he hypothesizes to exist in the Cretaceous.

No theory put forward to date has received anything approaching general acceptance. I will put forward three more. The first one is really only an extension of an existing theory, while the second and third may be new.

The No-Disappearance Theory

The first theory is that the dinosaurs didn't die out. This is not a novel suggestion, but is one which has gained increasing support in recent years. The old idea of dinosaurs as just big lizards, typical reptiles, is falling into disrepute in the light of new discoveries and research.

The first nail in the coffin of the older theories was when it was realised that many of the dinosaurs were 'warm-blooded' (that is, maintained a relatively constant body temperature), like modern mammals [Ostrom, 1978]. They had to be warm-blooded to maintain levels of activity which were clearly much above those thermodynamically possible for a 'coldblooded' reptile. A clear example is of the flying dinosaurs, such as the pterodactyls. No modern reptile can fly, presumably because this mode of travel is not possible with sluggish reptile metabolism — but see the comment which appears towards the end of the last chapter.

In addition, it is believed that at least some of the pterodactyls were covered in fur, again a feature not found in any known modern reptile. The icthyosaurs, huge marine dinosaurs, apparently bore live young— they were not egg-layers [Stanley, 1987]. In fact, on close examination it gets harder and harder to find features which clearly distinguish the dinosaurs, or at least some of the later ones, from modern warm-blooded animals — birds and mammals.

One suggestion, in fact, has been that modern birds are the current dinosaurs, so that dinosaurs are not extinct at all, only their older forms are gone. The situation gets even more interesting when one looks at the most primitive mammals, the monotremes of Australia. There are only two animals in this ancient group, the Echidnas and the Duckbilled Platypus.

This platypus has a combination of features so bizarre as to make it understandable that the first specimens brought to Europe were widely assumed to be hoaxes, stitched together from different animals. The duck bill and webbed feet, coupled with fur, were very striking at the first encounter. Then it was found that the platypus lays eggs, and has a single passage for both excretion and copulation, just like birds. And, although a mammal, it does not have teats for the milk, this just oozes out through a network of pores.

Later came the discovery that males have poison glands, unlike all other mammals and birds. Recently it has been demonstrated that the platypus has an electrical detection system, like that of some fishes. But a more subtle and very recent discovery concerns body temperatures of the platypus and the other primitive monotreme, the echidna. These creatures do not maintain typical mammalian constancy of body temperature, instead they vary dramatically by some 10°C. A variation of this size could be enough to kill one of the higher mammals.

What it comes down to, is that there are no obvious fundamental differences between some dinosaurs, some ancient mammals like the platypus, and some modern birds like penguins. The inference is that there is no difference; the dinosaurs were just early forms of modern mammals and birds. The only point that remains, and is undisputed, is that all the big ones disappeared towards the end of the Mesozoic.

> *Proposition 12A*
>
> *Dinosaurs as a class are not extinct, they were only early forms of modern birds and mammals. Mass extinction was limited to larger forms of these classes*

The Great Extinction — Which One?

If Proposition 12A is true, this still leaves the matter of explaining why all the bigger animals became extinct towards the end of the Mesozoic. It appears that all animals with a mass of over around 40*kg* were affected. Plants were not involved in any mass changes, although of course they continued to evolve. The large marine animals, such as the ichthyosaurs, did disappear — modern marine giants like the whales are believed to have

developed from land-based ancestors during the Cenozoic.

To put some background in place for another proposition, we should look at another great extinction, one which is taking place today. This is one directly due to the activities of man.

Dramatic extinctions of species by man, such as that of the dodo, the large flightless bird of Mauritius, are a well-known cause of public concern. But behind these dramatic cases stands a huge, all-pervading influence on all species of life on Earth which stretches back well beyond modern man, well beyond civilization, to the beginnings of man.

This realization is comparatively recent, but evidence and suggestions supporting this trend are coming in thick and fast. Huge changes wrought directly and indirectly by man have affected this planet to an extent far exceeding those due to effects such as major climate shifts. In fact it appears that the influence of man on the isocons, those envelopes which define ecological niches, is now greater than that of any 'natural' factors.

Historical changes such as the conversion of the middle eastern 'Fertile Crescent' of the Bible into desert, and the degradation of the great grain fields of Carthage into useless arid lands in North Africa are well documented. But there is far more.

Figure 12.1 (taken from [Axelrod, 1967]) shows recorded evidence of the past distribution of the elephant in North Africa. Clearly the elephant was once native over the whole of this huge area, right up to the shores of the Mediterranean. There is no way that the elephant could survive in large numbers under present Saharan conditions, and the inescapable conclusion is that these conditions have changes dramatically since the time when the elephant ranged freely over this huge area.

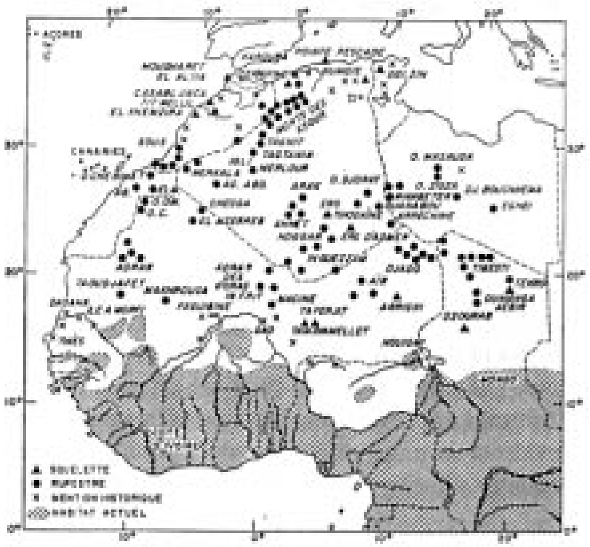

Fig. 12.1. Records of past distribution of the Elephant in North Africa

Was it way back in the distant past when these conditions were found? No, it was only yesterday, in the scale we are used to. Almost all the elephant records referred to are less than 10,000 years old, and some are as young as 4000 years, within the time of known civilizations and cities.

Around the Earth, extinctions of large animals of every sort have taken place under circumstances which show an increasing correlation with the development of mankind. We can reckon that man, as an evolved and intelligent thinker, has been active on Earth for around 100,000 years, with the emergence of what we can regard as the beginnings of civilizations going back more than 12,000 years. It is within these spans that the use of fire has been harnessed, and far-reaching changes have overtaken the Earth.

In North America, this period has seen the disappearance of a host of large animals. These