hours, and the latter in twenty-one and a half".

It seems quite beyond the bounds of chance for these very unusual objects to have been predicted, so accurately and so far ahead of time, almost as an aside in a satirical novel. On this occasion, the formulation of a suitable Proposition will be left as an exercise for the reader.

The Giant Planets

The second group, the Outer Planets, includes the so-called Gas Giants — Jupiter, Saturn, Uranus, and Neptune — and the outermost known planet, Pluto. The gas giants are much more massive than Earth, have enormously dense atmospheres, and multiple satellites, more of which come to light with each new flypast. Most of these satellites are small, but Jupiter has four huge ones, and Saturn and Neptune have a huge one each; two of these satellites are bigger than Mercury, the planet closest to the Sun.

Pluto is the odd man out as far as the Outer Planets are concerned. Very distant, and still not investigated in detail by any space probe, it is much more imperfectly known than the rest. In size it is similar to a large asteroid, but it has one comparatively large satellite, of half its own radius. Although it is, on average, the planet farthest from the Sun, its orbit is appreciably elliptical, and it is currently inside the orbit of Neptune. It has been suggested that it is an escaped gas-giant moon or errant asteroid, or has some other exceptional mode of formation.

For the whole solar system, the Sun is far and away the most significant source of heat and other energy, and the planets closer to the sun than Earth are much hotter, while the outer ones are much colder. This has a major effect on their atmospheres — materials which are atmospheric gases on Earth may be liquids, or even solids, on the outermost planets.

Atmospheres of the Planets

The atmospheres of the planets differ very considerably, both in composition and in mass or density, but we will see that, with one exception, they do fit into a general pattern. The exception is Earth itself.

In Chapter 11 it was shown that the two most important properties of an atmospheric gas molecule, from the viewpoint of this book, were its molecular weight and its temperature. When we need to tie in these properties with the conditions on a particular planet, we need also to consider the mass of the planet, the main determinant of its escape velocity.

Jupiter is easily the most massive of the planets, more than 300 times heavier than Earth. Its escape velocity is so high it is easily able to retain even hydrogen and helium, the lightest gases, and in fact almost all of its enormous atmosphere consists of these gases — a reflection of their high relative abundance in the Universe. However, Jupiter's atmosphere also contains some readily detectable carbon and nitrogen gases such as methane and ammonia.

As Jupiter is a long way from the sun, it is also very cold. This cold, and the immense amount of its atmosphere, means that compounds which are gases in its outer atmosphere may be liquids or even solids lower down, under the huge pressures (perhaps many millions of atmospheres).

As yet we do not know where the solid surface begins, and whether this surface is of the same rocky nature as those of the inner planets, or is frozen atmosphere. The low density given

for Jupiter in Table 15, 1.24 as opposed to the 5.50 for Earth, reflects the fact that this density is calculated for the whole planet, including its atmospheric components.

It seems likely that Jupiter's atmosphere is probably little changed from its primeval state, as far as composition is concerned. We can work from the assumption that the primeval atmospheres of all the planets were similar in composition to that of Jupiter now.

> *Proposition 15A*
> *The primeval atmospheres of all the planets had a similar composition to that of Jupiter now*

The actual present composition of Jupiter's atmosphere, at least the outer parts accessible to measurement, is about 90% hydrogen and 10% helium. The other gases present, such as compounds of nitrogen, oxygen, and carbon with hydrogen, make up less than 1% altogether.

The other three gas giants, Saturn, Uranus, and Neptune, follow the Jupiter pattern quite closely. All have high escape velocities, and as they are further out and so even colder than Jupiter, all their atmospheric gases, even the lightest ones, are moving too slowly to be lost to space. Their only difference is that some are cold enough to turn compounds which are gases in Jupiter's atmosphere into liquids or solids — ultimately leaving only hydrogen and helium, which both have low molecular weights (2 and 4) and a very low liquefaction temperature.

> *Proposition 15B*
> *Saturn, Uranus, and Neptune have similar 'primeval' atmospheres to Jupiter, except that they have less of the heavier atmospheric components due to freezing or liquefying out*

Information on Pluto's atmosphere is very uncertain, but it may have a very thin one consisting only of a little methane and possibly some neon. Pluto is so light that these heavier gases would only be retained at all because the intense cold would slow them right down.

Atmospheres of the Inner Planets

When we move from the Outer to the Inner planets, the picture changes completely. Each of the inner planets has a clearly-defined rocky surface, while their atmospheres have all been markedly changed from the primeval pattern, but in different ways.

Mars is the second smallest of the inner planets. Further out from the Sun than Earth, and hence colder, it has been able to retain only a residual atmosphere, less than one-hundredth of the pressure of that on Earth. This very thin atmosphere is believed to include about 95% carbon dioxide (molecular weight 44), 2.7% nitrogen (28), and 1.6% argon (40).

These figures are actually just about what we might expect. Because of the relatively small mass of Mars, and so fairly low escape velocity, all the lighter gases would be lost quite quickly. Hydrogen and helium, with molecular weights of 2 and 4, would go immediately. The next lightest gases, methane (16), ammonia (17), and water vapour (18), could hang on long enough for partial conversion into nitrogen (28) and carbon dioxide(44); anything not converted to these two heavier gases would be lost. Argon, an inert, heavy gas, would be largely retained, too heavy to be lost and too unreactive to be converted.

In contrast to Earth, Mars has an atmosphere with virtually no oxygen, which it could retain (*mw*=32), presumably because it has never been exposed to extensive oxygen generation through biological processes (Proposition 11E). The ratio of nitrogen to argon in Mars' atmosphere is instructive; Earth has a ratio of about 83.9, Mars has one of about 1.7. It seems clear that Mars has lost much more of its original nitrogen than Earth, purely because Mars itself is lighter, and medium-weight gases such as nitrogen are less able to be retained than heavier ones such as argon.

> *Proposition 15C*
> *Mars has lost much more of its atmospheric nitrogen than Earth because of its lower escape velocity*

In fact, if we assume as a first approximation that both planets once had the same nitrogen-argon ratio, and Earth has kept all its argon and nitrogen, while Mars has kept its argon but lost some of its nitrogen, the actual percentage lost turns out to be 98.7%. If all this nitrogen was restored to Mars' atmosphere, it would increase its atmospheric pressure by a factor of over 30, bringing it up to about a fifth of Earth's. This seems on the right track.

Moving now to the planet closest in to the Sun, Mercury, here we have an extremely hot, quite small planet. The complete lack of atmosphere is to be expected — even the heaviest gases would be boiled off quite quickly.

Venus the Mysterious

Venus is the most interesting of all the planets from our present viewpoint. Until the middle of the 1900s, Venus was very much a mystery planet. It is perpetually shrouded in thick clouds, so that the surface, and how far it lay beneath the clouds, was completely unknown. Even the time it took to rotate on its axis was not known. This left the field open for suggestions that Venus was a lush tropical swamp, perhaps inhabited by dinosaurs.

Data from the Venus probes, and from radar studies, have now given us a clearer picture of what turns out to be a very harsh and hostile environment. At the surface, which is is a typical rocky one like the other inner planets, pressures average around 90 times those of Earth. There are no seas, negligible free water in fact. The very dense atmosphere consists of about 96% carbon dioxide and about 3.5% nitrogen.

Venus is only a little smaller than Earth, with a slightly lower escape velocity, 10.4 instead of 11.2. It is closer to the Sun, and much hotter — surface temperatures around 450°C have been recorded by the probes. This temperature is actually higher than that on the surface of Mercury, which is even closer in.

Why should this be so? This high atmospheric temperature is usually ascribed to a sort of 'Greenhouse Effect', particularly because of all the carbon dioxide present. I believe this view is mistaken, not because we should expect higher temperatures at the bottom of thicker atmospheres (although this is true), but mostly because of the reflection-radiation ratio. We will throw more light on this matter when we come to look at the Greenhouse effect on Earth, in Chapter 17.

We will return to the matter of the mass or pressure of the atmosphere on Venus. Other things being equal, we would expect Venus to have a similar atmospheric pressure to Earth, or slightly less, because of its smaller size and higher temperature. Why does it have this exceptionally thick atmosphere?

There are two main parts to the answer. The first is that it is not Venus which has the exceptional atmosphere, it is Earth. Venus is the typical planet, Earth is out of line. Both planets have sufficient mass to retain most gases of medium weight or above. It will be interesting to see if the nitrogen-argon ratio on Venus is similar to that on Earth, as we would expect. The big difference is that Venus has not experienced the massive deposition of carbon dioxide into solid forms which took place on Earth (Proposition 11J). This in itself indicates that Venus has never developed any type of life capable of driving such a carbon-extraction process.

If all the carbon dioxide were removed from its atmosphere, Venus would experience a drop in atmospheric pressure by at least 96% — actually a bit more as carbon dioxide is heavier than nitrogen — and this would bring it down to between 2 and 3 Earth atmospheres. Again we are on the right track.

> *Proposition 15D*
> *Venus has a much higher atmospheric pressure than Earth because it has never experienced massive carbon deposition from its atmosphere*

Even so, this new figure is still rather higher than we would expect — it should be less than Earth. There is a minor point in that, as Venus has no seas the 'surface' pressure is comparable to that on Earth at the ocean bottom with the water removed, but this really makes very little difference. For the second part of the answer we will need to return to Earth itself.

The Earth and the Moon

The Earth/Moon system is actually close to being what is called a double planet. The Moon has about one eightieth of the mass of the Earth, and is roughly 400,000 km away. As a first approximation, the centre of gravity of the system therefore lies about one-eightieth of the way along a line from the centre of the Earth to the centre of the Moon.

The present radius of the Earth is about 6,400 km, so the centre of gravity lies only about 1,400 km below the surface, only one-fifth of the way down to the centre. If the centre of gravity was actually above the surface, then the Earth/Moon system would conform to the true definition of a double planet.

Now for the crunch. Some 300-400 million years ago, the Earth's radius was perhaps half what it is now, say around 3,200 km. If the Earth and the Moon had the same separation and masses as they have now, they would have formed a true double planet, with a centre of gravity some 1,800 km above the Earth's surface!

In actual fact, it appears quite likely that the Moon was once quite a lot closer to the Earth, but even so there is clearly scope for a double planet situation to have applied in the past. In a double planet, the two components tend to share atmospheres, especially if their mutual centre of gravity lies within the normal atmosphere of one component (and this is *more* likely if the Moon was once closer to the Earth).

Of course the centre of gravity is not the point at which the gravitational forces acting on a gas molecule between two bodies cancel out, but these two locations are linked. We can get a better feel for the situation by looking at another mind model.

Interaction between Gravity Wells

Figure 15.1 is a development of the 'gravity well' model shown for the Earth in Figure 11.1. The original model was simplified. That model, a cross-section of a funnel shape lying in a flat plain, only considered the Earth in isolation.

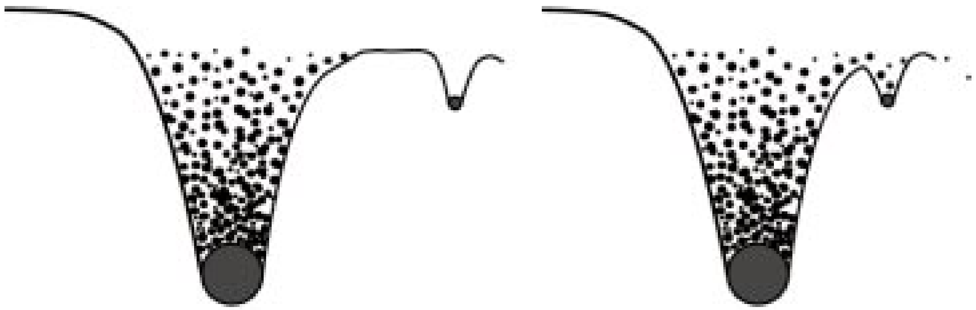

Fig. 15.1. Gravity wells for separated (left) and close (right) Earth-Moon systems

We can think of the gravity-well surface as being a huge flat sheet of very thin rubber. The Earth is then a heavy ball-bearing which is placed on the sheet and stretches it downwards to form the well shape.

We can extend this model by taking the Sun into account. The Sun is enormously heavier than the Earth, but is a long way away. We can think of the Sun as having its own gravity well, formed by a much heavier ball, placed a long way off on the rubber sheet. The Earth and its own tiny gravity well lies out towards the edge of the Sun's well, where its slope has become quite shallow. The Earth stays at the same distance from the Sun because it is running round the Sun, and holds its position on the sloping well-wall like a wall-of-death motorcyclist.

The first diagram in Figure 15.1 shows the gravity wells for the Earth and the Moon when they are fairly widely separated. The Moon lies high up in the Earth's gravity well and does not distort its shape much. That is close to the present situation.

The second diagram shows the Earth and the Moon much closer together. Their gravity wells are more merged together, with the rim of the Earth well 'dented' down, and so allowing atmospheric gases to overflow more easily. And, most important, the situation gives these gases greater scope to escape from the Earth-Moon system altogether, even though they may still remain within the Sun's immensely wider gravity well, elsewhere in the solar system.

In this way, at some stage of the Earth's history, a lot of its atmosphere is likely to have leaked off via the Moon. With its much smaller escape velocity, the Moon would have been unable to hold this atmosphere — of the solar system moons, only Saturn's giant moon Titan is able to hold a significant atmosphere, and Titan is much more massive and colder than our Moon. So here is a possible explanation for the fact that Earth has a thinner atmosphere than Venus even when carbon deposition is allowed for — Earth has a massive moon, while Venus has none.

> *Proposition 15E*
>
> *Earth has lost atmosphere through leakage via the Moon, especially when the Earth's radius was smaller and a double-planet situation was approached*

Life in the Universe

The vast rubber sheet in which the Sun's gravity well lies is part of an even vaster one extending over our whole Galaxy, and beyond that to other galaxies and to the remote ends of the Universe — if it has ends.

A question which has fascinated people ever since the existence of other planets was known is whether life, especially intelligent life, exists elsewhere in the Universe. Many views, ranging from the serious (such as Asimov [1979]) to the crazy, have been put forward.

So far no really positive evidence has emerged, and I will not be venturing a Proposition here. But we can note that the fact that no other planet in our solar system except Earth has an atmosphere containing much free oxygen, and that I have suggested that this oxygen originates only through the action of life. All the planets have immense reserves of oxygen in their rocky cores, oxygen is the most common element there, so it is not a question of unavailability.

Earth is also the only planet in the solar system with significant surface reserves of water. Water is made up of hydrogen and oxygen, and all the planets appear to have started off with huge reserves of hydrogen. Free hydrogen is easily lost except from the more massive planets. Water vapour can be retained by the middle-range planets, but this is always subject to breakdown in the outer atmosphere through the action of cosmic rays. The resulting hydrogen would be easily lost, and the oxygen retained, or reacted with methane to form carbon dioxide in a hydrocarbon-rich atmosphere.

In Asimov's book he tries to work out the probability of intelligent life existing elsewhere in the Universe, on making various assumptions as to the mode of formation of stars and planets, and the probability of occurrence of given conditions, whether normal or unusual. It does seem that our Earth is unusual. Earth life is believed to have originated in the water, and water is not common elsewhere in the solar system.

But perhaps the most unusual feature of Earth is its relatively large moon, unique among the inner planets. We have seen how the presence of the Moon may have affected the Earth's atmosphere, and we may wonder if the Moon may have been a crucial element in the formation of life on Earth. If so, it lessens the likelihood that life has arisen elsewhere, if the Earth-Moon system is truly very unusual.

The Expanding Planets

The Earth-Moon system may or may not be unusual, but there is nothing to suggest that it is not subject to the same physical laws as the rest of the Solar System, or indeed the rest of the Universe. We can therefore expect that if the Earth has expanded in the past, the same forces will have acted on the other planets, and evidence of this may be found on these planets.

In fact evidence of global changes of this sort were looked for on the other planets back in the days when Continental Drift was coming into its own, much earlier in the century. At that time, knowledge on the surfaces of the other members of the Solar System was quite sparse. What knowledge existed came entirely from telescope observations, and the only other world within proper reach of the telescope was one face of the Moon (the Moon always keeps the same face turned to Earth).

The Moon did show apparent evidence of volcanic activity, or at least of igneous rock flows, but its most prominent features were the huge impact craters which covered much of the visible surface. Further afield, the two closest planets were Venus, completely cloud-covered and enigmatic, and Mars.

Mars lies at the aggravating limit of resolution from Earth-based telescopes. Some surface details can be made out, but it was impossible to say for certain what they represented. At the beginning of this century, the American astronomer Percival Lowell was a strong advocate of the theory that a series of lines just barely visible on Mars was a network of canals containing irrigation water used by the inhabitants.

The advent of the space probes changed all this. Actual landings of remote-controlled vehicles have been made on both Venus and Mars, and even some simple analyses of rocks made. We have photographs of these rocky surfaces. Radar scans of the surface of Venus have given increasing information on its terrain. The surface of Mars has been mapped in fair detail from orbiting spacecraft.

Tiny Mercury, very close to the sun and for this reason very difficult to observe, is still not known in any detail. It does have a number of prominent surface features, mostly impact craters. To date, however, most of the relevant evidence has come from the two closest and best-studied planets, Venus and Mars.

Expansion on Venus

As the evidence accumulates, it lends increasing support to the view that the other planets are behaving similarly to Earth. Venus, similar in size to Earth, has a clear distribution of raised ‘continents’ and wide, flat ‘seabeds’, although of course the latter do not contain any water. And the interesting thing is that the ‘seabeds’ cover about 70% of the planet [Cambridge, 1985] — the same as on Earth.

At first the radar resolution was not good enough to show searched-for features similar to the midocean ridges of Earth, but these have now been found. An article in Scientific American [Fractured, 1986] describes these, crossing the Aphrodite Terra continent on the equator of Venus. It appears that a long fracture zone, very similar to our midocean ridges, stretches at least two-thirds of the way across Aphrodite Terra, and possibly runs right round the planet in its equatorial zone.

Of course, in the article this evidence is looked at from the conventional viewpoint, with no regard for an expanding Venus. The interior of Venus is assumed to be heated by radioactive decay, and the ‘midocean’ feature due to convective upwelling of hot rock. The author comments that “If new lithosphere is created near the Venusian equator, then old lithosphere must be destroyed by subduction near the poles, but so far no evidence of a subduction zone has been found”. Surprise, surprise.

It seems clear that the same type of domain movement as on Earth is occurring on Venus. However, the fact that the first prominent domain-boundary features observed on Venus run in an equatorial direction, while those on Earth run mostly north-south, may indicate that the Venus feature shows an earlier stage of expansion, perhaps similar to the Tethyan Girdle which earlier existed on Earth.

> *Proposition 15F*
> *Expansion of Venus is occurring in a similar way to Earth expansion, but may be at an earlier stage of development*

This slightly earlier stage of development may be expected, since Venus is somewhat smaller than Earth. This will be looked at again in the next Chapter.

Our Little Brother Mars

Although it is not the planet which is physically most comparable to Earth, Mars, the Red Planet, is perhaps the least hostile as far as human life is concerned. It is the only place we know of where a man might live with no more apparatus than a breathing mask and an insulating suit.

The Red Planet is red because of the colour of its terrain — waterless, eroded, and swept by thin winds able to support an occasional dust storm. Almost certainly the red rocks and dust are ‘rusty’ iron oxide colours, as in many Earth deserts. There is ample oxygen there, trapped in the rocks, but virtually none left in the atmosphere.

The terrain of Mars is not a featureless plain, but has a huge array of structural features, including giant volcanic calderas. The highest of these, Nix Olympica, is 25*km* high. But easily the most prominent topographic feature is a huge equatorial canyon, some 5000*km* long and with an average depth of 6*km*. Known as Valles Marineris (Figure 15.2), this great equatorial gash is the site of three out of the four largest volcanic calderas on Mars.

Incredibly enough, this vast canyon has been interpreted as evidence of former water erosion on Mars — after all, that was what caused Earth’s Grand Canyon, wasn’t it? No matter that water cannot exist on Mars (the air pressure is too low to allow liquid water). No matter that volcanos stand in a line along this feature.

In the light of evidence already given in this book, it seems obvious that Mars is in the early stages of planetary expansion, and that the Valles Marineris rift is part of a Tethyan Girdle in process of formation round the planet’s equator.

> *Proposition 15G*
> *Expansion of Mars is occurring in a similar way to Earth expansion, but is at a much earlier stage of development, with an Equatorial Girdle just emerging*

In Vulcan's Realm

In Chapter 8 we looked at the formation of volcanos on Earth, and concluded that these were locally-produced phenomena caused by domain-edge rubbing, and did not stem from any inner heat of the planet. We have seen that volcanos exist elsewhere in the Solar System, off Earth, and we can ask how they fit in with the theories put forward.

The most spectacular volcanos in our Solar System do not exist on any of the planets. They occur on Io, the innermost of Jupiter's four giant moons. Images from the space probes have shown huge eruptions from Io's surface, visible as giant plumes leaping up from the edge of the moon's disc.

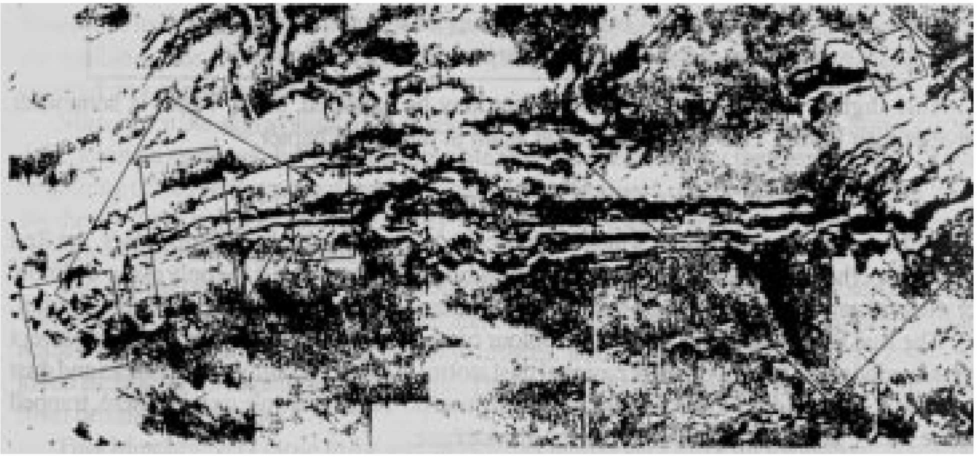

Fig. 15.2. The great equatorial canyon of Mars, Valles Marineris [Cambridge,1985]

Researchers have accepted the obvious fact that Io's volcanos have no connection with primeval internal heat welling up from its interior, and ascribed them to the effects on the surface of gravitational forces, caused by its giant companion, Jupiter. This view could be rephrased by saying that crustal movements on Io cause its volcanos — perhaps the same might apply on Mars, Venus, Mercury, the Moon, and even Earth?

This concludes our examination of the planets. Much remains to be discovered about them, but at present it can be said that they are known to contain nothing contradicting the ideas expressed here, and a great deal to support them. We can now move on to the *reasons* for the behaviour we have noted in the Earth and the other planets.

CHAPTER 16

THE COSMIC ENGINES

"The Universe: a wonderful and immense engine"
— George Santayana

Here is perhaps the place to look at some of the possible underlying reasons for the behaviour of the Earth in its past history of expansion and movement. As usual, I will venture forth with a number of Propositions. But it should be emphasized that these are in a separate class from those which have gone before.

The Propositions previously set out are generally attempts to explain *observed data*. Ones in this chapter mostly suggest mechanisms. Even if all the mechanisms suggested here should later be discredited, this does not affect the earlier Propositions.

Part 1 — Domain Movement

In Chapter 5 we saw that there was clear evidence of movements of parts of the Earth's crust relative to one another — already accepted as 'Continental Drift' and 'terranes' — and that it also appears that smaller parts (microdomains) have moved bigger distances relative to larger ones. Moreover, it appears that the direction of movement has been strongly away from the equator. We will first look more closely at a possible reason for this result.

The Fugitive Domains

We have seen that the earlier Continental Drift theories and the later Expanding Earth concept are not mutually exclusive, one is a more developed case of the other. It is clear that pieces of the crust do actually move relative to one another on the surface of the Earth, as in the case of India colliding with northern Asia. Even though the Earth is expanding, these domains are not completely passive subjects of the expansion occurring beneath them; they do actually move.

What drives the movement of these domains? Earlier we have seen that the suggestions of 'convection cells', with floating land masses being pushed aside by uprising currents of hot rock, are just not supported by any real evidence. So what causes the movement?

The explanation lies, I believe, in the principle of conservation of momentum. If a body (or a group of bodies) is in motion, its momentum (the figure got by multiplying its mass by its velocity), remains constant or 'conserved' in spite of events it undergoes.

If a series of flat bodies is connected loosely to the surface of a rotating sphere, and that sphere expands under them, what would we expect to happen to the flat bodies?

If the underlying expanding sphere continues to rotate at the same angular rate (same number of revolutions per day), and to a first approximation we can take this to be the case with the Earth in the recent geological past, then 'floating' land masses originally situated near the equator may be expected to move away, towards the poles, so that their momentum remains the same.

This is because if the rate of rotation is the same, the actual velocity of a point on the Earth's equator must increase in direct proportion to its radius if it expands. A floating body may be expected to move away from the equator with a sort of 'centrifugal force', towards a latitude where the surface velocity is the same as in its original position.

> *Proposition 16A*
> *Domain flight away from the equator occurs on an expanding Earth in an effort to conserve the momentum of the individual domains*

This suggestion could be tested physically, for example with magnetized discs sliding on the lubricated surface of a metal sphere, or theoretically, through computer simulation.

There are some other factors to consider here. One is the the point that smaller domains appear to have moved longer distances than larger ones. The other is the actual position of the Equator from time to time.

Effect of Domain Size on Movement

Evidence has been given that the microdomains and smaller domains have moved greater distances than larger domains to which they were once attached (Proposition 5H). The reasons for this are not entirely clear.

One possible line of reasoning is based on momentum conservation. A large domain extending right over the equator will have a centre of gravity on, or fairly close to, the equator. If the effect of momentum conservation is to cause movement away from the equator, such movements will be balanced or minimized by the fact that the two halves of the domain are pulling in opposite directions. Of course this only holds while the domain stays in one piece.

On the other hand, a microdomain on the outer edge of such an equatorial megadomain will have its centre of gravity some way from the equator, and the effects of 'centrifugal flight' will be greater. Also, close to the equator the Earth's surface is close to parallel with its axis, so there will be a difference in the degree of change in momentum with radius expansion, compared to a domain in middle latitudes (Figure 16.1).

In this diagram, a microdomain M is shown attached to a large equatorial domain D on an unexpanded Earth, and in various positions relative to D on an Earth of larger radius.

On the expanded Earth, M1 is the position of the microdomain if it remains attached to D. However, we would expect that if it broke away from D and just kept its own position relative to the underlying core it would have appeared to 'move' relative to D, down to M2. If the expanded sphere continued to rotate at the same speed as the unexpanded one, then to move to a position where its rotational speed and momentum were preserved, the microdomain would have to travel right down to M3.

There other considerations. As already noted (Proposition 7F), it seems that domain flight becomes less marked or disappears altogether as the Poles are approached. We have also seen (Proposition 5K) that domain flight may be affected by the gravitational influence of adjacent large domains. There is also a philosophical consideration.

If the Earth is expanding, and smaller domains are ending up further from the Equator than

previously adjacent larger domains, this situation could be viewed as larger domains *moving further from the Poles* than smaller ones. This is an alternative model which deserves consideration. However, it is a model which does not seem as satisfactory as the one already looked at, in that it does not explain the preponderance of equator-pointing peninsulas, or the apparent large shifts of isolated islands such as Iceland.

Domain Blocking

Whatever the basic mechanisms involved in domain movement, whenever you look at the position of a particular area, the important factor may just be one of physical blocking of movement. The Italian, Iberian, and Indian peninsulas are clear examples of domains which were moving north but whose movement was stopped when they ran into larger domains.

The highest large area on Earth is the Tibetan Plateau, which stands more than 4*km* above sealevel. This domain is reasonably central in the east Asian landmass. Rather than being pushed up, as is usually assumed for high areas, it may be that this plateau never had the chance to slide down; while other parts of the holodomain may have slid away into hollows created by Earth expansion, this may have happened to have been blocked from movement by adjacent domains.

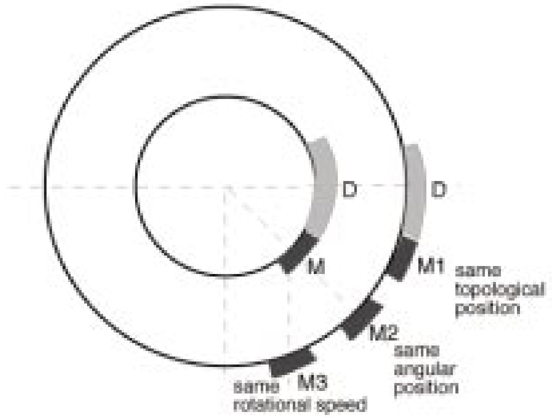

Fig. 16.1. Changes in momentum at different latitudes

It is usually assumed that India, breaking off from the Gondwanan continent low in the south, travelled a long way north before colliding with Laurasia. In fact, it is possible that the Indian megadomain was never more than a few hundred kilometres from Laurasia, so that the relative movement leading to creation of the Himalayas was only of this order, and the long 'skid marks' down the Indian Ocean actually represent the Earth expanding away under India. We have seen, in Chapter 5, that the Himalayas could have been formed from only 2-3*km* of domain material pushed together, so the actual 'run up' of India to the impact need not have been very long.

Thickness of Domains

At the end of Chapter 9 we arrived at a picture of the Earth (Fig. 9.2) in which the old broad, massive 'tectonic plates', extending down some 100*km* or more in the 'lithosphere', were replaced by a mass of smaller domains and sub-domains beneath them, of very varying thicknesses.

Another feature of the old 'tectonic plate' approach was the idea that these huge plates were floating on a layer of liquid rock within the Earth, like icebergs in the ocean. I have suggested that there is no such liquid layer. I also strongly suspect that actual calculations of the influence of any such liquid layer on movements would show them to be quite insignificant. It is as if the demolishers of an office tower on a hill would expect quite different results from a controlled implosion according to whether it had been raining or not.

Whatever, the tectonic plate idea assumes more or less uniform-thickness massive plates everywhere on the Earth. The domain approach does not. It is possible that the smaller microdomains, such as Rottnest, may be, like Laputa, only a few hundred metres or less thick.

What this implies is that these surface microdomains may be moving quite unsuspectedly, like snails on a slab of rock, without creating any obvious effects such as heating or rock metamorphism. The slab of rock may itself be inching its way downhill as soil is washed away under it, and the whole hillside may be part of a microdomain moving over a larger subdomain.

> *Proposition 16B*
> *Microdomains may be moving independently on underlying domains which are themselves in motion*

This Proposition is at the stage where it could be verified by careful actual measurements of relative movements; surveying instruments have now been developed which are just about capable of this level of accuracy. Let us revert briefly to the quotation about Rottnest which appeared at the head of Chapter 2. We have already shown how the earth movements suggested by the plant relationships in that quotation do appear to actually occur; now we can see their speed.

The basement limestone rocks on which Rottnest is situated are believed to be about 1.5*my* old. If Rottnest has moved 300*km* south in this period, simple calculation shows the average rate of movement to have been 20*cm/yr*. This is quite a large amount, which should be easily detectable with properly-designed measurements.

Of course, Rottnest may not be currently moving at all, it may be blocked on its undersea pedestal. The basement rock on which it moved could be above or below the level assumed, and hence of different age, and the reference point on the coast from which the 300*km* was measured could itself be moving, although variations here tend to increase the calculated speed rather than reduce them. Whatever, if the domain movements suggested actually exist, it should be possible to observe and measure them somewhere.

The Position of the Equator

There is quite a lot of geological evidence (e.g. [Carey, 1987]) that the position of the Earth's equator has varied somewhat in the past. This is not a new thought, such suggestions predate even the development of Continental Drift ideas. And of course the reasoning in this book makes the equatorial position almost a philosophical question — if domains and subdomains are moving freely about the Earth, like people milling in a crowd, what relevance is there in a line drawn across this crowd at some arbitrary point in the past?

There is, in fact, some relevance. We have seen, in the phenomenon of domain flight, that these movements have apparently been away from the equator of the time when movement

began. It has been suggested that when the split of the Holodomain into Laurasia and Gondwanaland occurred, this took place along the equator of that day. The Tethyan Girdle formed round the Earth by that event has had a strong influence on the Earth's subsequent history.

It is very obvious that the distribution of land between the northern and southern hemispheres is currently quite uneven, with far more in the north than in the south. This reflects the fact that the old Tethyan equator ran along a line between domains which is mostly much further north relative to its original position. As the jostling domains have moved to different extents, the line has become rather broken up, but appears most northernly in the Mediterranean, at about 35°N, and most southernly around southeast Asia.

In Table 6 there was a list of families suggested as originating in Laurasia, and of ones from Gondwanaland. There were far more in the Gondwanan section, presumably because more intense evolution occurs in the tropics, and almost all the current tropics were once part of Gondwanaland. Much more of Laurasia has ended up in cold polar regions where the opportunity for development is much poorer.

> *Proposition 16C*
> *More modern species are of Gondwanan origin than Laurasian because species development is more marked in the tropics, which are mostly parts of Gondwanaland*

The reason for the uneven distribution of land in the two hemispheres is not clear at present. It could be pure chance. However, there is another unevenness, more recent than the Tethyan one, which is happening because of the opening up of the Pacific Ocean.

The Pacific is very large, covering around a third of the entire Earth's surface, and it has opened up relatively recently and quickly. As a result, the hemisphere centered on a point in the South Pacific off New Zealand contains only 15% of the Earth's land surface. This does suggest that there have been at least two episodes of unevenness of domain redistribution, and that their cause is not related to the Earth's spin, as the Pacific episode has affected both hemispheres more or less equally.

There is some suggestion from plant family distributions of different early equator positions. In particular, the layout of the cycads (Fig. 4.13) leads to speculation about an equator which once dipped down towards southern Africa and Australia then up again to the Americas. The cycads are much older than the other plant groups featured, and could have originated under different conditions — but more evidence is needed on this one.

The Final Answer

As almost all of the concepts of domainography have only now been introduced with this book, it is not reasonable to expect that the whole field can be advanced to the stage of giving final answers in one go. In particular, much more detailed calculation is needed of the parts amenable to mathematical analysis. For the moment we must be content with pointing out that such calculations can be made.

In this work, we also need to keep in mind at every stage whether the assumptions used are justified. For example, it was assumed above, as a first approximation, that the Earth is rotating at the same rate as it did in the past. In fact there is evidence that the rate of spin is slowing down.

Most of this evidence comes from studies of growth patterns in fossil corals. Some of these show patterns, similar to the growth rings in trees, but with one 'ring' for each day rather than year. They indicate that in the past, the Earth had more than 400 days in a year.

This is usually taken to mean that the Earth turned more quickly on its axis in those days (an alternative, that the Earth took longer to go round the Sun, is much less likely). The implications of all the matters raised are going to need a lot of exploring!

Part 2 — Within the Planet

In Chapter 9 we had a good look inside the Earth, and a number of Propositions were made which differed greatly from accepted views. We can now go to develop some of these, and see some of the mechanisms for change which they imply. The first area to look at is the Earth's inner structure and composition.

Phase Changes and Density

Working from the conventionally-accepted data and figures given in Fig. 9.1, we arrived at a new scenario for the inner structure of the Earth. The idea that the Earth's density increases from the surface to the core, and does so through a number of abrupt changes or discontinuities as well as gradually, was not disputed. The idea that the Earth's temperature increases regularly towards the core, reaching several thousand degrees at the centre, was rejected. The idea that our planet has an iron-rich core was rejected. The observation that the upper layers of the Earth's crust are the source of heat which rises to the surface is undisputed, and a source for this heat was suggested.

The density of the Earth's inner substance is believed to increase from an average of around 2.7 at the surface to around 13.6 at the centre. The density of iron metal is around 7.9, and of its oxides and compounds a good deal less, so this density of itself gives no explanation for the high value at the Earth's centre. I have put forward part of an explanation (Proposition 9D), in suggesting that the density discontinuities are due to phase changes in the Earth's substance caused by the great pressures. We can make the picture more explicit.

It seems reasonable to suggest that the entire reason for density increasing as you approach the Earth's centre is that the rock substance is progressively more compressed as the weight of the overlying layers gets larger. At certain threshold pressures, the substance will undergo a specific rearrangement, a phase change. Between these key pressures, the substance will become progressively more compressed and hence of higher density, but stay in the same phase.

> *Proposition 16D*
> *Both the progressive and the abrupt increases in density encountered on approaching the Earth's centre are due to the increasing pressure of the overlying material*

If, then, the increase in density towards the centre is purely the outcome of the increasing pressure, this raises another possibility, concerning the *composition* of the Earth's substance. We have abandoned the iron core, we have suggested that the density discontinuities are due to pressure thresholds. We are left with nothing which necessarily requires the composition of the Earth substance to change with depth. The simple conclusion — and we will see in the next Chapter that we should always take the simplest way — is that it does not change.

> *Proposition 16E*
> *The composition of the Earth's solid substance is more or less uniform from the centre to the surface*

Of course this Proposition does not apply to the Domainosphere, the outer layer of the Earth where, as we have seen, the interaction of domains has led to segregation of components. This segregation has occurred directly, through domain rubbing and natural zone-refining (Propositions 14C, 14D). It has occurred indirectly, through domain uplift or land exposure, by erosion and leaching of rock components. And it has occurred biologically, through the action of life, as in the formation of fossil fuels.

What the Proposition suggests is that the *primeval* composition of the Earth's solid material was uniform. Only in the Domainosphere, the top 500*km* or so where domainographic processes are active, has this uniformity of composition been disturbed.

But hold on a minute — what about the Sial and the Sima layers, described at the start of Chapter 9, which are known to differ in chemical composition? Let us look more closely at these.

The Sial and the Sima

The Sial is the lighter layer of rock (density 2.7) which forms the majority of the Earth's continents. It is discontinuous, up to about 30*km* thick below the continents, but grading away to nothing at their edge. The Sima is slightly denser (2.9), is exposed at the deeper ocean beds, and is believed to underlie the Sial where the latter exists. The situation, as conventionally accepted, was illustrated in Figure 9.1.

Table 16. Percentage oxide composition of Sial and Sima

	Silicon SiO_2	Aluminium Al_2O_3	Iron Fe_2O_3+FeO	Calcium CaO	Magnesium MgO	Other —
SIAL	69	14	4	—	—	13
SIMA	48	15	11	11	9	6

Both layers consist essentially of igneous rocks, although of course both may be overlaid by sedimentary or metamorphic ones. These rocks are not of a fixed composition, but both are basically made up of metal silicates — compounds of silicon and oxygen with various metals. Where the two differ is in their respective contents of the metals.

It is conventional to represent the compositions in terms of the oxides of the elements. Table 16 (based on [Physical, 1977]) shows the approximate percentage compositions of the Sima and the Sial in this form.

It should be noted that these are average compositions. Most igneous rocks fall fairly easily into one group or the other, but it is possible to find examples which grade from one type into the other.

The main differences are that the Sial has much more silica, less iron, and almost none of the calcium and magnesium of the Sima. Iron and calcium are considerably heavier than silicon, and the higher proportion of these in the Sima accounts for its higher density.

The conventional view is that the Sial, being lighter, floated out and condensed first in the early days of the Earth, when it was all molten. Conventionally, also, the heat which currently flows out of the Earth was believed to come, at least in part, from this 'primeval' heat. I have already suggested (Proposition 9F) that the idea that the Earth now has a hot core is wrong. I have also suggested (Proposition 8E) that igneous rocks are all produced locally, from domain rubbing, and do not well up from deep inside the Earth.

If we put all these points together, we end up with a scenario very different to the conventional one. This leads to a number of important propositions, the first of which concerns the Sial and the Sima. It seems likely that the Sial was never formed separately to the Sima, but instead represents only worked-over and re-melted Sima.

> *Proposition 16F*
> *The acidic igneous rocks classed as Sial have been derived by the re-melting of worked-over and leached basic Sima rocks*

This Proposition explains the occurrence of the iron-rich ore beds formed in the early, Precambrian era, and the calcium- and magnesium-rich deposits (limestones) of the Paleozoic and later eras. It also explains the silica-rich deposits (sands and sandstones) of all ages. The implication is that the Sima is the 'primeval' rock, which, as already suggested, extends throughout the Earth.

> *Proposition 16G*
> *Rock of 'Sima-type' composition has extended throughout the Earth since it was first formed, and has only been modified near to the surface by domainographic processes*

An implication of this (which can be tested) is that the average composition of all rocks, sedimentary, metamorphic, and igneous, in the upper layers above the Sima, should when summed together be identical to that of the Sima (after allowing for the mainly atmosphere-derived components such as carbon).

Heat and the Earth

If we do not need the inner Earth to be molten to explain such things as floating tectonic plates, heat rising to the surface, or segregation of the Sial or other layers, then we might as well assume that it never was molten.

> *Proposition 16H*
> *The Earth was never molten*

Instead, in the absence of a better story, we can take it that the primeval Earth accumulated at a temperature not too different to now. After all, if the Earth condensed from part of a solar-system wide disc of gas, as one proposal has it, there is no need to assume this gas was hot. Even if the Earth was formed from material thrown out from the hot Sun, this material could radiate heat freely, and need not still be hot by the time it reached Earth's orbit. If the material was very fine, close to the molecular level, the concept 'heat' in fact means nothing; heat is a measure of the interaction of particles close enough to interact.

The same reasoning applies also to the other planets of the Solar System.

Composition of the Other Planets

In Table 15, values were given for the densities of the planets and major moons of the Solar System. There are some conclusions to be drawn from these densities.

The density values given for the Outer Planets and most of their moons are irrelevant, because those values include unknown proportions of atmospheric components, whether as gas, liquid, or solid. The only values we can use here are for the large bodies with known rocky surfaces, that is, the four Inner Planets and our own Moon.

In order of decreasing size of planet, these values are: Earth - 5.50; Venus - 5.25; Mars - 3.91; Mercury - 5.41; and Moon - 3.35. There is a clear progression here, with the smaller bodies having lower densities — the only hiccup is with Mercury. Notice also that as the bodies get smaller, their densities approach those of the upper few hundred kilometres of Earth, 2.7-3.3 (see Figure 9.1).

It seems worth examining the proposition that all the rocky planets, and probably the rocky cores of the giant planets, are made up of Sima-type material like Earth, which material shows the same compression and increase in density with depth as on Earth.

> *Proposition 16I*
> *All the Solar System planets and major moons have rocky centres made up of the same Sima-type material as Earth, subject to the same increase in density with depth*

The situation is best illustrated by noting the radius of the planet or moon and imagining it superimposed on the higher layers of the Earth shown in Figure 9.1, with the surfaces matching. Thus our Moon, with a radius of 1738*km*, would extend down to halfway down the Lower Mantle, with a density at its centre of between 4.3 and 5.5, and one at its surface of around 2.7. The fit with the actual average density of 3.34 is really quite good, particularly when you allow for the fact that more of a sphere's volume is closer to its surface than its centre (seven-eighths is above the half-radius mark, only one-eighth below).

Mars, with a radius of 3393*km*, would extend on Fig. 9.1 some way into the Outer Core, with a small part of its volume having a density of 10.0-12.3. Again this looks as if it fits in quite well with an average density of 3.95. Probably this area would benefit from detailed and careful calculations.

As to the apparent Mercury hiccup, which causes it to vary from the pattern, there are a number of possibilities. One is that there are exceptional circumstances with Mercury which cause it to vary from the pattern This may well be the case, although I cannot think of any reasons at the moment.

Another possibility is that there may be errors in the quoted figures. For example, in the case of Mercury, the mass may be somewhat in error. Usually planetary masses are calculated, with good accuracy, from observations of the orbits of their moons. Mercury does not have a moon, and it is also so close to the Sun it is difficult to make good observations. The mass may therefore be in error; earlier figures havein fact suggested that its mass was higher, with a density more than that of Earth. From the general sequence, we would expect Mercury to have a density of about 3.6. Time will tell what the real position is.

At least at the moment, the evidence available favours the suggestion in Proposition 16I. If, in fact, the rocky components of all the planets are made up of very similar material, it also seems likely that all the planets were formed in the same event and at the same time.

> *Proposition 16J*
> *All the Solar System planets were formed in the same event and at the same time*

Before leaving this area, we should look more closely at the phase changes in the Sima material, and their role in planetary expansion.

Sima Phase Changes and Expansion

In Figure 9.1, the values shown for the density of the Earth's substance vary from 2.7 at the surface to 13.6 at the core. There are a number of abrupt changes or discontinuities, the biggest being at the Mantle/Core boundary, where the density leaps from 5.5 to 10.0.

Is it possible to compress rock with a 'natural' density of around 2.9 to one of 10.0 or more? The answer is yes, if the pressures are great enough. There may be two quite different stages in this compression.

Many substances will alter to denser phases, when high pressures are applied, by rearrangement of their crystal lattice structures. For example, of the two main forms of the element carbon, the normal-pressure one is graphite, which has a density of 2.25. All the atoms are packed in flat sheets, with some separation beween the sheets. These sheets give graphite its ability to slip and lubricate, and also its ability to conduct electricity.

On the other hand, diamond is a 'frozen' high-pressure form of carbon. Its density is 3.52, more than 50% higher than graphite, and its atoms are all interlocked in a compact, three-dimensional construction. This structure gives diamond its great hardness.

We can number the Sima phases from I to V downwards from the surface, with I being the crustal phase, II and III the upper and lower Mantle, and IV and V the outer and inner Core. It seems possible that the densities for phases I-III, up to 5.5, could be achieved by appropriate crystal lattice structure rearrangements. But the leap to 10.0 looks less possible.

However, under very great pressures, matter can be compressed to an enormous degree, not by lattice rearrangements, but by actually crushing down the atoms themselves. Material crushed in this manner is called 'degenerate matter', and its density may be truly enormous. The example usually quoted is that of degenerate matter in the heart of 'black dwarf' stars, where one matchbox full would weigh more than our Earth.

A possible explanation for the high density of the phase IV and V Sima is that it consists of the lowest grades of degenerate matter.

> *Proposition 16K*
> *At the Mantle/Core boundary, phase III normal-matter Sima changes to phase IV degenerate-matter Sima*

This Proposition is not in conflict with an observed feature of the Mantle/Core boundary. Below this boundary, in the upper Core, earthquake waves behave similarly to what they do in liquid, while above it they do not. For this reason, the outer Core has been assumed to be liquid in the past. It now seems quite possible that this liquid-mimicking behaviour is a feature of phase IV degenerate matter. Certainly, at the enormous pressures involved, the normal concepts associated with 'liquid' and 'solid' begin to lose meaning.

It is worth pointing out that if the Earth once had half its current radius, for the same mass, its density would average eight times as much — that is the ratio of the two volumes of the current and unexpanded spheres. This density, around 44.16 instead of the current 5.52, would have to involve the use of degenerate matter. It is far higher than the density of the the most compact normal substances known, the densest element being osmium, at 22.59.

It is also now clear that the mechanism for planetary expansion involves changes in the planet's inner phases, progressively from denser to less dense forms.

> *Proposition 16L*
> *Planetary expansion occurs via the conversion of higher-density Sima phases into lower-density ones*

In some senses this is another way of looking at Proposition 9E, on the change in position of density discontinuities with pressure. It provides a mechanism for planetary expansion, but not a reason. For that, we must look at the next section.