of the distribution are where the plant was affected by a devastating disease in the 1930’s.

The points to be made from this map are that eelgrass has a clear Laurasian distribution, and that even though it is a marine plant, its current distribution was presumably brought about by Earth expansion after the species had evolved and separated off from a common southern-hemisphere stock.

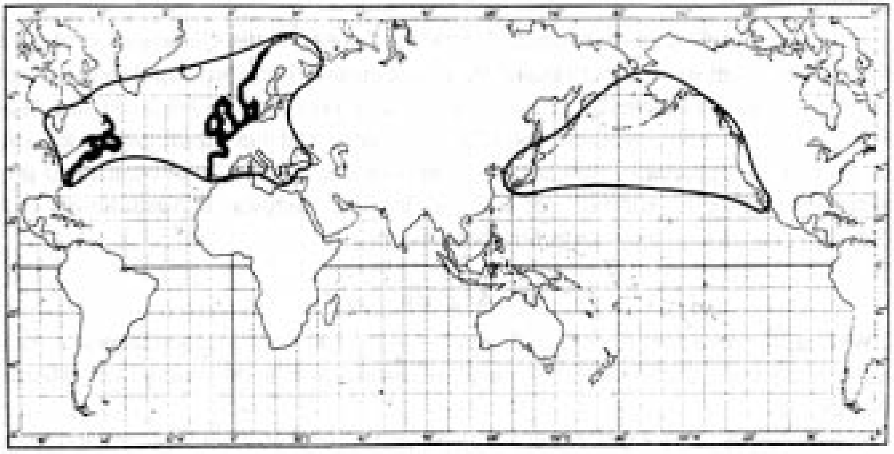

Fig. 6.2. Distribution of eelgrass, Zostera marina

Notice that the two parts of the distribution are no longer connected, although they must have been at some time in the past. Also that the vector carrying the wasting disease was able to cross the Atlantic (and hence had a different ecopressure boundary to eelgrass itself), but it did not reach into the Mediterranean (or across to the Pacific).

We have seen that the consequences of Earth expansion have been effective across the whole spectrum of animal and plant life, not only life on land, but life in the sea as well. Now we have enough evidence to go on and see how far we can reconstruct the Earth as it was in former days.

CHAPTER 7

PUTTING THE EARTH BACK TOGETHER

“We have been living in an Age of Analysis, when we have found out a great deal about many different aspects of the world in which we live. But now is the time to move into an Age of Synthesis, when we will put together all this body of knowledge”

— F.A. Sharr

We have now laid the groundwork for the task of trying to fit back together the vast spectrum of domains of every size, to reconstruct the original holodomain which once covered the whole of the Earth’s surface.

It would be nice to present here the complete picture, but, alas, that is quite impossible. It will require years of painstaking work by many people, plus probably the need to go out into the field and accumulate new evidence, before all the arguments will be settled and we feel that we really have got the thing right. All we can do here is make a start on the new area of investigation called Domainography, by putting together some working rules and giving a few possible answers.

The Rules of Domainography

The first aim of the approach must be to keep it as simple as possible — we will expand on this further in Chapter 17. When the broad outlines are established, then will be the time to find the exceptions to the rules and possibly to refine or extend those rules. At the same time, we know that the general rules will be extracted from a mass of individual, detailed examples.

What general rules should we have? We can start off with the following:

RULES FOR HOLODOMAIN RECONSTRUCTION

Rule 1. Larger landmasses are ***composites*** *of many domains.*

Rule 2. As domains broke up, the ***relative*** *positions of the pieces stayed the same, while their* ***distances apart*** *increased.*

Rule 3. There were no large ***rotations*** *of domains.*

Rule 4. Smaller domains have moved ***further*** *than larger ones.*

Rule 5. Domain splitting was according to the ***normal behaviour*** *of materials.*

The first rule is a basic assumption. Rule 2 simply means that if Domain 26A was to the east of Domain 26B before Domain 26 split, then 26A will always be more or less to the east of 26B, even though they may end up hundreds or thousands of kilometres apart.

Rule 3 is an interesting one. At this stage it is purely a rule of thumb. There is, in fact, a physical law, called the Coriolis Force, which does cause rotation of bodies moving away from or towards the Equator (this determines the direction of rotation of cyclones and the way water swirls down the plughole). But all instances of domain rotation observed to date seem small enough to make their existence questionable.

We might expect this rule to be broken when a smaller, irregularly-shaped domain impacts against a larger one at an oblique angle. India looks as if it might have rotated a few degrees anticlockwise when it ran into Laurasia and made the Himalayas. However this apparent effect could be illusory, caused by differences in the angle of viewing a landmass at different latitudes.

Rule 4 is also an observed rule of thumb, derived from the distributions of plants and animals which we have already examined. For Rule 4 to apply, it obviously must be physically possible; there is no way a microdomain is going to force its way through a megadomain it has run into, to keep up with its fellow which was off to one side of the megadomain.

Rule 5 is an important one, with many consequences. It just says that all domains are made up of masses of rocks which have known physical properties, and the domains will obey normal physical laws of every sort. The fact that we may not have a complete picture of some of these laws does not affect the point.

We already invoked Rule 5 when it was pointed out that the deep ocean trenches could not have been formed by pushing one slab of rock against another (see Proposition 3C) — such an act could not create a gap between them. Another consequence is that the new boundary formed when a domain was torn apart could not be especially complex.

Such a new boundary might well vary from very clean and straight (such as that of the coast of Israel and Lebanon) to somewhat irregular and jagged. But normal physical forces would not permit a break to be formed in the shape of a deeply concave bay, such the Gulf of Carpentaria on Australia's north coast. This must be a composite of some sort, there must be at least two domains involved in its formation. This also applies to any other 'complex' coastline or domain boundary, complex on a scale beyond that of erosional effects. We have already seen, for example, how major peninsulas involve at least two different domains.

This is important enough to extract as a new rule:

Rule 6. Areas with ***deeply concave edges*** *or other complex shapes must have been formed from at least two different domains.*

In addition, there is one more rule which has justification to be explained later (Chapter 8):

Rule 7. All ***mountain chains****, both on land and under the sea, represent domain boundaries.*

The last item in our armoury, before we look at actual re-assembly, is a useful technique.

The Rubber Band Technique

There is a convenient visual approach we can use in this. Look again at some of the plant distribution maps given in Chapter 4. Assume all the land areas have been divided up into domains.

Now regard the distribution boundary as a rubber band, and shrink this band down. It will tighten, and pull together all the domains which were once connected by the early distribution range of the plant genus or species. This will give a preliminary picture of how the domains involved once fitted together on the pre-expanded Earth.

This technique can be used not once for each domain, but hundreds of times — once for each plant species, genus, or family represented on it. It can even be used for 'races' within a species, and if the genetic patterns of individuals are available, say through the isozyme analysis method, it can be used with them too.

Of course this technique will also drag in a ring of domains which do not form part of the original distribution, but instead are just current neighbours of original domains, neighbours onto which the plants have spread through natural dispersion processes. These neighbour domains need to be discarded.

The width of the neighbour ring to be discarded depends on how specific the level of plant description is, and what the likely rate of natural spread is judged at. To deal with the last part first, we will set up the last of our rules, which is an attempt to put numbers to Proposition 2A:

Rule 8. Natural ***rates of spread*** *of a plant species average no more than 1 metre per year.*

At first sight, this estimate seems incredibly low. One metre per year is only 1*km* in a thousand years, which seems very little, however it is also 1000*km* in a million years, and that is quite a lot. Many plant species lie entirely within a range which is less than 1000*km* across. We have already suggested (Proposition 2I) that the half-life of a species is around one million years, so, in fact, this figure does seem to be of at least the right order of magnitude.

On the matter of plant description specificity, the broadest grouping, that of plant family, is too broad to be of much help here. Most modern plant families, such as the Fagaceae (which includes the oaks, chestnuts, and the northern and southern beeches) date back to the early part of the Cenozoic Era, 50-70*my* ago. This would give them the opportunity to spread 50-70,000*km*, much more than the distance right round the Earth (40,000*km*). However, again it does seem of the right order of magnitude, if anything favouring a *lower* figure than that in Rule 8.

We have never put a figure to the half-life of a plant genus, such as *Araucaria*, but it would be somewhere between the species half-life and the known age of the family it is part of. Suppose we put a value of 10*my* to this half-life. Then the average distance we would expect a genus to spread naturally would be 10,000*km*, and the most a species would extend would be 1,000*km*.

Although the Rubber Band technique presented above was a simple visual technique, it could in fact be developed into a computer approach, in which the width of the discardable neighbour rings could be easily varied to see the effect on the final re-assembly. I suspect that in many cases the width of these rings could be cut down to less than the distances implied by the above estimates without affecting the validity of the technique.

For example, look again at Figure 2.1, which shows the distributions of seven different *Canarium* species (the map for the whole genus is Fig. 4.7). It would be my contention that all the areas within the range of the most widely-spread species, number 1, *C. littorale*, were once joined and the species has ended up in the different major islands and peninsulas principally through Earth expansion. This is even though the name of the species means it is a sea-shore plant, and the seeds are designed to float and could well cross from island to island, making this is a worst-case example.

The current range of the species is about 2000*km* across. If the islands were all pushed together by tightening the rubber band, it would drop down to a width of around 1000*km* — which is equivalent to an overland spread from a single centre of only 500*km*.

Now we can look at different areas of the current world, suggesting how they may have been related in past times before the Earth expanded, and applying all the above rules. As usual, the main evidence comes from the distribution of plant species, genera, and families.

Australia

Australia appears to contain at least two megadomains, probably with a common boundary running roughly north-south through Lake Eyre and down to Spencer Gulf. In addition, it has either a long thin wedge or a microdomain shuffle belt running down the east coast, to the east of the Great Dividing Range.

The east coast geology looks more like a shuffle belt. Certainly there is a marked movement of species down the east side of Australia. Typical 'tropical' genera which extend as far south as northern New South Wales include *Canarium* (Fig. 4.7) and *Carissa*. The Bunya Pine (*Araucaria,* Fig. 4.4) of southern Queensland (but with an outlier in North Queensland, and most of the family in New Guinea) has also presumably been carried down on this belt.

The whole of the northeast coast of Queensland has a complex rain-forest flora with strong links with the northwest coast of South America. Virtually every major family present in that area of South America has close relatives in northeast Queensland, often in the same genus (*Pouteria, Syzygium, Endiandra, Litsea, Cryptocarya)*. The excellent fit of eastern Australia against western South America has already been remarked upon, the evidence is overwhelming that these two areas were once in contact.

In fact the evidence for this contact is much stronger than that for the Africa-South America contact which has been taken for granted since the earliest days of the Continental Drift idea, with its origins with Francis Bacon, right back when the Spanish and Portuguese explorers first mapped the southern Atlantic coasts.

This contact is a major distinction between the Continental Drift approach and its later Expanding Earth derivative. In the former, Australia is invariably placed at the opposite end of Gondwanaland to South America, and usually has adjacent New Guinea poking out into an unmapped sea. In the latter, Australia and New Guinea nestle snugly against South America and Central America, and the strong family links are easily explained.

Although the Myrtaceae family which contains the Eucalypts is well represented in South America (*Eugenia* has representatives in both domains), the typically Australian *Eucalyptus* is not. In fact the eucalypts are not especially common in the northeast Queensland rainforest, and this domain may have been separate from the rest of Australia at one time. Certainly the eucalypts appear to have evolved after the two megadomains separated. This separation presumably took place before the migration of monkeys from west Africa into northern South America.

The whole of the northern coast of Australia shows strong floristic links with adjoining areas of Asia. Nut-bearing genera such as *Canarium* and *Terminalia* are typical examples, although these extend well beyond the immediate area. One interesting genus is *Horsfieldia*, a relative of the nutmeg. This has around 80 species scattered through southeast Asia, including Indonesia and southern China, and one species, *H. australasica*, found only in the Northern Territory and the Gulf of Carpentaria. It has been recommended for development as a commercial nut species [Hearne, 1976].

Australia also has species of *Myristica* (nutmeg) and *Zizyphus* (jujube or chinese date) matching those found in southern Asia as far north as the Himalayas. The jujubes are notable for the fact that they thrive in arid inland areas and could not be expected to cross sea barriers.

The west coast of Australia shows typical features of microdomain flight, as we have seen with Rottnest Island and various peninsula formations. As far as more distant links are concerned, a major feature is the strong connection between southwest Australia and South Africa, as shown especially through the Proteaceae family. These, typified by the beautiful Proteas of South Africa and the Banksias of southern Australia, provide probably the strongest southern link between the two continents; there are hundreds of species in each. On the nut side, the Van Riebeck almond, *Brabejum stellatifolium*, of South Africa, is closely related to the woody pears (*Xylomelum)* of Western Australia.

There are plenty of links between northwest Australia and eastern Africa, as for example *Canarium* (Fig. 4.7). Recently a new species of blind hunting spider was discovered in the Cape Range peninsula of the west coast [Harris, 1988], and its nearest relative was noted as originating in southern Africa.

On balance, it seems likely that southwest Australia was once in actual contact with what is now southeast Africa. The fit is quite good. It is possible that Madagascar intervened, but this has probably come down from further north — see later. The separation of Australia and Africa must have been of middle age — not ancient, but before the evolution of the eucalypts.

It should be pointed out here that if Australia was in contact with Africa and South America on the west and east, and these two other continents were themselves in contact along their Atlantic coasts, this means a very tight fit of these three continents around the South Pole must have occurred, if their shapes were the same as now. This would have left very little room for Antarctica, even the small one which we have seen is actually there (Proposition 5B). All this is evidence both of re-seaming and domain shifting in the megadomains. It also implies a pre-expanded Earth somewhat smaller than that usually assumed, closer to 50% of the present diameter instead of the 55-60% sometimes assumed.

Direct evidence of modern plant links between Australia and Antarctica is virtually lacking, because Antarctica proper supports no higher plants, and there are no major islands between Australia and Antarctica. As for the island State of Tasmania, this is a typical island microdomain, with a flora easily represented as having evolved from a much earlier 'tropical' assembly, carried well to the south. It has *Nothofagus*, the Southern Beech, which it shares with the New Guinea highlands and with New Zealand and southern Chile. It has one representative of an ancient conifer genus, *Dacrydium*, most species of which are found in Malaya and Indonesia (Malesia), but which has representatives in New Zealand, New Caledonia, Fiji, and Chile.

More Propositions

The distribution of *Dacrydium* is a good starting point to generalize some inferences into formal propositions. No conifer is noted for its ability to spread by sea, and it appears impossible to explain this distribution rationally except by assuming that all the above areas, now tens of thousands of kilometres distant, were once linked. The distributions, and the current characteristics of the species involved, follow naturally from the following Propositions:

> *Proposition 7A*
>
> *In the early part of the current (Cenozoic) era, 50-70my ago, the immediate ancestors of most of our current plant genera were evolving out*

> *Proposition 7B*
>
> *This evolution took place in one or more 'equatorial bands' of physically interlinked domains extending right round the Earth, with easy spread of species along the bands*

> *Proposition 7C*
>
> *The climatic conditions in these equatorial bands were closer to those of currently temperate areas than to modern tropical ones*

One note to this last Proposition — it is based on the twin observations that there are a few families with representatives of the same (or closely-allied) genera in both southern-hemisphere and northern-hemisphere temperate areas, and that when representatives of these genera still exist in equatorial areas, they appear to have mostly retreated to the cooler upland areas.

Examples include the Beeches, represented in the north by *Fagus* and in the south by *Nothofagus*, with the latter having species in the uplands tropics, the willows (*Salix*), and the Junipers (*Juniperus*). Most instances of these dual-temperate genera fall easily into this pattern. The inference is that the families involved are the more ancient ones, and the corollary is that typical 'tropical' families are of more recent origin.

> *Proposition 7D*
>
> *Typical 'tropical' plant families are of relatively recent origin, less than about 50my old*

New Zealand and the Pacific Islands

In spite of its clearly temperate location, New Zealand is noted for the 'tropical' appearance of its plants. We have seen that it has one of the most southern representatives of the Sapotaceae, it also has representatives of *Eugenia, Aleurites, Freycinetia,* and a palm, *Rhopalostylis*, as well as a host of other 'tropical' genera. However, it has no native eucalypts or wattles, and evidently was not attached to Australia in recent times. It has very few deciduous trees, another indication of non-temperate origin.

In fact, in spite of the modern separations, New Zealand has links perhaps closer to Chile than to Australia, particularly in the South Island — it is quite possible that the two major islands were not so closely linked in the past. It seems likely that both islands have moved south relative to larger landmasses, possibly to different extents.

The islands of the Pacific show all the features of equatorial-band development and domain flight which we have come to expect. These islands are not tricky to reassemble into their pre-expansion conformations with a high degree of precision, purely by repeated rubber-banding of all their native species. The general picture is unmistakenly one of a tropical development band stretching from Indonesia across to Central America, split into thousands of smaller parts, with a few islands on the northern and southern limits of the band showing equatorial flight into more temperate areas.

In the rubber-banding, it is important to question (Proposition 6A) the usual assumption that many species have been introduced. The Hawaian group, in particular, has many species assumed to have been introduced, but which fit excellently into the expansion pattern. An example is the legume *Leucaena*, with 50 species in tropical America and two others stretching across through Hawaii to Polynesia. In fact is is probably more sensible to reverse the procedure, and determine whether or not a species has been introduced by seeing whether or not it 'rubber-bands' in a normal way. This test is quite independent of any historical evidence, such as the assumed spread of the coconut across the Pacific through the canoes of the islanders.

> *Proposition 7E*
>
> *The match of a plant's current distribution pattern with other local isocons gives evidence of whether or not the plant was introduced by man*

South and Central America

South America appears to contain two large domains, the bigger mostly made up of Brazil south of the Amazon, and the smaller the Guiana Highlands area to its north. It also has the most prominent domain shuffle belt in the world running down its west coast. There is an area of accreted islands or re-seamed domains east of Panama and extending over much of Columbia and Venezuela.

We have already seen how the western shuffle belt has acted as a raft to carry species southwards. A good example is the Pygmy Coconut, *Jubaea spectabilis*, which is confined to an area of central Chile (Fig. 4.14). Of course palms are typically tropical, but this one is the most southern and cold-resistant palm of all, able to withstand snow.

Like all palms, *Jubaea* is of Gondwanan origin. There are, however, a number of species of Laurasian origin which have managed to jump onto the shuffle belt. Figure 7.1 shows the distribution of modern and fossil occurrences of the walnuts, *Juglans*. It is taken from Berry's classic book [1923].

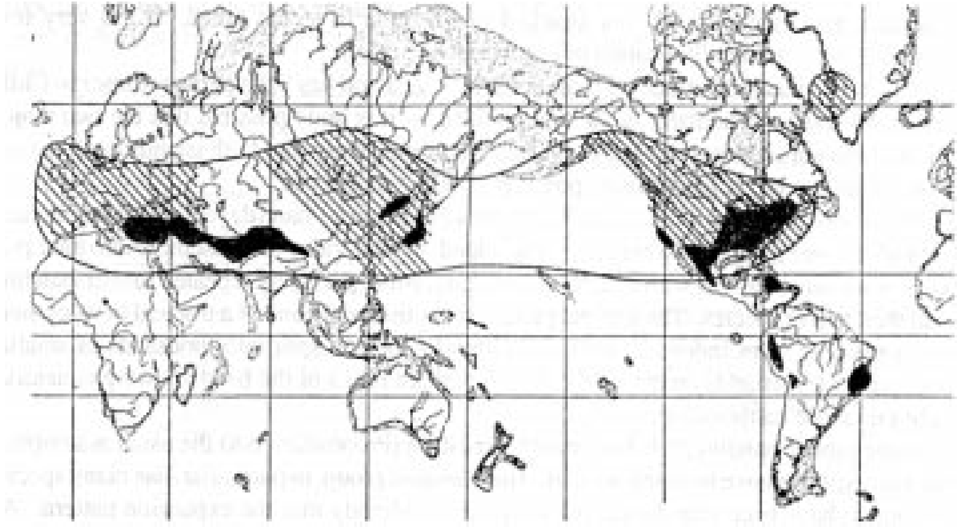

Fig. 7.1. Distribution of walnuts: modern (black areas) and fossil (shaded)

Notice that the modern walnuts occur right across what we can regard as the South Laurasian Equatorial Band — they are obviously Laurasian — and that the fossil occurrences (clearly somewhat sweepingly brushed in) extend up to Greenland. We know now why this is so. Notice also that occurrences of modern walnuts are shown in the Caribbean and extending down the Andes as far as Ecuador and Peru. These are also readily understandable, typical microdomain band shuffling.

But look again, and notice a large area shown for walnut in *eastern* Brazil, on the coast. This does not fit our pattern at all. I believe that it is an error.

Everyone can make mistakes — there may well be some in the maps I have put together myself — but the important point here is that we can use the reasoning developed so far to *predict* that this walnut placing is an error, and that prediction can be checked. Ability to produce predictions, and their verification, is one of the most important facets of any scientific theory.

Another interesting point which emerges, if you look at the various plant species of northern South America, is that species and genera on the Amazon Basin side are often quite different to those on the western coast. As an example, look at Figure 7.2, taken from Mitchell [1987], which shows the distribution of species of *Anacardium*, the cashew genus.

The Anacardiaceae family which includes the cashews has representatives across the tropics, including the Australian cashew, which however is no longer placed in the genus *Anacardium*, but in *Semecarpus*. The former is now restricted to 10 species, the nine shown in Fig. 7.2, and the cashew nut itself (*A. occidentale*), which occurs in the same area as the rest. However, the closest relatives to A*nacardium* are not species of *Semecarpus*, but the three species of *Fegimanra* which grow in tropical West Africa — again fitting the pattern precisely.

The point being made here is that neither the cashew genus itself, nor its close relatives, occur on the Andes coast of South America except in the extreme north, so it is presumably a fairly recent passenger on the shuffle belt. The genus does extend much further southwards on the east of the Andes, right down to northern Uruguay.

The walnut and cashew maps also help to define the status of the Caribbean islands and 'mainland' Central America. The walnut does not occur on the mainland, only on the islands. The converse is true for the cashew. Clearly there has been mixing of Laurasian and Gondwanan species in this zone, but the general position is consistent with the assumption that both parts are made up of a collage of microdomains which formerly lay right across the boundary of the two megadomains — part of what we have called the Tethyan Girdle. Detailed reconstruction involves only repeated application of the rubber-banding technique.

Fig. 7.2. Distributions of some species of Anacardium

It also seems that the present land bridge between North and South America is not particularly old, and previous land connections may have been further east. Mainland Central America is a clear aggregation of different domains, showing very obvious peninsulas and large lakes formed through the chance conjunction of different island outlines. The Galapagos islands off the coast of Ecuador have cacti (*Opuntia*) closely related to those of Mexico, and have been shifted southwards.

The relation of South America to Australia has already been discussed. The link between South America and Africa is obvious and inarguable. But even here, we can perhaps add a little, on relative ages.

The Brazil-West African connection is strong. We have seen it with the oil palm (Fig. 4.3) and with the cashew (Fig. 7.2). The connection can be shown again and again, through different plant families; a further good example is the custard apple genus, *Annona*. This is most widely represented in northern South America, although there are a few species right across tropical Africa and down the east coast. There is also a close relative, Asimina, which extends from Florida up the east coast of North America — of this more later.

But when you look further south, for connections between Argentina, Uruguay, and southern Africa, the links are quite weak. This can be seen from the Proteaceae map, Fig. 4.1, which has a notable blank area in southeast South America. The inference is that the southern gulf between Africa **and South America opened up** well before the northern separation.

Africa and the Indian Ocean

Africa appears to be a relatively simple construction. It contains a number of large domains — these could be represented as Nubia, Congo, Kalahari, Somali, and North and South Sahara. Most of these appear to have undergone some shifting and re-seaming, giving rise to features such as the Adamawa Highlands between Nigeria and Cameroon.

The most obvious domainographic feature of Africa is the east coast. This is another shuffle belt, not as dramatic as that of South America, but considerably more complex in the sizes and nature of the domains involved. These have all moved southwards, leading to such typical features as the many long, thin lakes. The Ethiopian Highlands and those surrounding Lake Victoria could probably be accorded the status of separate domains.

The plant distribution pattern is fairly plain — most families have bands of genera and species extending along the tropical lines of latitude, with extensions southwards along the east coast. The coffee genus, *Coffea*, is a typical example, as are the African examples of *Annona*.

In the north and east we run into the Tethyan Girdle, in this case including Spain, Italy, Greece, Turkey, and the Mediterranean islands, all mixtures of Laurasian and Gondwanan elements, with the former predominating. From the plant distributions, the Canary Islands are clearly Gondwanan and the Azores Laurasian. The Atlas mountains in northwest Africa are made up of several aggregated microdomains.

On the northeast, the major Arabian domain has separated off in the past and come back into contact, ending up with the triangular Sinai microdomain jammed in the gap. Arabia, which impacted with Laurasia to form the Zagros mountains, is shown by the plant distributions to be a Gondwanan domain. But it probably separated off relatively early, as it *has its own gener*a within the common families, such as the carob, Ceratonia siliqua, within the *legumes.* It even has its own families, such as the pomegranate, Punicaceae, with only one genus and two species, one of which is confined to the tiny island of Socotra in the Gulf of Aden.

India was indisputably part of Gondwanaland, and positioned against the east African domains, but finding its exact former position is complicated by the fact that these domains have been shifted south, possibly to differing extents.

Madagascar was probably positioned against where Mozambique is now, but again with the complication that the northeast half of Mozambique may have been shifted south relative to the southwest half. Madagascar has coffee species, which fi*ts in wel*l with the pattern. Another excellent 'tie-in' genus is Adansonia, the boab or baobab family. This has one species growing right across north-tropical Africa and down the east coast, extending also to India (supposedly 'introduced by Arab traders'!), and a second species native to the Kimberly area of northwest Australia. But the big concentration, some 8-10 species, is in Madagascar.

Application of rubber-banding to Madagascan species will reveal its former connections, and because the island has many unique species related distantly or closely to those elsewhere, it should also be possible to work out when the different splits occurred, whether anciently or more recently. Of course the various edges of this domain were probably formed at different times.

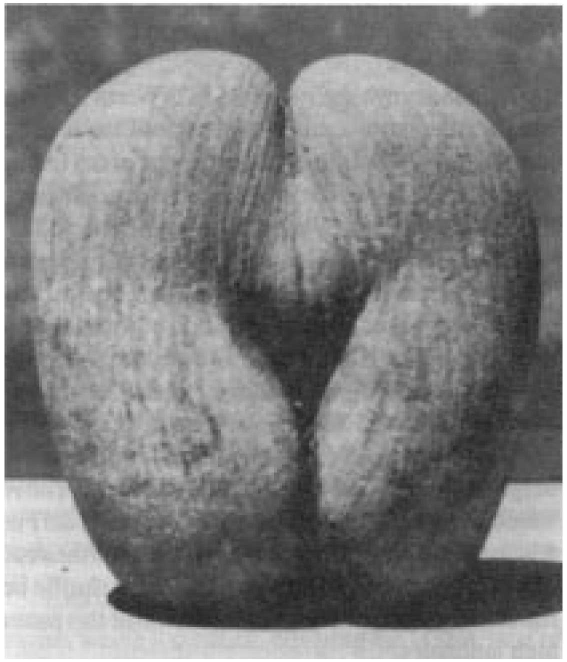

Fig. 7.3. A Coco-de-Mer nut

The major link across from east Africa and the Mascarenes through India, southeast Asia, Indonesia and across the Pacific to Central America has already been shown. An excellent subject for rubber-banding is provided by the Seychelles islands north of Madagscar. These tiny, scattered islands include some with towering granite cliffs, virtually unique for isolated oceanic islands, and clear evidence of their 'continental' origin.

The Seychelles has a number of endemic species (confined to that area), in the genera *Acalypha*, *Begonia*, *Carissa*, *Dillenia* (elephant apple), *Diospyros* (persimmon), *Eugenia*, *Ficus* (fig), *Grewia*, *Pandanus* (screwpine), and *Pittosporum*, all of which are typical of the major link. It also has the unique Double Coconut palm or Coco-de-Mer, *Lodoicea*, which has the largest seed in the world, weighing up to 20kg. It takes seven years for the fruit to mature, three years to germinate [Lionnet,1976]. The nut bears an astounding resemblance to portions of the human female anatomy (Fig. 7.3), so much so that observers could quite understandably assume that some cosmic prankster has been at work!

North America

We have already identified some of the domains which make up the present North American continent, which is of medium complexity. The major domainographic features are the marked movements of shuffle belts or other domain aggregates north, on both sides of the continent.

These shifts have carried palms up into California and Florida, and representatives of the Sapotaceae up into Florida (Fig. 6.1). Florida also has representatives of the Gondwanan custard-apple family, the Annonaceae. These include both Annona itself (the genus of the soursop, cherimoya, sugar apple, sweetsop, and most other custard apples) and also a genus restricted to North America, *Asimina*.

This contains several species, but the only one well known, even in North America, is the American Banana or Pawpaw (this is quite unrelated to the papaya, *Carica papaya*, which is also called a pawpaw in some parts of the world). The Asimina is said to be the largest native fruit in North America, good specimens weighing up to 500g. This again is a reflection of its origin, the larger fruits all originated in Gondwanaland — we will go into the reason for this later.

Asiminas grow over wide areas of North America, principally on the Mississippi domain and the Atlantic domain (the coast from Florida to New York). Their distribution is evidence that the genus was split off from the rest of the family some time ago. The boundary between *Asimina* and *Annona* is reasonably distinct, running across northern Florida, and indicates that Florida itself is a fairly recently accreted island domain.

Other domains which could be distinguished in North America include the Rockies, western Mexico, Laurentia and three or four other large areas in continental Canada. Presence of the Great Lakes shows interaction of a mess of microdomains, but the most complex area of all is the west coast, which will take much study to sort out in detail.

Alaska is a complex of microdomains, as are the islands of northern Canada and, beyond them, Greenland. The Aleutian islands, stretching from Alaska right across the North Pacific to Asia, provide a very graphic illustration of fragments falling from the movement of the huge hinge formed as the North Pacific opened up. The Aleutians, and the Alaska Peninsula with which they terminate, appear to parallel Tierra del Fuego and the islands and submarine ridges which sweep down from South America to Antarctica, in that they represent the oldest ends of a microdomain shuffle belt. Both these shuffle belt ends show divergence from the usual equatorial-flight patterns, and indicate that this pattern of behaviour may not always apply in high latititudes.

Proposition 7F

Propositions relating to equatorial flight of domains may lose validity at high latitudes

North America also shows a similar pattern to South America, in that plants native to the west coastal strip appear to ‘intervene’ between those east of the Rockies and the relatives of the latter across the Pacific. There is a strong link between the Texas-southern Mississippi flora and those of eastern Asia which appears to ‘jump’ over the west coast flora. This can be seen in the distribution maps of *Pistacia* (Fig. 4.10) and *Carya* (Fig. 4.11). The ‘jump’ is very obvious in Figure 7.4, from Berry [1923], showing the distribution of the magnolia family.

Try explaining the distributions in Figure 7.4 on the basis of migration across Bering Strait land bridges! There are also many other examples in Berry [1923], often with distribution maps, showing the same pattern with such diverse genera as Tulip tree (*Tupilifera*), Sweetgum (*Liquidambar*), Tupelo (*Nyssa*), and Sassafras.

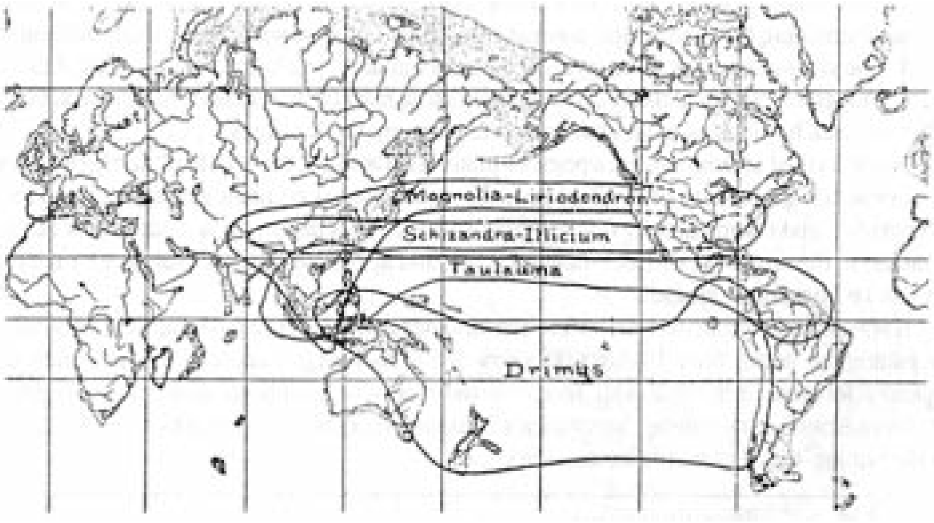

Fig. 7.4 Distributions of genera of the Magnolia family

This pattern is not confined to plants. The existence of relational links between the fossil dinosaurs of China and western North America is well known and is the subject of current study [Holley, 1987]. What is interesting is that the American dinosaur occurrences are mostly east of the Rockies, especially in the Canadian province of Alberta. Of course all these points confirm that the western shuffle belt has moved north along the coast, driving a wedge between the main North American flora and their counterparts at the same latitudes on the Asian coast.

Europe

Europe is a mess. The only major domain which it contains, covering the USSR west of the Urals and the North European Plain over as far as Germany, is structurally part of Asia (although it has undergone some re-seaming, along the Central Russian Uplands and the Volga Heights). Everything else is accreted and distorted domains and microdomains.

Running all along its south it has the scattered parts of the Tethyan Girdle — the band of island domains left from the original split of the holodomain into Gondwanaland and Laurasia. European domains in this band include Spain, Italy, Greece, the Mediterranean islands, and on to Turkey and the Central Asian republics of the USSR south of the Caucasus. All these domains have predominantly Laurasian rather than Gondwanan flora, and so should probably be classed with Laurasia. Also probably included with them is Ireland.

Ireland has, in its south-west corner, native occurrences of the Strawberry-Tree, *Arbutus unedo*. This also occurs right across the Mediterranean, and other species in the genus extend the range eastwards into the USSR (along the Tethyan Girdle) and, in the usual pattern, across the Atlantic (including the Azores) into Mexico and southwest U.S.A. (there is a concentration of seven species in Mexico).

The inference is that Ireland once lay in this band, and in fact, Ireland does fit quite snugly against northwest Portugal. Britain is a most complex mishmash of microdomaFrance,

France, Germany, central Europe and the Balkans are also much re-worked, the most prominent feature being the Alps, formed when Italy collided with the northern domains.

To the north, Denmark, Norway, Sweden and Finland clearly consist of several domains pushed together. The Scandinavian mountains show marked dissection through the action of glaciers, which brings us to an observation concerning the Ice Ages.

When looked at from the viewpoint of plant distributions, the whole of northern Europe is notable for the poverty of its plant species. It has almost no plant genera confined to its boundaries, and comparatively few endemic species. This makes the application of rubber-banding to the area more difficult than for most, and also raises the question of why the area should be botanically sparse.

It appears that the answer to the last question lies in the Ice Ages. These were very recent in geological terms, only 10-110,000 years ago (.01-.11my). There seems no doubt that glaciers formerly extended well south of their present European distribution, reaching southern Britain, for example. Inevitably, a consequence of being overrun by massive glaciers is the wiping-out of plant life in the area overrun.

Proposition 7G

Northern Europe has a relatively low level of plant diversity because much of it was cleared of living plants through the action of glaciers

Of course, when the glaciers retreated, vast areas of blank ecological niches were exposed, and plants came in to colonise these niches reasonably quickly. But because the ice ages were not so very long ago — not only within the era of the species of man, but butting right up against the development of civilization — there has just been insufficient time to develop the diversity of species and families which exist elsewhere.

It might be asked why the same situation does not exist across the whole of the temperate parts of the Northern Hemisphere. To some extent it does, in that colder areas are relatively poorer in plant diversity, but there is also another possibility. That is, that the recent ice-age glaciers were not centered on the North Pole (as is usually implicitly assumed), but were displaced more onto the European side for some reason.

Proposition 7H

Ice-age glaciers were not centered on the North Pole, but had an area of influence displaced over into northern Europe

Asia

We have already seen that all the domains along the southern boundary of present-day Asia — including Arabia, India, Indochina, and southern China — are Gondwanan 'borrowings' since accreted to Laurasia. The Iran-Afghanistan domain is probably also one of these borrowings. The Tethyan Girdle which shows up in the Americas and Europe apparently either was never formed or was absorbed. There is a parallel formation, which includes the island domains and peninsulas of Indonesia, Malaya, and the Philippines, but in this the

Gondwanan influence is predominant.

In the main mass of Asia, north of the Gondwanan components, extensive re-seaming and shifting of domains has taken place, especially in south and west Siberia and in China. These actions have given rise to the many mountain ranges and to the strings of long lakes — such as Baikal and Balkhash — and to the Turfan Depression in northwest China.

The Siberian area is notable for having the largest isocon envelopes currently existing on our planet. Stretching across the vast plains are huge areas in which the ecological conditions are relatively uniform, and so a particular plant species may come to have a very wide extent. One of the most prominent plants in this respect is, of course, a nut tree, the Siberian Stone Pine (*Pinus sibirica*).

This plant extends densely over more than 50 million hectares [Savel'ev, 1980]. The potential for producing nuts is huge, as a large tree may produce 1500 cones each year. The average biological harvest of nuts from each hectare reaches 800kg, so the potential annual yield of nuts is 40 million tonnes. This is many times the total weight of all nuts which figure in world trade.

Fig. 7.5. Needles, cones and nuts of the Siberian Stone Pine

From the domainographic viewpoint, the most interesting area in Asia is the Pacific Coast. This shows extensive evidence of domain flight. Japan and Korea, though rich in Laurasian flora such as oaks (*Quercus*), also have Gondwanan components such as yams (*Dioscorea*) and cycads which have clearly come up from much further south. Both show the typical north-south oriented island or peninsula form, as do Sakhalin and Kamchatka to their north.

Southern China is one of the most floristically diverse regions of the world, with dense intermixtures of Laurasian and Gondwanan components. Any proposed boundary line would be open to argument, but it could lie somewhere along the line of the Nan Shan range.

As elsewhere, extensive equatorial flight has taken place along this coast. The whole of Manchuria and southeast USSR has apparently shifted north. The position is made more complex by the fact that domains of every size have been involved; we already saw in Chapter 5 (Fig. 5.3) how the northeast USSR coast was a mass of microdomains. Instead of a straightforward shuffle belt like that of South America, we have a great mingling and jostling of large and small domains.

Plant distributions reflect the northward movement. A good example is the genus *Actinidia*, which contains the kiwifruit, A*ctinidia deliciosa*. The kiwifruit, once called the chinese gooseberry, is one of 40 species in the genus, which is distributed not only in China (and across to Burma) but also north, right up into Siberia, where there are some very cold-hardy species. As well as Actinidia, the Actinidaceae family contains the genus *Clematocle-*

thra, with 10 species confined to China, and the big genus *Saurauia*.

In Asia *Sauraia* overlaps the southern range of *Actinidia*, extending through Burma (six species) as far east as Nepal. But *Sauraia* is also well represented in America, with species running from southern Mexico through Central America and right down the west coast as far as Chile. The genus is absent from the Caribbean and almost absent from the Guianas and Brazil. Again this is an absolutely typical pattern, the family showing strong links across the north equatorial Pacific, and strong equatorial flight, northwards in Asia and southwards in America.

The Polar Regions

Because of the paucity of living plants in the polar regions, it is hard to apply standard rubber-banding techniques to these areas. However, some information can be got from studies of fossil plants and of animal distributions. Although difficult to apply, studies of marine flora and fauna may also be productive.

Having looked at where domain movements have taken place around the planet, we are now in a position to move on to the effects of these movements on the local landscapes — how they got their ups and downs.

CHAPTER 8

MAKING MOUNTAINS OUT OF MOVEMENTS

"Rocks rich in gems, and mountains big with mines,
that on the high equator ridgy rise"
— James Thomson, 'The Seasons'

How Mountains are Made

Mountain building (or, in the jargon, orogeny) is a topic which has been been one of the basics of geology. Details of the manner and conditions under which most of the Earth’s present mountain chains were formed, and the times at which they arose, have reached a settled state.

However the basic mechanisms by which mountains have been formed are not so settled, there has been no completely satisfying explanation for why mountains have been formed where they were. If you look at the mountains on Earth, they mostly fall into one of two classes, which we can call ‘long’ and ‘fat’.

The ‘long’ mountains are those which form extensive chains. A prime example is the Andes Mountains in South America, stretching right down the west coast of the continent. Often they are regarded as an extension of the Rocky Mountains of North America, connected to these by the mountain chain running right through Central America. Other mountain chains have been identified which are partly submerged, like the Aleutian Island chain in the north Pacific, or even wholly submerged like the mid-Atlantic ridges.

‘Long’ mountains are almost always associated with volcanic activity, either now or in the past. As a result, they are usually assumed to have been formed by volcanic activity. If the mountain chain is part of a continent, the rocks which make it up are usually high in silica, of a class called ‘acidic’ or continental. In contrast, mountain chains formed in the sea have rocks which, like the sea-bed around them, are lower in silica and are called ‘basic’ or oceanic. Both types of rock are classed as ‘igneous’ (derived from fire), that is, they are assumed to have been

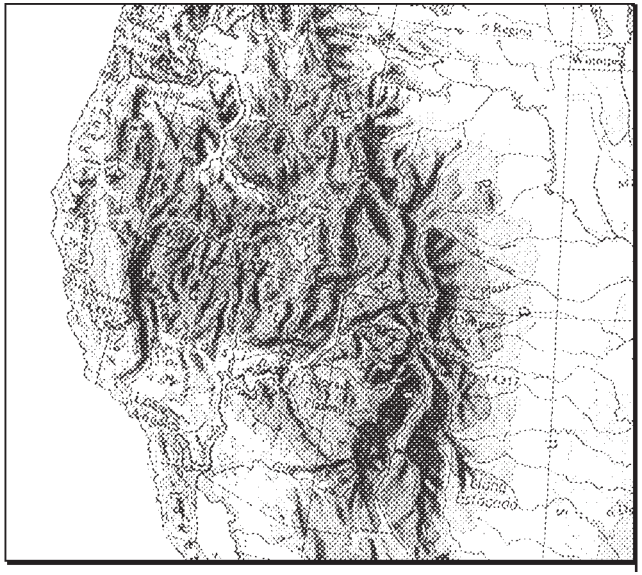

Fig. 8.1. Mountains of the western U.S.A.

formed from the cooling down of molten rock.

‘Fat’ mountains, in the sense used here, tend to be oval in outline rather than linear, and often contain plateaus and wide basins. The rocks they contain are often of sedimentary origin rather than of igneous (volcanic) origin, and sometimes they contain elaborate folded structures, in which beds of sedimentary rock have clearly been crumpled up and pushed against each other, sometimes right over each other. They usually don’t contain volcanos. And they are not found submerged, as ‘undersea massifs’, on the deeper ocean beds.

A clear example of ‘fat’ mountains is the Himalayas. Fat mountains are assumed to result from various forces of compression occurring in the Earth’s crust. The origin of these forces is often glossed over, but is sometimes purely a matter of impact. The Himalayas are now generally accepted as resulting from an impact between India (drifting north after breaking off from Gondwanaland) and that part of Laurasia which is now occupied by western China and the south-eastern section of the USSR.

Other mountains appear more mixed in origin. However, in these, it is usually possible to say that *both* the ‘long’ mechanism and the ‘fat’ mechanism have operated, rather than a single ‘intermediate’ mechanism. Thus the mountains of the western United States (Fig. 8.1) appear to consist of a ‘long’ component, running along parallel to the coast, backed by a ‘fat’ component (the ‘Rockies’ proper) further inland.

In Chapter 7 we had evidence that most of the present land surface is a patchwork of ‘domains’ of very varying sizes, pushed together or pulled apart by forces associated with Earth expansion. This leads very naturally to the suggestion that *all* mountain-building is a result of forces due to Earth expansion, expressed through the interaction of Earth domains.

> *Proposition 8A*
> *All mountains have been created through the interaction of domains*

Taking the ‘fat’ mechanism first, the suggestion is that all ‘fat’ mountains have been formed by impacts between Earth domains. As the domains are very varied in size, composition, and origin, the resulting landforms are themselves very varied. Some areas may have been worked over more than once, having been impacted from more than one side. As already noted, such a mechanism has already been accepted for the origin of the Himalayas. Other fairly clear ‘fat’ areas are the Swiss-Austrian Alps, formed by the impact of Italy against what is now central Europe, and the Pyrenees, formed by Spain hitting against France.

> *Proposition 8B*
> *‘Fat’ mountains have been created by domain impacts*

The suggested origin of ‘long’ mountains is more controversial. As these mountains are almost invariably associated with volcanos, to date it has been implicitly assumed that the volcanism caused the mountains. From the evidence already given in this book, it appears that a simpler and more reasonable explanation is that ‘long’ mountains are formed by the frictional action of domains sliding one against the other. As before, the domains are in motion because of Earth expansion.

> *Proposition 8C*
> *‘Long’ mountains have been created by domain rubbing*

It is reasonable that any two domains in sliding contact will have somewhat rough edges, which do not match each other. If they move relative to one another, the ‘burrs’ along the edges will naturally pile up to create local high spots. If they continue to slide and rub, or if there is a chain of them active in a shuffle belt, eventually a whole mountain chain will be built up along the junction.

This gives a simple explanation for an observed phenomenon. It also leads to a most important conclusion relating to volcanos and other geothermic phenomena such as hot springs.

The Origin of Volcanos

Volcanos are hot — hot enough to contain molten rock. It has been more or less taken for granted in the past that this hot rock has welled up from the molten core of the Earth, which has pushed up through ‘lines of weakness’ in the crust.

In the next chapter, we will see that the concept that the heat of volcanos comes from the Earth's molten core has little evidence to support it. Leaving the evidence of this point aside for the moment, we can see that it has a vital implication for the origin of volcanos. If their heat does not come from the molten core of the Earth, where does it come from?

It appears likely to me that the heat in volcanos is generated by frictional heating of the edge rocks of two domains sliding one against the other. The intense heat generated through friction is well known — a classic example is making fire by rubbing two sticks together.

The heat generated through friction is usually dependent on the coefficient of friction (‘roughness’) and the masses and relative speed of the objects rubbing together. When we are talking about about Earth domains, these masses are enormously large compared to the everyday objects we see involved in friction, and their capacity to generate heat is equally enormous. It is certainly easily great enough to melt rocks.

> *Proposition 8D*
> *Volcanos are created by the friction between rubbing domains*

This proposition accords well with the fact that the molten rocks coming out of volcanos are generally of similar overall chemical composition to the surrounding country. If they were really formed by molten core rock, pushing up through ‘weak places’ in the Earth’s crust, they might all be expected to be of ‘basic’ composition like the rock assumed to underlie the ‘acidic’ continental material. In practice, only volcanos sitting on oceanic-rock sea beds produce basic-rock flows, those which are sited on typical continental rocks produce acidic-rock flows.