MANUAL OF

Tree Statics and Tree Inspection

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Introduction

The treely friend

Didn't we always yearn for this: to have a friend who is big and strong, who we can look up to with complete confidence? Who protects us, when we are being followed. Who listens to us, when our heart is overflowing. Who sits with us in silence, when we need quietude. Who comforts us, when we are sad. Who sings along with the wind, so we can be happy again. Who always has good counsel, if only we become quiet enough and take the time to listen to him. A friend who touches us softly whenever we are with him, and who is so strong that we feel protected in his presence.

The German language knows an apt expression for such an ideal friend. Or rather, the Alemannic-Swiss dialect knows this expression, but, unfortunately, even in this dialect it is not used very often nowadays. In this dialect, this kind of friend we would all love to have, is called: a treely friend. Why? Perhaps, because the tree has always been there for us and has faithfully accompanied humankind throughout the ages.

To our ancestor, the tree was a big and strong friend. Back then, an incredibly long time ago, when they roamed the wide steppes of Africa together with the wild beasts. Suddenly, there he was, standing amid the gleaming bright vastness. In a world parched by the sun and swept by the winds which whirled up the sand and turned the air yellow. There he stood: branches rising up high into the sky, roots buried deep in the ground and firmly anchored. With that mighty trunk and clad in this exciting fresh green. Only a friend can stand alone like this, only a friend can wait like this, till the time has come. Immediately, our ancestors wanted to be close to him. They gathered in his shade. They enjoyed the cool, his breath of fresh air amid the dusty afternoon heat. They had found their friend at last. The tree became their host and protector. They climbed up into the tree and made their homes in his wide and leafy canopy. They enjoyed the steady gentle sway of the branches. They enjoyed the great view up there. In the evenings, they watched TV together, full HD, with a screen as wide as the world. The sky turned red on the horizon, this particular red which you can only find in Africa. A lion roared in the distance, and they felt safe up in their tree. They made love up there, and gave birth to their children in the wide, round tree junction. And soon after, the children were swinging from branch to branch.

They taught their children to speak the language of nature. The taught them to sing together with the birds, and to read the pictures of clouds up in the sky. Far below them, the tree's roots dug deeper and deeper into the soil. The tree inhabitants felt the water rising inside of the tree. From the very big trunk up to the thick branches and from there to the thinner twigs and into the green leaves. Sometimes, when they had plenty of time and it had gone quiet, the tree told them stories: he told stories of a time his ancestors had told him about. Of a time, when the first trees rose from the plains, back then, long before their time. He told them of the sky which brought the fresh rains with its clouds. Of the rain which charmed the steppe into greenness and soon after let thousands of flowers bloom. He told them of the sun, so endlessly far away, but he was still feeding on its sunlight.

And sometimes, he also told them of his inside. He showed them what his interior looked like. For inside of him was nothing and all. His innermost was hollow, because the wood there had long since died and disintegrated. Nothing but a big cavity remained, and many animals of the world had made it their home. But on the exterior, under the bark, on the shoots and on the root tips, the tree was still young and full of life. There were even parts where life had not been born yet. There were embryonic cells, waiting to be awakened. The seed, just as young and new as it had been so unimaginably long ago, when it had germinated, and the tree had grown from it.

For a long time, our ancestors were so happy up in the tree, that they forgot to ponder how they lived and why they lived that way, because a world of soft swaying and security left nothing to be desired.

And yet, later on, our ancestors climbed down from the tree, evolved into humans and started to discover and conquer the world. The manifold memories of their old friend, the tree, were engraved upon their hearts. Time and again, they told stories about him. They made him a part of their new lives and their language. The treely friend, who was strong as an oak, who was able to relieve their pains. First, the stories he had told became little twigs of beech, later, they became characters.

And these stories grew into different branches of the same story. The story which started when the ancestors of humankind still sat up in their trees, and when their story had not yet become so knotty and branchy. Back then, before the first tribe slid down the tree trunk and still kept it as their family tree. Back then, before they began to take root in this restless world.

Yes, and later on, these people started to build temples with columns like trees. With a broad column base like a root crown, with a thick shaft like a tree trunk and with a column capital like a crown break. Columns for temples, for worshipping the gods and, later on, columns for banks and other palaces.

Palaces as a substitute for the protective tree groves, where they had lived in safety, back then, long ago.

Martin Erb

The tree as a natural structure

At first sight, it seems as if engineering expertise and technology and the tree as a natural being do not complement each other. The tree, as a living organism, seems much too complex to be assessed from a technical perspective. It is true, classical constructive engineering seems to be working to clear-cut specifications which easily can be devised as formulas. However, these arguments are also often used in order to avoid venturing into unknown territory. It is sometimes argued that experiences show that the organism of the human body are equal to the organism of trees. Sudden occurrences – such as a stroke or heart failure – are being referred to in order to compare a detailed tree inspection to a visit to the doctor

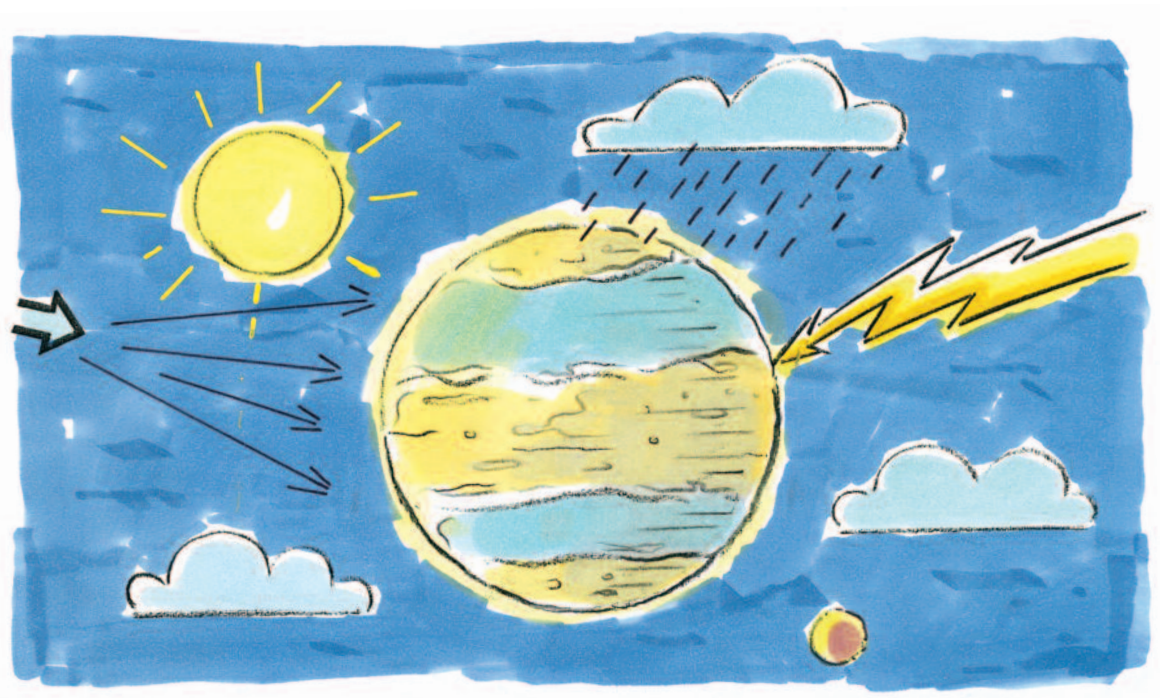
Content

1 The age of the trees

1.1 Beginnings

The tree has a long history. It has been going on for much longer than the history of mankind. And yet: the very first tree must have been born someday. Where did it come from? How was it brought to life? And why did it even come to this? This story is far longer than the history of the tree itself. A couple of billion years after the big bang, the Earth, together with myriads of other objects, was formed out of gas and dust particles.

By going through long and chaotic processes, the Earth took on a shape that gradually resembled its current form. The seas were formed, and the first continent, Pangaea, emerged.



The little big bang starting life

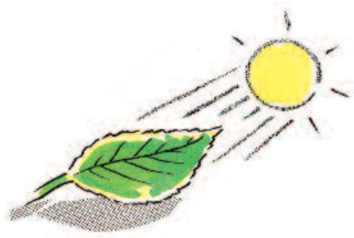
Eventually, in all this chaos, life arose for the first time. Why this happened, only the gods – if they exist – know. The Earth in its early history was not a friendly environment: there was no oxygen, the sunlight reached the surface of the Earth without any filter, it was rather hot and uncomfortable. And yet, in spite of everything, the first micro-organisms, bacteria, came into life by transforming inorganic matter into organic matter (= derived from living organisms). They were able to do this because they carried out chemosynthesis. They obtained the energy necessary for their existence from inorganic matter and produced organic matter in the process. From the resulting primordial soup, the first plants (bacteria, algae, fungi) gradually developed. At some point during this process, the first chlorophyll/leaf green was also formed. This little big bang started the real engine of life.

Assimilation, or photosynthesis, as the essential engine of further life on planet Earth, started its continuous operation.

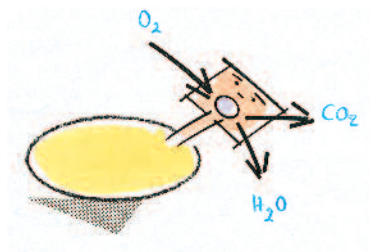
From the chemical point of view, photosynthesis splits water into hydrogen and oxygen which is then released. The split off hydrogen synthesises with carbon dioxide. The result is a carbon compound which takes the form of sugars. Luckily, this compound is relatively stable and not unstable, like nitroglycerin, for instance. If that was not the case, we could not easily bang the kitchen cupboard door shut with an elegant swing of the hip, let alone carelessly stir the sugar in our coffee.

The sun supplies the chlorophyll with the energy needed for the conversion. The green leaf can actually be compared to a solar cell. Of course, it does not convert solar energy into electricity, but into carbohydrates which can be used for many purposes. The plant transforms these carbon compounds into starches and fats, depending on its needs, which are then transported and stored.

The reverse process of photosynthesis is dissimilation or respiration. All higher organisms do breathe/respire. Man considers himself to be a higher organism, and as you cannot deny that he is breathing, he might actually be a higher organism.



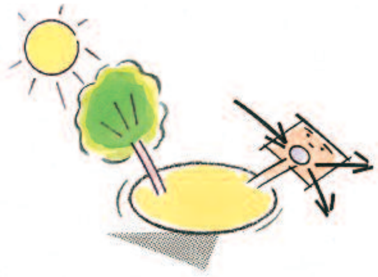
Through the intake of food, namely by eating carbon compounds and their subsequent burning and breakdown, these higher organisms obtain the energy necessary for their vital functions.



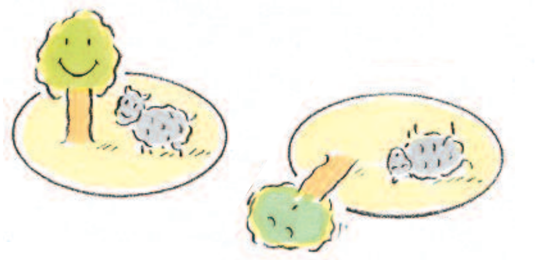
During dissimilation, hydrogen and carbon are gradually being oxidized, releasing energy in the process. If this process did not happen gradually, the result would be an oxyhydrogen explosion. Thus, our breathing is a controlled oxyhydrogen reaction.

This sounds all rather complicated. For the interested layman: please refer to our table section (chapter 6).

The production of energy reserves



If the energy bound in photosynthesis was exhaled right away, nothing much would have happened on Earth. Because carbon compounds are relatively stable, they could be stored for longer periods, stocking up on "energy reserves, as it were." At first, carbon compounds accumulated in the bodies of the developing organisms. As long as these organisms were alive, the energy reserves were stored in their bodies, and once they died, other organism took on the breakdown of the reserves.



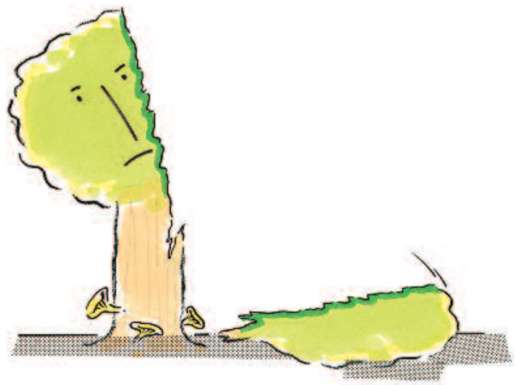
For life on Earth profited from everything that could be temporarily detracted, as deposits for instance, from the natural cycle of that time. Everything that could not be broken down after death, hence did not decompose, held on to the assimilated carbon compounds. This way, the oxygen released during the production could remain in the atmosphere which thus gradually transformed it into a friendlier environment for higher organisms.

Eventually, much later, man took his first breath and reached for the next liana.

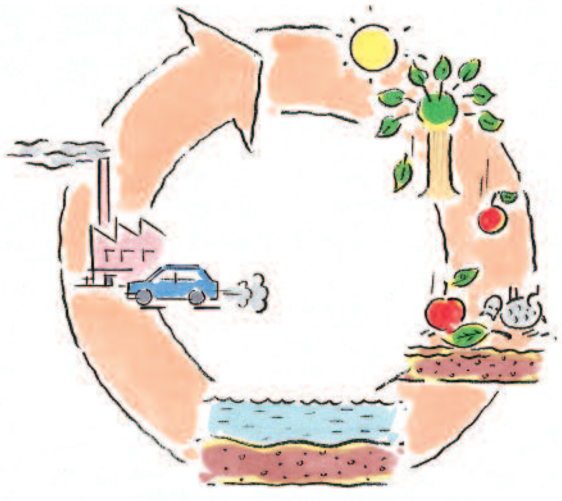
Carbon compounds - nature's currency

The products of a tree, the carbon compounds, are the main currency of nature's economic system. A large part of all existing organisms needs to feed on them. Since a tree produces and stores many carbon compounds, its significance in nature's economic system is correspondingly high.

The tree exchanges some parts of its production freely: it grows new leaves and sheds the old, for instance. Or it offers a supply of fruit which, together with the seeds, can contain a considerable reserve of energy.



The carbon cycle could be described as nature's cycle of money. It is the essential driving force behind the existence of life on this planet.



In its leaves, the plant produces organic matter from carbon dioxide and water. This organic matter consists of carbon compounds which have stored energy. The leaves use the energy from the sun for this conversion process. This means, carbon compounds are storing solar power. The carbon is stored in the woody parts of the plant, and parts of it are given away again in the form of fruits or shed leaves.

Fruits provide food for humans and animals which is then burned to release energy. In the process, carbon dioxide is produced. Leaves, branches, dead plants and animal parts develop into humus which is organic matter. In the process of decay, the organic matter releases carbon dioxide once more. In cases where organic matter cannot decay, which happens, for instance, if it is cut off from oxygen under deep layers of sediment or at the bottom of the sea, the formation of fossil fuels results. Energy reserves such as peat, coal, natural gas or petroleum have formed from decayed organisms. When burning or consuming fossil fuels, the same amount of energy and carbon dioxide is set free which was needed for their formation. Thus, in the course of our planet's evolution which lasted billions of years, 26×10^{15} t of carbon dioxide were produced by plant activity. Of this amount of carbon dioxide, two thirds are stored in fossil deposits and one third in organic products (sparkling water is not one of those products but champagne, animals and plants are). Today, by burning fossil fuel reserves, man emits substantial amounts of carbon dioxide into the atmosphere. Should this activity change the current distribution of carbon, the climate, and with it the species composition of Earth's ecosystems, will change.

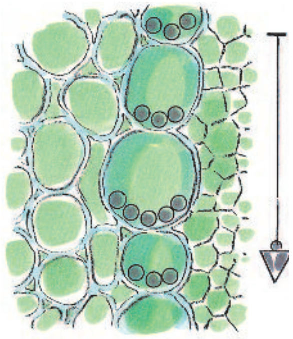
In doing so, humankind joins the ranks of threatened species.

2 Tree biology

2.1 Biological evolution

Geological eras - The emergence of plants and trees

The geological history of the Earth has been divided into several eras. These eras have been organised into geological systems (also called periods or formations), epochs, and phases. The classification of the eras followed the development of animal life during the Archaean, Paleozoic, Mesozoic and Cenozoic era. The development of the plant world has been classified into the Eophytic, Palaeophytic, Mesophytic and Cenophytic Era correspondingly. The eras of the plant world do not coincide with the eras of the animal world.



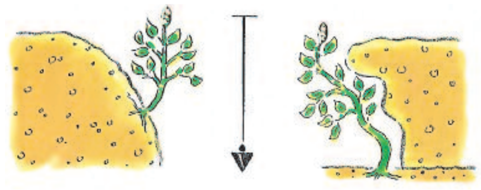
The diagram shows the so called statolithes, starch granules (big grey dots), inside of the cells of a shoot axis. The statolithes move easily inside of the cell and always settle at the bottom of it, irrespective of the cell's location. This way, they stimulate a response to gravity.

Geotropic growth in tilted shoot axises and main roots is caused by a high concentration of plant growth hormone (dark dots) at the bottom of the cell.

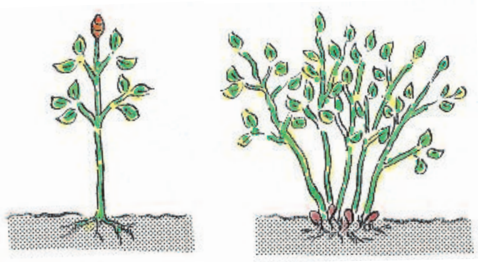
Life on Earth starts

The first life forms on Earth developed in the sea. The corresponding era, regarding the eras of the plant world, has been called Eophytic (Eos = almost, nearly).

400 million years ago, in the ancient times of the Earth, plants started to conquer dry land from the sea. This period is called Palaeophytic era (Greek – palaiós = ancient, phytón = plant). The first plants had a simple structure and had to adapt to life on land. Most of all, life on land meant for these plants the necessity to increase their stability, to cope with the law of gravity and to prevail against it. Accordingly, the first land plants were algae and mosses which develop little vertical growth. Space soon became scarce, and the competition prompted plants to grow in height. From this moment on, it was important for plants to adapt their growth to the principles of statics and to comply with the laws of statics. The plants which did not succeed in doing so disappeared in the long term. But those plants which managed to raise their energy processing leaves above the other plants gained a distinct



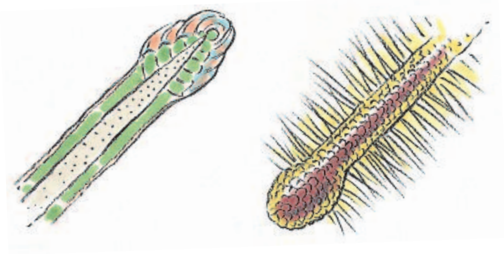
competitive advantage. The plants grew taller and taller, and in the course of 100 million years, trees developed.



Statics determine the evolution of trees

One way to get ahead of competitors is to grow away up into the space above them. But the taller growing plants had to develop load-bearing structures in order to resist both increased wind load and longer levers. A requirement for vertical growth is the corresponding secondary growth of the load-transferring tree parts. In excess of a certain height, a durable structure becomes necessary which is able to take load. This means, the structure will have to last several years. Only constructions lasting for just one year renew their basic set-up on an annual base. As a result, the vertical growth and with it the competitive edge of these plants is considerably restricted. The annual renewal of a structure means a waste of energy, and nature will punish waste sooner or later.

The first trees, the club-moss trees, consisted mainly of bark. Up to 99 % of their trunk cross section was made up of bark. The outermost layer consisted also of bark, like in modern trees. Bark consists of cork, a very durable material which is not easily decomposed by fungi or animals and has excellent

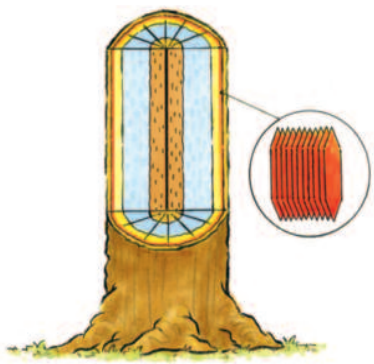


Shoot tip Root tip (according to Braun)

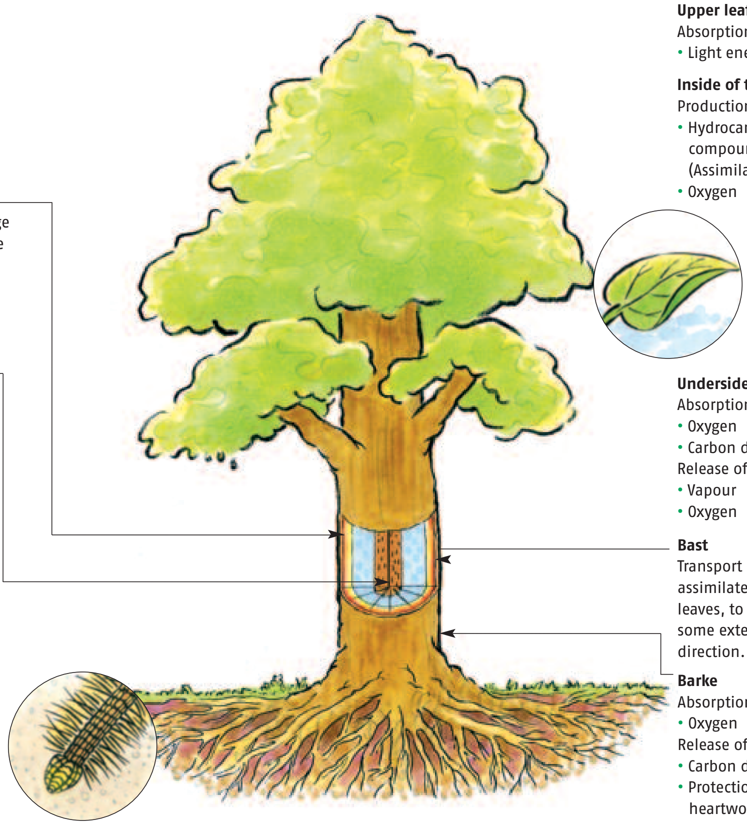
insulating properties. Cork has a very poor static load carrying capacity though, and for this reason, the first trees reaching a height of 30 m had a trunk of up to 5 m in diameter. The most common club-moss trees were the scale trees (*Sigillaria*) with leaves up to one metre long and 10 cm thick which were situated at the unbranched tuft of the plant.

Other scale trees (*Lepidodendron*), also belonging to the club-moss trees, already had trunks branching out like a fork. This enabled them to seize a bigger horizontal space. Other tree species of the time were horsetail and tree fern. They reproduced by means of spores, like fungi and ferns. The first trees producing seeds, the *Cordaites*, appeared during the Jurassic Period, about 200 million years ago.

They belonged to the gymnosperms and became the tallest trees of their time. Their seeds were not embedded in fruit pulp but hung bare from the ends



of short stalks. Later, the conifers evolved out of these plant species, cone bearing coniferous trees (Konos = cone). All of these trees species are extinct. Only one



has survived: the Ginkgo, the oldest gymnosperm which can be verified already for the Lower Permian Period. It is one of the most resilient plants.

The first broad-leaved trees which still exist today, such as the willow or the magnolia, appeared much later, about 100 million years ago. The great age of the broad-leaved trees began about 60 million years ago. Tree statics had also undergone an evolution. Instead of the mighty layer of bark, wood had taken on the structural function of load transfer. Wood has a much higher load-bearing capacity which allows for a more slender vertical growth of the trunks. The larger diversity of species facilitated finer variations in regard to tree statics and to the mechanical properties of wood.

From the fierce competition for light, two fundamental concepts in statics emerged.

The conquerors

Conquering tree species can grow very fast which enables them to capture more of the available sunlight. But in the course of their conquest, they have to neglect their structural strength. The load transferring parts are relatively weak. Such tree species fail easily through breakage or windthrow. As a result, the trees give way continually to new growth.

TYPICAL CONQUERORS: poplar, willow and also robinia.

The steadfast trees

The species of these trees are not as fast growing, but they possess a better structural strength. Their load transferring parts had been strengthened and protected against attackers. The steadfast tree species are less vigorous, but, once established, they can occupy their space for a very long time. Because of their stable structure, they can also get very old.

TYPICAL STEADFAST TREES: oak, lime and also plane.

Presumably, conquerors were the first evolving tree species of each respective epoch. They were the trees which could grow faster than the already existing plants. It can be assumed that they were also able to thrive in environments which were unsuitable for their competitors. The first trees were pioneers, and the environments they conquered were extreme: very wet or very dry, lacking in nutrients or holding an excess of nutrients. A balancing layer of humus was still lacking, and the climate was even more hostile than it is in the cities of today. The tree pioneers conquered these environments in competition with other plants. By colonising hostile environments, or environments which were at least hostile to plants, the pioneer trees changed these environments. Fallen leaves and tree parts built up a layer of humus which was held in place by the roots of the trees. The trees also had a balancing effect on heat and humidity and functioned as windbreaks. On the newly formed fertile soils and with a change in climate conditions, succeeding, more highly developed tree species proved to be more successful competitors than the pioneers. The improved conditions put them in a position where they could produce more substance to improve their safety and growth. Gradually, the trees began to live longer.

The pioneer trees colonised one new environment after the other. The transition from the older coniferous trees to the geologically younger broad-leaved trees was heralded by the pioneers of the broad-leaved trees. But these new tree species did not defy the coniferous trees in the environments the coniferous trees had already colonised. Magnolia and willows were able to thrive in all the environments where disasters like floods, landslides, earthquakes or forest fires had caused gaps in the existing vegetation. Their much higher growth rate and the fact that they were less demanding enabled them to fill in existing gaps in the vegetation much faster than the slow growing coniferous trees. Apart from their rapid growth, the

broad-leaved trees possessed another property which proved to be vital in extreme situations: if parts of their crowns are lost, they are capable to immediately produce new growth from the remaining tree parts.

Some of them can even survive the loss of all tree parts above ground. A willow cut back to the trunk will sprout again immediately, while most coniferous trees are not able to grow back like this.

The broad-leaved trees which came after the pioneers of the broad-leaved trees possessed a greater static stability, lived longer, and still grew faster than the coniferous trees already present. They predominantly colonised areas where their existence was more endangered, but where their improved system for water transport also gave them an advantage over the coniferous trees. As a result, the coniferous trees were increasingly forced to retreat to environments the broad-leaved trees could not adapt to, either because they needed longer vegetation periods or because they were less heat-tolerant. These processes contributed to the distribution patterns of the tree species of today. The more adaptable and faster growing